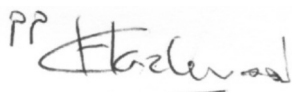


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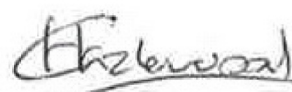
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## Document history

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29 Oct 2020	03-00	ELB	MDA	CMG	Final version including Arterial Drainage extension task.
13 Mar 2020	02-00	ELB	MDA	DMR	Final draft for OPW review.
12 Nov 2019	01-00	ELB	MDA	DMR	First draft for OPW review.



## Glossary

AD	Arterial Drainage – schemes to artificially enhance the drainage capacity of channels, to reduce water levels and water logging of adjacent flood-prone agricultural lands.
AEP	Annual Exceedance Probability; represents the probability of an event being exceeded in any one year (%).
AFA	Area for Further Assessment – An area where, based on the Preliminary Flood Risk Assessment and the CFRAM Study Flood Risk Review, the risks associated with flooding were assessed as potentially significant.
ALTBAR	Mean elevation of catchment.
AMAX	Annual maximum flood flow.
ARTDRAIN2	Proportion of river network length included in Arterial Drainage Schemes.
BFIHOST	Base Flow Index derived from HOST soil data for the UK.
BFI <sub>SOIL</sub>	Base Flow Index from Irish Geological Soils dataset. Often used as a permeability indicator.
CFRAM	Catchment Flood Risk Assessment and Management – the CFRAM studies developed more detailed flood mapping and measures to manage and reduce the flood risk for the AFAs.
DRAIN D	Drainage density.
DTM/DEM	Digital Terrain Model/Digital Elevation Model.
EPA	Environmental Protection Agency.
FAI	Flood Attenuation Index.
FARL	Index of flood attenuation due to reservoirs and lakes.
FEH	Flood Estimation Handbook.
FRMP	Flood Risk Management Plan.
FSU	Flood Studies Update.
FSR	Flood Studies Report.
GEV	Generalized Extreme Value distribution.
GLO	Generalised Logistic distribution.
HA	Hydrometric Area. Ireland is divided up into 40 Hydrometric Areas. Some of these have been combined to create the Units of Management.
HEFS	High-End Future Scenario to assess climate and catchment changes over the next 100 years assuming high emission predictions from the Intergovernmental Panel on Climate Change.
HOST	Hydrology of Soil Types dataset, in which 29 soil classes are grouped by hydrological properties, particularly their ability to transmit water both vertically and horizontally.
HPW	High Priority Watercourse: a reach modelled within an AFA.

ICPSS	Irish Coastal Protection Strategy Study.
IfSAR	Interferometric Synthetic Aperture Radar: a DTM dataset.
mAOD (P)	Metres Above Ordnance Datum at Poolbeg lighthouse, Dublin.
MPW	Medium Priority Watercourse: a reach modelled outside of an AFA.
MRFS	Mid-Range Future Scenario to assess climate and catchment changes over the next 100 years assuming medium emission predictions from the Intergovernmental Panel on Climate Change.
NIFM	National Indicative Fluvial Mapping project – will produce second generation indicative fluvial flood spatial data that are of a higher quality and accuracy to those produced for the first cycle PFRA.
OPW	Office of Public Works, Ireland.
OSi	Ordnance Survey Ireland.
PCD	Physical Catchment Descriptor.
PFRA	Preliminary Flood Risk Assessment – a national screening exercise, based on available and readily-derivable information, to identify areas where there may be a significant risk associated with flooding.
Q <sub>MED</sub>	Median annual flood used as the index flood in the Flood Studies Update. The Q <sub>MED</sub> flood has an approximate 50% AEP.
S1085	Typical slope of the river reach between 10%ile and 85%ile along its length.
SAAR	Standard Average Annual Rainfall.
UAF	Urban Adjustment Factor.
UoM	Unit of Management. The divisions into which the River Basin District is split in order to study flood risk.
URBEXT	Proportional extent of catchment area mapped as urbanised.
WMS	Web Map Service. A web mapping protocol, defined by the Open Geospatial Consortium, that is commonly used to serve mapped data in raster format to a web page or GIS desktop application.

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# 1. Introduction

The Office of Public Works (OPW), as the leading agency for flood risk management in Ireland, minimises the impacts of flooding through sustainable planning.

Under this remit, a first cycle National Preliminary Flood Risk Assessment (PFRA1), completed in 2012, identified areas at significant flood risk known as Areas for Further Assessment (AFAs), and included the production of national indicative fluvial flood maps for all rivers with a catchment area greater than 1 km<sup>2</sup>, for three flood event probabilities (the 10%, 1% and 0.1% AEP events). The Catchment Flood Risk Assessment and Management (CFRAM) programme subsequently developed more detailed flood mapping and measures to manage and reduce the flood risk for the AFAs. Under the CFRAM programme (2011 to 2016), detailed hydraulic modelling was carried out for 300 AFAs countrywide, within six CFRAM Projects covering 29 River Basins and other location-specific projects; these produced around 40,000 flood maps which support planning decisions and emergency response.

Article 14.1 of the Floods Directive (Council of the European Communities, 2007) indicates that the PFRA, and the flood hazard and risk maps, should be reviewed, and if necessary updated, at regular intervals. The National Indicative Fluvial Mapping (NIFM) project was therefore commissioned in order to provide a second cycle of the PFRA flood maps. The objectives were to provide improved flood mapping outside the AFAs (now covered by the CFRAM maps) and, in addition, take climate change into account. This report is the final project report for the NIFM project.

The NIFM project has produced second generation indicative fluvial flood spatial data that are of a higher quality and accuracy to those produced for the first cycle PFRA. This covers 27,000 km of river reaches, separated into 37 drainage areas, consisting of 509 sub-catchments. This data set will enable improved flood risk assessment for areas outside those zones designated as AFAs. It has taken account of potential climate change impacts on flooding, as specified by the Floods Directive (Article 14.4). The mapping procedure has established flood hazard areas; these are the areas that are liable to flood with Annual Exceedance Probabilities (AEPs) of 0.1%, 1%, and 5%, for three climate change scenarios: Current Scenario, Mid-Range Future Scenario (MRFS), and High-End Future Scenario (HEFS). The project has delivered higher quality flood maps, improving upon the outputs of the first cycle PFRA (PFRA1) outside CFRAM modelled extents.

The NIFM project divided naturally into two phases to first allow the process to be trialled and proven for two initial pilot Units of Management, UoM 18 (Munster Blackwater) and UoM 26 (Upper Shannon), and then rolled out to the remaining watercourses that needed to be modelled countrywide (denoted 'subject watercourses'). The Pilot Study Areas were selected judiciously, in order to capture the widest possible range of potential modelling challenges that would be faced during the national roll out.

The pilot study phase was carried out between January and July 2019 and the production of draft flood maps for the whole country was carried out between July and December 2019. Following a detailed review of the nationwide draft flood maps, it was recognised that the channel capacity estimates (and hence the flood outlines) could be improved in those UoMs that contain significant areas of benefiting lands with Arterial Drainage. An improved method was developed and trialled for those UoMs. Final flood maps were then produced by October 2020.

## 1.1. Report structure

The roll out of the piloted methodology to the national subject watercourses is introduced in Chapter 2, with Chapters 3, 4 and 5 describing the updates to the piloted methodology that were carried out during the roll out for the hydrological assessment, hydraulic modelling, and processing of results, respectively. Chapter 6 describes the quality assurance techniques that were used throughout the process. Chapter 7 provides a critical assessment of the applied methodology; an assessment of the accuracy of the flood extents is provided in Chapter 8. Finally, Chapter 9 makes suggestions for future improvements of the flood extents, based upon the preceding assessment of the methodology and of the accuracy of the results, as well as making suggestions for further applications of the flood extents.

The main report is followed by Appendix A, which contains the full Pilot Study Report, for ease of reference, Appendix B, which contains the Technical Note describing the data review of the project extension for Arterial Drainage, and Appendix C, which contains the subsequent Technical Note describing the Arterial Drainage pilot study.

## 2. Description of the applied methodology

The overall pragmatic approach to this national-scale flood mapping project was designed to combine intelligent automation of the repetitive processes, such as hydrological calculations and the burning of watercourses into the 2D model mesh, with experienced hydraulic modelling and critical quality assurance techniques. The approach built upon the outputs from significant earlier studies carried out under the Flood Studies Update and CFRAM programme studies. It was designed to enable straightforward and efficient six-yearly updates to the flood risk assessment.

The major tasks are shown in the workflow diagram of Figure 2.1, falling under the following broad headings:

1. Gathering of data;
2. Hydrological assessment;
3. Hydraulic modelling;
4. Generation of flood spatial data;
5. Classification of reaches.

Some of the tasks needed to happen in series, while others were able to proceed in parallel; indeed, the sharing of hydrological information with the hydraulic modelling sub-tasks was essential to the efficiency of the process. Within each workflow task, there was a workflow process. Within and between tasks, there were Quality Assurance (QA) checks that were designed to complement the automated processes and identify issues in those processes; some of these are visible on Figure 2.1 (labelled QA1 to QA7).



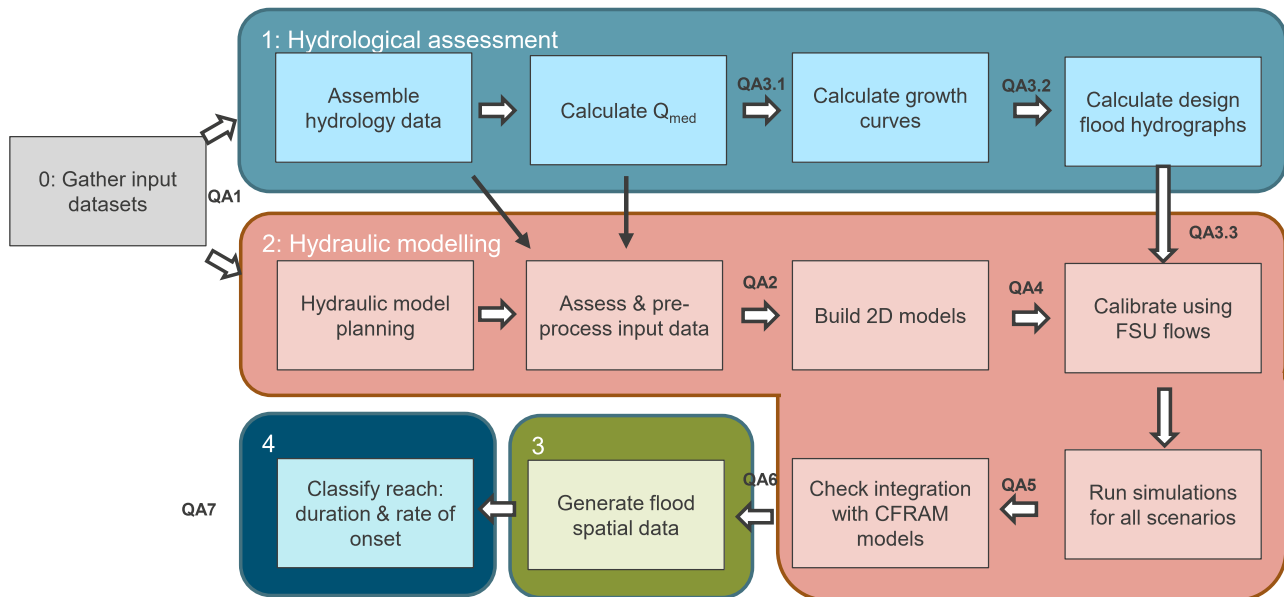


Figure 2.1: Overview of the workflow sequence of tasks involved

For the Pilot Study, the methodology was trialled across all subject watercourses with a catchment area of greater than 5 km<sup>2</sup> including the CFRAM areas. For the national roll out, the method was not applied in areas that lay within CFRAM modelled extents, except for a 500 m overlap at each boundary where matching of flood extents was achieved. The methodology was applied to each of the drainage areas in Ireland, referred to as Units of Management (UoM).

Full details of the method are given in the Pilot Study Report (*MCR6058-RT001-R04-00.pdf*), which is included here as Appendix A. The Pilot Study raised a number of issues which resulted in adjustments to the methodology in specific locations or for specific tasks, but the overall workflow sequence was not affected. The methodology was further refined, after the nationwide draft flood maps were produced, for those seven UoMs having significant areas of benefiting lands with Arterial Drainage; these were highlighted where sufficient improvements were deemed to be possible and sufficient supporting data were available, namely UoMs 03, 06, 07, 08, 09, 23, and 24.

All adjustments made to the piloted methodology during the national roll-out, and its refinement for benefiting lands with Arterial Drainage, are documented below.

### 3. Hydrological assessment

The hydrological components of the NIFM project were based fundamentally upon the Flood Studies Update (FSU) data and methods, along with CFRAM programme data.

The most up-to-date dataset of annual maxima flow data was required for the hydrological assessment. Due to the timing of the earlier relevant hydrological assessments (the Flood Studies Update (FSU) and CFRAM studies), they were based upon a gauged dataset that ended in 2012. More recent annual maxima (AMAX) data were acquired in order to calculate factors for  $Q_{MED}$  values and growth curves to be used in the NIFM project.

FSU Physical Catchment Descriptor (PCD) data were available at 500m intervals along all watercourses, representing the key parameters required for use in the development of hydrological information for Ireland, such as calculation of the index flood flow ( $Q_{MED}$ ) and hydrograph shapes at ungauged locations. In addition, flood growth factors and growth curves had been derived under the CFRAM studies, and the approach for this NIFM project was designed to use this information as far as possible. A nationwide review of CFRAM growth factors and curve fitting was carried out in order to develop a pragmatic approach for the national roll out. CFRAM growth factors had been derived on a range of different bases for different Units of Management (UoM); for some UoMs, the growth factors were grouped into bands of relevant catchment size (UoM 01, 06, 07, 09, 10, 11, 12, 13, 14, 15), at others, the factors were grouped by reaches (UoM 23, 24, 25, 26), while in others, the factors were developed at local gauge locations. Growth curves for each UoM were recalculated for the extended AMAX data series, which covered the more recent period (2012 to 2016) since the dataset used for the FSU and CFRAM studies had ended. The change in the growth factors as a result of the additional years of flow data was calculated for each OPW gauge. The growth curves for each UoM based on CFRAM growth curves were then scaled to account for the additional years of flow data.

The hydrological assessment therefore contained four main steps:

1. **Assemble hydrology data.** The first step was to extract the relevant Physical Catchment Descriptor (PCD) data for each FSU-node in the study area.
2. **Calculate  $Q_{MED}$ :** From these data, the index flood flow ( $Q_{MED}$ ) could be estimated at every location, and adjusted based upon the more recent annual maximum gauged data, which were obtained for the 149 OPW gauges up to the 2016 hydrometric year. A map showing the countrywide  $Q_{MED}$  adjustment factors calculated from AMAX versus PCD-derived values was presented in the Pilot Study Report, and is reproduced here as Figure 3.1.
3. **Calculate growth curves:** Growth curves were then derived so that the peak flow for the required return period could be estimated; these were based upon the curves that had been developed under the CFRAM programme studies, with adjustment factors applied to account for the impact of the recent annual maximum data. The impact of recent flow data (2012 to 2016) on CFRAM growth curves was assessed by generating growth curves for the two periods (the historical period to 2012 as used in the CFRAM analyses; and the historical period to 2016). The growth curves were fitted using the GEV distribution. The change in the GEV growth curve as a result of the additional four years of flow data was calculated for each OPW gauge. The growth curves for each UoM based on CFRAM growth curves were then scaled to account for the additional recent years of flow data. A single adjustment factor was developed for each UoM based on an average of the gauges (Figure 3.2). The adjustment factor was then applied to the growth factors.
4. **Calculate design flood hydrographs:** Finally, the full shape of the flood hydrograph could be defined using the FSU approach for deriving the characteristic flood hydrograph at ungauged sites. This was based upon the Unit-Peak-at-Origin UPO-ERR-Gamma curve, which had performed better in comparison to other curves in fitting the derived non-parametric hydrograph.



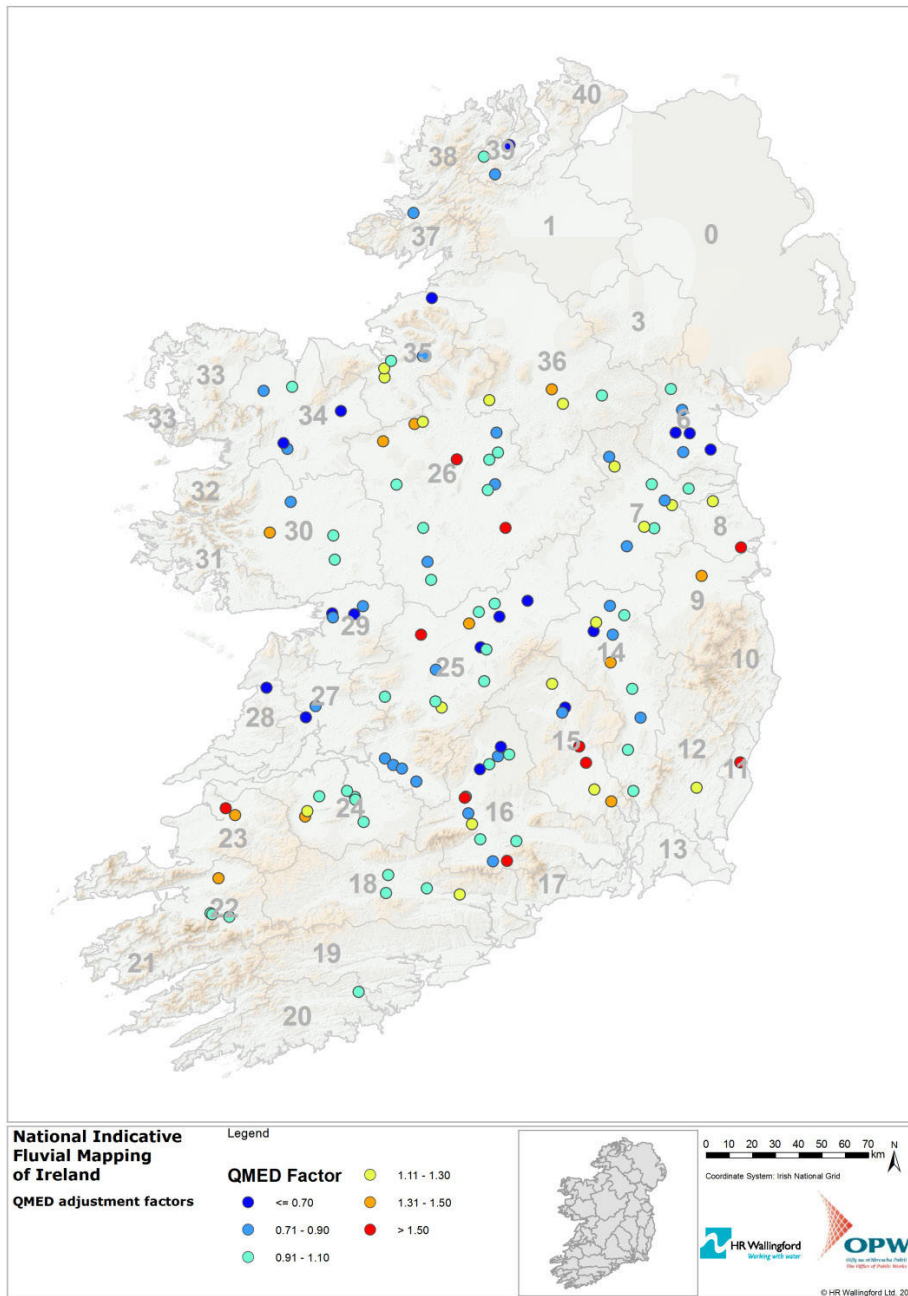


Figure 3.1: Map showing  $Q_{MED}$  adjustment factors calculated from AMAX versus PCD-derived values

Source: HR Wallingford

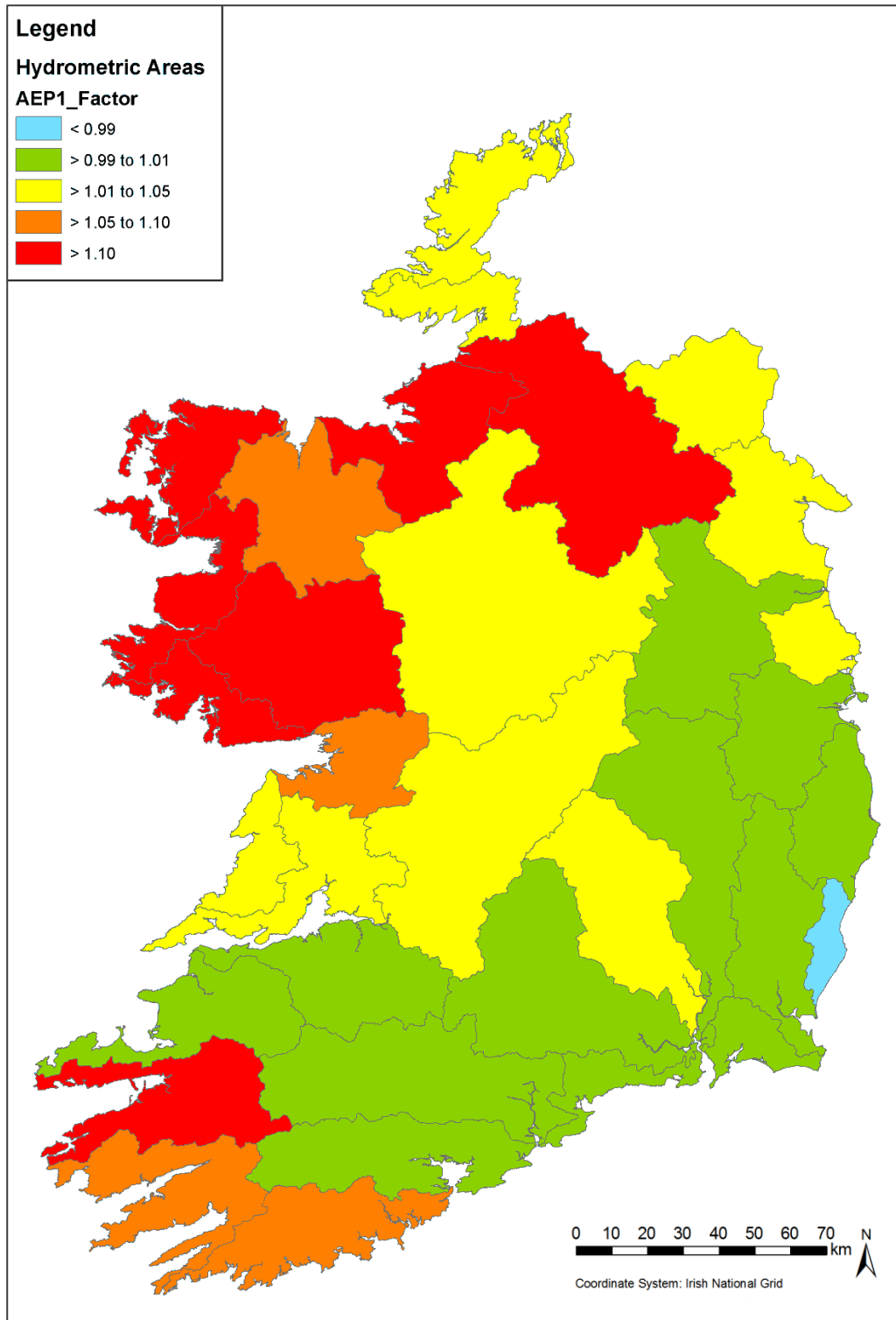


Figure 3.2: Map showing growth factor adjustments per Unit of Management for 1% AEP flood

Source: HR Wallingford

Adjustments and enhancements to the piloted approach, used in the national roll out for the hydrological assessment, were as follows:

- A method was developed to provide inflow data on the border with Northern Ireland (Section 3.1);
- Modified hydrograph shapes were needed in some areas, as identified in UoM 27 (Section 3.2).

These are described below.

### 3.1. Handling missing FSU data on border with Northern Ireland

For subject watercourses which cross or form the border between the Republic of Ireland and Northern Ireland, some issues were encountered during the NIFM data validation checks (i.e. UoMs 01, 03, 06, 35 and 36). The FSU Physical Catchment Descriptors (PCDs) in some locations were found to be erroneous, notably having catchment areas that were incorrect. Using these erroneous data would have had an impact on the flow calculations that are dependent upon those PCDs during the national roll out, and it was therefore important that the erroneous data were identified and an alternate approach to flow generation used in those locations. A similar problem had been encountered during PFRA1 (OPW, 2012), and during the North Western - Neagh Bann CFRAM Study (OPW, 2016), and a similar solution was found.

The alternate approach used here was based upon the generation of inflows using the Flood Estimation Handbook (FEH) data for the affected areas. FEH catchment descriptors were acquired from the FEH website for all relevant locations, with values adjusted using area correction factors. The index flood flow  $Q_{MED}$  for rural locations was then calculated using the revised FEH statistical approach equation (Kjeldsen et al., 2008) as presented in Equation 3.1.

$$Q_{MED} = 8.3062AREA^{0.851}0.1536^{1000/SAAR}FARL^{3.4451}0.046^{BFIHOST^2}$$

Equation 3.1: Revised FEH model for calculation of  $Q_{MED}$

Source: Kjeldsen et al., 2008

Where: AREA is the catchment area (km<sup>2</sup>), SAAR is the standard average annual rainfall (mm) based on measurements from 1961-1990, FARL is an index of flood attenuation due to reservoirs and lakes, and BFIHOST is the base flow index derived from Hydrology of Soil Types (HOST) soil data for the UK.

The FEH-derived flow values were used in place of PCD-derived FSU values, and quality checks were carried out to ensure that the values were sensible. To ensure consistency of generated flows along partially affected river reaches, such as those straddling Northern Ireland and the Republic of Ireland, the FEH method was used along the whole reach down to the junction with the main river.

### 3.2. Adjusted hydrograph shape calculation for UoM 27

The official design flood hydrograph shape generation equation, derived under Flood Studies Update (FSU) Work Package (WP) 3.1, was used to generate hydrographs. Quality Assurance checks ensured that the generated hydrographs were reasonable before they were used in the hydraulic modelling.

The hydrographs generated by this approach were generally reasonable. However, for UoM 27 (Shannon Estuary North), some unrealistic hydrographs were found to be produced by this method. This UoM contains lots of lakes and the catchments are rather flat. The generated hydrographs show unrealistic recession limbs, continuing at high flow rates for a very long time (of the order of years). The FSU method was

developed with a limited dataset in this area, with a lack of larger return period flood events upon which to base the analysis (such as that of 2015).

In terms of the NIFM project, the use of unreasonably long hydrographs would affect the accuracy of the flows, as well as the flood duration classification. A modified approach was therefore investigated.

### 3.2.1. Modified FSU approach

The FSU WP3.1 approach, for an ungauged site, uses regression-based expressions involving relevant Physical Catchment Descriptors (PCDs) to estimate the values of relevant hydrograph descriptors which are then applied, following a parametric approach, to produce its characteristic flood hydrograph and hence, by rescaling, its design flood hydrograph (OPW, 2009). It was found that the Unit-Peak-at-Origin (UPO-ERR-Gamma) curve performed better in comparison to other curves in fitting the derived non-parametric hydrograph.

The final report for WP3.1 recommends that where flood routing is being carried out, requiring the complete hydrograph, then the regression models for the three curve descriptors of the UPO-ERR-Gamma curve ( $n$ ,  $Tr$  and  $C$ ) are used for the production of the characteristic flood hydrograph. The regression models developed under FSU research are, when  $BFI_{SOIL}$  data are available:

- $T_r = 54.98 BFI^{1.32} (1+ALLUV)^{-13.08} (1+ARTDRAIN)^{-3.70} S1085^{-0.20}$
- $C = 310.75 BFI^{3.44} FARL^{-4.88}$
- $n = 1 + 2.90 BFI^{-1.12} FARL^{4.37}$
- $W_{75} = 34.74 BFI^{1.86} FARL^{-3.95} (1+ALLUV)^{-12.20} (1+ARTDRAIN)^{-3.32} S1085^{-0.25}$
- $W_{50} = 63.05 BFI^{2.11} FARL^{-4.55} (1+ALLUV)^{-10.24} (1+ARTDRAIN)^{-3.17} S1085^{-0.25}$ .

Where:

- $n$  is the shape parameter of the UPO-ERR-Gamma curve
- $Tr$  is the translation (or location) parameter (in hours) of the UPO-ERR-Gamma curve and,
- $C$  is the recession constant (in hours) of the exponential curve drawn from the point of inflection on the receding side of the UPO-ERR-Gamma curve.

The report provides the following caveat for the method:

“In the case of an ungauged site, care should be taken in producing the characteristic flood hydrograph, and hence the design flood hydrograph, using the regression relations. As emphasized in subsection 4.1 and as reiterated in subsection 4.5.2.1, attempts should be made to verify the design flood hydrographs produced for a scheme by making observations, if possible, of the flood events occurring at the site during the period over which the design is being produced and indeed up to the time of actual implementation of the scheme, using even such sparse data to update the design.”

This method has been used in NIFM, and quality assurance checks on the shape have been carried out as far as possible. Our investigation found that the recession parameter of the exponential recession curve (the  $C$  parameter) was responsible for the anomalous hydrograph shapes that had been noted in UoM 27, and this problem was particularly noticeable at higher return periods. When the WP3.1 approach was derived, using the UPO-ERR-Gamma curve, a maximum  $C$  value of 829.75 was found in the observed data set. The  $C$  values used had a mean of 116.04 and a standard deviation of 132.33, such that the majority of the data are captured with a maximum  $C$  value of 300. In UoM27 for example, the hydrograph characteristics at node

27\_1180\_3 included a C value of 2003.5, which is well beyond the values used in deriving the method. The map of Figure 3.3 shows the location of the node, as a red kite symbol.

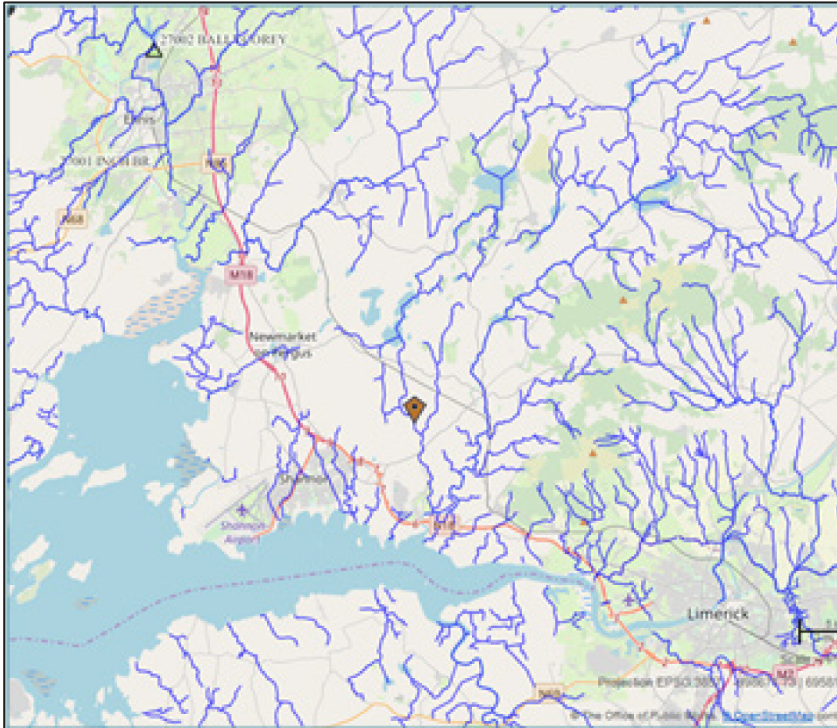


Figure 3.3: Map showing location of node 27\_1180\_3

Source: OPW FSU Web Portal

The very high C values appear to be related to very low FARL values, where FARL is the index of flood attenuation due to reservoirs and lakes. When FARL drops below 0.75 there is a rapid increase in the value of C calculated by the FSU equation. A selection of calculated C values in UoM 27 is given in Table 3.1.

Table 3.1: Variation of C parameter value with FARL

Node	FARL	C parameter
27_634_9	0.80	210
27_612_2	0.75	355
27_711_3	0.70	974
27_1180_3	0.60	2,004
27_156_1	0.55	3,067
27_329_3	0.13	1,642,672

Investigations were carried out at node 27\_1180\_3 to trial different methods for curve fitting and for realistic C parameter values, shown in the graphs of Figure 3.4.



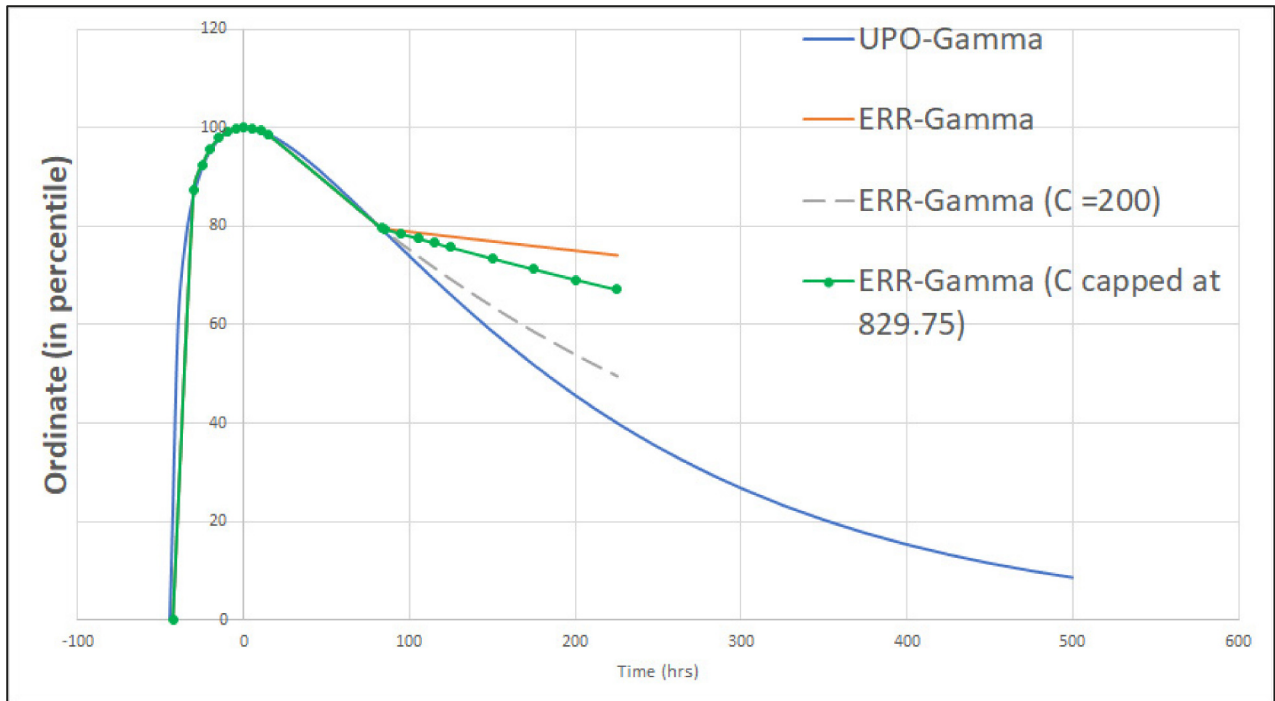


Figure 3.4: Tests on curve fitting at node 27\_1180\_3

In order to maintain a consistent approach for the roll-out, rather than implementing a different curve-fitting technique at affected nodes,  $C$  values capped at 300 were tested.

### 3.2.2. Results

The flow hydrograph shape for node 27\_1180\_3 with the  $C$  value capped at 300 is shown in Figure 3.5.

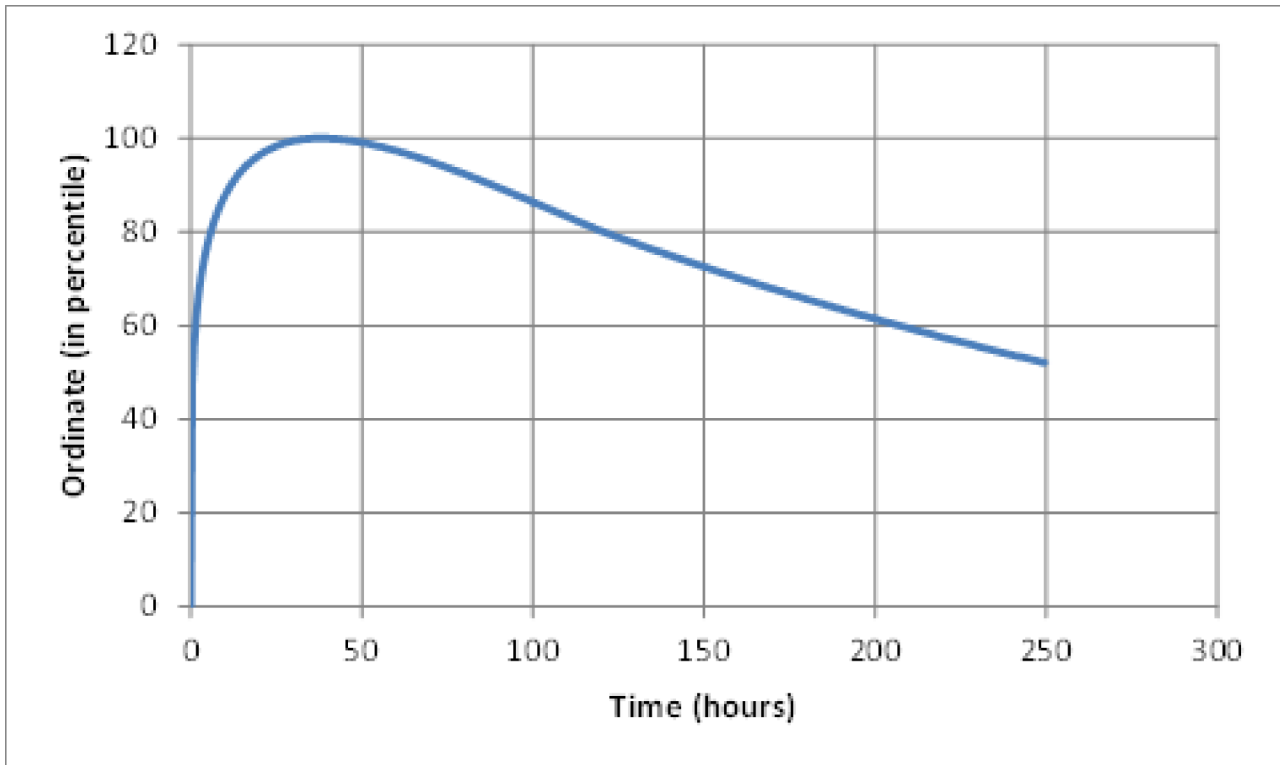


Figure 3.5: Hydrograph shape with C value capped at 300

The results of the testing indicated that this was a reasonable approach which captured anomalous high C values, giving more realistic hydrograph recessions. Historical observed data were available from 1954 at gauge 27002 (Ballycorey), which has an A1 FSU classification, indicating that its flows are reliable to up to 1.7 times  $Q_{MED}$ . The shapes of the hydrograph at 27001 during flood events were studied, in particular the recession limb, and similar shapes to that shown in Figure 3.5 were noted.

## 4. Hydraulic modelling

Hydraulic modelling was undertaken for all subject watercourses with an upstream catchment area of greater than 5 km<sup>2</sup>. The software InfoWorks ICM was used for the hydraulic modelling task. It was selected because it is bench-marked by the Environment Agency in England, solves the full Shallow Water Equations (SWE) with shock capturing, uses irregular triangular meshing and has a high speed of model simulation. It also enables modelling flexibility and auditing, which enable application to a wide range of catchments, and easy tracking of model development.

Our approach was based upon the development of a series of reach to sub-catchment-scale hydraulic models. The models are all 2D high resolution irregular mesh models for the river channel and floodplain. It is well established that this approach can overcome known instability issues that can arise with 1D/2D coupled models. The benefits of irregular meshes, in terms of representing flow routes, structures and flexibility regarding resolution, compared to regular grids, is also well established.

The hydraulic model configuration task contained 11 main steps, under the main headings shown in the workflow diagram of Figure 2.1:

### Hydraulic model planning:

1. Model extent definition: Sub-catchments were defined using a combination of lakes and stream order, with a view to building a separate model for each sub-catchment;
2. Definition of the model domain: Based upon the use of the Digital Terrain Model (DTM) to track along the rivers and select the regions where the DTM cells were less than the specified tolerance above the river node level.

### Assess & pre-process input data:

3. Estimation of the river channel surface elevation: The surface elevation of the river channel was estimated at each FSU node by taking the lowest elevation on the cross-section, with cross-section spacing every 50 m capturing the detailed local slope changes;
4. Definition of channel capacity for different channel types, with corrections for the proportion of the channel captured by the DTM;
5. Estimation of channel width based upon  $Q_{MED}$  and channel depth using the Manning equation;
6. Representation of river crossings with embankments.

### Build 2D models:

7. Specification of the 2D model mesh: The 2D irregular mesh was derived using terrain-sensitive meshing so that finer resolution mesh elements were used in zones of greatest topographic change;
8. Definition of roughness: Manning's  $n$  roughness values were estimated for each land use category in the CORINE land cover dataset;
9. Simplified representation of bridges: the channel roughness  $n$  was set to 0.2 at bridges to give a reasonable approximation of the afflux impact on water levels upstream of the bridge;
10. Identification of errors in the DTM: the IfSAR DTM was examined with particular focus upon known limitations;
11. Definition of the downstream boundary, via either sea levels, CFRAM model water levels, or water levels from the downstream model.

**Calibrate using FSU flows:** the design flood hydrographs from Stage 1 (Hydrological Assessment) were checked; the modelled flows were compared with the design flows at nodes spaced less than 10km along the river network.

**Run simulations for all scenarios:** The models were then run for all scenarios and annual exceedance probabilities.

**Check integration with CFRAM models:** Where necessary, checks were carried out to ensure consistency in general and with particular focus on the links to CFRAM models.

Adjustments and enhancements to the piloted approach for the hydraulic modelling, as well as some small additional activities, are as follows:

- Extraction of data for western UoMs, where digital data were not available for use in the automated process;
- Handling missing CFRAM water level data, which were required for defining downstream model boundaries for all scenarios;
- Adjusting model domain to cover entire flooded areas;
- Enhancement to better represent the capacity of Arterially Drained channels.



These are described below.

## 4.1. Extraction of data for western UoMs (from pdfs)

Node data for parts of particular Western UoMs' CFRAM models were not available in digital format to match the other areas. The missing digital data covered the Medium Priority Watercourses (MPWs) in those areas. The affected UoMs were:

- UoM 29: ~ 5 boundaries needing CFRAM water levels;
- UoM 30: ~ 17 boundaries needing CFRAM water levels;
- UoM 34: ~ 15 boundaries needing CFRAM water levels;
- UoM 35: ~ 21 boundaries needing CFRAM water levels.

Water level data for the nodes were available via tables on Adobe Acrobat (.pdf) maps, for the AEPs labelled as 10%, 1% and 0.1%. Locations of the corresponding cross-sections were available in shapefiles. The data were extracted from the .pdf maps and converted to a format that could be used in the modelling.

## 4.2. Handling missing CFRAM water level data

In situations where the NIFM model had a CFRAM model at its downstream boundary, the maximum water level for the NIFM design event was taken from the nearest CFRAM node (that contains results). The maximum water level could then be fitted to the design hydrograph shape derived for the FSU node. CFRAM water level data were therefore required for each of the three model scenarios (Current, Mid-Range Future Scenario and High-End Future Scenario) and for each annual exceedance probability.

In some locations within UoM 19 (the River Lee catchment), CFRAM water level data were missing from the High-End Future Scenario (HEFS) results. HEFS represents a relatively extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictive analysis, and with the allowances for increased flow, sea level rise, increased rainfall depths, land movement, urbanisation and forestation at the upper bounds of widely accepted projections. For the NIFM inflow modelling, in order to estimate the missing CFRAM HEFS water level values, the proportional increase in flow was used as the basis for the calculation. The flow increase between the Current scenario and HEFS was known to be 30%, and the flow increase between the Current scenario and MRFS was known to be 20%. We therefore calculated the difference in water level between MRFS and the Current scenario, divided it by two (to represent the additional 10% increase from 20 to 30%) and then added this amount to the MRFS water level to create a HEFS water level.

In other locations, within UoM 08 (Fingal East Meath area), no CFRAM nodes exist. Therefore, it was necessary here to use similar catchments and derive ratios between their CFRAM water level results values for Current and HEFS scenarios, and apply these to the UoM 08 model boundaries.

In some areas, CFRAM water levels looked erroneous. In UoM 06, CFRAM water levels for the HEFS scenario were significantly higher than those for the MRFS scenario. Also, CFRAM water levels did not always increase with return period – there were inconsistent values around the 10 or 20 year event in the Current and MRFS scenarios. In these cases the HEFS water levels were estimated from the Current and MRFS values, rather than using these erroneous data.

### 4.3. Adjusting model domain to cover entire flooded areas

In some locations, the automated process to define the model domain (i.e. the region where the DTM cells were less than the specified tolerance above the river node level) had not captured the entire flooded area. This meant that the flood extent was constrained by the 2D model domain. In many cases this occurred where a tributary river enters the wide flat floodplain of a main river. Where this occurred, the floodplain domain representation was extended so that the water levels and the flooded extents would be more accurate.

### 4.4. Enhancement to better represent Arterially Drained channels

In those UoMs containing significant benefiting lands with Arterially Drained (AD) channels, the automated process of channel capacity estimation (based upon a factor of 135% applied to  $Q_{MED}$ ) needed adjustment to better represent reality, and thus improve the flood extents. A data review for all 11 potentially affected UoMs (documented in Technical Note #02: *MCR6058-TN002-R01-00.pdf* – Appendix B) recommended revised  $Q_{MED}$  factors for the smaller channels in seven of the UoMs, and the use of the original approach in the remaining four UoMs (where the evidence of the data showed no real difference, or there were insufficient data to draw a conclusion).

Subsequent testing of the modified  $Q_{MED}$  factors in two pilot UoMs (UoM 07 in the east, and UoM 24 in the west) was based upon a range of evidence and resulted in a final recommended set of  $Q_{MED}$  factors for the seven UoMs. The pilot was documented in Technical Note #03: *MCR6058-TN003-R03-00.pdf* (Appendix C). The revised  $Q_{MED}$  factors were applied as follows:

- 03: Factor = 190% for Stream Order 1 and 2 channels;
- 06: Factor = 190% for Stream Order 1 and 2 channels;
- 07: Factor = 190% for Stream Order 1 and 2 channels;
- 08: Factor = 190% for Stream Order 1 and 2 channels;
- 09: Factor = 190% for Stream Order 1 and 2 channels;
- 23: Factor = 170% for Stream Order 1 channels only;
- 24: Factor = 170% for Stream Order 1 channels only.

## 5. Processing of results

Following successful model simulations, the results processing task contained two main steps, under the headings shown in the workflow diagram of Figure 2.1:

1. **Generate flood spatial data:** comprised generation of flood extent, flood depth, flood level, and flood node spatial data for all subject watercourses;
2. **Classify reach: duration and onset of flooding:** comprised classification of reaches of all subject watercourses by the estimated duration of flooding to occur along that reach, as well as representative indicators of the rate of onset of flooding.

Adjustments and enhancements to the piloted approach for the processing of results are as follows:

- Handling missing CFRAM extent data;
- Clipping of NIFM extents to CFRAM extents;

- File naming convention;
- Clipping of coastal boundary;
- Merging with lakes coverage data;
- Cleaning self-intersections.

These are described below.

## 5.1. Clipping of NIFM extents to CFRAM extents

The approach to merging of the CFRAM and NIFM extents ensures that there is no overlapping of CFRAM and NIFM flood extent data when they are overlaid, based on a clean cut at upstream boundaries of CFRAM; this approach was selected to ensure that the NIFM and CFRAM results would be clearly distinguishable from one another, although in some locations it results in gaps in the flood extent. It also incorporates an alternative jigsaw approach for tributaries not modelled in CFRAM, giving a smoother transition between the two sets of results in those locations.

In some locations, the CFRAM flood outline was fragmented and narrow for a few hundred metres, and in many places the required 500 metre overlapping reach with NIFM was difficult to determine. Therefore, in a conservative approach to ensure that all relevant locations were modelled, the NIFM modelling covered all river segments where less than 85% of the segment length had been modelled previously under CFRAM. As a result, the NIFM dataset covers a greater length of watercourses than the prescribed subject watercourses plus overlapping reaches originally required.

In some locations, CFRAM extent data were missing for some return periods, and the approach to handling these situations is described below. The approach to clipping for the two circumstances described above is then described.

### Handling missing CFRAM extent data

CFRAM model extents were missing in various locations and for a range of Annual Exceedance Probabilities (AEPs) and scenarios; the full list is given below, along with information on the CFRAM extent used to clip the NIFM data in each case:

- All locations for the 5% AEP for the HEFS scenario;
- UoM 08: all missing except for: 1% and 0.1% AEP Current; 1% and 0.1% AEP MRFS (NIFM clipped to 0.1% AEP Current extent);
- UoM 15: Kilkenny missing all except for 1% and 0.1% AEP current (NIFM clipped to 0.1% AEP Current extent);
- UoM16: Missing 5% AEP for all scenarios; Clonmel all missing, except for 1% AEP Current (NIFM clipped to 0.1% AEP Current extent);
- UoM 19: Missing most of 5% AEP for all scenarios and all HEFS AEPs (NIFM clipped to 0.1% AEP Current extent);
- UoM 23: All AEPs/scenarios missing for lower River Feale (only the 5% HEFS has full coverage) (NIFM data remain unclipped).

### 5.1.1. NIFM modelled reach merged with CFRAM modelled reach

The NIFM flood extent data have been clipped based on the CFRAM maximum flood extent (i.e. the 0.1% HEFS). Whilst this extent is by definition smaller than the model domain, it is reasonable to assume that this is the maximum flood extent from the CFRAM mapping. The NIFM data are clipped, making a cut perpendicular to the NIFM smoothed river centre line, at the maximum HEFS 0.1% flood extent. This is shown conceptually in Figure 5.1, where the dashed red line shows the cut location for the NIFM dataset.

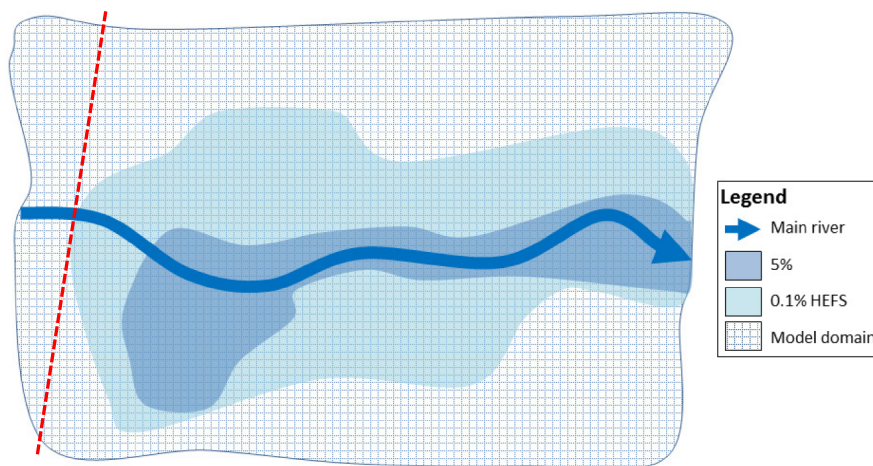


Figure 5.1: Conceptual diagram of the CFRAM model domain for a reach of river showing the cut line in red

### 5.1.2. NIFM modelled tributary merged with CFRAM modelled reach

In some locations, the CFRAM studies include tributaries and in other locations they do not. Where the tributaries are not modelled in CFRAM, an alternative tributary clipping has been implemented (Figure 5.2), termed a 'jigsaw' approach. The figure demonstrates this alternative approach at a tributary which is not modelled in CFRAM (as identified by the CFRAM modelled river centrelines layer), where the NIFM flood extent data has been cut using the jigsaw approach based on the corresponding CFRAM flood extent.

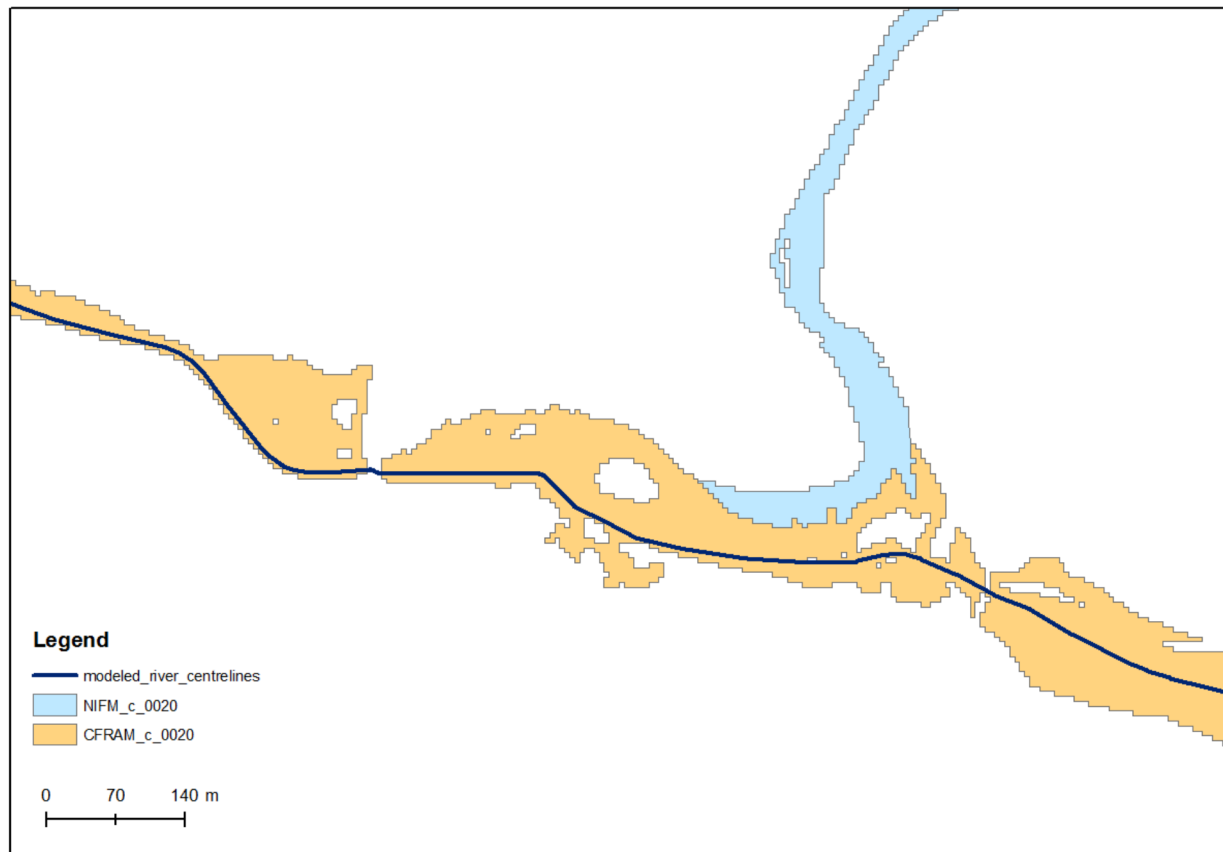


Figure 5.2: Example of NIFM data cut at a tributary based on the corresponding CFRAM flood extent

Note that, although the NIFM flood extent data have been clipped for the purposes of the CFRAM merge, the full NIFM flood extent data are available to OPW for future use as needed.

## 5.2. File naming convention

In order to use a file naming convention that complied with the Flood Spatial Data Specification, with revision numbering that would not clash with that used in the Pilot Study (i.e. for UoMs 18 and 26), the status and revision number codes were implemented as follows:

- First draft: *d01* (with *d04* for UoMs 18 and 26);
- Final draft: *d02* (*d05* for UoMs 18 and 26);
- Final deliverables: *f01* (*f04* for UoMs 18 and 26).

## 5.3. Clipping of coastal boundary

To improve the representation of the coastline in the NIFM datasets, coastal clipping was carried out using OSi PRIME High Water Mark coastal boundary data.

## 5.4. Merging with lakes coverage data

The river channels through lakes were modelled in NIFM, but the full extents of the lakes needed to be represented. To achieve this, the EPA lakes coverage data were used. First, inline lakes were identified. Where lakes were not already represented in the NIFM extents, the lake was added to the NIFM extent.

To obtain representative values for depth, level and speed for these lakes, worst case scenario values were obtained by intersecting each lake's extent with the depth, level and speed grids for the 0.1% AEP HEFS scenario. The median values for each lake were calculated from zonal statistics. These median values were then used in these new lake locations in the depth, level and speed grids for each AEP and scenario.

## 5.5. Cleaning self-intersections

In some instances, self-intersecting polygons were created by the results processing methodology. Such self-intersections cause problems for data validation checks, and create errors when the files are opened in some GIS tools. To clean the self-intersections, an FME tool (Geometry Validate) was used with a buffer distance of 10mm). Wherever such cleaning was carried out, it was recorded in the metadata (see Section 6.1).

# 6. Quality assurance & metadata

A number of quality assurance (QA) and simple data integrity checks were undertaken to assess the validity and quality of the modelling and results at each stage; some of the main checks are labelled on Figure 2.1. QA checks carried out at various stages are summarised below.

Model data preparation:

- Check on CFRAM and Arterial Drainage reaches: A manual task to ensure that the reaches flagged as being within CFRAM and Arterial Drainage channels have been assigned appropriately throughout the UoM. The intention is to flag all segments that are entirely covered by the CFRAM model, but if only a partial section of the segment is covered, then do not flag the segment as being in CFRAM. Similar process with Arterial Drainage channels;
- Check on  $Q_{MED}$ : Checks that the calculated  $Q_{MED}$  values increase with distance downstream along the river network. Nodes where  $Q_{MED}$  decreases are output for checking and the values adjusted;
- Check on channel polygons: A manual step to check that a channel polygon has been built for all river segments successfully;
- Check on 2D mesh zones: A manual step to check that the 2D zone covers the expected floodplain extent based on the DTM;
- Check on results lines: A manual step to check that all results lines generated are sensible and complete;
- Check downstream boundary file: A manual check that peak water levels taken from CFRAM are sensible based on the ground level at the downstream boundary.

Hydraulic modelling:

- Check that model components have imported and meshed correctly;
- Check that flow routes through road and rail embankments are included in the model mesh. Where openings are not included in the DTM or model mesh these were added manually;



- Check model results: A manual check that the flood extents are checked to ensure the model domain is sufficient, a manual check on the water level long sections, and a manual check on the model flows against the design flows.

Generation of results:

- Check results of post-processing to generate extents and grids;
- Check the integration of the extents with those of CFRAM, and their re-projection;
- Check the maximum flows and levels from InfoWorks ICM.

The QA process on model results identified sub-catchments in each UoM for which adjustments were required. The sub-catchments' models were modified and re-run in order to improve the results in these areas. The re-runs undertaken are summarised in Table 6.1.

Table 6.1: Model re-runs required for each UoM following the QA process

Unit of Management (UoM)	Reason the QA identified a re-run was required	Number of sub-catchments that were re-run
1	Flooding limited by model domain	1
3	Flooding limited by model domain	2
	Downstream boundary	1
6	None	None
7	Flooding limited by model domain	10
	Downstream boundary	8
8	Flooding limited by model domain	2
9	Flooding limited by model domain	7
10	Flooding limited by model domain	2
11	Flooding limited by model domain	2
12	Flooding limited by model domain	5
13	Flooding limited by model domain	2
	Defence elevation	1
14	Flooding limited by model domain	27
	Downstream boundary	3
15	Flooding limited by model domain	11
	Inflow	1
16	Flooding limited by model domain	21
	Sub-catchments merged	6
	Downstream boundary	3
17	Flooding limited by model domain	5
18	None	None
19	Flooding limited by model domain	7
	Sub-catchments merged	2
	Hydrology	1
20	Flooding limited by model domain	7
	Downstream boundary	1

Unit of Management (UoM)	Reason the QA identified a re-run was required	Number of sub-catchments that were re-run
	Hydrology	1
21	Flooding limited by model domain	2
22	Flooding limited by model domain Downstream boundary	7 8
23	Flooding limited by model domain	10
24	Flooding limited by model domain Downstream boundary	7 10
25	Flooding limited by model domain Inlet structures to lake	24 3
26	Flooding limited by model domain Downstream boundary	30 1
27	Flooding limited by model domain	18
28	Downstream boundary	1
29	None	None
30	Downstream boundary	7
31	Flooding limited by model domain	5
32	Downstream boundary	3
33	Flooding limited by model domain Downstream boundary	6 21
34	Flooding limited by model domain Downstream boundary	2 5
35	Flooding limited by model domain Downstream boundary	4 2
36	Flooding limited by model domain Downstream boundary	2 7
37	Flooding limited by model domain	2
38	Downstream boundary	5
39	Flooding limited by model domain Downstream boundary	4 14
40	Downstream boundary	14

A Quality Control Report accompanies the delivered dataset for each UoM. This summarises the set of quality control checks that are carried out on the data prior to delivery; a sample of the template was provided in the Pilot Study Report (included here as Appendix A). Each report has a header table that summarises the testing to indicate whether all tests were passed or not, along with final sign off by the lead modeller, lead GIS analyst and Project Manager. There then follows a set of tables with data quality measures under the main headings of:

- Extents;
- Nodes;
- Reaches;



- Models.

Typical sub-headings include:

- Completeness. Commission and omission of data (where 'commission' indicates that data have been incorrectly included, and 'omission' means that they have been incorrectly left out);
- Logical Consistency. Conceptual consistency, domain consistency, format consistency and topological consistency of data;
- Positional Accuracy. Positional accuracy of data;
- Temporal Quality. Accuracy of time measurement, temporal consistency and temporal validity of data;
- Thematic Accuracy. Classification correctness, non-quantitative attribute correctness and quantitative attribute accuracy of data;
- Topology specific conformance tests.

## 6.1. Metadata

Metadata accompany the GIS data files using an embedded xml file with the same file name.

In addition to the required metadata elements, an additional element has been added to capture any repairs to self-intersections that were carried out; more specifically, this reports on any self-intersections that were repaired, using the 0.01m buffer method, and the number of features to which this procedure was applied.

## 7. Critical assessment of the applied methodology

The applied methodology has been proven to work successfully to produce flood hazard maps for 27,000 km of subject watercourses, for nine different scenario/AEP combinations, in a relatively short period of time. Some sample results of the applied methodology are presented below, followed by a critical assessment of the method.

### 7.1. Results of the applied methodology

Sample outputs of the applied methodology are presented below; a location map (Figure 7.1) shows the location of the areas shown in the subsequent figures. These show samples of the mapping of flood extent, depth, level and velocity, as well as node data and reach classification. One figure (Figure 7.9) demonstrates the impact of the refined method used on Arterially Drained channels (for more examples, see Appendix C).

