Shannon Catchment-based Flood Risk Assessment and Management (CFRAM) Study

Hydraulics Report
Unit of Management 24

Final Report

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Appendix F National Technical Co-ordination Group (NTCG) Guidance Note no. 22 (GN22)

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Glossary

AEP	Annual Exceedance Probability	The probability that a certain flow value will be exceeded in any one year. For example the flow associated with the 1% AEP event at a particularly location has a 1 in 100 chance of being exceeded in any year. A 5% AEP event has a 1 in 20 chance of being exceeded in any year.
AFA	Area for Further Assessment	An area that is considered to be at potentially significant risk of flooding, thereby justifying its inclusion for further assessment. Note that the term AFA is a replacement term for what was previously referred to as an APSR (Area of Potential Significant Risk). AFAs include cities, towns, villages, and individual risk receptors (IRR)
CFRAM Study	Catchment-based Flood Risk Assessment and Management Study	The five year study covering the whole River Shannon catchment area which gives a picture of past flooding and areas at risk of future flooding, and sets out a prioritised set of specific measures for reducing and managing flood risk.
HEP	Hydrological Estimation Point	A location along a watercourse (MPW and HPW) at which flood flows are estimated for a range of flood events of different frequencies.
HEFS	High-End Future Scenario	Potential future scenario representing climate change impacts not significantly outside the range of accepted predictions available, and with the allowances for increased flow, sea level rise etc. at the upper bounds of widely accepted projections
HPW	High Priority Watercourse	Watercourses that could give rise to existing or potential future fluvial or estuarine flooding within an AFA
IRR	Individual Risk Receptor	A receptor that warrants consideration of flood risk in its own right (rather than within an AFA), typically major infrastructure. Note that an IRR is a specific type of AFA
Manning's 'n'	Manning's 'n'	An empirical value used widely in hydraulic modelling to describe the hydraulic roughness of an area along (or over) which water flows. Higher values indicate a "rougher" surface.

MPW	Medium Priority Watercourse	Watercourses that could give rise to existing or potential future fluvial or estuarine flooding outside of AFAs. River reaches between AFAs, or between an AFA and the sea are also defined as MPWs.
MRFS	Mid-Range Future Scenario	Represent a 'likely' future scenario based on the wide range of predictions available and with the allowances for increased flow, sea level rise, etc. within the bounds of widely accepted projections
OSi	Ordnance Survey Ireland	The base mapping (ortho aerial imagery, vector data and raster data) used throughout the study and this report is owned by Ordnance Survey Ireland and is reproduced under a licence agreement.
RBD	River Basin District	The natural geographical and hydrological units for water management, as defined during the implementation of the Water Framework Directive.
UoM	Unit of Management	The division of the study area into major catchments and their associated coastal areas.
1D domain	1D domain	The part of a hydraulic model which is defined by flow in 1 dimension. This is used for flow that is within the banks of a watercourse as the flow is essentially in one direction.
2D domain	2D domain	The part of a hydraulic model which is defined by flow in 2 dimensions. This is used for flow that is out of bank, spreading across a floodplain or other area. The flow is characterised by flood water spreading in two dimensions (in plan view) once it overtops the banks of a watercourse. Tidal flooding is also typically in 2 dimensions.

1 Introduction

1.1 Shannon CFRAM Study Area

The Shannon (the "Study Area") is the largest River Basin District (RBD) in Ireland, covering approximately 17,800km^2 and more than 20% of the island of Ireland. The RBD includes the entire catchment of the River Shannon and its estuary as well as some catchments in North Kerry and West Clare that discharge directly to the Atlantic.

The Shannon River rises in the Cuilcagh Mountains, at a location known as the Shannon Pot in the counties of Cavan and Fermanagh. The river flows in a southerly direction before turning west and discharging through the Shannon Estuary to the Atlantic Ocean between counties Clare and Limerick. Whilst the River Shannon is 260km long from its source to the head of the Shannon Estuary in Limerick City, over its course the river falls less than 200m in elevation. The Shannon RBD is characterised as an 'International RBD' as it extends into Northern Ireland. However, there are no areas identified as being at significant flood risk in the Shannon RBD within Northern Ireland, and no significant cross-border issues.

Significant tributaries of the Shannon include the Inny, Suck and Brosna. There are several lakes in the RBD, including Lough Ree, Lough Derg and Lough Allen.

Other important rivers within the RBD include the Maigue, Deel and Feale discharging into the Shannon Estuary from the south, and the Fergus, Owenogarney (or Ratty) and Cloon discharging into the estuary from the north.

The RBD includes parts of 17 counties: Limerick, Clare, Tipperary, Offaly, Westmeath, Longford, Roscommon, Kerry, Galway, Leitrim, Cavan, Sligo, Mayo, Cork, Laois, Meath and Fermanagh. While much of the settlement in the RBD is rural there are six significant urban centres within the RBD - Limerick City, Ennis, Tralee, Mullingar, Athlone and Tullamore.

As defined under the Water Framework Directive (WFD) a RBD is divided further into Units of Management (UoM). The UoM constitute major catchments or river basins (typically greater than 1000km^2) and their associated coastal areas, or conglomerations of smaller river basins and their associated coastal areas. The Shannon RBD (and by definition the Shannon CFRAM Study Area) and the UoMs within the Shannon RBD are shown in Figure 1.1 on page 7. There are five UoMs within the Study Area, as marked on Figure 1.1:

- Tralee Bay – Feale (Hydrometric Area 23 – 'HA23') – UoM 23
- Shannon Estuary South - (Hydrometric Area 24 – 'HA24') – UoM 24
- Shannon Upper and Lower (Hydrometric Area 25 & 26 – 'HA25 & 26') – UoM 25/26
- Shannon Estuary North and Mal Bay (Hydrometric Area 27& 28 – 'HA27 & 28') – UoM 27/28

1.2 Hydraulics Report Scope

The specification for the Hydraulics Report is set out in Section 7 of the Catchment – based Flood Risk Assessment and Management (CFRAM) Studies Stage 1 Project Brief (June 2010) and elements of Sections 2.21 to 2.23 of the Shannon CFRAM

Study Stage II Project Brief (October 2010). Relevant extracts are included in Appendix A. It should be noted that programme dates noted in Appendix A are superseded.

The scope requires a single Hydraulics Report for each UoM. Each Hydraulics Report is required to cover both fluvial hydraulic models and coastal flooding models where applicable.

There are no hydraulic models or coastal flooding models required for UoM 28 under the scope of works for the Study Area, so therefore no associated Hydraulics Report for this UoM is required. There are therefore four Hydraulics Reports for the Shannon CFRAM Study Area, one for each UoM in which at least one fluvial hydraulic model or coastal flooding model exists.

1.2.1 Fluvial & Coastal Hydraulic Models

The Shannon CFRAM Study Area is comprised of 38 fluvial and / or coastal hydraulic models, split between the UoMs. The model numbers and AFA/IRR names are a unique identifier enabling easy identification of the relevant model covering a particular AFA of interest. The prefix “N” refers to the “North” part of the Shannon RBD which is all models covering UoM 25/26, while the prefix “S” refers to the “South” part of the Shannon RBD covering UoM 23, 24, and 27. The North and South identifiers do not represent any formal administrative or regional boundaries; they are used for convenience within this study due to the study’s large geographic area.

There are two IRRs within the Shannon RBD (Tarbert Power Station and Shannon Airport) which are at risk of flooding from tidal and wave conditions only and therefore are being appraised as standalone coastal flooding models. Table 1.1 summarises the 62 AFAs and 4 IRRs being represented across the 38 hydraulic models.

Table 1.1 List of Hydraulic Fluvial & Coastal Models by UoM

UoM	Model Ref	AFA/IRR names	Fluvial (F) or Coastal (C) models
UoM 23	S14-a	Abbeyfeale, Listowel	F
	S14-b	Moneycashen	F / C
	S14-c	Athea	F
	S15	Abbeydorney	F
	S16	Tralee	F / C
	S17	Banna	F / C
UoM 24	S05	Ballylongford	F / C
	S06	Adare, Clarina	F / C
	S07	Croom	F
	S08	Kilmallock, Charleville	F
	S09	Foynes	F / C

UoM	Model Ref	AFA/IRR names	Fluvial (F) or Coastal (C) models
	S10	Rathkeale, Askeaton	F / C
	S11	Newcastle West	F
	S12	Dromcolliher, Milford	F
	IRR4	Tarbert Power Station (IRR4)	C
UoM 25/26	N01	Boyle, Drumshanbo, Leitrim, Carrick-on-Shannon	F
	N02	Mohill, Dromod, Longford, Cloondara	F
	N03	Edgworthstown, Abbeyshrule, Ballymahon	F
	N04	Roscommon	F
	N05	Mullingar	F
	N06	Kilbeggan, Clara, Pollagh	F
	N07	Clonaslee, Rahan	F
	N08	Castlerea, Athleague	F
	N09	Ahascragh, Ballinasloe	F
	N10	Lanesborough Power Station (IRR1), Athlone, Shannonbridge Power Station (IRR2), Shannon Harbour	F
	N11	Roscrea, Birr	F
	N12	Portumna, Killaloe / Ballina, O'Brien's Bridge, Casteconnell, Springfield	F
	N13	Borrisokane	F
	N14	Nenagh	F
	N15	Cappamore, Newport	F
	N16	Limerick City and Environs	F / C
UoM 27	S01	Ennis	F / C
	S02	Quin	F
	S03	Bunratty, Sixmilebridge	F / C
	S04	Shannon,	F / C
	IRR3	Shannon Airport (IRR3)	C.
	S18	Kilrush	F / C
	S19	Kilkee	F / C

1.3 Context for Hydraulics Report under the EU Floods Directive

The four Shannon CFRAM Study Hydraulics Reports, representing each of the UoMs, have all been produced to support the OPW in its legislative role to report flood hazard and develop a management plan for all significant flood risk areas across Ireland. This is required under the EU "Directive on the assessment and

management of flood risks" (2007/60/EC), commonly referred to as the "Floods Directive".

1.4 Structure of this Report

1.4.1 Main Report

This Hydraulics Report covers all hydraulic modelling and mapping aspects relating to this UoM 24. The "Main Report" i.e. this document excluding appendices, is structured to reflect the specific reporting requirements of the CFRAM Studies Project Brief as follows:

Section 1 Provides an introduction to the Hydraulics Report and sets the context and scope of this activity within the Shannon RBD.

Section 2 Provides a description of the Hydrometric and Hydrological Information used in the Fluvial Hydraulic Modelling and Coastal Flooding Modelling.

Section 3 Describes, in general terms, the approach to Fluvial Hydraulic Model construction and calibration.

Section 4 Describes, in general terms, the approach to Coastal Flooding Model construction and calibration

Section 5 Presents the approach to flood hazard and flood risk mapping.

With specific reference to the detailed requirements of the Hydraulics Report, as set out in the CFRAM Studies Project Brief, Table 1.2 shows how these requirements are met within the structure of this report.

Table 1.2 Project Brief Requirements and Links to this Report

Brief Requirement	Hydraulics Report Section and Description
Surveys	*Section 3.3 - Survey Data and Base Mapping* This section describes the flood defences, the channels, the structures and the floodplain survey data that was collected for the development of the hydraulic models.
Development of Fluvial Hydraulic Models	*Section 3 – Hydraulic Model – Summary of Methodology* This section details the methodology followed in the development of the fluvial hydraulic models.
Model Calibration	*Section 3.5 - Hydraulic Model Calibration and Sensitivity Model Runs* This section details the process involved in the calibration of the hydraulic models. The purpose of the calibration process is to test the confidence of the results and to ultimately identify flood outlines, flood depths, and flood hazards.

Development of Coastal Flooding Models	*Section 4 - Coastal Flooding Model Construction* This section addresses the coastal flooding model construction process in general terms.
Development of Flood Hazard Mapping	*Section 5 – Flood Hazard Mapping* This section describes the methodology behind development of the flood hazard maps.

1.4.2 Report Appendices

A series of appendices to this Hydraulics Report are relevant to summarising our adopted modelling approach. These are:

Appendix A Relevant extracts from CFRAM Studies Project Stages I and II defining the scope of the Hydraulics Report.

Appendices B Fluvial Hydraulic Model Appendices. Each hydraulic model with a fluvial only component has an individual Appendix section numbered B1, B2, B3, B4 etc, covering specified elements of the models for UoM 24.

Appendices C Fluvial/Coastal Hydraulic Model Appendices. Each hydraulic model with coastal only or coastal and fluvial components has an individual Appendix section numbered C1, C2, C3, C4 etc, covering specified elements of the models for UoM 24.

Appendix D Shannon CFRAMS Design Tidal Hydrographs

Appendix E National Technical Co-ordination Group (NTCG) Guidance Note no. 23 (GN23)

Appendices B and C provide specific information for each respective model. This enables different stakeholders to easily identify the models that may be of interest to them, allowing them to view the **relevant model Appendix section**. Table 1.3 summarises the Appendix section reference for each model and the relevant AFA for UoM 24.

Table 1.3 Fluvial Hydraulic Model and Fluvial/Coastal Model Appendices for UoM 24

Appendix Section	Hydraulic Model Reference	AFA	County
Appendix B1	S07	Croom	Limerick
Appendix B2	S08	Killmallock	Limerick
		Charleville	Cork
Appendix B4	S11	Newcastle West	Limerick
Appendix B3	S12	Milford	Cork
		Dromcolliher	Limerick
Appendix C1	S05	Ballylongford	Kerry
Appendix C2	S06	Adare	Limerick
		Clarina	Limerick
Appendix C3	S09	Foynes	Limerick
Appendix C4	S10	Rathkeale	Limerick
		Askeaton	Limerick
Appendix C5	IRR4	Tarbert Power Station	Kerry

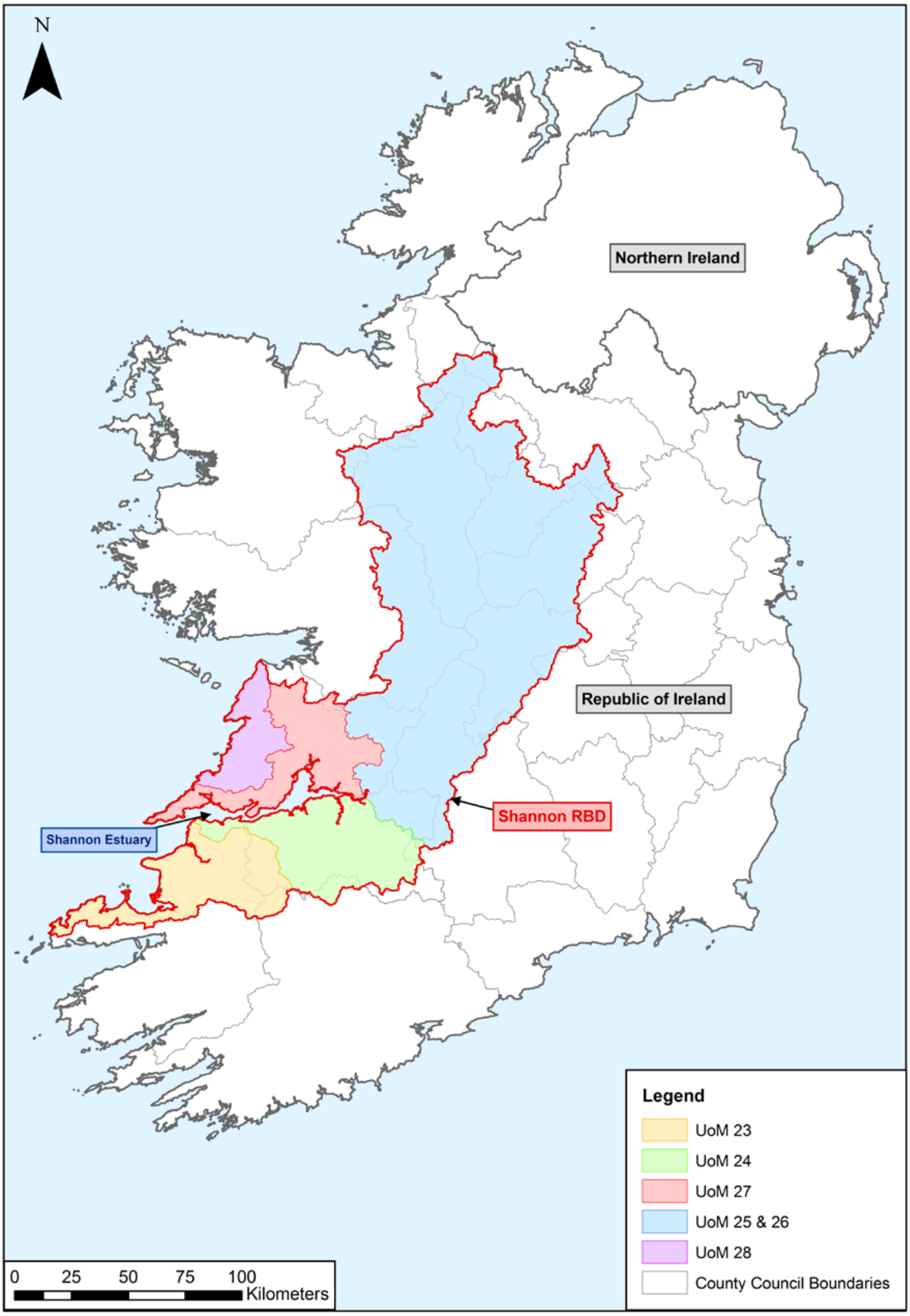

Figure 1.1 Shannon RBD and its Units of Management

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2 Hydrological and Hydrometric Information

2.1 Catchment Description

The Shannon Estuary South Unit of Management (or UoM 24) is shown in its wider context within the Shannon RBD in Figure 1.1, and in more detail in Figure 2.1. It encompasses areas of four counties; Kerry, Limerick, Cork and Tipperary. It consists of a fertile limestone plain, known as the 'Golden Vale' bounded on the north by the Shannon Estuary and on the west and south and east by the Mullaghareirk Mountains, Ballyhoura Mountains, Galty Mountains and Slieve Felim Mountains. The total area of UoM 24 is approximately 2000km^2.

The unit of management is dominated by two main river catchments, the River Deel and the River Maigue, which together cover 65% of the unit of management. The coastline extends along the Shannon Estuary from the outskirts of Limerick City in the east to where it meets the Atlantic Ocean between Loop Head (County Clare) and Kerry Head (County Kerry), west of this unit of management.

The River Deel rises in the Mullaghareirk Mountains near Dromina. It flows roughly in a north-westerly direction through the mountains, where it is joined by numerous tributaries, including the Finglasha River and the Ahavarragh Stream which drains the lands upstream of Dromcolliher. Downsteam of Newcastle West, the River Deel is joined by the rivers Arra, Dooally and Daar, which drain the steep topography of the Knockanimpaha Mountains which bound the west of the catchment. Downstream of the confluence the River Deel flows north east, through agricultural plains and roughly follows the direction of the N21 towards and through the centre of Rathkeale. Flowing north from Rathkeale the Deel flows through Askeaton, and on to the Shannon Estuary. Where the River Deel enters the Shannon Estuary, the catchment area is approximately 486.1km^2.

The River Deel catchment drainage scheme was completed in 1968 and focused on improved drainage for agricultural purposes. Arterial Drainage schemes have historically been undertaken at various locations within the River Maigue and River Deel catchments for agricultural purposes.

East of the River Deel catchment, and bounded to the south by the River Blackwater catchment, lies the River Maigue catchment. The River Maigue drains an area of approximately 806km^2, from its source in the Ballyhoura Mountains (County Cork) to where it enters the Shannon Estuary approximately 10km north of Adare.

Rising north of Milford in North Cork, the River Maigue flows east to join the River Loobagh approximately 3km north of Charleville, and then flows north through Bruree. Just downstream of Bruree, the River Maigue is joined by the significant tributary of the Morningstar River, which drains a catchment area of approximately 131.9km^2. Continuing northwards, just upstream of Croom, the River Maigue is joined by the third significant tributary of the River Camogue. From Croom, the River Maigue flows north-west towards Adare where the River Maigue becomes tidally influenced.

Table 2.1 below indicates the main sub-catchments and watercourses modelled in this unit of management. As already mentioned, the main sub-catchments consist primarily of the River Deel and the River Maigue catchment to the Shannon Estuary. All outstanding catchments are classified as 'Other'. In accordance with the scope,

the Ballinacura catchment, which includes Limerick, has been included within the Shannon Upper and Lower Unit of Management UoM 25/26.

Table 2.1 Sub-catchment and models within UoM 24

Sub-catchments	Main Watercourses	AFAs	Model Reference
Deel	Deel (River)	Milford	S12
	Ahavarragh (Stream)	Dromcolliher	
	Deel (River), Daar (River), Ehernagh (Stream), Arra (River), Doally (River)	Newcastle West	S11
	Deel (River)	Rathkeale	S10
	Deel (River)	Askeaton	
Maigue	Loobagh (River) Ahatrishnaun (Stream)	Killmallock	S08
	Glen River	Charleville	
	Maigue (River)	Croom	S07
	Barnakyle (River)	Clarina	S06
	Maigue (River)	Adare	
Other	Ballyline (River)	Ballylongford	S05
	Roberstown (River)	Foynes	S09

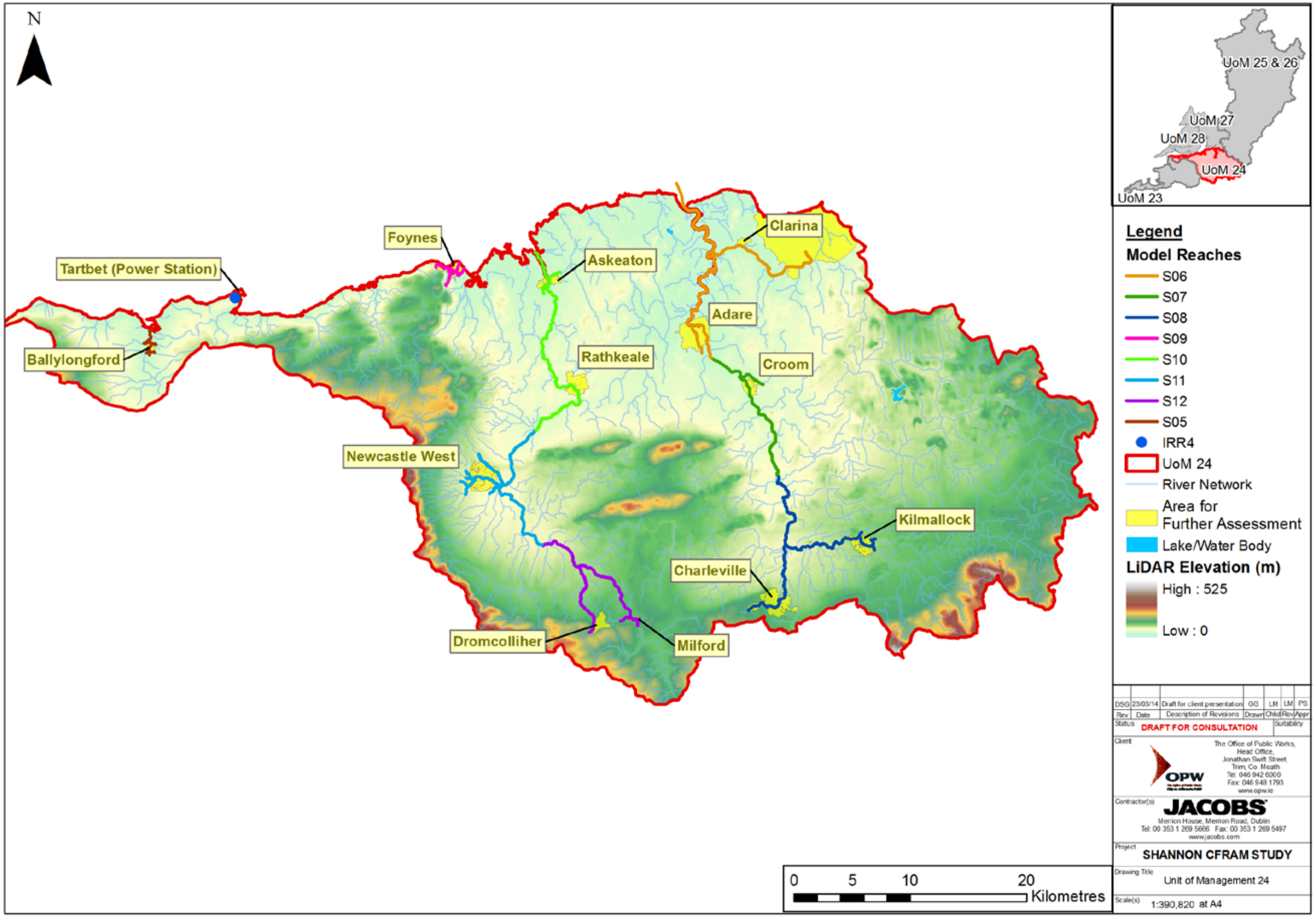

Figure 2.1 UoM 24 Study Area and hydraulic models

2.2 Hydrometric Data

Details of the hydrometric data used in the study, and the relevance to each UoM within the Shannon RBD, is discussed in the Preliminary Hydrological Assessment and Method Statement, produced as part of the **Inception Report** in 2012.

There is also a **Hydrology Report** associated with each UoM prepared in conjunction with this Hydraulics Report, which provides significant information with regard to the hydrometric data used.

Details of the Hydrology Report are not repeated within this Hydraulics Report, although the key aspects are noted.

The focus for the use of hydrometric data within the Shannon RBD is on river gauging stations where there are time series records of both water level and flow. As noted in the Inception Report, there is limited sub-daily rainfall data available within the Shannon RBD, and therefore rainfall-runoff modelling has not been used. The derivation of flow estimates for input to the hydraulic models is therefore based on the statistical analysis of flows across the catchment. This is the case for all UoM's within the Shannon RBD.

Table 2.2 summarises the split of gauging station reviews across each of the UoMs, with a full list of the gauging station reviews undertaken for UoM 24 presented as Table 2.3.

Table 2.2 Hydrometric Gauging Stations for review across the Shannon RBD

Unit of Management	Number of GS for rating Review
UoM 23	3
UoM 24	11
UoM 25/26	28
UoM 27	2
UoM 28	0

2.3 Historic Data

In addition to the hydrometric data, historic flood information has also been used, where possible, to inform the development of the hydraulic models, and to check the validity of the model against historic events.

In principle, this requires recorded water levels and flows at a defined location and time. This can then be verified with flow estimates derived from gauging station data, enabling the accuracy of the hydraulic model to be verified.

Appendix F of the Hydrology Report for UoM 24 contains the relevant historic data available and used for each respective hydraulic model within UoM 24.

Table 2.3 Gauging Stations with a Rating Review within UoM 24

Hydrometric Gauging Station No.	Name of Station	River	UoM 24 sub-catchment
24001	Croom	Maigue	Maigue
24003	Garoose	Loobagh	Maigue
24006	Creggane	Maigue	Maigue
24008	Castleroberts	Maigue	Maigue
24011	Deel Bridge	Deel	Deel
24012	Grange Bridge	Deel	Deel
24013	Rathkeale	Deel	Deel
24015	Dromcolliher	Ahavarragh	Deel
24029	Inchirouke More	Deel	Deel
24030	Danganbeg	Deel	Deel
24034	Riversfield Weir	Loobagh	Maigue

2.4 Design Flows

Taking account of the gauging station reviews, historic flood information and the use of appropriate hydrological methods, design flows have been developed across the RBD at specified Hydrological Estimation Points (HEPs). These HEPs are typically at 5km spacing along watercourses, at the confluence of watercourses, and at the upstream and downstream AFA boundaries where the watercourse flows into and out of the AFA.

The design flows for each hydraulic model are provided in the relevant model Appendix section, with further information provided in the Hydrology Report.

2.5 Coastal Aspects of the Catchment

2.5.1 Sites for coastal flooding assessment

Table 2.4 list the AFA/IRRs within UoM 24 selected by the OPW for being at risk of flooding from coastal sources either through a combination of high tide and surge and/or due to wave overtopping. These areas are shown on Figure 2.3. For completeness, Table 2.4 also shows whether these areas are also at risk of fluvial flooding.

Table 2.4 Sites for coastal flooding assessment within UoM 24

Model reference	Name of AFA/IRR	Source of flood risk		
		Tide +Surge	Wave overtopping	Fluvial
S05	Ballylongford	Yes	No	Yes
S06	Adare	Yes	No	Yes
S06	Clarina	Yes	No	Yes
S09	Foynes	Yes	Yes	Yes
S10	Askeaton	Yes	No	Yes
IRR4	Tarbert Power Station	Yes	Yes	No

2.5.2 Coastal data

OPW have provided the results from the Irish Coastal Protection Strategy Study (ICPSS)[1]. This gives extreme tidal peak levels for the following annual probabilities: 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.1% for the south western coast and the Shannon Estuary. These peak levels along with tidal gauge level data (2003-2007) collected from the Shannon Foynes Port Company at Foynes, Carrigaholt and Limerick along the Shannon Estuary were used to produce design tidal hydrographs. This process is fully explained in Section 4.3 and Appendix D of this report. The design tidal hydrographs were used to inform downstream boundary conditions for the following hydraulic models: S05, S06, S09, S10 and IRR4.

OPW has also provided results from the ICWWS (Irish Coastal Wave & Water Level Modelling Study)[2] screening analysis which highlight coastal locations potentially vulnerable to wave overtopping for the south western coast and the Shannon Estuary.