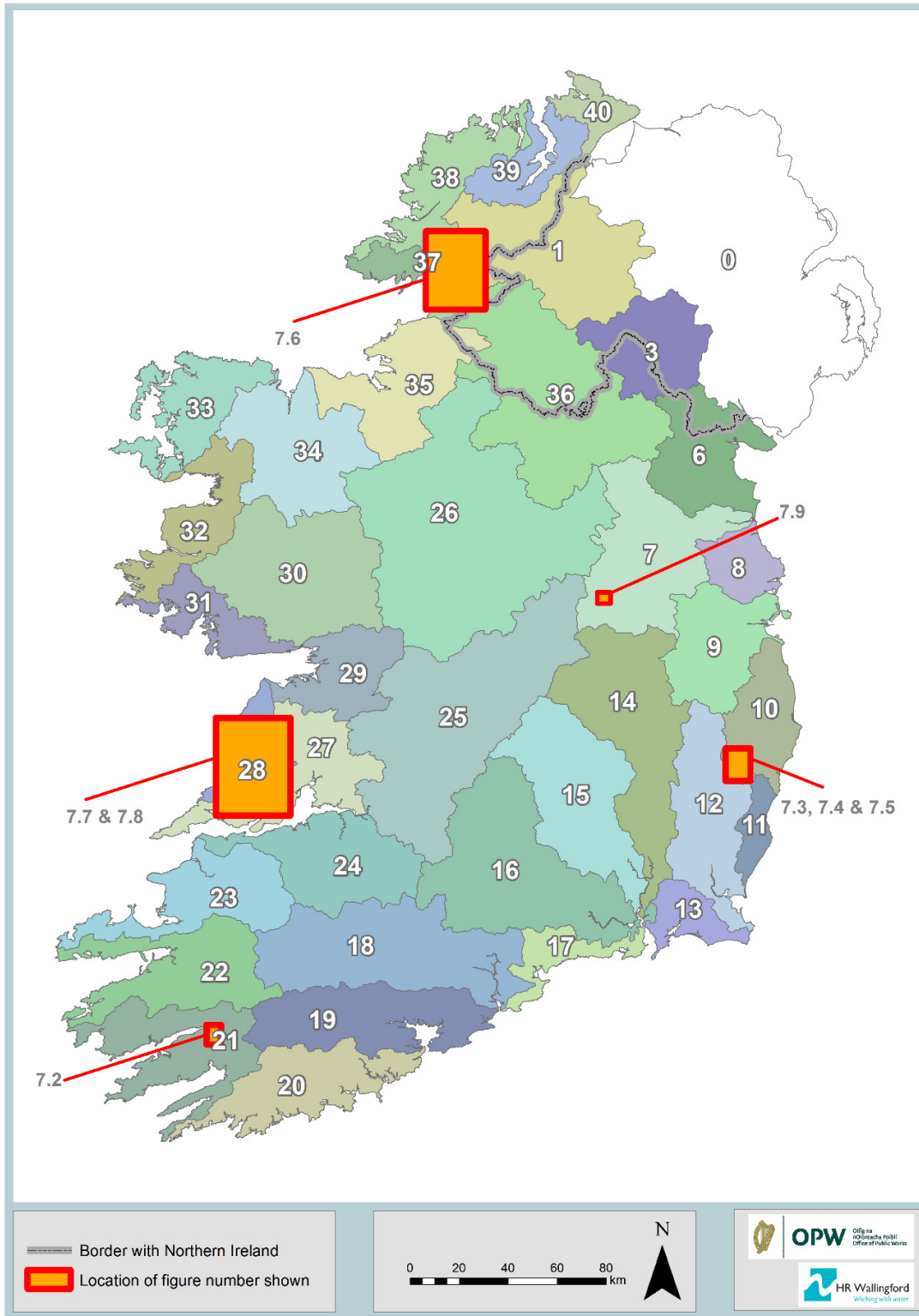


Figure 7.1: Map of UoMs showing sample results locations annotated with figure numbers

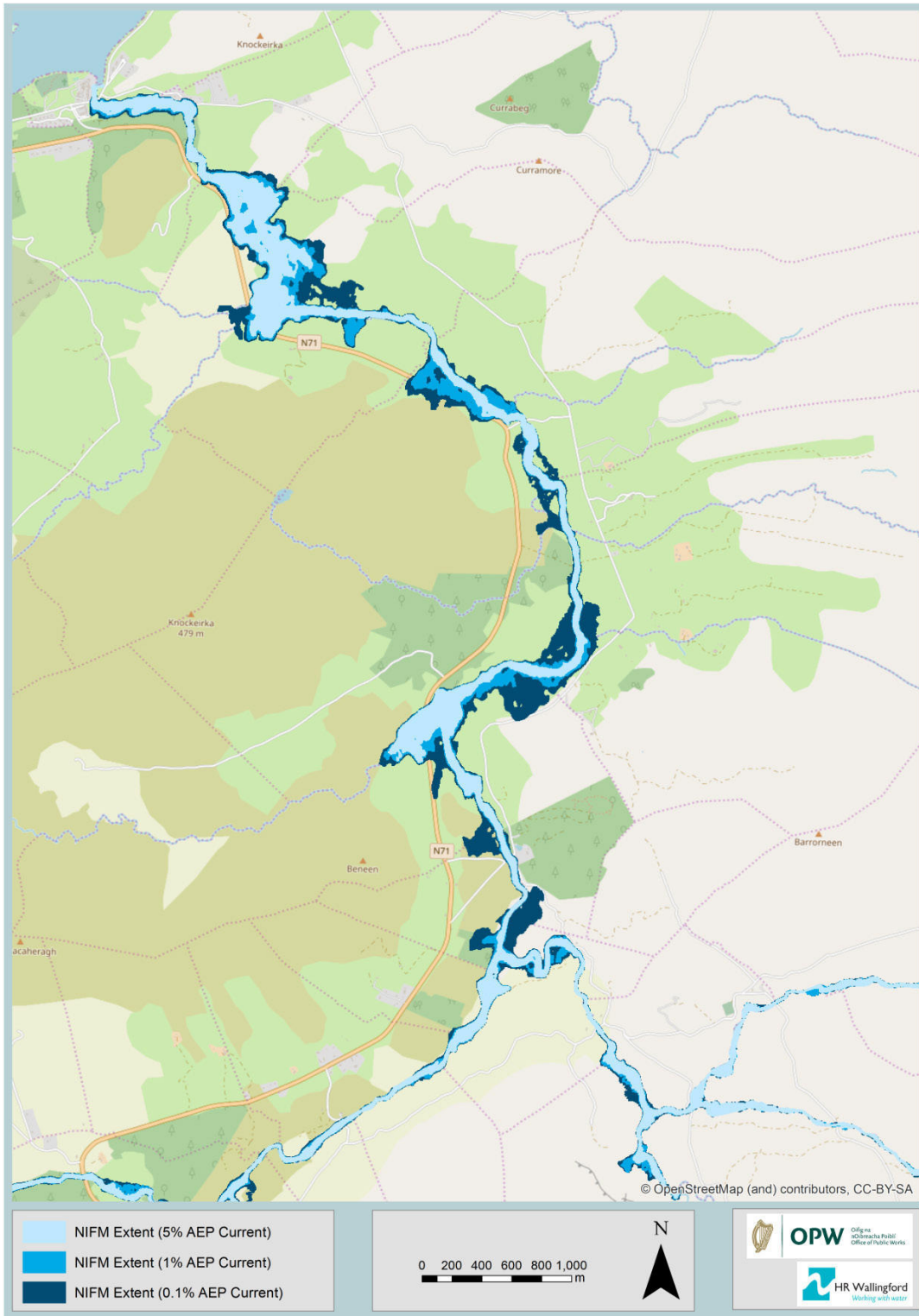


Figure 7.2: Sample results: flood extent spatial data

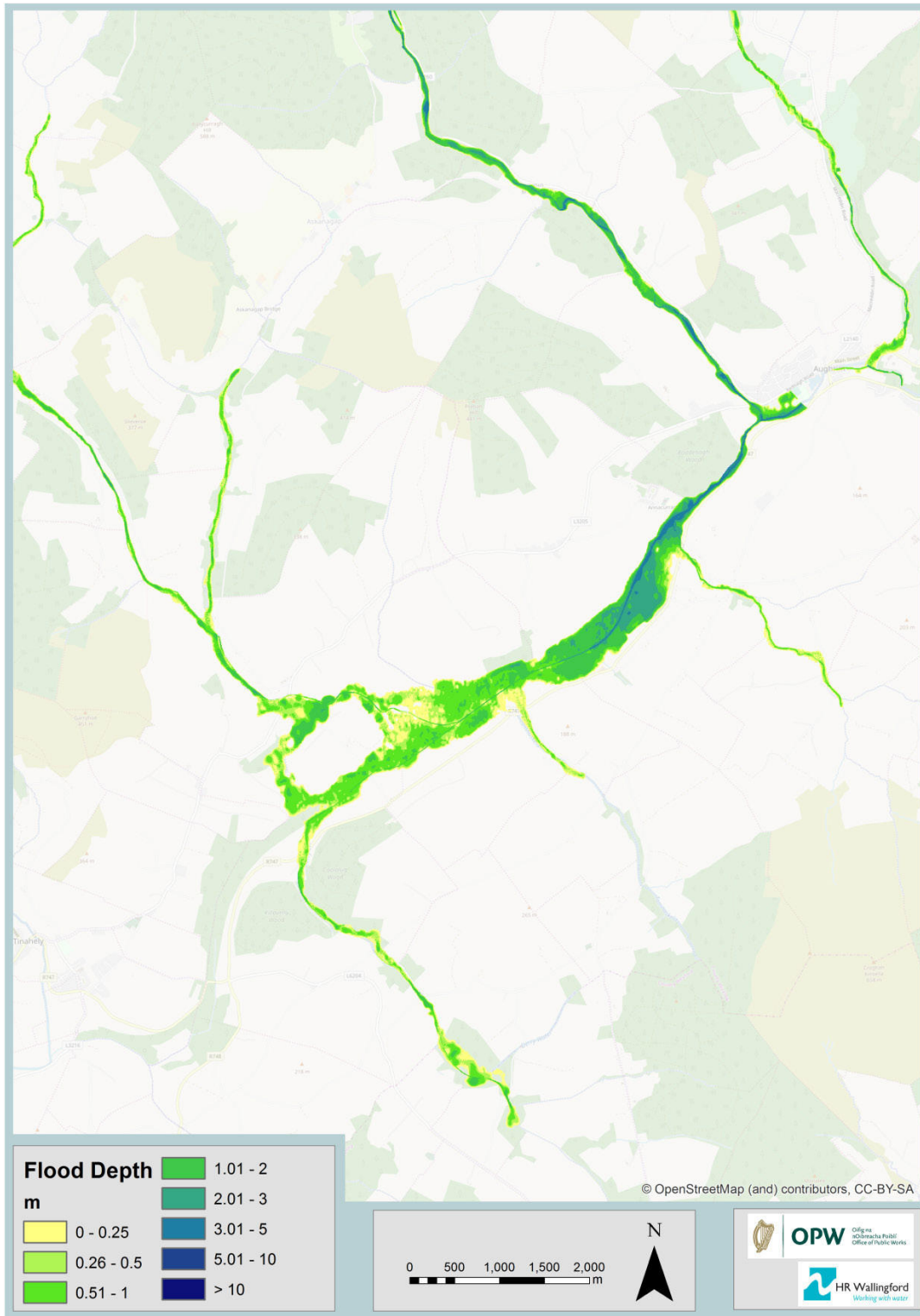


Figure 7.3: Sample results: flood depth spatial data



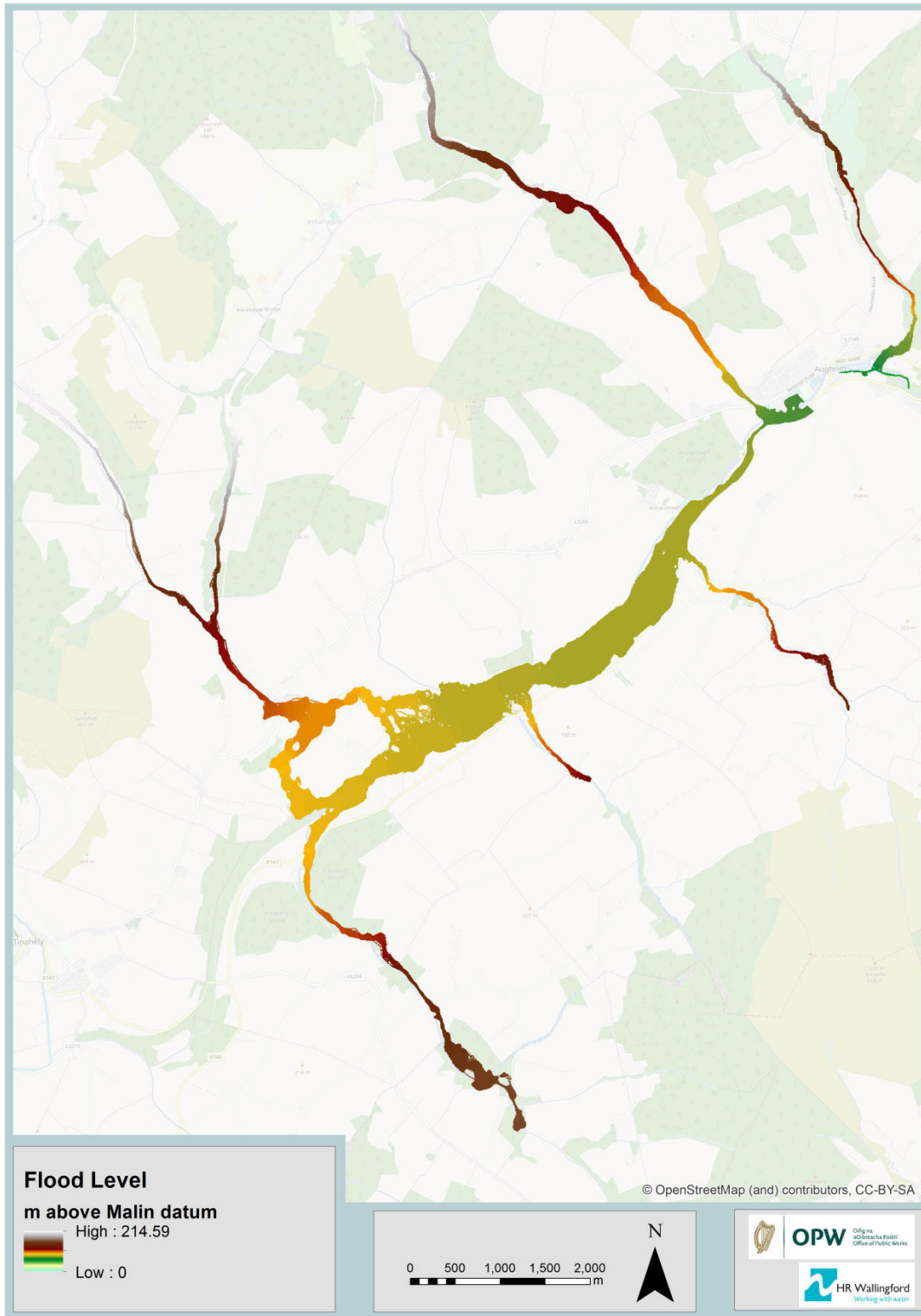


Figure 7.4: Sample results: flood level spatial data

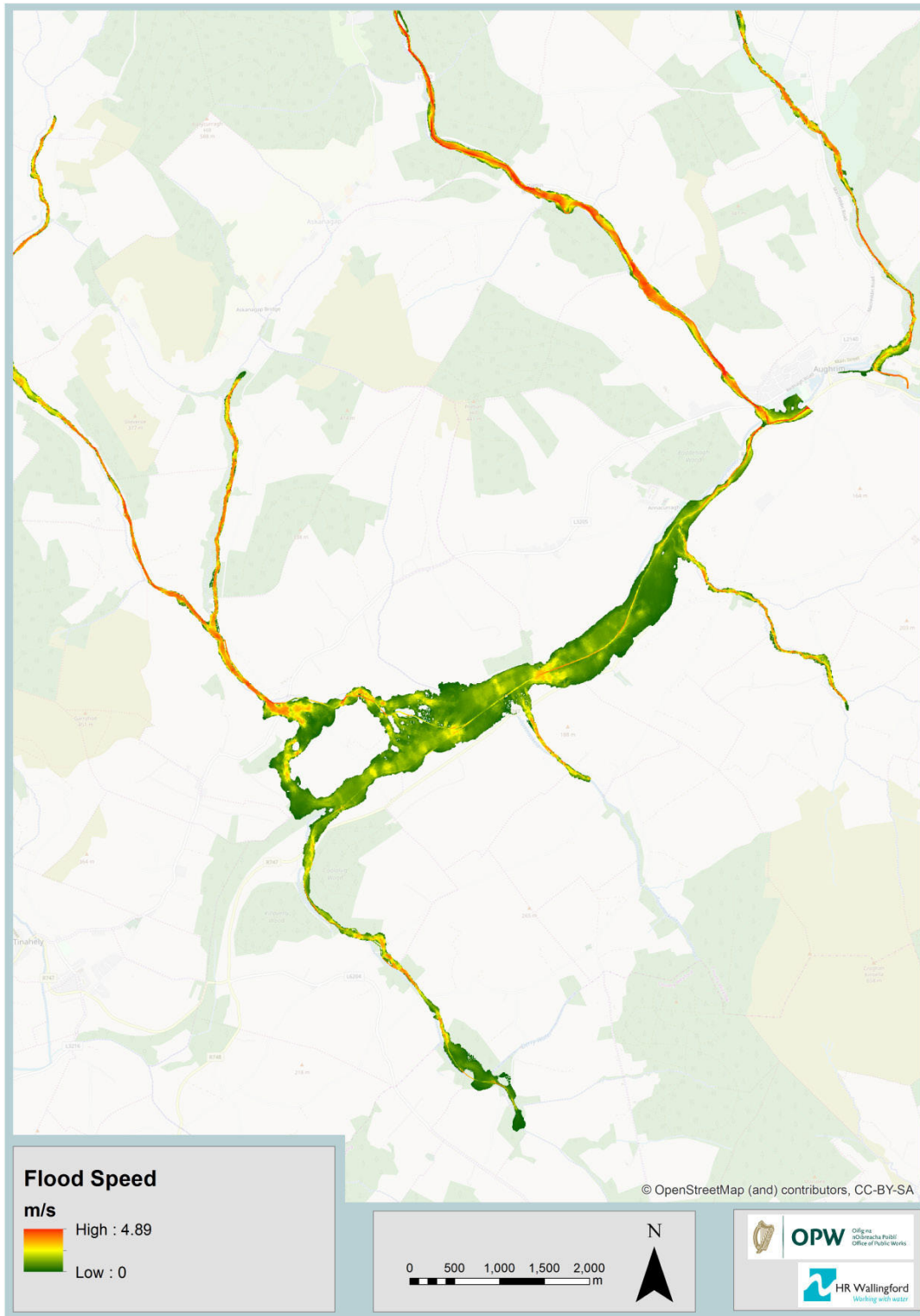


Figure 7.5: Sample results: flood velocity spatial data

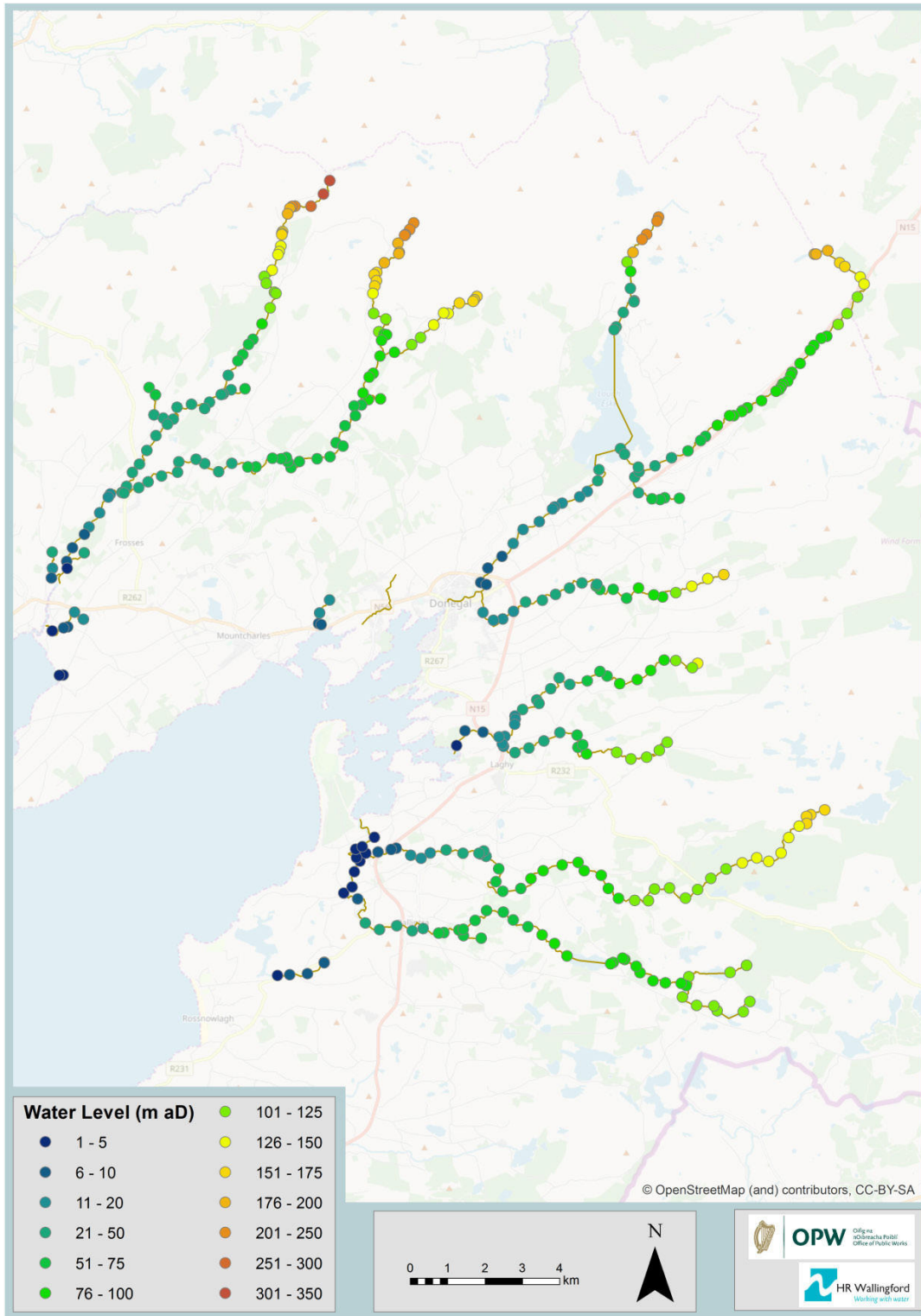


Figure 7.6: Sample results: flood node spatial data

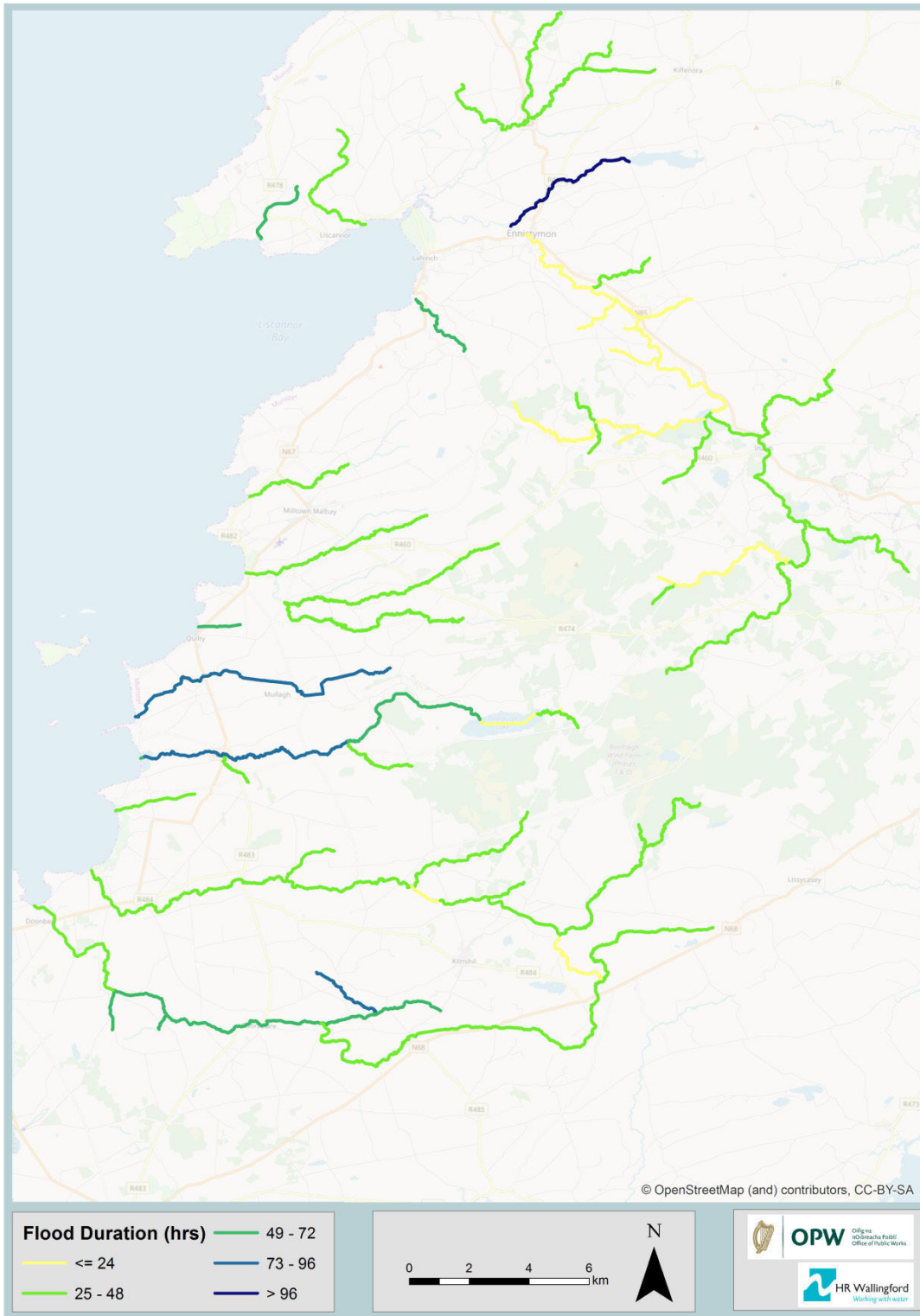


Figure 7.7: Sample results: Classification of reach by duration of flooding



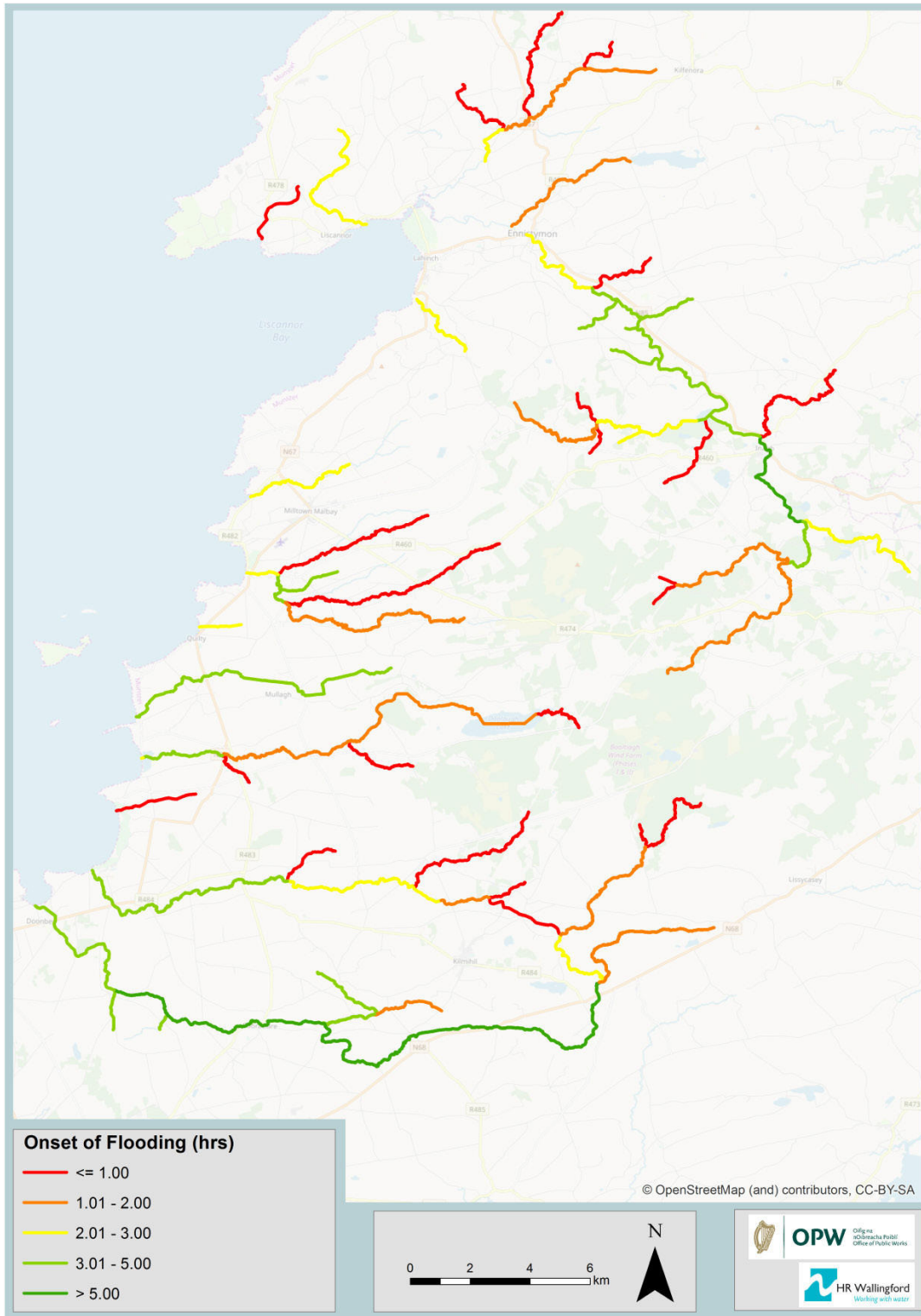


Figure 7.8: Sample results: Classification of reach by onset of flooding



Figure 7.9: Sample results for an Arterially Drained location: Comparison of flood extents on the Kinnegad River for the AEP 0.1% event flood extent (showing original extents and those of the refined AD pilot method)

## 7.2. Critical assessment

The applied methodology was a compromise between the need for national-scale flood inundation mapping, and the requirement for improvement over the results of PFRA1; in addition, the results of detailed CFRAM modelling were used to validate the NIFM results in the Pilot Study Areas.

The Pilot Study usefully identified aspects of the method that needed to be refined in order to improve results in certain areas, particularly for the circumstances encountered within those Units of Management (18 and 26). The assumptions tested in the modelling trials on the Pilot Study Areas, and the key resultant recommendations for the national roll-out were as follows, including updated aspects from the Arterial Drainage regional enhancement study:

- Defining the model domain: The DTM approach was trialled for both Pilot Study Areas and was used in the national roll out;
- Estimating the river channel surface elevation: The approach based upon 50 m spacing of cross-sections was trialled for both Pilot Study Areas and was used for the national roll out;

- Channel capacity and  $Q_{MED}$  adjustment for different types of channel: The following adjustments for a range of channel types were trialled for both Pilot Study Areas and used in the national roll out:
  - On rivers with a shallow slope, the channel capacity is approximately  $Q_{MED}$ ;
  - On moderately sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
  - On steeply sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
  - On rivers with arterial drainage works the channel capacity was originally defined as being approximately 135%  $Q_{MED}$ . This was updated to 190%  $Q_{MED}$  in the relevant eastern UoMs and 170%  $Q_{MED}$  in the relevant western UoMs;
  - On rivers through urban areas, the channel capacity is approximately  $Q_{MED}$ .
- Correction for proportion of channel captured by the DTM: The following adjustments were used, to account for part of the channel that was already captured in the DTM; these values represented the additional amount of channel capacity to create in the DTM for these categories:
  - Width < 5m: no adjustment;
  - Width >5m to <10m: adjust to 85% of full capacity;
  - Width >10m to <15m: adjust to 70% of full capacity;
  - Width >15m to <20m: adjust to 60% of full capacity;
  - Width >20m to 40m: adjust to 50% of full capacity;
  - Width > 40m: adjust to 35% of full capacity.
- Simplified representation of bridges: Setting the channel roughness  $n$  to 0.2 at bridges gives a reasonable approximation of the afflux impact on water levels upstream of the bridge. This approach was trialled for both Pilot Study Areas and used in the national roll out.
- Integration with CFRAM models: An approach based upon a simple union and dissolve of the NIFM and CFRAM datasets was trialled and used in the national roll out.

The Pilot Study Areas were judiciously chosen to capture the greatest possible set of circumstances to be encountered in the national roll out. The adjustments to the original method that are outlined above gave considerable improvements to the accuracy generally nationwide.

The applied method was developed and refined to offer the best results possible nationally. In some areas, this has meant that the methods were not quite as accurate as elsewhere. For example, the rules for channel size were necessarily generalised, but there are some locations where the river channels did not match these general rules and this affected the accuracy of the flood outlines. In arterially drained areas, the variability in the channel capacity could not be well-represented by a single value of 135%  $Q_{MED}$ , leading to inaccurate (over- or under-estimated) flood extents there, and so an additional study was carried out to derive updated, regionally-relevant  $Q_{MED}$  factors which gave more accurate results. Where modelled flood extents are smaller than would be expected, it is likely to be due to a combination of several contributory factors:

- the overall channel capacity being too big locally due to a greater than expected proportion of the channel being represented in the DTM;
- for rivers with very flat gradients, over-estimation of channel capacity by the Manning equation, which produces higher depths in these circumstances;
- the presence of alternative flow routes, such that water which could have caused floodplain flooding flows into other streams in areas of low channel capacity upstream of the reach in question;
- flow attenuation in small lakes.



The modelling did not include hydraulic structures such as control gates. This influenced the results in areas where flood control gates affected flooding, for example on tributaries of the River Shannon.

The definition of the model domain via a DTM approach has proven to be the best option in most catchments; however, in some locations this approach resulted in a domain that was too small, so that flood extents were unrealistically constrained. In those locations, the domains were extended and the models were re-run.

Integration of the NIFM model results with those of CFRAM, using a simple union and dissolve, has worked well.

Location-specific features that would benefit from further investigation are outlined in Section 9.1.

### 7.2.1. Assessment of flows

The modelled flows were compared with the design flows at nodes spaced less than 10km along the river network. The differences between the modelled flow and the design flow at each location were ranked and the key statistics are given in Table 7.1, for both the 50<sup>th</sup> and 75<sup>th</sup> percentile values. The percentiles are calculated across the whole range of the dataset that represents the difference between the modelled and design flows at all locations. The 50<sup>th</sup> percentile is thus the median of the values (with half of the values falling below this value, and half above), and the 75<sup>th</sup> percentile is the third quartile.

Table 7.1: Comparison of the modelled AEP 1% flows with the design AEP 1% flows

UoM	Absolute difference (%)		Difference (%)	
	P50	P75	P50	P75
1	3.8	9.8	-0.4	0.4
3	4.5	13.6	-3.3	-0.2
6	9.6	23.9	-8.0	-1.3
7	14.9	27.0	-12.8	-2.0
8	12.2	30.4	-12.2	-3.4
9	5.1	12.6	-2.0	0.0
10	5.2	10.4	-0.1	4.2
11	3.2	14.1	-0.2	-0.1
12	3.2	11.1	-0.7	0.0
13	4.1	9.5	-0.4	0.3
14	10.5	27.3	-3.5	0.0
15	7.0	20.1	-1.1	0.0
16	6.8	20.8	-2.8	0.0
17	5.9	13.3	-0.1	4.1
18 (Pilot)	4.6	10.7	-0.4	2.8
19	2.2	6.9	-0.2	0.0
20	2.2	6.1	-0.2	0.0
21	1.7	10.0	-0.1	0.0

UoM	Absolute difference (%)		Difference (%)	
	P50	P75	P50	P75
22	1.5	7.7	-0.6	-0.1
23	2.3	6.8	-0.1	1.4
24	10.0	32.0	-11	-1.9
25	10.1	27.6	-9.3	-0.9
26 (Pilot)	8.7	15.9	-7.0	-1.1
27	5.4	17.8	-3.8	-0.4
28	2.1	5.7	-0.2	0.0
29	7.2	12.8	-4.0	-0.1
30	6.9	19.3	-2.5	0.0
31	3.6	9	-1.7	0.0
32	1.4	7.3	-0.2	0.0
33	0.7	5.1	-0.1	0.0
34	3.5	11.5	-1.2	-0.1
35	4.6	13.7	-2.0	-0.1
36	4.8	11.1	-2.0	0.0
37	1.6	9.0	0.0	1.6
38	2.5	12.2	-0.2	0.0
39	2.6	5.3	-1.3	-0.1
40	0.4	3.5	-0.2	-0.1

In the majority of UoMs, the modelled flow is within a similar percentage difference to the design flow as in the Pilot Study catchments. However, in UoMs 07, 08, 14, 24 and 25 the modelled flows do not compare as well to the design flows. The revised Arterial Drainage method only slightly improved the flow results in UoMs 07, 08 and 24. The differences between the modelled flows and the design flows are due to:

- Headwater streams of similar size – where two headwater streams of a similar size join, the model may estimate higher flow than the design flow due to the timing of the relative inputs. This is considered to be a reasonable cause for difference with the design flow because the spatial proximity means that both stream catchments would respond to the same storm event;
- Lakes on headwater streams – in the modelling process headwater streams (stream order 1) were not split into a series of models at lakes, unlike on higher order streams; this means that the attenuation effect of the lake can lead to a lower flow in the model than in the design flow in the downstream reach;
- Floodplain storage – on some rivers there is significant floodplain storage where the flow is attenuated in the hydraulic model but not in the design flow. This means that the model has lower flow than expected from the design flow;
- Flooding from multiple watercourses – on some flat catchments the flood extent covers multiple streams where the water from each stream spreads across other streams. This can cause lower flows to be extracted from the model than the design flows on some streams and higher flows on others depending on the geometry.

## 8. Assessment of the accuracy of the flood extents

The preceding PFRA1 approach was undertaken for all nodes with a catchment area greater than 1 km<sup>2</sup>, for three flood event probabilities: 10%, 1% and 0.1% AEP. By comparison, the NIFM project has been undertaken for all nodes with a catchment area greater than 5 km<sup>2</sup>, for three flood event probabilities: the 5%, 1% and 0.1% AEP.

This section presents a comparison of NIFM results with those of PFRA1, followed by a statistical assessment of the accuracy of the results.

### 8.1. Results comparison with PFRA1

A key objective of the NIFM project was to produce flood maps that are an improvement on the first cycle PFRA mapping. This section provides comparisons between the first and second cycle PFRA maps.

Sample PFRA1 and NIFM results for four UoMs are given in Figure 8.1 to Figure 8.4. These show that the NIFM extents are visually more realistic. The NIFM model results do not extend upstream as far as those of the PFRA1 models, due to differing definitions in area of coverage. The NIFM model results include lakes that form part of the river network, giving a more sensible, continuous coverage.

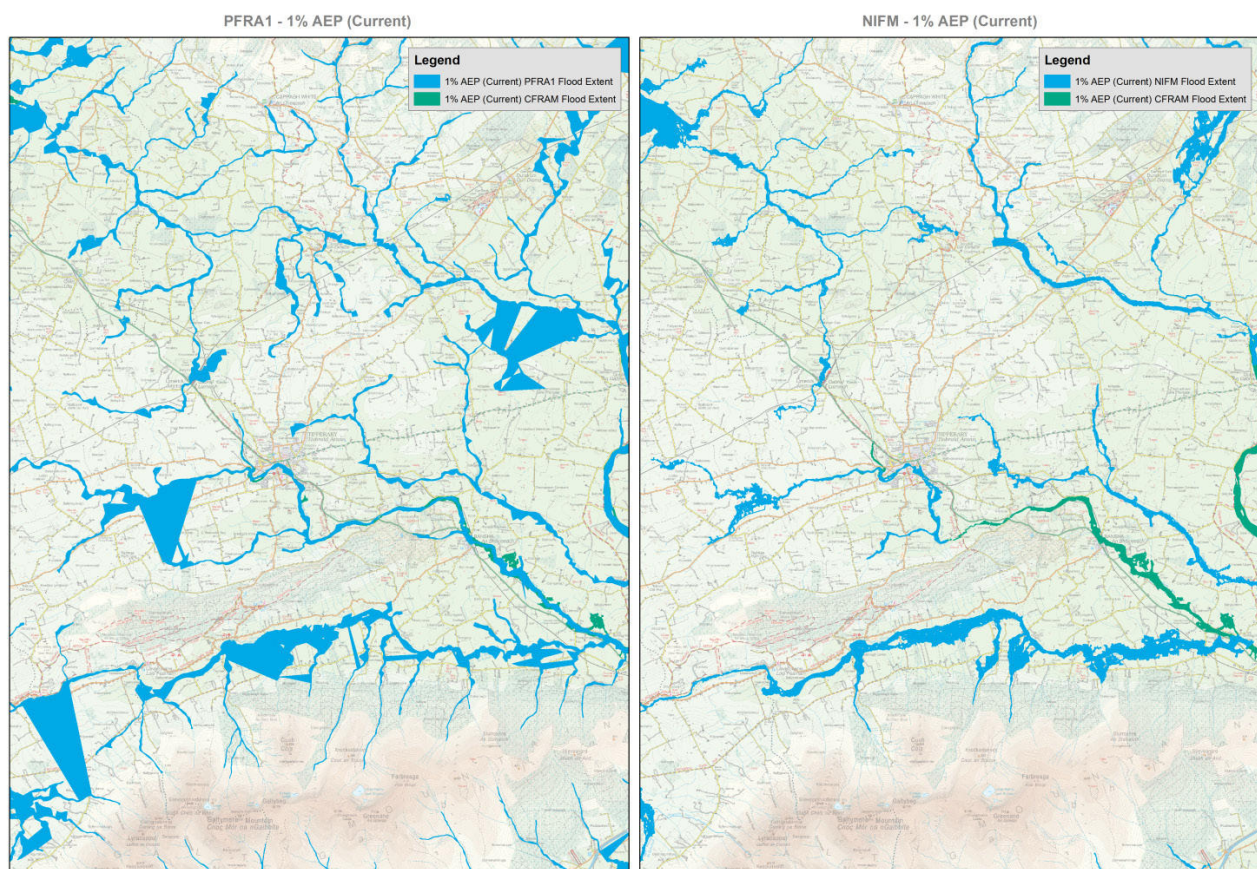


Figure 8.1: Sample PFRA1 versus NIFM model output for UoM 16

Source: HR Wallingford



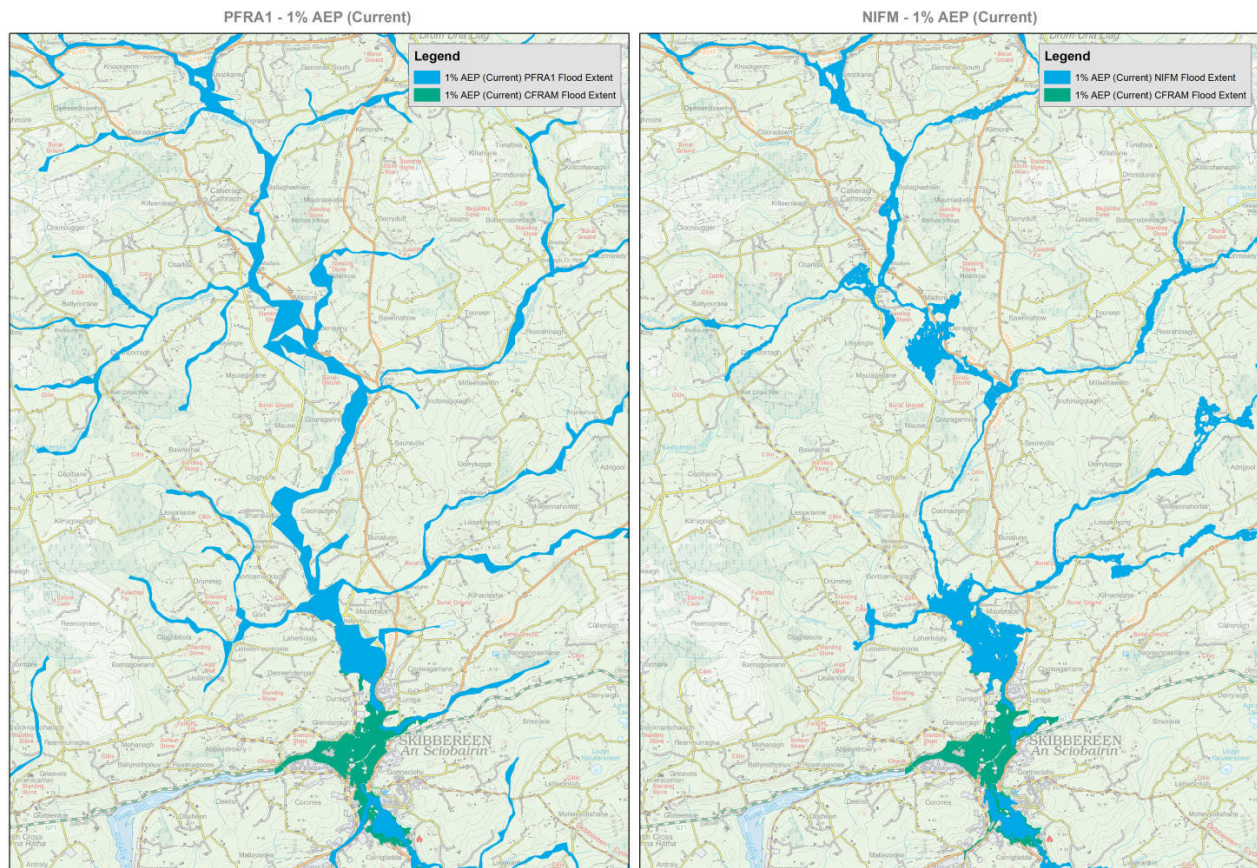


Figure 8.2: Sample PFRA1 versus NIFM model output for UoM 20

Source: HR Wallingford

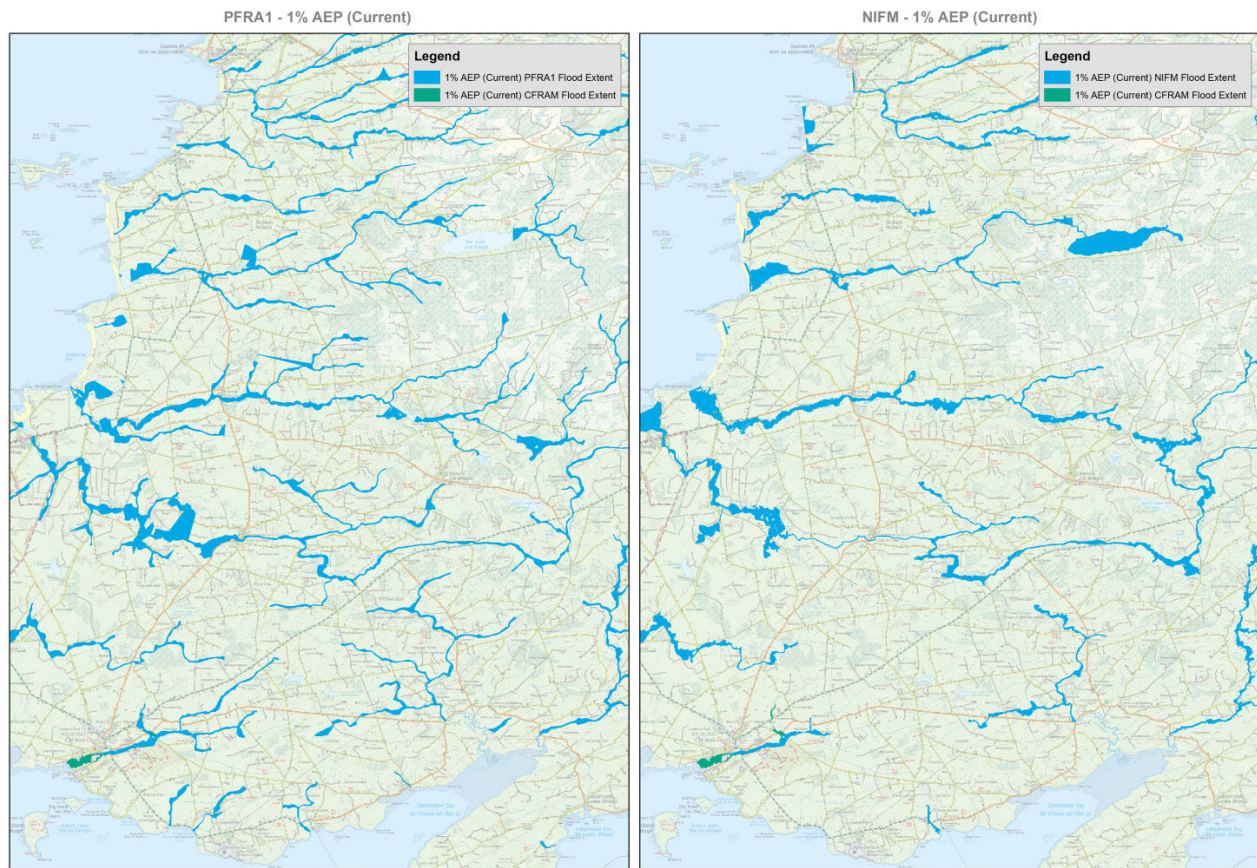


Figure 8.3: Sample PFRA1 versus NIFM model output for UoM 28

Source: HR Wallingford



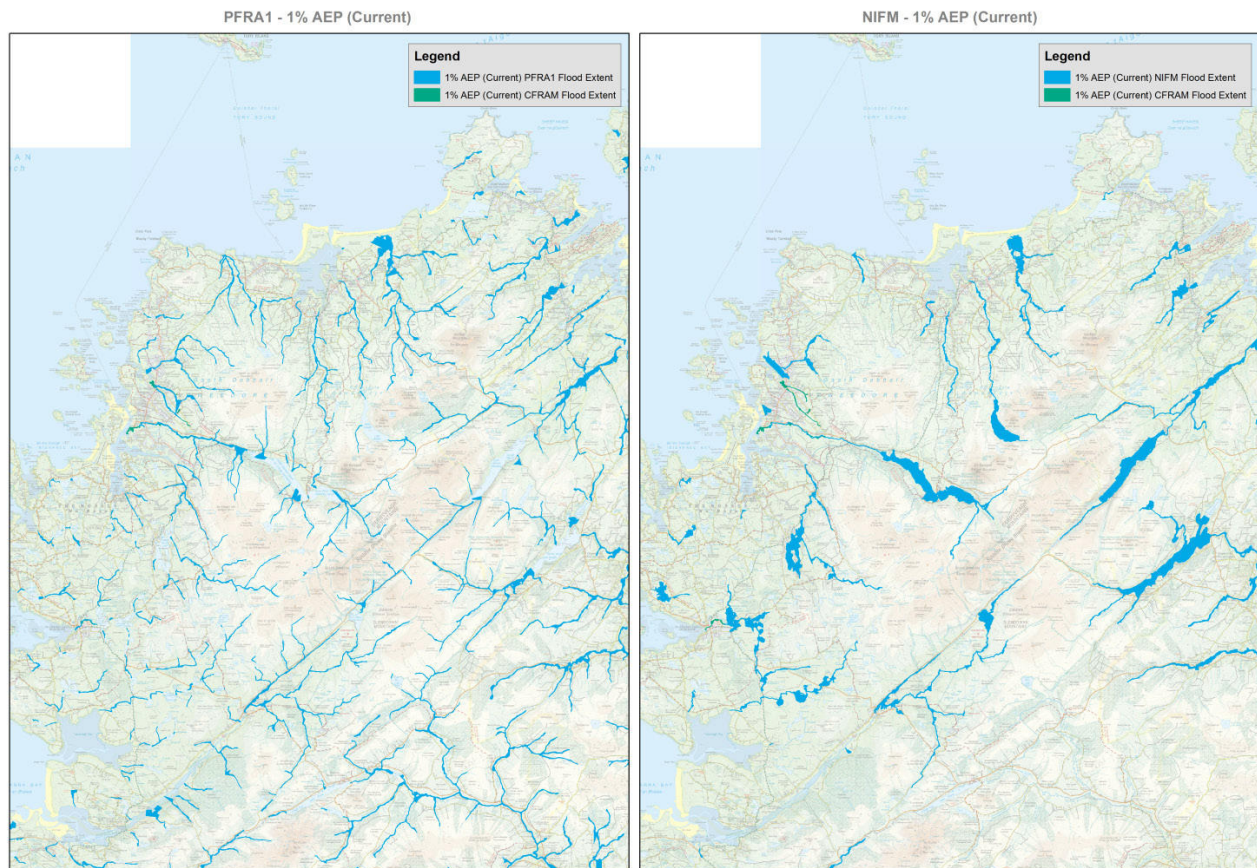


Figure 8.4: Sample PFRA1 versus NIFM model output for UoM 38

Source: HR Wallingford

## 8.2. Results improvement in areas of arterial drainage

In the UoMs containing significant benefiting lands with Arterially Drained (AD) channels, and, following the conclusion of the piloting to refine the automated channel capacity assumptions for AD channels, the flood extents have been reduced in many places.

The following maps provide an example comparison of the results prior to adjusting channel capacity for AD channels (Figure 8.5), and following the adjustment (Figure 8.6). Noting that all river channels shown in this location in UoM 3 are AD channels, it is evident that, after increasing channel capacity from 135% of  $Q_{MED}$  to 190% in stream order 1 and 2 channels, the flood extents have reduced in a number of areas. This is a particularly pleasing result at the AD channel headwaters where concern relating to excess flooding had been raised, following review of the draft results.



Figure 8.5: Flood extents in a location of arterial drainage in UoM 3 before channel capacity adjustment

Source: HR Wallingford



Figure 8.6: Flood extents in a location of arterial drainage in UoM 3 after channel capacity adjustment

Source: HR Wallingford



### 8.3. Statistical assessment of accuracy

Under the Pilot Study, a statistical assessment of the accuracy of the NIFM results versus PFRA1 results was possible due to the availability of more detailed, locally calibrated and validated results from the CFRAM programme models in UoM 18 and 26; a direct comparison of NIFM results versus PFRA1 results otherwise would show the difference between them, but would not show which is the more accurate. A statistical assessment was carried out as an additional analysis on the 1% AEP (100-year return period) results.

The flood extents from the NIFM pilot modelling were compared with CFRAM results (and the PFRA1 results with CFRAM results) for two measures:

- Total flood area;
- The *F* statistical measure from Horritt and Bates (2001), where  $F = \text{Number of cells that are wet in both the model AND the observed} / \text{Number of cells that are wet in either the model OR the observed}$ .

NB: An *F* value of 100% is a perfect fit where every wet cell is the same in the model and observed and a value of 0% would mean that none of the same cells are wet in the model and observed. This is a more advanced measure of fit than total flood area because it takes account of spatial coincidence between the models. For our analysis the 'observed' reference measure is the CFRAM flood extent.

#### UoM 18

- F statistic:
  - The *F* value comparing the NIFM Pilot Model with CFRAM is 85.5%;
  - The *F* value comparing PFRA1 with CFRAM is 76.9%.
- Wet Area:
  - In UoM 18 the wet area from the NIFM Pilot Model is 3% greater than that from CFRAM;
  - In UoM 18 the wet area from PFRA1 is 6% less than that from CFRAM.

#### UoM 26

- F statistic:
  - The *F* value comparing the NIFM Pilot Model with CFRAM is 73.3%;
  - The *F* value comparing PFRA1 with CFRAM is 52.7%.
- Wet Area:
  - In UoM 18 the wet area from the NIFM Pilot Model is 6% greater than that from CFRAM;
  - In UoM 18 the wet area from PFRA1 is 7% less than that from CFRAM.

In both UoMs the NIFM model achieved a closer fit to CFRAM than PRFA1 using both measures. In addition, the NIFM flood extents tended to be greater than those from CFRAM which means that they are generally conservative. It also reflects the fact that the NIFM modelling has taken into account the additional recent years of data, which included the significant December 2015 flood event.

## 9. Suggestions for future improvements and applications of the flood extents

The NIFM project has mapped fluvial flood hazard across all subject watercourses having a catchment area of greater than 5km<sup>2</sup>. A number of potential improvements to the method are suggested below, as well as some ideas for adding value to the dataset by its further application.

### 9.1. Suggested improvements

The Pilot Study Report made two recommendations for the refinement of the methodology, as follows:

1. **Review DTM for individual rivers:** The proportion of the channel captured by the DTM is accounted for through the channel width. In some cases, such as on the River Suck of UoM 26, the capture is variable and the link to channel width does not follow the rules developed elsewhere. In such cases, increased accuracy would be achieved through a review of the DTM for individual rivers. In the future, the use of higher accuracy DTM data (such as LiDAR data) would improve the overall accuracy of the approach. The higher horizontal spatial resolution (1m versus 5m of IfSAR) would pick up features that are not present in the IfSAR data, and would better capture the size of the channels, and the presence of any defences or small embankments along the rivers. The LiDAR data's higher vertical accuracy (0.2m RMSE versus 0.7m of IfSAR) would represent the features better. **Representation of hydraulic structures:** Improved representation of key structures would increase the accuracy of the model in those locations. This would require structure data, which would need on-site survey or, at the very least, photos of structures. This should include bridges and control structures.

The national roll-out of the methodology has indicated the following potential additional improvements:

2. **Remit extension:** The remit could be extended to cover all subject watercourses with catchment areas greater than 1 km<sup>2</sup>, to match that of PFRA1, although the FSU 7-variable equation is recommended for application to catchments greater in area than 5km<sup>2</sup> (Gebre and Nicholson, 2012). Based upon a small study of Irish catchments down to 2.8km<sup>2</sup> in area, for those smaller catchments, Gebre and Nicholson (2012) noted that IH124 (Institute of Hydrology Report No. 124: Marshall & Bayliss, 1994) overestimates flows, the FEH approach slightly overestimates, and the FSU 7-variable equation slightly underestimates. They derived a new regression equation, which looked promising for 'small' catchments, but their sample size was small (just 38 catchments), the minimum catchment area tested was 5km<sup>2</sup>, and they advised further research. In conclusion, they pointed out that for application in Ireland, the FSU 7-variable equation is preferable to FEH due to the availability of physical catchment descriptors to support the FSU methods. Therefore, for application under NIFM with an extended remit, it would be sensible to maintain consistency by using the FSU 7-variable equation throughout, but with caveats for the flows calculated for the smaller catchments.
3. **Representation of flood defences:** For more accurate representation of flood defences, detailed information would be required, including crest levels, although these structures are likely to be uncommon outside of the CFRAM extents. An example of the DTM not full capturing flood defence level was found in UoM 13.
4. **Bespoke structure representation:** For example, in UoM 37 the dam crest was missing from the DTM at one end of a reservoir. This supports the suggested improved representation of hydraulic structures identified in the Pilot Study.



5. **Modified slope for variable reaches:** The use of an average river slope for calculating a reach-based river depth could be improved for those rivers which have significant changes in slope. This would improve the estimation of channel capacity and the resulting flood extents.

## 9.2. Suggested applications

In addition to the improvements suggested above, the flood hazard mapping developed for the NIFM project could be further applied in a number of ways to add value to this product; these are outlined below.

### 9.2.1. Generation of results for additional AEPs

At present, the NIFM results represent the 5%, 1% and 0.1% AEPs. It may be desirable to generate inundation maps for additional AEPs, for instance, to match those run for the CFRAM studies (in which 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEPs were simulated). One benefit of this flexibility would be the ability to verify the return period of an observed event using a more complete library of national maps.

The flows of specified return periods for NIFM are generated by multiplying the index flood ( $Q_{MED}$ ) by relevant growth factors extracted from CFRAM growth curves that were updated nationally for each UoM. It would therefore be a straightforward task to generate flows for additional AEPs and use these to run the hydraulic models and thus to generate the additional spatial data.

### 9.2.2. National flood risk assessment

At present, the NIFM results represent maps of fluvial inundation as the hazard (i.e. the physical and statistical attributes of the flood waters). By combining the flood hazard data with information on the impacts of the flooding, that is, the exposure of people and assets to floods and the susceptibility of the elements at risk to suffer from flood damage, the flood risk can be derived.

Flood risk analysis requires an assessment of the consequences of flooding. Consequences are typically defined in terms of the number of properties flooded or the economic costs of flooding. For this analysis it would be possible to combine the fluvial flood maps generated under the NIFM project with the information available from the CFRAM Programme to quantify risk. For each return period and each scenario it would be possible to utilise existing property information to quantify the consequences of flooding countrywide. The GIS layers of flood hazard would be overlaid on a property layer to facilitate the consequence analysis (see Figure 9.1). The results can be presented in tabular format as well as a GIS interface. This would enable identification of areas that are at high risk of flooding and can thus help support priorities at a national scale for flood risk mitigation.

The automated method used for the flood hazard modelling of NIFM lends itself well to applying the results to receptor data in order to calculate flood risk. The main additional requirement would be electronic datasets of receptor data (e.g. shapefiles of properties, addresses).

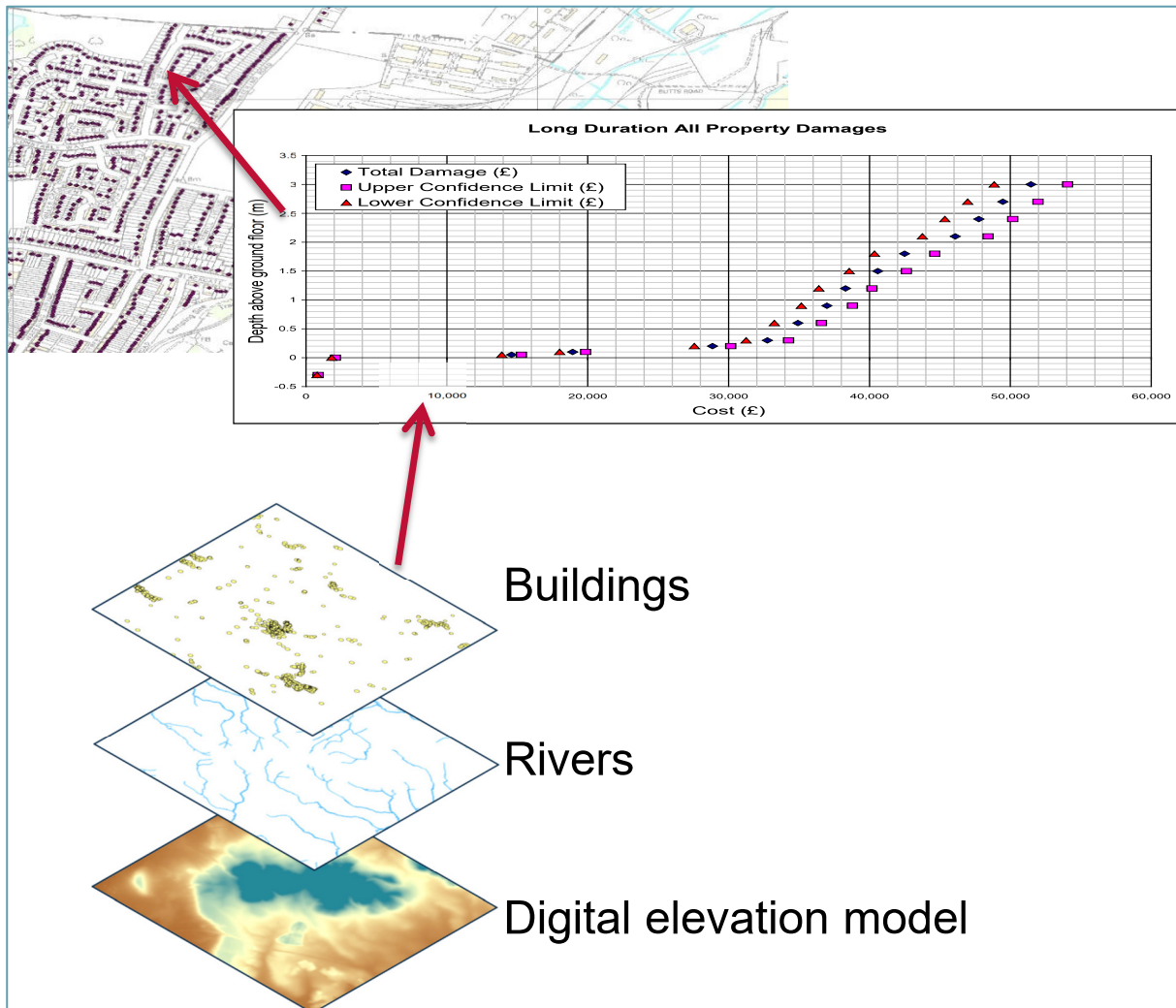


Figure 9.1: Example of the combination of spatial data to calculate flood risk

Source: HR Wallingford

### 9.2.3. Expansion to cover coastal flood hazard

The NIFM model results currently cover the fluvial extents of the subject watercourses, with downstream boundaries set as a tidal water level from the Irish Coastal Protection Strategy Study (OPW, 2011). The fluvial models could be extended further downstream to model the estuaries, including the combined effects of fluvial and coastal water levels.

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# Appendices

## A. Pilot Study Report

# National Indicative Fluvial Mapping project

Pilot Study Report: final version



MCR6058-RT001-R04-00

July 2019



## Document information

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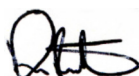
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## Glossary

AEP	Annual Exceedance Probability; represents the probability of an event being exceeded in any one year (%).
AFA	Area for Further Assessment – An area where, based on the Preliminary Flood Risk Assessment and the CFRAM Study Flood Risk Review, the risks associated with flooding were assessed as potentially significant.
ALTBAR	Mean elevation of catchment.
AMAX	Annual maximum flood flow.
ARTDRAIN2	Proportion of river network length included in Arterial Drainage Schemes.
BFI <sub>SOIL</sub>	Base Flow Index from Irish Geological Soils dataset. Often used as a permeability indicator.
CFRAM	Catchment Flood Risk Assessment and Management – the CFRAM studies developed more detailed flood mapping and measures to manage and reduce the flood risk for the AFAs.
DRAIN2	Drainage density.
DTM/DEM	Digital Terrain Model/Digital Elevation Model.
EPA	Environmental Protection Agency.
FAI	Flood Attenuation Index.
FARL	Index of flood attenuation due to reservoirs and lakes.
FEH	Flood Estimation Handbook.
FRMP	Flood Risk Management Plan.
FSU	Flood Studies Update.
FSR	Flood Studies Report.
GEV	Generalized Extreme Value distribution.
GLO	Generalised Logistic distribution.
HA	Hydrometric Area. Ireland is divided up into 40 Hydrometric Areas. Some of these have been combined to create the Units of Management.
HEFS	High-End Future Scenario to assess climate and catchment changes over the next 100 years assuming high emission predictions from the Intergovernmental Panel on Climate Change.
HPW	High Priority Watercourse: a reach modelled within an AFA.
ICPSS	Irish Coastal Protection Strategy Study.
IfSAR	Interferometric Synthetic Aperture Radar: a DTM dataset.
mAOD (P)	Metres Above Ordnance Datum at Poolbeg lighthouse, Dublin.
MPW	Medium Priority Watercourse: a reach modelled outside of an AFA.

MRFS	Mid-Range Future Scenario to assess climate and catchment changes over the next 100 years assuming medium emission predictions from the Intergovernmental Panel on Climate Change.
NIFM	National Indicative Fluvial Mapping project – will produce second generation indicative fluvial flood spatial data that are of a higher quality and accuracy to those produced for the first cycle PFRA.
OPW	Office of Public Works, Ireland.
OSi	Ordnance Survey Ireland.
PCD	Physical Catchment Descriptor.
PFRA	Preliminary Flood Risk Assessment – a national screening exercise, based on available and readily-derivable information, to identify areas where there may be a significant risk associated with flooding.
Q <sub>MED</sub>	Median annual flood used as the index flood in the Flood Studies Update. The Q <sub>MED</sub> flood has an approximate 50% AEP.
S1085	Typical slope of the river reach between 10%ile and 85%ile along its length.
SAAR	Standard Average Annual Rainfall.
UAF	Urban Adjustment Factor.
UoM	Unit of Management. The divisions into which the River Basin District is split in order to study flood risk.
URBEXT	Proportional extent of catchment area mapped as urbanised.
WMS	Web Map Service. A web mapping protocol, defined by the Open Geospatial Consortium, that is commonly used to serve mapped data in raster format to a web page or GIS desktop application.

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# 1. Introduction

The Office of Public Works (OPW), as the leading agency for flood risk management in Ireland, minimises the impacts of flooding through sustainable planning.

Under this remit, a first cycle National Preliminary Flood Risk Assessment (PFRA), completed in 2012, identified areas at significant flood risk known as Areas for Further Assessment (AFA), and included the production of national indicative fluvial flood maps.

The current National Indicative Fluvial Mapping (NIFM) project will produce second generation indicative fluvial flood spatial data that are of a higher quality and accuracy to those produced for the first cycle PFRA. This will cover 27,000 km of river reaches, separated into 37 drainage areas, consisting of 509 sub-catchments. This will achieve the following goals:

- Improved flood risk assessment for areas outside those zones designated as AFAs;
- Taking account of potential climate change impacts on flooding (Floods Directive, Article 14.4);
- Higher quality flood maps, improving upon the outputs of the first cycle PFRA outside CFRAM extents.

The project divides naturally into two phases to allow the process to be trialled and proven for two initial pilot Units of Management, UoM 18 (Munster Blackwater) and UoM 26 (Upper Shannon), and then applied to the remaining subject watercourses. The two Pilot Study Areas (Figure 1.1) have been selected judiciously, in order to capture the widest possible range of potential modelling challenges that will be faced during the national roll out; the catchments within these Units of Management range from predominantly rural to highly urbanised, steeply to gently sloping, with numerous lakes and arterial drainage channels in addition to the natural channel network.