For these locations, detailed wave and still water level model outputs are available in the form of shoreline prediction points and their associated predicted water level and wave climate (wave height H_{mo}, period T_p and mean direction) combinations for a range of annual probabilities (50%, 20%,10%, 5%, 2%, 1%, 0.5% and 0.1%). These outputs include both the current condition and two future scenarios (Mid Range Future Scenario [MRFS] and High End Future Scenario [HEFS]).

S09 and IRR4 are the models within UoM24 for which wave overtopping simulations are undertaken. The methodology adopted to carry out wave overtopping modelling is fully explained in Section 4.4 of this report.

[1] Irish Coastal Protection Strategy Study Phase 4 – South West Coast, December 2013 - RPS

[2] Irish Coastal Wave & Water Level Modelling Study – Coastal Areas Potentially Vulnerable to Wave Overtopping, RPS, November 2012

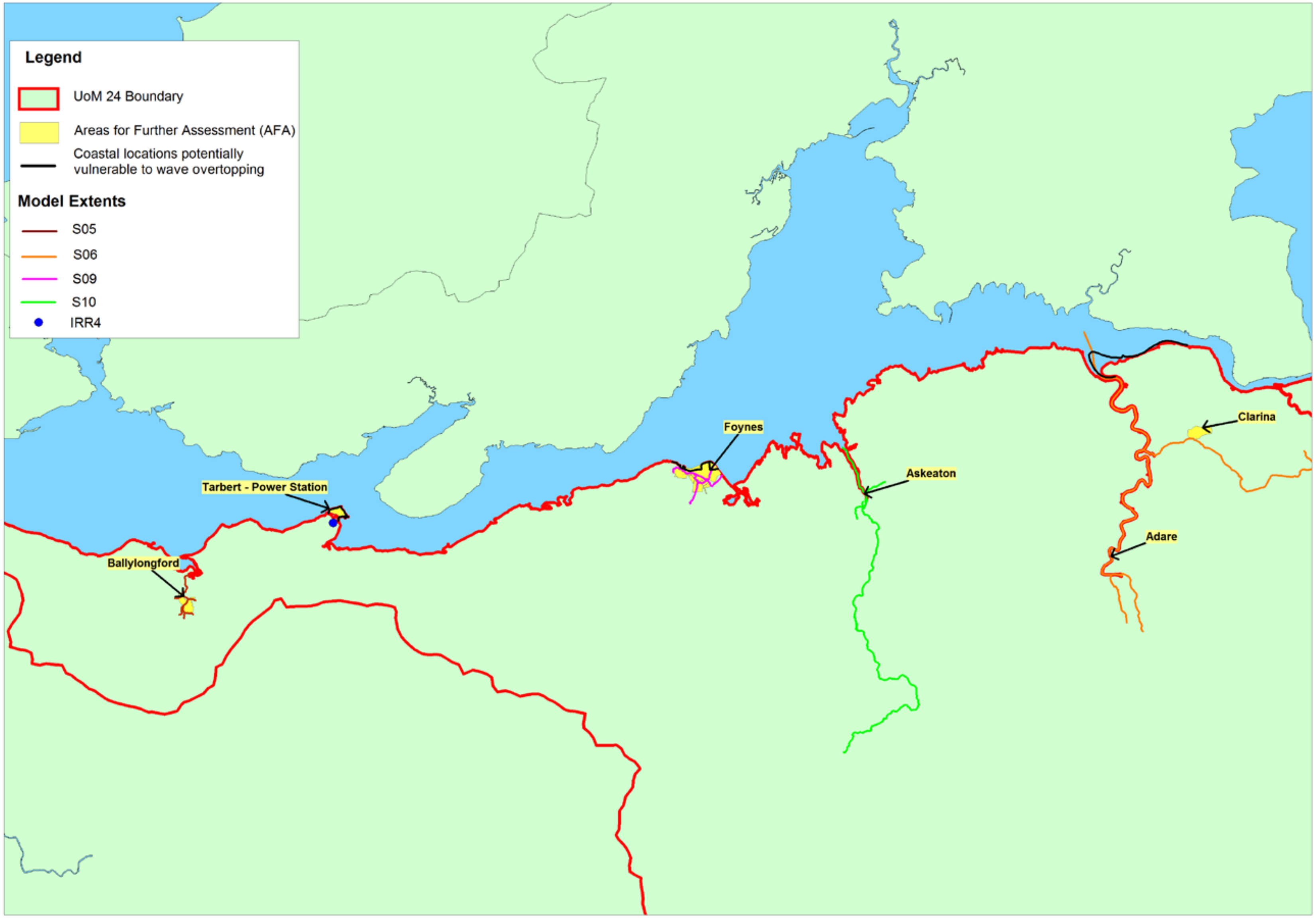

Figure 2.3 – AFAs and Models within UoM 24 for coastal flooding assessment

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3 Fluvial Hydraulic Model – Summary of Methodology

3.1 Introduction

Eight hydraulic models have been developed for HPWs and MPWs within UoM 24 to estimate fluvial design and potential future flood levels, depths, velocities and extents. Where possible the models have been calibrated and verified against observed flood events. The models have been run for fluvial design flood events with the following range of annual exceedance probabilities (AEPs):

- 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.1% for existing conditions and for the Mid-Range Future Scenario (MRFS)
- 10%, 1% and 0.1% for the High End Future Scenario (HEFS)

This section of the Hydraulics Report provides an overview of the model construction method, common to all the Shannon CFRAM fluvial hydraulic models. Further detail on each hydraulic model is then included in the relevant model Appendix section (Appendix B and C), covering specific information on the following elements:

- Basic Model Information
- Survey Data and Base Mapping
- Hydraulic Model Construction and Schematisation
- Hydraulic Model Calibration and Sensitivity
- Model Files and naming convention
- Key Model Assumptions

The following sections provide the overview of the relevant data and approach taken with regard to these elements.

3.2 Base Model Information

The base model information provided for each model covers:

- Model ID
- Unit of Management
- AFAs included within the model
- Primary watercourses and water bodies included within the model domain

3.3 Survey Data and Base Mapping

The base data required for the hydraulic model build is as follows:

- Mapping data in suitable formats to provide base mapping for the models
- Survey data for floodplain areas derived from LiDAR survey
- Topographic survey defining key ground levels, channel cross-sections
- Longitudinal sections, and levels and dimensions of critical structures
- Flood defence information[3]: type, extents and crest levels

[3] The Flood Defence Asset Database is provided as a separate deliverable to this report.

3.3.1 Base Mapping

The base mapping used throughout is standard OSi mapping at a scale of 1:50,000 provided in raster format. Within each relevant model Appendix section, the relevant 1:50,000 OSi tile reference(s) are noted for the area covered by the model.

To aid with the presentation of the flood mapping, this is supplemented by OSi NTF[4] vector mapping at scales of 1:5,000, 1:2,500 and 1:1,000 covering the entire Shannon RBD. There is no overlap between these mapping files; the scale at which mapping is available depends on the nature of the area. For example, rural areas are typically at 1:5,000 while town centres are typically covered by 1:1,000 map tiles.

3.3.2 Digital Terrain Model for 2D Model domain

For the development of the two dimension (2D) model domain, for those models that are constructed using a 1D-2D (ISIS-TUFLOW) approach, a Digital Terrain Model (DTM) is required for the 2D domain.

The data used for the 2D domain is a combination of high resolution LiDAR data covering the AFAs and the HPW reaches, combined with lower resolution IFSAR data for the areas outside of the AFAs and along MPW reaches.

The LiDAR data has a 2m horizontal resolution and a 200mm vertical accuracy. The IFSAR data has a 5m horizontal resolution and an approximate 500mm-1000mm vertical accuracy.

Due to the method by which the LiDAR data has been gathered (by flying defined flight lines over the area for which LiDAR data is to be captured) there is often LiDAR available for reaches outside the defined AFA boundary. Where this higher accuracy LiDAR data is available outside AFAs, it has been incorporated into the hydraulic models in preference to the IFSAR.

3.3.3 River Channel / Structures Survey

The topographic survey of the watercourse channels, estuaries and associated structures for UoM 24 has been undertaken by Blom and Murphy Surveys. The survey was procured by Jacobs from August 2012 to July 2013.

The channel and structure survey includes:

- **Channel cross-sections.** This includes the bank profile extending a short distance into the floodplain, the channel bed profile, the water level at the time of the survey, and an indicative location of the “top of bank”.

- **Longitudinal sections.** This includes sections along both river banks, picking up key features of the river bed profile such as weirs and along the river banks, such as high points, low points, start / end of flood defences walls etc.

- **Structure surveys.** This includes a section at the upstream and downstream faces of all identified structures. It also includes details of the structure and

[4] NTF is a vector mapping format provided by OSi. It can be translated into a Mapinfo/ArcGIS compatible format.

any flood relief features such as shapes, width, height, length, pier details, soffit level, deck level, springing levels.

- **Flood defence surveys.** Long section spot levels along the crest and the toe of formal flood defences.

The survey information has been provided in AutoCad, ArcGIS and ISIS format for the river cross-sections. Full details of survey outputs for each model are provided in the topographic survey deliverables submitted separately to this report.

3.4 Fluvial Hydraulic Model Construction and Schematisation

The model build process includes the following:

- Modelling approach and Software used for the 1D and 2D domains
- Model area covering the modelled reaches and the 2D domain
- River reaches defined within the model, covering both MPW and HPW
- Structures included in the model that have a hydraulic impact
- Floodplain schematisation
- Schematisation of the 2D domain (for 1D-2D models) including 1D elements and breaklines within the 2D domain
- Hydraulic roughness for in bank and out of bank flows
- Model boundaries – Inflows and Downstream conditions

3.4.1 Modelling Approach and Software

The software used and the modelling approach developed can vary, depending principally on the hydraulic complexity and scale of the river system network.

The vast majority of models developed on the Shannon CFRAM Study are dynamically linked 1D-2D models, where:

- 1D approach is adopted for the modelling of in-bank (channel) fluvial reaches for HPWs and for in-bank and out-of-bank (floodplain) modelling for MPWs.
- 2D approach is used for out-of-bank modelling for HPWs.

However in some instances, there are exceptions to these principles where a 1D approach is deemed appropriate for out-of-bank modelling of HPWs. Conversely there are also some examples where a 2D approach is used to undertake the out-of-bank modelling for MPWs.

The modelling approach used for each fluvial hydraulic model within UoM 24 is indicated within the relevant model Appendix section.

The 1D-2D models are constructed using the ISIS-TUFLOW link based on the combination of the one dimensional (1D) river modelling package ISIS (by CH2MHILL Software) and the two dimensional (2D) modelling software TUFLOW (by BMT WBM).

The methodology adopted for the hydraulic modelling of the river systems is based on the approaches described by the TUFLOW modelling manual. The user sets up a model as a combination of 1D network domain representing the river channel, dynamically linked to a 2D domain representing the adjacent floodplain, using the hydrodynamic programme to form a single model.

The 1D and 2D domains can be linked by three separate methods which are as follows:

- Replace part of a 1D model by nesting a 2D domain inside a broader scale 1D model
- Insert 1D networks underneath a 2D domain or through an embankment
- Replace or carve a 1D channel through a 2D domain

The general approach applied within this study is the latter, in which a 1D ISIS model of the river / watercourse system is “carved” through the 2D TUFLOW model of the floodplain as shown schematically in Figure 3.1.

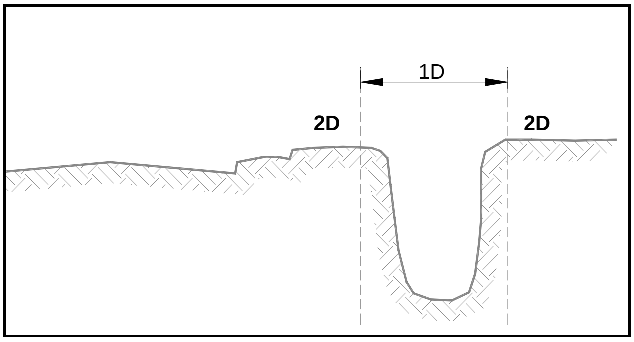

Figure 3.1 Modelling a river channel in one dimension and the floodplain in two dimensions (TUFLOW Manual, 2010)

In addition to this 1D-2D approach, there are also specific 1D elements which can be added within the 2D domain using ESTRY, which is a 1D software embedded within TUFLOW. This may be used, for example, if there is a culvert through a road or railway embankment that may be crossing a 2D represented floodplain. This allows the two sides of the floodplain to be linked via the culvert which is effectively a 1D flow path. This is outlined further under Section 3.4.9.

The specific model software versions used for each model are included within the relevant model Appendix section.

3.4.2 Model Area and Extent

The model area and the extent of both the 1D reaches and the 2D domain are included as an Annex to each relevant model Appendix section. These are in the form of a series of plans as follows:

- **Model extent plans** – These show the full modelled reaches, names of primary watercourses and the AFA boundaries.

- **Model schematic plans** – These show a series of maps at a larger scale than the model extent plan, detailing critical parts of the model schematisation. They include the AFA boundaries, MPW and HPW reaches, the 2D domain extent, cross-section locations and their model reference number, presence of spill units, reservoir units, flood defences, parallel channels, and other model details pertinent to the specific location.

3.4.3 Model Reaches

Each model is comprised of a series of model reaches. The reaches defined in the model are included in the relevant model Appendix section and are identified by the watercourse name, the reach identification number and the upstream and downstream model nodes.

3.4.4 ISIS river cross-sections

As already mentioned, topographic survey cross-sections across the river reaches have been provided in ISIS format and therefore are directly imported into the ISIS software.

Where required, interpolated cross-sections are added between the topographic survey sections to ensure model convergence where significant change occurs in the water level profile.

Panel markers are set at the top of bank to mark the change between channel and floodplain. Additional panel markers are also used to mark changes in roughness values across the floodplain for extended cross-sections.

Deactivation markers are used to deactivate out-of-bank areas within the cross-sections deemed to be hydraulically inactive in the ISIS model. These are, for example, widely applied across the reaches where out-of-bank areas are modelled in 2D.

3.4.5 Model Structures

The structures surveyed are typically bridges, culverts, weirs, sluices and gates. Not all surveyed structures have been included within the hydraulic model. Those structures not included in the model do not influence water levels during high flow events. For example, a low weir in the river channel becoming drowned out before out of bank flow occurs would not be included in the model unless deemed hydraulically necessary (e.g. part of the in-bank model calibration process).

For each model a structure schedule has been prepared and includes:

- topographic survey reference
- ISIS node reference
- type of structure
- modelling approach
- whether the structure is included in the model

The structure schedule(s) are included in an Annex to each relevant model Appendix section.

3.4.6 Floodplain Schematisation

The schematisation of the floodplain depends on the modelling approach adopted to model a particular reach and its adjacent floodplain. As mentioned previously, 1D approach is generally adopted for the modelling of in-bank (channel) fluvial reaches for HPWs and for in-bank and out-of-bank (floodplain) modelling for MPWs whilst 2D approach is used for out-of-bank modelling for HPWs.

Transition between 1D only and 1D-2D domains are therefore located near MPW/HPW interfaces; more precisely they are set up according to the local topography depicted by the LiDAR data preferably where the flood flow stays confined to the river channel or where the floodplain flow is well defined and run parallel to the river channel.

For the 1D (ISIS) only reaches, out-of-bank flow areas have been modelled by extending the river channel cross-sections or using reservoir units, spill units or parallel channels within the model.

With regard to the cross-section extension, this is done by using and extending the available cross-section survey using LiDAR or IFSAR, in a direction perpendicular to the 1D floodplain flow. Thus, the final cross-section is a combination of topographically derived ground levels and LiDAR / IFSAR. Where necessary, the LiDAR / IFSAR is adjusted by ground truthing to take account of the lower vertical accuracy of the LiDAR and IFSAR compared to the ground survey. Where such adjustment is made, a comment has been left in the ISIS main model file at the relevant cross-section.

Reservoir units (flood storage areas) or parallel channels are used in combination with spill units where the floodplain ground levels are below the river bank top level (e.g. flood defended reach). In such a situation it is not always appropriate to use extended cross-sections to represent floodplain flooding processes. Reservoir units across the floodplain are interlinked using either spill units or ISIS floodplain sections.

Where the floodplain is represented using a 2D approach, the 2D domain is based on a regular grid comprising individual square cells of a defined size. Each cell is given characteristics relating to the topography such as ground elevation, hydraulic roughness (see Section 3.4.10) and initial water level. For some models there may be more than one 2D domain defined.

On either side of the modelled watercourses, boundary lines define the bank crests. At these locations, there are 2D open flow boundary cells to represent the dynamic links between the 1D network and the 2D TUFLOW domain. 2D cells falling within the 1D network domain are ignored by the model and considered as inactive.

At each 1D ISIS model node, the corresponding river cross-sections are either trimmed or the floodplain area within the cross-sections deactivated at bank top level to match the 2D domain topography. The 1D model nodes are then connected to the 1D-2D boundary cells, allowing flood water to spill to and from the 2D domain when the calculated water level exceeds the banks' crest elevation.

3.4.7 2D Domain Grid Size

For the 1D-2D models, multiple 2D domains can be defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow. Within each relevant model Appendix section, the number of 2D domains, the grid size and area covered by each domain is given.

3.4.8 Model Breaklines/Z-shape polygons in the 2D Domain

Breaklines are used in the 2D grid to accurately represent any geographical features that could have a significant impact on the propagation of the flood wave across the floodplain. It is particularly useful where the TUFLOW fixed grid discretisation does not guarantee that the crest along, for example, a wall, is picked up from the DTM. Breaklines are also used to incorporate surveyed features into the 2D model grid such as formal flood defences, surveyed bank tops, bridge parapets etc.

In a similar manner Z-shape polygons are used to correct any LiDAR anomalies picked up by the model grid or add additional features such as bridge decks that are often missing in the LiDAR data.

The features represented by the Z lines are listed under Section 3.7 of the individual Hydraulic Model Reports.

3.4.9 Floodplain Structures in the 2D Domain

As noted under Section 3.4.1, 1D elements can be included in the 2D model using ESTRY software to represent structures permitting hydraulic connectivity across the floodplain. These can include a variety of features including: culverts under roads or railways, pedestrian subways, highway underpasses, a road under a railway bridge / viaduct (although these may also be represented as 2D features).

Specific 1D elements included in each model are listed in the relevant model Appendix section.

3.4.10 Hydraulic Roughness

Hydraulic roughness, or friction, is represented by Manning's coefficient "n" in the hydraulic models. The value of 'n' accounts for a range of factors that influence overall roughness either in the channel or across the floodplain. Factors included within the overall evaluation of Manning's 'n' include bed materials and size, vegetation, surface irregularities, channel bed forms, erosional and depositional features, channel sinuosity, and obstructions, all of which influence channel and floodplain conveyance.

Manning's 'n' is a semi-empirical parameter and cannot by directly measured; however a number of established reference literatures such as Chow[5] and UK Environment Agency guidance[6] give advice on the selection of the roughness coefficients for channels and floodplains.

The values adopted in the models are highly variable but are generally in the range 0.025 for a relatively smooth, even, un-vegetated channel, up to 0.090 for out of bank flows across woodland. However, these are not strictly defined limits.

Floodplain Roughness

To represent the friction within the floodplain, Manning's 'n' has been defined based on the EPA Land Use classification for the floodplain areas where a 1D approach has been considered. This classification is provided as a GIS file, and for each

[5] Chow, V.T., Open Channel Hydraulics, 1984, McGraw Hill, Singapore
[6] Fisher K., Dawson H., Roughness Review, Project W5A-057, July 2003 DEFRA/Environment Agency

different land use identified, a value for n has been assigned. Example areas are listed in Table 3.1. The incorporation of this GIS data into the ISIS software allows Manning's 'n' to be specified automatically for every cross-section data set across the floodplain.

Table 3.1 Example of Roughness definition within 1D floodplain areas based on EPA Land Use Classification

Land Use classification Level 3 Code	Manning's "n" value	Land Use description
231	0.035	Pastures
243	0.045	Heterogeneous agricultural land
122	0.025	Roads
111	0.100	Buildings
324	0.060	Transitional Woodland scrub
313	0.090	Forests
141	0.035	Green urban areas

To represent the friction within the floodplain areas represented in 2D, Manning's 'n' has been defined based on the more refined OSi NTF vector mapping classification. This classification is also provided as a GIS file, and for each different land use identified, a value for n has been assigned, as listed in Table 3.2. The incorporation of this GIS data into the 2D model DTM allows Manning's 'n' to be specified automatically for every grid cell within the 2D domain.

Table 3.2 Example of Roughness definition within 2D models based on OSi NTF Land Use Classification

NTF Land Use classification	Manning's "n" value	Land Use description
618	0.045	General Rural land
557	0.025	Roads
600	0.100	Buildings
611	0.060	General Urban
527	0.080	Woodland / Dense vegetation
583	0.035	Parkland / Sport grounds

It should be noted that the use of filtered LiDAR data to inform the 2D model DTM means that buildings are not inherently represented in the grid. Given the fact that any building is an obstruction to the flow and would have a major impact on the overland flow routes, a very high roughness value (0.100) has been attributed to each building/house within the study area to model the effect of the obstruction to flow. This is not a "true" Manning's 'n' value for a building, but is a technique that allows the obstruction from the building to be adequately factored in.

Channel Roughness

Channel roughness is defined for HPWs and MPWs reaches. Each reach is split into sections as appropriate depending on bed material, bank side vegetation and channel sinuosity and irregularities.

For each section of reach, a single Manning's 'n' value is set from left bank to right bank in each ISIS cross-section. This is a compound value which is estimated from photos, survey information and using the previously referenced UK Environment Agency roughness guidance.

For each MPW and HPW reaches within a model a channel roughness schedule is prepared, which includes details of Manning's 'n' values determined for each section of reach as described above.

3.4.11 Model Boundaries - Inflows

For each model, a detailed hydrological analysis of the river system catchment is carried out in order to produce hydrological inflows to the hydraulic model. This analysis is fully discussed in the UoM 24 Hydrology Report. The hydrological assessment also defines how to distribute the catchment flows within the hydraulic model i.e. flow boundaries are generally set at the upstream extents of a model and also distributed laterally at appropriate HEP locations. The flows are reconciled with hydraulic influences during the HEP calibration process described in Section 3.5.2.

The Critical Duration is established intrinsically by virtue of the hydrological methodology employed (taking the maximum levels from the main and tributary flows) and is not established through hydraulic routing. The method is explained in the UoM 24 Hydrology Report.

The peak inflow values used for each modelled design event are included in the relevant model Appendix section, along with the HEP reference name and the model node at which the inflow hydrographs are applied.

3.4.12 Model Boundaries – Downstream Conditions

The downstream boundary conditions selected for purely fluvial models are in general, free flow boundaries set at the downstream limits in the 1D ISIS model and the 2D domain. This equates to the flow being at "normal depth" for the channel slope at the downstream limit of the models. For each model, checks are made to ensure the normal depth assumption is reasonable and flood flows "leaving" the model are not in reality subject to a backing up effect from hydraulic structure or other floodplain features located downstream.

Other downstream conditions are possible. For example, a stage-discharge boundary condition may be appropriate if the downstream extent of the model is at a significant control structure which would remain as the hydraulic control during times of extreme flood and for which an existing rating curve is available.

Within each relevant model Appendix section, the type of boundary condition, its location, and model node are noted.

3.5 Hydraulic Model Calibration and Sensitivity Model Runs

Calibration of hydraulic models and the associated sensitivity analysis to test the confidence of the results based on uncertainty in the model input parameters is a critical part of hydraulic model development.

The following aspects are integral to the approach, as described in the following sections:

- Model Calibration and Verification taking account of relevant gauging stations and historical events
- Calibration to Hydrological Estimation Points (HEP)
- Sensitivity of modelled water level to key parameters – roughness, inflow, influence of structures, downstream boundary condition

3.5.1 Model Calibration and Verification to Historical Events

The approach to model calibration is described in National Technical Co-ordination Group (NTCG) Guidance Note no. 23 (GN23). This is included for reference in Appendix D. The fundamental points to note, with regard to achieving the best model calibration, are that the following data must be known:

- **Flow** at the point of interest
- **Water level** at the point of interest
- **Channel / hydraulic controls influencing the water level** at the location of interest so that the model is representative of the situation

Where there is uncertainty in any of these three variables, the accuracy of the calibration is reduced. As some catchments are gauged and some are ungauged, there is more flood history with reliable flow and water level data in some AFAs than others; and local hydraulic features have more of an influence in some locations than others; the reliability of each model's calibration is varied.

Wherever possible, a range of in bank and out of bank events are used for calibration and verification. However, as noted in GN23, the lack of data in some locations makes calibration of the model unfeasible. Under these circumstances, a reality check against known flooding events (or events that caused flooding elsewhere but are known <u>not</u> to have caused flooding at the location of interest) is a useful part of a qualitative assessment to increase confidence in the model output in the absence of reliable quantitative data.

The use of photographs and anecdotal evidence of past events has also been used to validate flood extents modelled.

For each model, an analysis of available flood event data and high flow data for possible consideration as calibration and verification events has been carried out. Results of these analyses are covered in the Hydrology report.

Within each relevant model Appendix section, a summary of the calibration and verification events along with associated model calibration results is provided.

3.5.2 Verification to HEP

Hydrological Estimation Points (HEPs) are independently derived hydrological values, the details of which are provided within the Hydrology Report. Verification of the hydraulic models to the HEPs is carried out for the 10%, 1% and 0.1% AEP design events simulated.

The timing of the inflow hydrographs is adjusted to account for the travel time in the modelled reaches. This is done through an iterative process whereby the model is firstly run with the main river upstream inflow, then, at each iteration, the next downstream lateral inflow is added with its peak flow time adjusted to coincide with the peak time of the propagating flood wave as it is routed down the main river. This process is repeated until the most downstream lateral inflow is added. In this manner, the design hydrograph peaks and shapes are preserved within a reasonable degree of accuracy throughout the models. Total peak flows predicted by the hydraulic models at HEPs are then compared to the HEP predictions. Where necessary, hydrological inflows to the hydraulic model are scaled up or down to ensure that the modelled total peak flows remain within ±10% of the HEP predictions.

3.5.3 Model Sensitivity

Sensitivity tests are carried out on the hydraulic models in order to assess the sensitivity of the modelled systems to alterations in a number of key hydraulic parameters.

The results of the sensitivity analysis give an indication of the confidence levels that can be placed in the results being generated by the respective model.

For each model within UoM24, the sensitivity runs are carried out for the 1% AEP fluvial event. The following sensitivity tests have been carried out:

- Sensitivity to hydraulic roughness: Manning's 'n' values are both increased and decreased by 20%
- Sensitivity to hydrological inflows. All hydrological inflows are both increased and decreased by 20%
- Sensitivity to afflux parameters at key structures within an AFA. Afflux parameters are varied to reduce or increase the head loss during a 1% AEP flood event at key structures susceptible to having an impact on the flood extents
- Sensitivity to the downstream conditions. Depending on the type of the downstream boundary conditions chosen for a specific model, changes are made to assess how far upstream the design water levels are affected

Within each relevant model Appendix section, the results of the sensitivity tests for Manning's n and inflows are compared to the base case scenario and processed to determine the average peak water level difference and where the maximum water level difference occurs throughout the models; for other changes, the distance the effect is noticed in the water level results up and downstream of the changed parameter (e.g. downstream boundary conditions) is reported. An assessment is then made of the significance of the change on flood risk. The sensitivity results also inform the Uncertainty mapping, which shows the maximum impact of the sensitivity runs.

3.6 Model files and naming convention

The hydraulic model files associated with each model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. Within each relevant model Appendix section, there are details (names and purpose) on the model files included.

A generic convention is adopted to keep a consistent approach to the naming of the main ISIS (.dat) and where applicable TUFLOW (.tcf) files.

Model naming is as follows:

ModelNumber_QXXX_Source_Scenario_RunType_StatusVersion

Where:

- Model Number is a unique model ID (e.g. N05)
- QXXX is the flood frequency of the event simulated expressed in return period (e.g. Q100 for the 1% AEP event)
- Source is the source of flooding using either Flu for fluvial, Co for coastal, Mi for mixed (fluvial and tidal) and Wa for wave overtopping
- Scenario uses either C for current, M for MRFS and H for HEFS
- Run Type uses either Des for Design runs, Cal for calibration runs, Val for validation runs and Sen for sensitivity testing.
- StatusVersion uses IssV# for any model version that is delivered to the OPW.

Of a particular note, where joint probability runs are simulated, the Source element in the file name uses "FluMi" for fluvially-dominated event and "CoMi" for tidally-dominated event; this for a given flood frequency.

In each ISIS model, the 12-character node labels also follow a naming convention, which is described in Table 3.3.

Table 3.3 ISIS node label naming convention

Character	Description
1 2	**Model Reach Number** *Model reaches are specific to a watercourse. They are numbered from downstream to upstream. Model reach number is incremented at every confluence with a tributary and also at each model boundary for the watercourses whose full extent is covered by several hydraulic models (e.g. River Shannon).* Example: "01"
3 4 5	**Watercourse Reference Name** *Watercourse reference is unique across the entire UoM.except for small bifurcations off a main river (cut, loop) where the letter"X" replaces the last letter of the watercourse reference.* Example: River Brosna = "BRA", branch off the Brosna = "BRX"
6 7 8 9	**Cross-section chainage (m)** *Cross-section chainage starts at zero at the downstream end of each model reach* Example: "15010"

10	
11	**Structure reference:**
12	*Two letters are usually used to indicate the structure type (bridge, weir, culverts) and the upstream or downstream node* Example for a bridge: "bu" for the upstream node and "bd"for the downstream node.