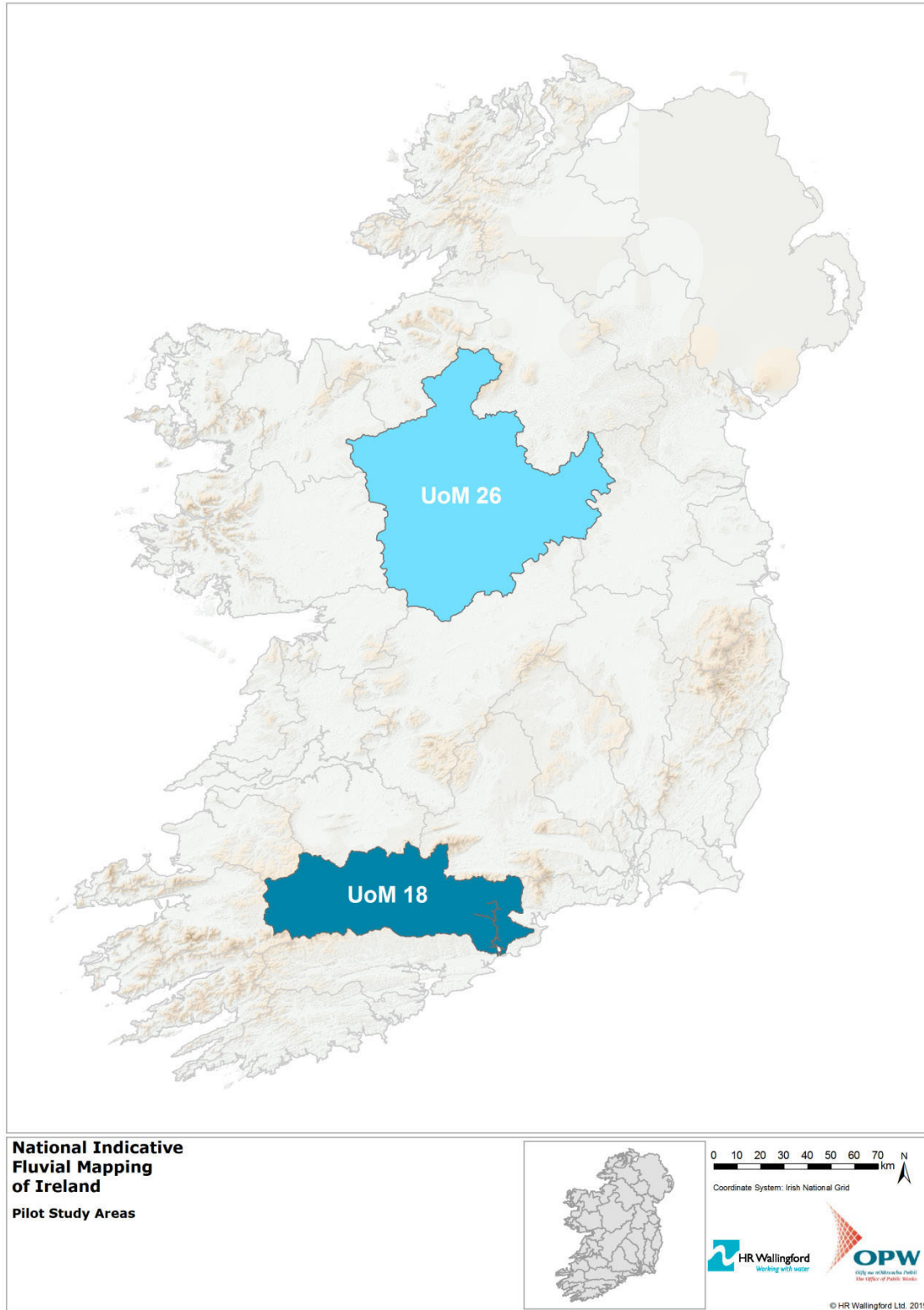


Figure 1.1: Map of Ireland showing the two Pilot Study Areas



## 1.1. UoM 18: Munster Blackwater

UoM 18 is situated in the South Western River Basin District, and is one of five UoMs in the district. Its major catchments and reaches are shown in Figure 1.2, with the UoM outline in black (showing the tidal reaches). The modelling of UoM 18 under the CFRAM study included over 230 km of modelled watercourses across nine Areas for Further Assessment (AFAs) and four intervening Medium Priority Watercourse (MPW) reaches (OPW, 2016b). In Figure 1.2, a distinction is made between High Priority Watercourses (HPWs), which are those areas modelled within AFAs, and MPWs, which are the areas modelled outside of the AFAs.

Main urbanised areas are found at Mallow, Fermoy, Kanturk and Youghal, and these contain a number of flood defence schemes that have been constructed in response to numerous historical flood events.

The River Blackwater is considered tidal as far as Lismore (33 km inland), and the River Bride tributary is tidal as far as Tallow Bridge (30 km inland).

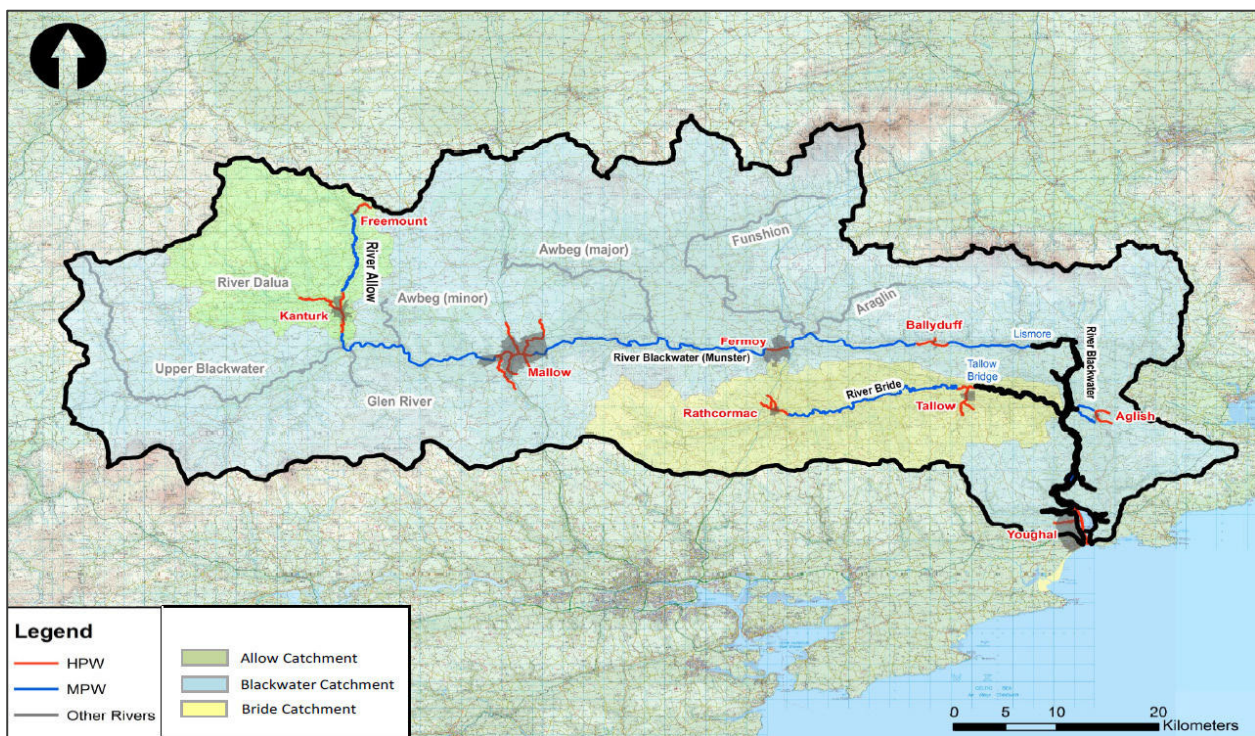


Figure 1.2: Map of UoM 18 showing major catchments and reaches, HPWs and MPWs

Source: OPW (2016a)

Under this project, for the Pilot Studies, the CFRAM model areas have been simulated in addition to the other subject watercourses (with catchment areas of greater than 5 km<sup>2</sup>); for the national roll out, the CFRAM modelled areas will not be simulated bar a 500 m overlap at the boundary.

For UoM 18, the subject watercourses therefore have had the catchments of area less than 5 km<sup>2</sup> removed, which significantly reduces the length of very small headwater tributaries. Then, removing the CFRAM modelled extents reduces the length of the main rivers (Stream Order 5+) to around 35% of the total. Medium-sized rivers (Stream Orders 2 to 4) are reduced to around 96% of the total, and small tributaries with catchment areas greater than 5 km<sup>2</sup> (Stream Order 1) are all modelled. For the definition of Stream Order, see Section 4.2.

The reaches of UoM 18 modelled under the CFRAM study are shown in Figure 1.3; these cover an area from upstream of Kanturk to its outfall at Youghal, the River Allow, River Bride and a number of smaller tributaries.

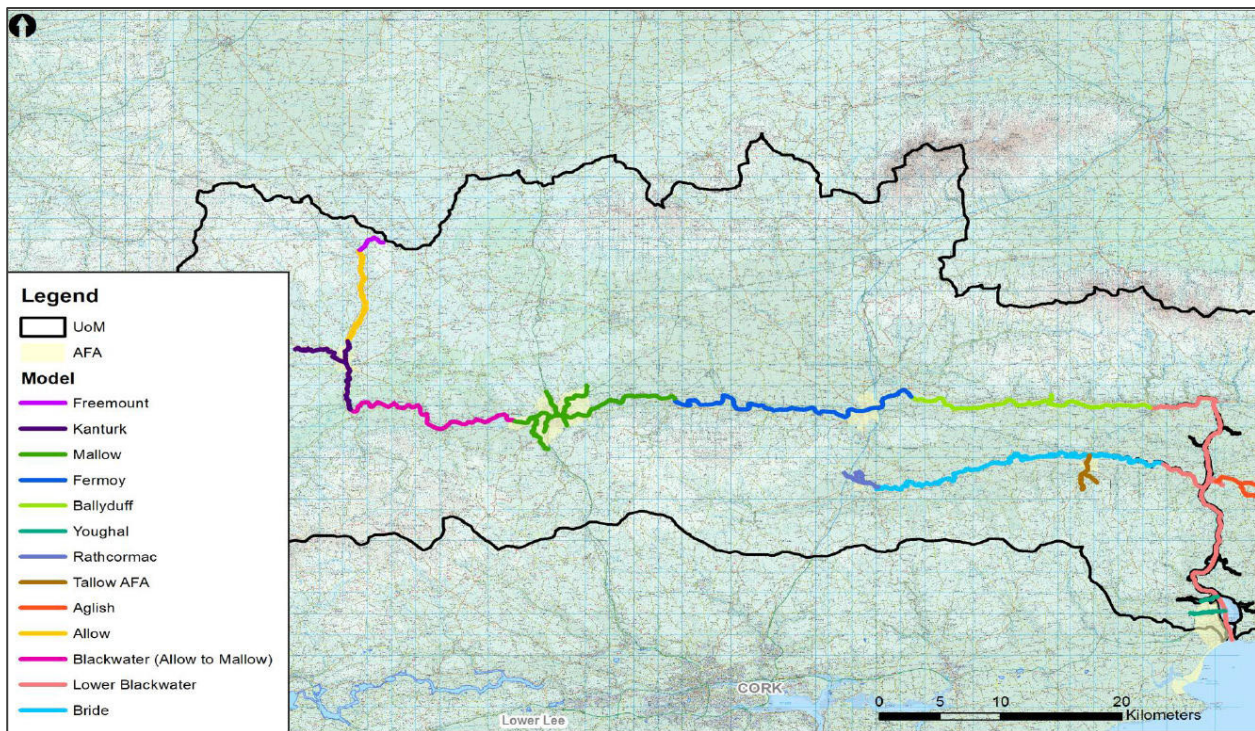


Figure 1.3: Map showing UoM 18 reaches modelled under the CFRAM programme

Source: OPW (2016b)

Figure 1.4 shows the subject watercourses for UoM 18, with the reaches covered by CFRAM studies highlighted. In total, 1100 km of watercourses have been modelled in UoM 18, of which 147 km are within the CFRAM extents and so will not be modelled in the national roll-out.



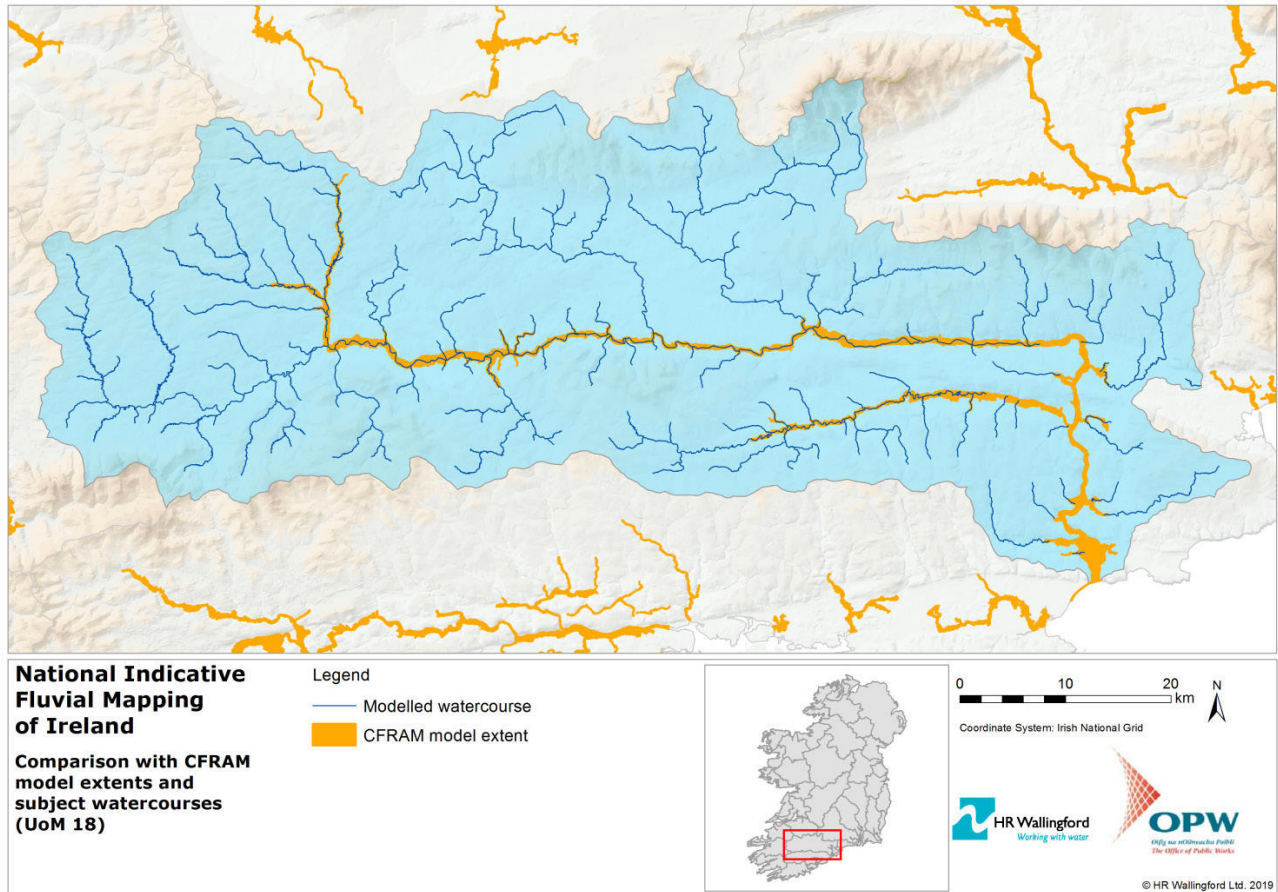


Figure 1.4: Map showing UoM 18 subject watercourses with CFRAM extents highlighted in orange

## 1.2. UoM 26: Upper Shannon

UoM 26 is situated in the Shannon International River Basin District (IRBD); its international classification reflects the fact that it extends into Northern Ireland. Across the whole of the Shannon catchment, there are 35 AFAs and 2 Individual Risk Receptors, reflecting the size and levels of urbanisation of the catchment.

Significant tributaries of the Shannon in UoM 26, which represents the Upper Shannon catchment, include the River Inny, and the River Suck, as well as the Shannon-Erne Waterway. There are several important lakes, including Lough Ree and Lough Allen. Its major catchments and reaches are shown in Figure 1.5, which also indicates the hydraulic model reference IDs (N01, *etc.*) from the CFRAM study.

Main urbanised areas are found at Boyle, Carrick-on-Shannon, Longford, and Athlone and these contain a number of flood defence schemes that have been constructed in response to numerous historical flood events.

UoM 26 contains a number of arterial drainage channels which were designed and built following the Arterial Drainage Act (1945) whereby OPW undertook various of arterial drainage schemes to improve land for agricultural production.

The River Shannon flows from UoM 26 into UoM 25 before reaching the sea, and so there is no tidal boundary to consider in UoM 26.

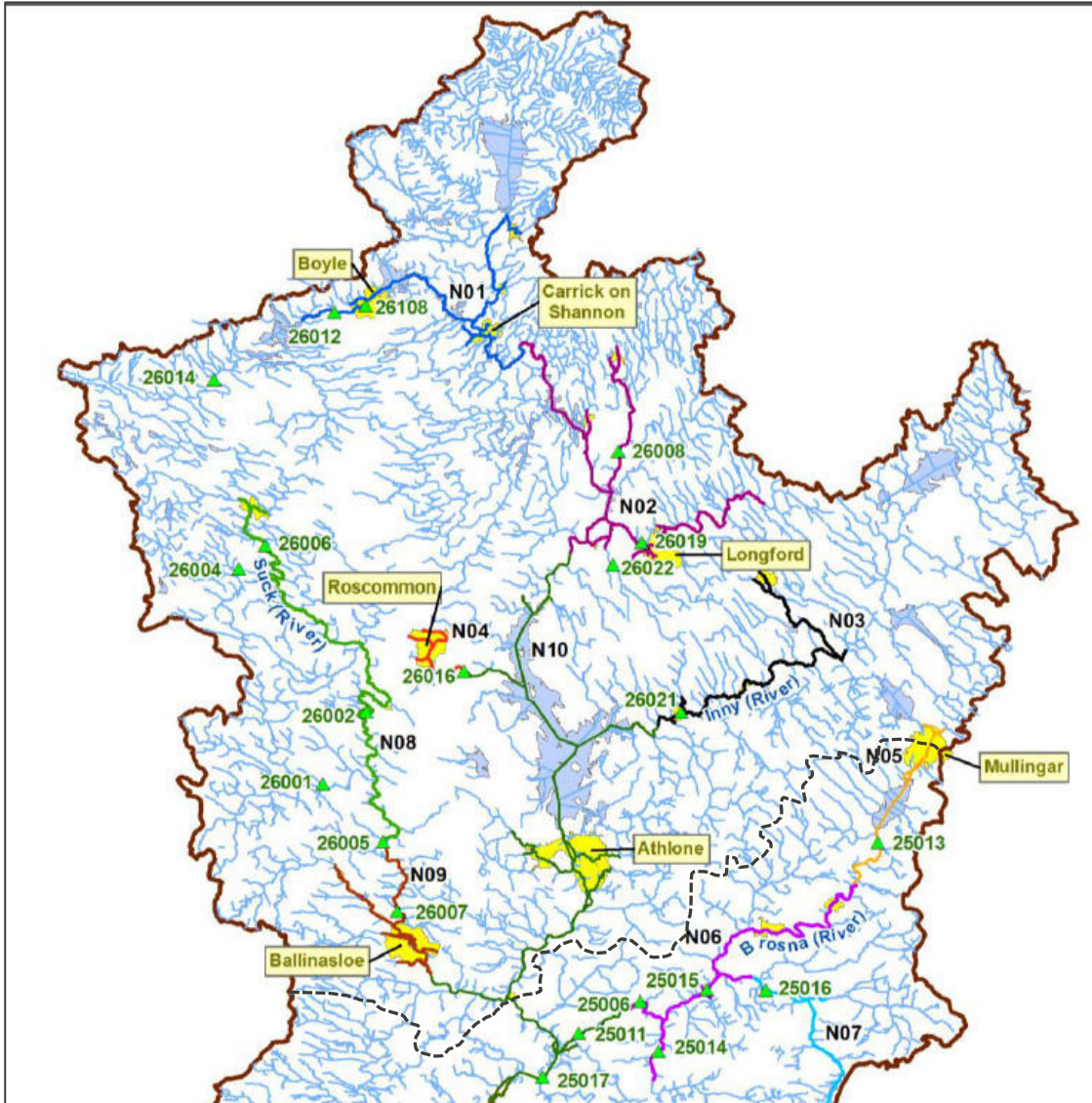


Figure 1.5: Map of UoM 26 showing major catchments and reaches, CFRAM model codes, and the boundary with UoM 25 (black dashed line)

Source: OPW (2016c)

Figure 1.6 shows the subject watercourses for UoM 26, with the extents of reaches covered by CFRAM studies highlighted. In total, 2150 km of watercourses have been modelled in UoM 26, of which 412 km are within the CFRAM extents and so will not be modelled in the national roll-out. For UoM 26, the subject watercourses have had the catchments of area less than 5 km<sup>2</sup> removed, which significantly reduces the length of very small headwater tributaries. Then, removing the CFRAM modelled extents reduces the length of the main rivers (Stream Order 5+) to around 35% of the total, medium-sized rivers (Stream Orders 2 to 4) are reduced to around 95% and small tributaries (Stream Order 1) are reduced to around 84% (for the definition of Stream Order, see Section 4.2).



The main reach of the Upper Shannon is highly controlled, with numerous structures that affect its natural flow regime. This reach lies inside the CFRAM extents and is not representative of the reaches to be included in the national roll-out of this NIFM methodology.

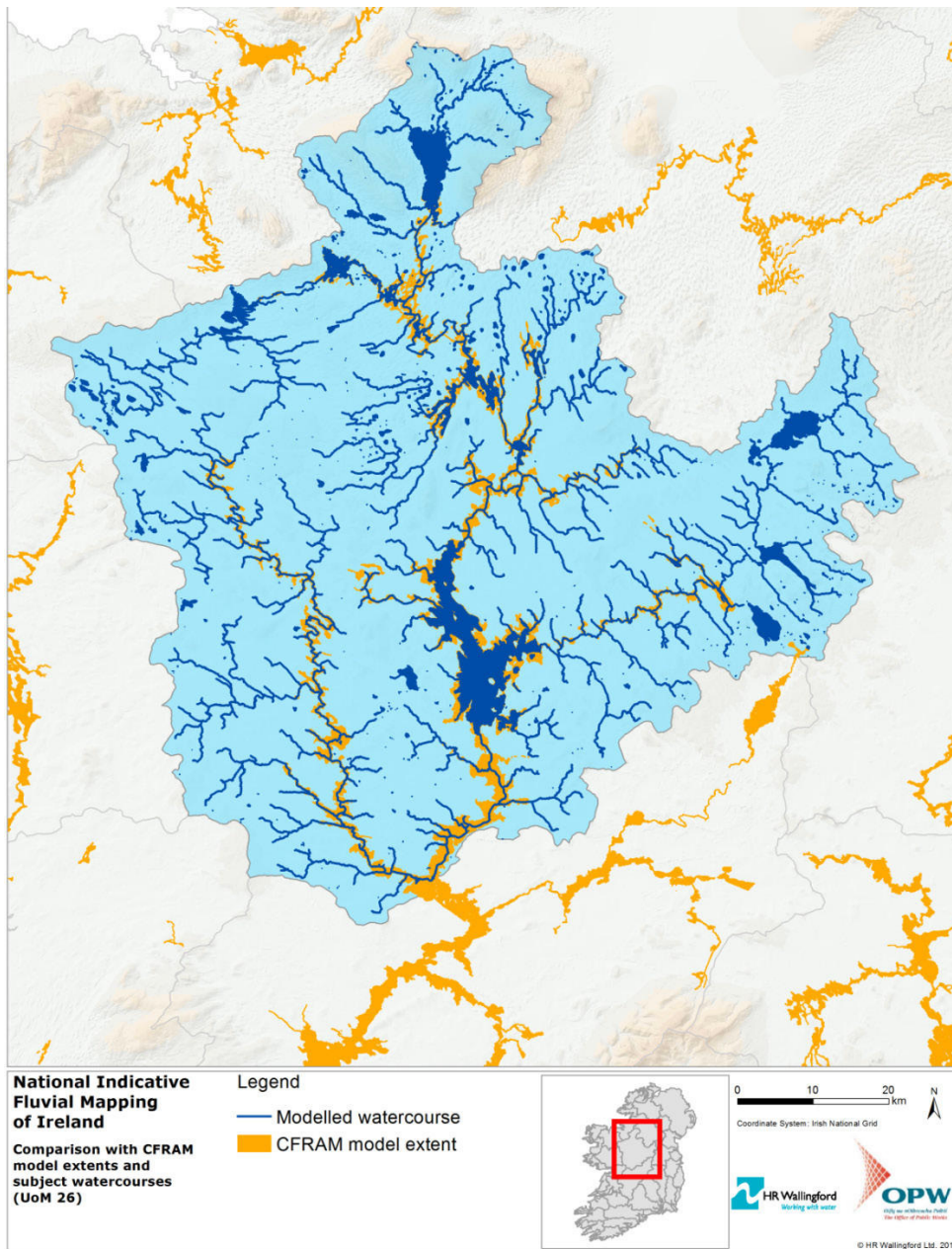


Figure 1.6: Map showing UoM 26 subject watercourses with CFRAM extents highlighted in orange



## 1.3. Report structure

This report is split into eight main chapters, as follows:

- Chapter 2 describes the overall NIFM piloted methodology, including the approach and workflow, followed by a detailed description of the gathering of data and resources;
- Chapter 3 describes the hydrological analysis that has been carried out based upon CFRAM and FSU studies;
- Chapter 4 details the development and simulation of the 2D hydraulic models for the two Pilot Study Areas, and the tests of assumptions made in the modelling;
- Chapter 5 describes how the results were processed in order to generate flood spatial data and to classify the reaches in terms of the duration of flooding and the rate of onset of flooding;
- Chapter 6 presents an analysis of the results for Pilot Study Area UoM 18, with reference to those obtained by the CFRAM study modelling, and available historical flood event data;
- Chapter 7 presents an analysis of the results for the Pilot Study Area UoM 26 with reference to those obtained by the CFRAM study modelling, and available historical flood event data;
- Chapter 8 summarises the assumptions tested in our modelling trials on the Pilot Study Areas, and our key resultant recommendations for the national roll-out;
- Chapter 9 presents recommendations for further refinement of the methodology.

The main report is followed by three Appendices; these list the CFRAM model growth factors that have been used, the CORINE land cover classes and corresponding roughness values, and give an example of the QA check-sheet template.

## 2. Description of piloted methodology

The overall pragmatic approach to this national-scale flood mapping project has been designed to combine intelligent automation of the repetitive processes, such as hydrological calculations and the burning of watercourses into the 2D model mesh, with experienced hydraulic modelling and critical quality assurance techniques. The approach builds upon the outputs from significant earlier studies carried out under the Flood Studies Update and CFRAM programme studies. It has been designed to enable straightforward and efficient six-yearly updates to the flood risk assessment.

The major tasks are shown in the workflow diagram of Figure 2.1, falling under the following broad headings:

1. Gathering of data;
2. Hydrological assessment;
3. Hydraulic modelling;
4. Generation of flood spatial data;
5. Classification of reaches.

Some of the tasks needed to happen in series, while others were able to proceed in parallel; indeed, the sharing of hydrological information with the hydraulic modelling sub-tasks was essential to the efficiency of the process.

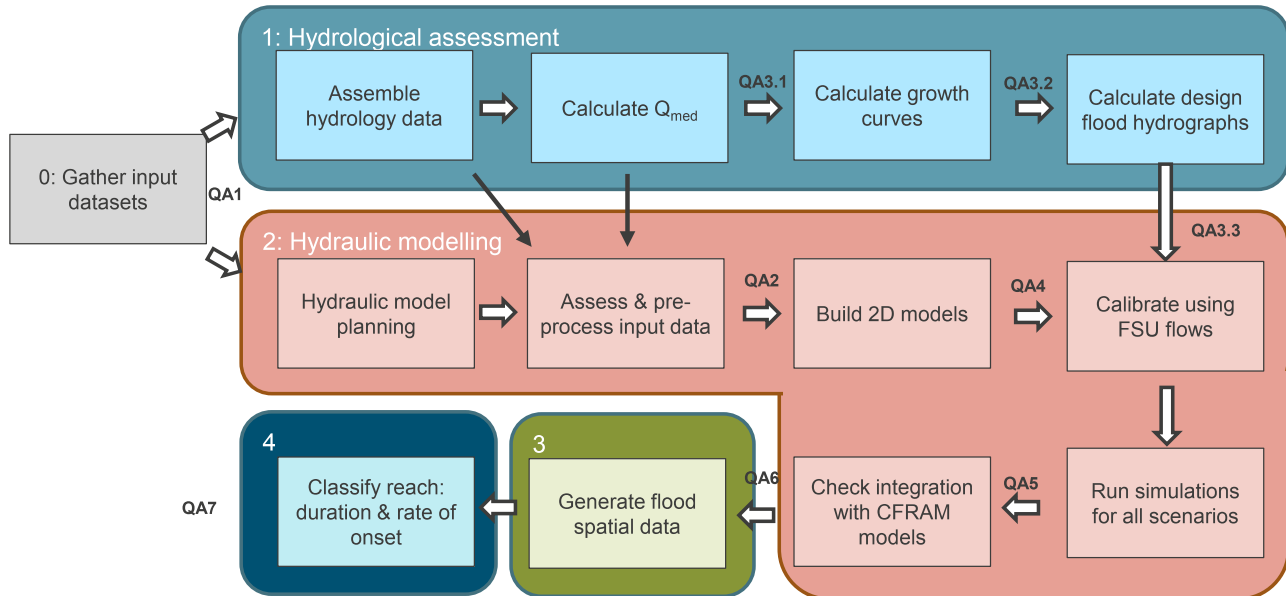


Figure 2.1: Overview of the workflow sequence of tasks involved

Within each workflow task, there is a workflow process, of the form presented in Figure 2.2. This shows the input and output data sets, automated and manual processes, and quality assurance (QA) activities. It also represents the iteration that can be required where a QA activity has highlighted the need for an adjustment to the process.

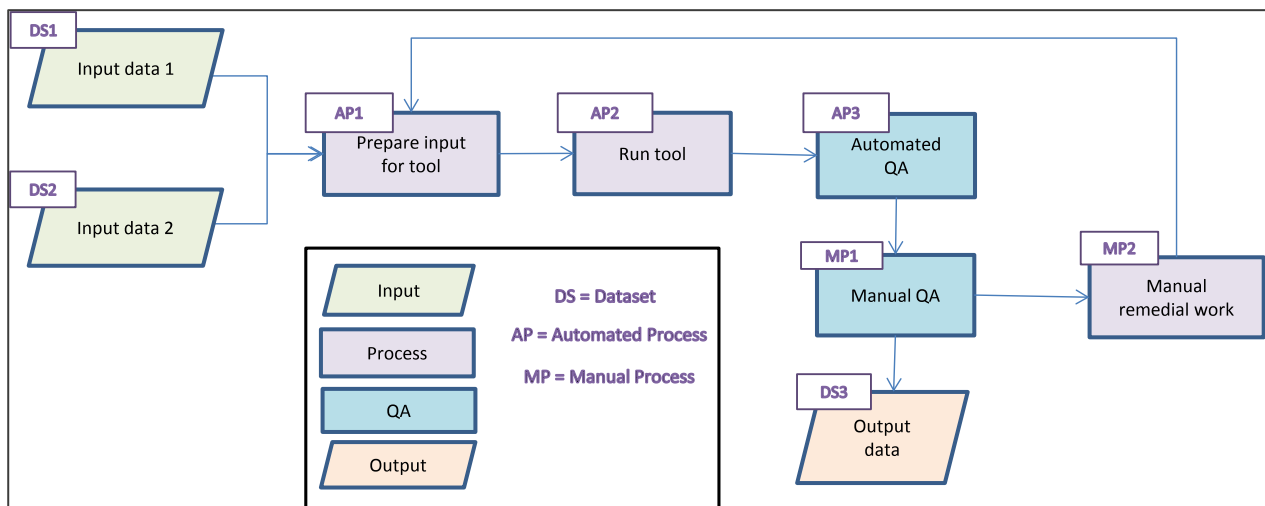


Figure 2.2: Example of a workflow process within a task of the overall workflow

## 2.1. Gathering of data and resources

Data required for the project, for the Pilot Study Areas and the national roll out, were gathered at the start of the project. Data were immediately logged to systematic folders upon receipt, and their attributes checked and recorded (e.g. spatial extents, co-ordinate system, datum, completeness). The data gathered are detailed below, along with the data assessment that has been carried out in each case.

### Flood Studies Update (FSU) node data

At proposal stage, shapefiles of all 134,000 FSU nodes for the ungauged locations, at 500 m intervals, were acquired, by hydrometric area. For each node, more than 20 Physical Catchment Descriptors (PCDs) were available, in addition to Irish National Grid Eastings and Northings; the full set is listed in Table 2.1. Of the full set, those used in the analysis are highlighted in bold font.

Table 2.1: Physical Catchment Descriptors available for FSU nodes

Descriptor	Units	Definition
<b>AREA</b>	km <sup>2</sup>	Catchment area (from DTM)
ALTBAR	m	Mean elevation of catchment
<b>SAAR</b>	mm	Standard-period Average Annual Rainfall
<b>FARL</b>		Index of Flood Attenuation from Lakes and Reservoirs
URBEXT	%	Proportional extent of catchment area mapped as urbanised (from CORINE)
FOREST		Proportional extent of forest cover
PEAT	%	Proportional extent of catchment area classified as peat bog (from CORINE)
PASTURE	%	Proportional extent of catchment area classed as grassland/pasture/agriculture (from CORINE)
ALLUV	%	Proportional extent of floodplain alluvial deposit (from EPA/TEAGASC subsoils)
FLATWET		Proportion of time soils expected to be typically quite wet
SAAPE	mm	Standard-period Average Annual Potential Evaporation
FAI		Flood attenuation index
<b>BFI<sub>soil</sub></b>		Soil Base Flow Index (estimate of BFI derived from soils, geology and climate data)
NETLEN	km	Total length of river network above gauge
STMFRQ		Number of segments in river network above gauge
<b>DRAIN</b>	km/km <sup>2</sup>	Drainage density
MSL	km	Main-stream length
<b>S1085</b>	m/km	Main-stream slope (excluding top 10% and bottom 15%)
TAYSLO	m/km	Taylor-Schwartz measure of mainstream slope
ARTDRAIN		Proportion of catchment area mapped as benefitting from arterial drainage schemes
<b>ARTDRAIN2</b>		Proportion of river network length included in Arterial Drainage Schemes

Source: OPW (2014)

### Recent annual maxima flow data for gauges

The most up-to-date dataset of annual maxima flow data was required for the hydrological assessment. Due to the timing of earlier relevant hydrological assessments (the Flood Studies Update (FSU) and CFRAM studies), they were based upon a gauged dataset that ended in 2012. More recent annual maxima (AMAX) data were required in order to calculate factors for  $Q_{MED}$  values and growth curves.

More recent data were obtained for the 149 OPW gauges up to the 2016 hydrometric year (inclusive). The data represented water level gauge readings (depths in metres), level gauge readings in mAOD (Poolbeg datum: P; note that this project uses Malin datum: M), and derived flow data (cumecs; estimated via rating equations), along with the dates of the maximum values.

Of the 149 gauges, 128 had suitable data for the hydrological analysis, with 21 having been noted to indicate problems relating to the calculation of flows in the associated gauge listing (such as problems with the rating equation); the 128 gauges with suitable data are mapped in Figure 2.3.

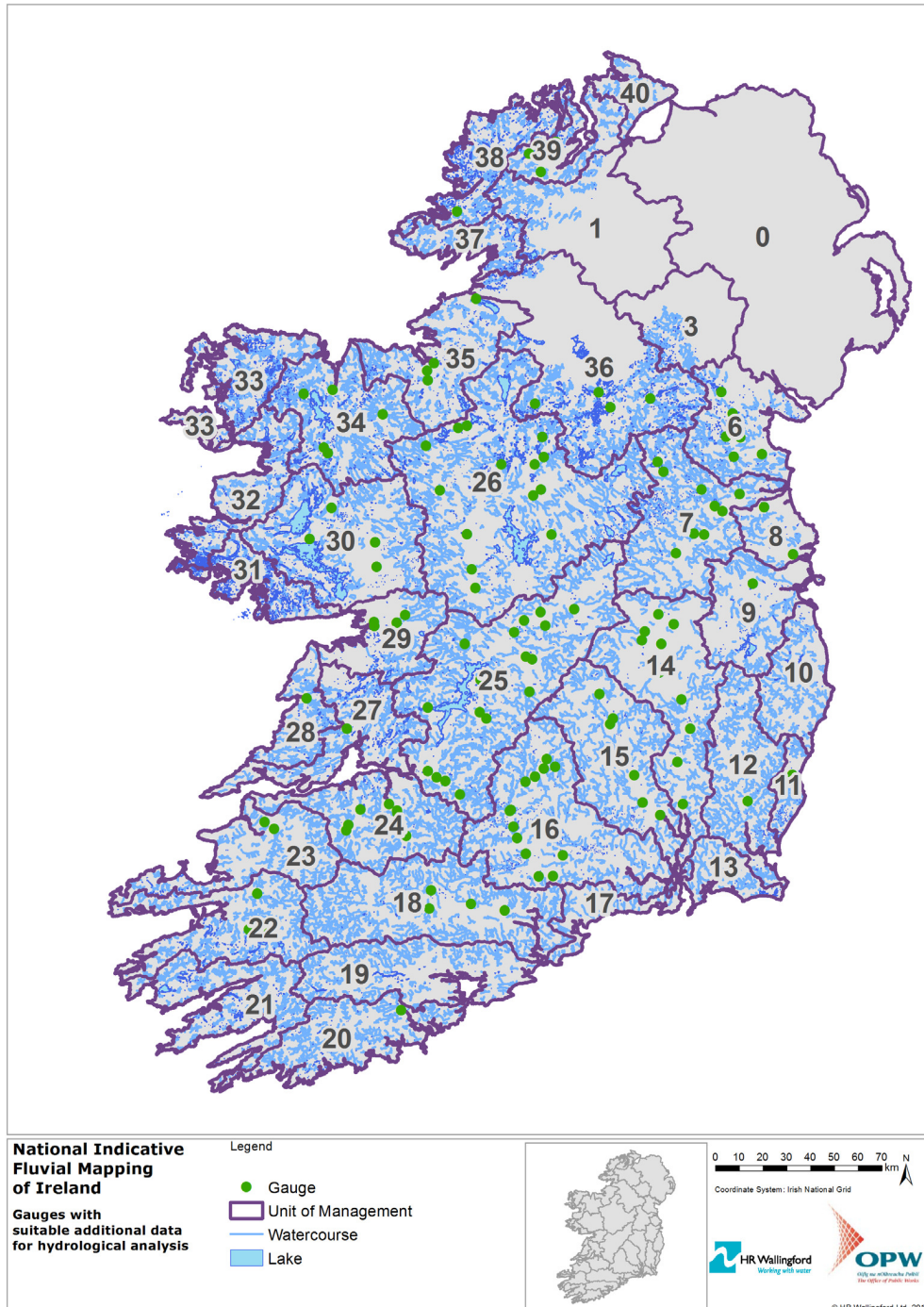


Figure 2.3: Map of Ireland showing 128 gauges with suitable additional data for hydrological analysis

Source: OPW



### **Gauged water level data**

Gauged water level data for historical events at key locations in the two UoMs were extracted from the relevant CFRAM hydraulics reports, along with their estimated return periods for key events (where available).

### **Road and rail datasets**

Road and rail datasets were required for the hydraulic modelling in order to identify bridges and significant structures affecting flow routes over the flood plains.

The datasets provided by OPW were from Ordnance Survey Ireland's (OSi) PRIME2 central database of spatial information. Roads and Rail vector layers were obtained as displayed in Figure 2.4.

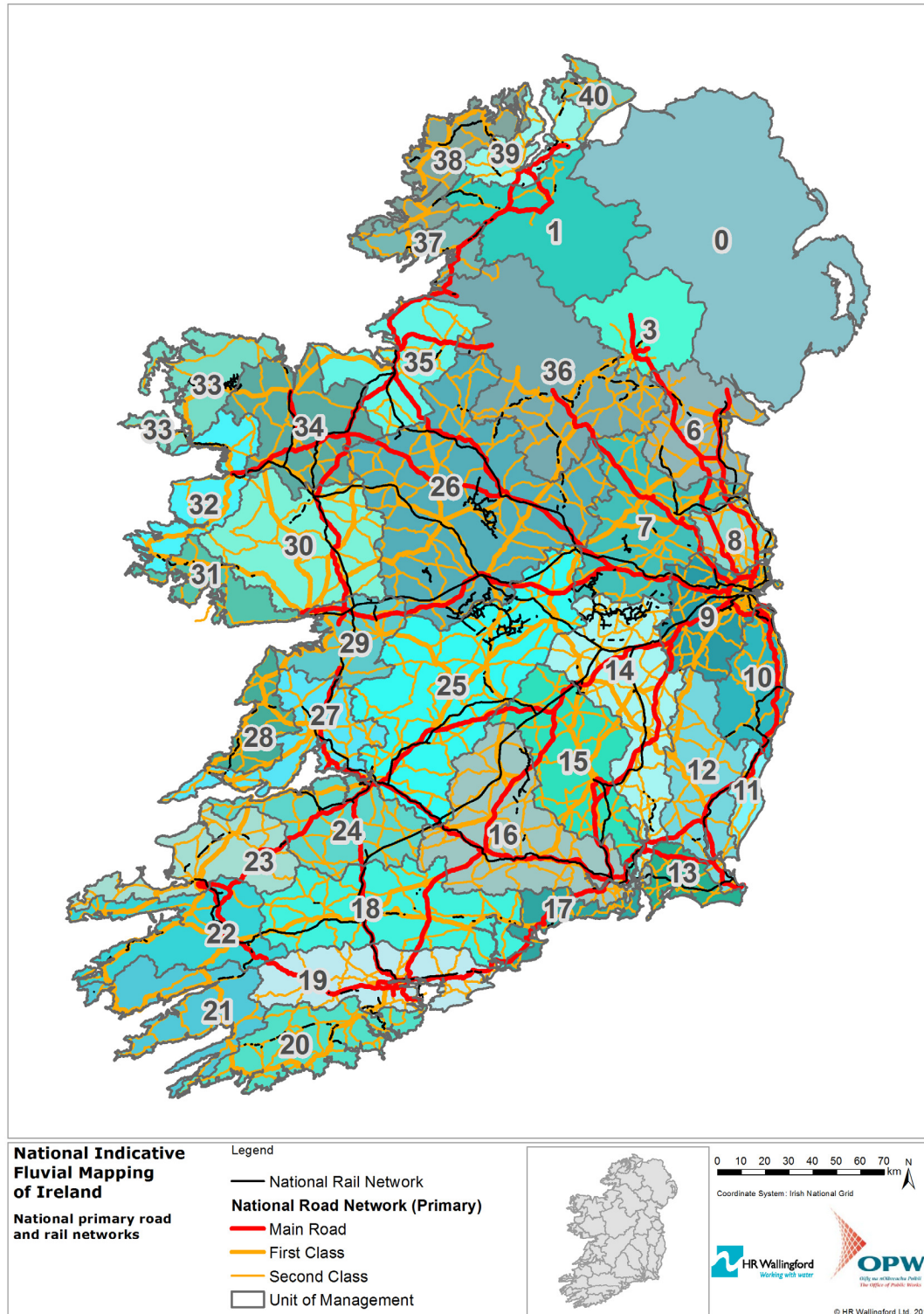


Figure 2.4: Map of Ireland showing road and rail network vector layers

Source: OSi

## CFRAM data and reports

Under this project, flood mapping is being produced for all areas outside of the Catchment Flood Risk Assessment and Management (CFRAM) Study extents, except for the pilot studies which have modelled the CFRAM extents too. The CFRAM programme consisted of highly detailed hydrological and hydraulic studies for important flood prone areas within each Unit of Management, and therefore provides a rich source of information which this project has been designed to use wherever possible. CFRAM data and supporting information were therefore gathered, notably:

- Model node data: Peak water levels and flows for the range of return periods (50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEPs) at model results locations, which are generally nodes, such as cross-sections in the 1D model, typically at intervals of 1 to 2 km along the reach;
- Modelled flood extent polygons for a range of AEPs: see a sample in Figure 2.5;
- Topographic survey data used in the models of the Pilot Study Areas, for checking channel shape assumptions;
- Hydrology and hydraulics reports, describing the methodologies used and the results obtained;
- Model data for the Pilot Study Areas.

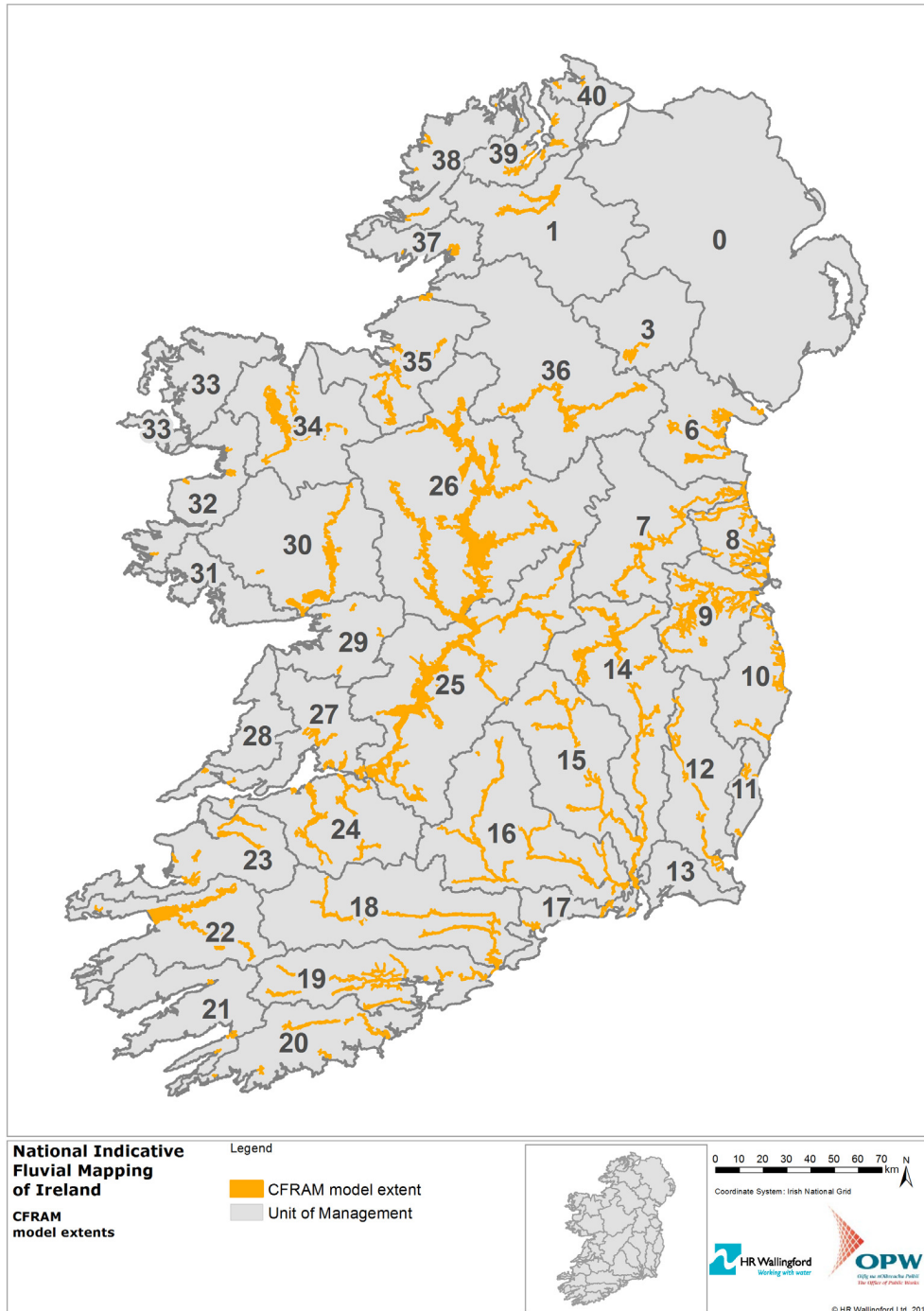


Figure 2.5: Map of Ireland showing CFRAM modelled flood extents for 0.1% AEP

Source: OPW

### **EPA watercourses data**

The original Environmental Protection Agency (EPA) watercourses dataset, from which the subject watercourses would be derived, was supplied by OPW at tendering stage in GIS format as: *WATER\_RivNetRoutes* and *WFD\_LakeSegment*. This original dataset was not continuous through the lakes, and therefore required work to establish such connectivity ready for the subsequent modelling tasks.

An updated EPA watercourses dataset (*Rivers Geometric Network*) was subsequently made available, as a river network with connectivity, which will be used for the national roll-out.

### **Digital Terrain Model data**

Digital Terrain Model (DTM) data were required for development of the 2D models of the river channels and flood plains. For this purpose, the national Interferometric Synthetic Aperture Radar (IfSAR) DTM dataset was obtained. The dataset has 0.01 m vertical resolution and 5 m horizontal resolution, with 70 cm vertical accuracy resolution. These data were delivered as 5 km square tiles, which were joined into sets covering each Unit of Management.

In addition, shapefiles showing the extents of available LiDAR data (from the CFRAM studies) were also obtained. LiDAR data were used in the CFRAM studies for the AFAs and HPW reaches; therefore, the CFRAM studies benefitted from a higher resolution of the underlying topography data in those areas, relative to the IfSAR data used in this NIFM study, and this can be expected to have an impact on the results. (Figure 2.6).



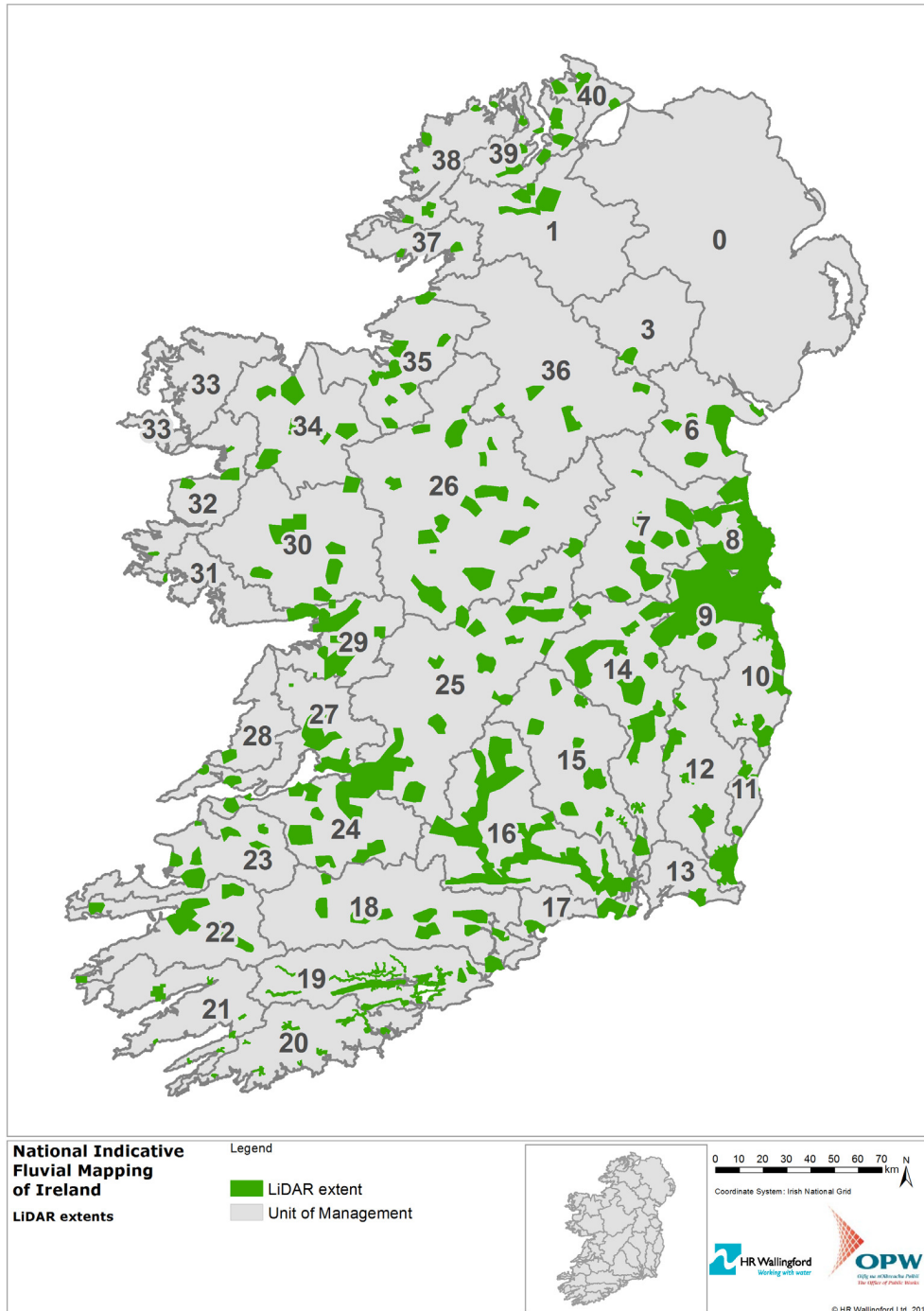


Figure 2.6: Map showing extents of LiDAR data available to CFRAM studies

Source: OPW

### **Additional drainage features**

In addition to the river channel network, there are several features that should be taken into account when modelling the flow of water. In certain areas, such as the Pilot Study Area UoM 26 (Upper Shannon), there are significant arterial drainage features which were designed and built following the Arterial Drainage Act (1945) whereby OPW undertook a number of arterial drainage schemes to improve land for agricultural production. Such arterial drainage involved the artificial widening and deepening of main rivers and important tributaries in order to increase their effectiveness in draining their catchments; areas that benefitted from arterial drainage under the Act, are termed 'Benefitted lands', and data on these was also acquired. There are numerous embankments which also affect the natural drainage mechanism and must therefore be taken into account. These features are found primarily in a band running across the centre of Ireland, and are present in UoM 26, as shown in Figure 2.7.

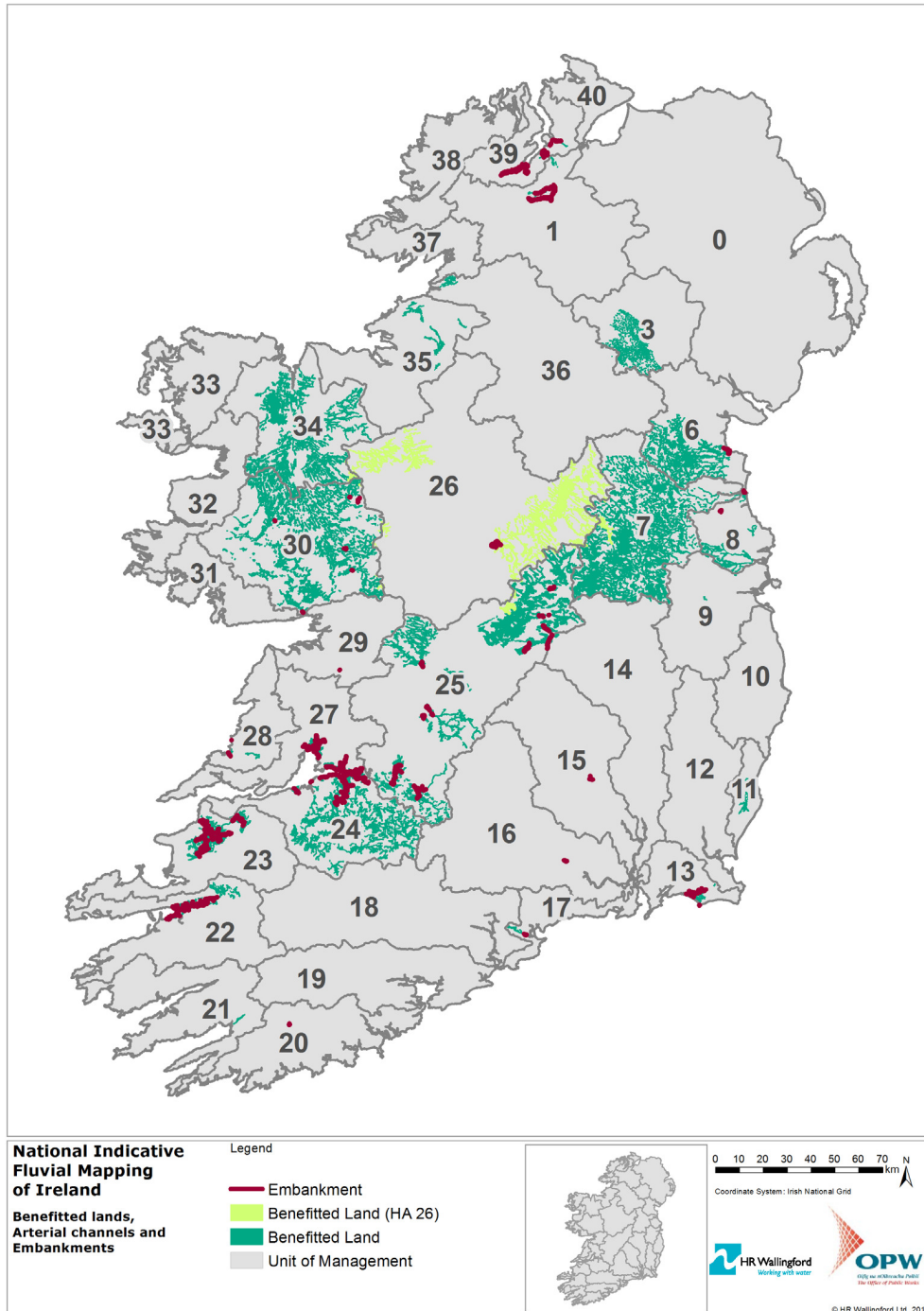


Figure 2.7: Map of Ireland showing embankments, benefitted lands and arterial drainage channels, with those of UoM 26 in light green

Source: <http://maps.opw.ie/drainage>

## Land cover data

Land cover data were required for specification of roughness values for the hydraulic modelling. Roughness values are key to the movement of water through the channel network and the floodplain, and form a main parameter for calibration of the simulated water levels and flows.

The principal source of land cover data is the **Co-ORDination of INformation on the Environment (CORINE)** data set, which is available across the European Community. It represents an inventory of land cover in 44 classes, and is available as a cartographic product, at a scale of 1:100 000. CORINE data are available for the 2012 snapshot from the EPA website; a newer, but unvalidated version for 2018 is also available, via Copernicus (a European system for monitoring the Earth). Since the latter version was unvalidated at the time of modelling the Pilot Study Areas, it was decided to use the validated 2012 version for this project. A cross-check on mapped changes between the 2012 and 2018 datasets<sup>1</sup> showed little difference between the two datasets (Figure 2.8).

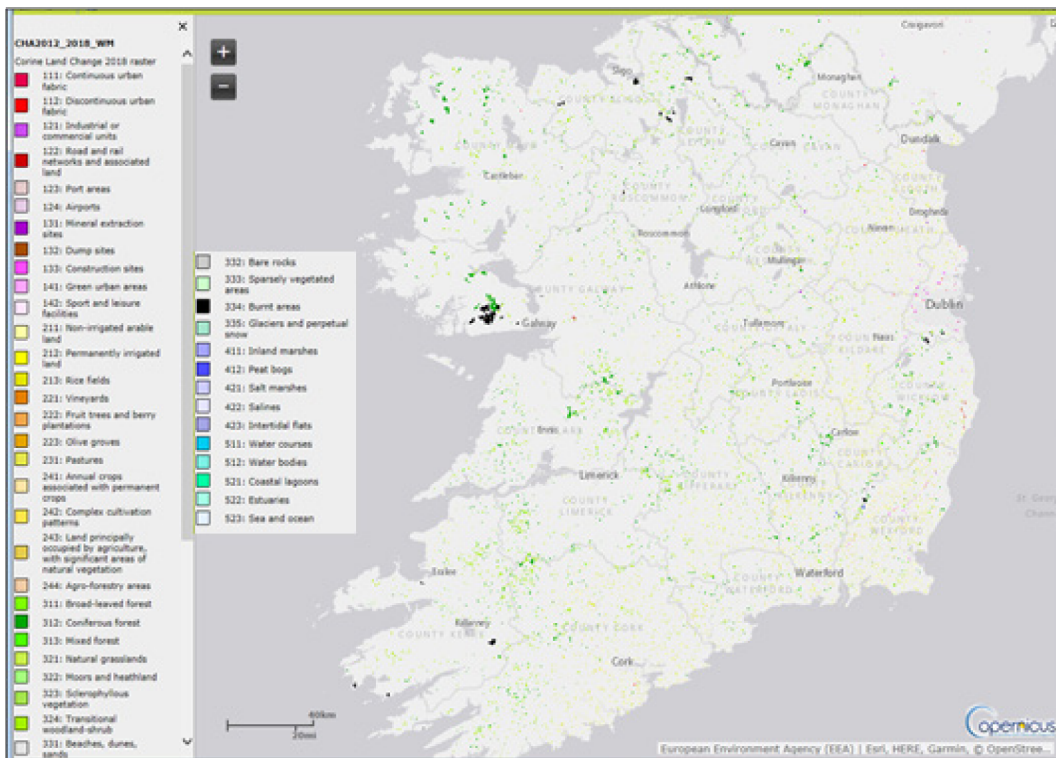


Figure 2.8: CORINE Land Cover programme: map showing land cover / land use changes between year 2012 and 2018

Source: Copernicus <https://land.copernicus.eu/pan-european/corine-land-cover/lcc-2012-2018>

<sup>1</sup> See <https://land.copernicus.eu/pan-european/corine-land-cover/lcc-2012-2018>



## Background raster mapping for context behind our GIS outputs

OPW granted the project team temporary access to a number of mapped layers for the use of providing context behind mapped outputs from the project. The primary layer used for this purpose was the OSi Discovery Series layer, which was made available via a WMS.

### Coastal water level data

Water level data at locations along the coastline are required as downstream boundary conditions for the fluvial models. The dataset used here is from the Irish Coastal Protection Strategy Study (ICPSS). Work packages 2 and 3 of the ICPSS comprised an assessment of the hazard and potential risk from coastal flooding at a strategic level. At present, the available data are in report format only, and are currently not available as digital datasets. A map showing an example of the extraction points is presented in Figure 2.9, from the ICPSS report.

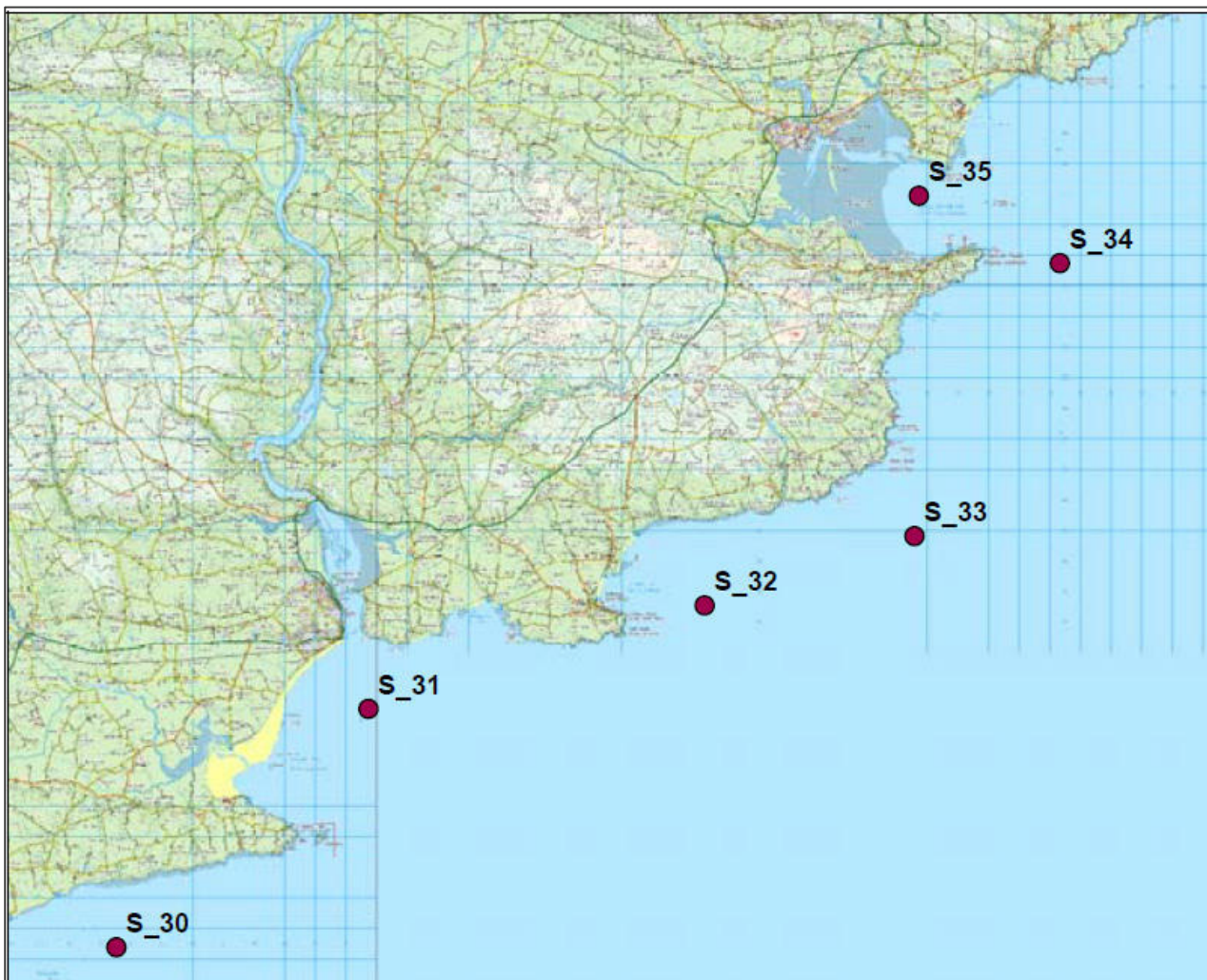


Figure 2.9: Location of extraction points along the south coast, relevant to UoM18

Source: OPW (2011)

Relevant data for the modelling were tabulated extreme water levels for different return periods for the specific locations.



### 2.1.1. Hardware and software resources

The primary types of software that have been used on the project are hydraulic modelling software and Geographic Information Systems (GIS). The following specific software packages have been used:

- ArcGIS for GIS spatial data processing tasks;
- InfoWorks ICM v8.5 (1D and 2D) for hydraulic modelling;
- Feature Manipulation Engine (FME) for data management and conversion.

Model simulations using have been carried out on a Dell PowerEdge R740 Server with the following specifications:

- 2 x Intel Xeon Gold 6128 3.4GHz CPU;
- 256GB RAM;
- NVIDIA Tesla P100 12GB GPU;
- 2 x 600GB HDD;
- Windows Server 2016;
- InfoWorks ICM 8.5.9 engine.