3.7 Key Model Assumptions

Model specific assumptions are described in Section 6 of the relevant model Appendix section. In addition, there are generic assumptions which are summarised below.

3.7.1 Structures

Bridges

- USBPR and Arch Bridge units are used to represent bridges. In both units, the orifice mode is activated to allow for orifice flow when a structure becomes surcharged. For short bridges with a low soffit (e.g. farm or driveway access bridge), orifice units are preferably used as the structure is likely to become rapidly surcharged when the flow increases.
- Each bridge is associated with a spill unit to allow for spilling over the bridge under extreme conditions. When using the extended cross-section approach to model the floodplain area, the spill unit is also extended over a longer distance than the bridge itself to represent flow paths on either side of the structure. Where a 1D-2D approach is adopted, the spill extends up to the 2D domain or is removed if the deck area is large enough to be represented in the 2D domain.
- The calibration coefficient in bridge units is usually set to the default value of 1.0. This value is only changed if supported by observed water level data during the calibration process.

Weirs

- Available ISIS units (e.g. round nose broad crested weir, labyrinth weir, sharp crested weirs etc) are used to represent weirs with a regular crest profile.
- Unless changed during the calibration phase, default weir and velocity coefficients are used.
- For irregular shaped weirs and large steps (>500mm) in the river slope profile, spill units are used.

Culverts

- Long culverts (length > 5m) are modelled using appropriate conduit, inlet and outlet units. Whilst short culverts are modelled as orifice units.

- Roughness coefficients used for the culvert barrel are selected based on the material of construction from the survey photographs, plus reference to publications[7].
- If the inlet and outlet are very different in shape, the first half of the structure is represented using conduit units representative of the inlet and the second half using conduit units representative of the outlet, i.e. the change in section is assumed to occur halfway through the culvert.

3.7.2 Spills

- Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain).
- Spill profile geometry is defined using topographic survey data and LiDAR/IFSAR.
- Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.

3.7.3 Confluences

- ISIS junction units are used at confluences allowing water levels to be considered at each river section connected to a junction.
- If no survey section data is available at the junctions, river sections are determined from the nearest upstream and downstream surveyed sections. Chainage correction and changes in river bed elevation when copying these sections are implemented so that the bed level at all junction sections are identical, i.e. no sudden drop in bed level.

3.8 Quality Assurance

Modelling work carried out as part of the CFRAM study follows the Jacobs Quality Management procedures whereby any work is checked, reviewed and verified before being approved for release to the OPW. Throughout the hydraulic modelling process, quality checks are being undertaken by the modeller and a senior modeller as checker and reviewer respectively, to ensure that the models accurately represent the river and coastal systems.

Table 3.4 shows the key stages throughout the modelling process when Quality Assurance (QA) audits are carried out.

Table 3.4 Stages at which Quality Assurance Audits are carried out throughout the modelling process

Stage	Purpose
Data Collection	Ensure all data required to carry out the modelling is collected and suitable for use in the models.
Model Input Statement	Defines in detail the modelling approach for each model extent.

[7] HR Wallingford and D.I.H. Barr, Tables for the hydraulic design of pipes, sewers and channels, 6th edition, Volume II, 1994

Model construction	Ensure each model is built to industry standard, is sufficiently robust and stable, has suitable mass balance conservation and that the schematisation meets the Project brief requirements.
Calibration to historical flood events	Ensure calibration of the hydraulic model to historical events is correctly undertaken and compliant with the Project Brief.
Calibration to HEPs	Ensure calibration of the hydraulic model to HEPs is correctly undertaken and compliant with the Project Brief.
Completion of the design runs for each scenario: existing, sensitivity tests, etc.	Ensure model results are appropriate with regards to model performance (i.e. stability, mass balance conservation), consistency between events of different severity and “ground truthing” of the outputs.
Flood Mapping	Ensure flood maps are consistent with model results and compliant with the Project Brief.

Each of these quality checks are documented through a series of check list forms populated by the modeller, checker and reviewer to allow for a detailed level of checking whilst providing an audit trail at different stages of a model development.

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4 Coastal Flooding Model Construction

4.1 Introduction

For consistency across the entire Shannon RBD, for those Units of Management for which coastal flooding models have been developed (UoM 23, 24 and 27), this section reports the coastal flooding model construction process in general terms.

In UoM24, Tarbert Power Station (IRR4) is the only area for which a standalone coastal model has been developed as the risk of flooding is not subject to any fluvial influence. For the areas where flooding is subject to both tidal and fluvial influences, the relevant hydraulic models i.e. the ones with estuarine reaches have been developed to simulate coastal flooding as well as fluvial flooding. As already mentioned, the following sections focus only on the coastal modelling aspects of these models.

4.2 Coastal hydraulic model construction and schematisation

The coastal model build process includes the following:

- Modelling approach and Software used for the coastal floodplain areas
- Model area covering the coastal floodplain
- Coastal Floodplain schematisation
- Hydraulic roughness
- Model boundaries – Tidal and wave conditions

4.2.1 Modelling Approach and Software

As specified in Section 7.3.1 of the CFRAM Studies Project Brief Stage 1, a two dimensional approach is adopted to simulate the propagation of coastal floodwaters inland using TUFLOW modelling software produced by BMT WBM. A 1D approach using the ESTRY software is used to represent small structures (e.g. culverts under road or railway embankment) across the coastal floodplain.

The specific model software versions used for each model are included within the relevant model Appendix section.

4.2.2 Model Area and Extent

The extent of the 2D coastal domain is determined to accommodate the largest expected flood extent using LiDAR data and ICPSS extreme tidal peak levels. Consideration of the AFA boundary is also given to ensure the model area encompasses the AFA areas subject to coastal flooding.

Model area and extent are included as an Annex to each relevant model Appendix section.

4.2.3 Coastal floodplain Schematisation

The 2D coastal domain is based on a regular grid comprising individual square cells of a defined size. Each cell is given characteristics relating to the topography such as ground elevation, hydraulic roughness (see Section 4.2.4) and an initial water level if required.

The data used to inform the 2D grid with ground elevation is a combination of high resolution LiDAR data covering the AFAs, combined with lower resolution IFSAR data for the areas outside of the AFAs.

Due to the method by which the LiDAR data has been gathered (by flying defined flight lines over the area for which LiDAR data is to be captured) there is often LiDAR available for areas outside the defined AFA boundary. Where this higher accuracy LiDAR data is available outside AFAs, it has been incorporated into the hydraulic models in preference to the IFSAR.

As for the fluvial models, the domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the coastal floodwater flows. For the models sharing a fluvial component the orientation of the grid is according to the fluvial floodplain flows.

As for the fluvial models, breaklines/Z-shape polygons and 1D elements are used in the 2D coastal domains in a similar fashion described in Section 3.4.8 and 3.4.9 respectively. In particular breaklines are used to incorporate into the model grid surveyed crest levels of formal coastal flood defences.

Within each relevant model Appendix section, 2D coastal domain area, grid size, breaklines/Z-shape polygons and 1D elements included in each model are given. The features represented by the Z lines are listed under Section 3.7 of the individual Hydraulic Model Reports.

4.2.4 Hydraulic Roughness in the coastal floodplains

To represent the hydraulic friction within the coastal floodplains, Manning's 'n' has been defined based on the OSi NTF vector mapping classification which covers all AFA areas subject to coastal flooding. This classification is the same as used in the fluvial model. Refer to Section 3.4.10 and Table 3.2 of this report for a full description.

For coastal floodplain areas outside the AFA boundaries where OSi NTF data is not available, Manning's 'n' has been defined based on the EPA Land Use classification as described in Section 3.4.10 and Table 3.1 of this report.

4.2.5 Coastal Model Boundaries Conditions

As already mentioned the coastal models are developed to simulate flooding from coastal sources either through a combination of high tide and surge and/or due to wave overtopping. Therefore two types of boundary conditions are possible:

- Where coastal flooding arising from the combination of high tide and a meteorological surge is to be simulated, a variable water level (Stage vs.Time) mimicking the sea level motion is applied. Section 4.3 and Appendix D provide a comprehensive description on how such tidal hydrographs are derived. The boundary condition is set along the coastal fringe of the modelled area including the estuarine section for the models with a fluvial component.

- Where coastal flooding arising from wave overtopping is to be simulated, a flow hydrograph associated with the wave overtopping rate of discharge is

applied. Section 4.5 provides a full description on how such flow hydrographs are derived. The boundary condition is set only along the coastlines prone to wave overtopping as identified in the Irish Coastal Wave & Water Level Modelling Study.

Within each relevant model Appendix section, the type of boundary condition and its location are indicated.

4.3 Production of design tidal hydrographs to inform boundary conditions of coastal models

The approach taken to define the tidal boundary conditions in the current situation for the hydraulic models along the Shannon Estuary is fully provided in Appendix D of this report. A summary of the approach specific to UoM24 is provided in this section.

4.3.1 Data used

The following available datasets are used to produce the design tidal surge hydrographs as boundary conditions for the models shown on Figure 2.3.

- ICPSS Predicted Extreme Water Levels (Tide and Surge) for the following design events: 50%AEP, 20%AEP, 10%AEP, 5%AEP, 2%AEP, 1%AEP, 0.5%AEP and 0.1%AEP at various locations along the Shannon Estuary.
- Foynes, Carrigaholt Tidal gauge records (2003-2007) obtained from Shannon – Foynes Port Company
- Admiralty Tide Tables information for port locations along the Shannon Estuary[8]
- OSi Conversion Graphs (Poolbeg-Malin head datum) including levelling information for port locations

4.3.2 Methodology

A four-stage approach is followed to develop the downstream tidal hydrographs assigned to each model.

Stage 1: Production of mean Spring tidal cycles at key ports

Tidal records collected at port locations: Carrigaholt and Foynes have been used to extract typical Spring tidal profiles (i.e. level hydrograph shapes). These have been scaled to generate mean Spring tide profiles ranging from Mean High Water Spring (MHWS) to Mean Low Water Spring (MLWS) levels using information from the Admiralty Tide Tables for Carrigaholt, Foynes Island and Mellon Point classified as secondary ports. For the case of Tarbert Island, as it is a standard port, a typical Mean Spring tide curve is available in the Admiralty Tide Tables and has therefore been used. These key port locations are shown in Figure 4.1. Details of the calculations carried out to determine MHWS and MLWS levels to Malin Head datum are provided in Appendix D.

[8] Admiralty Tide Tables, United Kingdom and Ireland, Vol 1 NP 201-06, (2006)

Figure 4.1 Key ports listed in the Admiralty Tide Tables for which MHWS and MLWS information is available

Stage 2: Association of ICPSS prediction points with mean Spring tidal cycles at key ports

Each ICPSS prediction point[9] for which extreme water levels combining tide and surge have been estimated is shown on Figure 4.2. These have been associated with a mean Spring tidal cycle for the key ports mentioned above. This allocation is based on the nearest port location but also takes into consideration tidal hydrodynamics within the Shannon Estuary.

Table 4.1 below describes the association of the ICPSS prediction points relevant to UoM24 with the mean Spring profiles at the key ports.

Table 4.1 Allocation of prediction points to ports

Port/Spring profile	ICPSS (Prediction Point Reference) relevant to UoM24
Foynes	S18
	S19
	S21
Mellon Point	S25
Kilrush	S9
Tarbert Island	S12

[9] Prediction point references used in Figure 4.2 and Table 4.1 are the IPCSS Prediction point references used in the ICPSS report.

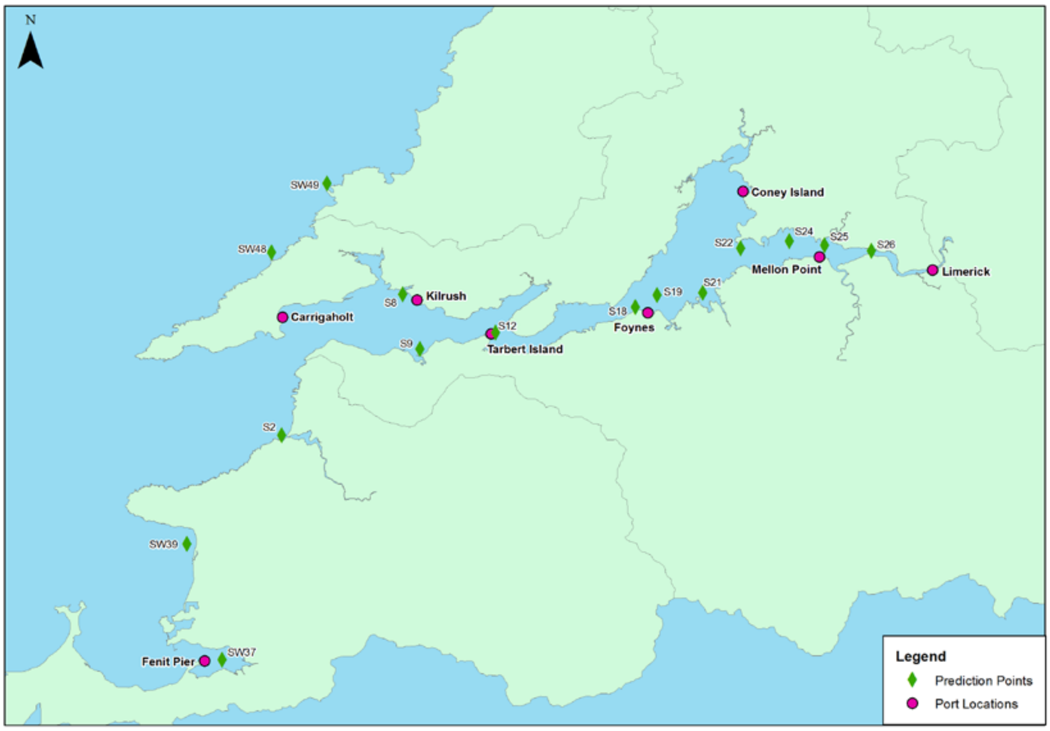


Figure 4.2 ICPSS prediction point and key port locations

Stage 3: Production of design hydrographs at the ICPSS prediction points

Using the spring profiles and the available ICPSS extreme water levels for a range of annual probabilities, a series of design tidal hydrographs have been produced at each prediction point. The tidal hydrographs represent the effect of 30hr meteorological surges of increasing intensity on the mean Spring profile associated with each ICPSS prediction point. The 30hr surge duration means that 3 tide cycles are affected. The surge effect is centred such that middle high tide level matches with the extreme water levels taken from the ICPSS data.

This process is illustrated on Figure 4.3.

It is acknowledged that a 30hr meteorological surge duration is a key, though considered realistic, assumption to the production of the design tidal hydrographs. Sensitivity tests as described in Section 4.6 are carried out with the hydraulic model to assess the effect on predicted flood risk of varying surge duration in the tidal boundaries.

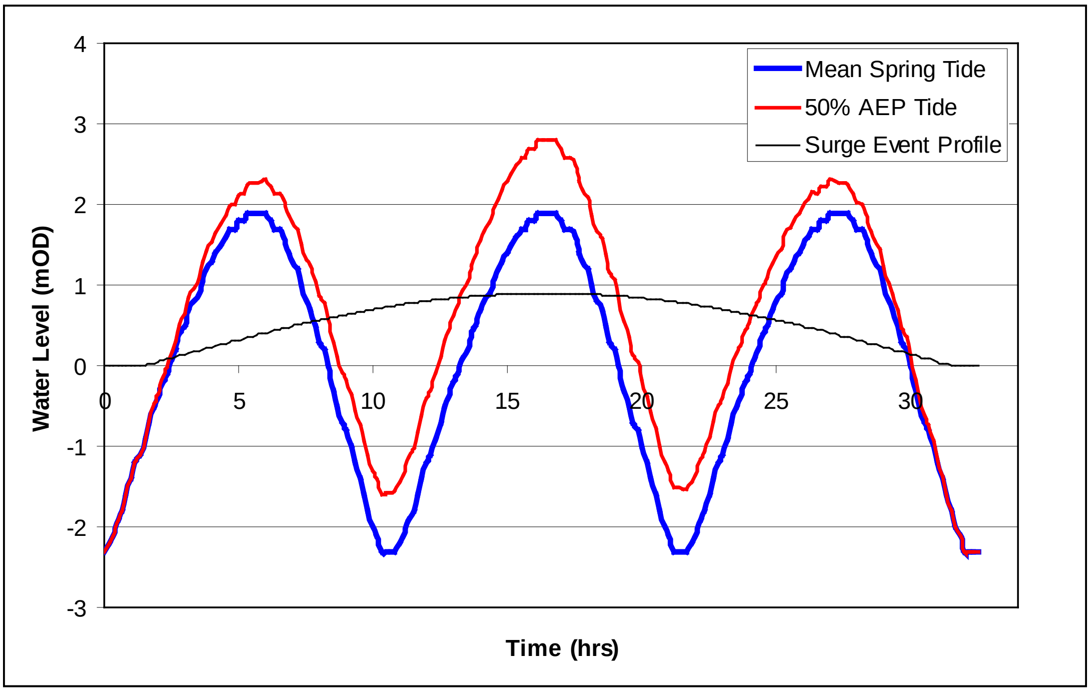


Figure 4.3 Example showing how a design tide hydrograph is produced

Stage 4: Allocation of design tidal hydrographs to the hydraulic model

In a final step, the different model downstream boundaries have been assigned to the closest prediction points and their associated design tidal hydrographs. For most of the models, direct allocation is deemed appropriate except for the hydraulic model S09 (AFA Foynes) where linear interpolation between two prediction points has been carried out. An example of this is shown in Figure 4.4.

Table 4.2 below lists the prediction points assigned to each model downstream boundary

Table 4.2 Allocation of ICPSS prediction points to model coastal boundary

ICPSS (Prediction Point Reference)	AFAs – Model No
S9	Ballylongford – Model S05
S25	Adare / Clarina - Model S06
S18 – S19	Foynes – Model S09
S21	Askeaton – Model S10
S12	Tarbert – Model IRR4

Within each relevant model Appendix section, coastal boundary location and associated design tidal hydrographs are indicated.

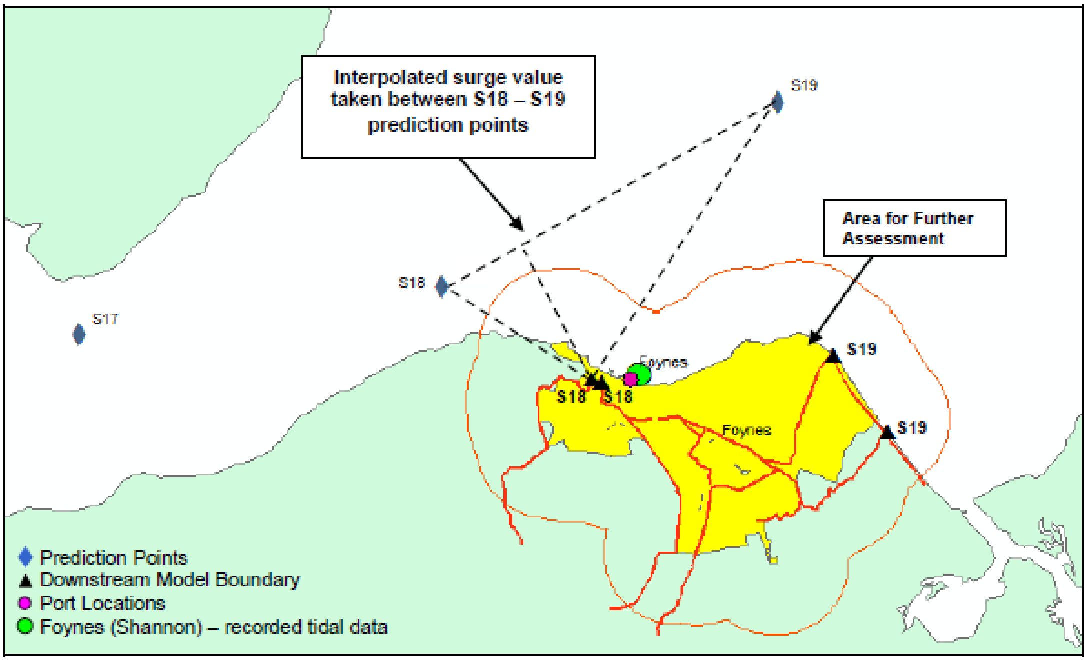


Figure 4.4 Model downstream boundary assignment for model S09 (Foynes AFA)

4.3.3 Changes made to the design tidal hydrographs for future scenario (MRFS and HEFS)

Changes have been made to the design tidal hydrographs for the design events under the MRFS and HEFS scenarios. They consist of a simple increase of the overall hydrograph according to the mean sea level rise and land movement allowances defined in Table F.1 of Appendix F in Shannon CFRAM Study Stage I Project Brief.

These allowances are summarised in Table 4.3 below.

Table 4.3 Future scenario allowances

	MFRS	HEFS
Mean Sea Level Rise (to 2100)	+500 mm	+1000 mm
Land Movement	-50 mm	-50 mm
Total change made to the tidal hydrographs	+550mm	+1050mm

4.4 Joint probability analysis for fluvially- and tidally-influenced models

A joint probability analysis of the coincidence of fluvial flood flows and coastal flood levels in the Shannon Estuary has been carried out. Methodology and outcomes of this analysis are detailed in the Hydrology Report for UoM 24.

Table 4.4 below is the main output of the joint probability analysis. It presents the combinations of design fluvial flood events and design tidal flood events that are used for the modelling of design events in areas of both fluvial and tidal influence. As required by the Project brief, in these areas two set of design runs are required to determine on one hand fluvially-dominated flood risk (odd number scenarios in Table 4.4) and on the other hand tidally-dominated flood risk (even number scenarios in Table 4.4).

Table 4.5 lists the hydraulic models in UoM24 for which such runs are carried out

Table 4.4 Combinations of fluvial and tidal events adopted for modelling in areas of both fluvial and tidal influence.

	Joint Probability Design Event (AEP)	Combinations suggested by the joint probability analysis (AEP)		Combinations adopted for modelling (AEP)	
Scenario	Overall AEP	Fluvial	Tidal	Fluvial	Tidal
1	50%	50%	500%	50%	500%
2	50%	**500%**	50%	50%	50%
3	20%	20%	500%	20%	500%
4	20%	**500%**	20%	50%	20%
5	10%	10%	200%	10%	200%
6	10%	**200%**	10%	50%	10%
7	5%	5%	100%	5%	100%
8	5%	**100%**	5%	50%	5%
9	2%	2%	50%	2%	50%
10	2%	50%	2%	50%	2%
11	1%	1%	20%	1%	20%
12	1%	20%	1%	20%	1%
13	0.5%	0.5%	10%	0.5%	10%
14	0.5%	10%	0.5%	10%	0.5%
15	0.1%	0.1%	2%	0.1%	2%
16	0.1%	2%	0.1%	2%	0.1%

Remarks on the adopted scenarios for modelling:

- For fluvial events of a lower magnitude than that for a 50% AEP event as highlighted in bold in column 3 of Table 4.4, design event data is not available. Therefore the tidally-dominated scenarios 2, 4, 6 and 8 have been run with a 50% AEP fluvial flow as indicated in column 5.

- Peak tidal levels associated with the design tidal events of lower magnitude than a 50% AEP event are not readily available from the ICPSS data. However they have been generated using extrapolation techniques for the relevant prediction point as shown on Figure 4.5 below.

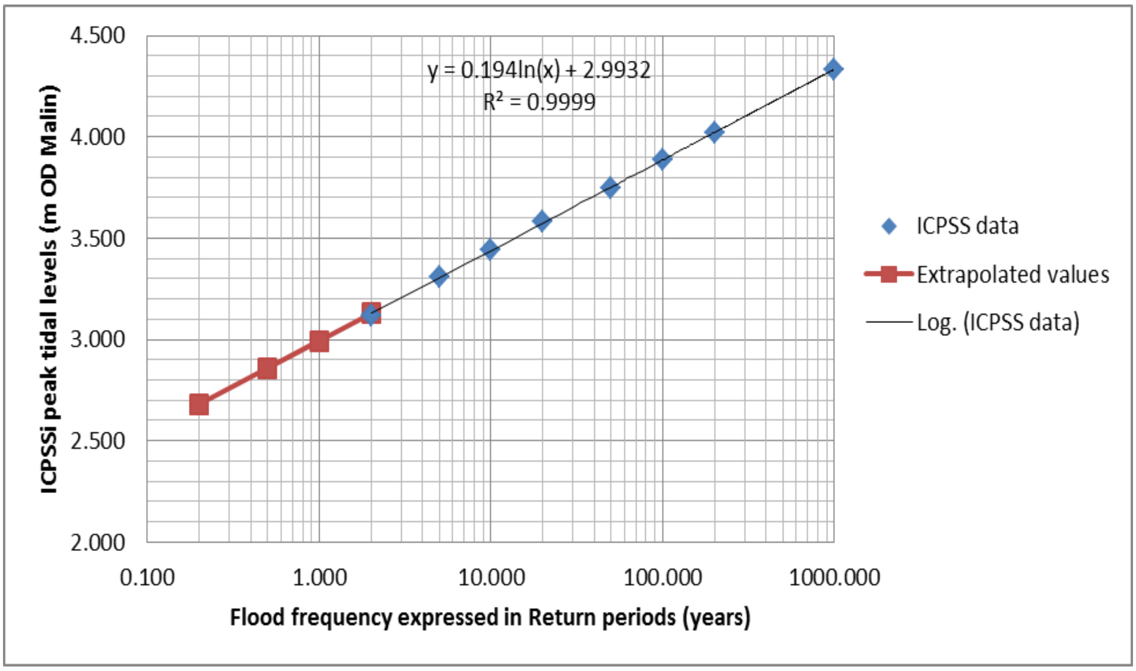


Figure 4.5 Extrapolation of ICPSS data fro high frequency tidal events

Table 4.5 Hydraulic models in UoM24 for which joint probability runs are required

Model No	AFAs affected
S05	Ballylongford
S06	Adare / Clarina
S09	Foynes
S10	Askeaton

4.5 Production of design wave overtopping discharge hydrographs to inform boundary conditions of coastal models

ICWWS data supplied by OPW shows areas potentially vulnerable to wave overtopping (see Section 2.5.2 and Figure 2.3). Foynes (Model S09) and Tarbert Power Station (IRR4) are the two locations within UoM24 where modelling is required to simulate flooding arising from wave overtopping of coastal defences.

To generate suitable boundary conditions to the hydraulic models, ICWWS data has been used following a four-step approach described below.

4.5.1 Step 1: Selection of coastal defence reaches

At each site, coastal defences vary in height, type and orientation relative to the mean direction of the incident waves. Therefore coastal defences prone to wave overtopping are divided in discrete reaches of similar characteristics (height, type and orientation) and allocated a wave prediction point according to its geographic proximity and the mean direction of the incident waves.

4.5.2 Step 2: Wave characteristics selection for the selected reaches of coastal defence:

For each flood event annual probability, ICWWS data consists of six combinations of extreme coastal water levels with predicted significant wave heights (‘Hmo’), peak wave period (‘Tp’) and mean wave direction. For each combination, the mean overtopping discharge (in m3/s per m of coastal defence length) associated with the wave characteristics and the type of flood defence (sea dikes, embankments and vertical wall) involved will be calculated. This calculation is to be carried out using the Neural Network method.

It should be noted that for the case when, for a given annual probability event, the water levels provided exceed the average elevation of the coastal defence reach overtopping will no longer occur and there will be tidal flooding. Is this case the tidal flooding the flood risk from wave overtopping will be considered along with the tidal flood risk.

4.5.3 Step 3: Generating a wave overtopping discharge hydrograph for the selected reaches of coastal defences

As quoted from the overtopping manual, “in reality there is no constant discharge over the crest of a defence during overtopping. The process of wave overtopping is very random in time and volume”. A simplified approach is followed here to generate a wave overtopping discharge hydrograph (Flow vs. Time) which is input in the hydraulic models at the landward side of the defences.

A wave overtopping discharge hydrograph is to be generated assuming 12 hour storm surge duration. Overtopping is to be assumed to occur for the full 12 hour storm surge duration. As the rate of overtopping varies with freeboard, the height of the crest of the defence above still water level, overtopping discharge rates are to be calculated at 30 points along the tidal curve. These discharge rates will be used to create the inflow hydrographs. The duration of overtopping is to be typically limited to the hours where the tidal water levels are at their peak.

4.5.4 Step 4: Simulating flooding arising from wave overtopping

Once the wave overtopping discharge hydrographs are generated for all the reaches of coastal defences under consideration at a particular site; these flow inputs will be applied directly to the hydraulic model using a flow versus time boundary along the landward side of the flood defences.

Within each relevant model Appendix section, wave overtopping boundary locations and associated discharge hydrographs will be indicated.

The wave overtopping models will be run for the full range of probabilities specified in Section 6.5.1 of the Project Brief for existing conditions and for the MFRS, and for the 10%, 0.5% and 0.1% AEP design events for the HEFS.

4.6 Hydraulic Model Calibration and Sensitivity Model Runs

4.6.1 Model Calibration and Verification to Historical Events

The approach to model calibration for the coastal models is described in Section 3.2.4 of the National Technical Co-ordination Group (NTCG) Guidance Note no. 23 (GN23) in Appendix D. The fundamental points to note, with regard to achieving the best model calibration, are that the following data must be known:

- **Tidal hydrograph and wave conditions** – as the driving force leading to coastal flooding
- **Water levels** recorded on the coastal floodplain and/or within the estuarine reaches
- **Coastal floodplain conditions – any topographic feature influencing the water level** across the floodplain at the time/date when the coastal flooding occurred.

For each model, an analysis of available flood event data for possible consideration as calibration/"reality checking" has been carried out. Results of these analyses are covered in the Hydrology report.

In UoM24 the availability of usable information is very limited and therefore none of the coastal models have been fully calibrated. However, for some models, some form of verification has been possible through "reality checks" carried out on the flood extents obtained and cross referenced with anecdotal evidence of flooding arising from tidal inundation and/or wave overtopping, if it exists.

Within each relevant model Appendix section, a summary of the calibration/"reality checking" process along with associated results is provided.

4.6.2 Model Sensitivity

Sensitivity tests are carried out on the hydraulic models in order to assess the sensitivity of the modelled systems to alterations in a number of key hydraulic parameters.

The results of the sensitivity analysis give an indication of the confidence levels that can be placed in the results being generated by the respective model.

For each coastal model within UoM24, the sensitivity runs are carried out for the 0.5% AEP tidal event. The following sensitivity tests have been carried out:

- Sensitivity to hydraulic roughness: Manning's 'n' values have both been increased and decreased by 20%
- Sensitivity to hydrological inflows. All hydrological inflows have both been increased and decreased by 20%
- Sensitivity to afflux parameters at key structures across the estuarine reaches. Afflux parameters have been varied to reduce or increase the head loss during a 0.5% AEP flood event at key structures susceptible to having an impact on the tidally dominated flood extents
- Sensitivity to the downstream conditions. Changes are made to the tidal boundaries by varying by +/-50% the surge duration component in the design tidal hydrographs to assess how the coastal flood outlines are affected.

Within each relevant model Appendix section, the results of the sensitivity tests are compared to the base case scenario and processed to determine the significance of the change in flood risk.

4.7 Model files and naming convention

The hydraulic model files associated with each coastal model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. Details (names and purpose) on the model files are included within each relevant model Appendix section.

The same model naming convention previously described in Section 3.6 is adopted for the coastal models.

4.8 Key Model Assumptions

Model specific assumptions are described in Section 6 of the relevant model Appendix section. In addition, there are generic assumptions which are summarised below.

As already mentioned in Section 4.3, the design tidal hydrographs used as downstream conditions are based on estimated ICPSS extreme water levels and hydrograph shapes derived using a mean Spring profile from the nearest port location and assuming a meteorological surge of 30hr duration.

For the hydraulic model with both fluvial and tidal components, the timing of the tidal hydrograph as downstream condition is adjusted so that the time of the highest tidal level coincides with the time of the maximum water levels within the estuarine reach for fluvial dominated event. This is a conservative approach that allows for a worst case scenario.

4.9 Quality Assurance

The same level of quality checking as previously described in Section 3.8 of this report is carried out on the development of coastal hydraulic models.

5 Flood Hazard Mapping

The following section describes the development of the flood hazard maps for the Shannon CFRAM study. The flood map type, information and format are provided, along with details relating to the associated processes.

5.1 Flood Map Type

The maps produced fall into one of the following five types:

- **Flood extent:** These maps show the extents of flooding associated with a design flood event for a given annual probability. Additional information such as tabulated peak flows and water levels are also shown (see Section 5.3).
- **Flood zone:** These maps show flood zones A, B and C, to facilitate implementation of the Guidelines on the Planning System and Flood Risk Management (DoEHLG & OPW, November 2009).
- **Flood depth:** These maps show the depths of flooding associated with a design flood event for a given annual probability.
- **Flood velocity:** These maps show the velocities of floodplain flows associated with a design flood event for a given annual probability.
- **Flood hazard:** These maps show the hazard (or 'risk to life') associated with a design flood event for a given annual probability as a function of the depth and velocity (see Section 5.7).

5.2 Flood Map Format

The flood maps are produced in both digital (GIS) and print ready (PDF) format, as follows:

- **GIS Format:** Geographical Information System (GIS) format refers to the display and representation of data produced by the models (and subsequently displayed on the print ready format maps) in digital format with both spatial and not spatial attributes defined. These files can be interrogated by users on their own GIS platforms and software.
- **Print Ready:** This format refers to the printable versions of the maps. This format allows for a wide range of users to access and view a complete standalone map including title block and legend in a single PDF.

Table 5.1A and B sets out the type of maps produced for each of the scenarios (current only) for the design flood event probabilities simulated with the hydraulic model.

Table 5.1 A - Shannon CFRAM Study “Print Ready” flood map outputs

	Current								MRFS								HEFS							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
Flood Extent Maps			✓			✓		✓			✓			✓		✓								
Flood Zone Maps						✓		✓																
Flood Depth Maps			✓			✓		✓																
Flood Velocity Maps			✓			✓		✓																
Flood Hazard Function Maps			✓			✓		✓																

Grey cells indicate that no map is required

Table 5.1 B - Shannon CFRAM Study “GIS” format flood map outputs

	Current								MRFS								HEFS							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
Flood Extent Maps	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓			✓		✓
Flood Zone Maps						✓		✓						✓		✓								
Flood Depth Maps	✓	✓	✓	✓	✓	✓	✓	✓			✓			✓		✓								
Flood Velocity Maps	✓	✓	✓	✓	✓	✓	✓	✓																
Flood Hazard Function Maps			✓			✓		✓																

Grey cells indicate that no map is required

5.3 Flood Extent Maps

5.3.1 Methodology

The flood extent maps are the extents of flooding along the modelled reach. The production technique for these maps differs depending on the model type used (i.e. whether 1D or 2D) and the processing requirements of the results. The procedure for each of model types is provided below.

- **1D Model Results:** First, the peak water levels at each node are extracted from the 1D ISIS model. Then a water surface profile is generated, based on a triangulated interpolation of model results (peak water levels) and model geometry information at each cross-section. The water surface profile is then subtracted from the LiDAR/IFSAR elevation grid at the corresponding location. This results in a 1D flood depth grid being created. This grid is processed into an extent polygon.
- **2D Model Results:** Flood extents are generated by processing the depth grid produced across the 2D domain by the model. In a 1D-2D linked models the 1D and 2D flood depth grids are combined. There is no particular flood depth threshold under which flooding is not reported**.** The combined flood depth grid is then converted into an extent.

In both instances described above, the results require post processing to ensure “Dry” and “Wet” islands are removed. These refer to holes or small areas separated hydraulically from the extents. A clean-up process is carried out to remove polygon islands or small holes (<100m²).

Ponding will occur where fluvial flow paths convey water into topographic depressions in the floodplain. As a result areas of ponding will not be removed. Wet islands which are disconnected from the fluvial contributions (which related to the 1D result processing) have been removed.

With regards to format of the print ready maps, the key requirements of these are provided below:

- **Map scale:** Maps are produced at 1:5,000 scale for AFAs and at 1:25,000 with background mapping at 1:50,000 for areas outside the AFAs, with the mapping in greyscale.
- **Map layers shown:** Fluvial flood events are shown for 10%, 1% and 0.1% AEPs, and are coloured using a transparent fill from dark blue to light blue. Also shown are points along the river centreline, with a table on the map showing the flow for 10%, 1% and 0.1% AEP (at selected locations) and water level at each point for 10%, 1% and 0.1% AEP. Areas benefiting from defences are shown by a grey hatched area.

5.3.2 Flood mapping in tidally- and fluvially-influenced areas

Tidal flood maps are produced for the 10%, 0.5% and 0.1% AEP events using the same methodology described above.

In areas where flooding is subject to both tidal and fluvial influence additional sets of flood maps are produced as defined in Section 7.5.2.1 of the project brief Stage I with an annotation text box showing the tidal/fluvial influence boundary.

5.3.3 Mapping uncertainty

Uncertainty is presented as per the Guidance Note 22 v5.5 (please see Appendix F), relating to sensitivity and uncertainty but is limited to the 1% AEP flood extent (0.5% AEP for coastal model). This is because the sensitivity analysis (described in Sections 3.5.3 and 4.6.2 and compliant with the mandatory suggested sensitivity runs) has been carried out for the 1% AEP event only (0.5% AEP for coastal models).

The sensitivity results have been used to generate outlines which have then been merged to create a single "worst case" outline. This is then compared to the 1% AEP design event on maps in addition to the flood extent maps listed in Table 5.1 A.

5.4 Flood Zone Maps

Flood zone maps show three zones: within the 1% AEP, between the 1% (and 0.5% AEP for coastal areas) and 0.1% AEP and outside the 0.1% AEP. The maps have been developed following the publication of the Guidelines on Planning and Flood Risk Management (Guidance note 33) and are based on the undefended scenario runs for the flood events mentioned above. The flood zone maps are generated using the outer flood extents associated with the undefended runs undertaken.

5.5 Flood Depth Maps

Flood depth maps show where the water would flow and the resulting peak depths that would be achieved for a specified annual exceedence probability. The maps are useful in planning and design to understand the depth of flooding in an area and they allow emergency responders to determine rescue areas, evacuation areas and potential evacuation routes. Flood depths also form the basis for the economic assessment.

The map borders, features and general components of the hardcopy depth maps are the same as the flood extent maps. The key features particular to the depth maps are:

- The 10%, 1% and 0.1% are shown on individual maps
- Depth information is only required for the current situation
- Flood depths are shown on the map in six graduated classes, coloured light blue to purple for low to high depths respectively.

5.6 Velocity Mapping

Flood velocity maps are only required for AFAs and not for MPW reaches.
The 2D models output velocity to the 2D grid which has a cell resolution of typically 5-20m (see Section 3.4.7). The 2D velocity output is therefore readily extracted to generate velocity maps. For the channel and floodplain represented in 1D, velocity distribution map is created using the predicted maximum velocity at each model node and GIS interpolation.

The key features particular to the velocity maps are:

- The 10%, 1% and 0.1% are shown on individual maps
- Velocity information is only required for the current situation and HPW reaches

- Flood velocities are shown on the map in five graduated classes, coloured yellow to red for low to high velocities respectively.

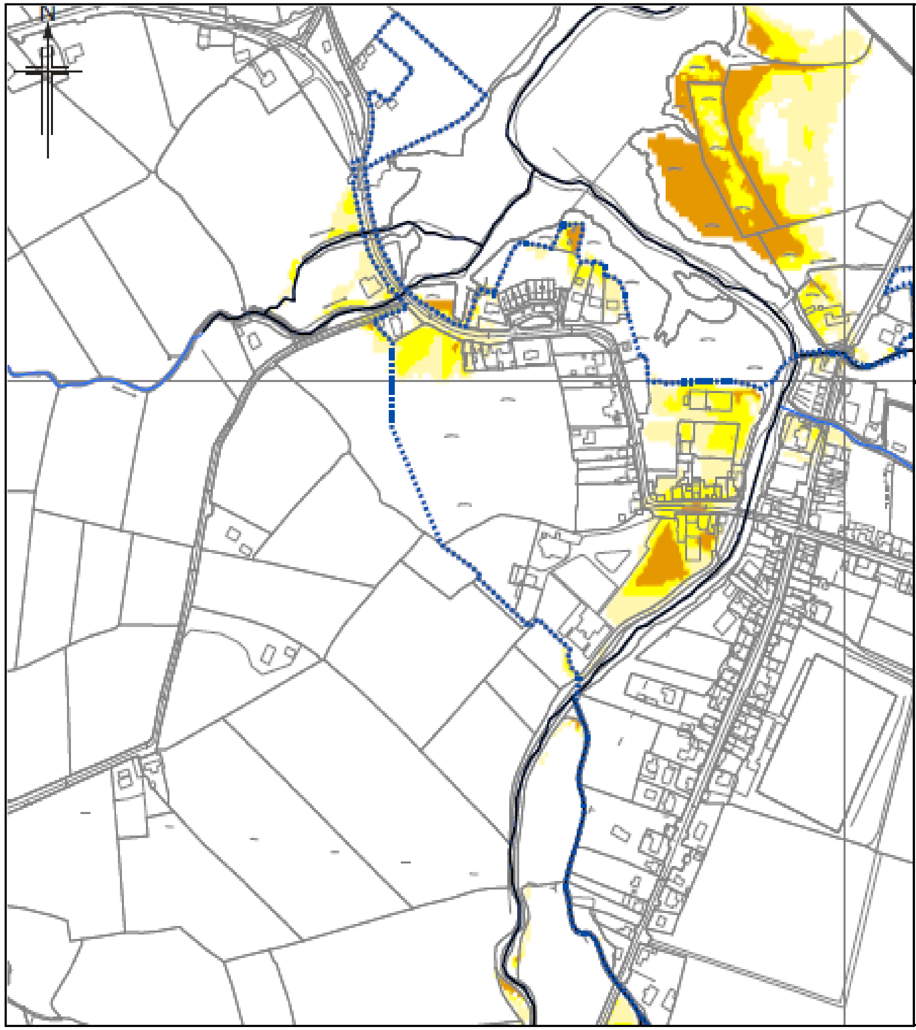
5.7 Flood Hazard Function Mapping

Flood hazard function maps show the risk to life which may be experienced for a particular flood event. This is calculated as a function of the depth and velocity of the flood waters. The Shannon CFRAM Study uses the methodology and concept set out in the Defra / EA guidance Flood Risks to People Phase 2 Study[10] to calculate flood hazard without a debris factor. The flood hazard function maps are created by calculating the hazard from the depth and velocity grids, as follows:

$$Hazard = d \times (0.5 + v)$$

The classifications of the degree of flood hazard are shown in Figure 5.1 along with the graduated colours used to display the flood hazard on the maps. An example of a flood hazard map is also shown in Figure 5.1.

[10] DEFRA 2006, Flood Risks to People, Phase 2, FD2321/TR1, The Flood Risks to People Methodology



Flood Hazard

- Low (< 0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (> 2.0)

Thresholds for Flood Hazard Rating H = d x (v+ 0.5)	Degree of Flood Hazard	Description
< 0.75	Low	Caution - " Flood zone with shallow flowing water or deep standing water"
0.75 - 1.25	Moderate	Dangerous for some (i.e children)-" Danger : Flood zone with deep or fast flowing water"
1.25 - 2.0	Significant	Dangerous for most people - " Danger : Flood zone with deep fast flowing water"
> 2.0	Extreme	Dangerous for all- " Extreme Danger : Flood zone with deep and/or fast flowing water"

Figure 5.1 Flood hazard map classifications

6 Conclusions and Recommendations

6.1 Conclusions

Calibration and verification was possible for Models S06, S07 and S11 using the information gathered up to Summer 2012 which was the date the topographic survey was complete. The above models were calibrated to within the specified tolerances. High level verification was possible for Model S05 using photographs of recent flood events. It was not possible to complete historical calibration for the other models within this UoM due to a lack of historical data.

The resulting flood maps form a representation of the predicted existing risk using all data made available up to the Summer of 2012 and were displayed at Public Consultation Days (PCD's) held in each AFA. Table 6.1 below provides information on the dates of the PCD and numbers of people attending. Further this these consultation days a national consultation exercise on the Draft Flood Maps was launched in November 2015 where objections could be made on the maps. There were no objections received on the UoM 24 maps.

Table 6.1 - Shannon CFRAM Study UoM 24 Public Consultation Days

AFA	County	Date of Public Consultation	Venue	Number of Attendees
Adare	Co. Limerick	Tuesday 14th April 2015	Adare Library, Main Street, Adare, Co. Limerick	25
Clarina	Co. Limerick	Tuesday 14th April 2015	Ballybrown/Clarina Community Resource Centre, Ballybrown, Co. Limerick	19
Newcastle West	Limerick	Thursday 12th March 2015	Aras William Smith O'Brien, Limerick City & County Council Offices, Gortboy, Newcastle West, Co. Limerick	24
Foynes	Limerick	Thursday 19th March 2015	Foynes Community Centre, Main Street, Foynes, Co. Limerick	45
Ballylongford	Kerry	Monday 15th December 2014	Ballylongford Parish Hall, Ballylongford, Co. Kerry	28
Croom	Limerick	Thursday 6th November 2014	Croom Enterprise Centre, Croom, Co. Limerick	16
Askeaton	Limerick	Thursday 6th November 2014	Askeaton Library, The Quay, Askeaton, Co. Limerick	9

AFA	County	Date of Public Consultation	Venue	Number of Attendees
Rathkeale	Limerick	Thursday 6th November 2014	Rathkeale Library, Main Street, Rathkeale, Co. Limerick	9
Milford	Cork	Thursday 11th September 2014	Milford Community Hall, Milford, Co. Cork	14
Dromcolliher	Limerick	Thursday 11th September 2014	Dromcolliher Library, Dromcolliher, Co. Limerick	7
Kilmallock	Limerick	Wednesday 10th September 2014	Kilmallock Library, Kilmallock, Co. Limerick	6
Charleville	Cork	Wednesday 10th September 2014	Charleville Library, Main St. Charleville, Co. Cork	5

The conclusion from this PCD exercise is that no amendments to the flood outlines were justified as a result.

6.2 Recommendations

In some AFAs, the lack of gauge data resulted in higher degree of uncertainty in the resulting predicted flood risk particularly the AFA of;

- Newcastle West
- Milford
- Charleville

Recommendations have been made for additional gauge stations in these AFAs.

It is also recommended that on future iterations of the flood model and maps, are verified against flood events which have occurred post Summer 2012.

Appendix A Extracts from the Project Brief

Extract from Section 7 of the CFRAM Studies Stage I Project Brief (June 2010)

7.8. HYDRAULICS REPORT

The Consultant shall submit to the OPW detailed, technical Hydraulics Reports that shall set out the work and analysis undertaken in relation to, and the findings and conclusions of, the surveys as defined within Section 5 and the hydraulic analysis as defined within Section 7, except for the work defined in Section 7.6 and 7.7, which shall be reported upon in the Preliminary Options Reports.

The Consultant shall supply the following as part of, or as an accompaniment to, the Draft and Final Hydraulics Reports:

- All survey data, including digital data files, as detailed in Section 5.
- Digital hydraulic model files, including, but not necessarily limited to, calibration, verification, design run and sensitivity analysis model and results files, for the work detailed in Section 7, excluding Section 7.6 and 7.7.
- A copy of the defence asset database with all flood defence asset geometric and condition survey completed and accurately entered, including the defence asset survey deliverables, as detailed in Section 5.1 and 5.2 and Appendices C and D
- Digital copies of the GIS-Format and Print-Ready Format Flood hazard maps, as detailed in Section 7.5

The OPW, assisted by the Steering Group and other experts as deemed necessary by the OPW, shall review the Draft Hydraulics Reports and submit observations to the Consultant within six (6) weeks of receipt.

The Consultant shall review the observations submitted by the OPW, and prepare and submit to the OPW a Draft Final Hydraulics Reports that suitably addresses the observations of the OPW within four (4) weeks of receipt of the observations from the OPW.

The OPW, assisted by the Steering Group and other experts as deemed necessary by the OPW, shall, within four (4) weeks of receipt, review the Draft Final Hydraulics Reports to ensure that all observations have been appropriately addressed. In the event that the OPW does not consider that all observations have been appropriately addressed, the OPW shall submit further observations to the Consultant to be addressed by the Consultant as set out above. In the event that the OPW is satisfied that all observations have been appropriately addressed, the Consultant shall re-submit the Draft Final Hydraulics Reports as the Final Hydraulics Reports.

The Consultant shall prepare and submit separate Draft, Draft Final and Final Hydraulics Reports for each Unit of Management within the Study Area.

The Consultant shall provide a number, as identified in the tender documentation for the Specific Tender Stage (Stage II), of bound sets of printed hardcopies of each set of Draft and of Final flood hazard maps as set out in Section 7.5 and above.

Extract of Sections 2.21 to 2.23 of the Stage II Project Brief (October 2010)

2.21 Section 7.3.1 – Coastal Flooding Model Development

For the APSRs where the OPW shall provide the Consultant with wave data (see Section 2.19 herein, amending Section 6.5.4 of the Generic Specification), the Consultant shall develop the coastal flooding models such that they will be able to simulate flooding from wave overtopping of defences as well as from tide and surge events.

2.22 Section 7.3.3 – Coastal Flooding Model Design Runs

For the APSRs where the OPW shall provide the Consultant with wave data (see Section 2.19 herein, amending Section 6.5.4 of the Generic Specification), the Consultant shall run the coastal flooding models to simulate flooding for the design flood events to determine flood levels, extents and other parameters for flooding that would be projected to arise from wave overtopping [as well as such runs for tide and surge events (i.e., based on data provided as set out in Sections 6.5.4 and 7.3 and Appendix E of the Generic Specification)], for the full range of probabilities specified in Section 6.5.1 of the Generic Specification for existing conditions and for the MRFS, and for the 10%, 0.5% and 0.1% AEP design events for the HEFS. The Consultant shall produce flood mapping for the flooding that would be projected to arise from wave overtopping as set out in Sections 7.5 and 8.3 of the Generic Specification [as well as such mapping for tide and surge events].

2.23 Section 7.8 – Hydraulics Report

The fourth bullet point under the second paragraph of Section 7.8 of the Generic Specification (starting 'Digital copies of the GIS-Format …') is deleted in its entirety and replaced with:

- Digital copies of the GIS-Format and Print-Ready Format flood hazard maps and flood risk maps, as detailed in Section 7.5 and 8.3

The Consultant shall supply as an accompaniment to the Draft and, amended as necessary, Final Hydraulics Report a set of GIS files and summary report for each Unit of Management, providing the information set out in Appendix V.

The fourth paragraph of Section 7.8 of the Generic Specification (starting 'The Consultant shall review the observations submitted …') is deleted in its entirety and replaced with:

> The Consultant shall review the observations submitted by the OPW, and prepare and submit to the OPW a second Draft Final Hydraulics Reports that suitably addresses the observations of the OPW within four (4) weeks of receipt of the observations from the OPW.

The fifth paragraph of Section 7.8 of the Generic Specification (starting 'The OPW, assisted by the Steering Group and other experts as deemed necessary by the OPW, shall, within four (4) weeks of receipt, review the Draft Final Hydraulics Reports …') is deleted in its entirety and replaced with:

> The OPW, assisted by the Steering Group and other experts as deemed necessary by the OPW, shall, within three (3) weeks of receipt, review the second Draft Final Hydraulics Reports to ensure that all observations have been appropriately addressed. In the event that the OPW does not consider that all observations have been appropriately addressed, the OPW shall submit further observations to the Consultant to be addressed by the Consultant as set out above. In the event that the OPW is satisfied that all observations have been appropriately addressed, the Consultant shall re-submit the second Draft Final Hydraulics Reports, and accompanying flood hazard and risk maps, as the Draft Final Hydraulics Reports and the Draft Final Flood Maps.

The Consultant shall provide twenty-five (25) bound and printed hardcopies of the Draft Hydraulics Report.

The Consultant shall provide twenty-five (25) bound and printed hardcopies of the Draft Final Flood Maps.

The Draft Final Flood Maps (including the hazard and risk maps, as set out in Sections 7.5 and 8.3 of the Generic Specification) shall be put out to public and stakeholder consultation for a period of three (3) months.

The Consultant shall review all submissions made during the three (3) month public and stakeholder consultation period, that should close no later than 30/09/2013, and shall provide written appropriate responses to each and all submissions to the OPW within one (1) month (i.e., by 31/10/2013) for review and, subject to clarification of any queries on the response by the Consultant, issue to the submitter.

The Consultant shall submit, no later than 31/10/2013, the first version of the Final Hydraulics Reports and Flood Maps that shall be amended revisions the Draft Final Hydraulics Reports (and all components thereof) and Draft Final Flood Maps that address the submissions and comments raised during the public and stakeholder consultation period, subject to discussions with the OPW and Steering Group.

The OPW, assisted by the Steering Group and other experts as deemed necessary by the OPW, shall, within two (2) weeks of receipt, review the first version of the Final Hydraulics Reports and Flood Maps. In the event that the OPW does not consider that all observations have been appropriately addressed, the OPW shall submit further observations to the Consultant to be addressed by the Consultant, after which the Consultant shall submit a revised version of the Final Hydraulics Reports and Flood Maps within two (2) weeks. In the event that the OPW is satisfied that all observations have been appropriately addressed, the Consultant shall re-submit the Reports and Maps as the final versions of the Final Hydraulics Reports and Final Flood Maps

The Consultant shall provide twenty-five (25) bound and printed hardcopies of the Final Hydraulics Report.

The Consultant shall provide twenty-five (25) bound and printed hardcopies of the Final Flood Maps.

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Appendix B Fluvial Hydraulic Model Appendices

Fluvial Hydraulic Modelling Report	
1. Basic Model Information	
1.1 General Information	
Model ID:	S07
Unit of Management	24
AFA included in the model	Croom
Primary Watercourses / Water Bodies	River Maigue River Laskiltagh
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A1.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B3 – Figure B3.1

2. Survey Data and Base Mapping	
2.1 Base Mapping:	OSi data base mapping at scale 1:50k
2.2 DTM for 2D Model Domains:	**Within AFA:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFA: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 165
2.4 Defence Asset Survey Data	The defence asset database has been completed for this Model Area. No formal or informal effective defences have been identified within the model area.
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:** ISIS Version 3.6.0.156
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - AFA boundary

2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included**

3.3 Model Reaches:	The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
River Maigue	04MGU	04MGU09757	04MGU00000
	03MGU	03MGU03560	03MGU00033
River Laskiltagh	01CRB	01CRB02417	01CRB00000

Total model HPW length (km):	4.60	**Total model MPW length (km):**	11.92

3.4 Model Structures:

A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	11
Bridges:	☒	How many?	7
Fixed crest weirs:	☒	How many?	6
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation

Out-of-bank areas for MPW reaches have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections.

Out-of-bank areas for HPW reaches, within Croom AFA, have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections.

Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple (e.g, parallel to river flow). 1D-2D modelling is required where HPWs flow through urban areas and out-of-bank flows will form complex flow paths.

An overview of the floodplain schematisation is available in the maps shown in Annex A.

3.6 Hydraulic Roughness	Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:	
MPW In-bank Bed and Bank Sides	Minimum 'n' value:	0.035
	Maximum 'n' value:	0.040
HPW In-bank	Minimum 'n' value:	0.035
	Maximum 'n' value:	0.045
Floodplain (ISIS Model)	Manning's 'n' for out-of-bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:	
	Land Use	**Manning's 'n' Value**
	Pastures	0.035
	Dense Vegetation	0.080
	Road Network	0.025
	Buildings	0.100
3.7 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.	
3.8 Model Boundaries - Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report relevant to Unit of Management 24.	
(a) Current Situation (Main Model)	Peak inflows (m3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2)	

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1223_1	04MGU09757	78.3	100.3	113.2	125.0	140.1	151.2	162.3	187.9
24_1223_2	04MGU09757	9.5	12.2	13.8	15.2	17.1	18.4	19.8	22.9
24_229_2	04MGU06143	3.7	4.7	5.3	5.9	6.6	7.1	7.6	8.8
24_194_2	04MGU03267	37.4	48.0	54.1	59.8	67.0	72.3	77.6	89.9
24_806_3	04MGU01197	3.0	2.7	3.0	3.3	3.7	4.0	4.3	5.0
24_1594_1	04MGU00000	1.8	1.6	1.8	2.0	2.2	2.3	2.5	2.9
24_1120_6	01CRB02417	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
24_1120_8	01CRB01305	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

(a) Current Situation (Trib)									
24_1223_1	04MGU09757	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
24_1223_2	04MGU09757	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
24_229_2	04MGU06143	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
24_194_2	04MGU03267	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
24_1594_1	04MGU00000	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
24_1120_6	01CRB02417	2.6	3.3	3.8	4.2	4.7	5.0	5.4	6.3
24_1120_8	01CRB01305	0.4	0.6	1.0	0.7	0.8	1.4	0.9	1.8
(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.								
HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
Main Model									
24_1223_1	04MGU09757	93.9	120.3	135.8	150.0	168.1	181.5	194.8	225.5
24_1223_2	04MGU09757	11.4	14.7	16.5	18.3	20.5	22.1	23.7	27.5
24_229_2	04MGU06143	4.4	5.6	6.4	7.0	7.9	8.5	9.1	10.6
24_194_2	04MGU03267	44.9	57.6	64.9	71.8	80.4	86.8	93.2	107.9
24_806_3	04MGU01197	3.6	3.2	3.6	4.0	4.5	4.8	5.2	6.0
24_1594_1	04MGU00000	2.1	1.9	2.1	2.3	2.6	2.8	3.0	3.5
24_1120_6	01CRB02417	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
24_1120_8	01CRB01305	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Tributary Model									
24_1223_1	04MGU09757	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
24_1223_2	04MGU09757	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
24_229_2	04MGU06143	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
24_194_2	04MGU03267	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
24_1594_1	04MGU00000	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
24_1120_6	01CRB02417	3.1	4.0	4.5	5.0	5.6	6.0	6.5	7.5
24_1120_8	01CRB01305	0.5	0.7	1.2	0.8	0.9	1.7	1.1	2.2

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.			
HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
Main Model				
24_1223_1	04MGU09757	147.2	196.6	243.9

24_1223_2	04MGU09757	17.9	23.9	29.8
24_229_2	04MGU06143	6.9	9.2	11.4
24_194_2	04MGU03267	70.3	93.9	116.9
24_806_3	04MGU01197	3.9	5.2	6.4
24_1594_1	04MGU00000	2.3	3.1	3.8
24_1120_6	01CRB02417	1.8	1.8	1.8
24_1120_8	01CRB01305	0.3	0.3	0.3
Tributary Model				
24_1223_1	04MGU09757	26.0	26.0	26.0
24_1223_2	04MGU09757	6.	6.4	6.4
24_229_2	04MGU06143	2.5	2.5	2.5
24_194_2	04MGU03267	19.5	19.5	19.5
24_1594_1	04MGU00000	0..8	0..8	0.8
24_1120_6	01CRB02417	4.9	6.5	8.2
24_1120_8	01CRB01305	1.3	1.8	2.5

3.9 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow. The spills into the reservoirs have been digitised from the LiDAR using ISIS mapper. This tool creates a spill unit containing the highest points 5 metres to the left and right of the line required. This method allows for a more accurate spill definition than just taking the points from the ISIS cross sections.
3.10 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows: The downstream end of the model corresponds to Castleroberts gauging station. A review of the rating equation at this station was carried out by Jacobs as part of the Shannon CFRAM study (see Hydrology Report for UoM 24). The revised rating equation at this station was used as the downstream boundary (Flow-Head Boundary) for this hydraulic model.