### 2.1.2. Folder structure and naming convention

The folder structures for incoming data, work in progress (WIP) and deliverables are organised in a consistent and well-established structure. A register of incoming data and deliverables is completed as a matter of course.

To facilitate efficient data processing tasks for each UoM, as well as provide the ability for batch processing of the same task for multiple UoMs concurrently (in preparation for the national roll-out of the modelling), scripts were developed and parameters were set in FME workbenches to generate folders and datasets that were consistently named across each UoM. Each acquired or derived dataset was assigned a unique dataset ID and details recorded in a dataset register.

At the results reporting stage, the naming conventions for file and field names prescribed in the Flood Spatial Data Specification were followed.

## 3. Hydrological analysis

The hydrological analysis contained four main steps. The first step was to extract the relevant Physical Catchment Descriptor (PCD) data for each FSU-node in the study area. From these data, the index flood flow ( $Q_{MED}$ ) could be estimated at every location. Growth curves were then derived so that the peak flow for the required return period could be estimated. Finally, the full shape of the flood hydrograph could be defined. Each step is described in detail below.

### 3.1. Extraction of PCDs

The FSU-node PCDs were extracted from a nationally-compiled dataset, as shapefiles, for the two Pilot Study Areas, using the 'HA' (Hydrometric Area) attribute as a filter. A similar process took place to extract the rivers for the Pilot Study Areas. The nodes were then reconciled with the rivers to establish linear referencing between the two datasets, and to remove nodes that recorded an upstream catchment area of less than

5 km<sup>2</sup>. Since this NIFM project has a focus on fluvial flooding, the extents of the FSU node dataset were taken as the extents for the modelling; i.e. estuaries and tidal reaches are not modelled.

A topological network was generated from the river polylines and a unique referencing system was generated for both the rivers and the nodes to ensure referential integrity between the two datasets. The original supplied IDs were unique numbers that were already assigned to the nodes and rivers (the fields being SEG\_CD for the rivers and NODE\_ID for the nodes). These IDs could not be re-used because of the requirement to merge two or more river segments (that would have had different IDs) together, if the intersecting tributary line needed to be removed due to having no nodes with an area greater than 5 km<sup>2</sup> assigned to it. Despite this, a mapping between the original IDs and the newly defined IDs was generated so that any of the model data and results could be referred back to the original datasets.

The nodes that were removed were saved to a separate dataset to the retained nodes and were assigned a reason for removal (e.g. upstream area less than 5 km<sup>2</sup>, or cleaning of duplicates) as an attribute during the automated processing. This was to facilitate a manual check to confirm that the correct nodes had been retained for the modelling.

Maps showing both the compiled rivers and nodes datasets for both pilot areas, with subject watercourses that were retained or removed according to the procedure described above, are presented in Figure 3.1 and Figure 3.2. These show the retained subject watercourses (wide green lines with black centrelines) and removed watercourses (pale blue lines).

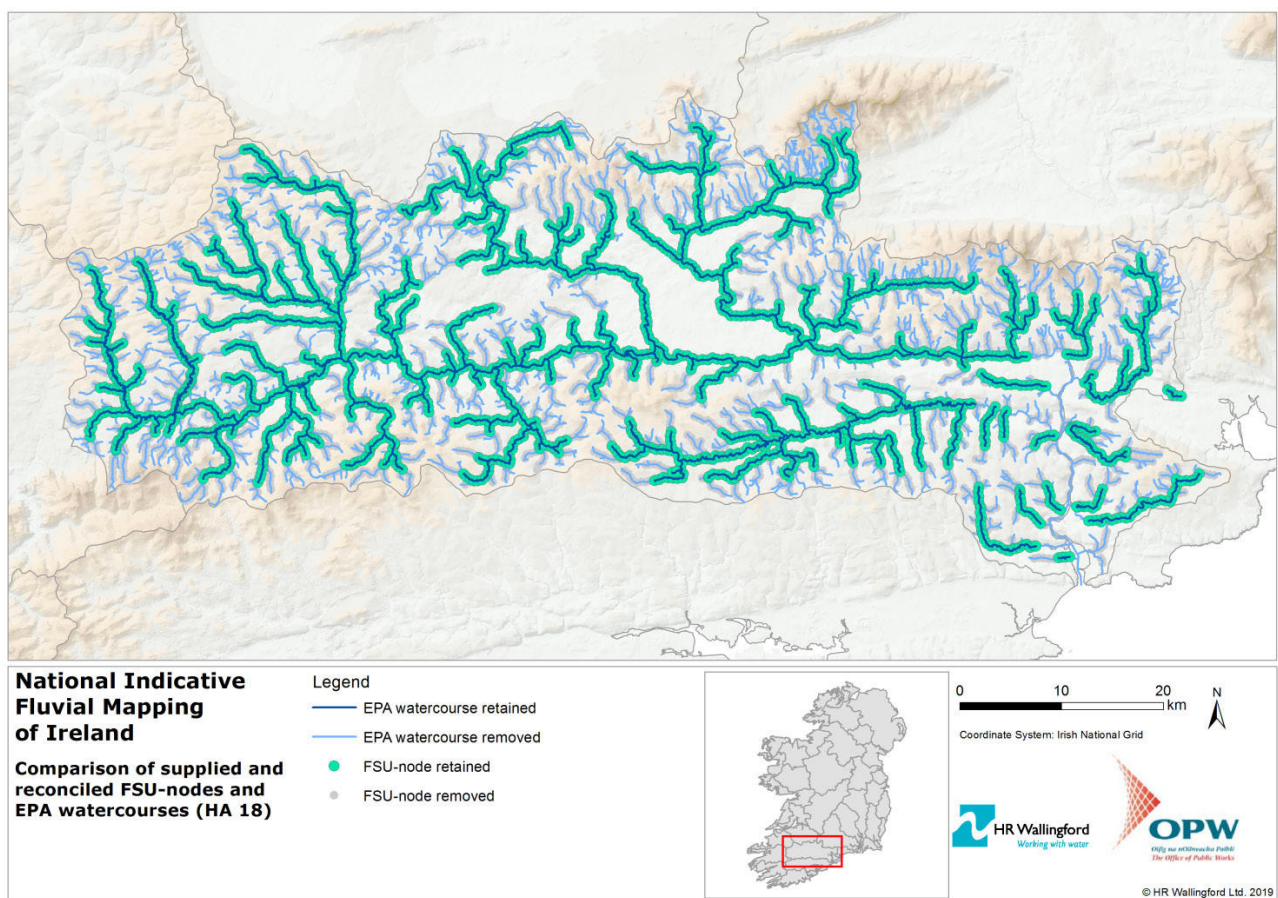


Figure 3.1: FSU-nodes and EPA subject watercourses for UoM 18

Source: OPW

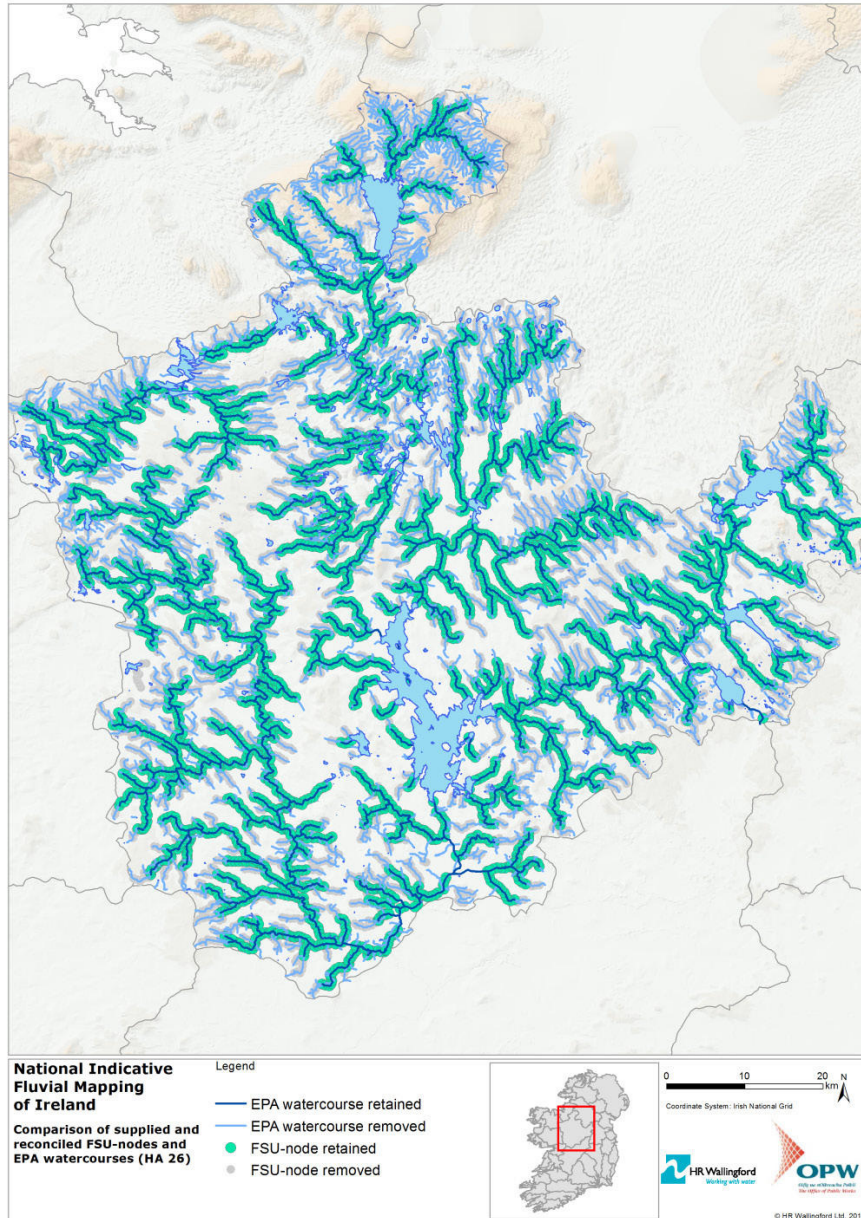


Figure 3.2: FSU-nodes and EPA subject watercourses for UoM 26

Source: OPW

### 3.2. Estimation of the index flood flow ( $Q_{MED}$ )

Estimation of the index flood flow ( $Q_{MED}$ ) involved the following steps:

- Estimation of  $Q_{MED}$  at ungauged locations from PCDs;
- Adjustment of  $Q_{MED}$  using gauged data;
- Urban adjustment to  $Q_{MED}$ ;
- QA checks.



These steps are described below.

### Estimation of $Q_{MED}$ at ungauged locations from PCDs

Estimation of the index flood flow ( $Q_{MED}$ ) at ungauged locations followed the guidance in Flood Studies Update Work Package 2.3 (Murphy, 2009). The FSU seven-variable equation for calculating the index flood at rural locations was used as presented in Equation 3.1.

$$Q_{med} = 1.237 \times 10^{-5} AREA^{0.937} BFI_{soil}^{-0.922} SAAR^{1.306} FARL^{2.217} DRAIN^{0.341} S1085^{0.185} (1 + ARTDRAIN2)^{0.408}$$

#### Equation 3.1: Equation for estimating $Q_{MED}$ at ungauged sites

Source: Murphy (2009)

The calculated  $Q_{MED}$  at each FSU node was checked to ensure that the flow did not decrease along a reach in the downstream direction. Where a drop in flow was found, the value was set equal to the flow at the upstream node. The  $Q_{MED}$  was also checked at confluences to ensure that the flow on the downstream reach was not lower than the highest flow on each tributary.

### Adjustment of $Q_{MED}$ using gauged data

The extended, gauged AMAX dataset, described above, was used to perform an adjustment to the  $Q_{MED}$  values calculated from the PCDs.

Significant flood events occurred in the winter of 2015, when a series of storms (Desmond, Eva, Frank) affected large parts of Ireland. The AMAX series extension data included hydrometric year 2015 (December 2015 to January 2016), and the AMAX flow of that year was in the top five events for the whole record at 85 out of 123 gauges with data (i.e. approximately two-thirds of the gauged series indicated that the 2015 flood events had an important status in the historical record).

The  $Q_{MED}$  adjustment factor is the ratio between the AMAX  $Q_{MED}$  value and the PCD-derived  $Q_{MED}$  value; these are mapped for each gauge in Figure 3.3. The map shows that the adjustment factors vary within hydrometric areas, although within UoM 18 the variation is quite small; the adjusted values were used in the modelling.

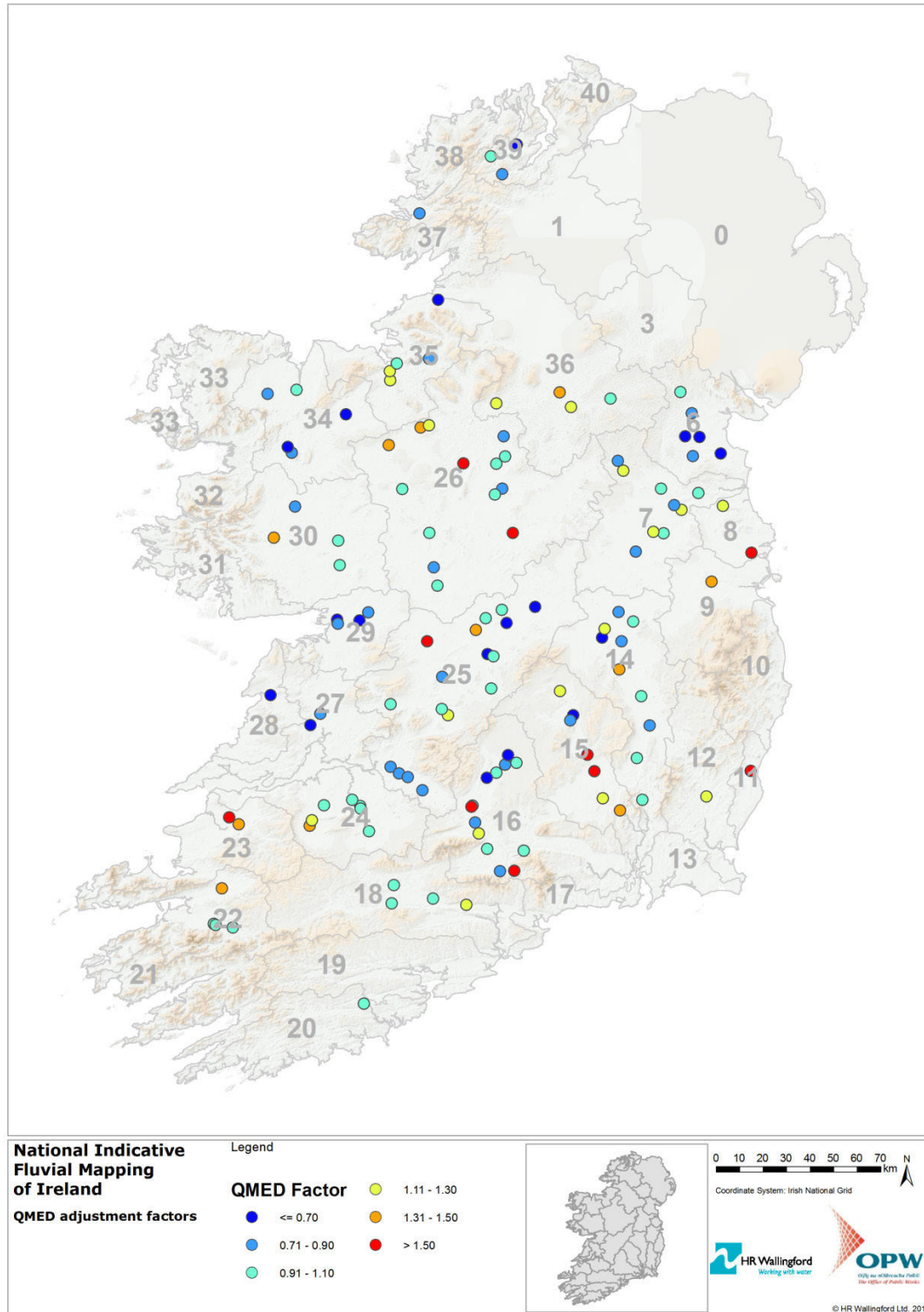


Figure 3.3: Map showing  $Q_{MED}$  adjustment factors calculated from AMAX versus PCD-derived values

Source: HR Wallingford



The adjustment factors from these gauged locations have been applied to the FSU-derived  $Q_{MED}$  values by applying the pivotal site approach.

In line with the FSU recommended approach, pivotal sites have been used; a pivotal site being the gauging station that is considered most relevant to a particular flood estimation problem at the subject site, ideally, lying a short distance upstream or downstream from the subject site at which the flood estimation is required. Pivotal sites were selected as the nearest downstream gauge on the same river (see Figure 3.4 and Figure 3.5); in the circumstances where no downstream gauge exists, the nearest gauge has been used. Traditional alternative approaches to this method, such as the use of analogue catchments, can be potential sources of error (Morris, 2003); furthermore, the selection of analogue catchments is subjective and therefore difficult to implement on a widespread, automated basis such as the approach being used in this project. Kjeldsen et al., (2008), following research based upon the newer, longer HiFlows-UK flood database, and feedback from FEH users, suggest that preference should be given to sites with geographical proximity rather than similarity of catchment characteristics, and so this approach has been used here.

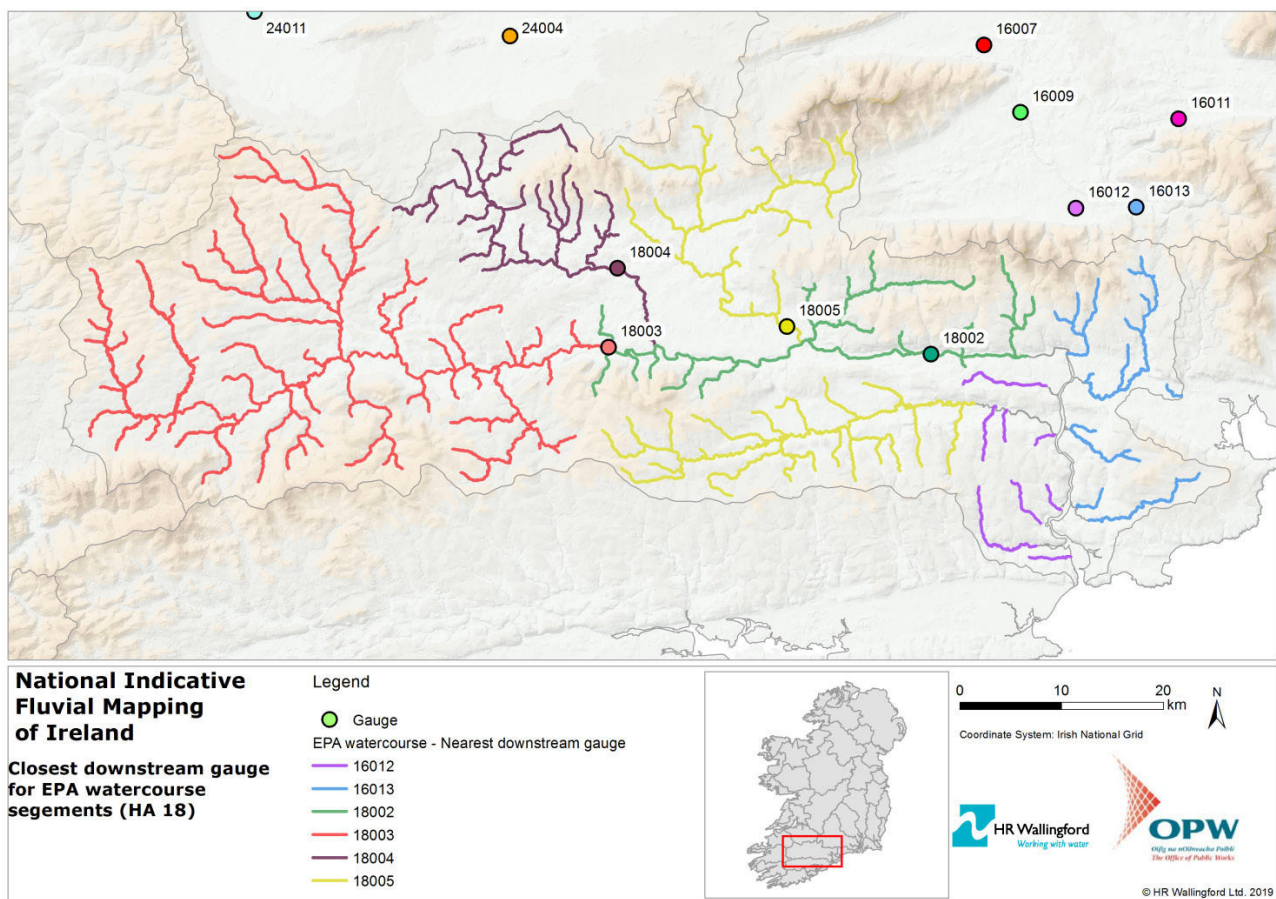


Figure 3.4: Closest gauge based on catchment centroids or downstream gauge in UoM 18

Source: HR Wallingford

The  $Q_{MED}$  adjustment factors for each gauge used in UoM 18 are given in Table 3.1.

Table 3.1:  $Q_{MED}$  adjustment factors for each gauge used in UoM 18

Gauge	Adjustment factor
18003	1.022
18002	1.132
18005	1.009
18004	0.955
16012	0.837
16013	2.198

The  $Q_{MED}$  adjustment factors for each gauge in UoM 26 are given in Table 3.2 and the nearest gauge for each reach is shown in Figure 3.5.

Table 3.2:  $Q_{MED}$  adjustment factors for each gauge used in UoM 26

Gauge	Adjustment factor
25017	1.322
26007	0.959
26005	0.898
26021	1.706
26002	0.938
26022	0.952
26019	0.839
26006	1.047
26018	1.684
26014	1.418
26008	0.924
26009	0.960
26012	1.307
26108	1.140
26010	0.863

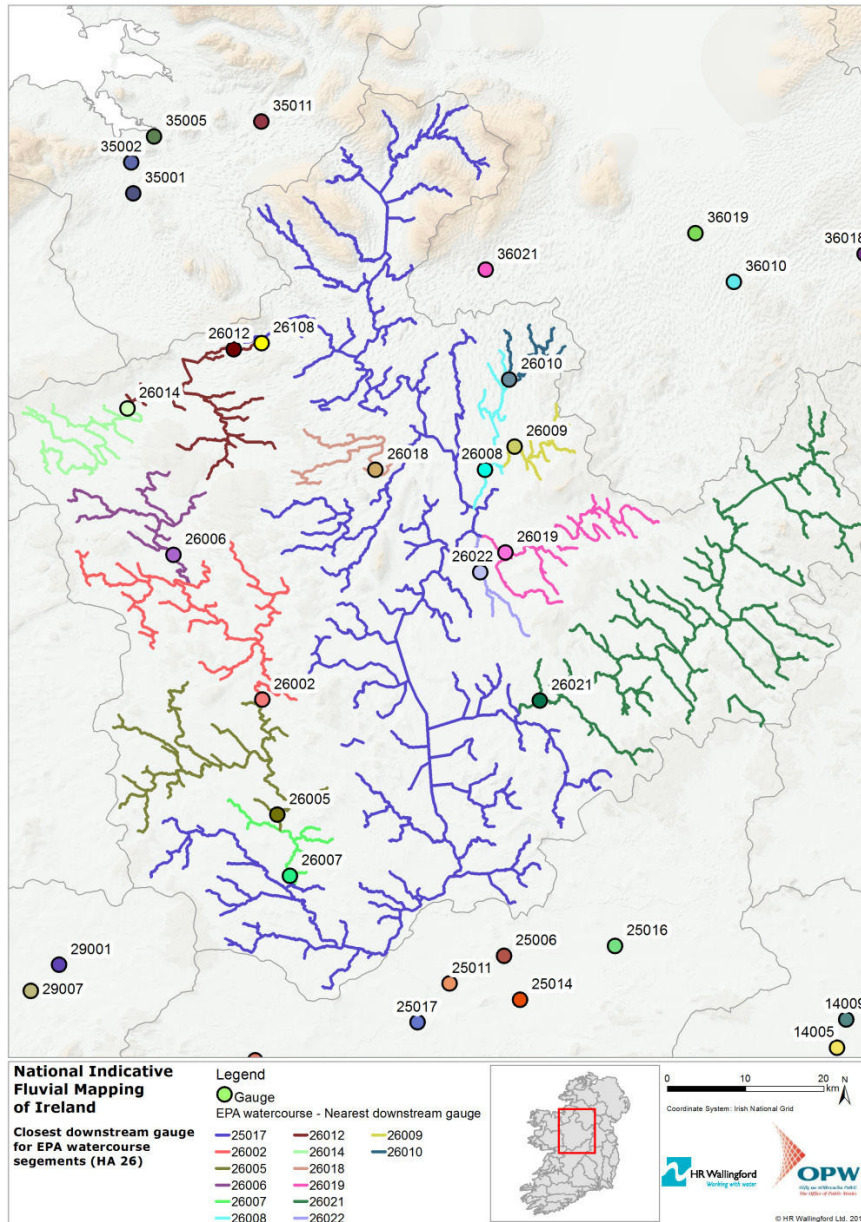


Figure 3.5: Closest gauge based on catchment centroids or downstream gauge in UoM 26

Source: HR Wallingford

### Urban adjustment to $Q_{MED}$

Since the equation for calculating  $Q_{MED}$  was based upon essentially rural catchments, an adjustment for urbanisation was required. Therefore, the recommended adjustment for urbanisation (the Urban Adjustment Factor, UAF) was calculated from Equation 3.2, and applied to the rural  $Q_{MED}$  value estimated after application of the gauge adjustment factor.

$$UAF = (1 + URBEXT)^{1.482}$$

Equation 3.2: Calculation of Urban Adjustment Factor

Source: Murphy (2009)

### QA checks

The values of  $Q_{MEDurb}$  were then checked to ensure that the flow does not decrease in the downstream direction. Where a decrease in flow is found between nodes, the flow was adjusted to be the same as the flow at the upstream node.

## 3.3. Estimation of the flood growth curve

Flood growth curves in the Republic of Ireland tend to be relatively mild, with the 100-year flow typically no more than about double the mean annual flow (Reed and Martin, 2005). Figure 3.6 shows the regional growth curves from the Flood Studies Report, in which Regions 1 to 10 cover England, Scotland and Wales, for comparison with Ireland. This mildness is largely due to attenuation in lakes and on flood plains, such as that demonstrated widely in UoM 26. As a consequence of this, the proportion of in-channel flow is high; estimation of channel capacity is important in this project, since the flooding is sensitive to channel size. Efforts to represent the channel geometry as accurately as possible are documented in Section 4.3.



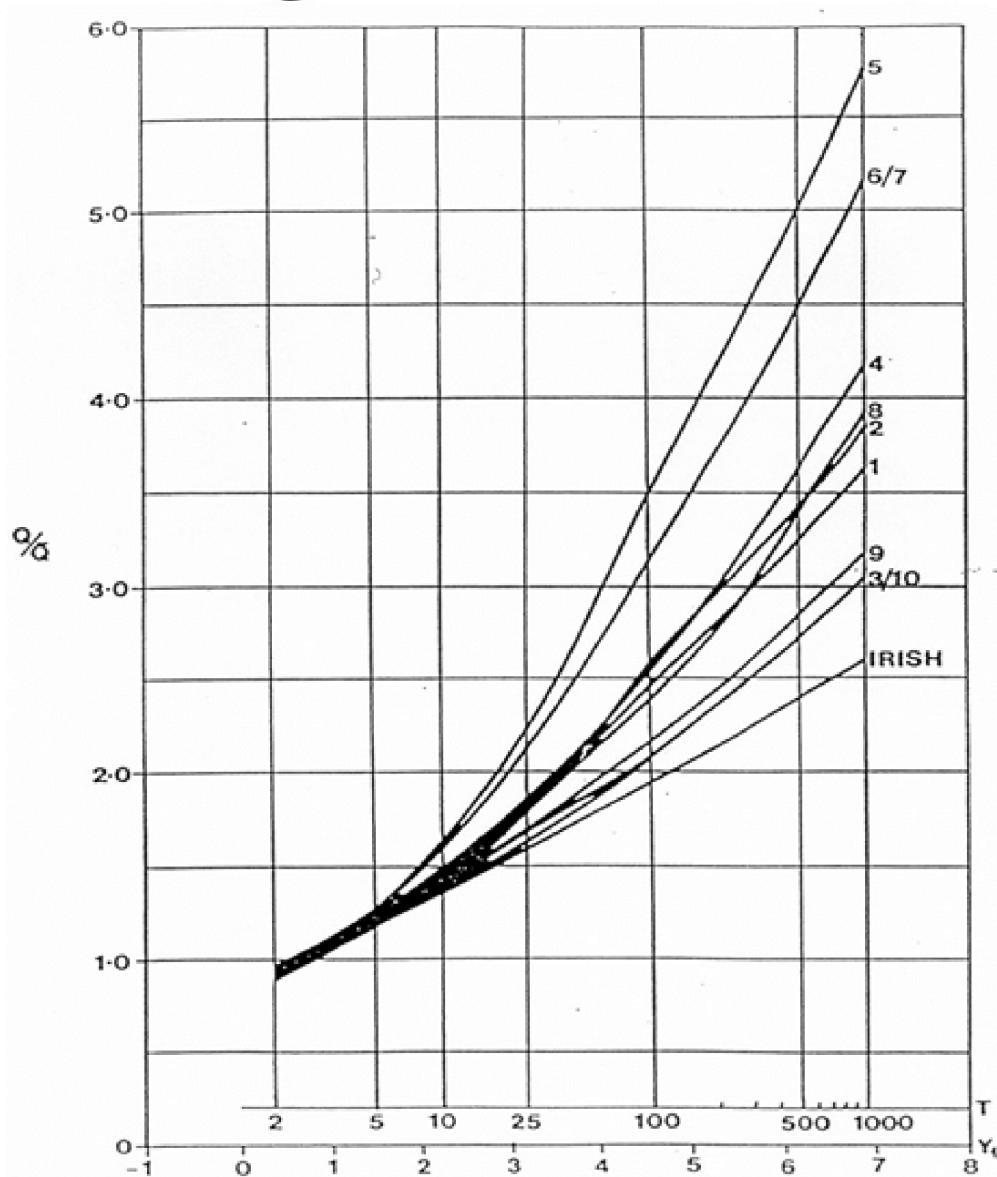


Figure 3.6: Regional Growth Curves for the British Isles

Source: NERC (1975)

The FSU approach to flood frequency estimation is based on the index flood method in which the peak magnitude of the T-year flood ( $Q_T$ ) at any location is estimated as the product of an index flood ( $Q_{MED}$ ) and a flood growth factor ( $X_T$ ) at that location:

$$Q_T = Q_{MED} * X_T$$

Equation 3.3: Calculation of the peak magnitude of the T-year flood

Flood growth factors and growth curves had already been derived under the CFRAM studies, and the approach for this project was designed to use this information as far as possible. A nationwide review of

CFRAM growth factors and curve fitting was carried out in order to develop a pragmatic approach for the national roll out, to be tested in the Pilot Studies.

In some cases, the CFRAM studies had resulted in numerous growth factors within a river system; for some UoMs, the factors were grouped into bands of relevant catchment size (UoM 01, 06, 07, 09, 10, 11, 12, 13, 14, 15), at others, the factors were grouped by reaches (UoM 23, 24, 25, 26), while in others, the factors were developed at local gauge locations (UoM 18, 20).

Such differing approaches and baseline information offering challenges for transition from growth curve to growth curve, as well as for consistency not only within a river system but across a wider area. In order to address these challenges for this national mapping project, growth curves were developed using the following steps:

- Baseline growth curve information was extracted from CFRAM studies;
- The impact of recent flow data on CFRAM growth curves was assessed and a single adjustment factor was developed for each UoM based on an average of the gauges;
- The adjustment factor was applied to the growth factors.

The procedure is detailed below. This was considered to be a sensible compromise between the high levels of detail in some UoMs, and earlier approaches that had been based upon a single growth curve for the whole country.

### **Baseline growth curve information from CFRAM studies**

For the Pilot Study Areas, the relevant CFRAM growth factors and curve fitting information were extracted from the relevant hydrology reports. The information for UoM 18 is presented in Table A.1. The information for UoM 26 is presented in a range of tables for the different catchments and reaches:

- Suck catchment: Table A.2;
- Inny catchment: Table A.3;
- Hind catchment: Table A.4;
- Upper Shannon catchment: Table A.5.

### **Assessing the impact of recent flow data on CFRAM growth curves**

The growth curves derived under the CFRAM programme were based upon data only up to 2012. It was therefore necessary to ascertain the impact of the series extension (2012 to 2016) upon the growth curves. In order to do this, growth curves for the two periods were generated:

- Historical period to 2012 (that used in the CFRAM analyses);
- Historical period to 2016.

Growth curves for the Pilot Study Areas are shown in Figure 3.7 (UoM 18) and Figure 3.8 (UoM 26). These growth curves were fitted using the GEV distribution. Under the CFRAM studies, growth curves were fitted using a number of different distributions, with the GEV and GLO tending to give the best fit. Research has shown that these distributions, and particularly the GEV, are widely applicable, and are suitable for use in Ireland (OPW, 2009; Ahilan *et al.*, 2012).

The green line shows the growth curve for the historical period up to 2012 and the red line shows the growth curve for the period of record up to 2016. The dotted lines show the uncertainty range in the best estimate (95% confidence interval).

### HA: 18 GEV model

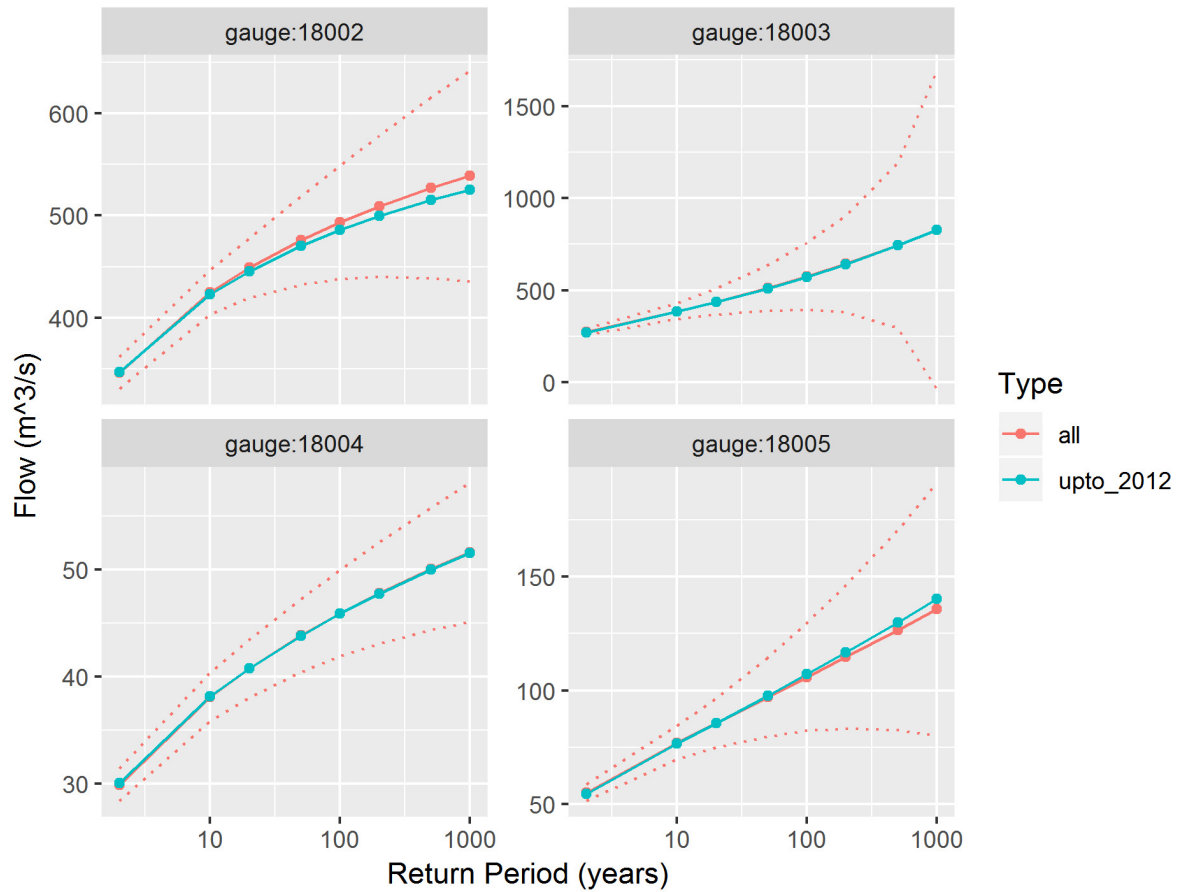


Figure 3.7: Growth curves for gauges in UoM 18, fitted using the GEV distribution. The 95% confidence intervals are shown as dotted lines

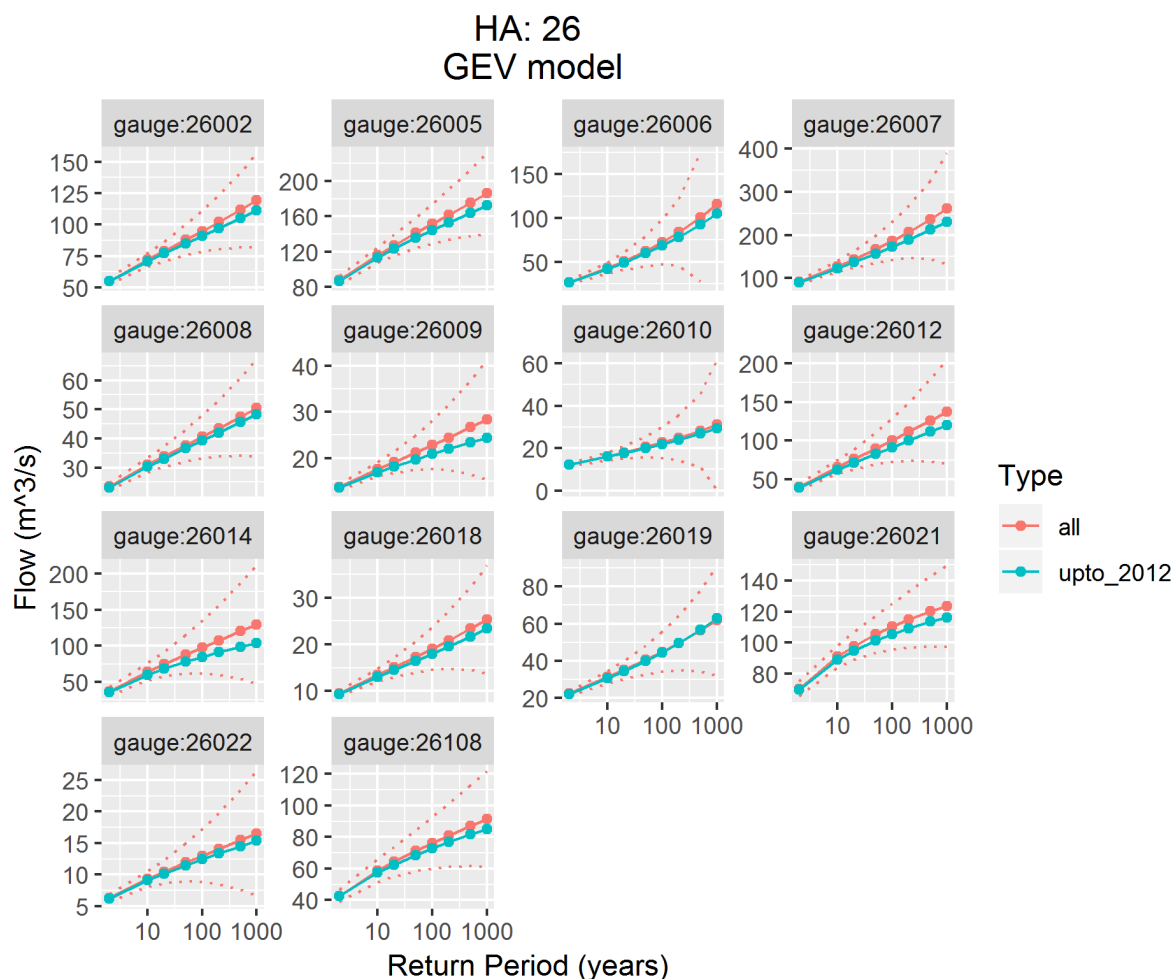


Figure 3.8: Growth curves for gauges in UoM 26, fitted using the GEV distribution. The 95% confidence intervals are shown as dotted lines

The change in the GEV growth curve as a result of the additional four years of flow data was calculated for each OPW gauge. The growth curves for each UoM based on CFRAM growth curves were then scaled (Table 3.3) to account for the additional four years of flow data.

Table 3.3: Average growth curve adjustment factors

UoM	5% AEP	2% AEP	1% AEP	0.1% AEP
18	1.001	1.001	1.001	1.001
26	1.028	1.040	1.049	1.083

There is little change in the growth factors in UoM 18 as the result of the additional years of annual maximum flow data. In UoM 26 there is a 5% increase in the growth factor for the 1% AEP flood and an 8% increase in the growth factor for the 0.1% AEP event.



### 3.4. Derivation of the flood hydrograph

Following the FSU procedures, for an ungauged site, the 'characteristic flood hydrograph' is produced using regression analysis of the available data of river discharge and PCDs of the gauging stations in the region. During the course of FSU research for Work Package 3.1, it was found that the Unit-Peak-at-Origin UPO-ERR-Gamma curve performed better in comparison to other curves in fitting the derived non-parametric hydrograph.

The shape of the flood hydrograph for this project was therefore derived using this approach, with FSU equations based on catchment descriptors (OPW, 2009). The regression models developed under FSU research are, when  $BFI_{SOIL}$  data are available:

- $T_r = 54.98 BFI^{1.32} (1+ALLUV)^{-13.08} (1+ARTDRAIN)^{-3.70} S1085^{-0.20}$
- $C = 310.75 BFI^{3.44} FARL^{-4.88}$
- $n = 1 + 2.90 BFI^{1.12} FARL^{4.37}$
- $W_{75} = 34.74 BFI^{1.86} FARL^{-3.95} (1+ALLUV)^{-12.20} (1+ARTDRAIN)^{-3.32} S1085^{-0.25}$
- $W_{50} = 63.05 BFI^{2.11} FARL^{-4.55} (1+ALLUV)^{-10.24} (1+ARTDRAIN)^{-3.17} S1085^{-0.25}$

Where:

$T_r$  is the translation or location parameter of a Gamma hydrograph (hours);

$C$  is the recession parameter of an exponential recession curve (hours);

$n$  is the shape parameter of a Gamma hydrograph;

$W_{75}$  is the width of exceedance at the 75 percentile of the peak flow (hours);

$W_{50}$  is the width of exceedance at the 50 percentile of the peak flow (hours).

The percentage of the peak flow at each time interval of the rising limb of the hydrograph is calculated using:

$$p = ((t / T_r)^{n-1}) * \exp(-((t-T_r) * (n-1) / T_r)) * 100$$

The percentage of the peak flow at each time interval of the falling limb of the hydrograph is calculated using:

$$p = ((t + T_r / T_r)^{n-1}) * \exp(-((t-T_r) * (n-1) / T_r)) * 100$$

Until the point of inflection ( $t_{infl}$ ) which is calculated from:

$$T_{infl} = T_r / (n-1)^{0.5}$$

The percentage of the peak flow at each time interval of the falling limb of the hydrograph after  $t_{infl}$  is calculated using:

$$p = p_{infl} * \exp(-(t-t_{infl}) / C)$$

An example hydrograph produced using the UPO-Gamma method is shown in Figure 3.9.

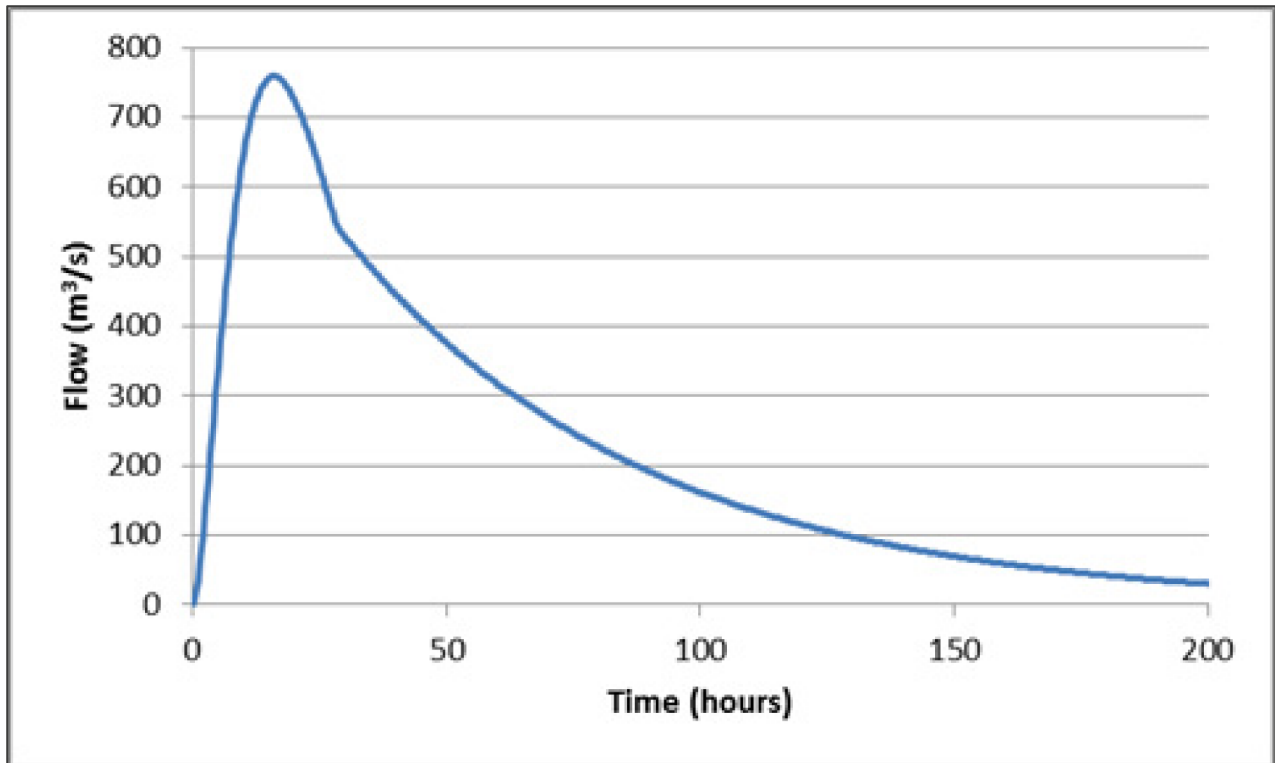


Figure 3.9: Example hydrograph produced using the UPO-Gamma method

### Application to model reaches

The values of  $T_r$ ,  $C$  and  $n$  calculated at each node showed random variations along a river reach. To produce consistent hydrograph shapes the values were aggregated to the river segment and then adjusted to ensure consistency along the river. The values of  $T_r$  and  $C$  was adjusted so that  $T_r$  increases in the downstream direction. These flow hydrographs were applied in the hydraulic modelling using the peak flows from the adjusted  $Q_{MED}$  values and derived growth curves.

## 3.5. Climate scenario flow factors

The main objective of this mapping procedure is to establish flood hazard areas. These are the areas that are liable to flood with Annual Exceedance Probabilities (AEPs) of 0.1%, 1%, and one more frequent AEP that best represents out of bank flows (the 5% event was selected following the initial pilot modelling), for three climate change scenarios:

- Current Scenario: reflects the current situation; these are the flows calculated from the procedure described above;
- Mid-Range Future Scenario (MRFS): represents a 'likely' future scenario, based on the wide range of predictive analysis and with the allowances for increased flow, sea level rise, increased rainfall depths, land movement, urbanisation and forestation within the bounds of widely accepted projections. This has been represented in the modelling as an increase in flows of 20%, and an increase in mean sea level of 0.5 m over the Current Scenario;

- High-End Future Scenario (HEFS): represents a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictive analysis, and with the allowances for increased flow, sea level rise, increased rainfall depths, land movement, urbanisation and forestation at the upper the bounds of widely accepted projections. This has been represented in the modelling as an increase in flows of 30%, and an increase in mean sea level of 1.0 m over the Current Scenario.

## 4. Hydraulic modelling

### 4.1. Approach

Hydraulic modelling has been undertaken for all subject watercourses with an upstream catchment area of greater than 5 km<sup>2</sup>, including the sections of watercourse modelled under the National CFRAM Programme, which will remain unmodelled during the roll out.

InfoWorks ICM has been used for the hydraulic modelling task. It was selected because it is bench-marked by the EA, solves the full Shallow Water Equations (SWE) with shock capturing, uses irregular triangular meshing and has a high speed of model simulation. It also enables modelling flexibility and auditing, which enable application to a wide range of catchments, and easy tracking of model development.

Our approach has been based upon the development of a series of reach- to sub-catchment-scale hydraulic models. The models are all 2D high resolution irregular mesh models for the river channel and floodplain. It is well established that this approach can overcome known instability issues that can arise with 1D/2D coupled models. The benefits of irregular meshes, in terms of representing flow routes, structures and flexibility regarding resolution, compared to regular grids, is also well established.

### 4.2. Model definition

In order to determine the spatial extent of each model, a map of each Pilot Study UoM was prepared of all watercourses on the EPA watercourse layer with catchment area greater than 5 km<sup>2</sup>. Maps of the relevant watercourses of UoMs 18 and 26 are presented in Figure 3.1 and Figure 3.2.

Two approaches to the definition of model extents have been trialled, defined by a set of rules taking account of key factors such as main tributary junctions, significant changes in flow rate and/or critical storm duration, and sub-catchments. These approaches have been designed to avoid the discontinuities in flows that can occur in hydraulic modelling when compared with the design hydrographs from the hydrological analysis, for example downstream of confluences.

Following the initial pilot modelling, the approaches were combined to create sub-catchments based on rules that take into account stream order and the presence of lakes. A separate 2D hydraulic model was built for each sub-catchment.

For UoM 18, the 60 sub-catchments are shown in Figure 4.1; the model extent excludes the estuary since this is beyond the extent of the FSU-nodes and the fluvial nature of this project. The stream order is a method of describing the drainage network of a catchment. The Strahler (1952) method was used to assign stream order:

- Tributaries originating at a source are designated stream order of 1;
- The junction of two streams of the same stream order forms a downstream channel segment with that stream order plus 1;

- Where there is a junction of two streams with different stream orders, the downstream segment has the same stream order as the higher order tributary.

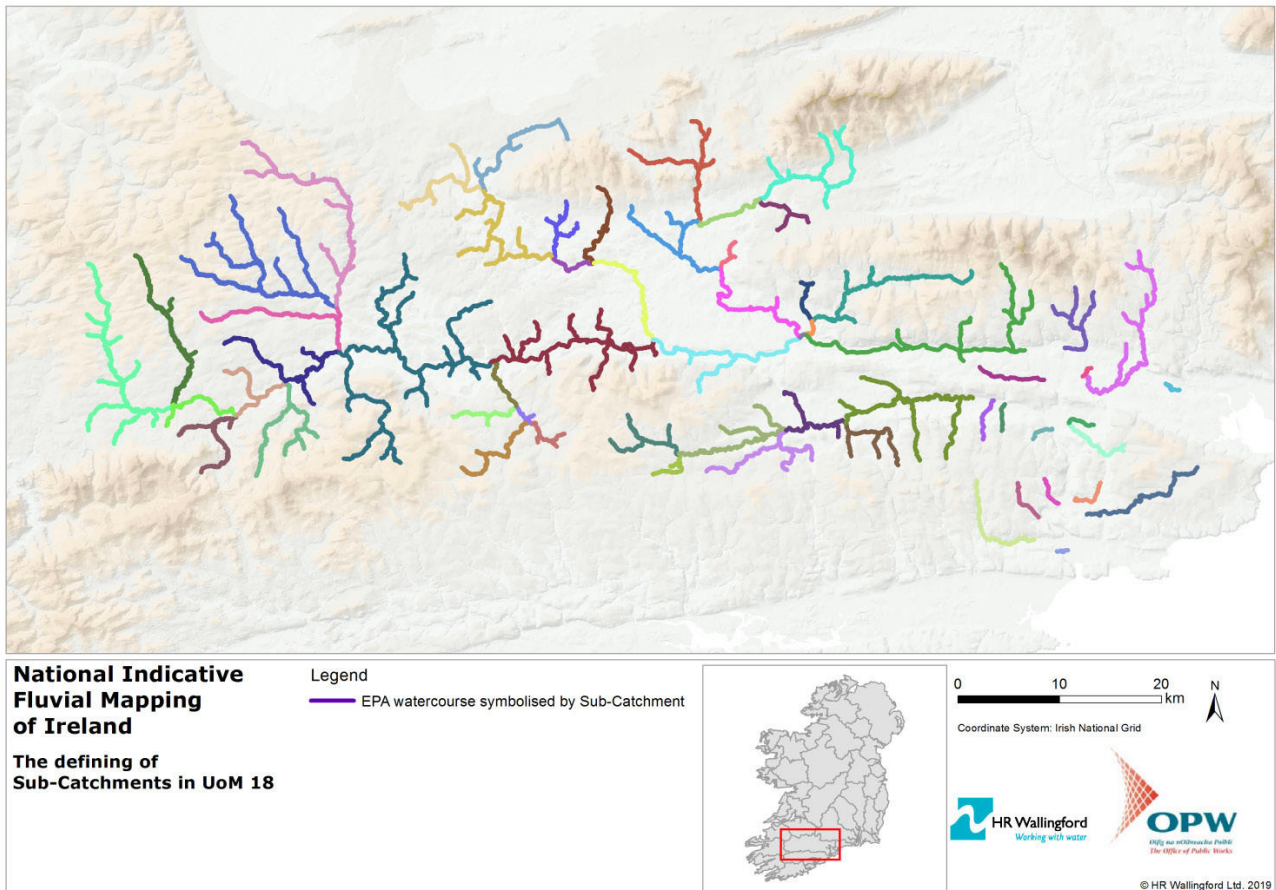


Figure 4.1: Map of UoM 18 showing the defined sub-catchments and their reaches

Source: HR Wallingford

For UoM 26, the catchments of the Rivers Inny and Suck were trialled, since these exhibit the characteristics that will be seen in the national roll out, whereas the main Shannon is highly controlled and thus less typical of the non-CFRAM areas to be modelled in the roll out. These catchments were broken into a series of 50 sub-catchments, which were defined using a combination of lakes and stream order (Figure 4.2). A separate model was built for each sub-catchment.



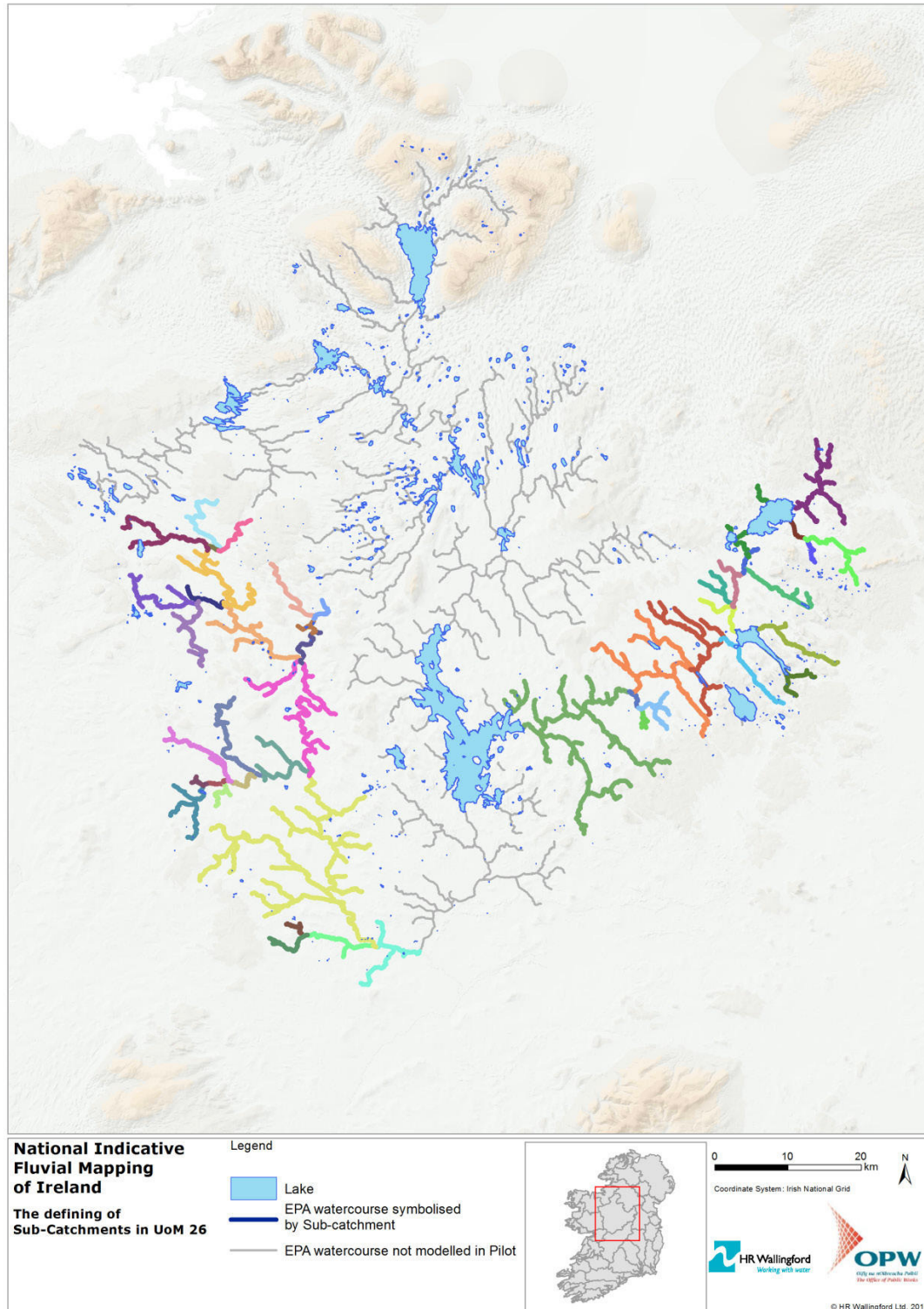


Figure 4.2: Map of UoM 26 showing the defined sub-catchments and their reaches

## 4.3. Geometry

The steps involved in calculating, testing and refining the model geometry, including setting the model domain, estimating the river channel surface elevation and characteristics, are described below. Where different options were trialled, the decision on the best option to roll out is specified in bold font.

### 4.3.1. Defining the model domain

Two approaches to define the extent of the model domain were piloted:

- Cross-section approach – where cross-sections are created perpendicular to the river centreline at each FSU node with elevations taken from the IfSAR DTM at 5 m intervals. The cross-section is terminated when the elevation increases above a threshold. The threshold was set based on stream order. The end points of the cross-sections on the reach are connected to create the model domain;
- DTM approach – on UoM 26 an alternative approach was used because the flat, wide floodplains meant that cross-sections on different rivers crossed. This meant that creating an outer zone was more complicated than in UoM 18. The alternative approach was developed to use GIS queries on the river and the DTM data to derive the model domains. By tracking along the rivers and selecting the regions where the DTM cells are less than the specified tolerance above the river node level, the model domain has been created.

The results of the UoM 18 pilot identified some areas where the cross-section approach did not generate a domain that was large enough. The second approach was shown to perform best on the most complicated catchment UoM 26 and the run-time was better than that of the cross-section approach. The results provided here were based upon the DTM approach.

**The DTM approach has been finally trialled for both Pilot Study Areas and is recommended for the national roll out.**

### 4.3.2. Estimating the river channel surface elevation

The surface elevation of the river channel was estimated at each FSU node by taking the lowest elevation on the cross-section. The elevations were checked to ensure that the elevation did not increase in the downstream direction. High elevations were removed. Linear interpolation was used between the nodes spaced at 500 m intervals to set the channel elevation in the mesh cells of the 2D model.

The use of cross-sections at 500m intervals has meant that on some of the smaller tributaries the river channel is not properly represented in the hydraulic model. Figure 4.3 shows an example of where the river channel is dry because the channel is not well represented based upon cross-sections spaced every 500m.



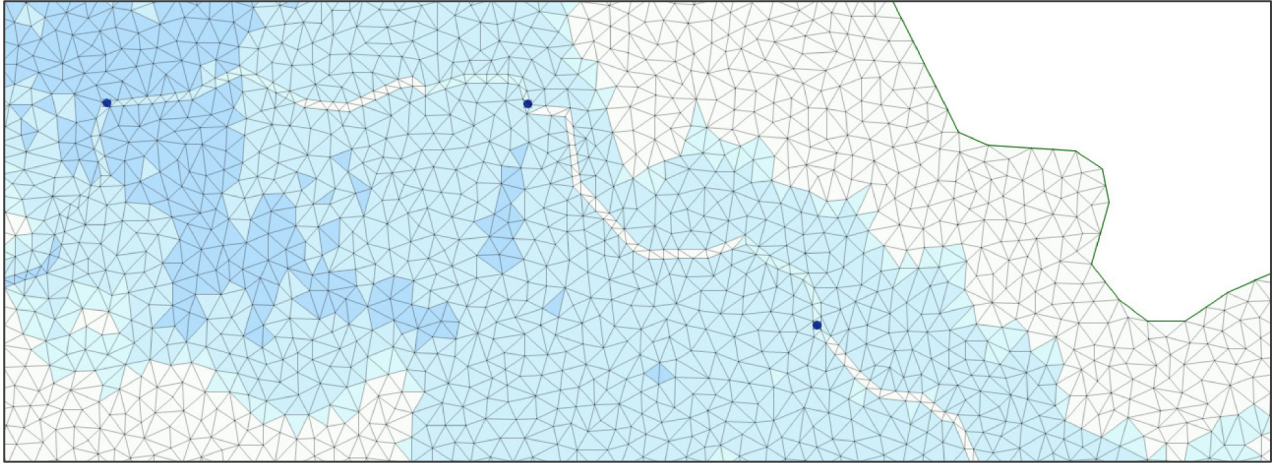


Figure 4.3: Poor representation of the river channel

A revised method was then used with cross-section spacing every 50 m capturing the detailed local slope changes. Figure 4.4 shows that the river channel is then well represented in the hydraulic model.

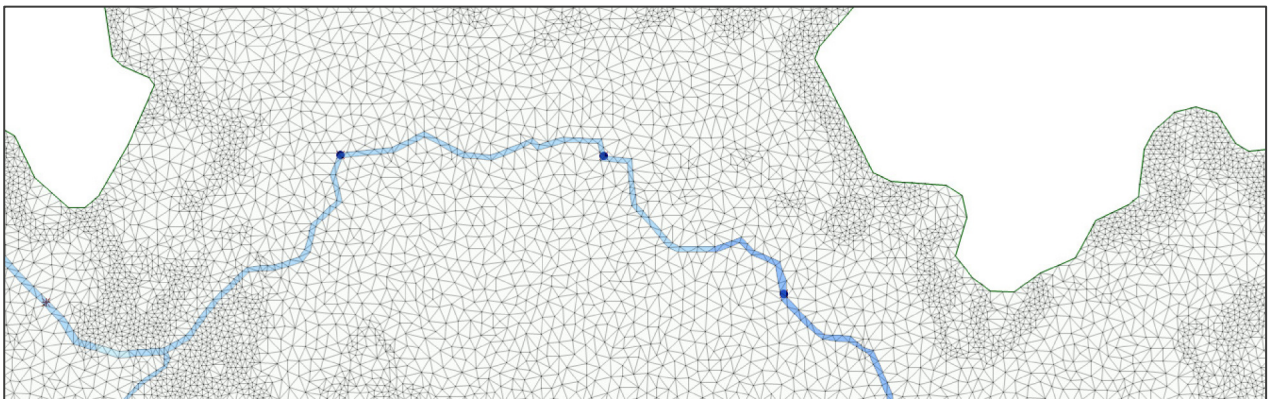


Figure 4.4: Corrected representation of the river channel

**The approach based upon 50 m spacing of cross-sections has been finally trialled for both Pilot Study Areas and is recommended for the national roll out.**

#### 4.3.3. Estimating the river channel characteristics

Each of the steps taken to define the river channel characteristics is described in the sub-sections below.

##### **Channel capacity and $Q_{MED}$ adjustment for different types of channel**

The starting assumption was that all watercourses are “bank-full” for peak flows in the  $Q_{MED}$  event and that any flows above  $Q_{MED}$  are floodplain flows. However, the validity of this assumption varies depending on the nature of the watercourse, such as for urban watercourses (where the natural channel has often been modified to carry more flow to mitigate the risk of flooding), Arterial Drainage channels (where the natural channel has been modified to carry more flow to drain agricultural land), and steep watercourses (typically having lower conveyance capacities than similar channels of lower slope, described in research by Ahilan et al., 2013). This assumption was tested on samples of each type of watercourse.

Sample cross-sections were taken from the CFRAM survey data provided for UoM 18 and 26. The channel width, depth, and local reach slope were derived and  $Q_{MED}$  was taken from the CFRAM study data. The channel capacity was estimated using the Manning equation and compared to  $Q_{MED}$  (Table 4.1). Some of the cross-sections produced estimated flow capacities that did not fit the general pattern (18KEEN00082H, and 18BRID00889H), these were excluded from developing general rules on the capacity of different types of channels. The general observations were as follows:

- On shallowly sloping rivers, the channel capacity is approximately  $Q_{MED}$ ;
- On moderately sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
- On steeply sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
- On rivers with arterial drainage works the channel capacity is approximately 135%  $Q_{MED}$ .

### Investigation of channel capacity through urban areas

In the Pilot Study Areas, CFRAM cross-section surveys were analysed to estimate the flow capacity in both rural and urban areas. This investigation identified that:

- River Blackwater through Mallow: no significant change in channel capacity through the urban area compared to the river in rural areas;
- River Blackwater through Fermoy: no significant change in channel capacity through the urban area compared to the river in rural areas;
- River Allow through Kanturk: there is a significant increase in channel capacity (30 to 50%) in the urban reach compared to rural areas;
- Dromore Commons (a small tributary of the Blackwater at Mallow): no significant increase in channel capacity in the urban area (possibly +10%);
- River Suck: did not appear to have a significant increase in channel capacity in the urban areas compared to the rural.

In summary, for the Pilot Study Areas, the majority of those reaches in urban areas did not show a significant change in channel capacity compared to the surrounding rural areas.

### Comment on the pilot study results in urban areas

The pilot study modelling (Sections 6 and 7) did not include an urban adjustment to channel capacity. The results show that in the key urban areas of Mallow, Fermoy and Ballinasloe, the modelled flood extents and water levels fit well to those from the CFRAM studies and to observations from historical floods. In Kanturk, the model produces slightly more flooding than shown in the CFRAM model in the AEP 5% and 1% events; in the AEP 0.1% HEFS event, the model produces similar flood extents to those of the CFRAM model.

Furthermore, results from earlier versions of the models in the Pilot Study Areas were re-examined. In those models, urban areas had an effective channel capacity of approximately 1.5 times  $Q_{MED}$ , due to pre-existence of part of the river channel in the DTM (a circumstance which was recognised and corrected in subsequent versions of the model, described later in this section). The results showed significantly less flooding and lower water levels in the urban areas of Mallow and Fermoy than the CFRAM model results. It can be concluded that a global increase to channel capacity through all urban areas would therefore underestimate both the water levels and flood extents in such urban areas.

### Analysis of gauge sites in urban areas

Ahilan *et al.*, (2013) assessed the bank-full capacity of Irish rivers at gauging stations finding that 66% of sites had a bank-full flow recurrence interval between 1 and 5 years. The data presented in their paper has



been re-analysed to calculate the ratio of the bank-full flow calculated from the cross-section to the gauged  $Q_{MED}$ .

The median for rural sites was a bank-full flow of 97% of  $Q_{MED}$  and the median for urban sites 170% of  $Q_{MED}$ , however there is considerable scatter in the data (Figure 4.5). This suggests that an increase in channel capacity through urban areas compared to rural areas might be appropriate in some cases, however there is not a consistent increase that would apply to all urban areas.

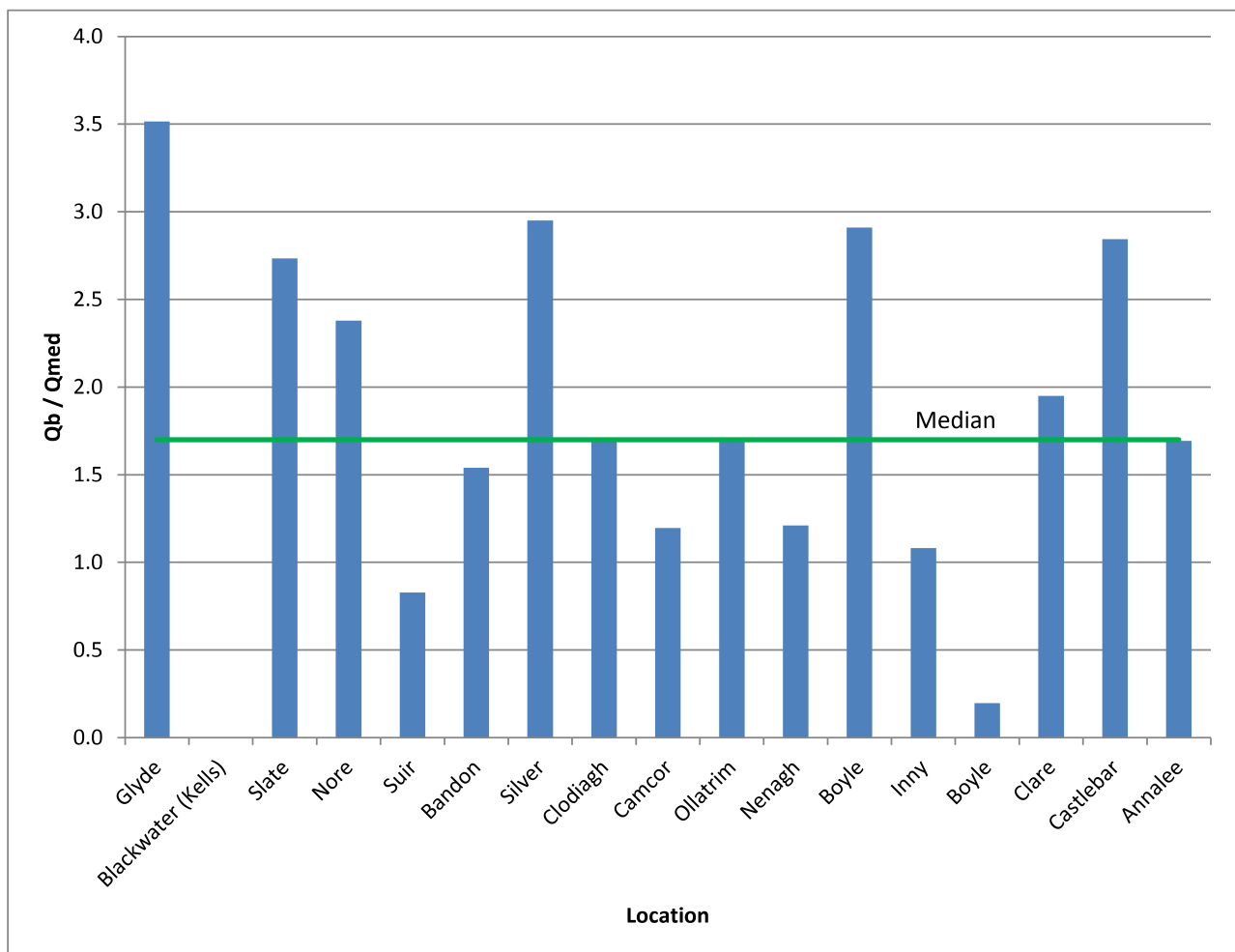


Figure 4.5: Calculated ratio of bank-full flow to  $Q_{MED}$  for a range of urban river reaches

Source: Ahilan *et al.* (2013)

Furthermore, it is worth noting that these sites may contain a bias towards higher than expected channel capacity because gauging sites would be expected to contain flows of above average recurrence interval. At gauging sites, the full flow range must be controlled within well-defined channel banks (Ahilan *et al.*, 2013) (Figure 4.6 and Figure 4.7).



Figure 4.6: Gauge 06014: River Glyde at Tallanstown

Source: <http://waterlevel.ie/hydro-data/home.html>



Figure 4.7: Gauge 15002: River Nore at John's Bridge

Source: <http://waterlevel.ie/hydro-data/home.html>

In order to assess the impact of flood mitigation works in urban areas outside of the Pilot Study Areas, flood-prone urban areas of the national roll-out have been examined. This review had a particular focus upon flood mitigation works that have been already constructed, or that are in the design or construction phases<sup>2</sup>; the great majority of these are within CFRAM extents, as summarised below:

- Schemes at construction: one scheme out of nine is not in CFRAM extents;
- Schemes post-construction: four schemes out of 26 fluvial schemes are not in CFRAM extents (of which, three schemes are on the River Tolka);
- Other schemes completed since 1995: one scheme out of 17 is not in CFRAM extents.

Therefore, significant channel modifications have been made in areas that will not be modelled in the national roll-out for NIFM.

It was therefore concluded that the best approach is not to apply an increase to channel capacity in the modelled urban areas. This will mean that the results may be on the conservative side in those urban areas that do have slightly increased channel capacity; it will not under-estimate the flood extents in those urban areas that do not have increased channel capacity compared to rural areas. It is anticipated that the results for the AEP 5% scenario would be most influenced, with little impact on the AEP 0.1% results.

**These adjustments for a range of channel types have been finally trialled for both Pilot Study Areas and are recommended for the national roll out.**

<sup>2</sup> <https://www.opw.ie/en/flood-risk-management/operations/flooddefenceschemes/#d.en.23394>

Table 4.1: Details of channel width, depth and  $Q_{MED}$  at key locations in each UoM

UoM	Section	Width (m)	Depth (m)	Slope (1m in ...m)	$Q_{MED}$ (m <sup>3</sup> /s)	Ratio of calculated flow capacity to $Q_{MED}$	Channel type
18	18KEEN00082H	5	1.5	50	2.8	3.5	Steep
18	18ALLO02245H	10	1.3	150	23.0	0.9	Rural, steep
18	18ALLO01996H	10	1.5	350	23.8	1.0	Rural, steep
18	18ALLO00413H	20	2	600	106.3	0.6	Rural, steep
18	18BLAC09822H	30	3	1100	285.0	0.6	Rural, moderately steep
18	18BLAC06677H	40	3.5	1500	374.0	0.7	Rural, moderately steep
18	18BRID00889H	25	2.5	17,500	98.5	0.3	Rural, flat, estuary?
18	18BRID04148H	10	1.5	400	28.6	0.7	Rural, steep
18	18DALU00715H	15	2	150	46.9	1.2	Rural, steep
26	26SUCK10876	10	2	100	47.3	1.1	Rural, steep
26	26SUCK09445	15	2.5	1900	32.0	1.0	Rural, moderate slope
26	26SUCK06687	50	1.5	1100	65.7	1.1	Rural, moderately steep
26	26SUCK03006	45	2	4500	86.3	0.8	Rural, flat
26	26SUCK01514	50	3	3100	107.0	1.1	Rural, flat, controlled?
26	26INNY00171	25	3	1000	72.8	1.5	Rural, moderately steep with arterial drainage
26	26INNY01894	35	3	4500	61.8	1.2	Rural, flat with arterial drainage

### Correction for proportion of channel captured by the DTM

The initial hydraulic modelling and sensitivity analysis identified that the DTM already contained a proportion of the river channel for the larger rivers (wider than 10 m). The cross-sections from the DTM were compared to the relevant CFRAM survey cross-sections. Examples of the comparisons for channels in a range of width categories are shown in Figure 4.8 through to Figure 4.11. These show that only the additional part of the channel needs to be added where the DTM already contains part of the channel.

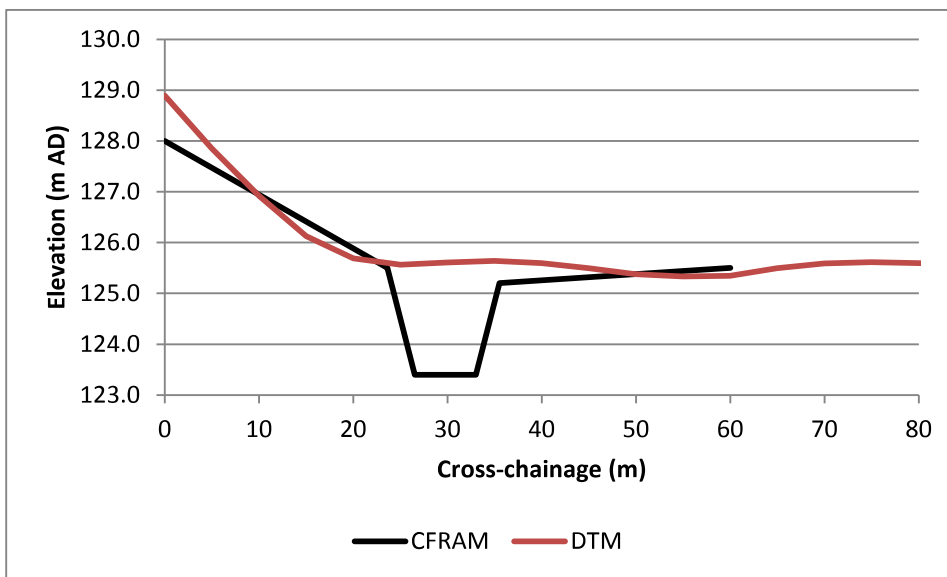


Figure 4.8: Comparison of DTM and CFRAM cross-sections for a river with a channel less than 10m wide

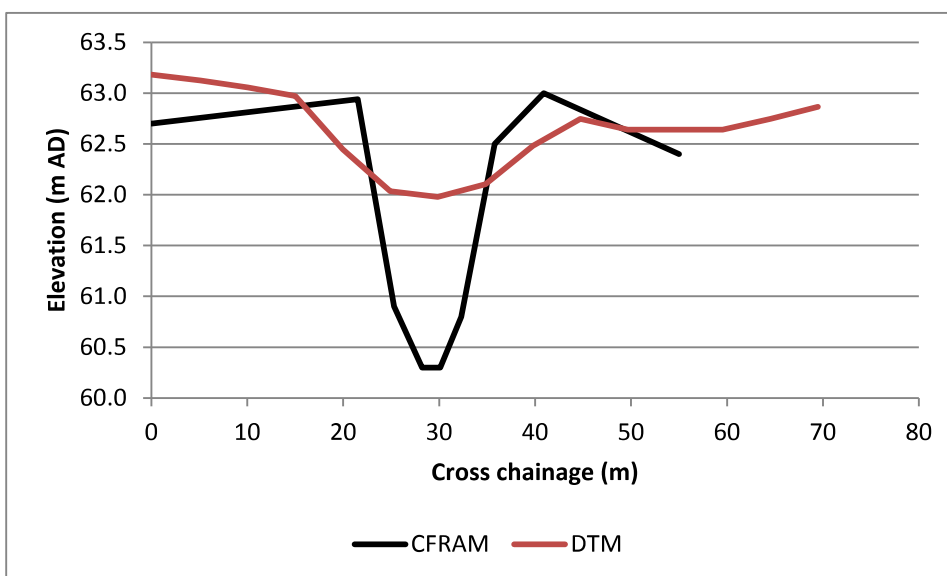


Figure 4.9: Comparison of DTM and CFRAM cross-sections for a river with a channel around 15m wide



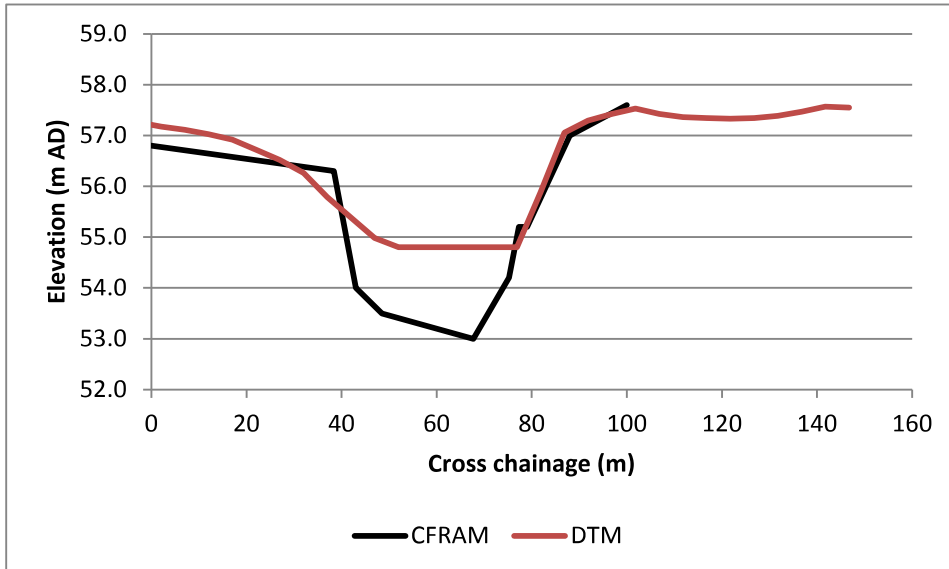


Figure 4.10: Comparison of DTM and CFRAM cross-sections for a river with a channel around 20m wide

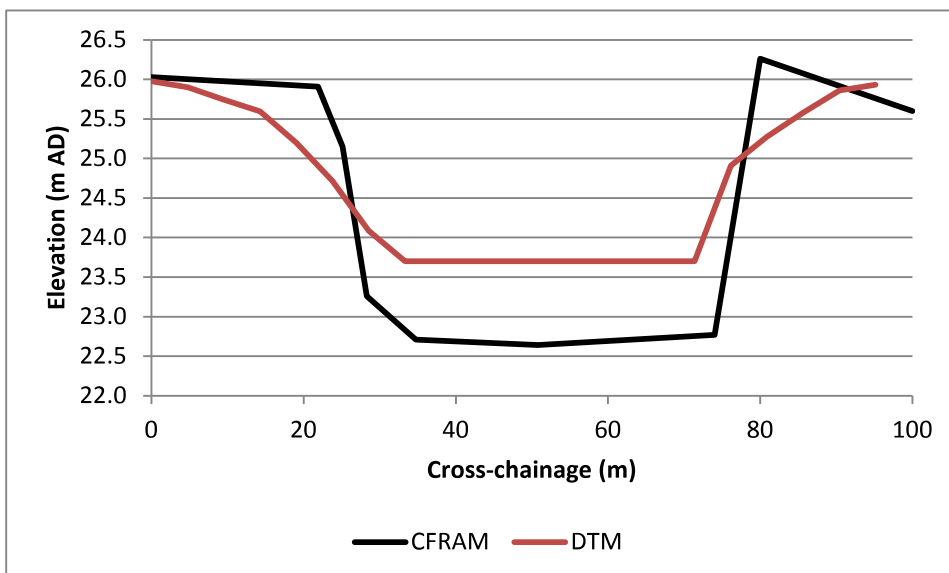


Figure 4.11: Comparison of DTM and CFRAM cross-sections for a river with a channel greater than 40m wide

The following adjustments are suggested based on these observations, to account for part of the channel that is already captured in the DTM; these values represent the additional amount of channel capacity to create in the DTM for these categories:

- Width < 5m: no adjustment;
- Width >5m to <10m: adjust to 85% of full capacity;
- Width >10m to <15m: adjust to 70% of full capacity;

- Width >15m to <20m: adjust to 60% of full capacity;
- Width >20m to 40m: adjust to 50% of full capacity;
- Width > 40m: adjust to 35% of full capacity.

These factors are then multiplied by the  $Q_{MED}$  adjustment for the relevant channel type to obtain the channel size to add to the 2D mesh.

#### Estimation of channel width based on $Q_{MED}$

A range of geomorphological relationships were used to estimate the channel width based on  $Q_{MED}$  (from the CFRAM studies); these were (Table 4.2):

- Nixon (1959): a simple method developed based upon research on gravel-bed rivers and canals in Britain;
- Hey and Thorne (1986): an empirical approach to estimation of channel geometry, including provision for vegetation type, bed material size and bed-load transport. Designed originally for application to calculate bank-full dimensions of stable, mobile gravel-bed rivers;
- Richards (1976): an approach which recognises the importance of riffles and pools on width:depth ratios.

The Richards (1976) equation was selected as most representative based on the application to UoM 18, offering the best match to channel width measured at the trial locations. In UoM 26, none of the geomorphological relations was particularly accurate on the larger rivers having navigation structures, or in the reaches of the River Inny that are artificial due to arterial drainage works. Overall, the Richards (1976) equation was selected since it will be the most widely applicable, particularly for the rivers to be modelled in the roll-out.

Table 4.2: Geomorphological relationships trialled at key sections in each UoM

UoM	Section	Width (m)	Nixon (1959)	Hey and Thorne (1986)	Richards (1976)
18	18KEEN00082H	5	5.2	5.8	5.5
18	18ALLO01996H	10	14.9	15.3	11.7
18	18ALLO00413H	20	31.0	30.0	19.7
18	18BLAC09822H	30	50.3	46.7	27.8
18	18BLAC06677H	40	57.4	52.8	30.6
18	18BRID00889H	25	29.9	29.0	19.2
18	18BRID04148H	10	16.3	16.6	12.5
18	18DALU00715H	15	20.8	20.7	14.8
26	26SUCK10876	10	20.8	20.8	14.8
26	26SUCK09445	15	17.2	17.5	12.9
26	26SUCK06687	50	24.5	24.1	16.7
26	26SUCK03006	45	28.0	27.3	18.3
26	26SUCK01514	50	31.1	30.1	19.8
26	26INNY00171	25	25.7	25.3	18.7
26	26INNY01894	35	23.8	23.5	17.7

## Estimation of channel depth using Manning equation

The channel depth was then estimated using the Manning equation and automated GIS methods used to produce the spatial data that defines the channels within the models.

The geometry of the river channel in the hydraulic model is set using these widths and depths estimated from  $Q_{MED}$ , the reach slope and Manning's  $n$  in order to define how the channel is burned into the 2D mesh.

## Representation of river crossings with embankments

A method was developed to identify road and rail river crossings that have significant embankments above the general floodplain level (see example in Figure 4.12). Cross-sections were generated perpendicular to the transport route (road and rail) wherever those routes crossed a watercourse. Extending for 50 m upstream and downstream of the transport route (road and rail), the ground level profiles were extracted from the DTM. Where the level of the mid-point in the profile was greater than 1.5 m above the mean of the upstream and downstream ends of the profile, the crossings were flagged and output to a file for rapid review using Google Earth. The outputs were sorted in descending order to ensure that the manual review focused on the most significant locations (see examples in Figure 4.13 and Figure 4.14).

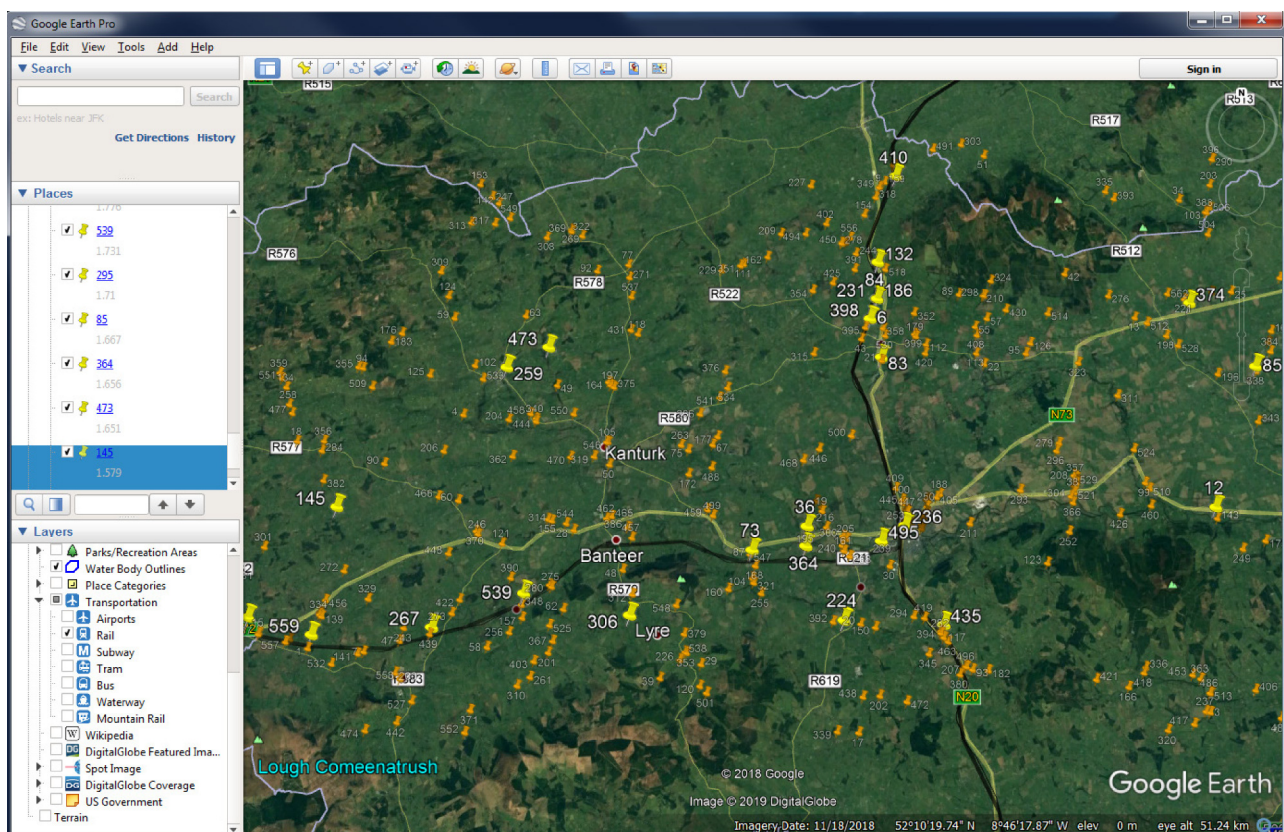


Figure 4.12: Significant and all river transport crossings identified by the automated GIS method for review

Source: HR Wallingford



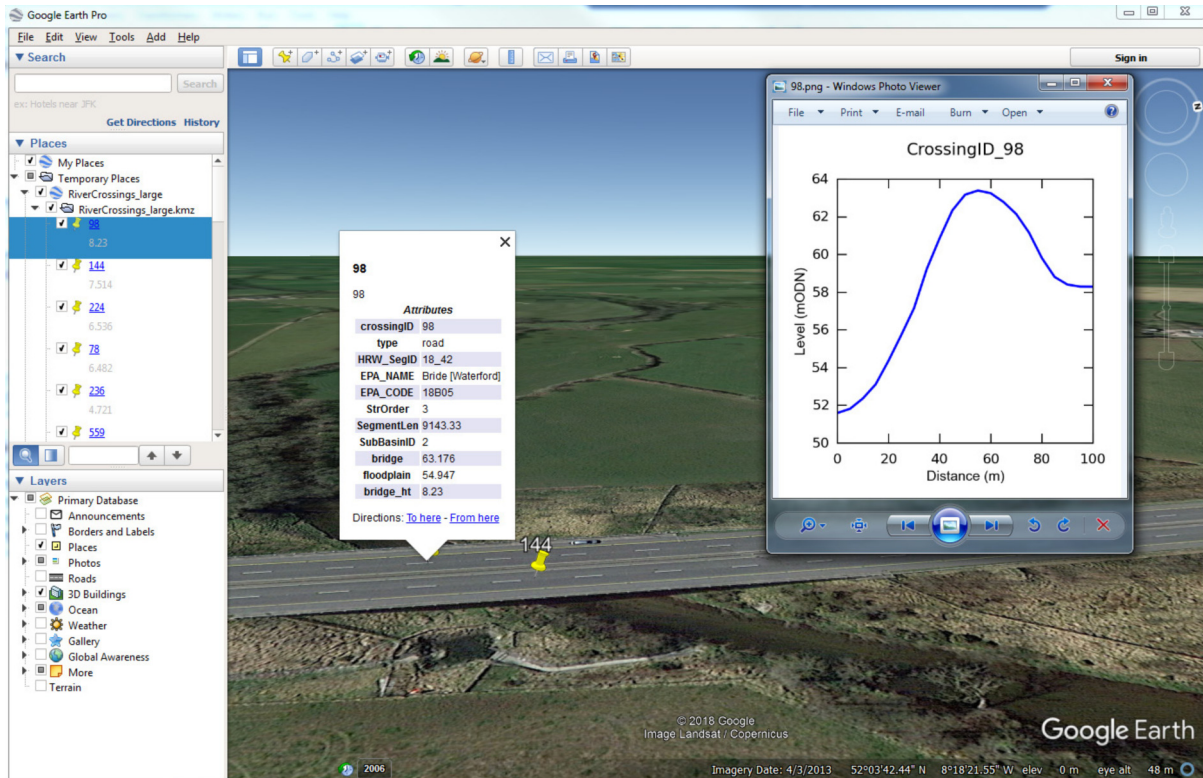


Figure 4.13: Example showing the location of a significant bridge

Source: HR Wallingford

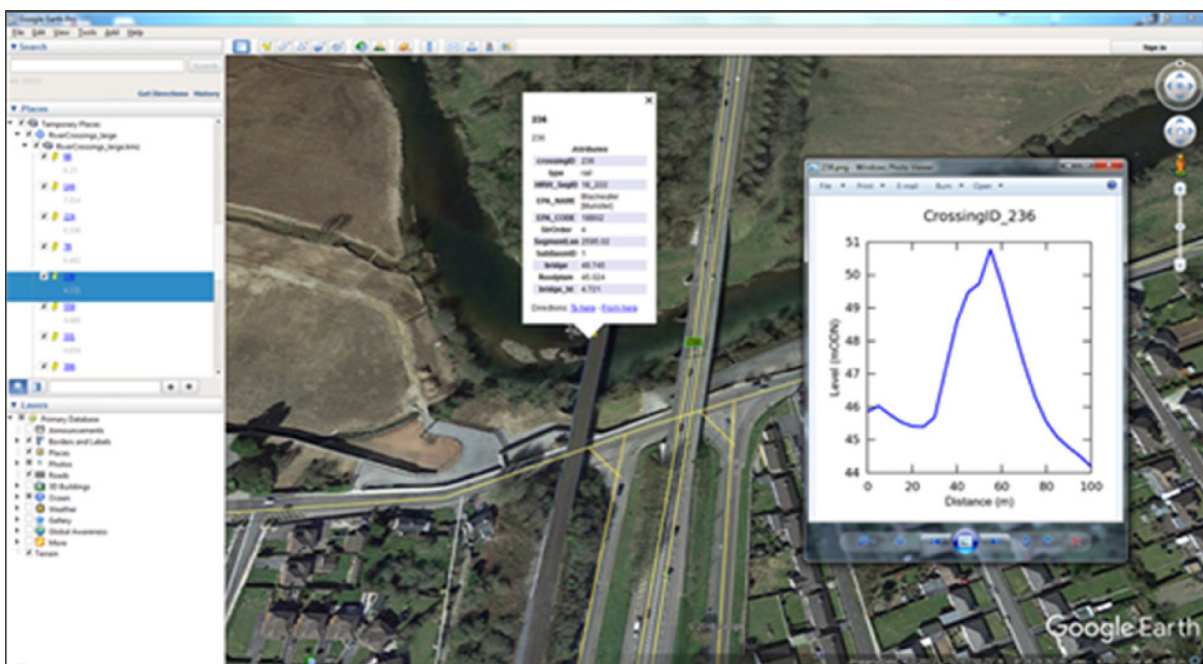


Figure 4.14: Example of the railway bridge and road bridge at Mallow on the River Blackwater

Source: HR Wallingford



The output of the review using Google Earth helped to determine whether or not the embankment across the floodplain acts as a barrier to flows. Where the embankment in the DTM is not a complete barrier to flow, a clear span motorway bridge for example, the model mesh is edited to remove the embankment.

### Specification of the 2D model mesh

An irregular mesh was derived using terrain-sensitive meshing so that finer resolution mesh elements were used in zones of greatest topographic change. The maximum mesh element area was set to 400 m<sup>2</sup> and the minimum to 25 m<sup>2</sup>. An example of the model mesh is shown in Figure 4.15.

The region shown in Figure 4.15 is at Mallow on the River Blackwater (see Figure 4.14 for context). In the mesh figure it can be seen that the elements take advantage of many of the benefits of irregular mesh model grids. These include:

- Mesh elements are aligned to features of interest in the map:
  - The channel can be clearly identified with lower ground levels and smooth sides;
  - Elements are also aligned with significant topographic features.
- Mesh element sizes vary according to features of interest and significant changes in ground elevation slope:
  - Finer mesh elements can clearly be seen in the mesh in the location of the bridge and weir as well as areas with steep slopes (commonly alongside the river channel).

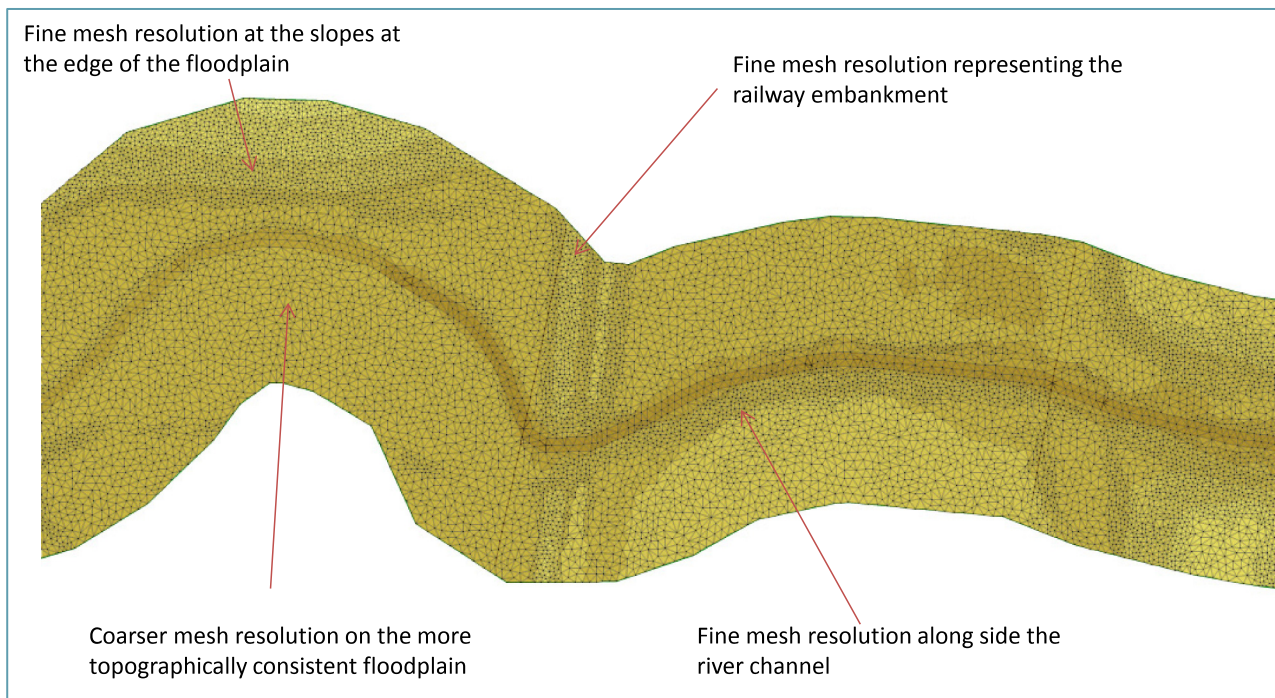


Figure 4.15: The model mesh at Mallow on the River Blackwater

## Definition of roughness

Manning's  $n$  roughness values have been estimated for each land use category in the CORINE land cover dataset. The values have been assigned based on experience and review of the roughness values used in CFRAM studies for the pilot areas.

In order to specify Manning's  $n$  roughness values for the hydraulic modelling, CORINE land cover data for 2012 had been acquired (Section 0). A consistent and applicable set of roughness values needed to be defined for each relevant land cover class, for use in the Pilot Study Areas and the national roll out. A range of sources of information on mapping land cover classes to roughness values was used, including CFRAM models for the Pilot Study Areas and our team's experience of similar tasks. The full set of derived roughness values is presented in Appendix B.

## Simplified representation of bridges

The initial pilot testing assumed that the river channel was clear at the location of a bridge. The results identified that modelled water levels upstream of arch bridges was lower than that in CFRAM model results and lower than that measured at gauging stations. The following options were trialled as a sensitivity analysis to identify the most appropriate method to represent bridges:

- Adjustment of the channel size through the bridge;
- Adjustment of channel roughness to  $n = 0.2$ ;
- Adjustment of channel roughness to  $n = 0.5$ .

The results of these sensitivity tests indicated that setting the channel roughness  $n$  to 0.2 at bridges gave a reasonable approximation of the afflux impact on water levels upstream of the bridge.

**This method of  $n = 0.2$  at bridges has been applied in the final pilot modelling.**

Caveat: It should be noted that bridges have not been specifically represented in the modelling.

## Identification of errors in the DTM

The IfSAR DTM is known to include certain limitations. These important limitations were tested during the pilot stage using a range of techniques, and the outcomes are outlined in each case, as follows:

- Tree and vegetation canopy may not be entirely removed from the DTM, such that these appear as solid structures on the DTM and may give the impression of solid obstructions to flow in the model (such as false river banks). The approach taken to check for this limitation was to generate cross-sections along a reach of interest, and check the continuity of the elevations (especially of the river banks) along the reach. In this way, anomalous high banks at particular locations could be easily, visually identified. No such issues were found in our trials. An example of the check is shown in Figure 4.16;

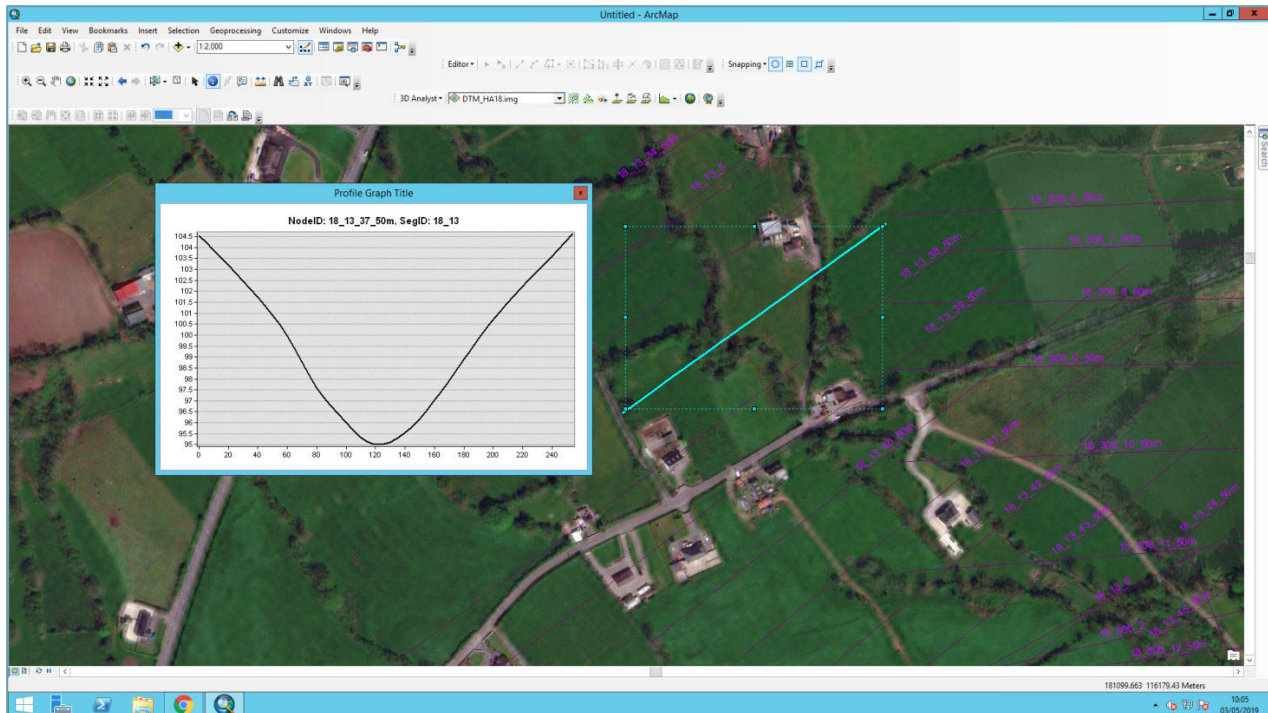


Figure 4.16: Searching for tree canopy effects in the DTM through visual inspection of successive cross-sections

- Culverts and bridge decks over watercourses may be represented in the DTM resulting in 'false blockages' in the hydraulic model: these were investigated as part of the river crossings review process outlined above (this section) and a small number of adjustments were made on UoM 18;
- Edge effects at the boundaries between earth and water surfaces: a manual visual check was carried out on the Pilot Study Areas and no issues were found.

### Definition of the downstream boundary

The downstream boundary of each model was based on data from one of three sources:

- Sea level at a coastal boundary: For the purposes of the Pilot Study Area modelling, only UoM 18 has a coastal downstream boundary, and so the relevant data were easy to extract from the relevant report; in this case, for the south coast, between Carnsore Point and Bantry Bay. A map showing the relevant location (S\_31) is presented in Figure 2.9, as extracted from the ICPSS report. Extreme water levels for S\_31 are presented in Figure 4.17.
- Water level from a CFRAM model: The maximum water level for the design event is taken from the nearest CFRAM node (that contains results). The maximum water level is fitted to the design hydrograph shape derived for the FSU node. This method was used to define the downstream boundary of the Upper Shannon in UoM 26.
- Water level from the model of the downstream reach: Within the UoM where the river system has been broken into a series of sub-catchments for modelling, the water levels for the downstream boundary are taken from the results of the downstream model. An area of overlap has been included between the two models.

		<b>Point S_31</b>
<b>Coord- inate</b>	<b>Longitude</b>	<b>-7.83</b>
	<b>Latitude</b>	<b>51.92</b>
Height to mean sea level for different AEP	50%	2.25
	20%	2.35
	10%	2.42
	5%	2.49
	2%	2.58
	1.00%	2.65
	0.50%	2.71
	0.10%	2.87
MSL to OD Malin		-0.211
seich / set-up allowance		0.150
Height to OD Malin for different AEP	50%	2.19
	20%	2.28
	10%	2.36
	5%	2.42
	2%	2.52
	1.00%	2.58
	0.50%	2.65
	0.10%	2.81

Figure 4.17: Extreme water levels for S\_31 used for the UoM 18 downstream boundary

Source: OPW (2011) - Table 6

## 4.4. Run simulations for all scenarios

In order to provide consistent water levels where the models join, accounting for any backwatering that may occur, the models have been run in order from downstream to upstream. This enables the downstream boundary conditions of the models to be taken from the results of the downstream model ensuring good agreement between the models at overlapping boundaries.

## 4.5. Check integration with CFRAM models

The maximum water level at the downstream boundary for models that enter a CFRAM modelled reach has been taken from the results at the nearest CFRAM node.

The use of the downstream boundary water level from CFRAM means that differences in the flood extent between NIFM and CFRAM is relatively small (Figure 4.18). The flood extents are merged in the overlap region using a union, so that a conservative flood extent is generated. An example of the integration process is shown for a tributary downstream of Kanturk in UoM 18 in Figure 4.19 and Figure 4.20.

Whilst testing this automated procedure on the Pilot Study Areas, it was noted that in some cases the CFRAM extents do not comply with some of the topological criteria that need to be adhered to by NIFM (such as removing disconnected polygons and filling holes less than 25 square metres). This makes the



smooth feathering/merging of NIFM results with CFRAM potentially problematic, affecting the automated merging process and having a negative impact on achieving the NIFM topological criteria.

**The approach taken here has therefore involved a more simple union and dissolve of the two datasets, and this is our recommendation for the national roll out.**

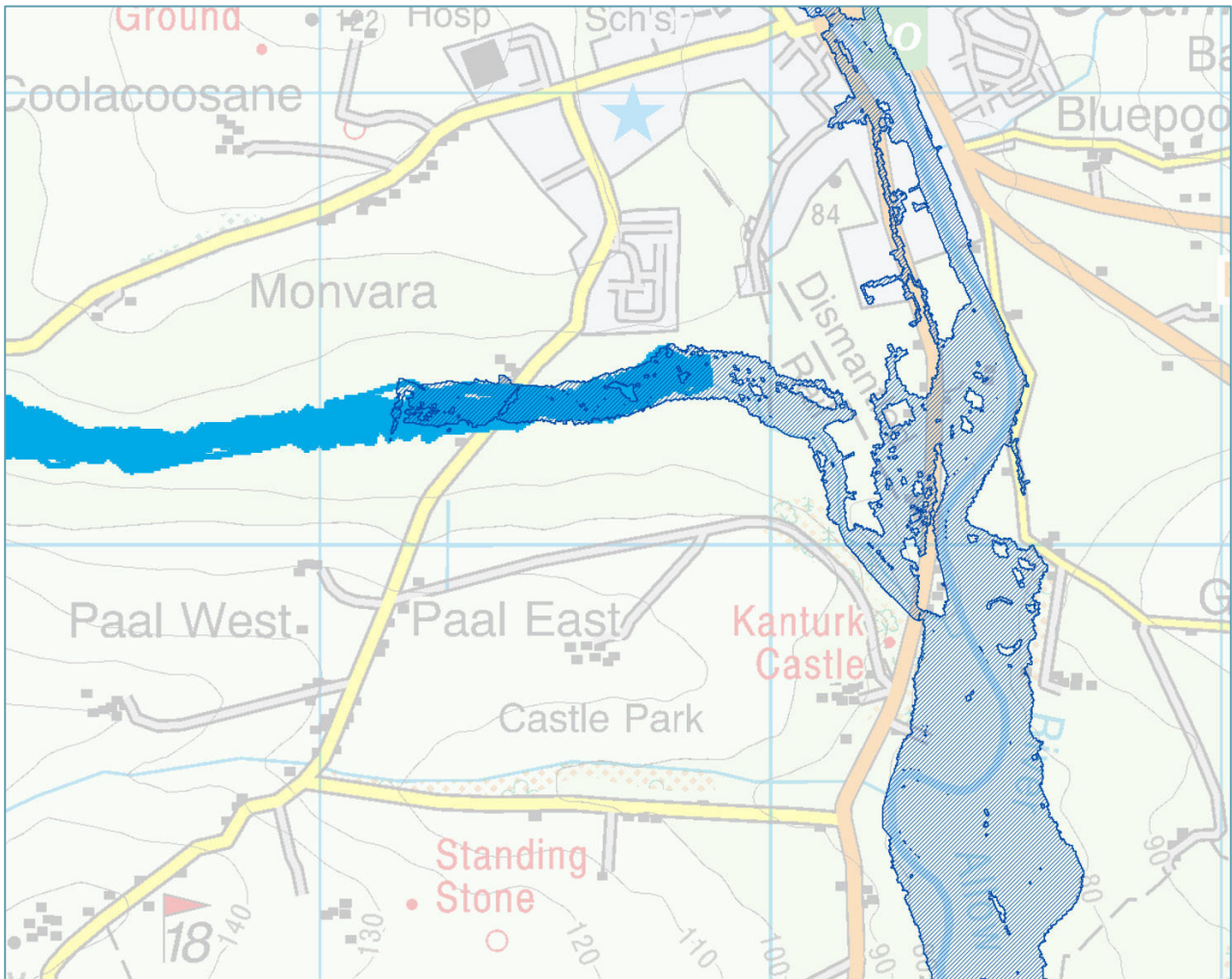


Figure 4.18: Example of the separate NIFM and CFRAM flood extents

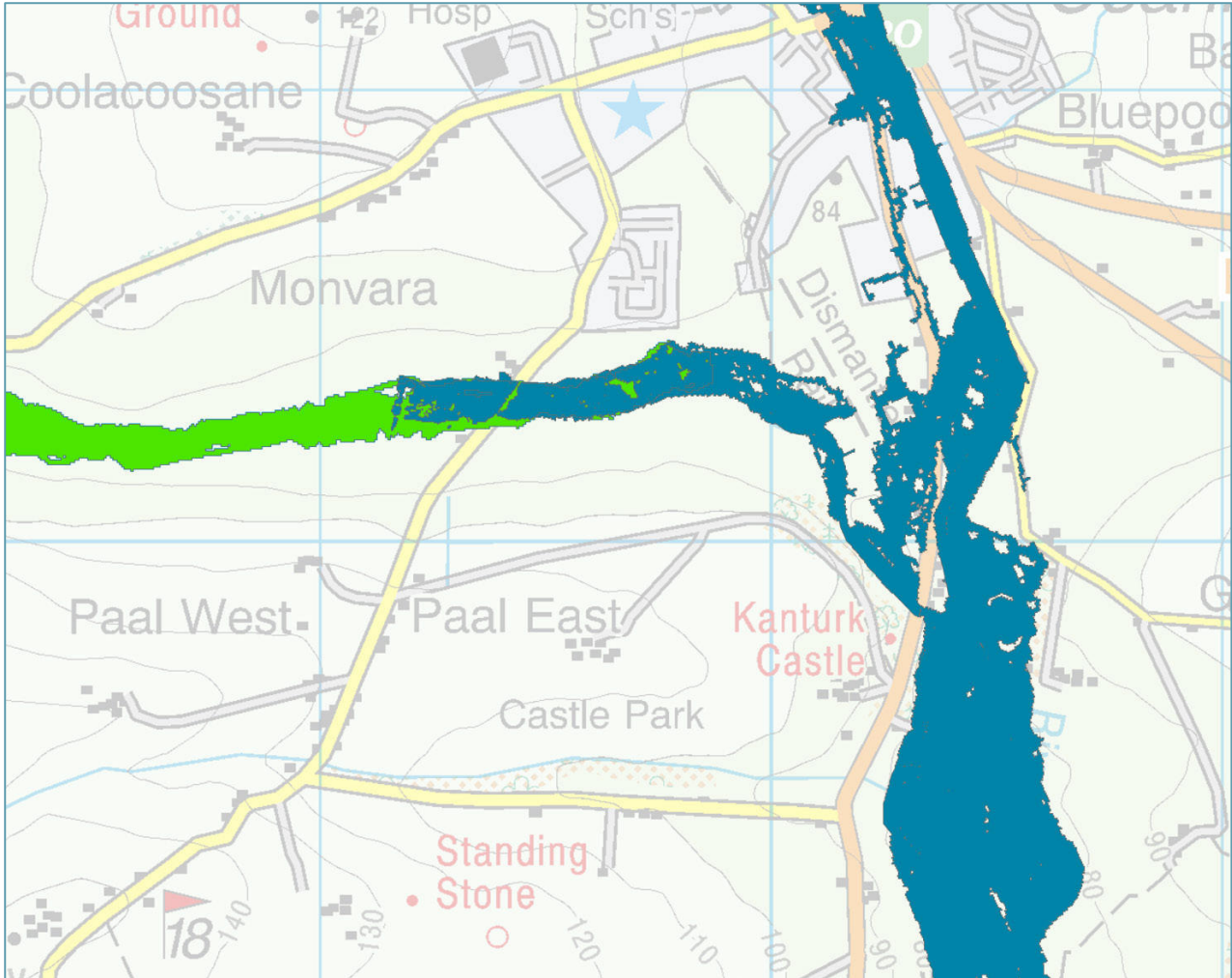


Figure 4.19: Flood extents merged using a union process

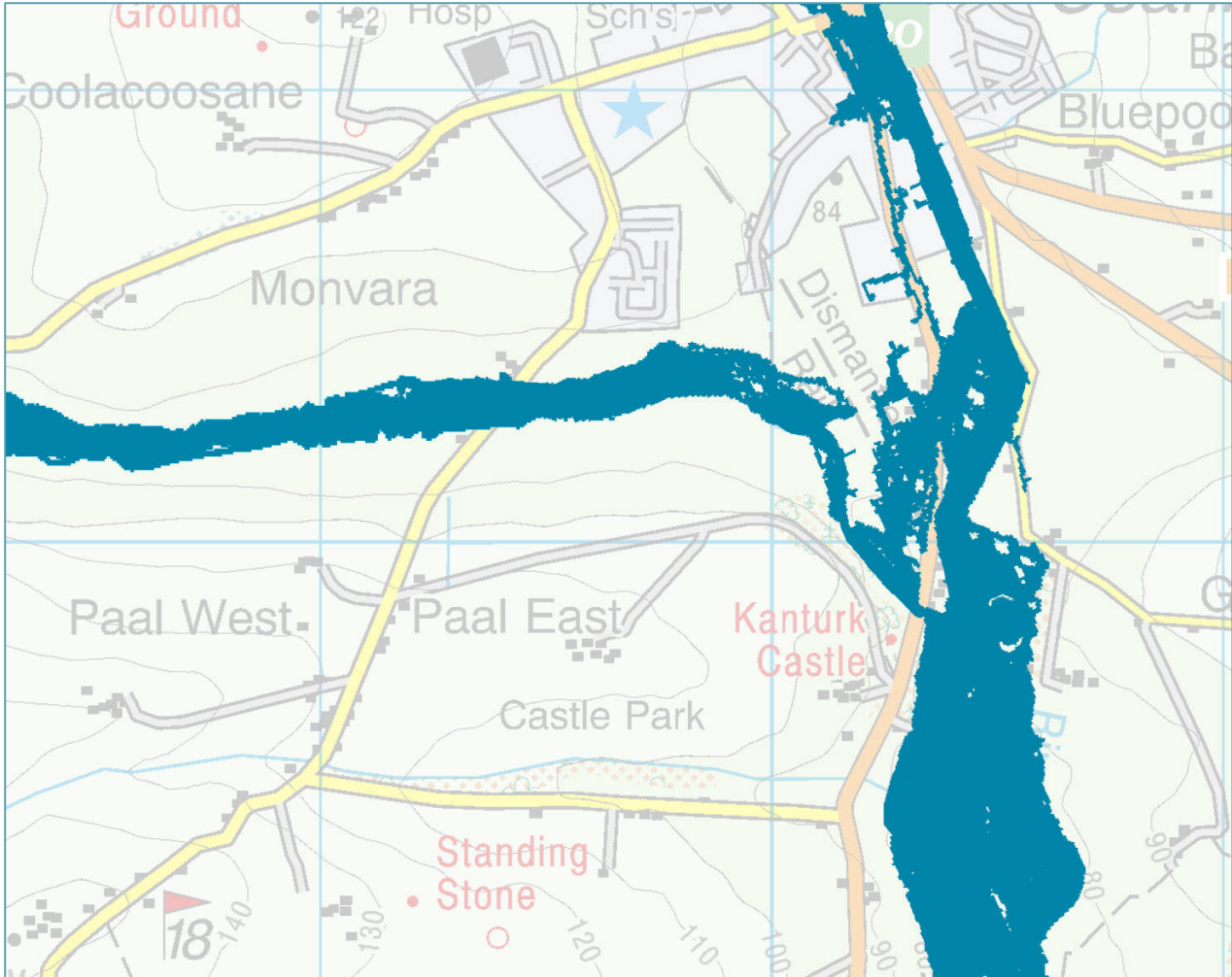


Figure 4.20: Merged flood extents

## 5. Processing of results

### 5.1. Quality assurance of the model results

A number of simple data integrity checks were undertaken to assess the validity and quality of the model results; these comprised:

- The maximum water level from each simulation is summarised for all FSU nodes. At each node a warning message is displayed if the water level does not increase with return period;
- Visual check that the 0.1% AEP flood extent is greater than the 1% AEP flood extent, which is greater than the 5% AEP flood event. This also includes a check that the flood extent is not constrained by the model domain boundary;
- Comparison with PFRA1 flood extents for AEP 1% results: The comparison was carried out in areas where there are more detailed, locally calibrated and validated results (i.e. in CFRAM areas). A direct



comparison of NIFM results versus PFRA1 results otherwise would show the difference between them, but would not show which is the more accurate. Therefore, the flood extents from the NIFM pilot modelling have been compared with those of CFRAM (and from the PFRA1 with CFRAM) for two measures:

- Total flooded area;
- The  $F$  statistical measure from Horritt and Bates (2001), where  $F$  is the number of cells that are wet in both the model AND the observed data sets versus the number of cells that are wet in either the model OR the observed data sets.

NB: An  $F$  value of 100% is a perfect fit where every wet cell is the same in the model and observed data sets, and a value of 0% would mean that none of the same cells are wet in the model and observed data sets. This is a more advanced measure of fit than total flooded area because it takes account of spatial coincidence between the models. For our analysis the 'observed' reference measure is the CFRAM flood extent.

A Quality Control Report is generated for the model results (MCR6058-RT02: Quality Control Report). A copy of the QA check-sheet template is included in Appendix C.

## 5.2. Generation of flood spatial data

Following the QA and sign-off of the model by the Senior Modeller, the results are exported for each model and AEP in shapefile format. Automated methods are then used to perform the post-processing of the results.

Firstly, the results are clipped to 5 km tiles to enable efficient and parallelised post-processing.

Next, each 5 km tile is processed independently. Due to there being overlaps with different mesh geometries at the boundaries between models, the results are transferred onto a 5m resolution vector grid which coincides with the DTM raster grid cells. Where there are overlaps, the modelled water levels are assessed to find the highest level in each 5m cell and all results for the cell are taken from that particular model. The cell depth is calculated in the floodplain as the difference between the water level and the DTM ground level. In the river channels, the cell depth is taken as the modelled depth. The depth, level and speed results are exported as a geotiff formatted raster tile. Lastly, the wetted cells in the vector grid are merged to produce the model extent.

A third stage is undertaken to merge the model extents for each tile. The *geotiff* format results are not merged nationally since this would produce very large raster files that may be difficult to use, so they have been merged by UoM.

A set of example results files are shown in Figure 5.1 to Figure 5.3. The maps show the depth, level and speed outputs respectively. In each map, the extents are also shown and the layer names shown in the legend are as specified in the scope of works.



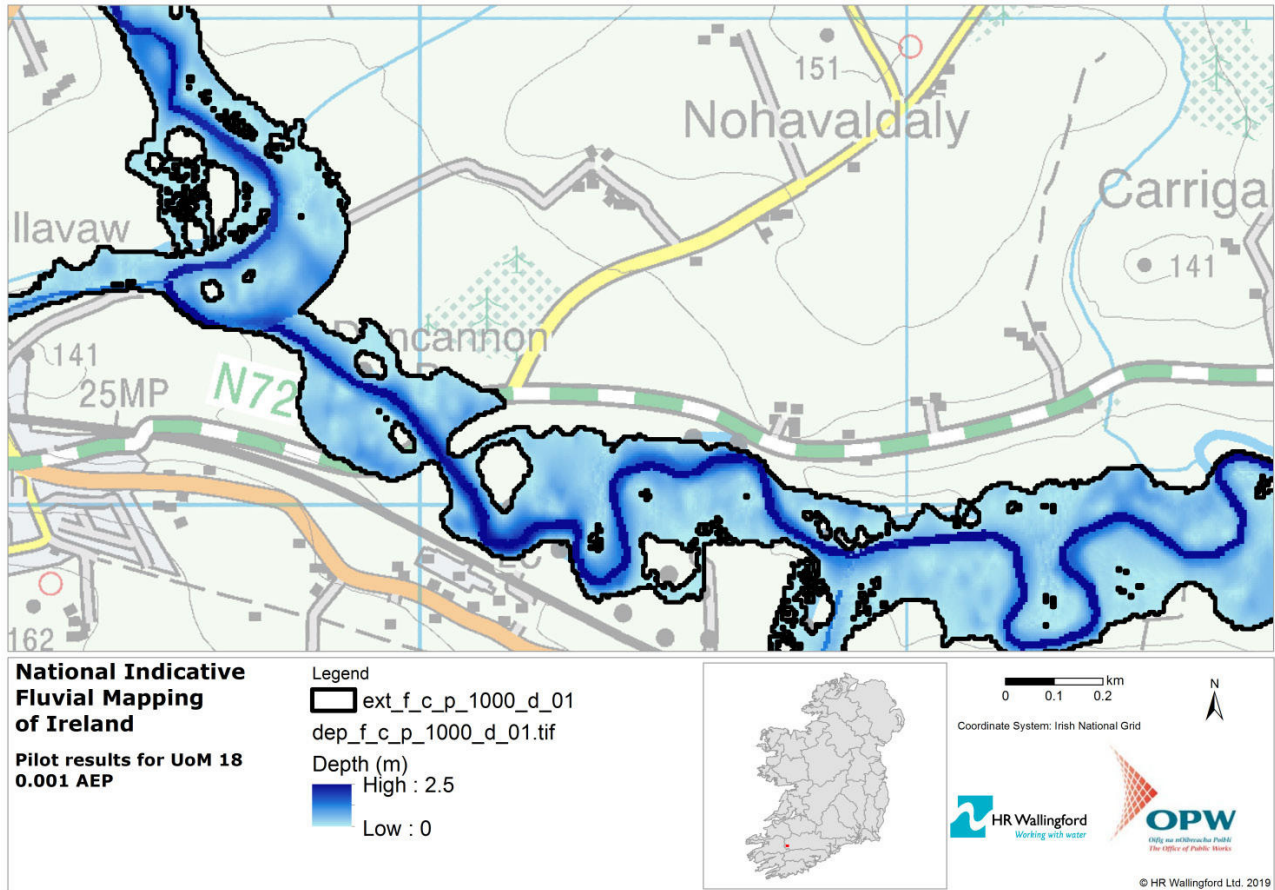


Figure 5.1: Example of the pilot depth results for UoM18

Source: HR Wallingford

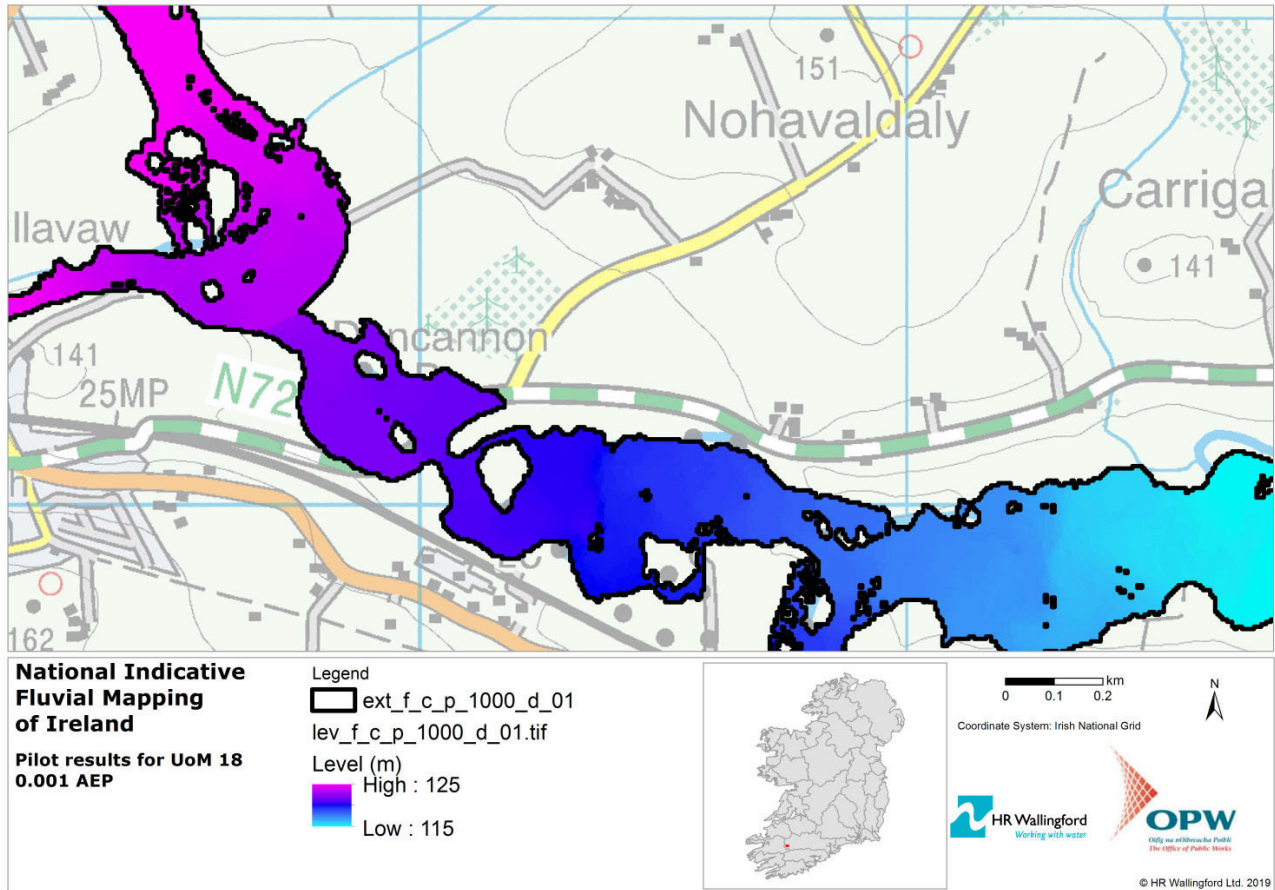


Figure 5.2: Example of the pilot level results for UoM18

Source: HR Wallingford

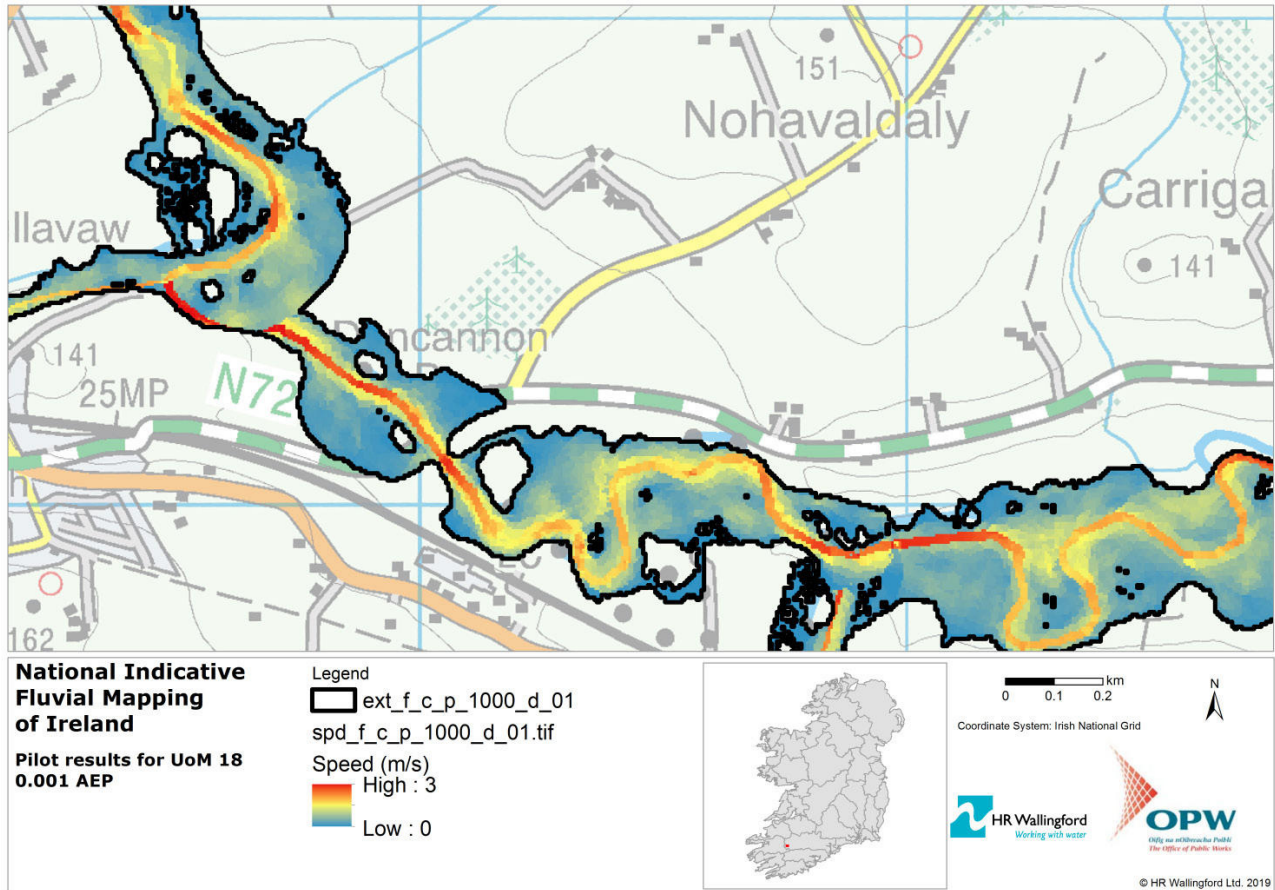


Figure 5.3: Example of the pilot speed results for UoM18

Source: HR Wallingford

### 5.3. Classification of reaches

The results of the 2D hydraulic models have been interrogated to determine the duration that each model element is inundated above a threshold and the time to the onset of flooding. The thresholds for duration and onset of flooding have been tested on the pilot sites, and classification bands are suggested below. This represents a pragmatic approach; since there is such a wide variation in duration and onset for different cells in the floodplain along a particular reach, the two measures will give conservative indications for flood risk and warning management, since they would not be based on the first to flood nor the longest to flood but would be more representative of the reach's floodplain cells as a whole. The suggested definitions are:

- **Duration of flooding:** The subject watercourse reaches are classified according to the estimated duration of flooding to occur along each reach. Reach duration (hours) is defined as the 75<sup>th</sup> percentile of the inundation duration of all floodplain (i.e. non-channel) cells that are closer to the reach than any other reach.
- **Rate of onset of flooding:** The rate of onset of flooding (hours) is defined as the 25<sup>th</sup> percentile of the time of first inundation of all floodplain (i.e. non-channel) cells that are closer to the reach than any other.