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events	The approach to model calibration is documented in the Main Hydraulics Report. The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F). A full account of the model calibration approach and results is provided in Annex C. A summary of the calibration and verification events along with associated model calibration results is as follows:
Catchment Gauging	Is modelled catchment: Gauged ☒ Ungauged ☐

Gauging Stations	**Station Number**	**Watercourse**	**Location**	**ISIS Node Reference**
	24001	River Maigue	Croom	04MGU01372
	24008	River Maigue	Castleroberts	03MGU00033

Calibration and verification events	**Event Date**	**Station Number**	**Difference between Modelled and Observed Water Level (mm)**	**Root Mean Square Error**	
				HPW	**MPW**
Event 1 (GS 24001 to GS24008)	23/01/2002	24008	+40	N/A	40
Event 2 (GS 24001 to GS24008)	19/11/2009	24008	-20	N/A	20
Event 3 (GS 24001 to GS24008)	09/03/1995	24008	+30	N/A	30
Event 4 (GS 24001 to GS24008)	30/12/1998	24008	0	N/A	0

Summary of Findings	No hydrometric data was deemed suitable for calibrating the hydraulic model upstream of Croom gauging station (24001) or the River Laskiltagh, as outlined in the Hydrology Report for Unit of Management 24 Appendix F. It was possible to calibrate the model for two in-bank historical events and one out-of-bank historical event, and to verify the model for one out-of-bank event for a reach of the River Maigue between Croom gauging station 24001 & Castleroberts gauging station 24008. The results suggest that the model calibrates well for the two “in-bank” historical events and for the “out-of-bank” event with all results within the acceptable range of +/-0.2m for a HPW. The calibration was successfully verified with no stage difference between the modelled peak water level and observed peak water level. The model was also verified using anecdotal evidence (see photographs in Annex C) from the December 1998 event. The flood levels shown in the photographs were found to be in agreement with the predicted flood levels in the River Maigue channel.

4.2 Calibration to HEP	Calibration of the hydraulic model to the HEP target flows has been carried out for all design events simulated (10%, 1% and 0.1% AEP). Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincided with the peak time of the propagating flood wave as it was routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Where required, inflows to the hydraulic model were scaled up/down to ensure that the modelled total peak flows remain within ±10% of the HEP target flows. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. Agreement between the HEP target flow and the modelled flow was not met at HEP points 24_1223_1 and 24_1223_2. These HEP points are located outside the upstream extent of the model. The modelled flow for these HEPs has been taken at the most upstream cross section of the model which is located downstream of the two HEP points, therefore it is not possible to get agreement between these HEP target flows and the modelled flows at these HEPs. All other HEP target flows and model flows for all other HEPs were within the 10% agreement. The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: 2.47%, 2.44%, and 2.41% for the 10%, 1% and 0.1% AEP events respectively.

HEP Reference Name	Node in the Hydraulic Model	Annual Exceedance Probability							
		Percentage Difference (%)							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1223_1	09DEL00012u	10.9	10.9	12.2	10.9	10.9	12.2	10.9	- 12.2
24_1223_2	04MGU09757	10.9	10.9	12.2	10.9	10.9	12.2	10.9	- 12.2
24_229_2	04MGU09757	- 0.1	- 0.2	- 0.1	- 0.1	- 0.2	- 0.1	- 0.1	0.1
24_194_2	04MGU06560	- 0.2	- 0.2	- 0.2	- 0.2	- 0.2	- 0.2	- 0.2	0.1
24_805_2	04MGU03267	- 0.2	- 0.3	- 0.2	- 0.3	- 0.3	- 0.2	- 0.3	0.2
24_806_2	04MGU02664	- 0.2	- 0.3	- 0.2	- 0.3	- 0.3	- 0.2	- 0.3	0.2
24_806_3	04MGU01791	- 0.2	- 0.3	- 0.2	- 0.3	- 0.3	- 0.2	- 0.3	0.2
24_806_5	04MGU01215	0.5	- 0.3	- 0.2	- 0.3	- 0.3	- 0.2	- 0.3	0.2
24_806_6	04MGU00235	0.5	- 0.3	- 0.2	- 0.3	- 0.3	- 0.2	- 0.3	0.2
24_1594_1	04MGU00071	1.9	1.6	0.8	1.4	1.3	0.6	1.2	- 0.5
24_1594_2	03MGU03463	1.9	1.6	0.8	1.4	1.3	0.6	1.2	- 0.5
24_1594_3	03MGU03159	1.9	1.6	0.8	1.4	1.3	0.6	1.2	- 0.5
24_1594_8	03MGU02651u	1.0	0.6	- 0.2	0.4	0.3	- 0.4	0.3	0.5
24_1120_6	03MGU00033	0.1	0.0	0.1	- 0.1	- 0.1	0.1	- 0.1	0.0
24_1120_8	01CRB02417	0.1	0.0	0.1	- 0.1	- 0.1	0.1	- 0.1	- 0.1
24_1120_11	01CRB01429	- 7.0	- 9.0	- 8.9	- 7.8	- 11.2	- 8.7	- 11.9	- 8.7

<table>
<tr><td>4.3 Model Sensitivity</td><td colspan="4">Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. In each case the sensitivity run was carried out for the 1% AEP fluvial event. Sensitivity test results are provided in the following tables. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work.</td></tr>
<tr><td rowspan="3">+20% Manning's 'n'</td><td>Watercourse</td><td>Average Water Level Difference (m)</td><td>Maximum Water Level Difference (m)</td><td>Cross-section / Reach where the Maximum Difference occurs</td></tr>
<tr><td>River Maigue</td><td>+0.13</td><td>+0.30</td><td>04MGU00016</td></tr>
<tr><td>River Laskiltagh</td><td>+0.09</td><td>+0.20</td><td>01CRB01536</td></tr>
<tr><td rowspan="3">-20% Manning's 'n'</td><td>Watercourse</td><td>Average Water Level Difference (m)</td><td>Maximum Water Level Difference (m)</td><td>Cross-section where the Maximum Difference occurs</td></tr>
<tr><td>River Maigue</td><td>-0.13</td><td>-0.45</td><td>04MGU00071</td></tr>
<tr><td>River Laskiltagh</td><td>-0.02</td><td>-0.19</td><td>01CRB01536</td></tr>
<tr><td rowspan="3">+20% inflows</td><td>Watercourse</td><td>Average Water Level Difference (m)</td><td>Maximum Water Level Difference (m)</td><td>Cross-section where the Maximum Difference occurs</td></tr>
<tr><td>River Maigue</td><td>+0.16</td><td>+0.46</td><td>04MGU02181u</td></tr>
<tr><td>River Laskiltagh</td><td>+0.05</td><td>+0.25</td><td>01CRO1731c2i</td></tr>
<tr><td rowspan="3">-20% inflows</td><td>Watercourse</td><td>Average Water Level Difference (m)</td><td>Maximum Water Level Difference (m)</td><td>Cross-section where the Maximum Difference occurs</td></tr>
<tr><td>River Maigue</td><td>-0.19</td><td>-0.79</td><td>04MGU02181su</td></tr>
<tr><td>River Laskiltagh</td><td>-0.05</td><td>-0.22</td><td>01CRO1731c2i</td></tr>
<tr><td>Afflux at Key Structure
Weir discharge coefficient increased by 20%</td><td colspan="4">There are two structures within the Croom AFA which have a significant head loss during the 1% AEP flood event. The first is a labyrinth weir at cross-section 04MGU01791. The weir velocity coefficient was increased by 20% (to a value of 1.2) and resulted in a small decrease of 60mm to the maximum water level immediately upstream of the weir. However, the decrease in water level did not impact on the predicted flood outline as the floodplain is quite steep in this area.</td></tr>
<tr><td>Afflux at Key Structure
Weir discharge coefficient decreased by 20%</td><td colspan="4">The labyrinth weir (04MGU01791) velocity coefficient was decreased by 20% (to a value of 0.8) and resulted in an increase of 68mm to the maximum water level immediately upstream of the weir. However, the increase in water level did not impact on the predicted flood outline as the floodplain is quite steep in this area.</td></tr>
<tr><td>Afflux at Key Structure
Calibration coefficient increased by 20%</td><td colspan="4">The second structure is a bridge (Bridge Street) at cross-section 04MGU01329. The increase of the calibration coefficient resulted in a small increase of 44mm to the maximum water level immediately upstream of the bridge. However, the increase in water level did not impact on the predicted flood outline as the floodplain is quite steep in this area.</td></tr>
</table>

Afflux at Key Structure Calibration coefficient decreased by 20%	The reduction of the calibration coefficient at the bridge (04MGU01329) resulted in a decrease of 215mm to the maximum water level immediately upstream of the bridge. However, the decrease in water level did not impact on the predicted flood outline as the floodplain is quite steep in this area.
Downstream Conditions The stage in the HQ boundary is reduced by 0.2 m	Decreasing the stage in the downstream boundary condition has resulted in a decrease in maximum water level of 20mm at the downstream boundary (03MGU00033). The effect diminishing upstream can be seen for 450m upstream of the downstream boundary, but has no impact on the water levels and predicted flood extent in Croom AFA.
Downstream Conditions The stage in the HQ boundary is increased by 0.2 m	Increasing the stage in the downstream boundary condition has resulted in an increase in maximum water level of 20mm at the downstream boundary (03MGU00033). The effect diminishing upstream can be seen for 450m upstream of the downstream boundary, but has no impact on the water levels and predicted flood extents in Croom AFA.
4.4 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D.

5. Hydraulic Model Outputs

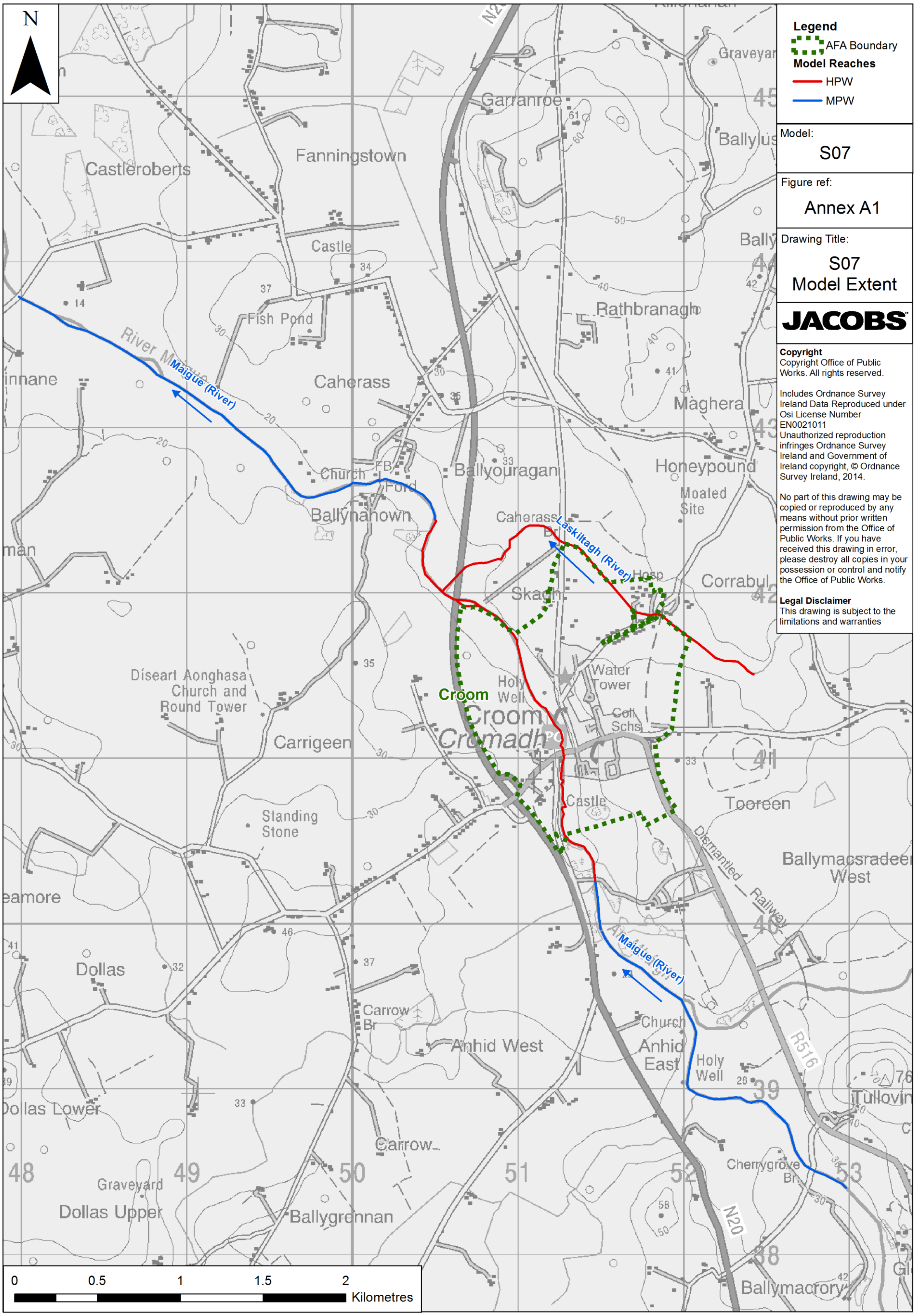
5.1 Mapping	Model outputs have been processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard All of the maps contain the maximum extent, depth, velocity and flood hazard for the combined main stream inflows and the tributary inflows. An explanation for the main stream inflows and the tributary inflows is provided in Section 6. Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP flood events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

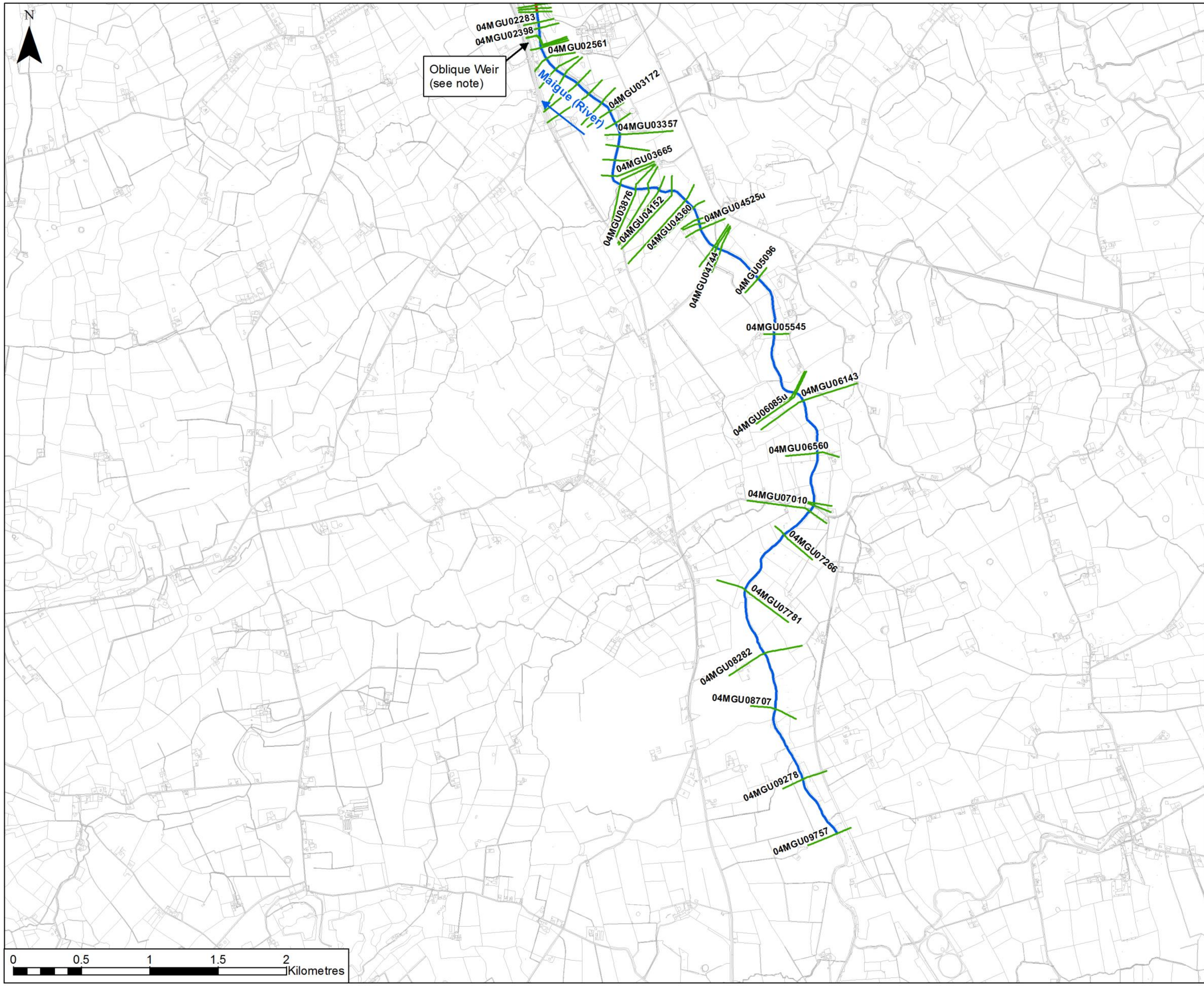
- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. The River Maigue is classified as the main channel. The River Laskiltagh is classified as the tributary. Inflow hydrographs were purposely produced for both the main channel and tributaries and two models were run. The first containing only the main channel inflows (main model), and the second containing only the tributary inflows (tributary model). The main stem model and tributary model share exactly the same geometry (structures and topography). The model outputs from all models were then merged picking up the maximum flood depths and extents to create the flood maps.

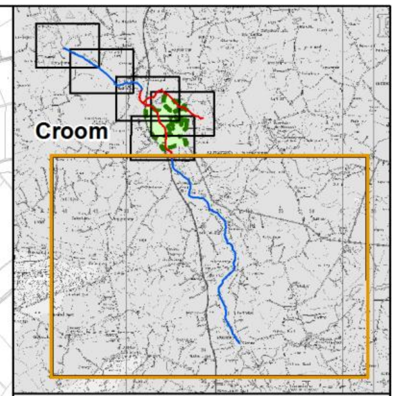
Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent



Annex A2 – Schematisation Maps





Legend

AFA Boundary

Model Reaches

HPW

MPW

1D Floodplain Schematisation

Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Oblique Weir - Sections shown on map are indicative of the weir location. Refer to structure schedule in Annex B for actual representation of the weir in the model.

Model: S07

Figure ref: Annex A2 (1)

Drawing Title: S07 Model Schematisation

Client:
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
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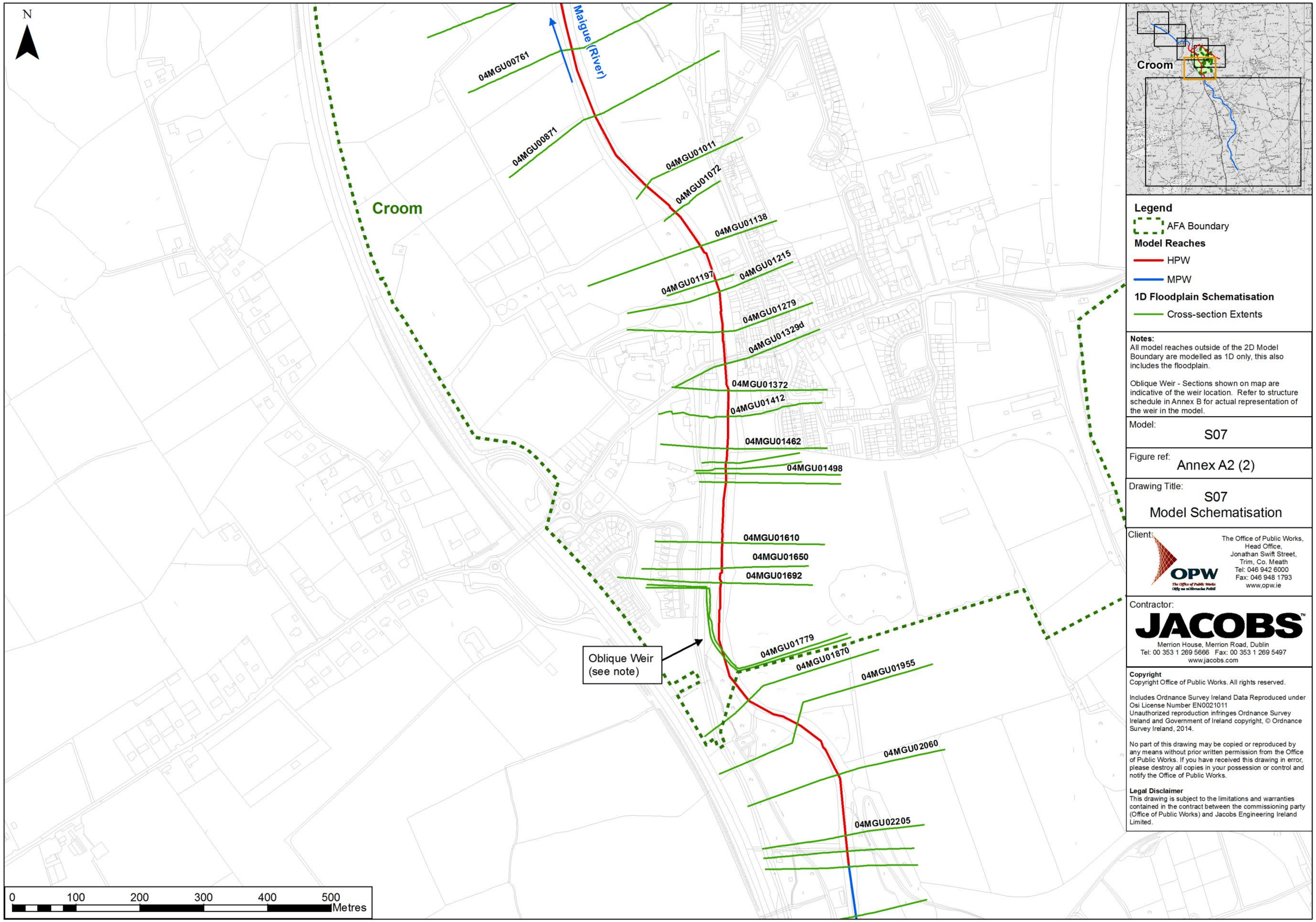
www.opw.ie

Contractor:
JACOBS
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com



N
Croom
Maigue (River)
04MGU00761
04MGU00871
04MGU01011
04MGU01072
04MGU01138
04MGU01197
04MGU01215
04MGU01279
04MGU01329d
04MGU01372
04MGU01412
04MGU01462
04MGU01498
04MGU01610
04MGU01650
04MGU01692
Oblique Weir (see note)
04MGU01779
04MGU01870
04MGU01955
04MGU02060
04MGU02205
0 100 200 300 400 500 Metres
Croom
Legend
AFA Boundary
Model Reaches
HPW
MPW
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Oblique Weir - Sections shown on map are indicative of the weir location. Refer to structure schedule in Annex B for actual representation of the weir in the model.
Model: S07
Figure ref: Annex A2 (2)
Drawing Title: S07 Model Schematisation
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Contractor: JACOBS
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Croom

Legend

AFA Boundary

Model Reaches

HPW

MPW

1D Floodplain Schematisation

Cross-section Extents

Notes: All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S07

Figure ref: Annex A2 (3)

Drawing Title: S07 Model Schematisation

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N
Croom
Laskiltagh (River)
Maigue (River)
01CRB00333
01CRB00434
01CRB00540
01CRB00924d
01CRB01032
01CRB01105
01CRB01219
01CRB01305
01CRB01429
01CRB01536
01CRB01560u
01CRB01629
01CRB01662u
01CRB01805
01CRB01924
01CRB02002
01CRB02114
01CRB02244
01CRB02306
01CRB02417
04MGU00560
04MGU00663
04MGU00761
04MGU00871
04MGU01011
04MGU01072
04MGU01138
04MGU01197
04MGU01215
04MGU01279
04MGU01329d
0 100 200 300 400 500
Metres
Croom
Legend
AFA Boundary
Model Reaches
HPW
MPW
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S07
Figure ref: Annex A2 (4)
Drawing Title: S07 Model Schematisation
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N
03MGU00332
03MGU00395
03MGU00466
03MGU00564
Maigue (River)
03MGU01130
03MGU01612
03MGU02109
03MGU02222
0
100
200
300
400
500
Metres
Croom
Legend
AFA Boundary
Model Reaches
HPW
MPW
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S07
Figure ref:
Annex A2 (5)
Drawing Title:
S07
Model Schematisation
Client:
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Contractor:
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Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for River Maigue

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24MAIG02827W and 24MAIG02826X	N/A	Weir	Labyrinth weir	N**
24MAIG02476E	04MGU06958	Bridge of 7.40 m wide	Arch bridge + Spill	Y
24MAIG02391W and 24MAIG02390X	04MGU06066	Weir	Round nose weir	Y
24MAIG02263D	04MGU04711	Bridge of 6.92 m wide	Arch bridge + Spill	Y
24MAIG02242W and 24MAIG02241X	04MGU04498	Weir	Round nose weir	Y
24MAIG02036W and 24MAIG02036X	04MGU02412	Weir	Labyrinth weir	Y
24MAIG02013D	04MGU02181	Bridge of 6.37 m wide	Arch bridge + Spill	Y
24MAIG01969W and 24MAIG01969X	04MGU01791	Weir	Labyrinth weir	Y
MGUE_0817	04MGU01329	Bridge of 1m wide	Arch Bridge + Spill	Y
24MAIG01813D	04MGU00116	Bridge of 18.09 m wide	Arch Bridge + Spill	N*
24MAIG01708D	03MGU02615	Bridge of 1.30 m wide	Arch Bridge + Spill	Y

*** Considering the size of the structure relative to the watercourse it was determined that the structure would have little or no hydraulic impact on the model.**
**** Structure outside of model extent.**

Schedule A.2 - Structure Schedule for River Laskiltagh

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24MAIC00171D and 24MAIC00170E	01CRB01731	Bridge of 8.44 m wide	Sprung Arch Culverts + Spill	Y
24MAIC00168E	01CRB01697	Bridge of 16.32 m wide.	Sprung Arch Culverts + Spill	Y
24MAIC00166D	01CRB01677	Bridge of 3.98 m wide.	Arch Bridge + Spill	Y
24MAIC00164D	01CRB01662	Bridge of 4.00 m wide.	Arch Bridge + Spill	Y
24MAIC00154D and 24MAIC00153E	01CRB01560	Bridge of 12.36 m wide.	Rectangular Culverts + Spill	Y
24MAIC00092E	01CRB00935	Bridge of 10.76 wide.	2 x Circular Culvert + Spill	Y
24MAIC00019D	01CRB00179	Bridge of 21.00 m wide.	2 x Rectangular Culverts + Spill	Y

Schedule B.1 – Manning's 'n' for HPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Maigue	04MGU02181u – 03MGU03077	0.035	Determined on a case by case basis using photos, videos and survey drawings	1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
River Laskiltagh	01CRB02417 – 01CRB01677	0.045		
	01CRB01668 – 01CRB00000	0.040		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Schedule B.2 – Manning's 'n' for MPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Maigue	04MGU09757 – 04MGU02205	0.040	Determined on a case by case basis using photos, videos and survey drawing	Land use EPA data has been used for assigning the floodplain roughness.
	03MGU02962 – 03MGU01130	0.040		
	03MGU00564 – 03MGU00033	0.035		

Annex C - Model Calibration Summary Note

The aim of this technical note is to describe the calibration methodology applied to the S07 model and report on the results.

Calibration Methodology:

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report (Appendix F). The results of this analysis concluded that there were two in-bank events and one out-of-bank event that could be used for calibration. There was also one out-of-bank event suitable for use as verification.

Hydrometric data recorded at two gauging stations on the River Maigue (Croom 24001 & Castleroberts 24008) for four historical events (March 1995, December 1998, February 2002 and November 2009) was found to be suitable for calibrating and verifying the S07 model along the section shown on Figure C.1. The section starts from within Croom AFA at gauging station 24001 and extends to gauging station 24008 (as seen in Figure C.1).

To facilitate the calibration process, the S07 hydraulic model was truncated to cover the River Maigue reach between gauging stations 24001 and 24008. The River Laskiltagh was removed from the truncated version of the model. All historical calibration runs were carried out using the truncated model. The truncated model includes part of Croom AFA.