The suggested categories for onset of flooding and flood duration are given in Table 5.1, and sample maps for reach and floodplain flood duration are given in Figure 5.4 and Figure 5.5 respectively.

Table 5.1: Suggested categories for onset of flooding and flood duration

Onset of flooding (hrs)	Flood duration (hrs)
0 to 1 hour	0 to 6 hours
1 to 3 hours	6 to 12 hours
3 to 6 hours	12 to 24 hours
6 to 12 hours	24 to 48 hours
12 to 24 hours	48 to 72 hours
24 to 48 hours	72 to 120 hours
48 hours +	120 hours +

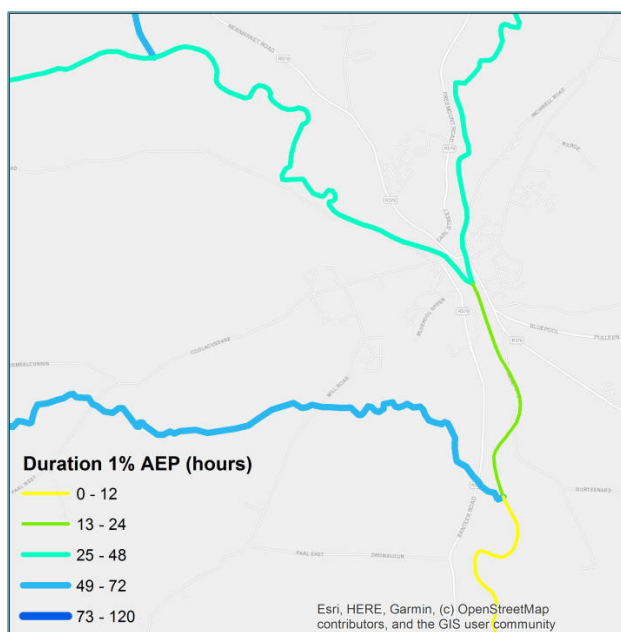


Figure 5.4: Sample map for reach flood duration

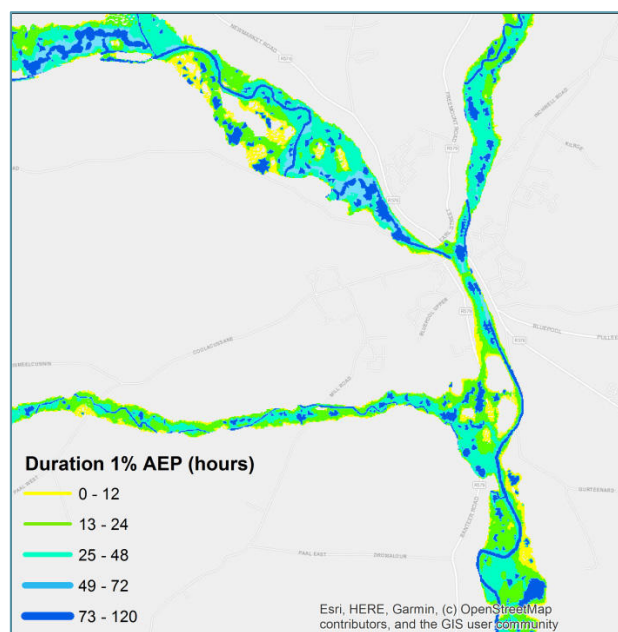


Figure 5.5: Sample map for floodplain flood duration

The data for duration and onset of flooding are mapped to the river network and provided as shapefiles. The outputs are also available as a 5 m horizontal resolution *geotiff* if required.

## 6. Analysis of results for UoM 18

### Comparison of results with CFRAM study results and historical events

The CFRAM studies provided a thorough investigation of the historical flood event record, and used key events for calibration and validation of their results. These studies used data available through to the summer of 2012. Since that time, several flood events had occurred across the country, including a particularly large flood event, which lasted in effect throughout December 2015 and January 2016. It was therefore necessary to assess the additional historical flooding evidence from summer 2012 to present.



## 6.1. Historical flood evidence

### Historical flood evidence from CFRAM studies

The CFRAM study hydraulic model for UoM 18 had been calibrated to the following flood events (OPW, 2016b) between Kanturk and Ballyduff, with estimated AEP values and ranks (in square brackets) from OPW (2016a; Table 4.2):

- 30<sup>th</sup> December 1998 (estimated as 20-50% AEP at Kanturk [7], 10-20% at Mallow [5], Fermoy [4], and Ballyduff [13]);
- 6<sup>th</sup> November 2000 (estimated as 20% AEP at Mallow [9], 10% at Ballyduff [8]); and
- 19<sup>th</sup> November 2009 (estimated as 20-50% AEP at Kanturk [10], 10-20% at Mallow [6], 10% at Fermoy [3], and 5% at Ballyduff [2]).

Rathcormac, on the River Bride, was calibrated to the following flood event:

- 30<sup>th</sup> January 2009 (estimated as 10% AEP [2]).

Each of these events had been considered good for calibration purposes, having received indicative calibration scores of greater than 10. Indicative calibration scores represent a combined score relating to the location, hydrology and data availability, each of which is scored from 0 (not available) through to 3 (good or likely) (OPW, 2016a).

Notes on the 'Calibration approach' (Table 7.1: OPW, 2016a) point out limitations of the available data, including this selection:

- **Significant catchment changes since event** makes calibration difficult;
- Calibrate main channel to large event data considering **spot levels are accurate to within +/- 0.25m**;
- Smaller tributaries should take note of **uncertainties due to blockage**;
- Extensive outline and photo information but no spot levels for 2010 event. Calibrate main channel to large event data considering that **spot levels are derived from extent**.

### More recent historical flood evidence

A range of evidence was available for consideration for validation of recent flood events. This is summarised in Table 6.1. Items in bold were considered useful for validation. This evaluation considered evidence of **fluvial** flood events, for **locations within the model extents**, with enough **information to locate the impacts** and/or **information on the magnitude of the event**. The map of Figure 6.1 shows the spatial distribution of the winter 2015/2016 flood events.

Table 6.1: Recent historical flood evidence for UoM 18

Location	Event	Evidence, and comment on viability for validation
Rathcormac, R. Bride	Feb 2014	Newspaper report. No specific information on flood locations, extents nor depths.
	Aug 2012	OPW Flooding Event Report Form and photographs. Describes a blocked culvert on a small tributary to the R. Shanowen, which is a small tributary of the R. Bride. Flooding caused by a blockage of a small stream not being modelled.
Mallow and Fermoy, R. Blackwater	Dec 2015 – Jan 2016	National Directorate for Fire and Emergency Management report on flood event impacts across RoI. <b>Useful map of ranked events across the country (Figure 6.1), and table of towns flooded, with dates.</b> The dates of initial reports of <b>flooding of both Mallow and Fermoy occurred on 30<sup>th</sup> December 2015.</b>

Location	Event	Evidence, and comment on viability for validation
	June 2012	Link to <a href="http://www.floodinfo.ie">www.floodinfo.ie</a> but no information available there.
Youghal, R. Blackwater	Oct 2017	OPW Flooding Event Report Form and map for a small catchment with a likely blockage.
	Dec 2015	Private report on flooding. Catchment too small for our study.
	Jan & Feb 2014	Tidal flooding.
	Oct 2012	Tidal flooding.
Multiple	Dec 2015	Flood Events_2015 12 05_CMFP.docx and Flood Events_2015 12 12,29,30.docx. Reports with maps and photos. <b>Includes some information on Fermoy, and Youghal (roads and properties affected).</b>
Tallow Bridge	Dec 2015	Photograph of flooding at Tallow Bridge – unclear of actual location.
Aglish	Dec 2014	OPW Flooding Event Report Form, plus photographs and GIS locations. Describes flooding of one property at Aglish Bridge, due to a blockage of a small stream.

Source: Various

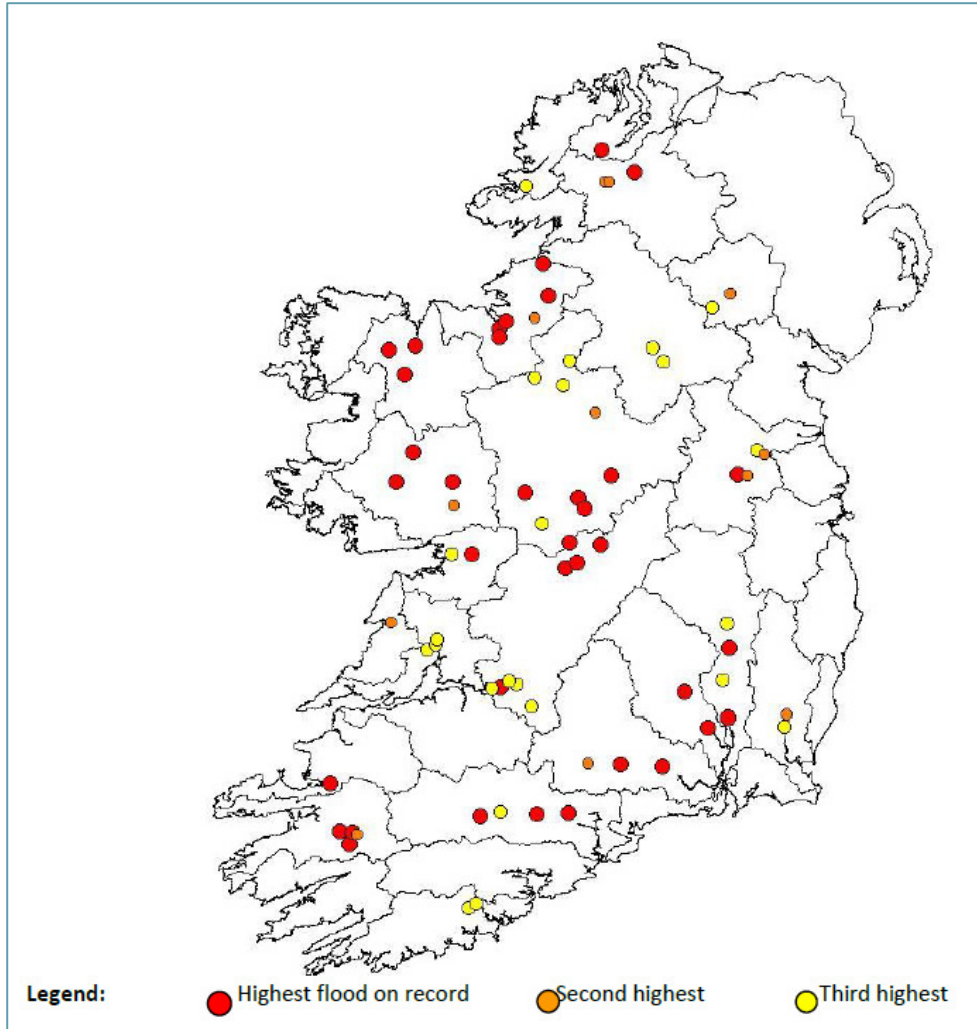


Figure 6.1: Spatial distribution of the winter 2015/2016 flood events

Source: Reproduced from Figure 7, NDFEM (2016)

Table 7 of NDFEM (2016) indicates that the dates of initial reports of **flooding of both Mallow and Fermoy occurred on 30<sup>th</sup> December 2015**. Also, OPW (2018) reported for **Tallow on 29<sup>th</sup> December 2015**:

“Water levels downstream of West Street Bridge between Tallow and Tallow bridge were significantly high causing the watercourses to overtop and flood the agricultural land and a significant section of the regional road (R634 - entering town from North). The stormwater network along West Street was unable to discharge to the Glenaboy river through a 300mm duckbill valve outfalling from a chamber immediately downstream of the bridge. 3 Nr. properties were flooded (1 to the west of the junction and 2 to the east). A flood level of 10.285mOD was measured.”

No indication of the return periods of the winter 2015/2016 event at key locations has been found.

In addition to these sources described above, historical flood information on the website *floodinfo.ie* has been accessed for a range of supporting information, including meeting minutes, reports and photographs.

## 6.2. River Blackwater at Mallow

### Calibration against CFRAM study results

The model results for the River Blackwater at Mallow have been compared to the results of the CFRAM model. Figure 6.2 to Figure 6.4 show that the modelled flood outlines compare well to those from the CFRAM model in the 5% AEP, 1% AEP and 0.1% AEP HEFS events.

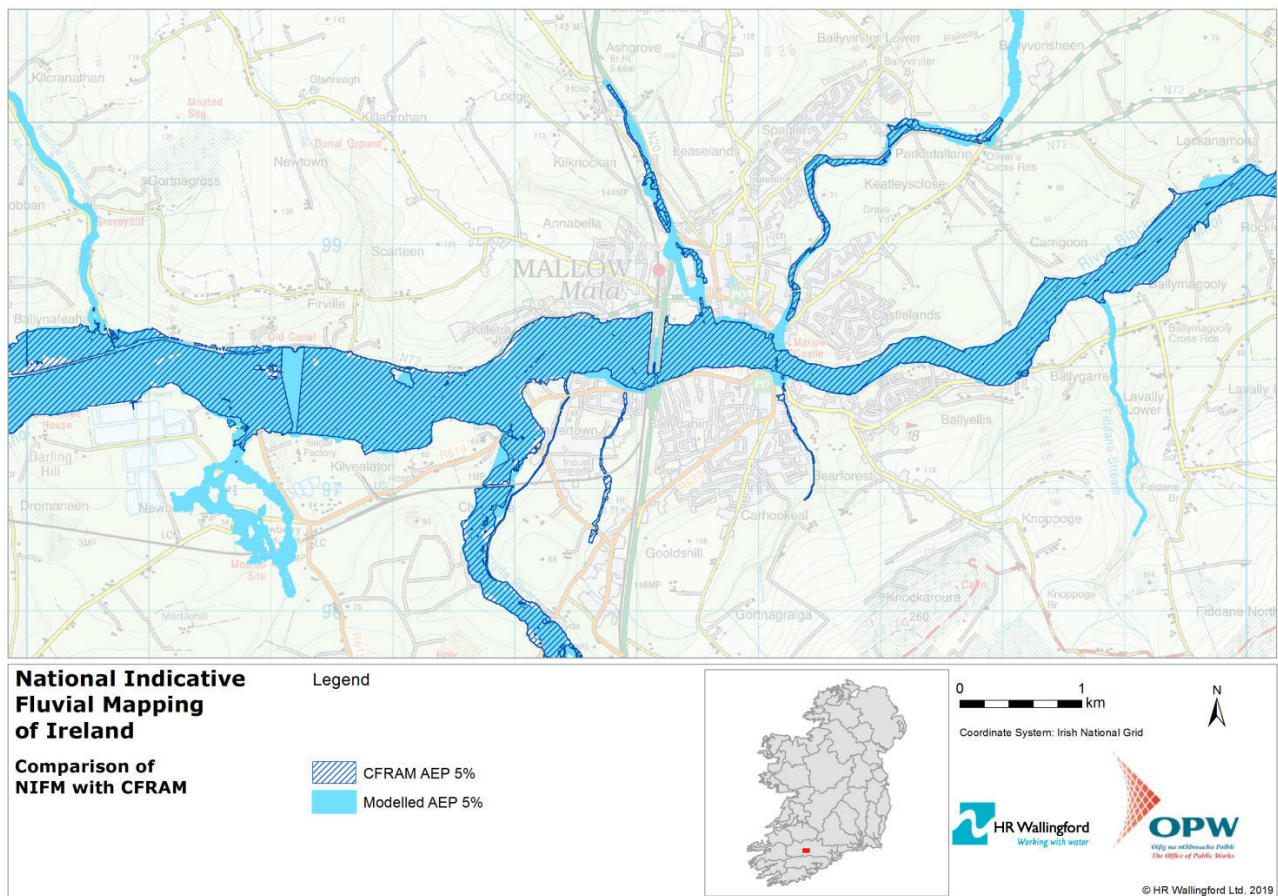


Figure 6.2: Modelled NIFM flood outline compared to CFRAM results for the 5% AEP flood at Mallow



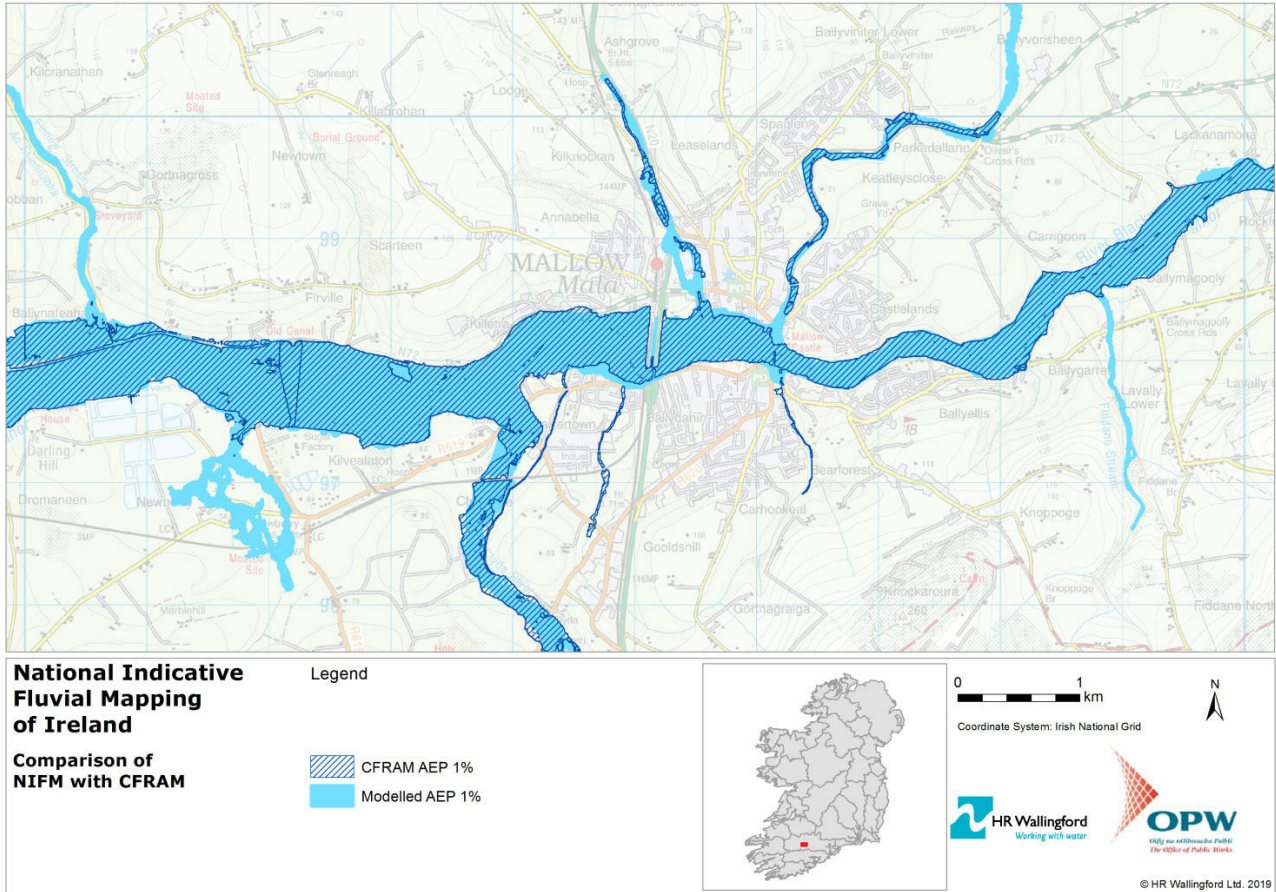


Figure 6.3: Modelled NIFM flood outline compared to CFRAM results for the 1% AEP flood at Mallow

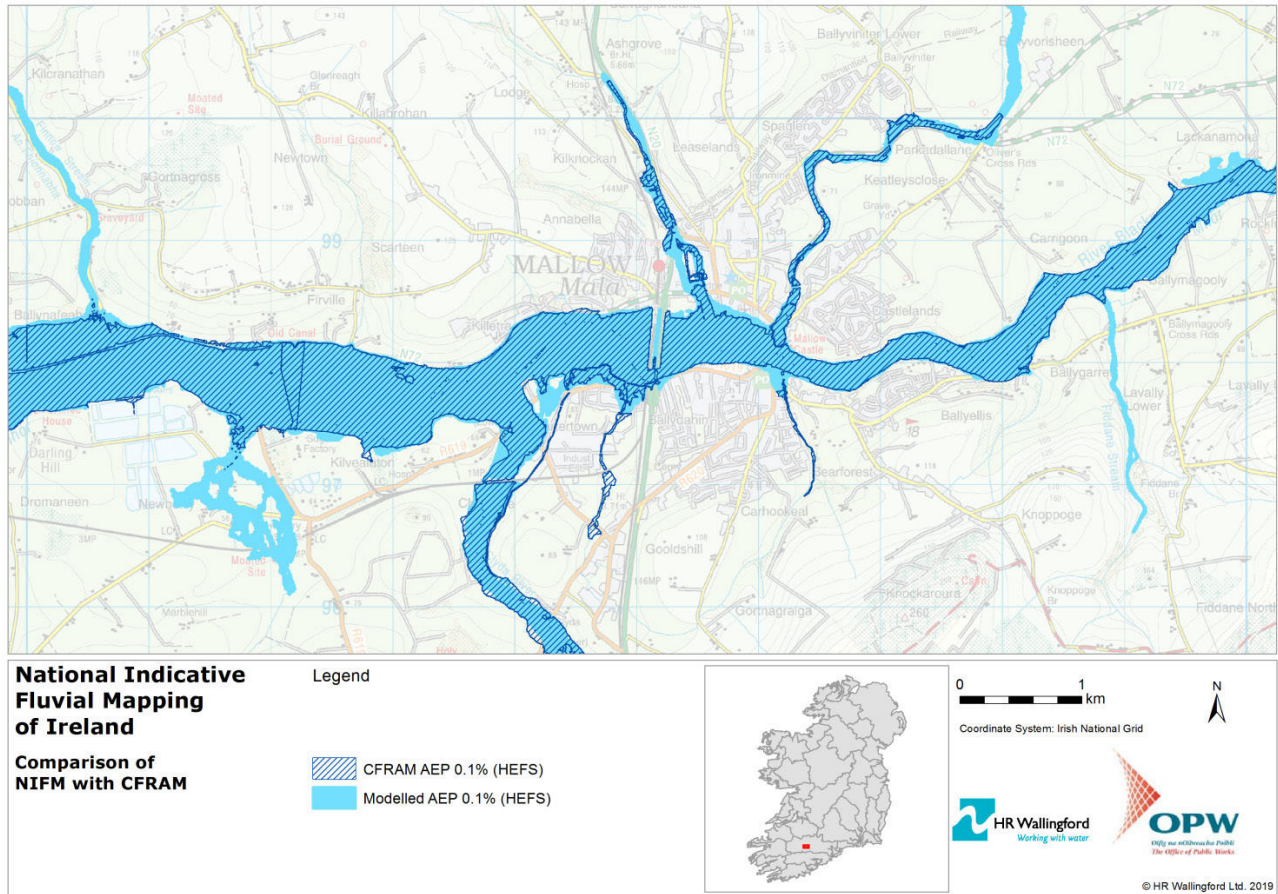


Figure 6.4: Modelled NIFM flood outline compared to CFRAM results for the 0.1% AEP HEFS flood at Mallow

Comparison of modelled water levels with those from CFRAM is shown in Figure 6.5. This shows that the NIFM modelled water levels compare well to those from the CFRAM model for the River Blackwater at Mallow.

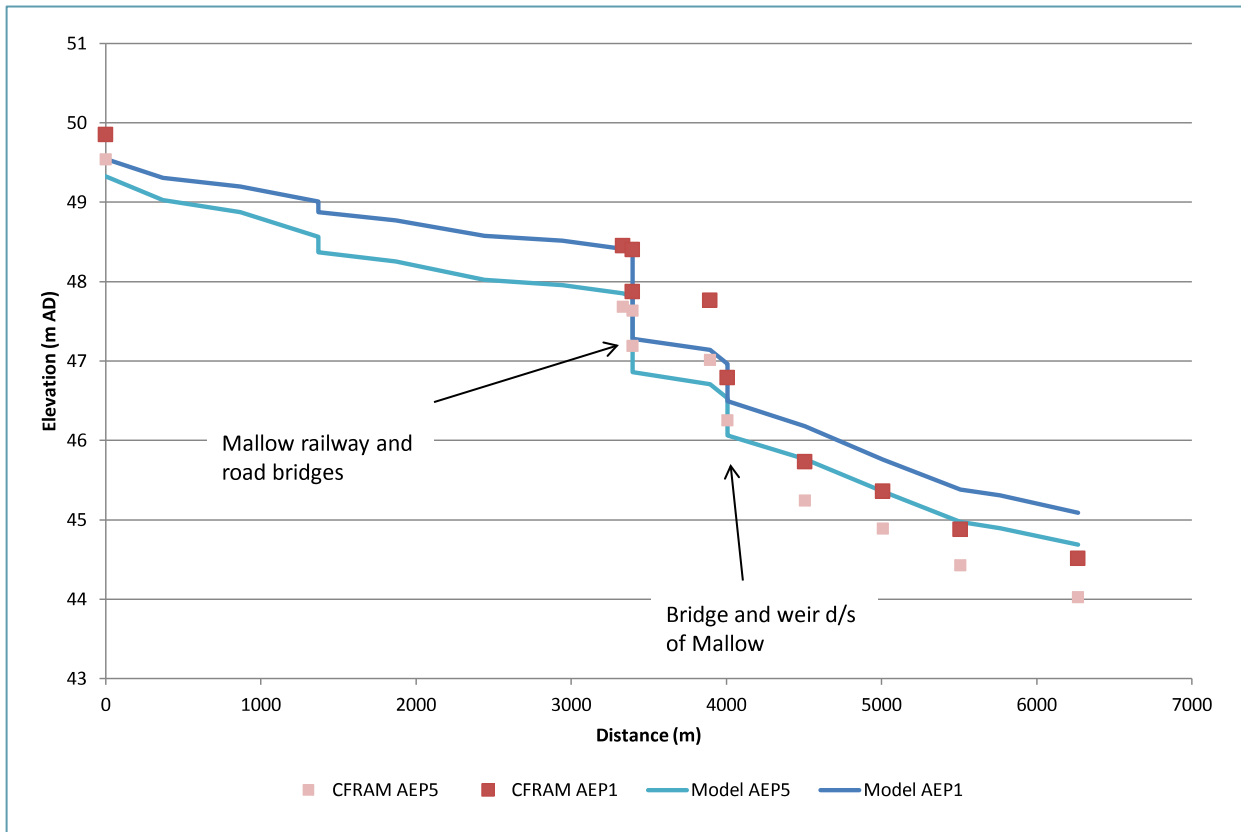


Figure 6.5: Modelled water levels compared to CFRAM results at Mallow

### Validation for the floods of 2000 and 1998

Evidence of historical flood events indicates that in Mallow, there are several key locations that are particularly flood prone (*floodinfo.ie*). These are shown as boxed numbers on the map of Figure 6.6 and photographs of Photograph 6.1 and Photograph 6.2 (locations and orientations of the photographs are also indicated on the map):

1. Cork racecourse, Mallow;
2. Mallow town centre;
3. Ballyellis, east Mallow.

NIFM model results all show flooding at these key locations.

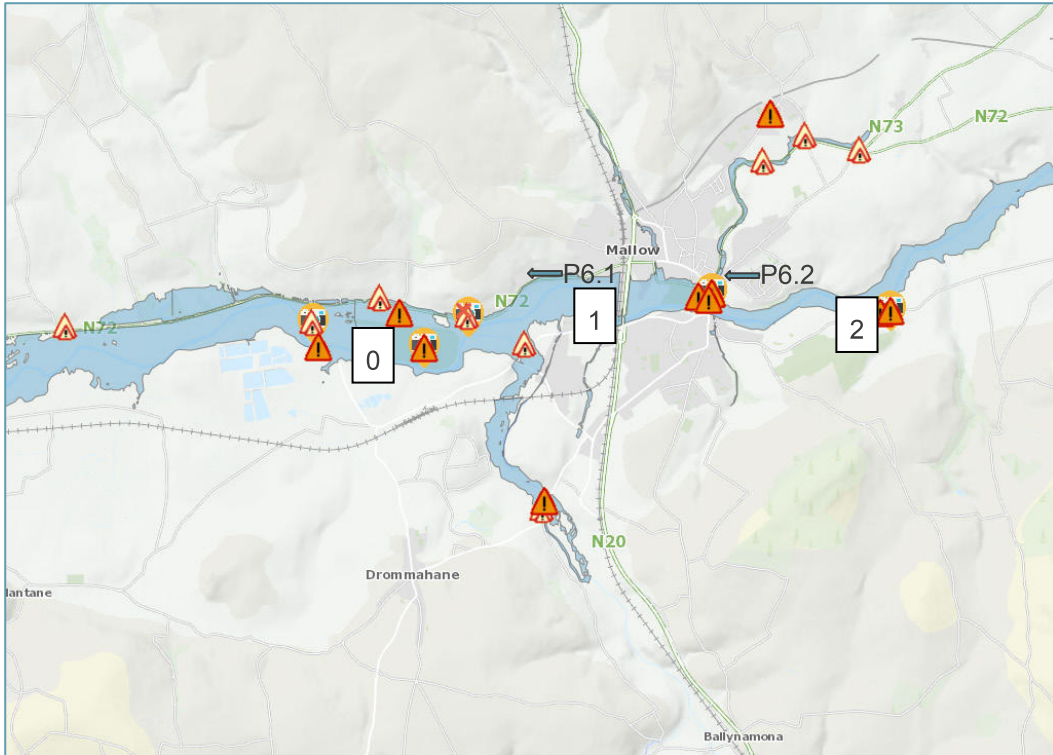


Figure 6.6: Map of flood prone locations in Mallow

Source: [floodinfo.ie](http://floodinfo.ie)





Photograph 6.1: Flood in Mallow, looking westwards, November 2000

Source: [floodinfo.ie](http://floodinfo.ie)



Photograph 6.2: Flood in Mallow, looking westwards, November 2000

Source: [floodinfo.ie](http://floodinfo.ie)

The flood event of November 2000 has been estimated as 20% AEP at Mallow. The photographic evidence has been compared with our 5% AEP (closest) results as shown in Figure 6.7 and Figure 6.8, showing a similar flood outline.



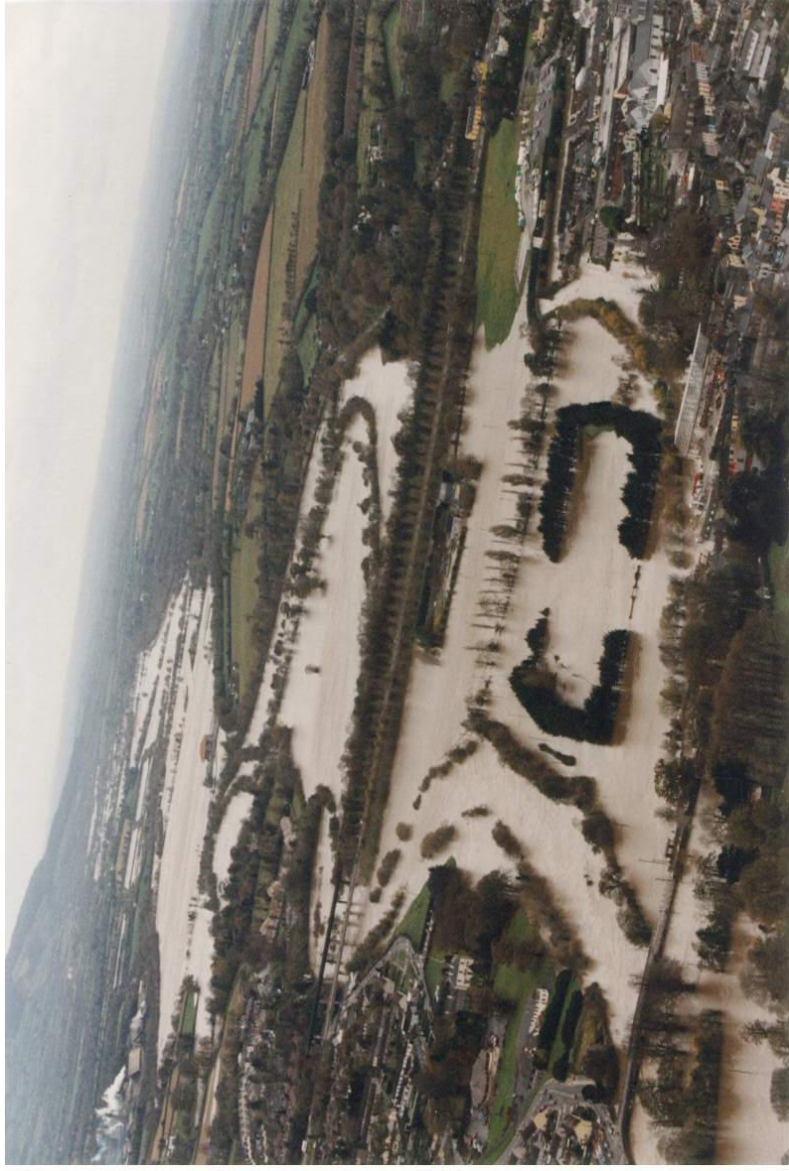


Figure 6.7: Aerial photograph of Mallow in flood of 2000

Source: [floodinfo.ie](http://floodinfo.ie)

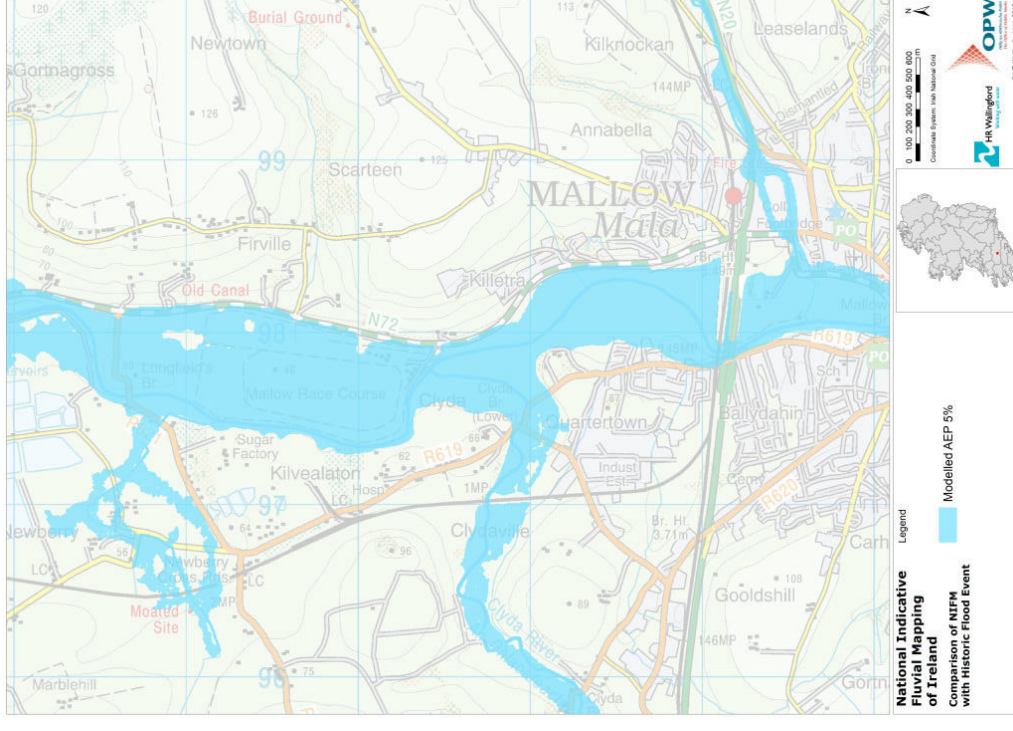


Figure 6.8: 5% AEP model results

Source: HR Wallingford

The 1998 flood was estimated to have an AEP of around 5 to 10% in the CFRAM study. In general the modelled 1% AEP water levels are above the observed water levels at Mallow, and the modelled 5% AEP are above and below the observed water levels depending on the location (as shown in Figure 6.9).

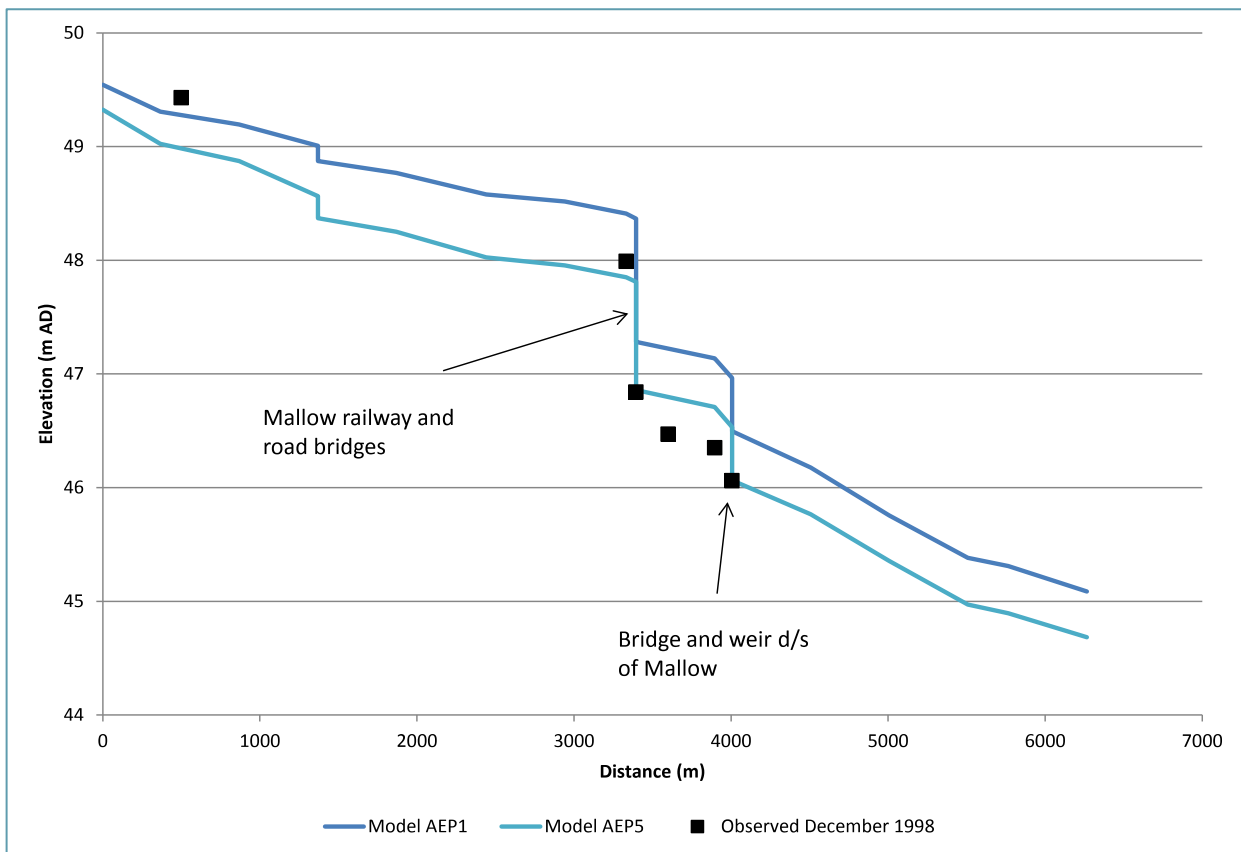


Figure 6.9: Modelled water levels compared to the observed 1998 water levels at Mallow

## 6.3. River Blackwater at Kanturk

### Calibration against CFRAM study results

The model results for the River Blackwater at Kanturk have been compared to the results of the CFRAM model and observations made during the 1998 flood. Figure 6.10 and Figure 6.11 show that the modelled flood outlines compare well to those from the CFRAM model in both the 5% AEP and 1% AEP events, respectively. Figure 6.12 presents the results for the 0.1% AEP HEFS flood at Kanturk, which compare well with the CFRAM results for the same scenario.



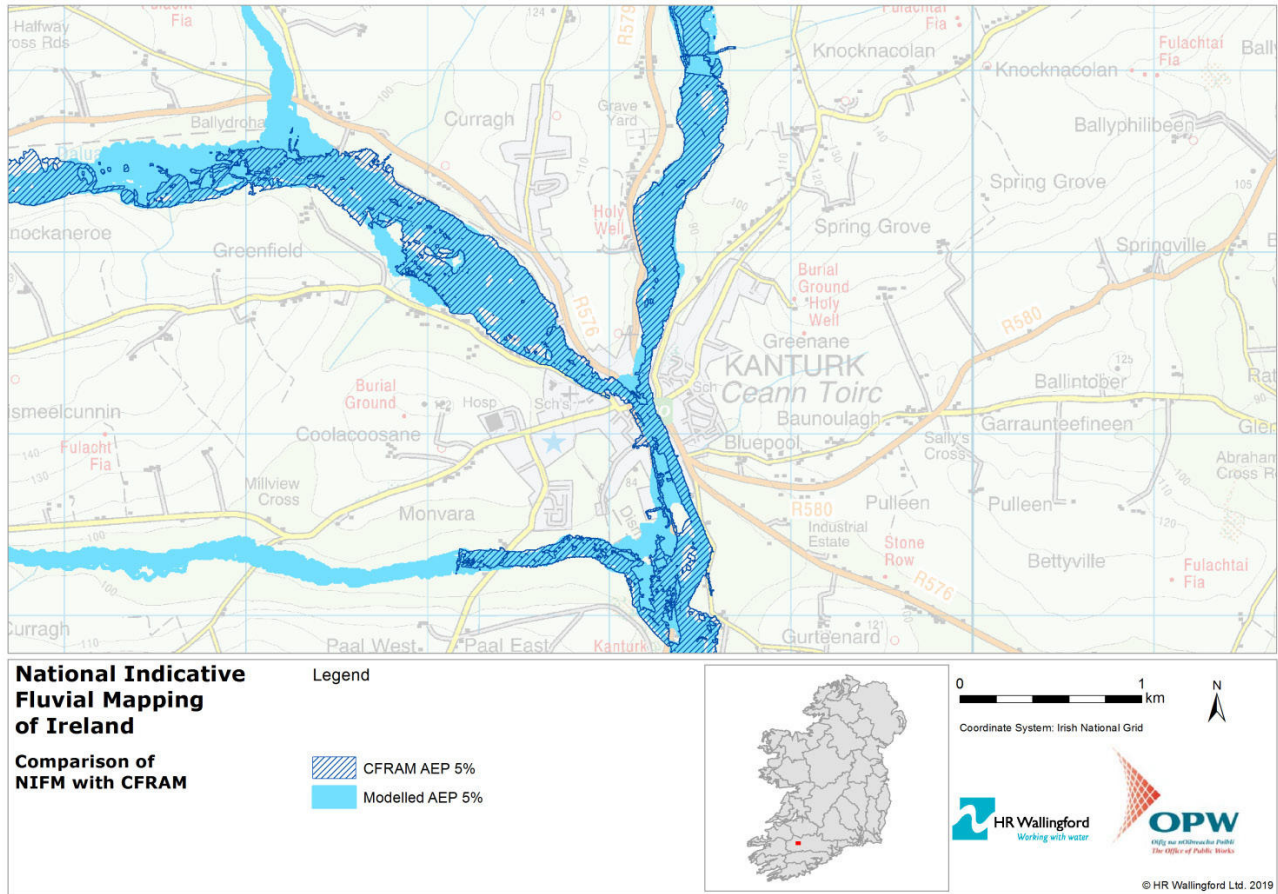


Figure 6.10: Modelled flood outline compared to CFRAM for the 5% AEP flood at Kanturk

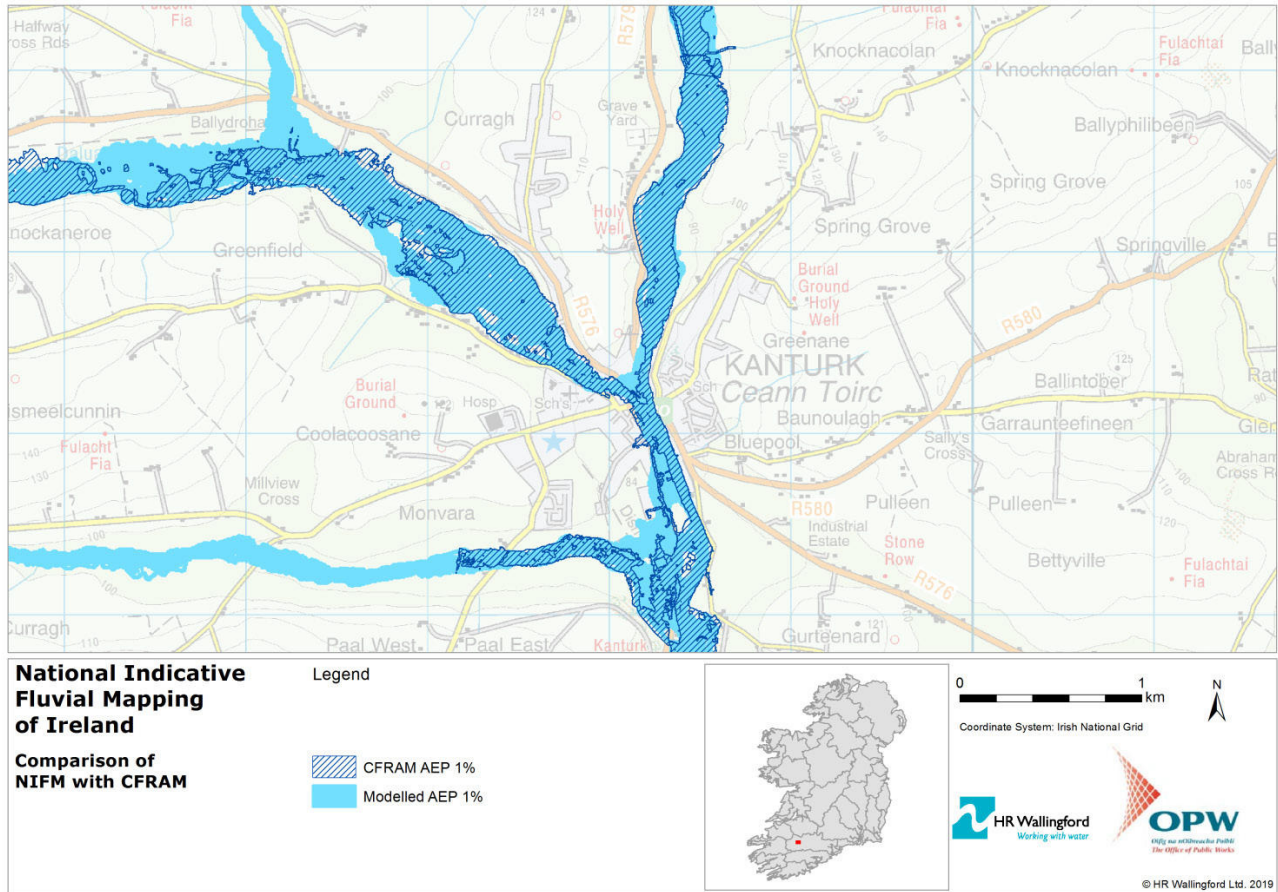


Figure 6.11: Modelled flood outline compared to CFRAM for the 1% AEP flood at Kanturk

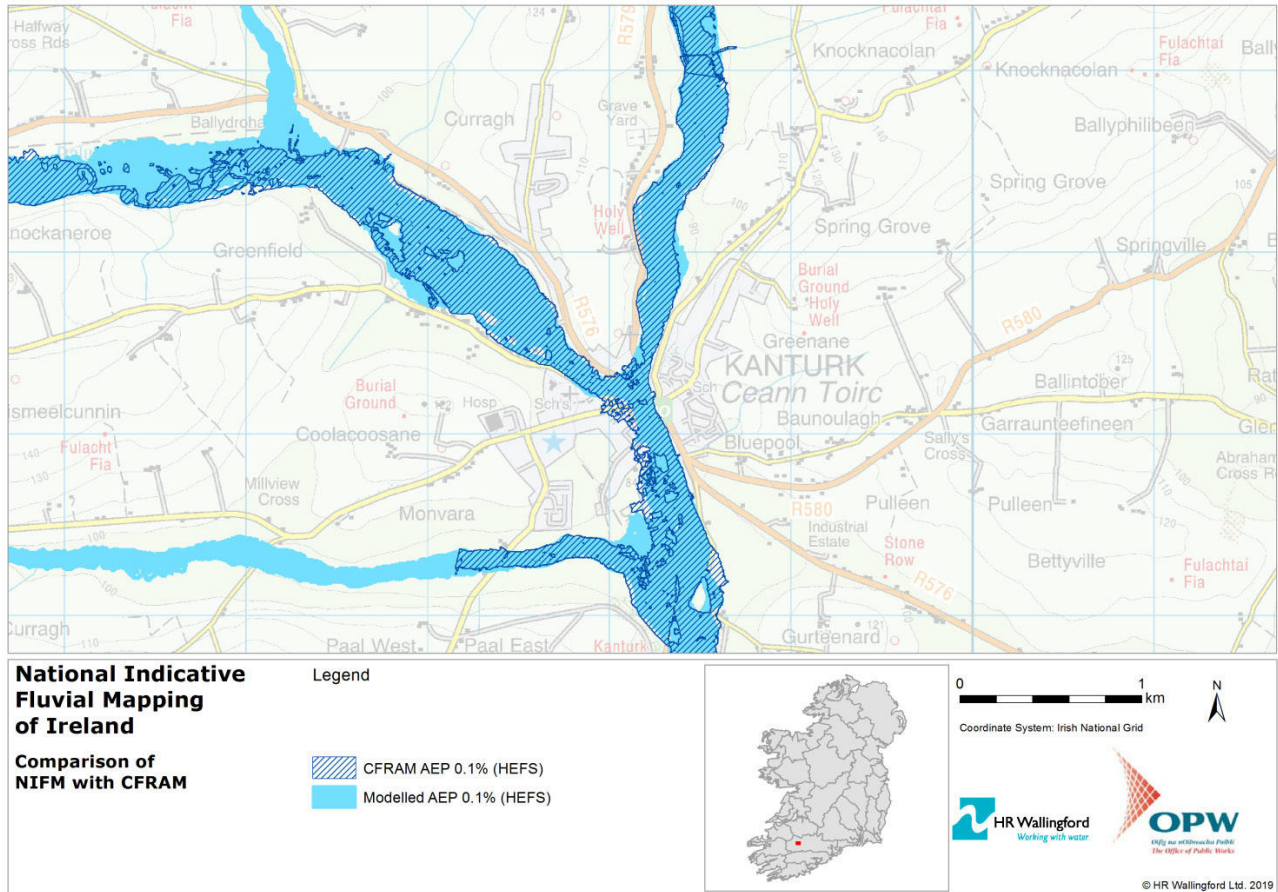


Figure 6.12: Modelled flood outline compared to CFRAM for the 0.1% AEP HEFS flood at Kanturk

### Validation for historical flood evidence

Evidence of historical flood events indicates that in Kanturk, there are several key locations that are particularly flood prone (Cork C.C., 2005). These are shown on the map of Figure 6.13:

- R579, Strand Street road flooding as a result of high flows in River Allow – recurring. Flood ID 5146;
- Land flooding in Oct 2004 from the Brogeen River – recurring. Flood ID 5147 & 5158;
- Land flooding at location of Kanturk Town Park due to high flows in River Dalua, occurs bi-annually – recurring. Flood ID 5148;
- Greenane near Kanturk. Historical recurring road flooding due to a drainage problem. This has been fixed recently. Flood ID 5154.

No photographs of historical floods at Kanturk were available, but NIFM model results all show flooding at these flood prone locations given above, by reference to the locations in Figure 6.13.





Figure 6.13: Locations prone to flooding in Kanturk

Source: OPW (2005)

## 6.4. Comparison with gauged water levels

Modelled water levels have been compared to gauged water levels (the AEP values of the gauged events were estimated in the CFRAM study) at the following gauging stations:

- 18001 Bride at Mogeely. The modelled water levels are around 0.5m higher than the gauged levels for the highest gauged events (Figure 6.14);
- 18002 Blackwater at Ballyduff. The modelled water levels are around 0.5m higher than the gauged levels for the highest gauged events (Figure 6.15);
- 18003 Blackwater at Killavullen. The modelled water levels are around 0.2m lower than the gauged levels for the highest gauged events (Figure 6.16);
- 18004 Awbeg at Ballynamona. The modelled water levels are around 0.1m higher than the gauged levels for the highest gauged events (Figure 6.17);
- 18005 Funshion at Downing Bridge. The modelled water levels are around 0.1m lower than the gauged levels for the highest gauged events (Figure 6.18);
- Blackwater through Mallow for the 1998 flood.

In general the modelled water levels compare reasonably well with the gauged water levels.



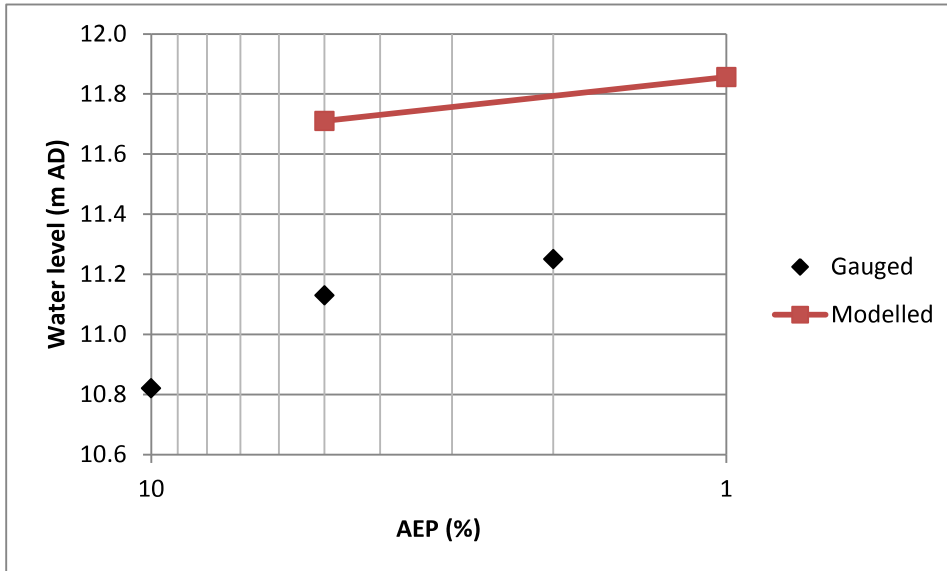


Figure 6.14: Gauge 18001: gauged versus modelled water levels

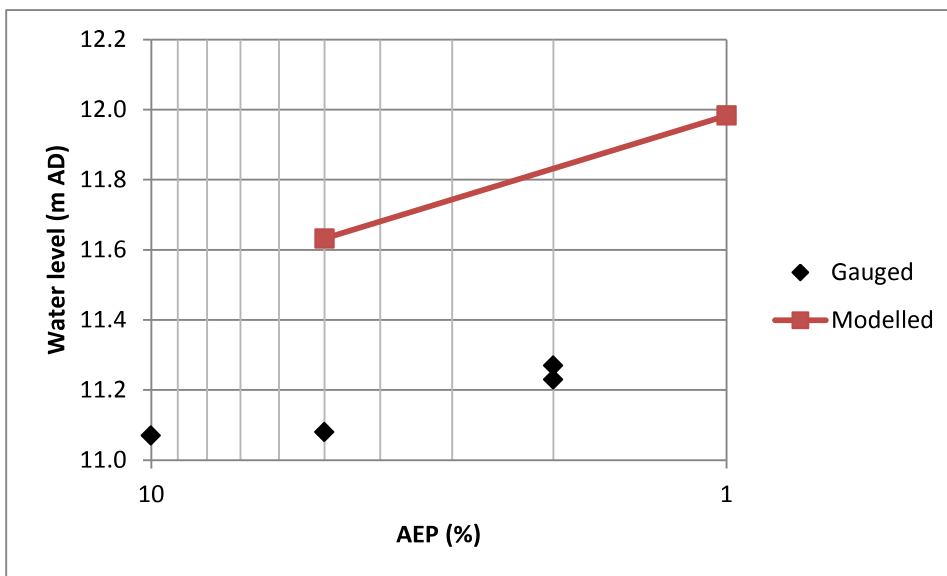


Figure 6.15: Gauge 18002: gauged versus modelled water levels

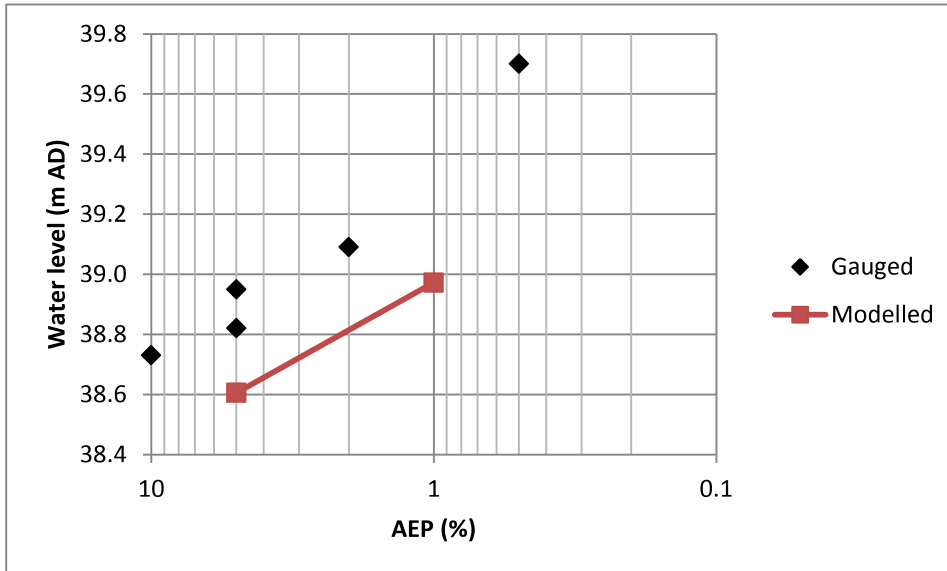


Figure 6.16: Gauge 18003: gauged versus modelled water levels

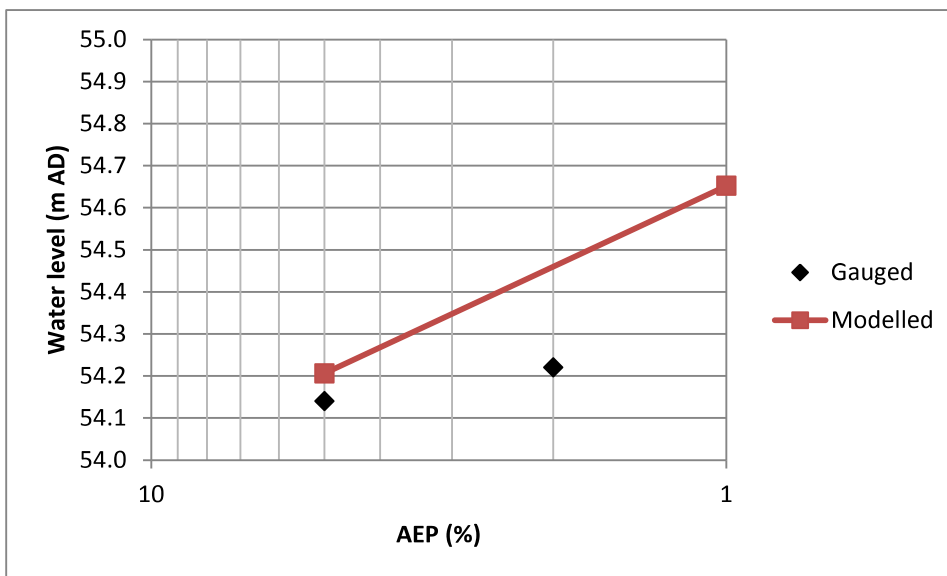


Figure 6.17: Gauge 18004: gauged versus modelled water levels

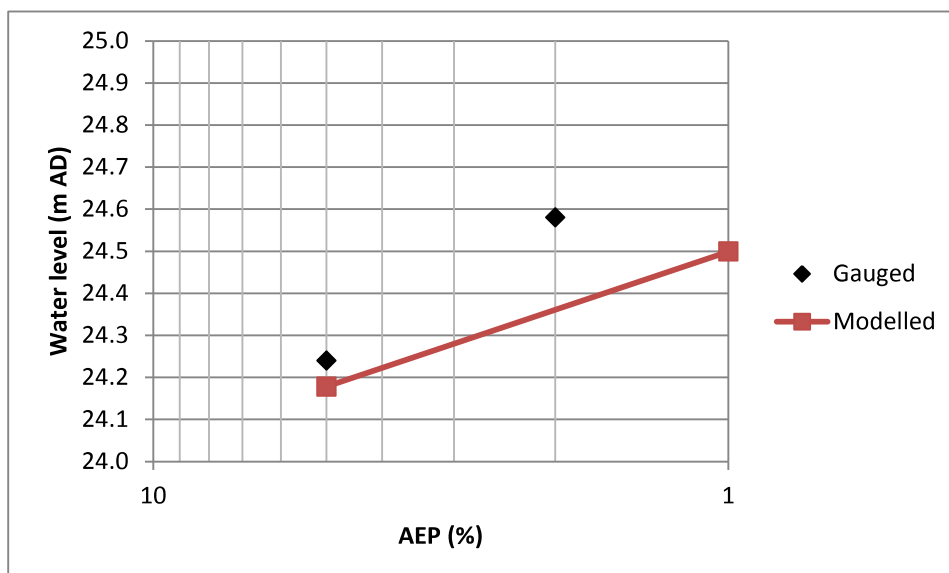


Figure 6.18: Gauge 18005: gauged versus modelled water levels

Figure 6.14 to Figure 6.18 show that the model results are within the range of 0.6 m above to 0.25 m below the gauge levels, with the majority of modelled levels exceeding the gauge levels. This is considered to be a satisfactory result taking account of the facts that the AEP values of the observed events are estimated and some of the gauge locations are upstream of bridges that have not been modelled in detail. The model results are slightly higher than the observed results, indicating that they are slightly conservative.

## 6.5. Comparison with FSU flows

The modelled flow results were compared against the hydrologically estimated flows; the comparison is presented in Table 6.2.

Table 6.2: Analysis of difference between modelled and hydrologically estimated flows: UoM 18

Type	Mean	Median	75 <sup>th</sup> Percentile	90 <sup>th</sup> Percentile
Difference	-2.8	-0.4	2.8	10.3
Absolute difference	8.5	4.6	10.8	21.4

These results show that at the majority of locations the difference between the modelled flow and the FSU design flow is relatively small because 75% of the locations have an absolute difference of less than 10% and for 90% of the locations the difference is less than 20%.

## 6.6. Comparison with PFRA1 flood extents

The purpose of the comparison of results with the PFRA1 flood extents is to demonstrate the improvement in the flood extents using the NIFM method. Maps of the comparison for the 1% AEP flood extents are presented for Mallow (Figure 6.19), Kanturk (Figure 6.20), and Rathmore (Figure 6.21).