The rating curve for gauging stations 24001 has been updated as part of the CFRAM study. The flows used as inputs to the model were estimated from the recorded stage at this station using the updated rating equation. A lateral inflow, estimated as 7% of the inflow at 24001, was applied to the model at the confluence of the River Maigue and the River Laskiltagh.

The inflow locations are shown in Figure C.1, as red circles. Peak water levels predicted by the hydraulic model were compared to the observed water levels at the Castleroberts gauging station (24008).

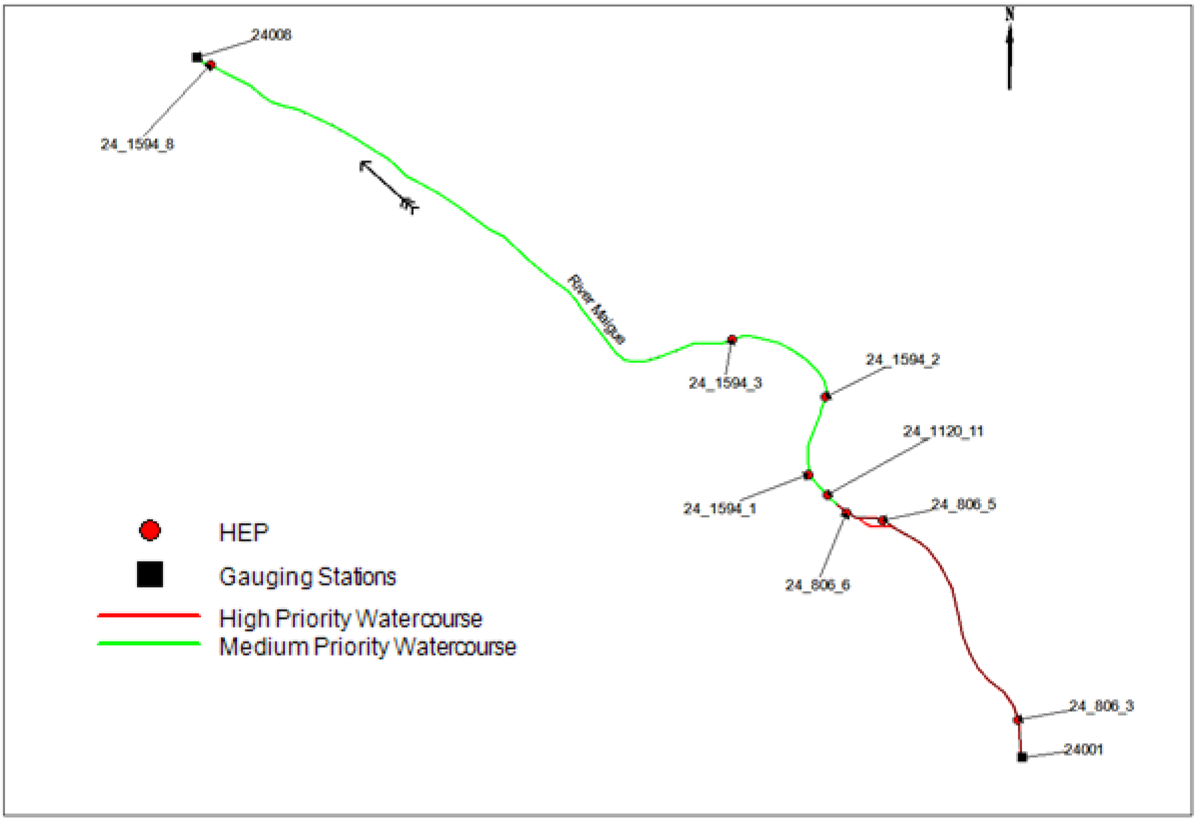


Fig C.1: S07 – Calibration Map

Calibration to Historical Events Results

Gauged flow from gauging station 24001 was input at ISIS node 04MGU01372 and the modelled and observed water levels at gauging station 24008 (ISIS node: 03MGU00033) were compared. The results of this comparison can be seen in Table C.1for peak levels and in Figure C.2 – C.4 for the stage hydrographs.

Table C.1: Historical Flood Events at Gauging Station 24008

Event	Historical Flood Event	Model maximum stage (m AOD*)	Observed maximum stage (m AOD*)	Difference (mm)
In-bank	2002	8.44	8.40	+40
In-bank	2009	8.46	8.48	-20
Out-of-bank	1995	8.82	8.79	+30

(* Datum is taken for Malin Head)

The stage results in Table C.2 indicate that the predicted peak water levels, without making any changes to the model schematisation/parameters, consistently replicate the various flood events within the acceptable range. The smallest difference (-20mm) occurs during the 2009 event, which is the in-bank calibration event. The largest difference (+40mm) occurs during the 2002 event, which is also an in-bank event. The results would suggest that the channel cross section geometry and roughness parameters set in the model provide a reasonable representation of the hydraulics in the river channel along this reach. For all events there is a good fit between the observed time to peak and the modelled time to peak as illustrated in Figures C.2 to C.4.

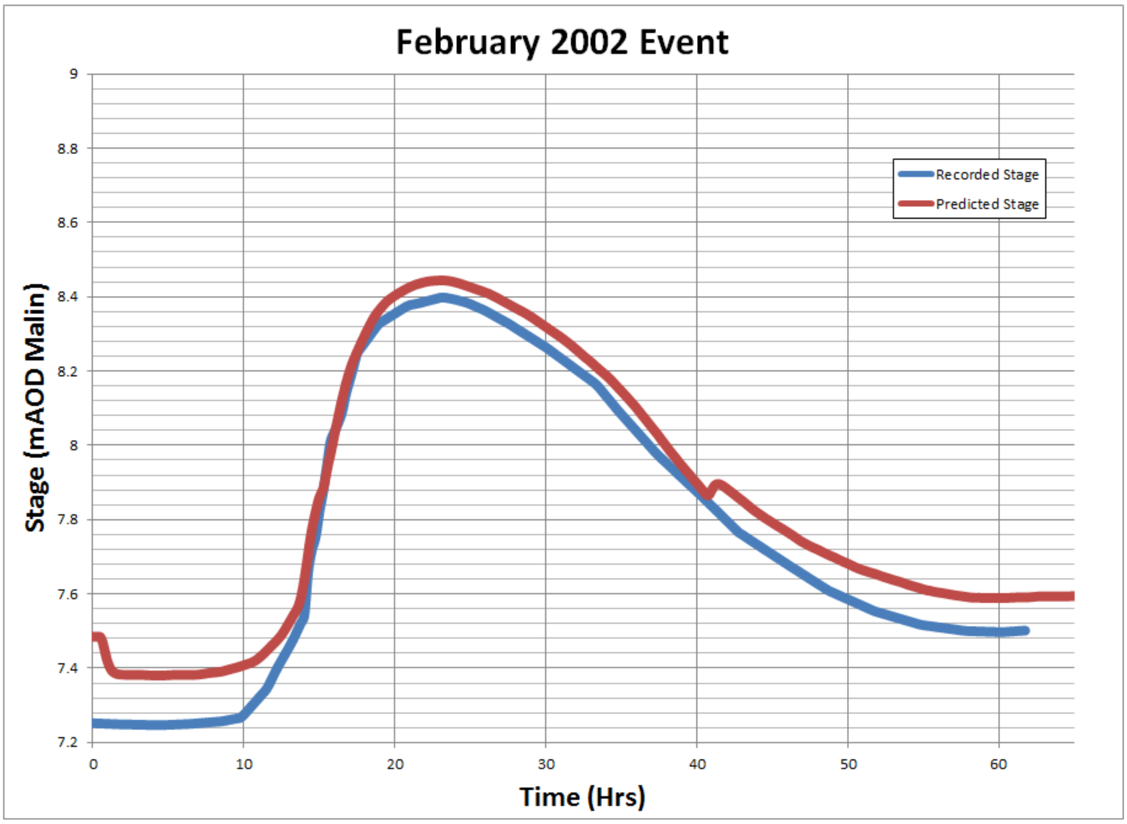


Figure C.2 - Modelled and observed water levels at gauging station 24008 for the 2002 event

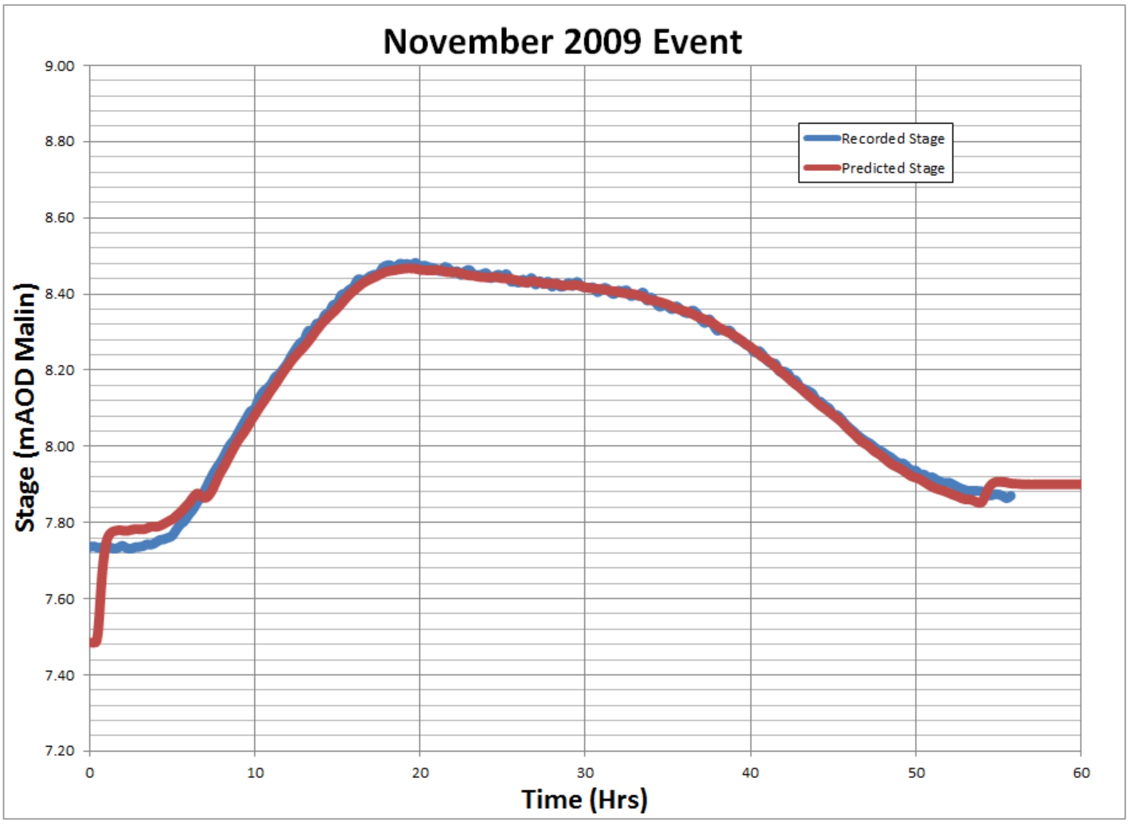


Figure C.3 - Modelled and observed water levels at gauging station 24008 for the 2009 event

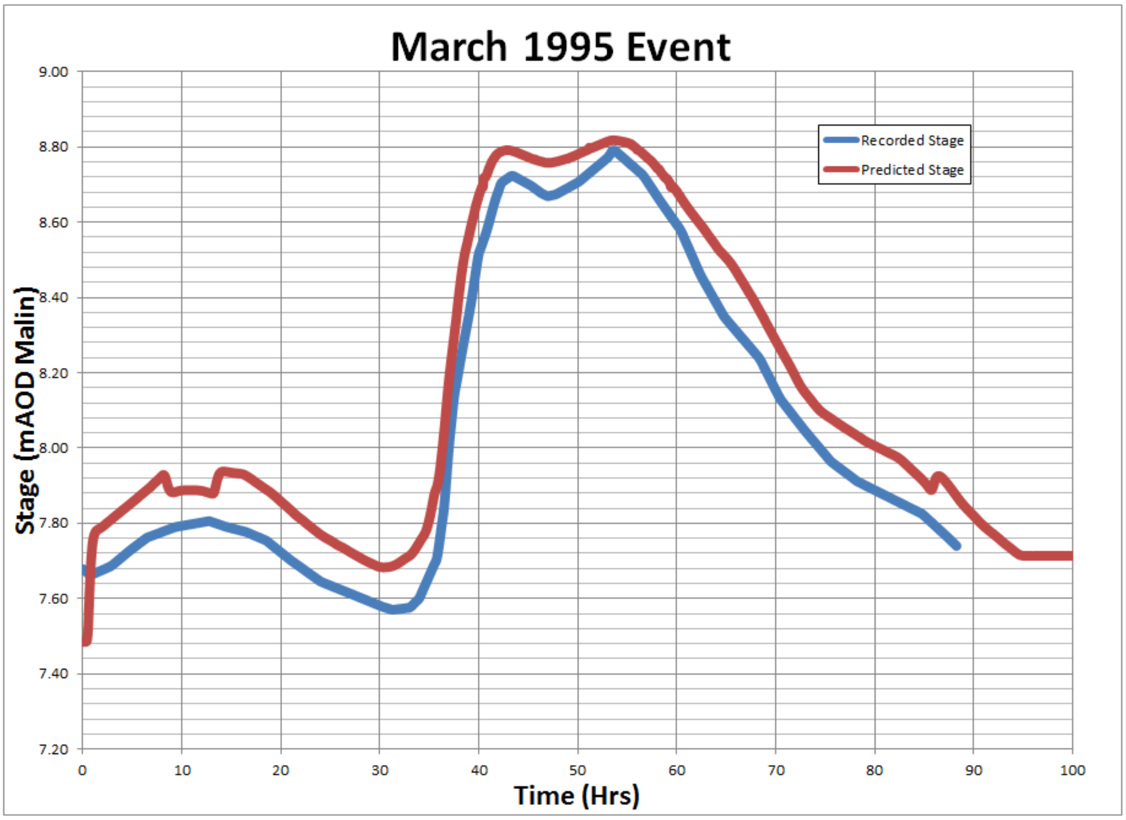


Figure C.4 - Modelled and observed water levels at gauging station 24008 for the 1995 event

Verification of the Model to One Historical Event

An out-of-bank event that occurred in December 1998 was used to verify the model calibration. The methodology used for the verification is the same as for the calibration events.

The modelled and observed water levels for the December 1998 event are reported in Table C.2.The results suggest that the model replicates the December 1998 flood event successfully with the difference between modelled stage and observed stage of 0mm and difference between the times to peak of less than 1hr.

Table C.2: Historical Flood Events at Gauging Station 24008

Event	Historical Flood Event	Model maximum stage (m AOD*)	Observed maximum stage (m AOD*)	Difference (mm)
Out-of-bank	1998	8.83	8.83	0

(* Datum is taken for Malin Head)

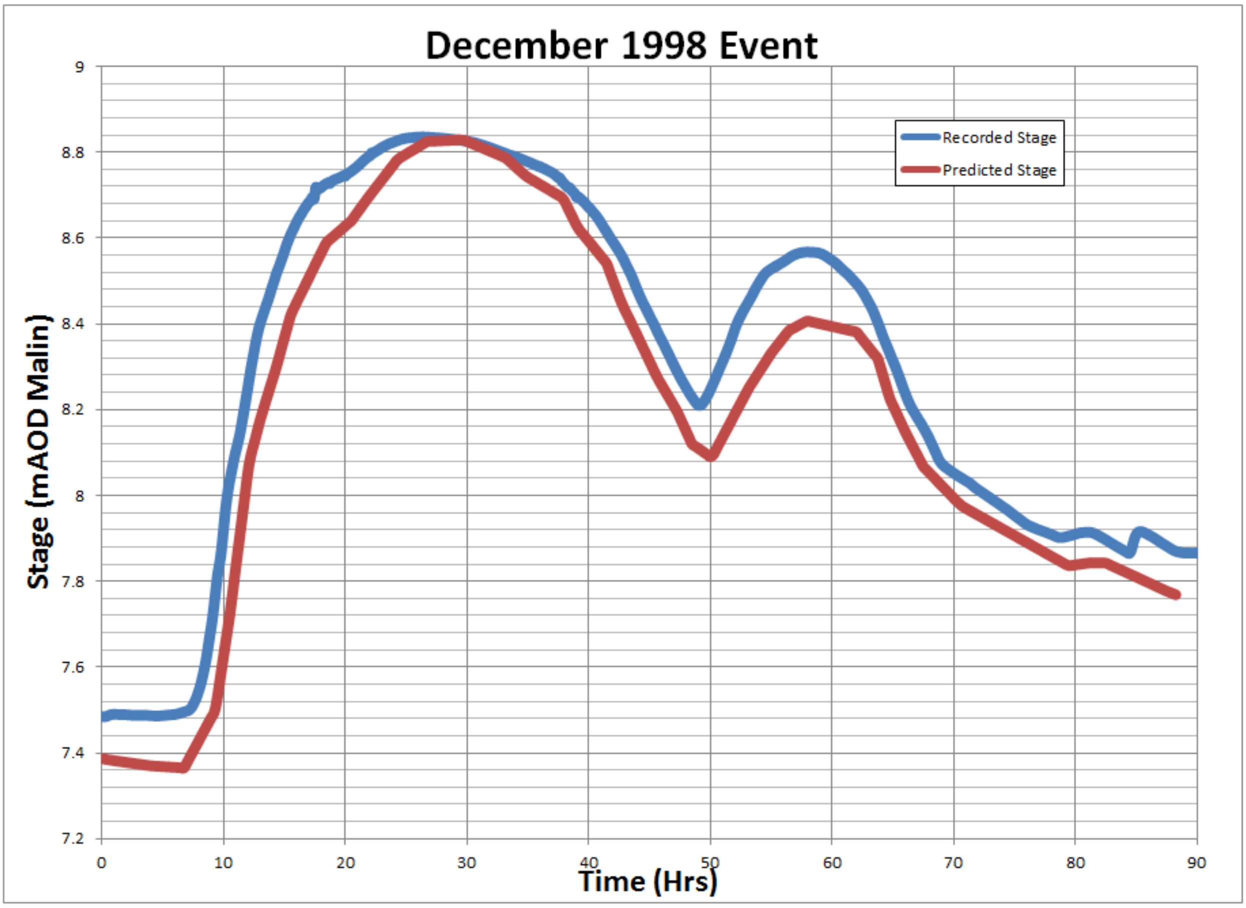


Figure C.5 - Modelled and observed water levels at gauging station 24008 for the 1998 event

Verification of the model using Anecdotal Evidence collected during the December 1998 Historical Event in Croom

Model outputs in the Croom AFA and Caherass, a townland between Croom AFA and the Castleroberts gauging station, were compared against photographs taken during the December 1998 flood event. It has been estimated that the annual probability of the December 1998 event was between the 10% AEP event and the 50% AEP event. The photographs, obtained from floodmaps.ie, are shown below on plates P1 to P5. Photograph P1 shows the footbridge at ISIS node 03MGU02615u downstream of the Croom AFA. The photograph shows that the water levels are within ~100mm from the soffit of the bridge. The model predicts waters levels of 400mm above the bridge deck in the 10% AEP event. According to the recorded stage at Croom gauging station the peak of the 1998 event occurred at 2:45am. As there is daylight in the photograph it is likely that the picture was taken when the water levels had receded. This would explain the discrepancy.

Photograph – P1

Photographs P2 to P5 are all taken from the main bridge within the Croom AFA (Bridge Street) at ISIS node 04MGU01329. Using cross-section survey data, the water line on the building in photograph P2 has been estimated to be 17.73mOD. The predicted maximum stage in the 10% AEP event is 17.78mOD. From these results it can be concluded that the flood levels shown in the photographs are in agreement with the predicted maximum water levels in the river channel.

Photograph – P2


Photograph – P3


Photograph – P4

Photograph – P5

Conclusions

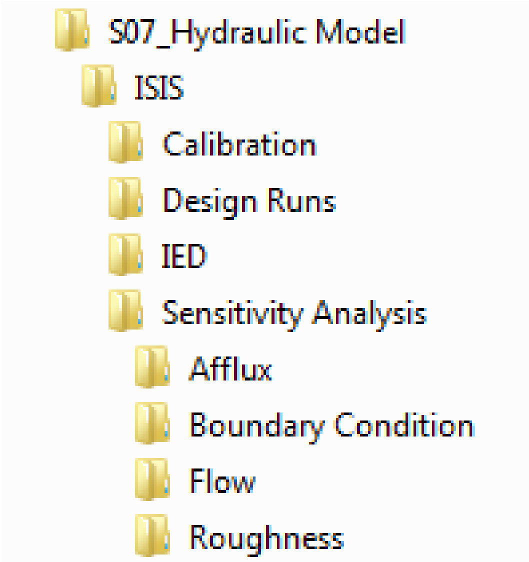
This note has analysed the results of the historical calibration carried out on one section of the S07 hydraulic model.

It was possible to calibrate the model for two in-bank historical events and one out-of-bank historical event, and to verify the model for one out-of-bank event.

The results suggest that the model calibrates well for the two “in-bank” historical events and for the “out-of-bank” event with all results within the acceptable range of +/-0.2m for a HPW. The calibration was successfully verified with no stage difference between the modelled peak water level and observed peak water level.

The model was also verified using anecdotal evidence from the December 1998 event. The flood levels shown in the photographs were found to be in agreement with the predicted maximum water levels in the river channel.

Annex D - Hydraulic Model Files

Model Files Folders Structure	
ISIS	

ISIS Files	
Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Historic Calibration Runs** S07_1995_Flu_C_Cal_His_Main_v1.DAT S07_2002_Flu_C_Cal_His_Main_v1.DAT S07_2009_Flu_C_Cal_His_Main_v1.DAT S07_1998_Flu_C_Ver_His_Main_v1.DAT **Design Runs – Current Scenario:** **Main Stream Model** S07_Q10_FLU_C_Des_Main_IssV1.DAT S07_Q100_FLU_C_Des_Main_IssV1.DAT S07_Q1000_FLU_C_Des_Main_IssV1.DAT **Tributary 2 Model** S07_Q10_FLU_C_Des_Trib_IssV1.DAT S07_Q100_FLU_C_Des_Trib_IssV1.DAT S07_Q1000_FLU_C_Des_Trib_IssV1.DAT
Hydrological Inflow Files	**Historic Calibration Runs** S07_Mar95_Cal_Main.IED S07_Feb02_Cal_Main.IED S07_Nov09_Cal_Main.IED S07_Dec98_Ver_Main.IED **Design Runs – Current Scenario:** **Main Stream Model** S07_Q10_DesignR_Main.IED S07_Q100_DesignR_Main.IED S07_Q1000_DesignR_Main.IED **Tributary Model** S07_Q10_DesignR_Trib.IED S07_Q100_DesignR_Trib.IED S07_Q1000_DesignR_Trib.IED

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs – Current Scenario						
1	S07_Q10_FLU_C_DES_MAIN_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.
2	S07_Q100_FLU_C_DES_MAIN_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.
3	S07_Q1000_FLU_C_DES_MAIN_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.
4	S07_Q10_FLU_C_DES_TRIB_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.
5	S07_Q100_FLU_C_DES_TRIB_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.
6	S07_Q1000_FLU_C_DES_TRIB_IssV1.DAT	0	100	2	Automated Preissmann Slot used with width of 0.1m and depth of 1m.	Convergence within manufacturer tolerance.

Sensitivity Analysis						
7	S07_Q100_FLU_C_Sen_Afflux_In_Main_IssV1.DAT	0	100	2	The coefficient of velocity is changed to 1.2	Convergence within manufacturer tolerance.
8	S07_Q100_FLU_C_Sen_Afflux_De_Main_IssV1.DAT	0	100	2	The coefficient of velocity is changed to 0.8	Convergence within manufacturer tolerance.
9	S07_Q100_FLU_C_Sen_Bdy_In_Main_IssV1.DAT	0	100	2	The stage in the downstream boundary is increased by 0.2m	Convergence within manufacturer tolerance.
10	S07_Q100_FLU_C_Sen_Bdy_De_Main_IssV1.DAT	0	100	2	The stage in the downstream boundary is decreased by 0.2m	Convergence within manufacturer tolerance.
11	S07_Q100_FLU_C_Sen_20FlDe_Main_IssV1.DAT	0	100	2	The flow in the main stem of the model has been decreased by 20%	Convergence within manufacturer tolerance.
12	S07_Q100_FLU_C_Sen_20FlIn_Main_IssV1.DAT	0	100	2	The flow in the main stem of the model has been increased by 20%	Convergence within manufacturer tolerance.
13	S07_Q100_FLU_C_Sen_20RoDe_Main_IssV1.DAT	0	100	2	The roughness has been decreased by 20%.	Convergence within manufacturer tolerance.
14	S07_Q100_FLU_C_Sen_20RoIn_Main_IssV1.DAT	0	100	2	The roughness has been increased by 20%.	Convergence within manufacturer tolerance.
15	S07_Q100_FLU_C_Sen_20FlDe_TRIB_IssV1.DAT	0	100	2	The flow in the tributary has been decreased by 20%	Convergence within manufacturer tolerance.

16	S07_Q100_FLU_C_Sen_20FlIn_TRIB_IssV1.DAT	0	100	2	The flow in the tributary has been increased by 20%	Convergence within manufacturer tolerance.
17	S07_Q100_FLU_C_Sen_20RoIn_Trib_IssV1.DAT	0	100	2	The roughness has been increased by 20%.	Convergence within manufacturer tolerance.
18	S07_Q100_FLU_C_Sen_20RoDe_Trib2_IssV1.DAT	0	100	2	The roughness has been decreased by 20%.	Convergence within manufacturer tolerance.

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Fluvial Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S08
Unit of Management	24
AFAs included in the model	Charleville & Kilmallock
Primary Watercourses / Water Bodies	Glen River River Maigue River Loobagh Ahatrishnaun Stream Ahnagluggin Stream
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A1.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B4 – Figure B4.1

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k Reference: OS1412_D, OS1612_D
2.2 DTM for 2D Model Domains:	**Within AFAs:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFAs: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 388

2.4 Defence Asset Survey Data	No defences have been identified within the model area in the defence asset database. A small embankment was identified on the left bank of the River Glen (See Section 6) but this is an ineffective informal flood defence. This structure was not included in the defence asset database as it does not tie into high ground at its upstream extent. It has been included in the model as it influences the flow path around the properties in the Meadow Vale housing estate. The location of the defence is outlined in Figure ref. Annex A2(2).
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:**	ISIS Version 3.6.0.156 Double Precision
	2D Domain(s):	TUFLOW Version: 2012-05-AE-iDP-w32
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.	

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary

2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
Glen River	01GLE	01GLE09766	01GLE00000
River Maigue	05MGU	05MGU07709	05MGU00000
	04MGU	04MGU10653	04MGU09757
Ahatrishnaun Stream	01AHT	01AHT00596	01AHT00000
River Loobagh	01LOO	01LOO08399	01LOO00000
	02LOO	02LOO01879	02LOO00000
	03LOO	03LOO00478	03LOO00000
Ahnagluggin Stream	01COE	01COE01070	01COE00000

Total model HPW length (km):	12.2	**Total model MPW length (km):**	23.4

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	16
Bridges:	☒	How many?	12
Fixed crest weirs:	☒	How many?	4
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation

Out-of-bank areas for MPW reaches have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections, or by using reservoir units.

Out-of-bank areas for HPW reaches, within the Charleville AFA, have been

<table>
<tr><td></td><td colspan="3">modelled using a 2D approach as set in the TUFLOW model.
Out-of-bank areas for HPW reaches, within the Killmallock AFA, have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections, or by using reservoir units.

Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple. 1D-2D modelling is required where HPWs flow through urban areas where out-of-bank flows will form complex flow paths.