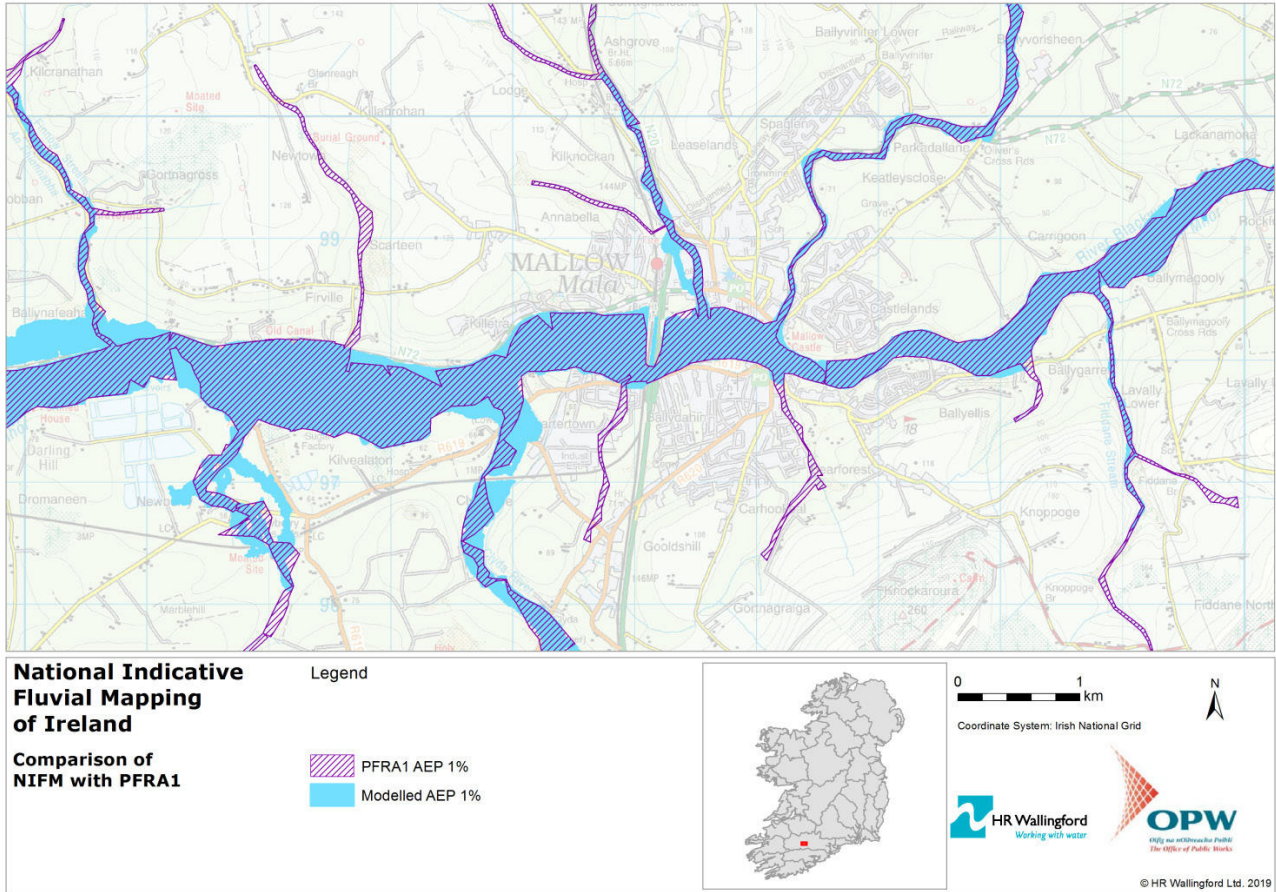


Figure 6.19: NIFM model versus PRFA1 results for 1% AEP for the River Blackwater at Mallow



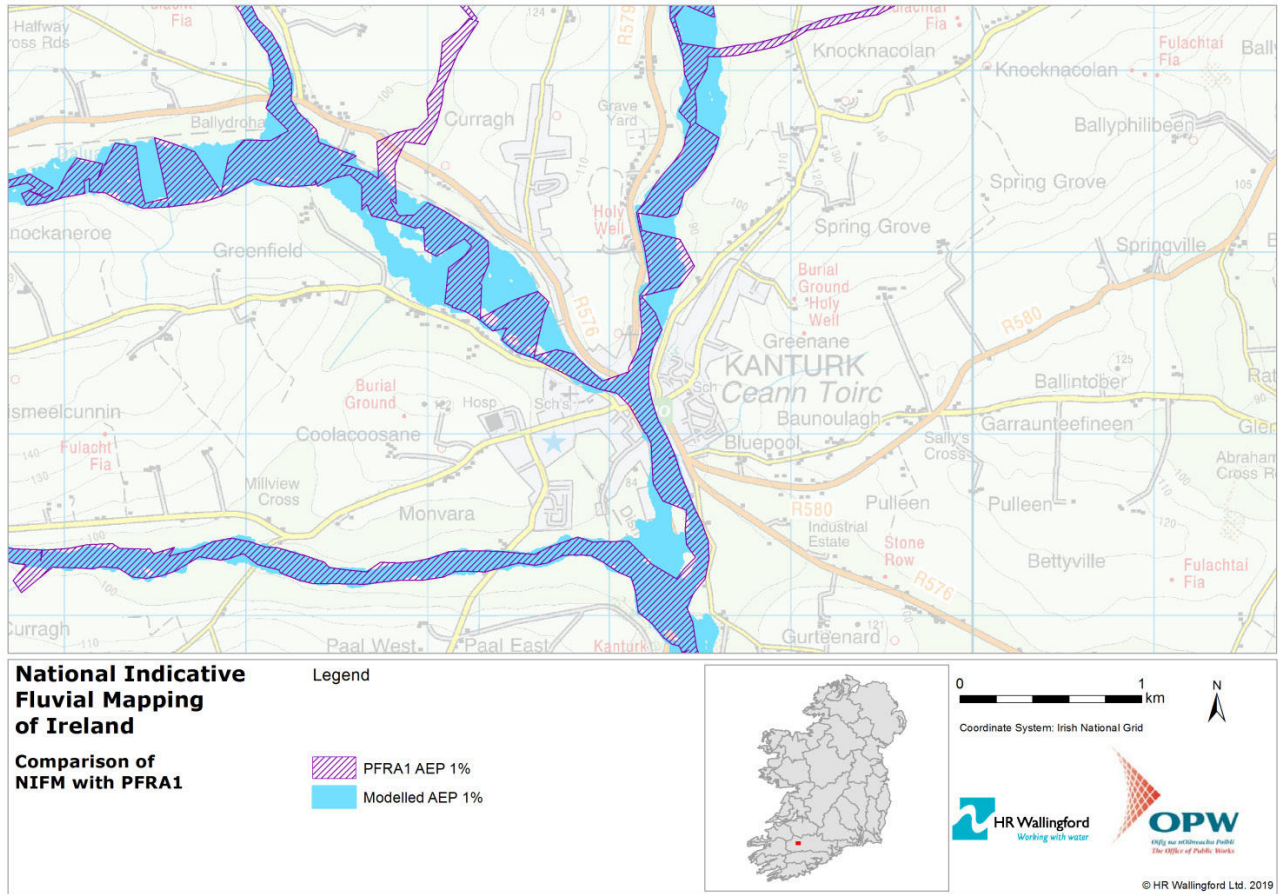


Figure 6.20: NIFM model versus PRFA1 results for 1% AEP for the River Blackwater at Kanturk

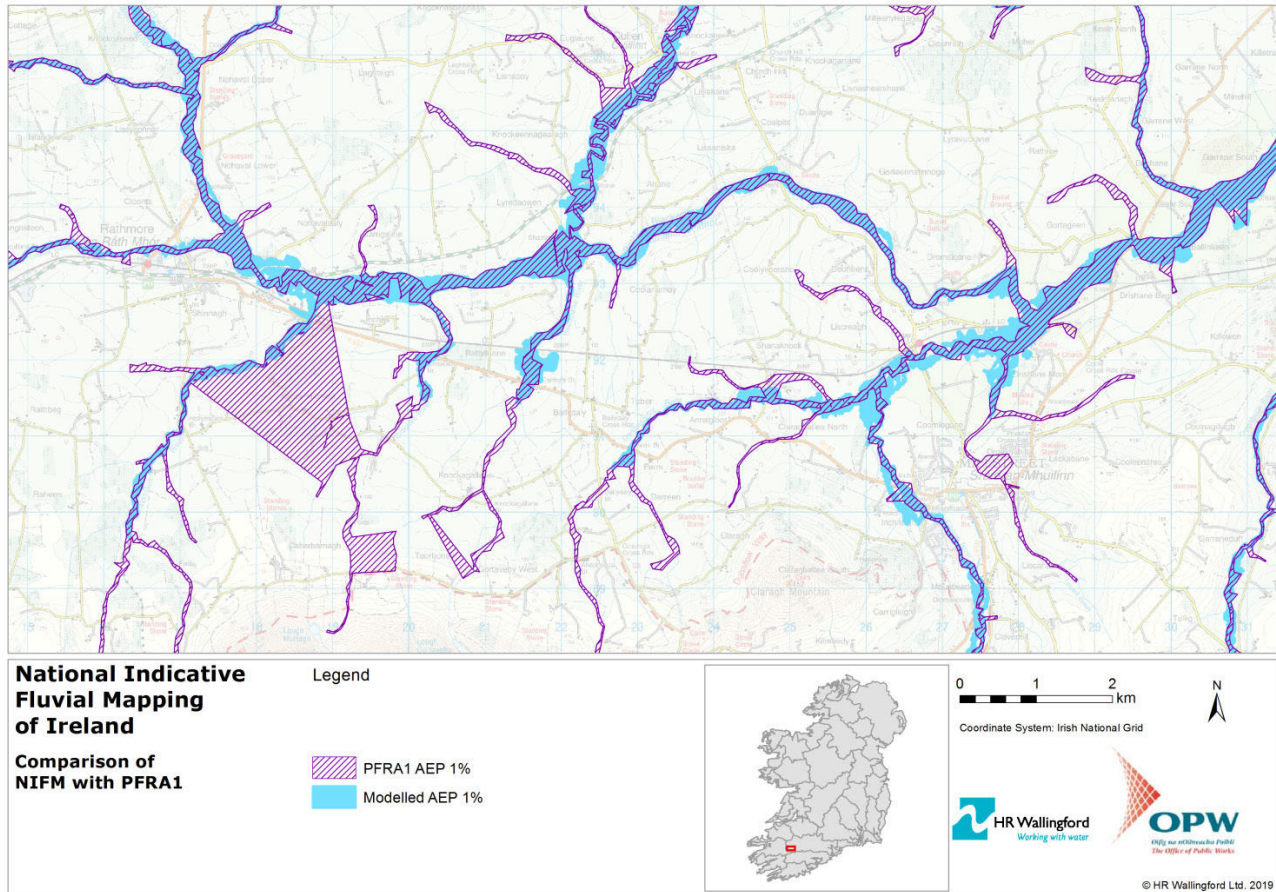


Figure 6.21: NIFM model versus PFRA1 results for 1% AEP for the River Blackwater at Rathmore

In terms of the statistical assessment of the NIFM modelled extents versus those of PFRA1, the following summary is drawn:

- **F statistic:**
  - The F value comparing the NIFM Pilot Model results with CFRAM is 85.5%;
  - The F value comparing PFRA1 results with CFRAM is 76.9%.
- **Wet Area:**
  - The wet area from the NIFM Pilot Model results is 3% greater than that from CFRAM;
  - The wet area from PFRA1 results is 6% less than that from CFRAM.

For UoM 18, the NIFM model achieves a closer fit to CFRAM than PFRA1 using both measures. In addition, the NIFM flood extents tend to be slightly greater than those from CFRAM which means that they are generally slightly conservative. It also reflects the fact that the NIFM modelling has taken into account the additional recent years of data, which included the significant December 2015 event.

## 7. Analysis of results for UoM 26

### 7.1. Historical flood evidence

#### Historical flood evidence from CFRAM studies

The CFRAM study hydraulic model for UoM 26 had been calibrated and validated to the following flood events for the various modelled reaches displayed on the map reproduced in Figure 1.5 (OPW, 2016d):

- Upper Shannon main stem (N01): **January 2005** and **November 2009**;
- River Boyle (N01): **November 2009**;
- Upper Shannon main stem (N02): Insufficient data;
- Upper Inny (N03): Flood observational data for Events 1 (**November 2009**) and 2 (December 1954) could not be used for calibration or verification. The Event 1 data were not specific enough to identify the locations, and the Event 2 data were from before the gauged flow records, and did not come with an estimated return period;
- R. Hind (N04): No calibration can be undertaken as no gauged data were available near the locations of flood event observations (in Roscommon). The modelled flood outlines were compared to the **November 2009** event known flood locations to verify that the model results seemed consistent with the observed data and to verify the estimated return period of the 2009 event (estimated between 50 years based on single site analysis with the EV1 distribution at gauging station 26016 and 200 years in the River Jiggy Flood Study Report;
- R. Suck - middle (N08): **November 2009**; **October 2002**; **February 2002**; **January 2005**;
- R. Suck – lower (N09): **November 2009**; **December 1999**;
- Upper Shannon into Lough Ree (N10): **November to December 2009**.

The CFRAM report recommends that any future calibration or validation should use the subsequent **December 2015 to January 2016** event.

#### More recent historical flood evidence

A range of evidence was available for consideration for validation of recent flood events. This is summarised in Table 7.1. Items in bold were considered useful for validation.

Table 7.1: Recent historical flood evidence for UoM 26

Location	Event	Evidence, and comment on viability for validation
Longford	Nov 2015	Photos without georeferencing information, so uncertainty over location.
	Dec 2015 – Jan 2016	National Directorate for Fire and Emergency Management report on flood event impacts across RoI. <b>Useful map of ranked events across the country (Figure 6.1), and table of towns flooded, with dates.</b> The dates of initial reports of <b>flooding of Athlone (5 Dec), Ballinasloe (5 Dec; 5 Jan), Shannonbridge (15 Dec), Carrick-on-Shannon (16 Dec).</b>
Ahascragh	Dec 2015	<b>OPW Flooding Event Report Form and map showing flooded properties. Flooding of R. Bunowen (tributary of R. Suck).</b>
Ballinasloe	Dec 2015	<b>OPW Flooding Event Report Form, with lists of flooded properties, two maps showing flood extents, and annotated photos.</b>

Location	Event	Evidence, and comment on viability for validation
Ballinasloe & Athlone	Jan 2014	Nine aerial photos with no georeferencing information.
Roscommon	Dec 2015 – Jan 2016	Lists of affected roads and numbers of properties in certain areas. Rather imprecise.
Carrick-on-Shannon	Dec 2015	<b>List of affected roads.</b>

Source: Various

In addition to these sources described above, historical flood information on the website *floodinfo.ie* has been accessed for a range of supporting information, including meeting minutes, reports and photographs. These are reported below.

## 7.2. River Suck

### 7.2.1. Calibration against CFRAM study results

The model results for the River Suck, at its upper, middle and lower reaches, have been compared to the results of the CFRAM modelling in those areas.

#### Ballinasloe (lower River Suck)

Figure 7.1 to Figure 7.3 show that the NIFM flood extents compare well to the CFRAM flood extents in the lower reaches of the River Suck, including the town of Ballinasloe, for the 5% AEP, 1% AEP and 0.1% AEP HEFS events, respectively. The AEP 5% flood outline slightly under-estimates the flood extent compared to CFRAM. The reasons for these differences are explained at the end of this section. The AEP 1% and AEP 0.1% results fit very well against the CFRAM model results, and are slightly conservative in some areas.

Maps of the extents are shown in Figure 7.1, Figure 7.2 and Figure 7.3 respectively.



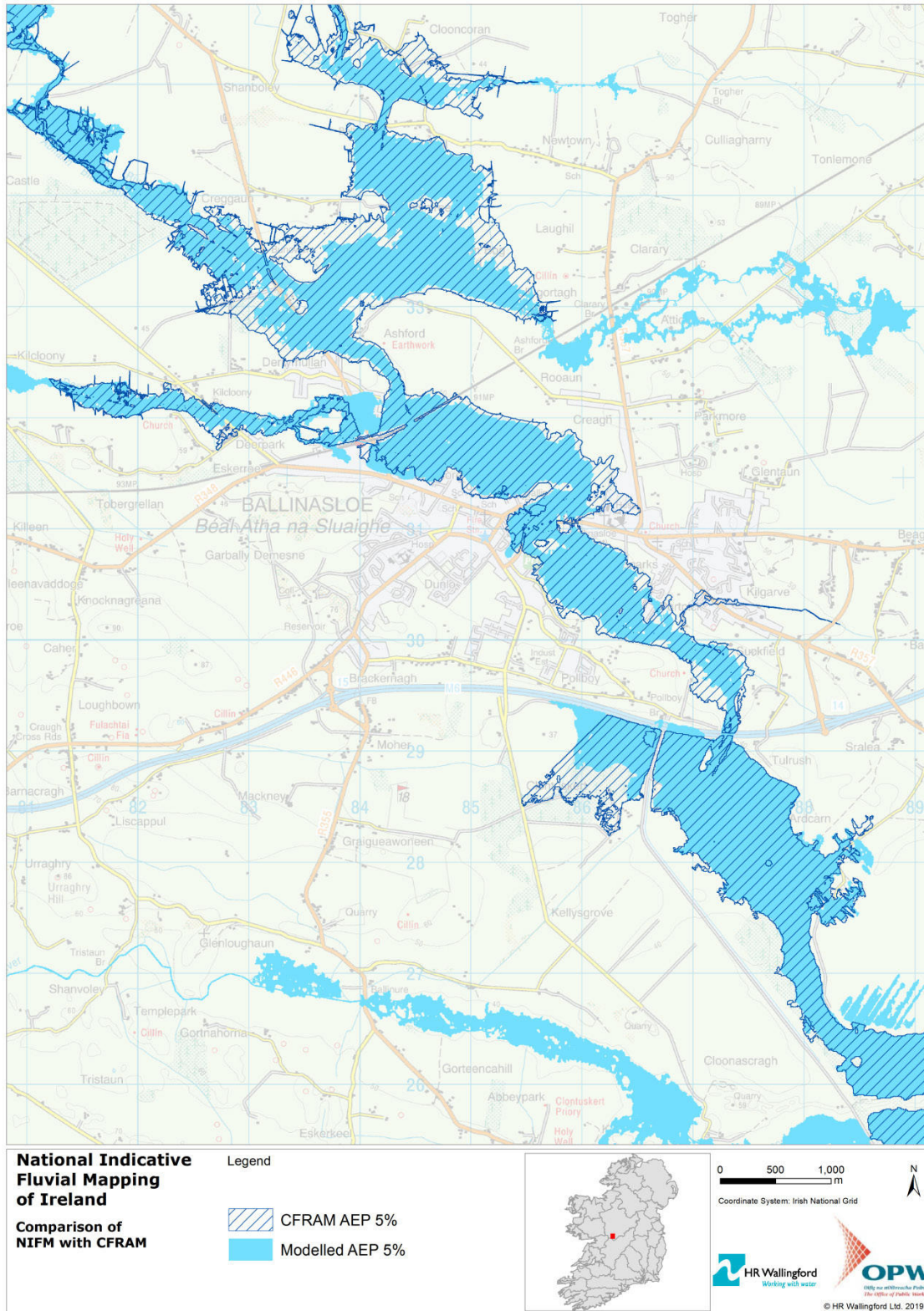


Figure 7.1: NIFM model versus CFRAM results for 5% AEP for the lower reach of the River Suck



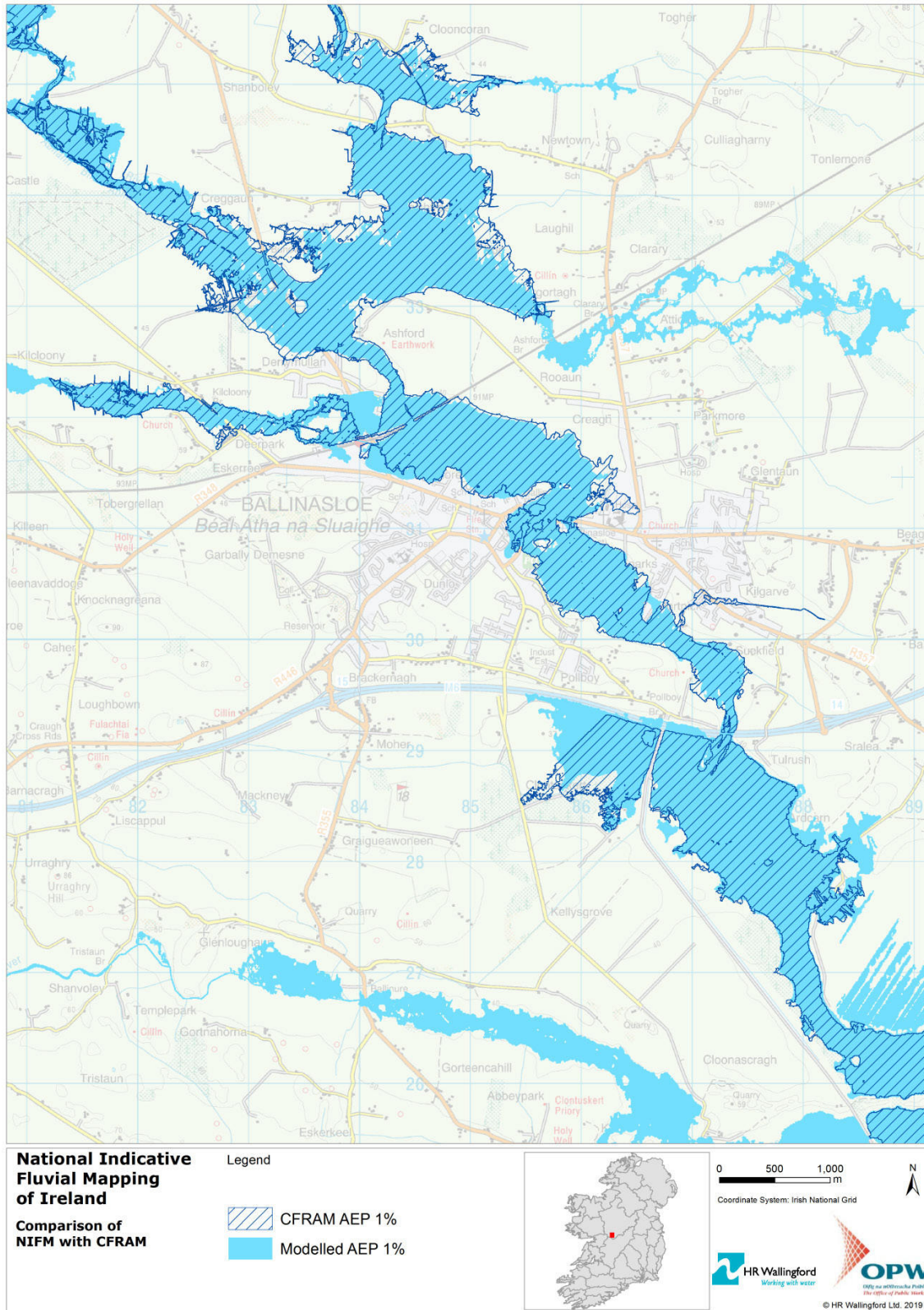


Figure 7.2: NIFM model versus CFRAM results for 1% AEP for the lower reach of the River Suck



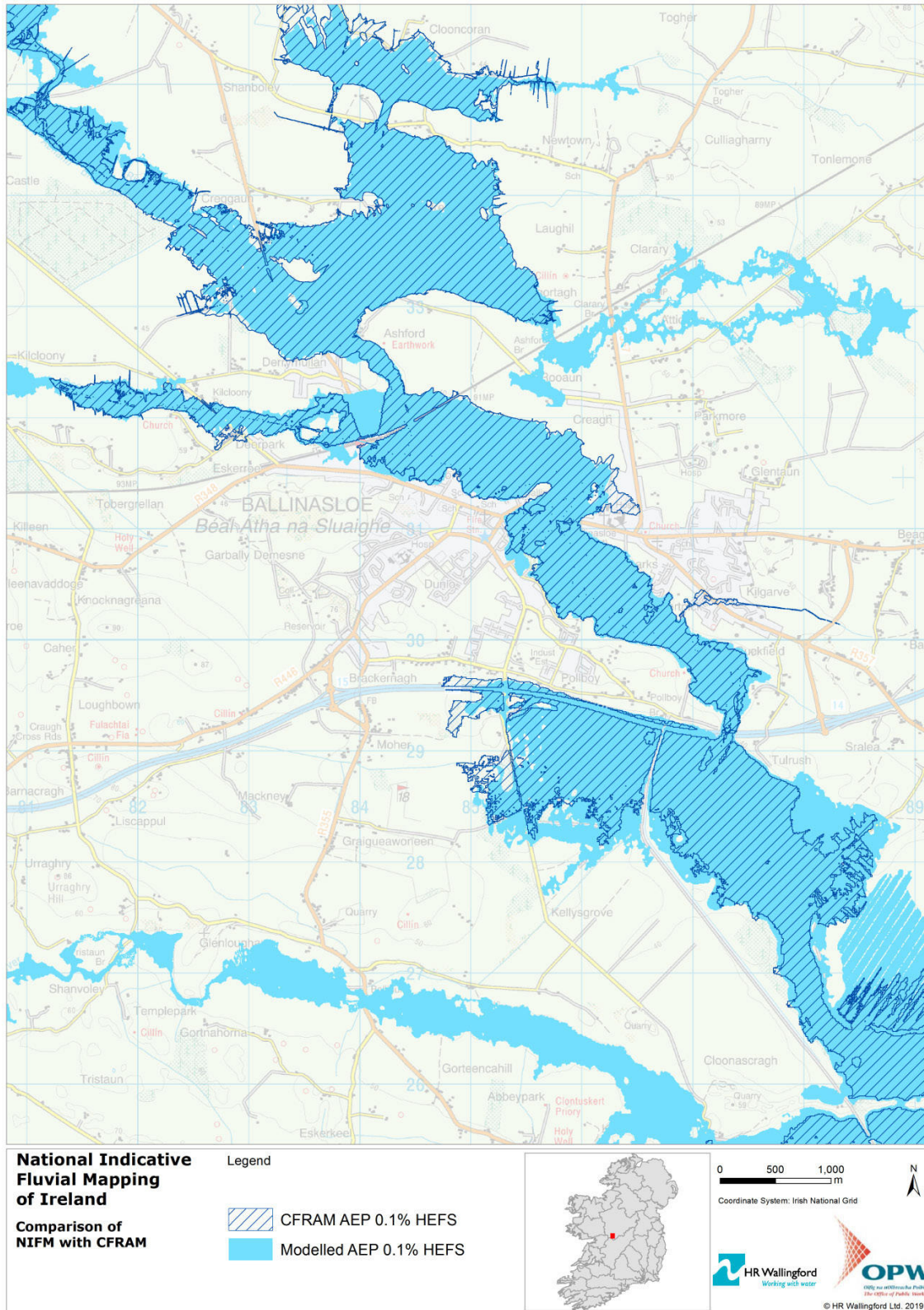


Figure 7.3: NIFM model versus CFRAM results for 0.1% AEP HEFS for the lower reach of the River Suck

Comparison of the modelled water levels with those from CFRAM (Figure 7.4) show that the model results compare well at the upstream and downstream ends of the reach and are around 0.5 m lower than CFRAM in the middle of the reach.

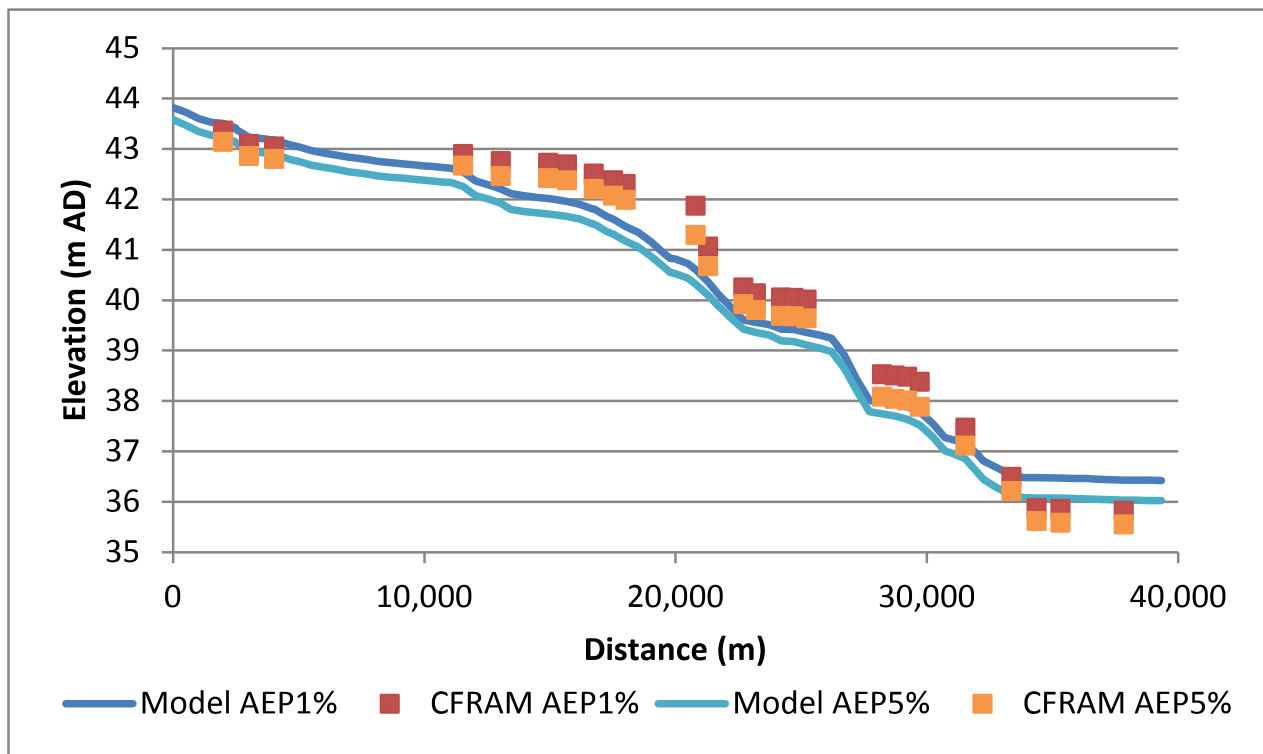


Figure 7.4: NIFM model water levels versus CFRAM for the lower reach of the River Suck

The reason that the modelled water levels are lower in the middle of the reach have not been investigated in detail but an initial review suggests that the following factors have affected the results:

- The proportion of the channel cross-section that is included in the DTM may be overestimated in the modelling using the standard method;
- The water levels in the CFRAM modelling have been raised by river structures including bridges, weirs and control gates.

Recommendations are given in Section 9 for further refinements of the methodology that could reduce these differences, although they are outside the scope of the present study.

### Ballygar (middle River Suck)

Figure 7.5 to Figure 7.7 show that the NIFM flood extents generally compare well to the CFRAM flood extents in the middle reaches of the River Suck for the AEP 5%, AEP 1% and AEP 0.1% HEFS events respectively. Three areas shown to flood in the CFRAM results are for streams with catchments less than 5 km<sup>2</sup>, which are not included in the NIFM model. The AEP 5% flood outline slightly under-estimates the flood extent compared to CFRAM.



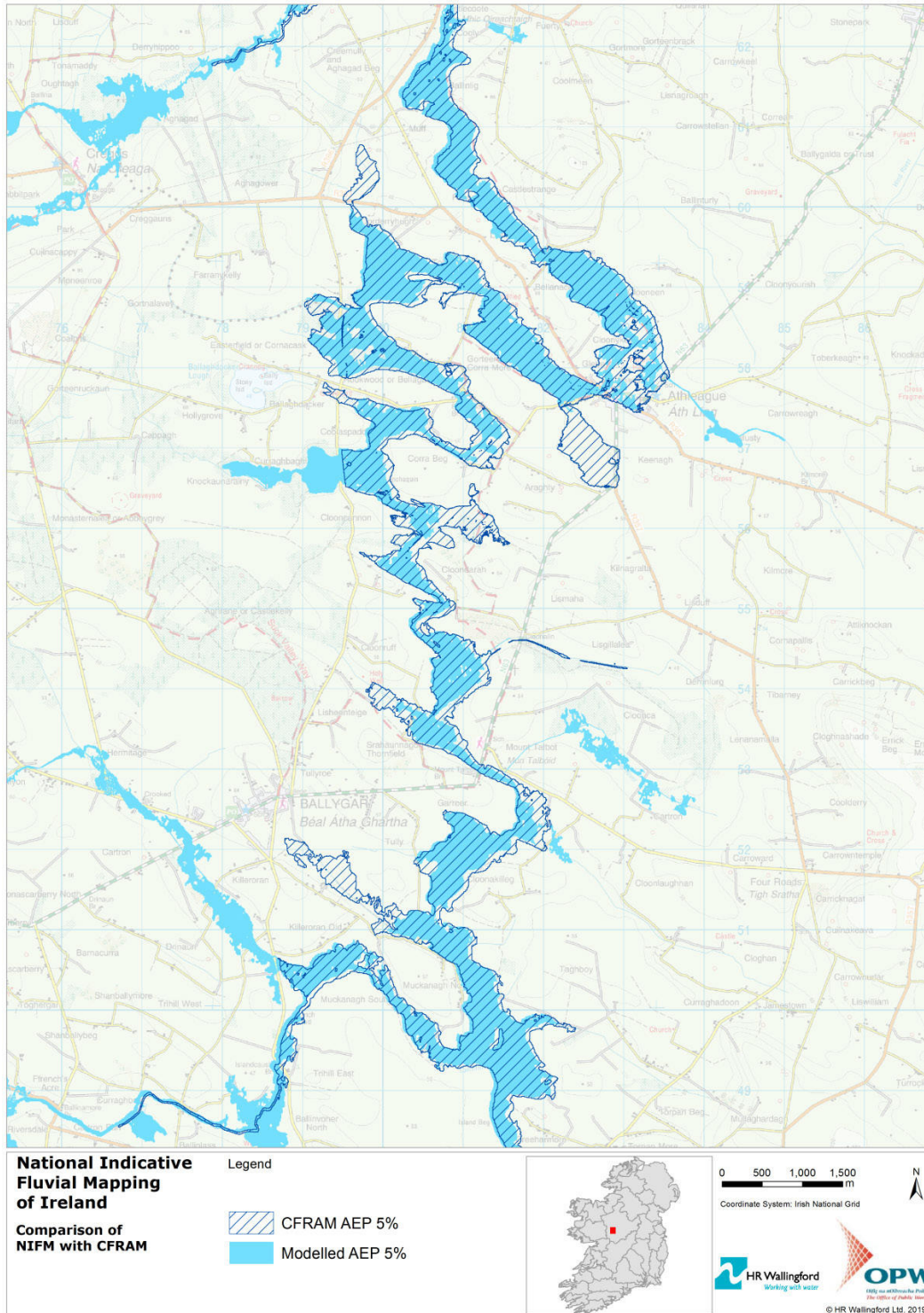


Figure 7.5: NIFM model versus CFRAM results for 5% AEP for the middle reach of the River Suck



Figure 7.6: NIFM model versus CFRAM results for 1% AEP for the middle reach of the River Suck



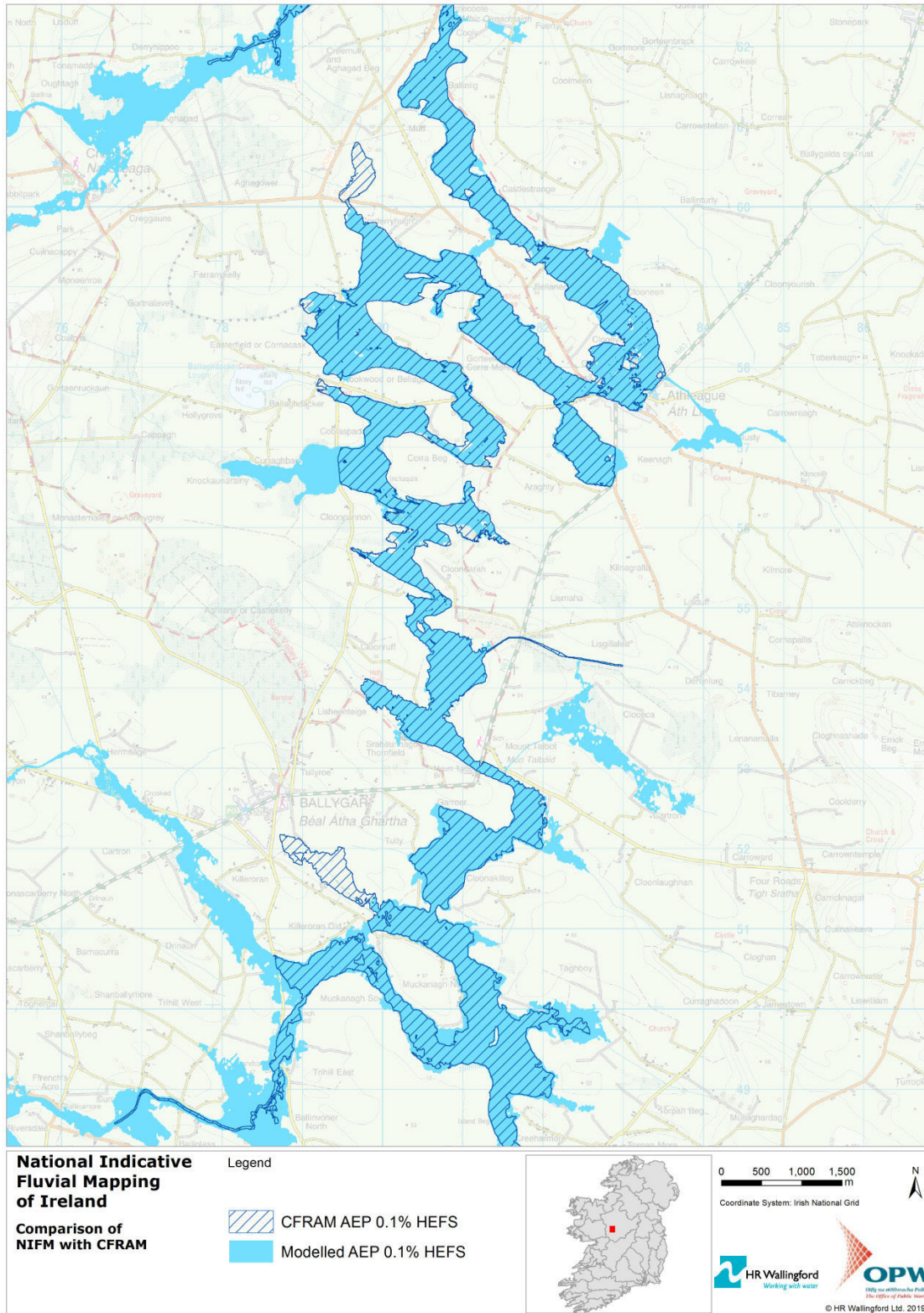


Figure 7.7: NIFM model versus CFRAM results for 0.1% AEP HEFS for the middle reach of the River Suck

Comparison of the modelled water levels with those from CFRAM (Figure 7.8) show that the model results compare well with CFRAM in the middle River Suck.

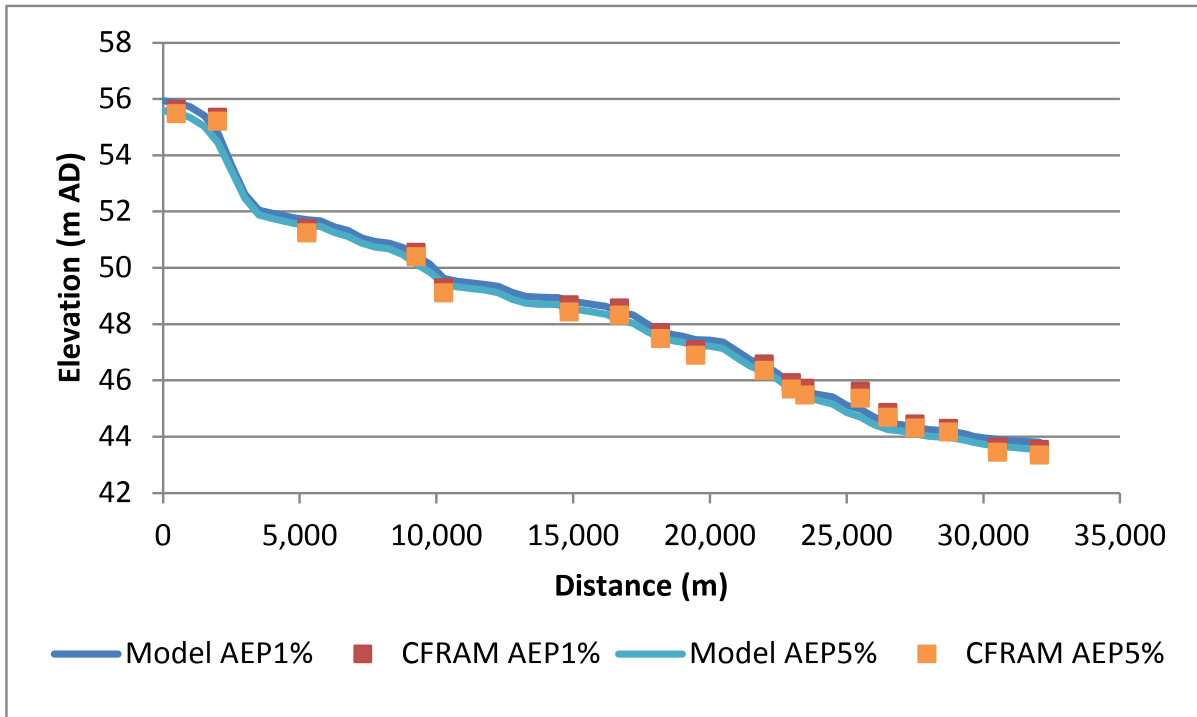


Figure 7.8: NIFM model water levels versus CFRAM for the middle reach of the River Suck

### Ballymore (upper River Suck)

Figure 7.9 to Figure 7.11 show that the NIFM flood extents generally compare well to the CFRAM flood extents in the upper reaches of the River Suck for the AEP 5%, AEP 1% and AEP 0.1% HEFS events respectively. The AEP 5% flood outline generally matches the CFRAM flood extents well in the upper reaches of the River Suck. There is one reach where the model slightly under-estimates the flood extent compared to CFRAM.



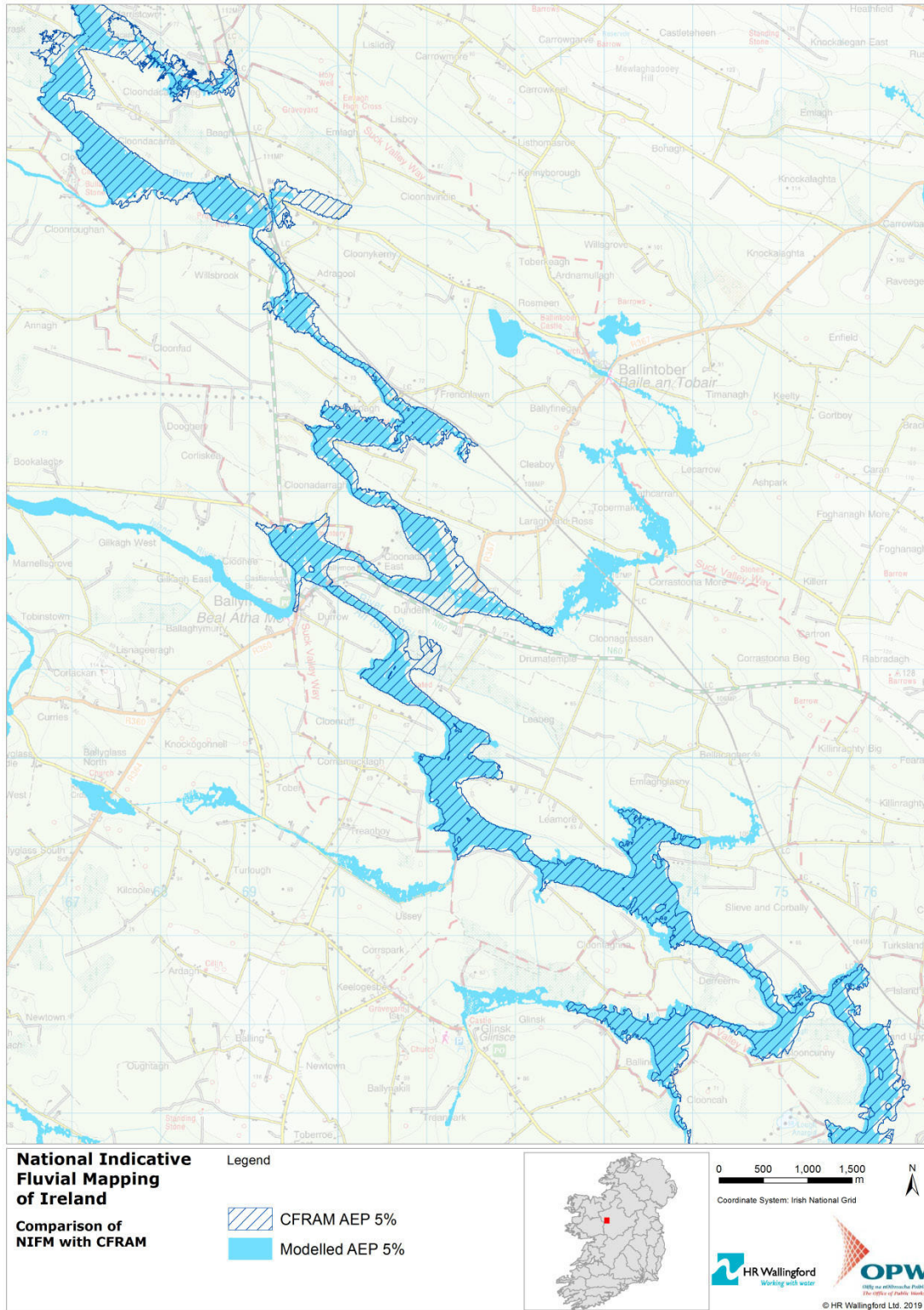


Figure 7.9: NIFM model versus CFRAM results for 5% AEP for the upper reach of the River Suck



Figure 7.10: NIFM model versus CFRAM results for 1% AEP for the upper reach of the River Suck





Figure 7.11: NIFM model versus CFRAM results for 0.1% AEP HEFS for the upper reach of the River Suck

Comparison of the modelled water levels with those from CFRAM (Figure 7.12) show that the model results compare well with CFRAM in the upper River Suck.

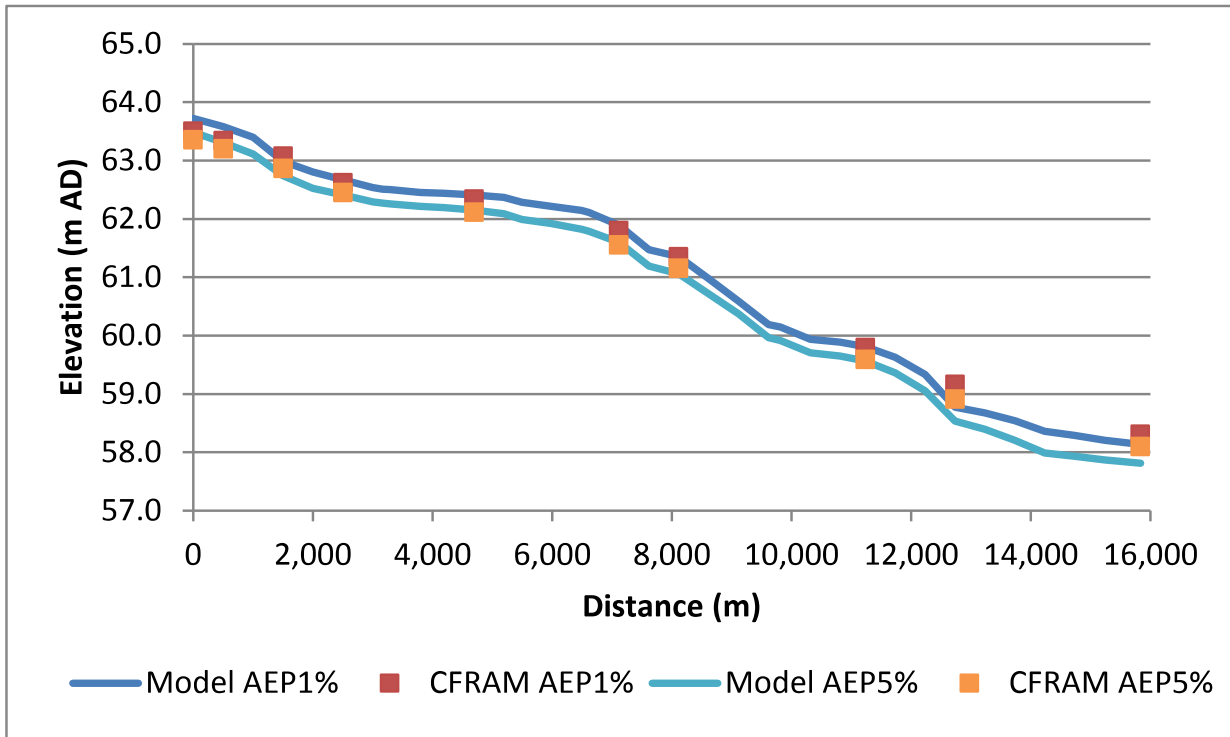


Figure 7.12: NIFM model water levels versus CFRAM for the upper reach of the River Suck

### 7.2.2. Validation for the flood of 2000

The flood event in 2000 was captured by aerial photography around Ballinasloe. The annual exceedance probability of this flood has been estimated as more frequent than 5% based on the gauged records. Comparison of the photographed flood extent with the modelled flood extent (in Figure 7.13 and Figure 7.14) shows that model flood extent compares well to that of the observed event.





Figure 7.13: Flood in 2000 at Ballinasloe

Source: [floodinfo.ie](http://floodinfo.ie)

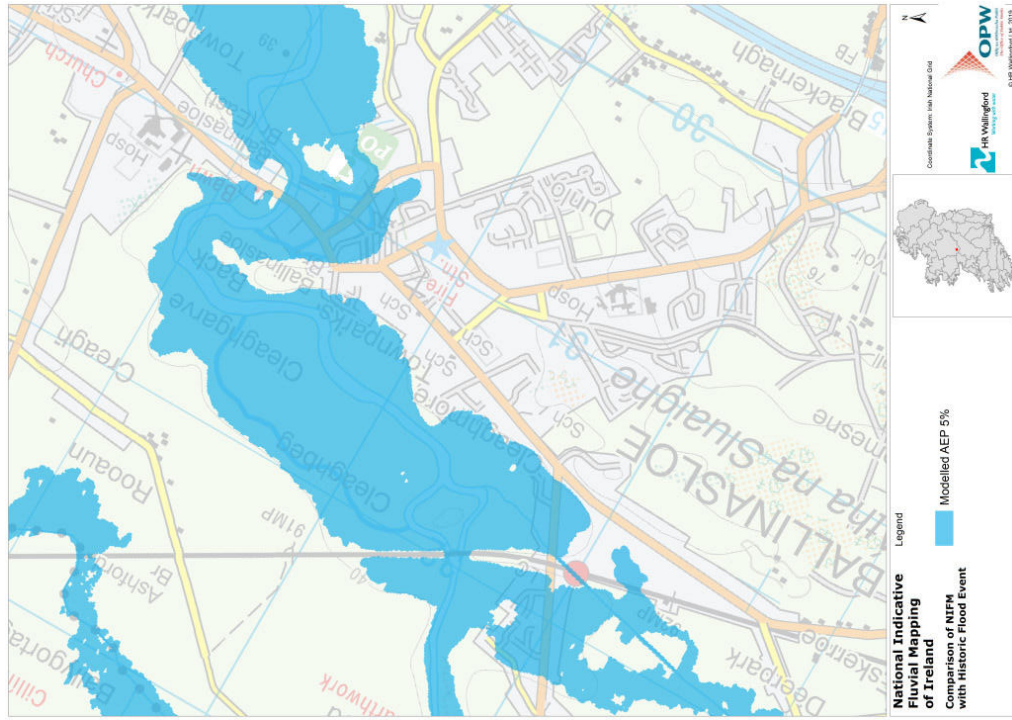


Figure 7.14: NIFM flood extent for the 5% AEP

## 7.3. River Inny

### 7.3.1. Calibration against CFRAM study results

The model results for the River Inny have been compared to the results of the CFRAM modelling in the lower reach, where CFRAM results were available, for 5% AEP (Figure 7.15), 1% AEP (Figure 7.16) and 0.1% AEP HEFS (Figure 7.17). Figure 7.15 to Figure 7.17 show that the NIFM flood extents generally compare well to the CFRAM flood extents on the River Inny and its tributary (the River Black) for the AEP 5%, AEP 1% and AEP 0.1% HEFS events respectively.





Figure 7.15: NIFM model versus CFRAM results for 5% AEP for the River Inny



Figure 7.16: NIFM model versus CFRAM results for 1% AEP for the River Inny





Figure 7.17: NIFM model versus CFRAM results for 0.1% AEP HEFS for the River Inny

Comparison of NIFM water levels with CFRAM on the lower Inny (Figure 7.18) shows that the modelled water levels are lower than CFRAM in the upper 5 km and are generally higher than CFRAM in the lower 20 km. Figure 7.19 shows that the modelled water levels compare well those from CFRAM on the River Black (tributary of the River Inny).

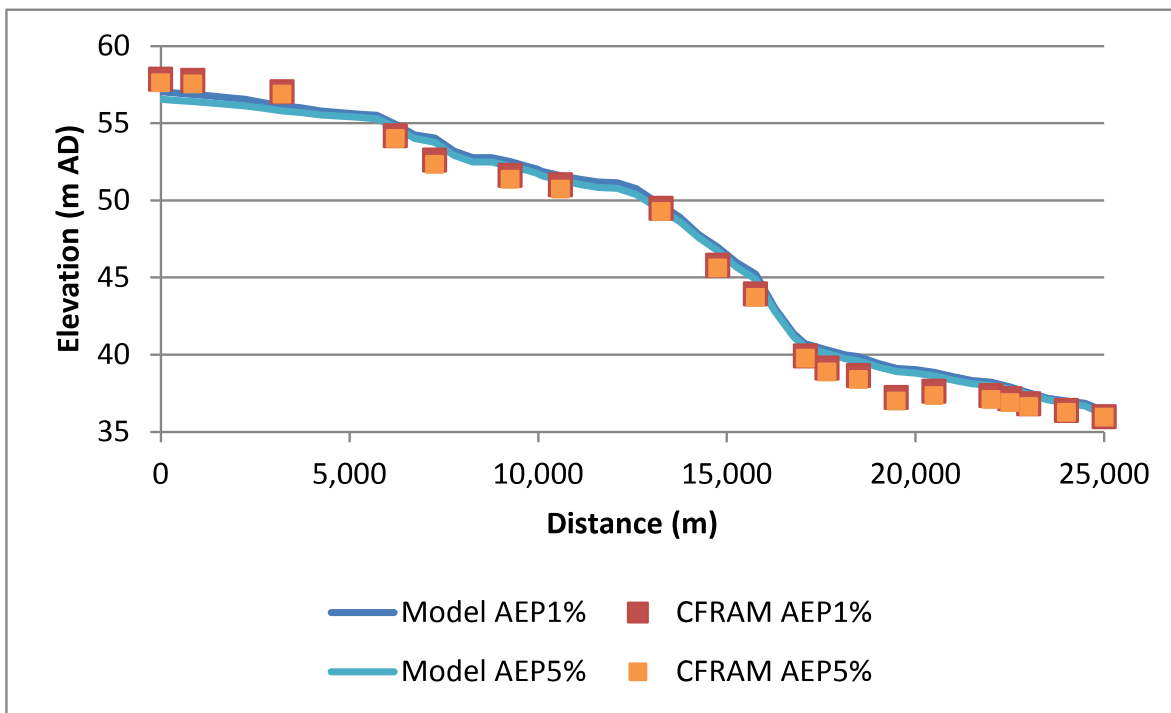


Figure 7.18: NIFM model water levels versus CFRAM for the lower reach of the River Inny

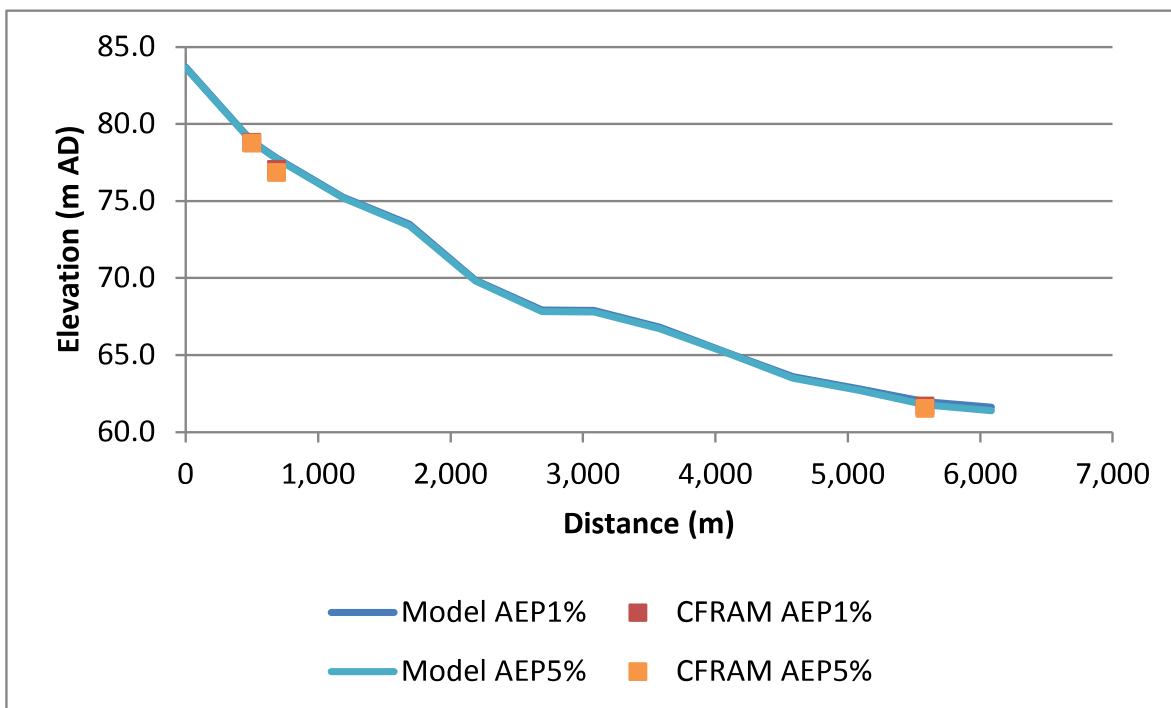


Figure 7.19: NIFM model water levels versus CFRAM for the River Black (tributary of the River Inny)

### 7.3.2. Validation for historical floods and benefited lands

As mentioned in Section 7.1, the key 2007 flood event data were not specific enough to identify the locations (also noted during the CFRAM study). No further evidence to support validation has been found via *floodinfo.ie*.

A comparison has been made between the flood extents predicted by the modelling and the area of land that benefits from arterial drainage (the 'benefitting lands'). The results for the River Inny are shown on Figure 7.20.



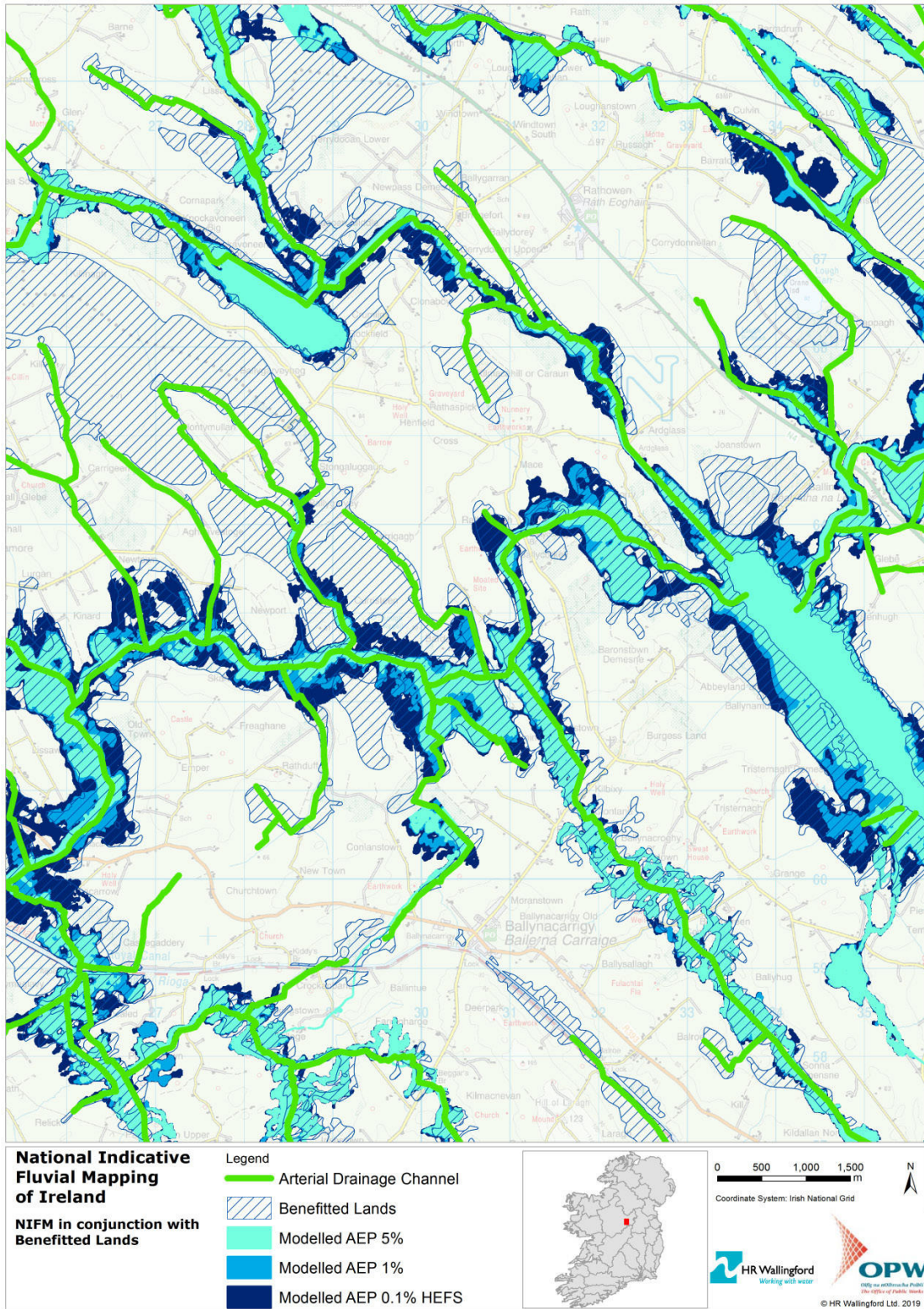


Figure 7.20: Comparison of NIFM results for all AEPs with extents of benefitted lands

The results show that the areas benefitting from arterial drainage are similar to the 5% flood extent predicted by the NIFM modelling, which has very similar flood extents to the CFRAM modelling. Many of the watercourses have catchment areas of less than 5km<sup>2</sup>. Whilst these have benefitting lands, they are not covered by the NIFM and CFRAM modelling. The overall comparison between the NIFM flood outline and the benefitting lands extent is reasonable although there are some areas where the benefitting land area exceeds the 5% flood extent and in some cases is greater than the 0.1% AEP HEFS scenario.

## 7.4. Comparison with gauged water levels

Water levels have been compared to the gauged water levels for the highest flood events at the following gauges:

- 26005 River Suck at Derrycahill (lower). The modelled water levels are around 0.4m lower than the gauged levels for the highest gauged events (Figure 7.21).
- 26002 River Suck at Rockwood (middle). The modelled water levels are around 0.15m lower than the gauged levels for the highest gauged events (Figure 7.22).
- 26006 River Suck at Willsbrook (upper). The modelled water levels compare well with the gauged levels for the highest gauged events (Figure 7.23).
- 26021 River Inny (lower). The modelled water levels are around 0.4m higher than the gauged levels for the highest gauged events (Figure 7.24).

In general this comparison shows that the model water levels are in the expected range based on the recorded flood levels.

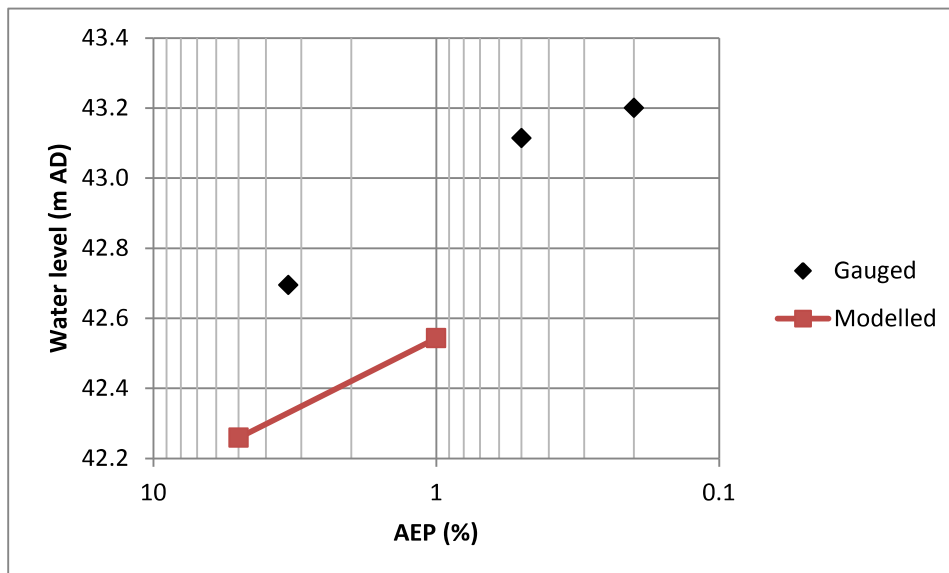


Figure 7.21: Gauge 26005: Gauged versus modelled levels

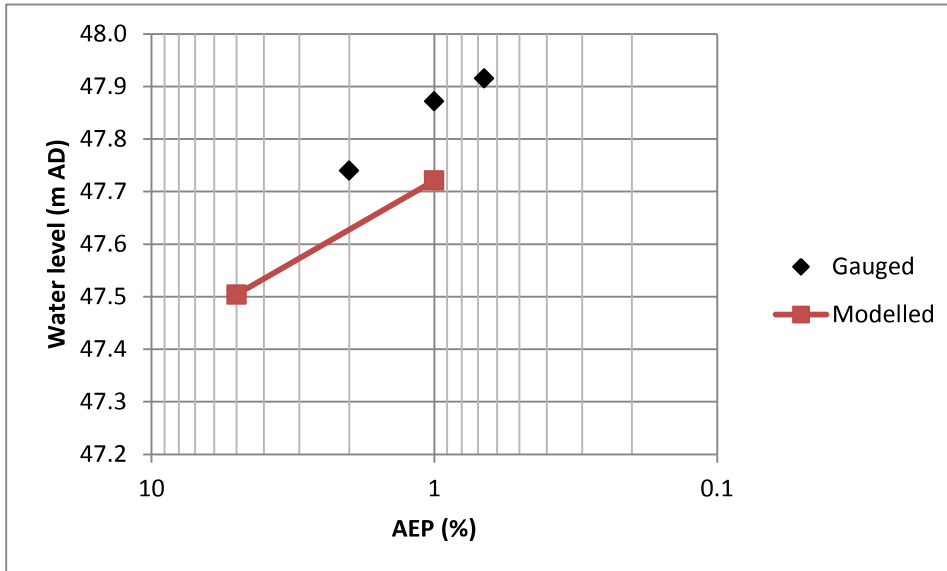


Figure 7.22: Gauge 26002: Gauged versus modelled levels

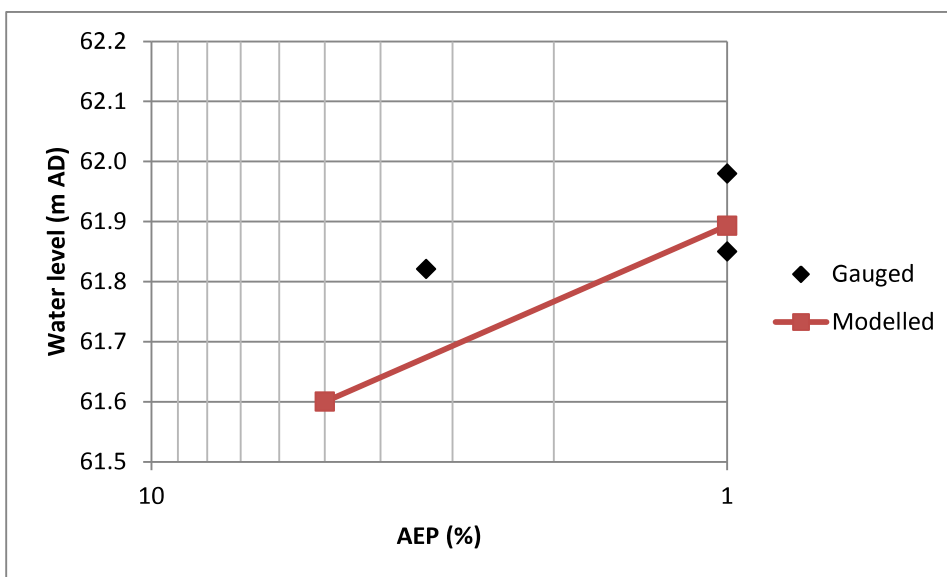


Figure 7.23: Gauge 26006: Gauged versus modelled levels

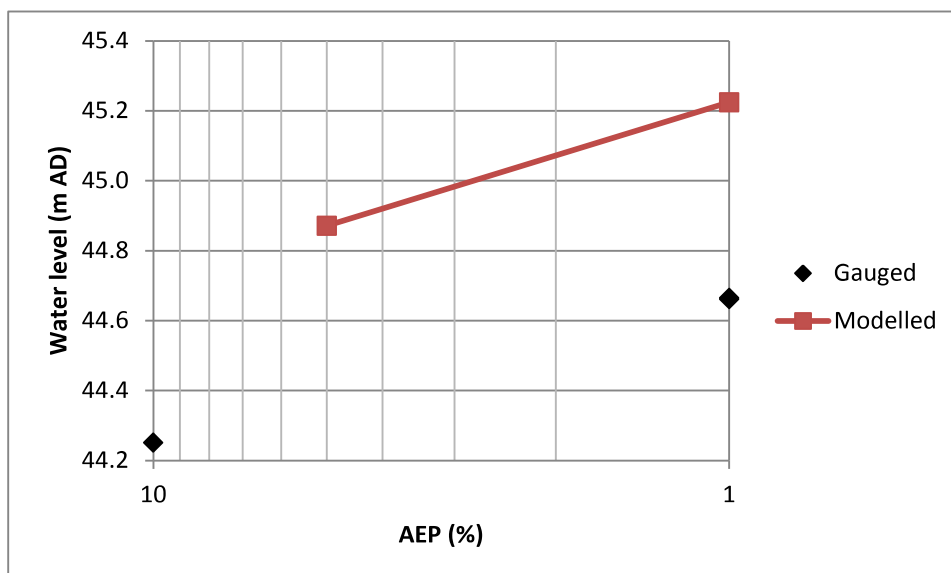


Figure 7.24: Gauge 26021: Gauged versus modelled levels

Figure 7.21 to Figure 7.24 show that the model results are within the range of 0.5 m above to 0.3 m below the gauge levels, with the majority of modelled levels below the gauge levels. This is considered to be a satisfactory result taking accounts of the facts that the AEP values of the observed events are estimated and some of the gauge locations are upstream of bridges that have not been modelled in detail.