An overview of the floodplain schematisation is available in the maps shown in Annex A.</td></tr>
<tr><td rowspan="4">3.6 2D Domain Grid Size:</td><td colspan="3">The number of 2D domains defined and the grid sizes of each 2D model domain are as follows:</td></tr>
<tr><td colspan="3">Number of 2D domains: 1</td></tr>
<tr><td>Domain 1: Charleville</td><td>Grid cell size (m): 8</td><td>Area (km^2): 4.375</td></tr>
<tr><td colspan="3">2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.</td></tr>
<tr><td>3.7 Model Breaklines in the 2D Domain:</td><td colspan="3">Bank tops, drains and bridge parapets are represented as breaklines in the 2D domain.
Details on the use of breaklines and the method used to alter DTM is provided in Section 3.4.8 of the Hydraulics Report for Unit of Management 23.</td></tr>
<tr><td>3.8 Floodplain Structures in the 2D Domain</td><td colspan="3">No floodplain structures have been included in the 2D model.</td></tr>
<tr><td>3.9 Hydraulic Roughness</td><td colspan="3">Hydraulic roughness (Manning’s ‘n’) has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning’s ‘n’ for the model as a whole is as follows:</td></tr>
<tr><td rowspan="2">MPW in-bank
Bed and bank sides</td><td>Minimum ‘n’ value:</td><td colspan="2">0.042</td></tr>
<tr><td>Maximum ‘n’ value:</td><td colspan="2">0.045</td></tr>
<tr><td rowspan="2">HPW in-bank</td><td>Minimum ‘n’ value:</td><td colspan="2">0.032</td></tr>
<tr><td>Maximum ‘n’ value:</td><td colspan="2">0.047</td></tr>
</table>

<table>
<tr><td rowspan="6">Floodplain (ISIS Model)</td><td colspan="2">Manning's 'n' for out-of-bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:</td></tr>
<tr><td>Land Use</td><td>Manning's 'n' Value</td></tr>
<tr><td>Pastures</td><td>0.035</td></tr>
<tr><td>Dense Vegetation</td><td>0.080</td></tr>
<tr><td>Road Network</td><td>0.025</td></tr>
<tr><td>Buildings</td><td>0.100</td></tr>
<tr><td rowspan="10">Floodplain (TUFLOW Model)</td><td colspan="2">Manning's 'n' for out of bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:</td></tr>
<tr><td>Land Use</td><td>Manning's 'n' Value</td></tr>
<tr><td>Buildings</td><td>0.100</td></tr>
<tr><td>Short grass, parks</td><td>0.030</td></tr>
<tr><td>General Urban</td><td>0.060</td></tr>
<tr><td>General Rural</td><td>0.045</td></tr>
<tr><td>Dense Vegetation</td><td>0.080</td></tr>
<tr><td>Roads</td><td>0.025</td></tr>
<tr><td>Railways</td><td>0.050</td></tr>
<tr><td>Water bodies</td><td>0.020</td></tr>
<tr><td>3.10 Spill Units</td><td colspan="2">Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain).
Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR.
Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.
The spills into the reservoirs have been digitised from the LiDAR using ISIS mapper. This tool creates a spill unit containing the highest points 5 metres to the left and right of the line required. This method allows for a more accurate spill definition than just taking the points from the ISIS cross sections.</td></tr>
<tr><td>3.11 Model Boundaries - Inflows</td><td colspan="2">Full details of the flow estimates and flow hydrographs are provided in the Hydrology Report relevant to the Unit of Management 24. Summary details are included within this section.</td></tr>
<tr><td>(a) Current Situation (Main Model)</td><td colspan="2">Following HEP calibration, the peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for the current situation.</td></tr>
</table>

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_171_5	01GLE00243	12.8	16.4	18.5	20.4	22.9	24.7	26.5	30.7
24_1469_13	01GLE004612	1.7	2.1	2.4	2.6	3.0	3.2	3.4	4.0
24_119_5	01GLE00737	2.1	2.7	3	3.3	3.7	4	4.3	5.0
24_563_2	01GLE02974	1.0	1.2	1	1.5	1.7	1.5	2.0	2.3
24_820_2	01GLE03499d	1.6	2.0	2.2	2.5	2.8	3	3.2	3.7
24_295_3	01GLE04099	1.5	1.9	2.1	2.4	2.7	3.1	3.1	3.5
24_1469_2	01GLE09766	1.8	2.3	2.6	2.9	3.2	3.5	3.7	4.3
	01GLE09431	1.8	2.3	2.6	2.9	3.2	3.5	3.7	4.3
	01GLE09334	1.8	2.3	2.6	2.9	3.2	3.5	3.7	4.3
24_1223_1	04MGU09757	19.1	24.5	27.6	30.5	34.2	36.9	39.6	45.9
24_189_3	04MGU10589u	1.2	1.5	1.7	1.9	2.1	2.3	2.4	2.8
24_188_2	05MGU00886u	3.7	4.7	5.3	5.9	6.6	7.1	7.7	8.9
24_190_1	05MGU07709	32.2	41.3	46.6	51.5	57.7	62.3	66.9	77.4
(a) Current Situation (Tributary 2 Model)									
24_1050_9	01AHT00596	1.0	1.0	1.1	1.2	1.4	1.5	1.6	1.8
24_1019_9	01COE01070	4.2	5.4	6.0	6.7	7.5	8.1	8.7	10.0
24_1469_2	01GLE09766	0.6	0.8	0.9	1.0	1.0	1.2	1.2	1.4
24_822_3	01LOO00000	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.7
24_822_2	01LOO00796	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8
24_828_1	01LOO04159wu	3.5	4.4	5.0	5.5	6.2	6.7	7.2	8.3
24_830_2	01LOO04800	3.4	4.4	4.9	5.5	6.1	6.6	7.1	8.2
24_824_1	01LOO08373	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4
24_755_1	02LOO01435	2.6	3.3	3.7	4.1	4.6	4.9	5.3	6.1
24_753_3	03LOO00478	26.3	33.7	38.1	42.1	47.1	50.9	54.6	63.2
(a) Current Situation (Tributary 3 Model)									
24_1050_9	01AHT00040	1.1	1.4	1.6	1.7	1.9	2.1	2.2	2.6
24_1019_9	01COE00012	1.6	2.1	2.3	2.6	2.9	3.1	3.4	3.9

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.

HEP Reference Name	Input Node in the Hydraulic Model	MRFS Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
Main Model									

24_171_5	01GLE00243	15.4	19.7	22.2	24.5	27.5	29.6	31.8	36.8
24_1469_13	01GLE004612	2.0	2.5	2.9	3.1	3.6	3.8	4.1	4.8
24_119_5	01GLE00737	2.5	3.2	3.6	4.0	4.4	4.8	5.2	6.0
24_563_2	01GLE02974	1.2	1.4	1.2	1.8	2.0	1.8	2.4	2.8
24_820_2	01GLE03499d	1.9	2.4	2.6	3.0	3.4	3.6	3.8	4.4
24_295_3	01GLE04099	1.8	2.3	2.5	2.9	3.2	3.7	3.7	4.2
24_1469_2	01GLE09766	2.2	2.8	3.1	3.5	3.8	4.2	4.4	5.2
	01GLE09431	2.2	2.8	3.1	3.5	3.8	4.2	4.4	5.2
	01GLE09334	2.2	2.8	3.1	3.5	3.8	4.2	4.4	5.2
24_1223_1	04MGU09757	22.9	29.4	33.1	36.6	41.0	44.3	47.5	55.1
24_189_3	04MGU10589u	1.4	1.8	2.0	2.3	2.5	2.8	2.9	3.4
24_188_2	05MGU00886u	4.4	5.6	6.4	7.1	7.9	8.5	9.2	10.7
24_190_1	05MGU07709	38.6	49.6	55.9	61.8	69.2	74.8	80.3	92.9
Tributary 2 Model									
24_1050_9	01AHT00596	1.2	1.2	1.3	1.4	1.7	1.8	1.9	2.2
24_1019_9	01COE01070	5.0	6.5	7.2	8.0	9.0	9.7	10.4	12.0
24_1469_2	01GLE09766	0.7	1.0	1.0	1.2	1.2	1.4	1.4	1.7
24_822_3	01LOO00000	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.8
24_822_2	01LOO00796	1.0	1.2	1.3	1.4	1.7	1.8	1.9	2.2
24_828_1	01LOO04159wu	4.2	5.3	6.0	6.6	7.4	8.0	8.6	10.0
24_830_2	01LOO04800	4.1	5.3	5.9	6.6	7.3	7.9	8.5	9.8
24_824_1	01LOO08373	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.6
24_755_1	02LOO01435	3.1	4.0	4.4	4.9	5.5	5.9	6.4	7.4
24_753_3	03LOO00478	31.6	40.4	45.7	50.5	56.5	61.0	65.5	75.9
Tributary 3 Model									
24_1050_9	01AHT00040	1.3	1.7	1.9	2.0	2.3	2.5	2.6	3.1
24_1019_9	01COE00012	1.9	2.5	2.8	3.1	3.5	3.8	4.1	4.6

(b) Future Scenarios		The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.		
HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
Main Model				

24_1019_9	01COE01070	3.6	4.8	6.1
24_1050_9	01AHT00596	1.9	2.7	3.3
24_171_5	01GLE00243	28.9	38.5	47.9
24_1469_13	01GLE004612	3.7	5.0	6.2
24_119_5	01GLE00737	4.7	6.2	7.8
24_563_2	01GLE02974	1.6	2.3	3.1
24_820_2	01GLE03499d	3.4	4.7	5.8
24_295_3	01GLE04099	3.3	4.8	5.5
24_1469_2	01GLE09766	4.1	5.5	6.7
	01GLE09431	4.1	5.5	6.7
	01GLE09334	4.1	5.5	6.7
24_1223_1	04MGU09757	43.1	57.6	71.6
24_189_3	04MGU10589u	2.7	3.6	4.4
24_188_2	05MGU00886u	8.3	11.1	13.9
24_190_1	05MGU07709	72.7	97.2	120.7
Tributary 2 Model				
24_1050_9	01AHT00596	1.4	1.9	2.4
24_1019_9	01COE01070	7.8	10.5	13.0
24_1469_2	01GLE09766	1.1	1.5	1.9
24_822_3	01LOO00000	0.5	0.7	0.9
24_822_2	01LOO00796	1.4	1.9	2.4
24_828_1	01LOO04159wu	6.5	8.7	10.8
24_830_2	01LOO04800	6.4	8.6	10.7
24_824_1	01LOO08373	1.1	1.4	1.8
24_755_1	02LOO01435	4.8	6.4	8.0
24_753_3	03LOO00478	49.5	66.1	82.2
Tributary 3 Model				
24_1050_10	01AHT00040	2.0	2.7	3.4
24_1019_11	01COE00012	3.1	4.1	5.0

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:
	A normal depth boundary was chosen to provide a free flow condition at the downstream end of the model. The slope parameter was taken from the local river bed slope. Sensitivity to this assumption is discussed in the relevant section below.

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events	The approach to model calibration is discussed in section 3.5 of the main Hydraulics Report. The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F). A full account of the model calibration approach and results is provided in Annex C of this appendix. A summary of the calibration and verification events along with associated model calibration results is as follows:
Catchment Gauging	Is modelled catchment: Gauged ☒ Ungauged ☐
Gauging Stations	

Station Number	Watercourse	Location	ISIS Node Reference
24003	River Loobagh	Garroose Bridge	01LOO00781

Summary of Findings	It was not possible to calibrate this model for any flood event, as outlined in Annex C. Further information is provided in Appendix B of the Hydrology Report for Unit of Management 24 and in the Calibration Sheet in Appendix F.
4.2 Calibration to HEP	Calibration of the hydraulic model to the HEP target flows has been carried out for all design events simulated (50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP). Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincided with the peak time of the propagating flood wave as it was routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Where required, inflows to the hydraulic model were scaled up/down to ensure that the modelled total peak flows remain within ±10% of the HEP target flows. The flows at the following HEP nodes were increased by varying amounts: 24_827_2, 24_295_3, 24_563_2. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. Agreement between the HEP target flow and the modelled flow was not met at HEP point 24_755_4. This HEP point is located alongside a reservoir unit and there is some circulation of flow in this area. The HEP target flows and model flows upstream and downstream of the reservoir were in agreement. The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: 4.13%, 4.78%, and 5.15% for the 10%, 1% and 0.1% AEP events respectively.

HEP Reference Name	Node in the Hydraulic Model	Annual Exceedance Probability Percentage Difference (%)							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1469_8	01GLE06988	23.2	10.2	-3.8	4.2	3.7	0	1.9	-3.1
24_1496_13	01GLE04617d	6.6	2.2	5.2	1.9	0.3	8.8	-0.5	7.8
24_295_3	01GLE04099	7.4	3.2	3.5	2.9	1.9	6.7	2.2	5.8

24_820_2	01GLE03499d	14.8	8.3	1.4	7.9	9.5	-1.6	15.7	-8.7
24_563_2	01GLE02974	10.9	8.9	2.7	5.8	-0.8	2.1	9.3	-0.4
24_563_3	01GLE02140	5.8	3.9	7.2	3.0	0.9	7.4	3.0	5.5
24_119_2	01GLE01509	9.0	5.4	5.2	4.8	3.2	3.5	4.6	1.4
24_119_4	01GLE01023	1.0	-2.5	3.5	-4.5	-4.6	4.5	-3.1	4.3
24_119_5	01GLE00737	-2.6	-5.6	6	-6.4	-6.0	5.7	-5.6	5.2
24_190_1	05MGU07709	2.9	0.7	0	0.3	1.8	-1.3	2.0	-1
24_190_2	05MGU07435	2.7	0.5	0.1	0.1	0.8	-1.2	1.7	-0.9
24_191_2	05MGU04395	2.5	0.4	0.2	0.0	0.7	-1.1	1.5	-0.9
24_187_1	05MGU02753	2.5	0.4	0.3	0.0	0.7	-1	1.5	-0.9
24_188_2	05MGU00886u	-4.3	-6.4	6.6	-6.8	-6.1	5.4	-5.3	5.5
24_189_3	04MGU10589u	-0.1	-2.0	2.6	-2.4	-1.7	1.2	-0.8	1.4
24_189_4	04MGU10589u	-0.1	-2.0	2.6	-2.4	-1.7	1.2	-0.8	1.4
24_753_3	03LOO00478	-9.7	-9.7	-0.2	-9.73	-9.72	-0.2	-9.7	-0.2
24_754_2	03LOO00058	0.0	0.0	0	-9.7	-9.7	0.1	0.0	0.1
24_755_1	02LOO01435	5.0	4.9	-5	0.0	0.0	-4.7	4.3	-4.8
24_755_2	02LOO01288	5.0	4.9	-4.9	4.4	4.3	-4.7	4.2	-4.8
24_755_4	02LOO00376	-4.4	-2.1	26.3	25.3	31.2	44.5	30.6	55
24_755_5	02LOO00087	4.7	4.6	-4.7	4.4	3.8	-4.6	2.6	-4.7
24_824_1	01LOO08373	-0.2	-2.6	-5.2	4.4	3.8	-5	-2.2	-5.2
24_824_4	01LOO06963	7.6	6.8	-7.1	1.7	0.0	-6.9	4.8	-7
24_824_6	01LOO06110	7.5	6.7	-6.9	6.3	6.0	-6.8	4.7	-6.8
24_824_7	01LOO05373	8.4	6.6	-6.9	6.0	5.6	-6.8	4.9	-6.8
24_830_2	01LOO04800	4.3	3.3	-3.8	6.6	5.7	-3.5	1.9	-3.6
24_830_4	01LOO04203	4.3	3.3	-0.9	11.4	2.5	-3.6	1.9	-3.6
24_825_2	01LOO04159wu	5.2	4.3	-1.7	3.2	2.5	-4.7	3.0	-4.6
24_828_1	01LOO04159wu	3.8	2.9	-0.2	4.2	3.5	-3.1	1.6	-3.1
24_828_4	01LOO04159wu	3.8	2.9	-0.2	2.7	2.1	-3.1	1.6	-3.1
24_827_2	01LOO01907	1.3	-1.4	4	2.7	2.1	0.7	-1.7	0.7
24_822_2	01LOO00796	-0.6	-1.5	4	-1.2	-1.6	0.7	-1.9	0.7
24_822_3	01LOO00000	-0.6	-1.6	7.6	2.8	-1.8	6.1	-2.0	5.1
24_1019_11	01COE00012	-0.5	-0.3	0	-0.6	-0.6	0	-0.6	1
24_1050_10	01AHT00040	0.1	0.6	0	0.1	0.0	0	0.0	0

4.3 Model Sensitivity	Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. In each case the sensitivity run was carried out for the 1% AEP fluvial event. Sensitivity test results are provided in the following tables. It can be seen that the Glen River and River Maigue are particularly sensitive to roughness and flow changes at their confluence. However, this does not impact on water levels within the AFA. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work.

+20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section / Reach where the Maximum Difference occurs
Glen River	+0.046	+0.510	01GLE02556
River Maigue	+0.160	+0.608	05MGU04325wd
River Loobagh	+0.107	+0.226	01LOO08310
Ahatrishnaun Stream	+0.097	+0.195	01AHT00055d
Ahnagluggin (Stream)	+0.091	+0.117	01COE00111u

-20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
Glen River	-0.064	-0.389	01GLE02556
River Maigue	-0.138	-0.334	05MGU04767
River Loobagh	-0.103	-0.254	03LOO00359
Ahatrishnaun Stream	-0.131	-0.210	01AHT00040
Ahnagluggin (Stream)	-0.114	-0.138	01COE00263

+20% inflows

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
Glen River	+0.062	+0.559	01GLE02556
River Maigue	+0.167	+0.247	05MGU04452
River Loobagh	+0.137	+0.368	01LOO08338u
Ahatrishnaun Stream	+0.173	+0.365	01AHT00062u
Ahnagluggin (Stream)	+0.052	+0.094	01COE00102d

<table>
<tr><td rowspan="6">-20% inflows</td><td>Watercourse</td><td>Average Water Level Difference (m)</td><td>Maximum Water Level Difference (m)</td><td>Cross-section where the Maximum Difference occurs</td></tr>
<tr><td>Glen River</td><td>-0.079</td><td>-0.471</td><td>01GLE05719u</td></tr>
<tr><td>River Maigue</td><td>-0.172</td><td>-0.386</td><td>05MGU04938</td></tr>
<tr><td>River Loobagh</td><td>-0.161</td><td>-0.530</td><td>01LOO06569</td></tr>
<tr><td>Ahatrishnaun Stream</td><td>-0.218</td><td>-0.452</td><td>01LOO08399</td></tr>
<tr><td>Ahnagluggin (Stream)</td><td>-0.062</td><td>-0.118</td><td>01COE01070</td></tr>
<tr><td>Afflux at Key Structure
Weir discharge coefficient increased by 20%</td><td colspan="4">There is one structure in the model within an AFA which has significant head loss during the 1% AEP flood event. It is a weir on the Glen River (01GLE5477s1u) located alongside the Newtownbarry road beside the Kerry group offices. The weir discharge coefficient was increased by 20% (to a value of 1.2). This resulted in a decrease of 25 mm to the maximum water level immediately upstream of the bridge. This decrease in stage diminishes upstream of the structure; no effect is seen 50 m upstream (01GLE05547d). This decrease in stage caused a negligible reduction in the predicted flood extent upstream of the weir.</td></tr>
<tr><td>Afflux at Key Structure
Weir discharge coefficient decreased by 20%</td><td colspan="4">The weir discharge coefficient was decreased by 20% (to a value of 0.8). This resulted in an increase of 24 mm to the maximum water level immediately upstream of the structure. This increase in stage diminishes upstream of the structure; no effect is seen 50 m upstream of the structure (01GLE05547d). This increase in stage caused an insignificant increase in the predicted flood extent upstream of the weir.</td></tr>
<tr><td>Downstream Conditions
Normal Depth downstream boundary slope doubled</td><td colspan="4">The change to the downstream boundary condition has resulted in a decrease in the maximum water level by 269 mm at the downstream model limit (04MGU09757). The effect diminishing upstream can be seen for 0.5km upstream of the downstream boundary, but has no impact on the water levels and predicted flood extent in the HPW.</td></tr>
<tr><td>Downstream Conditions
Normal Depth downstream boundary slope halved</td><td colspan="4">The change to the downstream boundary condition has resulted in an increase in the maximum water level by of 20 mm at the downstream model limit (04MGU09757). The effect diminishing upstream can be seen for 0.9km upstream of the downstream boundary, but has no impact o
n the water levels and predicted flood extents in the HPW.</td></tr>
<tr><td>4.4 Model Files</td><td colspan="4">The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D.</td></tr>
</table>

5. Hydraulic Model Outputs

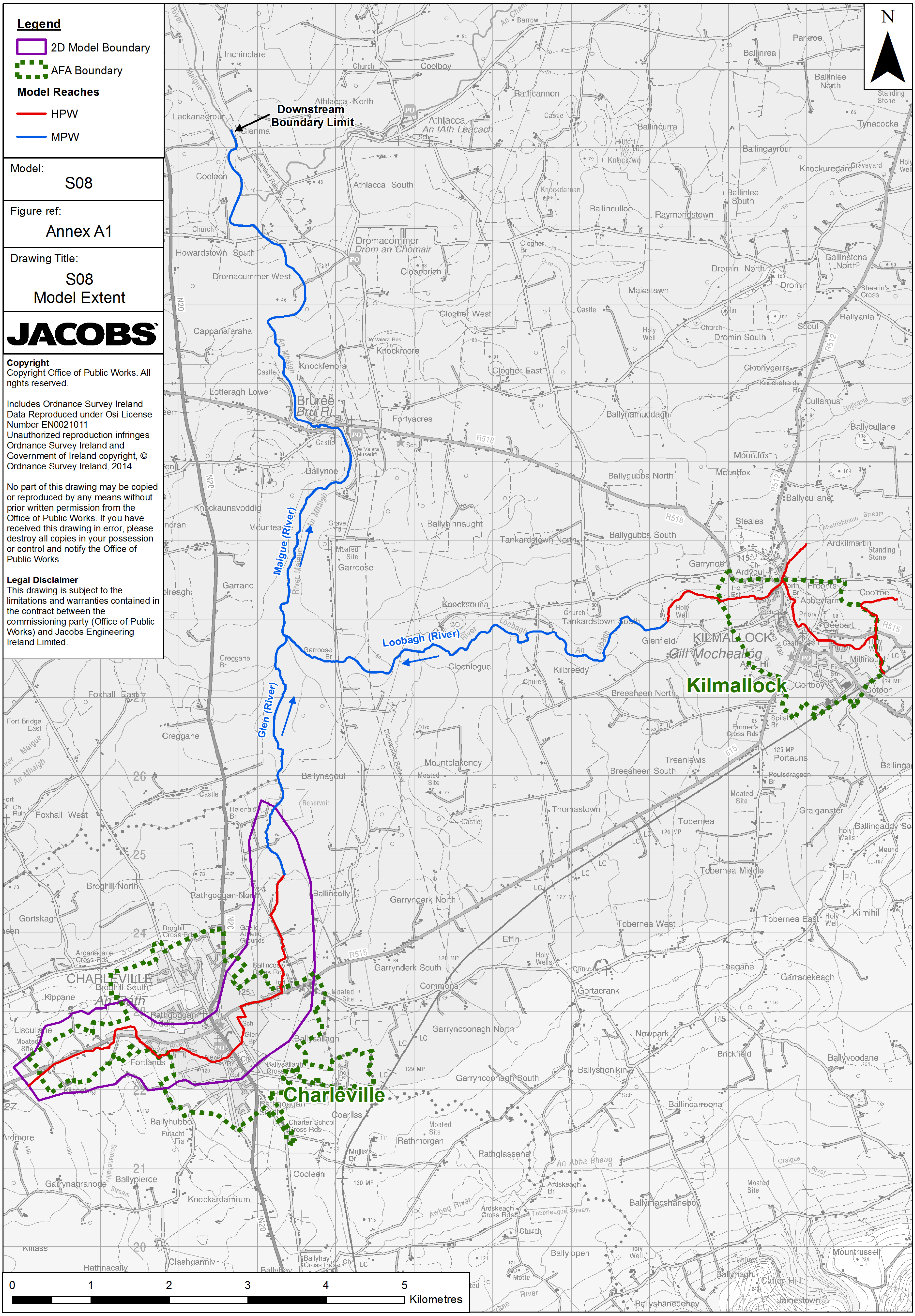
5.1 Mapping	Model outputs have been processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard All of the maps contain the maximum extent, depth, velocity and flood hazard for the combined main stream inflows and the tributary inflows. An explanation for the main stream inflows and the tributary inflows is provided in Section 6. Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP flood events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. The River Glen and River Maigue are classified as the main streams. The River Loobagh, Ahatrishnaun stream and Ahnagluggin stream are classified as tributaries. Inflow hydrographs were purposely produced for both the main streams and tributaries and three models were run. The first containing only the main stream inflows (Main stream model), the second containing only the River Loobagh tributary inflows (Tributary 2 model), and the third containing flows for the Ahatrishnaun stream and Ahnagluggin stream (Tributary 3 model). The main stream model and tributary models share exactly the same geometry (structures and topography). The model outputs from all models were then merged picking up the maximum flood depths and extents to create the flood maps.
- An informal ineffective flood defence (small embankment) has been included in the model and is located on the left bank of the River Glen, protecting properties in Meadow Vale estate. Although this structure has not been included in the asset defence database it has been included in the model as it influences the flow path around the properties in the Meadow Vale housing estate. It is not however, an “Effective Defence”. The location of the defence is outlined in Figure ref. Annex A2(2) .This model and the outputs presented in this report therefore do not represent the defended scenario.
- The upstream extent of the River Glen was unable to convey all flow intended for HEP point 24_1469_2. This resulted in a loss of flow to the floodplain. To avoid this, the inflow for 24_1469_2 was split over three cross sections; 01GLE09766, the most upstream cross section, 01GLE09431 and 01GLE09334, 335m and 432m downstream respectively.
- The River Glen has a steep bed profile at its upstream extent and flattens out at its downstream extent. Due to the river geometry, dummy flows were required at the upstream extent. These dummy flows resulted in out of bank flow along the downstream extent. To eliminate this problem the dummy flow has been abstracted at various locations along the downstream extent. Dummy flows were only used during periods of low flow and were “turned off” as soon as the level rose to a point where stability was achieved. In this way, the flows do not impact on the peak flow or level.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent


Legend
2D Model Boundary
AFA Boundary
Model Reaches
HPW
MPW
Model:
S08
Figure ref:
Annex A1
Drawing Title:
S08
Model Extent
JACOBS
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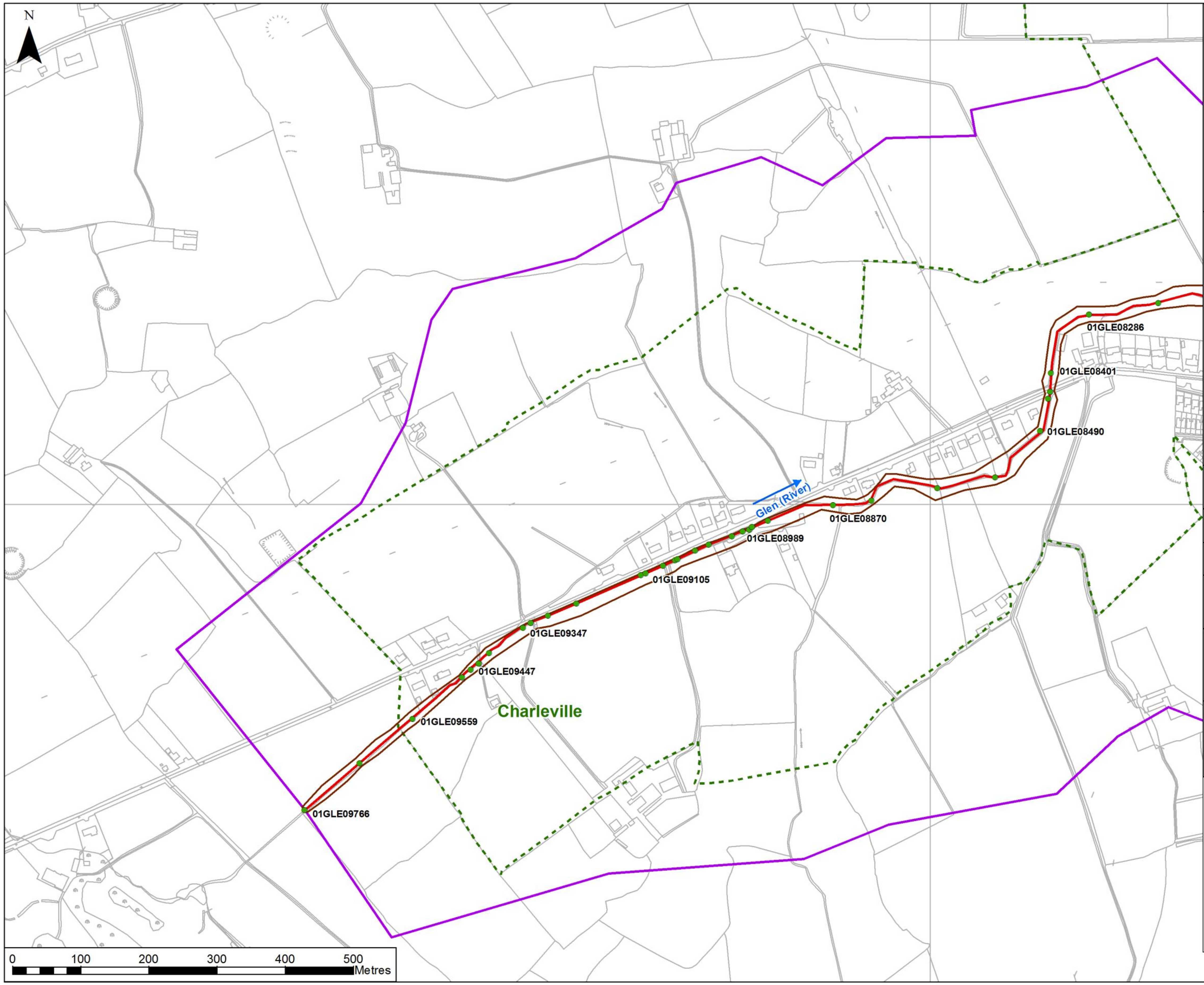
N
Downstream
Boundary Limit
Maigue (River)
Loobagh (River)
Glen (River)
Kilmallock
Charleville
0
1
2
3
4
5
Kilometres

Annex A2 – Schematisation Maps



Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Informal Defences

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- ISIS Reservoir Unit
- Cross-section Extents
- Spill

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S08

Figure ref: Annex A2 (1)

Drawing Title: S08 Model Schematisation

Client: The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
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Fax: 046 948 1793
www.opw.ie