## 7.5. Comparison with FSU flows

The modelled flow results were compared against the hydrologically estimated flows; the comparison is presented in Table 7.2.

Table 7.2: Analysis of difference between modelled and hydrologically estimated flows: UoM 26

Type	Mean	Median	95 <sup>th</sup> Percentile	75 <sup>th</sup> Percentile
Difference	-9.2	-7.0	5.9	-1.1
Absolute difference	12.0	8.7	30.0	15.9

These results show that at the majority of locations the difference between the modelled flow and the FSU design flow is relatively small because 75% of the locations have an absolute difference of less than 15%. The difference between the modelled flow and the FSU is slightly greater than that on UoM 18, which might be related to the flatter nature of the catchment meaning that there is more attenuation of the flow in the floodplain than in UoM 18.

## 7.6. Comparison with PFRA1 flood extents

The purpose of the comparison of NIFM results with the PFRA1 flood extents is to demonstrate the improvement in the flood extents using the NIFM method. Results for the Rivers Suck and Inny are presented in the sections below.



Overall, in terms of the statistical assessment of the NIFM modelled extents versus those of PFRA1, the following summary is drawn:

- F statistic:
  - The F value comparing the NIFM Pilot Model results with CFRAM is 68.6%;
  - The F value comparing PFRA1 results with CFRAM is 52.7%.
- Wet Area:
  - The wet area from the NIFM Pilot Model results is 15% greater than that from CFRAM;
  - The wet area from PFRA1 results is 8% less than that from CFRAM.

At the lower end of the River Suck, the boundary water level from the CFRAM model was applied on the Upper Shannon. On these large catchments, this may have over-estimated the water levels on the lower Suck because of coincident flood peaks between the River Suck and the Upper Shannon. In the national roll-out, this situation is unlikely to arise due to CFRAM coverage. The results have been re-analysed with two 5 km grid squares removed at the lower end of the River Suck. This gives:

- F statistic:
  - The F value comparing the NIFM Pilot Model results with CFRAM is 73.3%;
  - The F value comparing PFRA1 results with CFRAM is 52.7%.
- Wet Area:
  - The wet area from the NIFM Pilot Model results is 6% greater than that from CFRAM;
  - The wet area from PFRA1 results is 7% less than that from CFRAM.

For both Pilot Study Areas, the NIFM model achieves a closer fit to CFRAM than PFRA1 using both measures. In addition, the NIFM flood extents tend to be greater than those from CFRAM which means that they are generally slightly conservative. It also reflects the fact that the NIFM modelling has taken into account the additional recent years of data, which included the significant December 2015 event.

### 7.6.1. River Suck

The NIFM flood extents have been compared to those from PFRA1 for the lower, middle and upper reaches of the River Suck for the AEP 1% event in Figure 7.25 to Figure 7.27, respectively.

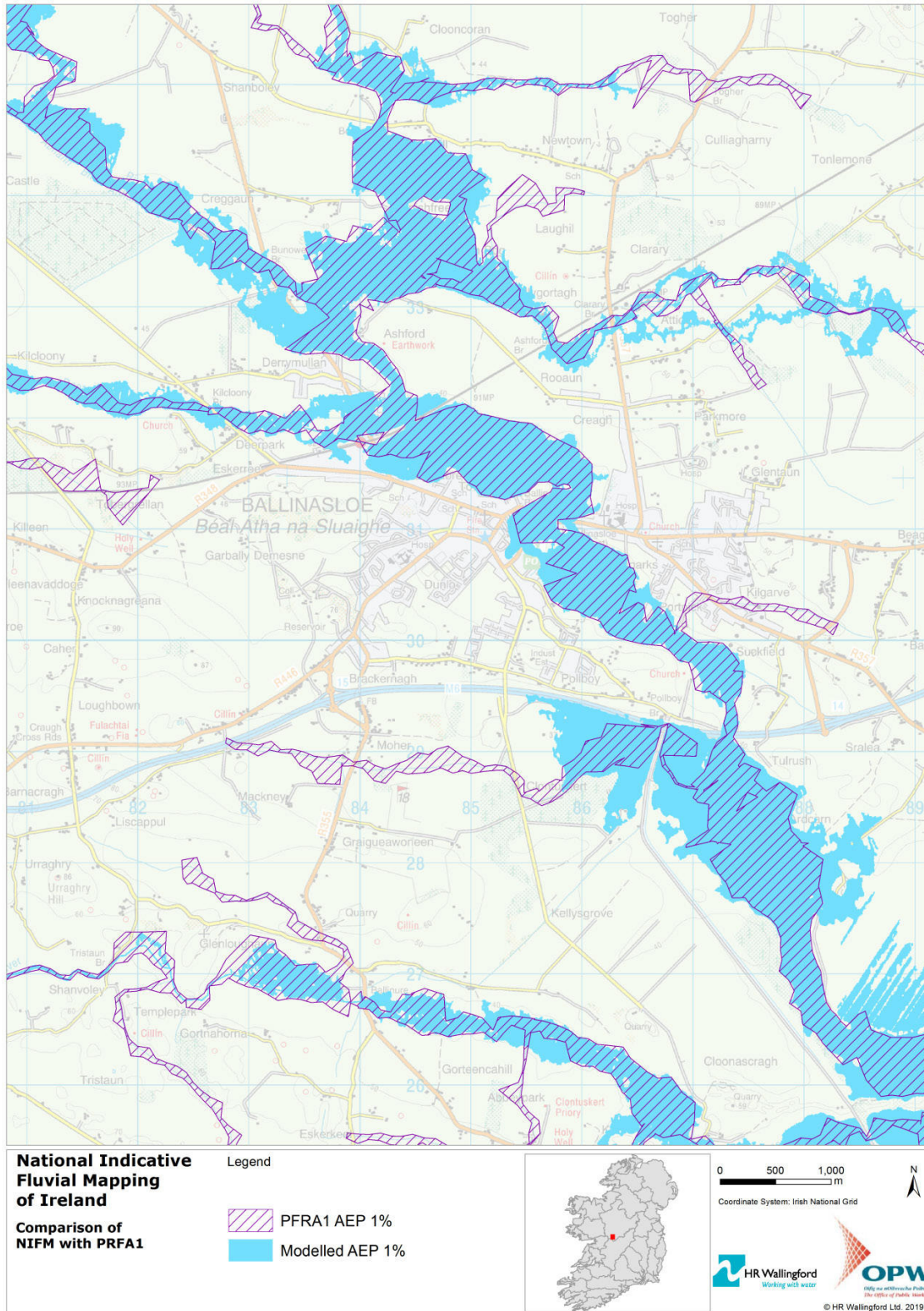


Figure 7.25: NIFM model versus PRFA1 results for 1% AEP for the lower reach of the River Suck



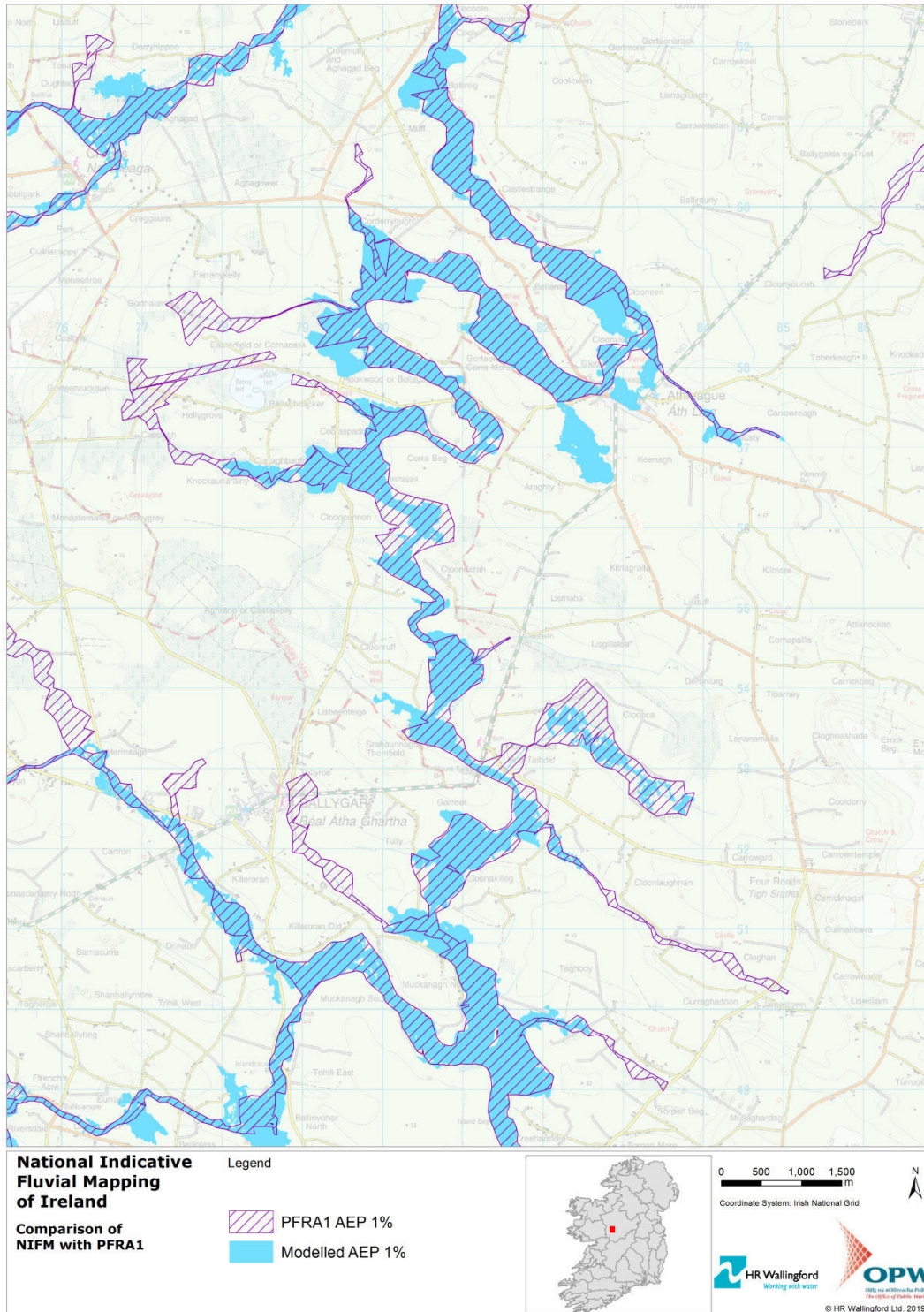


Figure 7.26: NIFM model versus PRFA1 results for 1% AEP for the middle reach of the River Suck



Figure 7.27: NIFM model versus PRFA1 results for 1% AEP for the upper reach of the River Suck



### 7.6.2. River Inny

The NIFM flood extents have been compared to those from PFRA1 on the Inny for the 1% AEP event (Figure 7.28).



Figure 7.28: NIFM model versus PFRA1 results for 1% AEP for the River Inny

## 8. Assumptions made in the methodology

The assumptions tested in our modelling trials on the Pilot Study Areas, and our key resultant recommendations for the national roll-out are as follows:

- Defining the model domain: The DTM approach has been finally trialled for both Pilot Study Areas and is recommended for the national roll out.
- Estimating the river channel surface elevation: The approach based upon 50 m spacing of cross-sections has been finally trialled for both Pilot Study Areas and is recommended for the national roll out.
- Channel capacity and  $Q_{MED}$  adjustment for different types of channel: The following adjustments for a range of channel types have been finally trialled for both Pilot Study Areas and are recommended for the national roll out:
  - On shallowly sloping rivers, the channel capacity is approximately  $Q_{MED}$ ;
  - On moderately sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
  - On steeply sloping rivers, the channel capacity is estimated as 80% of  $Q_{MED}$ ;
  - On rivers with arterial drainage works the channel capacity is approximately 135%  $Q_{MED}$ ;
  - On rivers through urban areas, the channel capacity is approximately  $Q_{MED}$ .
- Correction for proportion of channel captured by the DTM: The following adjustments are suggested based on these observations, to account for part of the channel that is already captured in the DTM; these values represent the additional amount of channel capacity to create in the DTM for these categories:
  - Width < 5m: no adjustment;
  - Width >5m to <10m: adjust to 85% of full capacity;
  - Width >10m to <15m: adjust to 70% of full capacity;
  - Width >15m to <20m: adjust to 60% of full capacity;
  - Width >20m to 40m: adjust to 50% of full capacity;
  - Width > 40m: adjust to 35% of full capacity.
- Simplified representation of bridges: Setting the channel roughness  $n$  to 0.2 at bridges gives a reasonable approximation of the afflux impact on water levels upstream of the bridge. This approach has been finally trialled for both Pilot Study Areas and is recommended for the national roll out.
- Integration with CFRAM models: An approach based upon a simple union and dissolve of the NIFM and CFRAM datasets is recommended for the national roll out.

## 9. Recommendations for further refinement of the methodology

Based upon the outcome of the modelling of the Pilot Study Areas, a number of additional refinements have been identified that could improve the method but are outside the current scope, as follows:

1. **Review DTM for individual rivers:** The proportion of the channel captured by the DTM is accounted for through the channel width. In some cases, such as on the River Suck of UoM 26, the capture is variable and the link to channel width does not follow the rules developed elsewhere. In such cases, increased accuracy would be achieved through a review of the DTM for individual rivers.

2. **Representation of structures:** Improved representation of key structures would increase the accuracy of the model in those locations. This would require structure data, which would need on-site survey or, at the very least, photos of structures. This should include bridges and control structures. For more accurate representation of flood defences, detailed information would be required, including crest levels, although these structures are likely to be uncommon outside of the CFRAM extents and thus in the national roll out of NIFM.

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## Appendices

### A. CFRAM model growth factors

Table A.1: UoM18: CFRAM growth curves and factors for a range of AEPs, defined at gauging stations

			Flood growth factor for AEP (%)							
			50	20	10	5	2	1	0.5	0.1
18001	Mogeely	LO Single/GLO Pooled	1.00	1.22	1.35	1.46	1.61	2.05	2.30	3.03
18002	Ballyduff	EV1 Single	1.00	1.35	1.58	1.79	2.08	2.29	2.50	3.00
18107	Fermoy	EV1 Single	1.00	1.35	1.58	1.8	2.09	2.31	2.52	3.02
18003	Killavullen	EV1 Single	1.00	1.35	1.58	1.80	2.09	2.31	2.52	3.01
18055	Mallow Rail Bridge	LN3 Single Site/Mallow Drainage Scheme	1.00	1.37	1.56	1.75	2.02	2.23	2.44	3.00
18006	CSET Mallow	LN3 Single Site/Mallow Drainage Scheme	1.00	1.37	1.56	1.75	2.02	2.23	2.44	3.00
18048	Dromcummer	Mallow Drainage Scheme	1.00	1.37	1.56	1.75	2.02	2.23	2.44	3.00
18009	Riverview	EV1 Single / GLO Pooled	1.00	1.32	1.54	1.76	2.05	2.28	2.87	3.15
18010	Allen's Bridge	EV1 Single / GLO Pooled	1.00	1.28	1.47	1.66	1.92	2.08	2.34	3.08

Source: OPW (2016a)

Table A.2: CFRAM growth factors applied to the Suck Catchment of UoM 26

Annual Exceedance Probability (%)	Growth factors reach 1	Growth factors reach 2	Growth factors reach 3	Growth factors reach 4	Growth factors reach 5	Growth factors reach 6	Growth factors reach 7
50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.45	1.29	1.16	1.21	1.21	1.26	1.35
10	1.71	1.48	1.28	1.37	1.34	1.43	1.58
5	1.95	1.66	1.39	1.54	1.47	1.59	1.81
2	2.28	1.90	1.56	1.81	1.64	1.80	2.10
1	2.52	2.08	1.69	2.06	1.77	1.96	2.31
0.5	2.76	2.25	1.85	2.35	1.89	2.12	2.53
0.1	3.32	2.66	2.26	3.23	2.18	2.49	3.03

Source: OPW (2016d)

Table A.3: CFRAM growth factors applied to the Inny Catchment of UoM 26

Annual Exceedance Probability (%)	Growth factors reach 1	Growth factors reach 2, 5	Growth factors reach 3, 4
50	1.00	1.00	1.00
20	1.24	1.40	1.28
10	1.38	1.67	1.46
5	1.50	1.93	1.64
2	1.67	2.26	1.86
1	1.79	2.51	2.03
0.5	1.91	2.76	2.20
0.1	2.18	3.33	2.60

Source: OPW (2016d)

Table A.4: CFRAM growth factors applied to the Hind Catchment of UoM 26

Annual Exceedance Probability (%)	Growth factors
50	1.00
20	1.43
10	1.71
5	1.97
2	2.32
1	2.58
0.5	2.83
0.1	3.43

Source: OPW (2016d)

Table A.5: CFRAM growth factors applied to the Upper Shannon Catchment of UoM 26

AEP (%)	Growth factors reach 1	Growth factors reach 2, 3, 4	Growth factors reach 5, 6	Growth factors reach 7	Growth factors reach 8	Growth factors reach 9, 11, 12	Growth factors reach 10, 13	Growth factors reach 14	Growth factors reach 15
50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.22	1.21	1.20	1.23	1.31	1.21	1.37	1.23	1.21
10	1.37	1.36	1.33	1.38	1.51	1.35	1.61	1.39	1.35
5	1.51	1.55	1.46	1.52	1.70	1.49	1.85	1.53	1.49
2	1.70	1.72	1.62	1.71	1.96	1.66	2.15	1.72	1.66
1	1.84	1.88	1.74	1.84	2.14	1.79	2.37	1.87	1.79
0.5	1.97	2.04	1.87	1.98	2.33	1.92	2.60	2.01	1.92
0.1	2.29	2.42	2.15	2.30	2.77	2.22	3.12	2.34	2.22

Source: OPW (2016d)

## B. Land cover classes and roughness values

Table B.1: Mapping of roughness values to CORINE land cover (CLC) codes and labels

CLC code	CLC label 1	CLC label 2	CLC label 3	Roughness value
111	Artificial surfaces	Urban fabric	Continuous urban fabric	0.1
112	Artificial surfaces	Urban fabric	Discontinuous urban fabric	0.1
121	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units	0.1
122	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	0.03
123	Artificial surfaces	Industrial, commercial and transport units	Port areas	0.1
124	Artificial surfaces	Industrial, commercial and transport units	Airports	0.1
131	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	0.1
132	Artificial surfaces	Mine, dump and construction sites	Dump sites	0.1
133	Artificial surfaces	Mine, dump and construction sites	Construction sites	0.1
141	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	0.035
142	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	0.035
211	Agricultural areas	Arable land	Non-irrigated arable land	0.045
212	Agricultural areas	Arable land	Permanently irrigated land	0.045
213	Agricultural areas	Arable land	Rice fields	0.045
221	Agricultural areas	Permanent crops	Vineyards	0.06
222	Agricultural areas	Permanent crops	Fruit trees and berry plantations	0.06
223	Agricultural areas	Permanent crops	Olive groves	0.06
231	Agricultural areas	Pastures	Pastures	0.04
241	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops	0.045
242	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	0.045
243	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	0.06



CLC code	CLC label 1	CLC label 2	CLC label 3	Roughness value
244	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	0.09
311	Forest and semi natural areas	Forests	Broad-leaved forest	0.09
312	Forest and semi natural areas	Forests	Coniferous forest	0.09
313	Forest and semi natural areas	Forests	Mixed forest	0.09
321	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grasslands	0.04
322	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland	0.06
323	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Sclerophyllous vegetation	0.06
324	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub	0.06
331	Forest and semi natural areas	Open spaces with little or no vegetation	Beaches, dunes, sands	0.03
332	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks	0.03
333	Forest and semi natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas	0.03
334	Forest and semi natural areas	Open spaces with little or no vegetation	Burnt areas	0.04
335	Forest and semi natural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow	0.03
411	Wetlands	Inland wetlands	Inland marshes	0.04
412	Wetlands	Inland wetlands	Peat bogs	0.04
421	Wetlands	Maritime wetlands	Salt marshes	0.04
422	Wetlands	Maritime wetlands	Salines	0.04
423	Wetlands	Maritime wetlands	Intertidal flats	0.04
511	Water bodies	Inland waters	Water courses	0.04
512	Water bodies	Inland waters	Water bodies	0.01
521	Water bodies	Marine waters	Coastal lagoons	0.01
522	Water bodies	Marine waters	Estuaries	0.03

CLC code	CLC label 1	CLC label 2	CLC label 3	Roughness value
523	Water bodies	Marine waters	Sea and ocean	0.02
999	NODATA	NODATA	NODATA	0.06
990	Unclassified	Unclassified Land Surface	Unclassified Land Surface	0.06
995	Unclassified	Unclassified Water Bodies	Unclassified Water Bodies	0.06
990	Unclassified	Unclassified	Unclassified	0.06

## C. QA check-sheet template

Data quality measure	Pass criteria	Outcome	Tester / Date
Measure 78: data product specification fail count	All tests passed	Pass/Fail	signature and date
<b>Final Sign-off.</b>			
Role	Name	Signature	Date
Lead Modeller			
Lead GIS Analyst			
Project Manager			

<b>Completeness. Commission and omission of data.</b>			
Data quality measure	Pass criteria	Outcome	Tester / Date
Measure 2: Number of excess item	Zero excess items	Pass/Fail	signature and date
Measure 4: number of duplicate feature instances	Zero duplicate geometries	Pass/Fail	signature and date
Measure 6. number of missing items	No missing items	Pass/Fail	signature and date
<b>Logical Consistency. Conceptual consistency, domain consistency, format consistency and topological consistency of data.</b>			
Data quality measure	Pass criteria	Outcome	Tester / Date
Measure 10: Number of items not compliant with the rules of the conceptual schema	Zero non-compliances.	Pass/Fail	signature and date
Measure 11: Number of invalid overlaps	No overlapping features.	Pass/Fail	signature and date

of surfaces			
Measure 16: number of items not in conformance with their value domain	Zero non-compliances.	Pass/Fail	signature and date
Measure 20: number of physical structure conflicts	Zero non-compliances.	Pass/Fail	signature and date
Measure 22: number of faulty point-curve connections	No faulty point-curve connections.	Pass/Fail	signature and date
Measure 26: number of invalid slivers	No slivers (or gaps).	Pass/Fail	signature and date
Measure 27: number of invalid self- intersect errors	No self-intersections.	Pass/Fail	signature and date
Measure 28: number of invalid self- overlap errors	No self-overlaps.	Pass/Fail	signature and date
<b>Positional Accuracy. Positional accuracy of data.</b>			
Data quality measure	Description	Test	Pass criteria
No relevant tests			
<b>Temporal Quality. Accuracy of time measurement, temporal consistency and temporal validity of data.</b>			
Data quality measure	Description	Test	Pass criteria
No relevant tests			



<b><i>Thematic Accuracy. Classification correctness, non-quantitative attribute correctness and quantitative attribute accuracy of data</i></b>			
<b>Data quality measure</b>	<b>Pass criteria</b>	<b>Outcome</b>	<b>Tester / Date</b>
Measure 63: number of incorrectly classified features	No incorrect classifications.	Pass/Fail	signature and date
<b><i>Topology specific conformance tests</i></b>			
<b>Data quality measure</b>	<b>Pass criteria</b>	<b>Outcome</b>	<b>Tester / Date</b>
Coordinate reference systems comply	Dataset produced in the correct CRS as specified.	Pass/Fail	signature and date
Positional accuracy	Watercourse geometries should be identical to (or subsets of in the case of headwaters) those of the supplied river network. River nodes will be no more than 5m from the watercourse geometries.	Pass/Fail	signature and date
Raster cell geometries	Grid resolution and origin are compliant with specification.	Pass/Fail	signature and date
Raster cell values comply with domain	Gridded data values are compliant with the value domain for the data type.	Pass/Fail	signature and date
Disconnected extent polygons	No disconnected polygons.	Pass/Fail	signature and date
Small holes	No small holes.	Pass/Fail	signature and date
Duplicate vertices	No duplicate vertices.	Pass/Fail	signature and date
Feature intersections	No overlapping features.	Pass/Fail	signature and date
Pseudo nodes	No pseudo nodes.	Pass/Fail	signature and date
Single-part geometries	No multi-part geometries.	Pass/Fail	signature and date
Internal boundaries	No unnecessary internal boundaries.	Pass/Fail	signature and date

<b>Modelling checks. QA checks made during the model build, simulation and post-processing phases</b>			
Data quality measure	Pass criteria	Outcome	Tester / Date
Source data acquired and complete	No gaps in source data coverage.	Pass/Fail	signature and date
Index of flood flows	Flows do not decrease in a downstream directions.	Pass/Fail	signature and date
Channel calculations verified	Channel Calculation flag data checked and verified to be OK.	Pass/Fail	signature and date
Bridges data reviewed	Modeller has checked the bridge data and updated the model using best engineering judgement.	Pass/Fail	signature and date
InfoWorks Model sanity checked	Model has been checked before and after the simulation for errors and instabilities. The results look sensible.	Pass/Fail	signature and date
Preliminary flood spatial data QA checked	The data checks have all been run successfully.	Pass/Fail	signature and date



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



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## B. Technical Note on Arterial Drainage extension: data review task



# National Indicative Fluvial Mapping Project: Arterial Drainage extension

## Technical note on Data Review task findings

09<sup>th</sup> July 2020

### 1. Overview

The First Draft deliverables of the National Indicative Fluvial Mapping (NIFM) Project for Ireland highlighted that in the arterially drained (AD) benefiting lands of the North Western, Western, Shannon and Eastern River Basin Districts (RBDs), there was greater than anticipated variation in the channel capacity versus the Index Flood ( $Q_{MED}$ ). Based upon the Pilot Study Areas, AD channels had been recommended to have capacities of approximately 135%  $Q_{MED}$ . This project extension aims to improve channel capacity estimates for AD channels, in order to obtain more accurate flood extents, with testing through a short pilot study in two Units of Management (UoMs) to ascertain the benefit of the refined approach, and possible roll-out to all relevant UoMs (03, 06, 07, 08, 09, 23, 24, 25, 30, 34 and 35). This note summarises the findings of the Data Review stage (Task 1.1), to support a decision on whether to proceed to pilot stage.

### 2. Data sources reviewed

The Data Review stage has analysed the following data sources:

- Boyne drawing: File *C1,21,9 (36-66)R.jpg*; Boyne catchment drainage scheme drawing showing long-section and cross-sections;
- AD design guidance: File *Arterial Drainage Design Doc.docx*; Describes the objectives, data required, design standards, design process;
- Guidance from Engineers: Information gathered during a telecom with OPW Engineers on 28<sup>th</sup> April;
- PWC report: File *Price Waterhouse Coopers - Report on Measurement of Return on Investment, Arterial Drainage Maintenance Programme.pdf*;
- AD scheme long-section data in spreadsheets;
- CFRAM AD channel capacity data;
- LiDAR data in areas having AD channels: limited coverage; none in UoM 03, 08, 09;
- GIS layers – drainage channels and chainages;
- Scheme drawings – scanned for specific schemes, where additional information was required for the UoM 24 Mague scheme (channels C1 and C1-10).

### 3. Findings of data review

The NIFM project had assigned channel capacities of 135%  $Q_{MED}$  to AD channels. This review aimed to ascertain evidence of a consistent channel capacity ( $Q_{MED}$ ) in AD areas (notably for NIFM modelled reaches of Stream Orders 1 and 2). If a consistent channel capacity value were found, this could then be compared with the  $Q_{MED}$  values used in the NIFM project and a  $Q_{MED}$  factor derived for each UoM. The findings are summarised in Table 1.

Table 1: Summary of findings, by Unit of Management and generally

UoM	Source	$Q_{MED}$ factor
03	(no data)	-
06	AD scheme long-section data in spreadsheets	189%
07	Boyne drawing and AD scheme long-section data in spreadsheets	193%
08	(no data)	-
09	(no data)	-
23	LiDAR data cross-sections (Stream Order 1 only)	169%
24	AD scheme long-section data in spreadsheets – limited data	250%
	LiDAR data cross-sections	171%
	Scanned drawings from Maigne scheme (Stream Order 1)	176%
	Scanned drawings from Maigne scheme (Stream Order 2)	132%
25	LiDAR data cross-sections	154%
30	LiDAR data cross-sections	151%
	AD scheme long-section data in spreadsheets	100%
34	CFRAM data (Stream Order 3 channel of 300% $Q_{MED}$ , reduced)	200%
	LiDAR data cross-sections	58%
35	LiDAR data cross-sections (2 No.)	177%
General	Discussion with Engineers – protection up to 100 year flood	180%
	AD Design Guidance document – rural lands (3 year flood)	110%
	AD Design Guidance document – built up areas (20 year flood)	150%
	PWC report – 60% increase in channel size	160%

### 4. Discussion

Of the sources of data, it is possible that the LiDAR data have not captured the full capacity of the channels, since LiDAR technology cannot penetrate the water surface to capture the height of the channel bed, and so their estimated factors are likely to be on the conservative side. The AD scheme spreadsheet data are probably the most accurate in terms of the original channel design; in reality, those channels are likely to

have reduced capacity due to siltation and vegetation growth wherever regular maintenance is insufficient, and so their estimated factors are likely to be on the high side.

The OPW Engineers suggested that the channels in the Eastern catchments are likely to have greater capacity than those in the West, and this is supported by the data. This theory is also supported by the PWC report, which noted that rural lands are becoming increasingly urbanised (notably in the East) and that AD channels would need to offer greater standards of flood protection, i.e. with greater capacity.

## 5. Recommendations

Our recommendations are as follows, by UoM:

- 03: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 06: Factor = 190%;
- 07: Factor = 190%;
- 08: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 09: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 23: Factor = 170% for Stream Order 1 channels only;
- 24: Factor = 170% for Stream Order 1 channels only – SO2 channels showed no real difference from earlier approach;
- 25: Use existing approach since no real difference noted;
- 30: Use existing approach since no real difference noted;
- 34: Use existing approach since no real difference noted/insufficient data;
- 35: Use existing approach since no real difference noted/insufficient data.

We would recommend one pilot in the Eastern group of catchments (03, 06, 07, 08, 09), and one in the Shannon (23, 24).

## C. Technical Note on Arterial Drainage extension: pilot study task



# National Indicative Fluvial Mapping Project: Arterial Drainage extension

## Technical note on Pilot Study task findings: v2 *DRAFT*

18<sup>th</sup> August 2020

### 1. Overview

The First Draft deliverables of the National Indicative Fluvial Mapping (NIFM) Project for Ireland highlighted that in the arterially drained (AD) benefiting lands of the North Western, Western, Shannon and Eastern River Basin Districts (RBDs), there was greater than anticipated variation in the channel capacity versus the Index Flood ( $Q_{MED}$ ). Based upon the Pilot Study Areas, AD channels had been recommended to have capacities of approximately 135%  $Q_{MED}$ .

This project extension aimed to improve channel capacity estimates for AD channels, in order to obtain more accurate flood extents, with testing through a short pilot study in two Units of Management (UoMs) to ascertain the benefit of the refined approach, and possible roll-out to all relevant Units of Management (UoMs: 03, 06, 07, 08, 09, 23, 24, 25, 30, 34 and 35).

Technical Note #02 (MCR6058-TN002-R01-00.pdf) summarised the findings of the Data Review stage (Task 1.1), to support a decision on whether to proceed to pilot stage, which was subsequently approved.

This Technical Note (#03) summarises the findings of the Pilot Study in two UoMs, through Tasks 1.2 to 1.4. It aims to support a decision on whether to proceed to roll-out the improved method to all relevant UoMs.

### 2. Identification of Pilot UoMs

As documented in Technical Note #02 (MCR6058-TN002-R01-00.pdf), the data review task (Task 1.1), the recommended factors to apply to  $Q_{MED}$  when defining the channel capacity in the model were as follows, by UoM:

- 03: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 06: Factor = 190%;
- 07: Factor = 190%;
- 08: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 09: Factor = 190% (no data but likely to be similar to neighbouring catchments);
- 23: Factor = 170% for Stream Order 1 channels only;
- 24: Factor = 170% for Stream Order 1 channels only – SO2 channels showed no real difference from earlier approach;

- 25: Use existing approach since no real difference noted;
- 30: Use existing approach since no real difference noted;
- 34: Use existing approach since no real difference noted/insufficient data;
- 35: Use existing approach since no real difference noted/insufficient data.

We recommended one pilot in the Eastern group of catchments (03, 06, 07, 08, 09), and one in the Shannon (23, 24) to identify spatial variations in the impact of changing the channel capacity of AD channels on the resulting flood extents and water levels.

In the Eastern group of catchments, UoM 07 had the greatest length of AD channels of Stream Orders 1 and 2, and was selected as the first Pilot UoM.

In the Shannon group of catchments, UoM 24 had the greatest length of AD channels of Stream Order 1, and was selected as the second Pilot UoM.

### 3. UoM 07 Pilot results

The revised Arterially Drained channel capacity factor of  $1.9 * Q_{MED}$  was applied to Stream Order 1 and 2 rivers and the channel size recalculated and updated in the hydraulic models. The models were re-run and the flood extents compared to the original flood extents, from the main NIFM project.

For reference, the extent of Arterially Drained channels, and other channel types in UoM 07, is mapped in Figure 1; this shows that Arterially Drained channels constitute a large proportion of the channels in the catchment.



Figure 1: Map showing extent of Arterially Drained channels and other channel types in UoM 07

Source: HR Wallingford

### 3.1. Statistical comparison of flood extents

The first comparison was made using the  $F$  statistical measure of fit described in Horritt and Bates (2001) for comparing modelled flood extents with predictions or observations; where  $F$  is the number of cells that are wet in both the updated model results AND the NIFM results versus the number of cells that are wet in either the updated model results OR the NIFM results.

$$F = \frac{Num(S_{mod} \cap S_{obs})}{Num(S_{mod} \cup S_{obs})}$$

Equation 1:  $F$  measure of fit

Source: Horritt and Bates (2001)

In this case,  $S_{mod}$  is the flood extent with the revised AD channels (from the updated model results) and  $S_{obs}$  is the original flood extent (from the NIFM results).

The flood extents were compared on a 5 metre grid. In this case, the  $F$  measure of fit is very similar to the comparison of flooded areas between the models.

The  $F$  statistic comparison for UoM 07 overall shows:

- For Annual Exceedance Probability (AEP) 5%, the new AD flood extents are 71% of those in the original NIFM model;
- For AEP 1%, the new AD flood extents are 81% of those in the original NIFM model;
- For AEP 0.1%, the new AD flood extents are 88% of those in the original NIFM model.

As might be expected, there are variations in the  $F$  statistic spatially within the UoM, with some rivers having greater differences between the new flood AD flood extents and those in the original NIFM model than others. To summarise:

- Around a third of the rivers have an  $F$  statistic lower than the overall value for the UoM for AEP 5% (e.g. less than 71% for AEP 5%);
- Around a tenth of the rivers have an  $F$  statistic less than 50% for AEP 5%;
- Around half of the rivers have an  $F$  statistic between 70 and 90% for AEP 5%, indicating moderate to low change in the flood extents;
- There are three rivers for which there is no change from the original NIFM model extent results.

## 3.2. Map-based comparison with NIFM flood extents

The flood extent results were assessed visually by comparing the mapped flood extents with those of NIFM. A selection of maps is presented here, showing the full range of impacts on the results. The maps show a selection of rivers which had large changes, some which had similar changes to the overall change for the UoM, and some which had little change.

Figure 2 to Figure 4 show the comparison of flood extents on the Kinnegad River (EPA Code 07K01) for the events AEP 5%, 1% and 0.1% respectively. These show that on this river there is significant difference in the flood extent with the revised channel capacity. The  $F$  statistical measure of fit is 29% for AEP 5%, 65% for AEP 1% and 80% for AEP 0.1% which indicates there is significant change from the original flood extents.





Figure 2: Comparison of flood extents on the Kinnegad River for the AEP 5% event

Source: HR Wallingford



Figure 3: Comparison of flood extents on the Kinnegad River for the AEP 1% event

Source: HR Wallingford





Figure 4: Comparison of flood extents on the Kinnegad River for the AEP 0.1% event

Source: HR Wallingford

On the Milltown River (EPA Code 07M04) the  $F$  statistical measure of fit is 70% which indicates there is a reduction of around 30% from the original NIFM flood outlines in the AEP 5% event. This is similar to the overall change measured for the UoM. Figure 5 to Figure 7 show the comparison of flood extents on the Milltown River for the events AEP 5%, 1% and 0.1% respectively.



Figure 5: Comparison of flood extents on the Milltown River for the AEP 5% event

Source: HR Wallingford





Figure 6: Comparison of flood extents on the Milltown River for the AEP 1% event

Source: HR Wallingford



Figure 7: Comparison of flood extents on the Milltown River for the AEP 0.1% event

Source: HR Wallingford

On the Craddanstown River (EPA Code 07C55) the  $F$  statistical measure of fit is 95% which indicates there is a reduction of around 5% from the original NIFM flood outlines in the AEP 5% event. This is an example of a river in the UoM for which the change to channel capacity has not resulted in significant change in the flood extent. Figure 8 to Figure 10 show the comparison of flood extents on the Craddanstown River for the events AEP 5%, 1% and 0.1% respectively.





Figure 8: Comparison of flood extents on the Craddanstown River for the AEP 5% event

Source: HR Wallingford

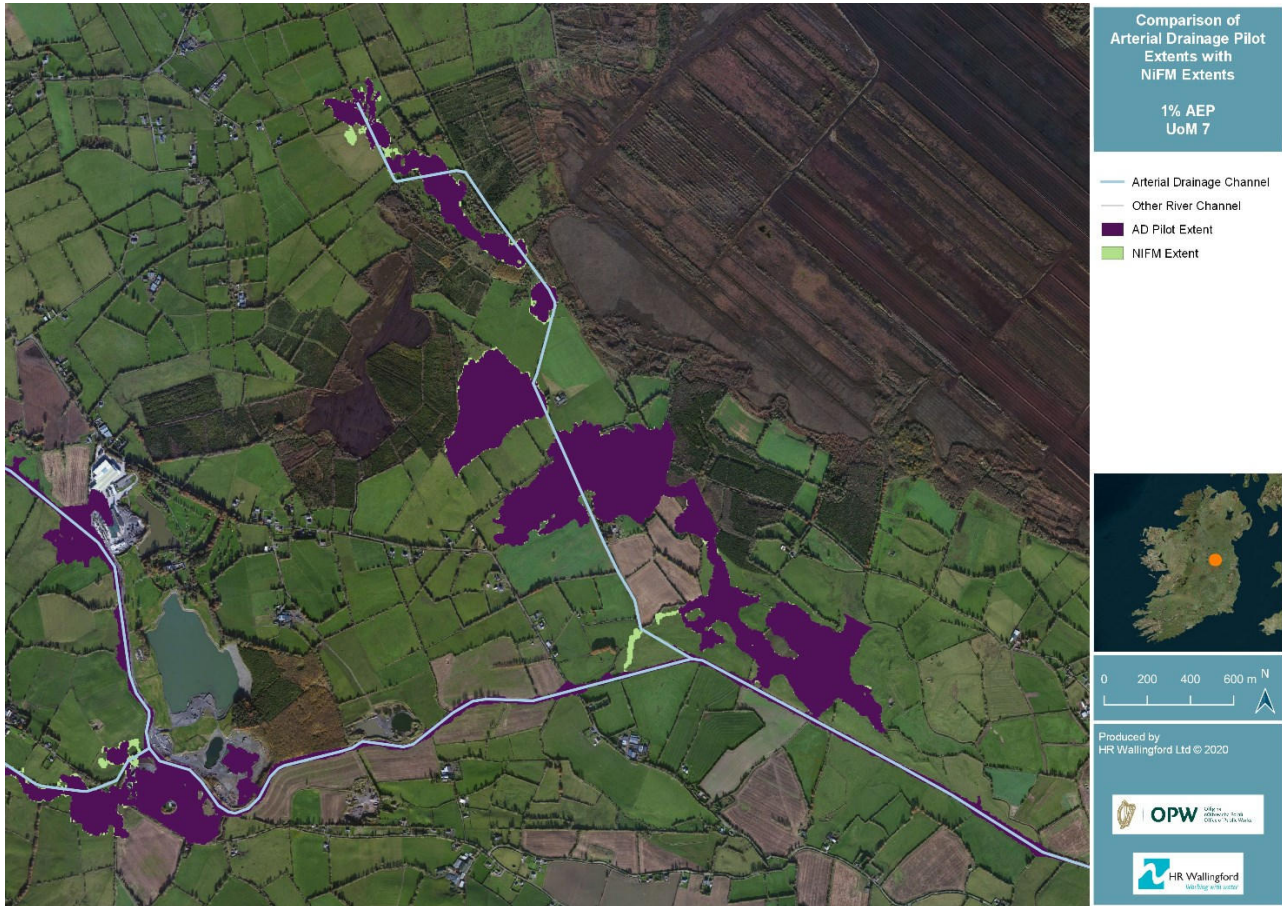


Figure 9: Comparison of flood extents on the Craddanstown River for the AEP 1% event

Source: HR Wallingford





Figure 10: Comparison of flood extents on the Craddanstown River for the AEP 0.1% event

Source: HR Wallingford

### 3.3. Comparison of water levels

The average change in maximum water levels in UoM 07 was calculated for each river where the revised channel capacity was applied. For UoM 07, the results show:

- AEP 5%: a decrease of 139 mm in maximum water level;
- AEP 1%: a decrease of 113 mm in maximum water level;
- AEP 0.1%: a decrease of 84 mm in maximum water level.

The average change in water level is relatively small, however there is significant variation both in the average change for each river and the change in water level along the river. The general change in water level shows that the increased channel capacity due to the revised AD method has reduced flood levels. To show the variation in the change in water level and to relate the magnitude of the changes in level to the change in flood extents, these are given for the three rivers shown as examples in Section 3.2.

The average change in water level on the Kinnegad River, as an example of a river with large changes in flood extent due to the revised arterial drainage capacity, are:

- AEP 5%: a decrease of 209 mm in maximum water level;
- AEP 1%: a decrease of 115 mm in maximum water level;
- AEP 0.1%: a decrease of 173 mm in maximum water level.

Average reduction in water level of around 200 mm has led to significant changes in the flood extent on this river. This is likely due to large extents of shallow flood depths in the original model that are no longer inundated.

The average change in water level on the Milltown River, as an example of a river with changes in flood extent similar to the UoM average due to the revised arterial drainage capacity, are:

- AEP 5%: a decrease of 79 mm in maximum water level;
- AEP 1%: a decrease of 66 mm in maximum water level;
- AEP 0.1%: a decrease of 55 mm in maximum water level.

Relatively low reductions in the average water level on the river are associated with localised changes in flood extents, where areas of shallow flood depths are no longer inundated, particularly at the upstream end of the river in the AEP 1% flood.

The average change in water level on the Craddanstown River as an example of a river with minor changes in flood extent due to the revised arterial drainage capacity, are:

- AEP 5%: a decrease of 35 mm in maximum water level;
- AEP 1%: a decrease of 31 mm in maximum water level;
- AEP 0.1%: a decrease of 34 mm in maximum water level.

Small reductions in the average water level on the river are associated with localised changes in flood extents, where areas of shallow flood depths are no longer inundated, only at the upstream end of the river in the AEP 5% flood.

### 3.4. Comparison of overlapping CFRAM extents

In UoM 07 there are some small areas where there is overlap of the new AD model results with CFRAM modelled extents. This has enabled a comparison of the model extents from the CFRAM models, the original NIFM models and the new AD flood extents, at three locations.

The AEP 1% results are mapped in Figure 11 for Clonkeen 07, Figure 12 for Coolree 07, and in Figure 13 for Ballivor.



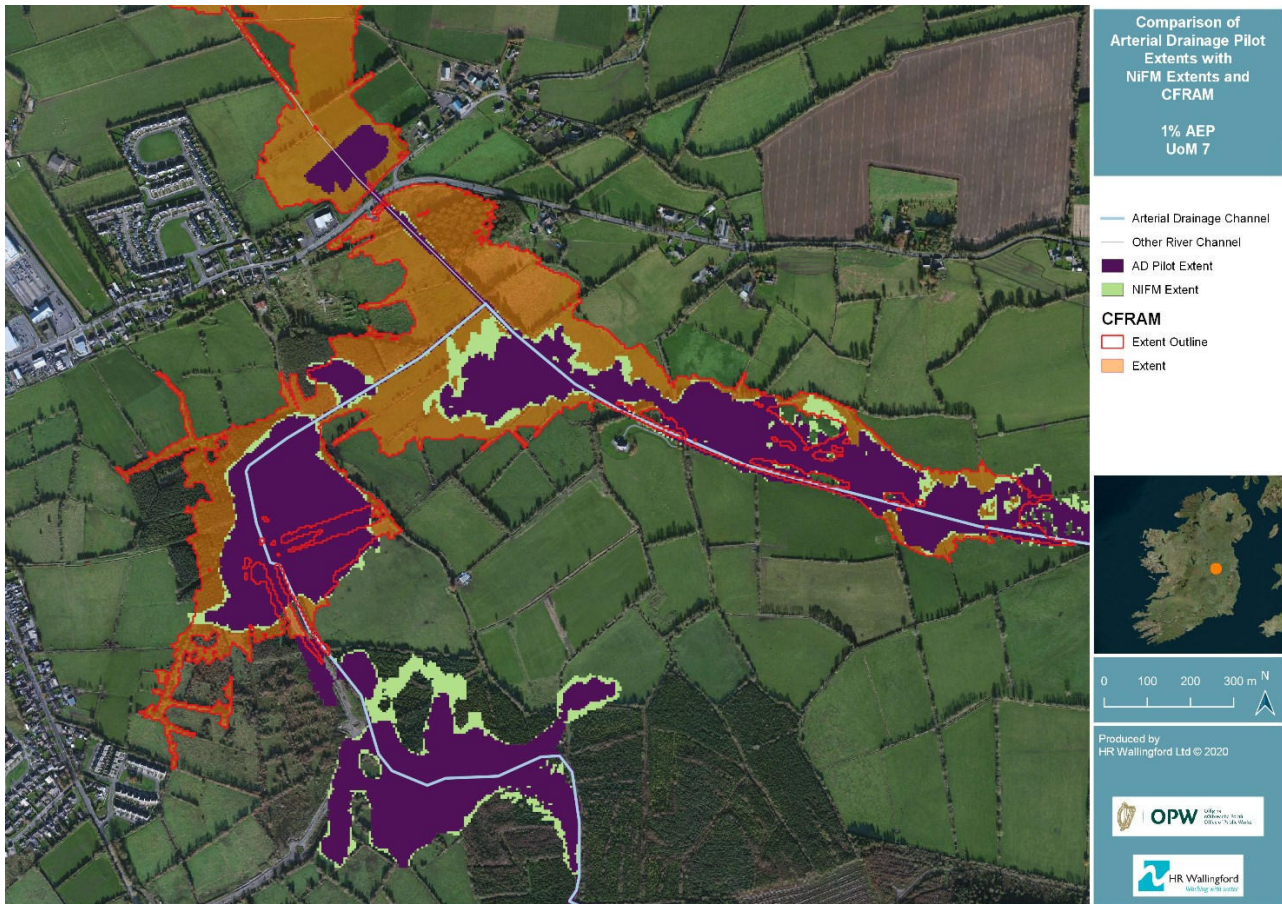


Figure 11: Comparison of flood extents on the Clonkeen 07 River for the AEP 1% event

Source: HR Wallingford



Figure 12: Comparison of flood extents on the Coolree 07 River for the AEP 1% event

Source: HR Wallingford





Figure 13: Comparison of flood extents on the Ballivor River for the AEP 1% event

Source: HR Wallingford

These results show that in general the flood extents from the new AD models have reduced in comparison with the NIFM model results. The flood extents from the new AD models have also reduced in comparison with the CFRAM model extents on average (and as shown by the  $F$  statistic below), as the CFRAM extents were generally larger than the original NIFM results. The match varies locally along the overlapping reach with some areas showing a better match to the CFRAM extents.

The  $F$  statistic comparison for these overlapping reaches of UoM 07, for AEP 1% shows:

For the Clonkeen 07 river:

- The  $F$  value comparing the NIFM model with CFRAM is 60%;
- The  $F$  value comparing new AD model with CFRAM is 53%.

For the Coolree 07 river:

- The  $F$  value comparing the NIFM model with CFRAM is 47%;
- The  $F$  value comparing new AD model with CFRAM is 46%.

For the Ballivor river:

- The  $F$  value comparing the NIFM model with CFRAM is 28%;

- The  $F$  value comparing new AD model with CFRAM is 34%.

### 3.5. Overall summary for UoM 07 results

In UoM 07, a significant reduction in the flood extents on a few rivers that had large flood extents in the original NIFM models appears to drive the low overall  $F$  values for the UoM. A large proportion of the rivers show moderate reductions in flood extents. There can be an improvement in flood extents with less ponding at the upstream ends of the rivers, even with  $F$  values close to 100% and small average changes in water level, as shown by the example of the Craddanstown River in Figure 8. In the few areas where there is an overlap with CFRAM extents, in general the flood extents from the new AD models have reduced in comparison with the NIFM model results.

## 4. UoM 24 Pilot results

The revised AD channel capacity factor of  $1.7 * Q_{MED}$  was applied to Stream Order 1 rivers, and the channel size recalculated and updated in the hydraulic models. The models were re-run and the flood extents compared to the original flood extents, from the main NIFM project.

For reference, the extent of AD channels, and other channel types in UoM 24, is mapped in Figure 14; this shows that AD channels constitute a large proportion of the channels in the catchment.



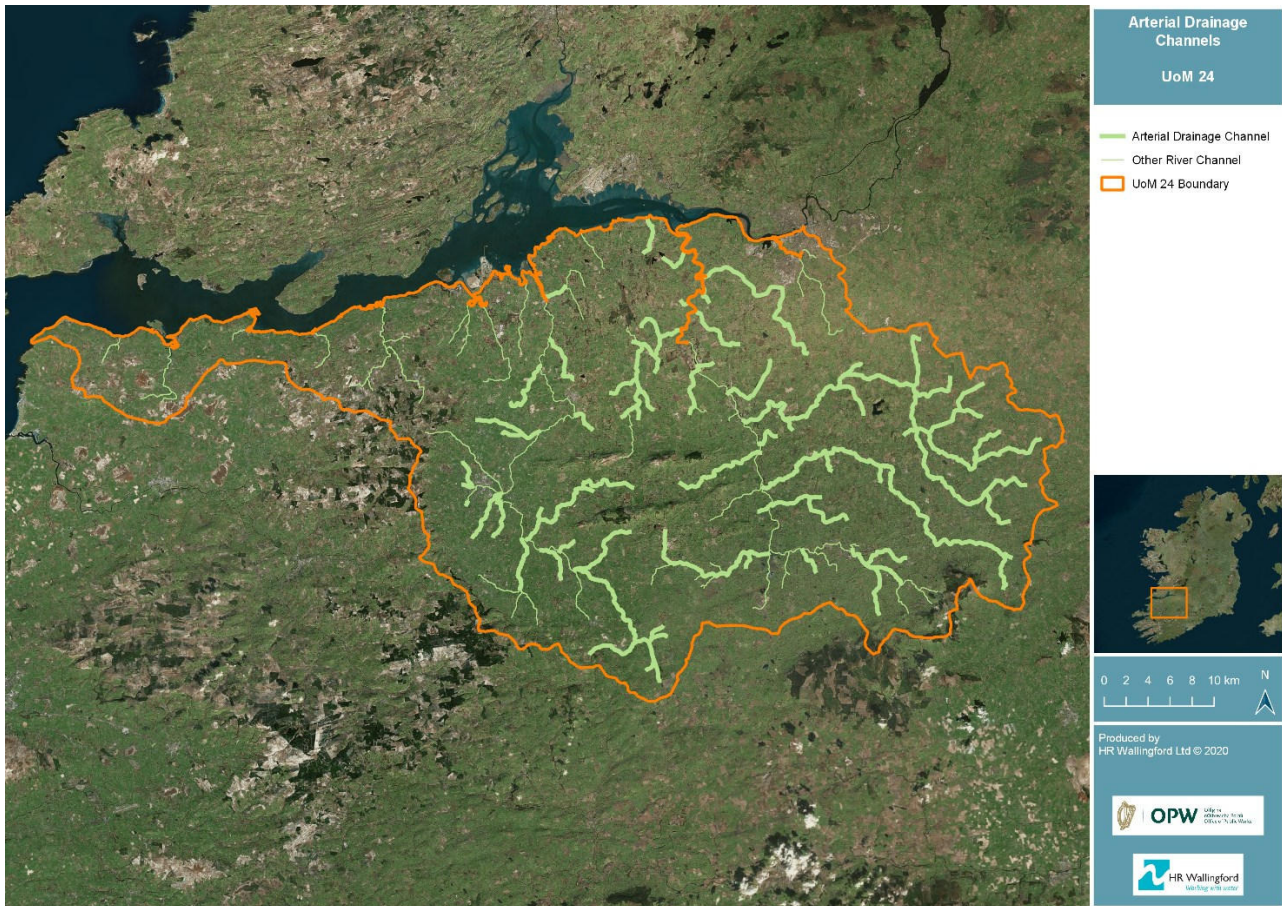


Figure 14: Map showing extent of Arterially Drained channels and other channel types in UoM 24

Source: HR Wallingford

## 4.1. Statistical comparison of flood extents

The  $F$  statistic comparison for UoM 24 overall shows:

- For AEP 5%, the new Arterially Drained flood extents are 83% of those in the original NIFM model;
- For AEP 1%, the new Arterially Drained flood extents are 87% of those in the original NIFM model;
- For AEP 0.1%, the new Arterially Drained flood extents are 91% of those in the original NIFM model.

Again, there is spatial variation in the results for the catchment; to summarise:

- Two rivers (out of a total of 56 which are AD and stream order 1) have significantly greater than average reduction in flood extents, with an  $F$  statistic of 50% or less;
- Around 40% of the rivers (twenty three) have  $F$  statistic values of less than average (83%) in the AEP 5% event;
- There are also seven rivers which have no real change in the flood extents in the AEP 5% event. These tend to be short lengths of rivers that join a larger river where the flood extent is influenced by flooding on the main river.



## 4.2. Map-based comparison with NIFM flood extents

The flood extent results were assessed visually by comparing the mapped flood extents with those of NIFM. A selection of maps is presented here, showing the full range of impacts on the results. The maps show a selection of rivers which had large changes, some which had similar changes to the overall change for the UoM, and some which had little change.

Figure 15 to Figure 17 show the comparison of flood extents on the Drumcomoge River (EPA Code 24D04) for the events AEP 5%, 1% and 0.1% respectively. These show that on this river there is significant difference in the flood extent with the revised channel capacity. The  $F$  statistical measure of fit is 37% for AEP 5% and 1%, and 53% for AEP 0.1% which indicates there is significant change from the original flood outlines even in very infrequent floods.



Figure 15: Comparison of flood extents on the Drumcomoge River (northern-most shown) for the AEP 5% event

Source: HR Wallingford





Figure 16: Comparison of flood extents on the Drumcomoge River (northern-most shown) for the AEP 1% event

Source: HR Wallingford





Figure 17: Comparison of flood extents on the Drumcomoge River (northern-most shown) for the AEP 0.1% event

Source: HR Wallingford

On the Ehernaugh Stream (EPA Code 24E01) the  $F$  statistical measure of fit is 82% which indicates there is a reduction of around 18% from the original NIFM flood extents in the AEP 5% event. This is similar to the overall change measured for the UoM. Figure 18 to Figure 20 show the comparison of flood extents on the Ehernaugh Stream for the events AEP 5%, 1% and 0.1% respectively. These show the greatest change in the flood extents occurs at the upstream end of the river in all three AEP events.



Figure 18: Comparison of flood extents on the Ehernaugh Stream (eastern-most long channel shown) for the AEP 5% event

Source: HR Wallingford





Figure 19: Comparison of flood extents on the Ehernaugh Stream (eastern-most long channel shown) for the AEP 1% event

Source: HR Wallingford



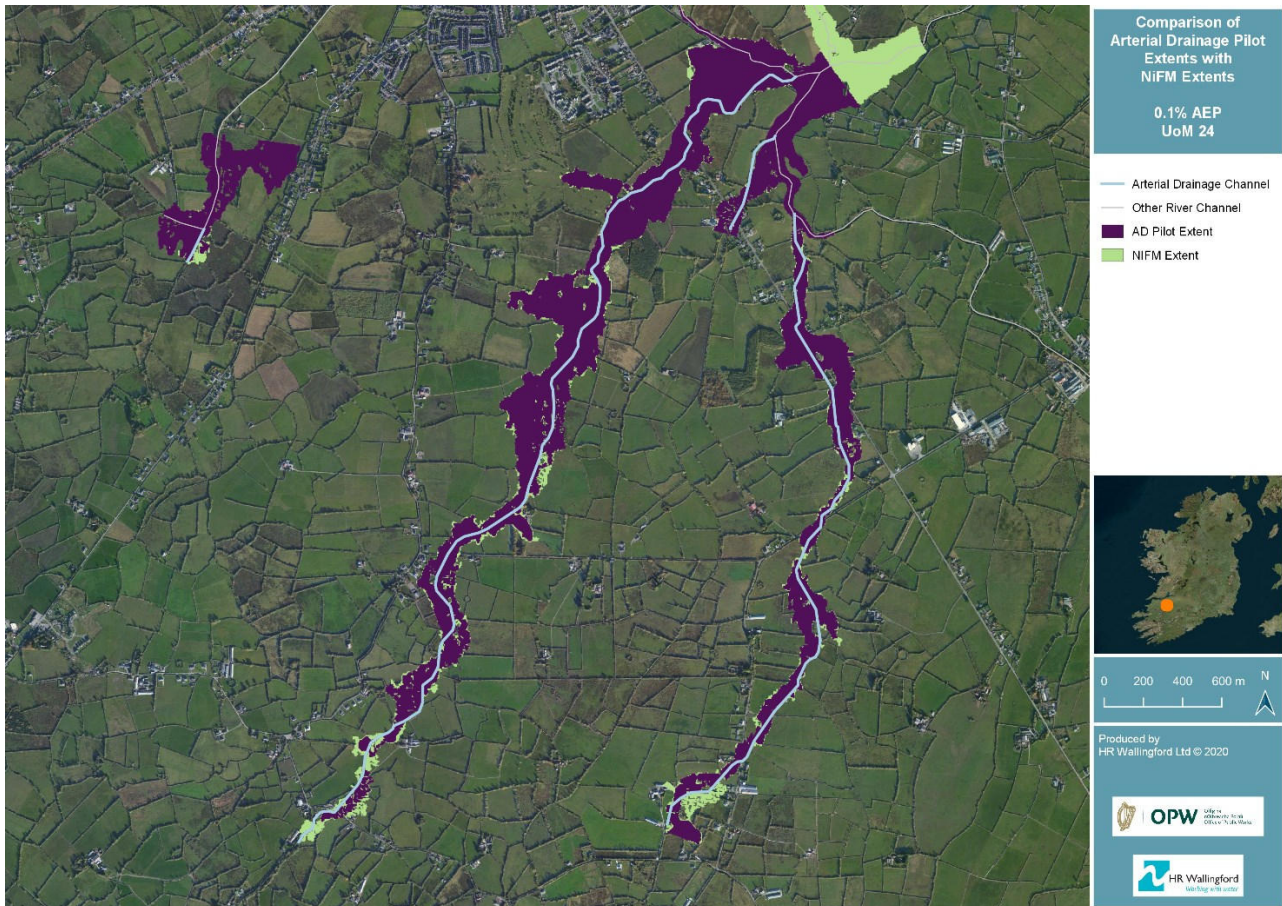


Figure 20: Comparison of flood extents on the Ehernaugh Stream (eastern-most long channel shown) for the AEP 0.1% event

Source: HR Wallingford

On the Morning Star River (EPA Code 24M02) the  $F$  statistical measure of fit is 95% which indicates there is a reduction of around 5% from the original NIFM flood outlines in the AEP 5% event. This is an example of a river in the UoM for which the change to channel capacity has not resulted in significant change in the flood extent. Figure 21 to Figure 23 show the comparison of flood extents on the Morning Star River for the events AEP 5%, 1% and 0.1% respectively. These show minor changes in the flood extents, which is reflective of the high  $F$  value.



Figure 21: Comparison of flood extents on the Morning Star River for the AEP 5% event

Source: HR Wallingford





Figure 22: Comparison of flood extents on the Morning Star River for the AEP 1% event

Source: HR Wallingford





Figure 23: Comparison of flood extents on the Morning Star River for the AEP 0.1% event

Source: HR Wallingford

### 4.3. Comparison of water levels

The average change in maximum water levels in UoM 24 was calculated for each river where the revised channel capacity was applied. For UoM 24, the results show:

- AEP 5%: a decrease of 68 mm in maximum water level;
- AEP 1%: a decrease of 63 mm in maximum water level;
- AEP 0.1%: a decrease of 56 mm in maximum water level.

The average change in water level is small, however there is significant variation both in the average change for each river and the change in water level along the river. The general change in water level shows that the increased channel capacity due to the revised AD method has reduced flood levels. To show the variation in the change in water level and to relate the magnitude of the changes in level to the change in flood extents, these are given for the three rivers shown as examples in Section 4.2.

The average change in water level on the Drumcomoge River, as an example of a river with large changes in flood extent due to the revised arterial drainage capacity, are:



- AEP 5%: a decrease of 84 mm in maximum water level;
- AEP 1%: a decrease of 90 mm in maximum water level;
- AEP 0.1%: a decrease of 86 mm in maximum water level.

Average reduction in water level of just under 100 mm has led to significant changes in the flood extent on this river. This is likely due to large extents of shallow flood depths in the original model that are no longer inundated.

The average change in water level on the Ehernaugh Stream, as an example of a river with changes in flood extent similar to the UoM average due to the revised arterial drainage capacity, are:

- AEP 5%: a decrease of 86 mm in maximum water level;
- AEP 1%: a decrease of 87 mm in maximum water level;
- AEP 0.1%: a decrease of 88 mm in maximum water level.

Reductions in the average water level of just under 100 mm on this river are associated with localised changes in flood extents, where areas of shallow flood depths are no longer inundated, particularly at the upstream end of the river in the all flood events.

The average change in water level on the Morning Star River, as an example of a river with minor changes in flood extent due to the revised arterial drainage capacity, are:

- AEP 5%: a decrease of 62 mm in maximum water level;
- AEP 1%: a decrease of 53 mm in maximum water level;
- AEP 0.1%: a decrease of 42 mm in maximum water level.

Reductions in the average water level of around 50 mm on this river are associated with little change in flood extents on this river.

## 4.4. Comparison of overlapping CFRAM extents

In UoM 24 there are very few areas where there is overlap of the new AD model results with CFRAM modelled extents. This has enabled a comparison of the model extents from the CFRAM models, the original NIFM models and the new AD flood extents at one location.

The AEP 1% results for Arra (southern river) and Doally (northern river) are mapped in Figure 24.



Figure 24: Comparison of flood extents on the Arra and Doally Rivers for the AEP 1% event

Source: HR Wallingford

These results show that in general the flood extents from the new AD models have reduced in comparison with the NIFM model results. The flood extents from the new AD models have also reduced in comparison with the CFRAM model extents on average (and as shown by the  $F$  statistic below), as the CFRAM extents were generally larger than the original NIFM results. The match varies locally along the overlapping reach with some areas showing a better match to the CFRAM extents.

The  $F$  statistic comparison for this overlapping reach of UoM 24, for AEP 1% shows:

For the Arra river:

- The  $F$  value comparing the NIFM model with CFRAM is 58%;
- The  $F$  value comparing new AD model with CFRAM is 55%.

For the Doally river:

- The  $F$  value comparing the NIFM model with CFRAM is 57%;
- The  $F$  value comparing new AD model with CFRAM is 53%.

## 4.5. Overall summary for UoM 24 results

In UoM 24, there is less variation in the flood extents based on the  $F$  statistic compared to in UoM 7. A large proportion of the rivers show moderate reductions in flood extents, with a few rivers having significant changes in flood extent and some with very little change. There can be an improvement in the flood extents, with less ponding at the upstream ends of the rivers, even with  $F$  statistic values close to 100%, as found on UoM 07. It is hard to draw conclusions from comparison with the CFRAM extents due to the lack of suitable locations, although there is a reduction in flood extents and a slightly better match with CFRAM extents.

## 5. Overall findings of pilot study

From the various sets of results for the two pilot UoMs, the new AD model has generally reduced the flood extents compared with the results of the NIFM model. In terms of assessing an improvement in accuracy, the best approach is to compare extents with those of the CFRAM models. There are only a few locations where there is an overlap with CFRAM extents, so it is difficult to draw precise conclusions. The results show that the new AD model outputs are generally smaller than the CFRAM model extents. The match varies locally along the overlapping reach with some areas showing a better match to the CFRAM extents.

A key issue with the NIFM model results was the appearance of extensive, unrealistic ponding in the upper catchments, in the Stream Order 1 channels primarily, and this has been clearly improved with the new AD model approach.

Although it is difficult to draw conclusions regarding the precise accuracy of the results of this new AD model, it is important to recognise that the new model benefits from tailored, evidence-based channel capacity calculations in these areas, which is an improvement over the more generalised method used in the original NIFM model. This logically gives greater confidence in the results of the new approach.

## 6. Recommendations

On the basis of the results of the Pilot UoMs, we recommend that:

- The revised AD channel capacity used in UoM 07 (stream order 1 and 2) is rolled out to the remaining east coast catchments (03, 06, 08, 09).
- The revised AD channel capacity used in UoM 24 (stream order 1) is rolled out to the remaining Shannon catchment (23) for stream order 1 channels.



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