Contractor: JACOBS
Merrion House, Merrion Road, Dublin
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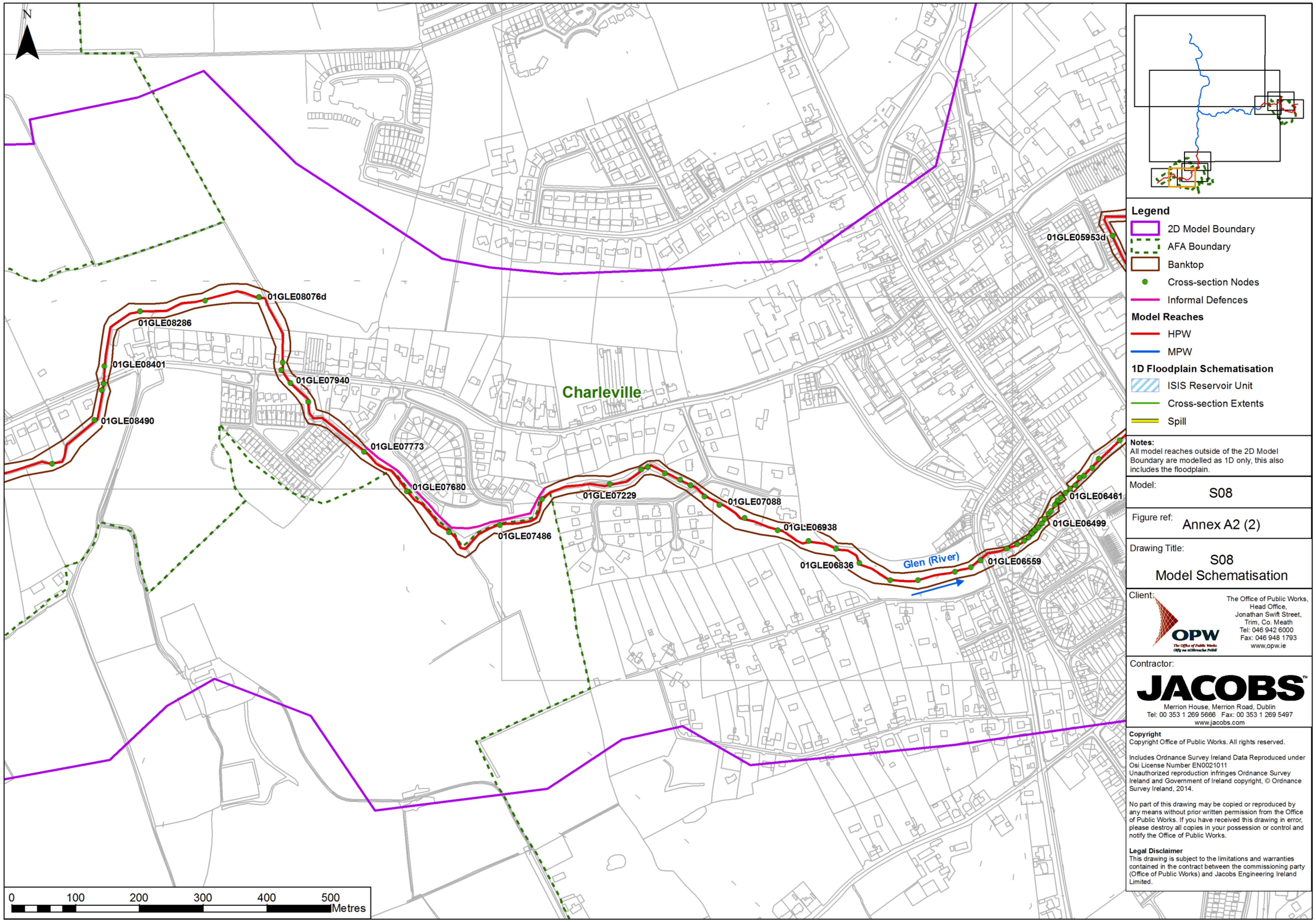

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01GLE08076d
01GLE08286
01GLE08401
01GLE08490
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01GLE07486
01GLE07229
01GLE07088
01GLE06938
01GLE06836
01GLE06559
01GLE06499
01GLE06461
01GLE05953d
Charleville
Glen (River)
0 100 200 300 400 500 Metres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Informal Defences
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Spill
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S08
Figure ref:
Annex A2 (2)
Drawing Title:
S08
Model Schematisation
Client:
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
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Fax: 046 948 1793
www,opw.ie
Contractor:
Merrion House, Merrion Road, Dublin
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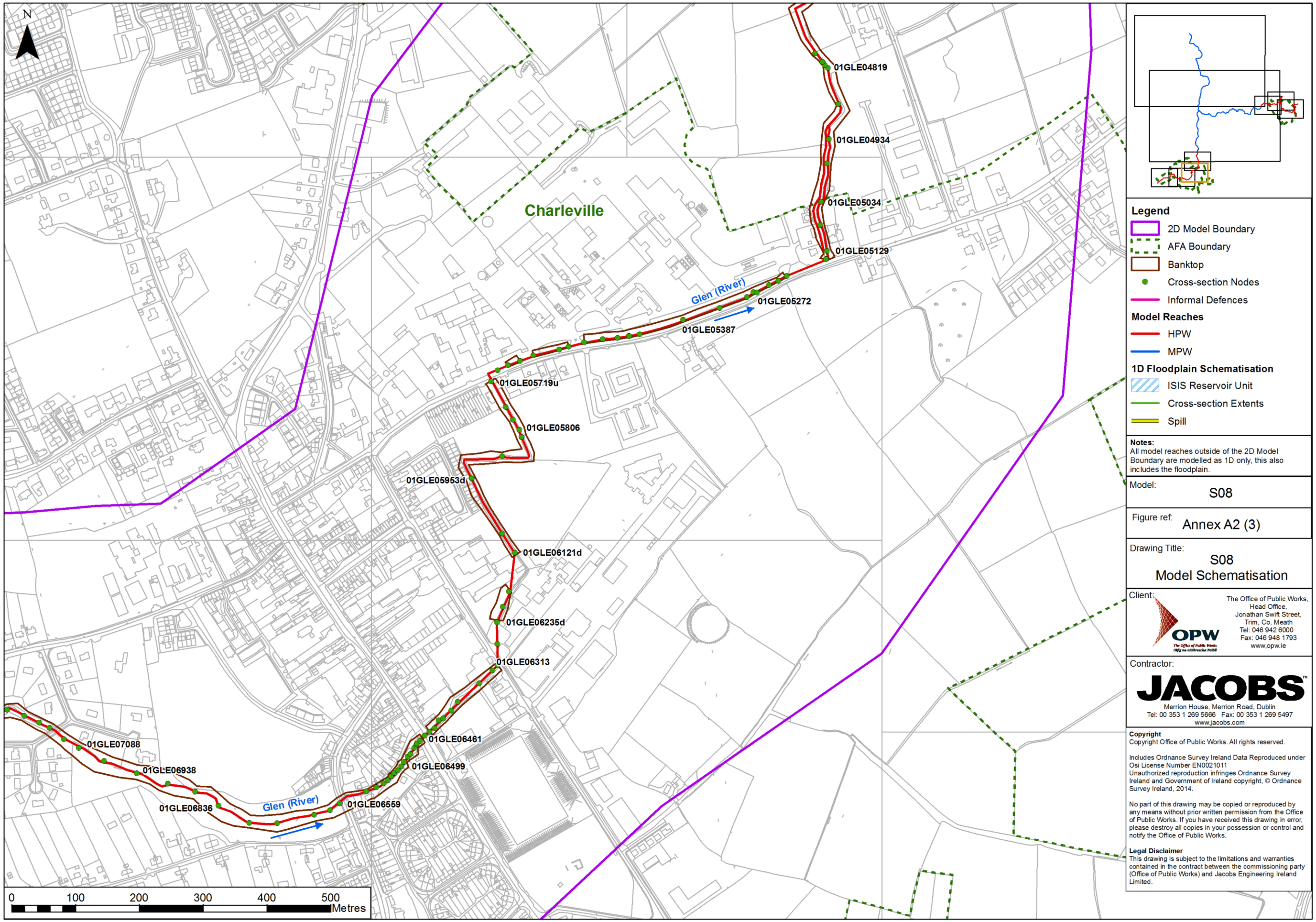

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Charleville
Glen (River)
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01GLE04934
01GLE05034
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01GLE05387
01GLE05719u
01GLE05806
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01GLE06121d
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01GLE06313
01GLE06461
01GLE06499
01GLE06559
01GLE06836
01GLE06938
01GLE07088
Glen (River)
0 100 200 300 400 500 Metres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Informal Defences
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Spill
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S08
Figure ref: Annex A2 (3)
Drawing Title: S08 Model Schematisation
Client:
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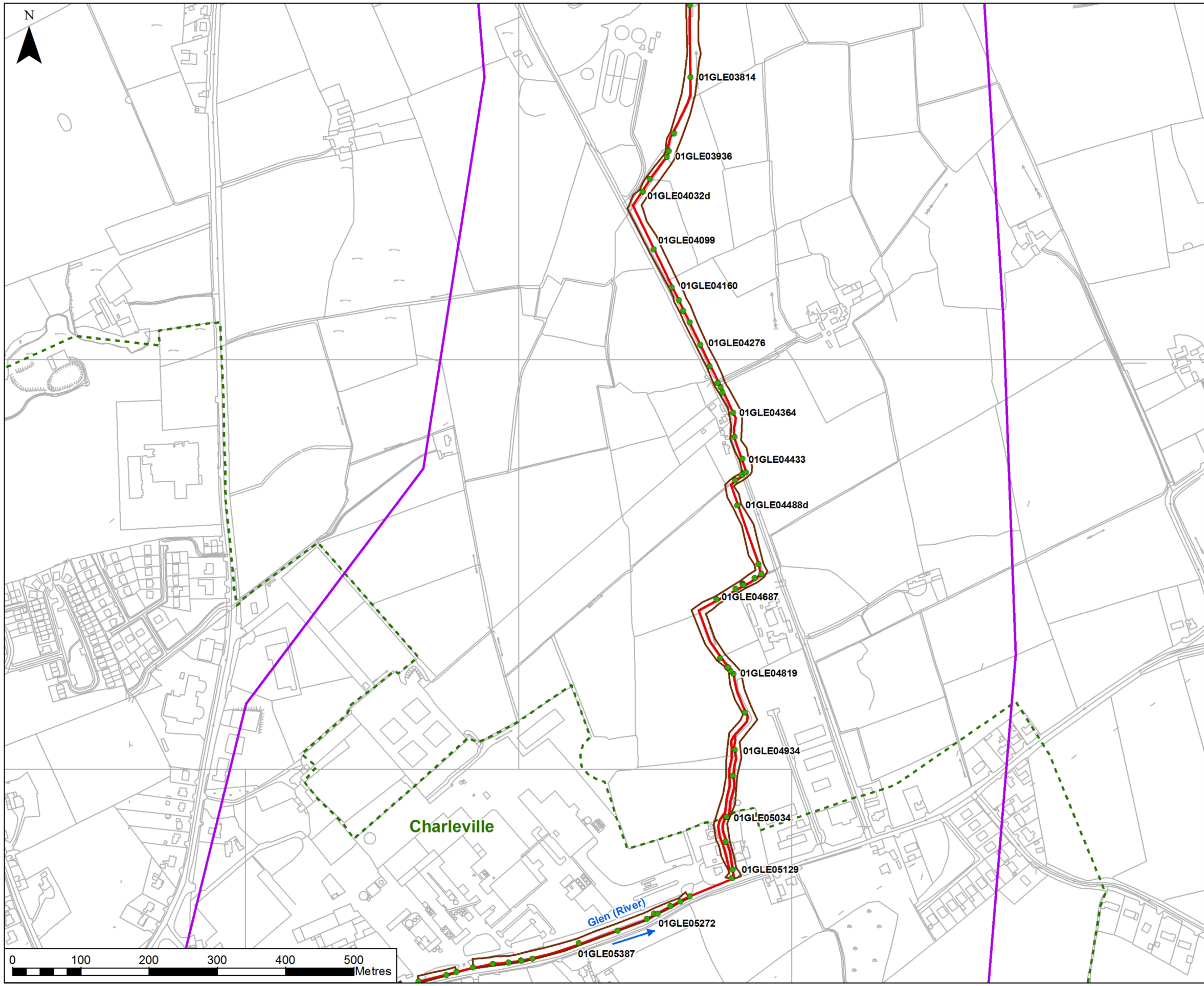

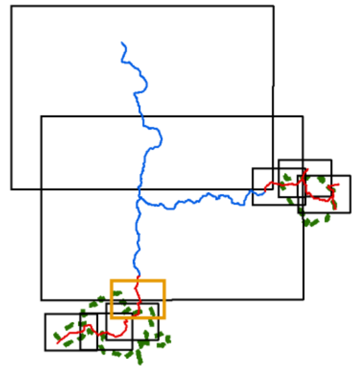

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Informal Defences

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- ISIS Reservoir Unit
- Cross-section Extents
- Spill

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S08

Figure ref: Annex A2 (4)

Drawing Title: S08 Model Schematisation

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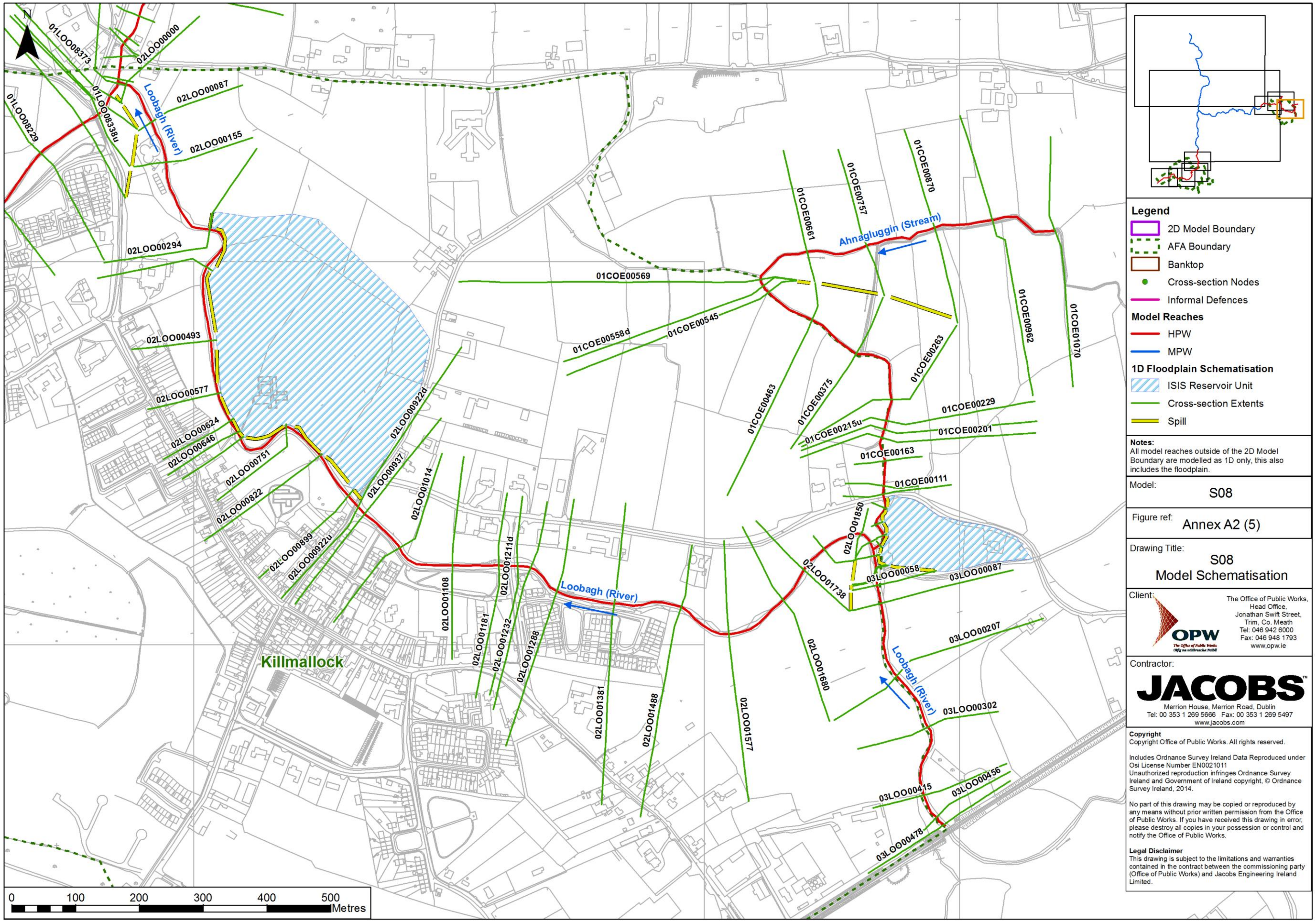
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2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Informal Defences
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Spill
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S08
Figure ref: Annex A2 (5)
Drawing Title: S08 Model Schematisation
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Killmallock
Loobagh (River)
Ahnagluggin (Stream)
01LOO08373
02LOO00000
01LOO08229
01LOO08338u
02LOO00087
02LOO00155
02LOO00294
02LOO00493
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02LOO01181
02LOO01211d
02LOO01232
02LOO01288
02LOO01381
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01COE00757
01COE00870
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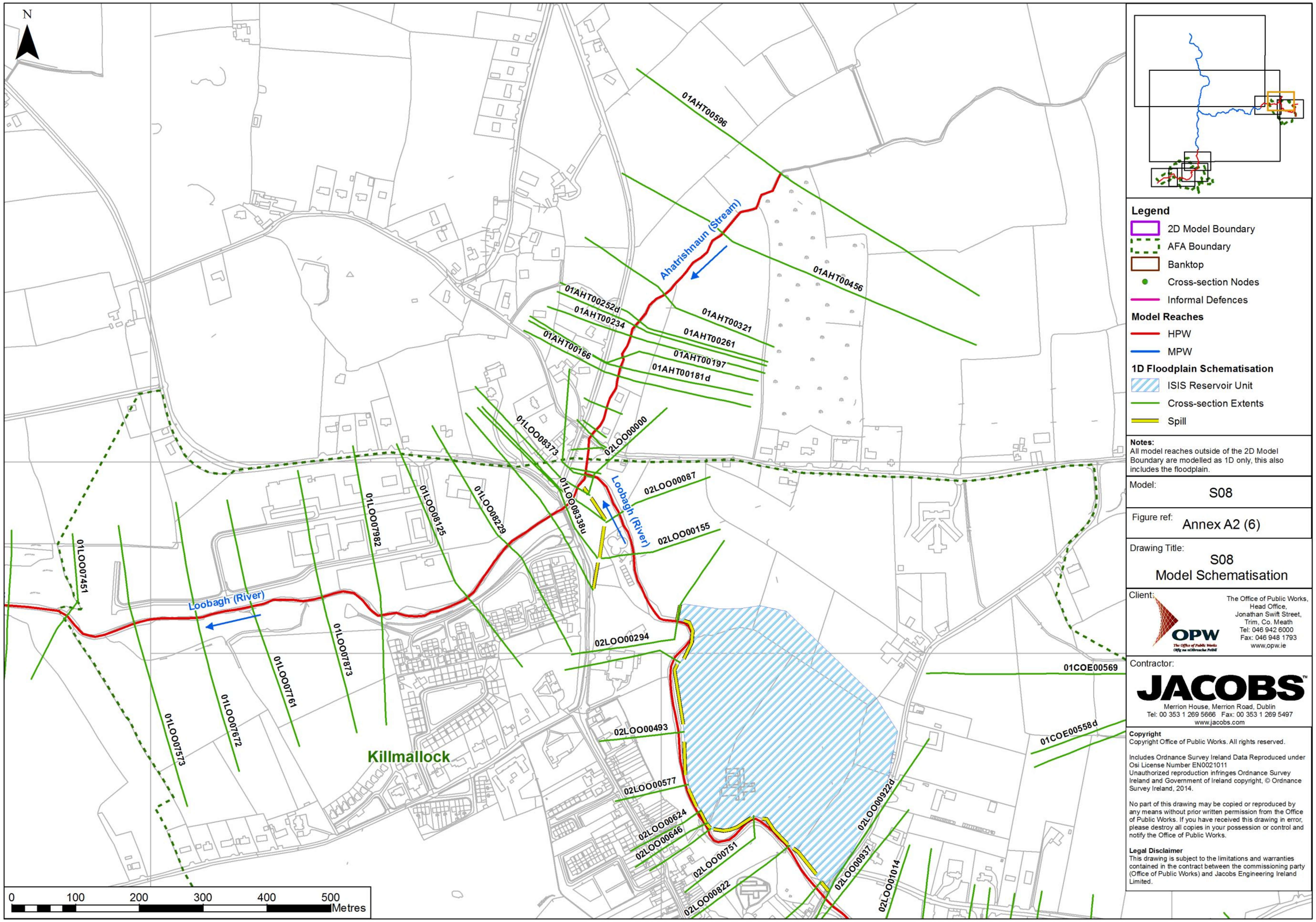

N
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01AHT00456
Ahatrishnaun (Stream)
01AHT00252d
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01AHT00166
01AHT00321
01AHT00261
01AHT00197
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2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Informal Defences
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Spill
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S08
Figure ref:
Annex A2 (6)
Drawing Title:
S08
Model Schematisation
Client:
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath Tel: 046 942 6000 Fax: 046 948 1793 www.opw.ie
Contractor:
Merrion House, Merrion Road, Dublin Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497 www.jacobs.com
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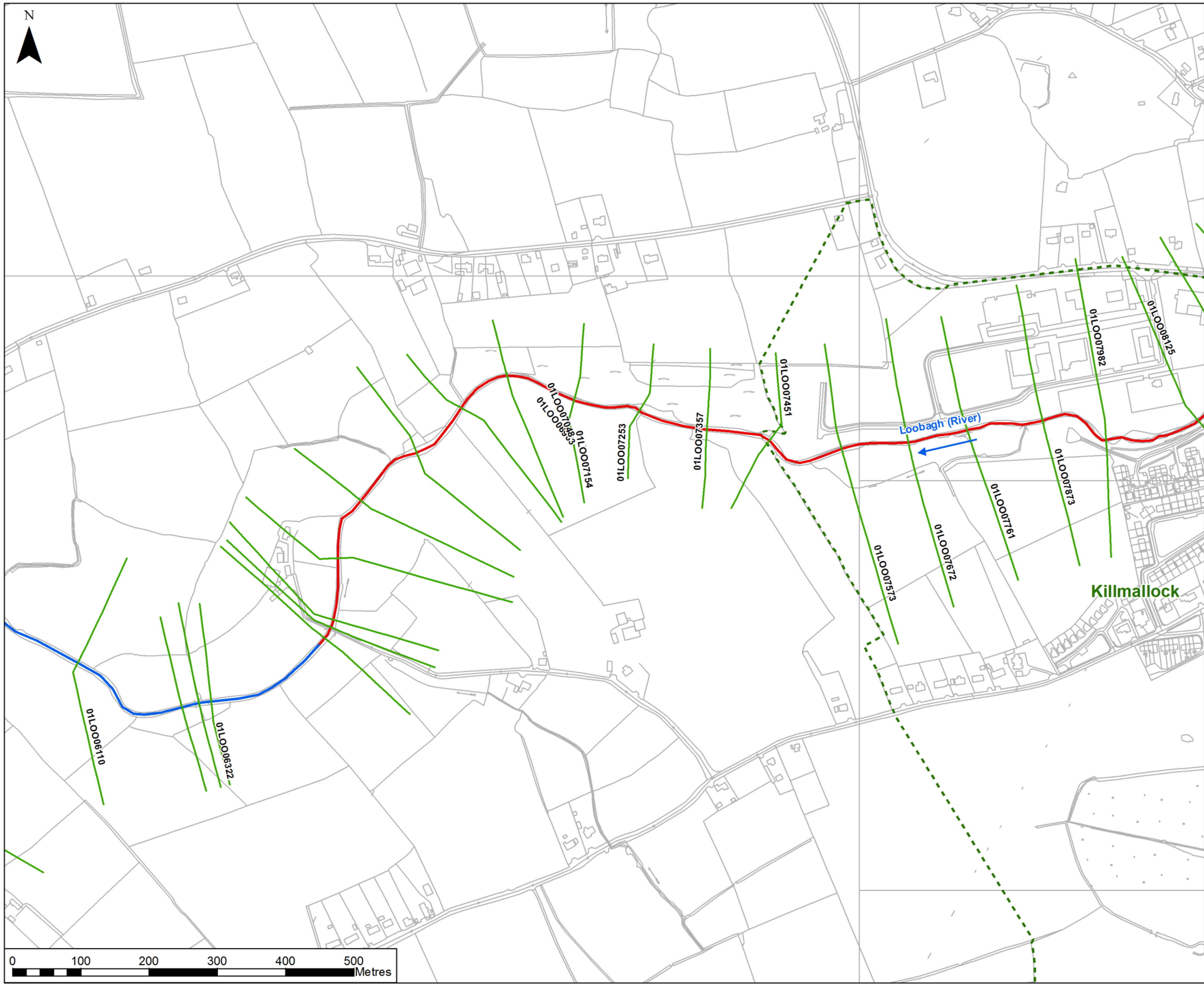

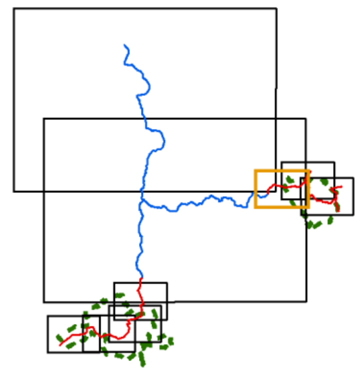

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Informal Defences

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- ISIS Reservoir Unit
- Cross-section Extents
- Spill

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S08

Figure ref: Annex A2 (7)

Drawing Title:
S08
Model Schematisation

Client:
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Tel: 046 942 6000
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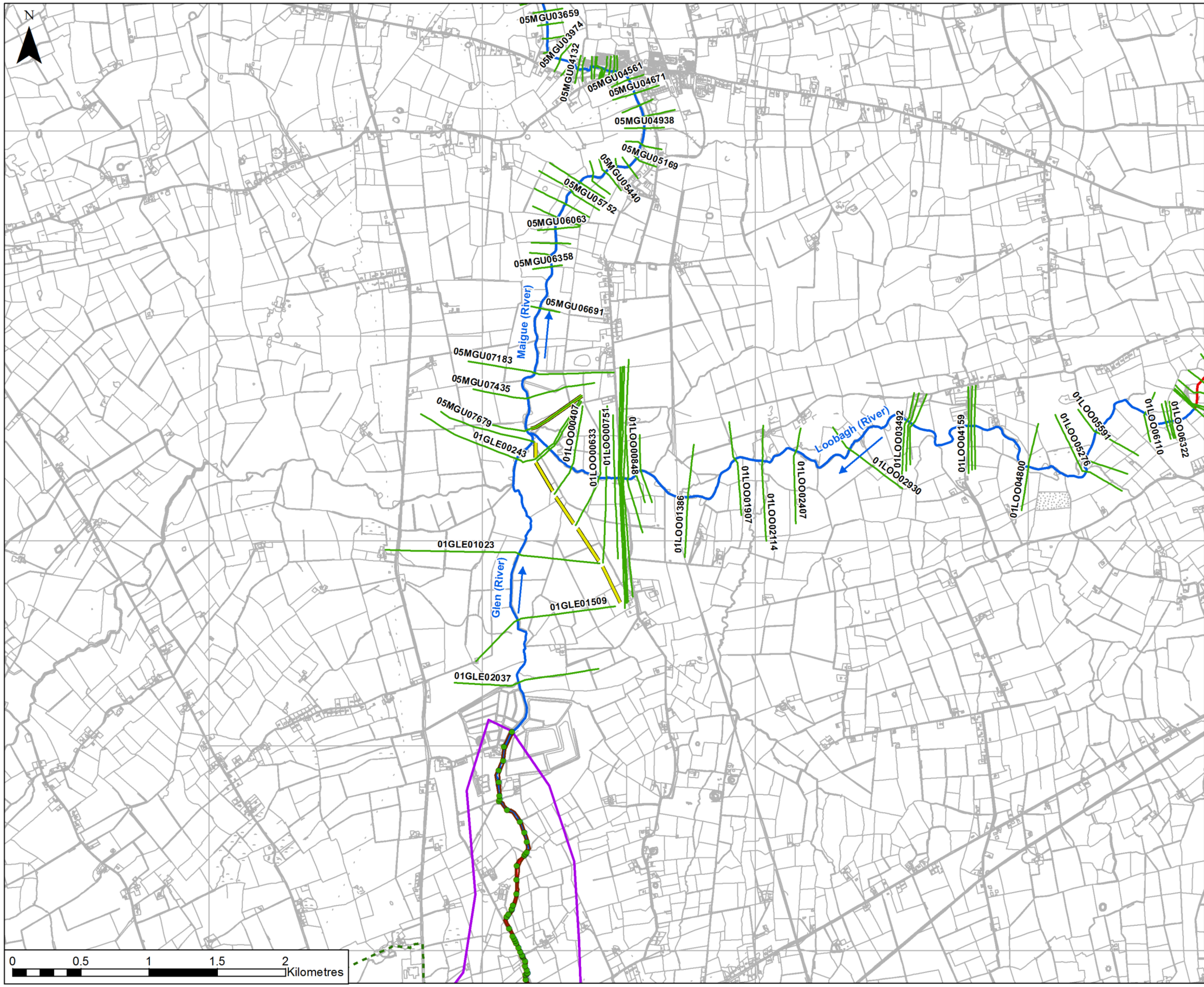

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Informal Defences

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- ISIS Reservoir Unit
- Cross-section Extents
- Spill

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S08

Figure ref: Annex A2 (8)

Drawing Title: S08 Model Schematisation

Client: The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath Tel: 046 942 6000 Fax: 046 948 1793 www.opw.ie

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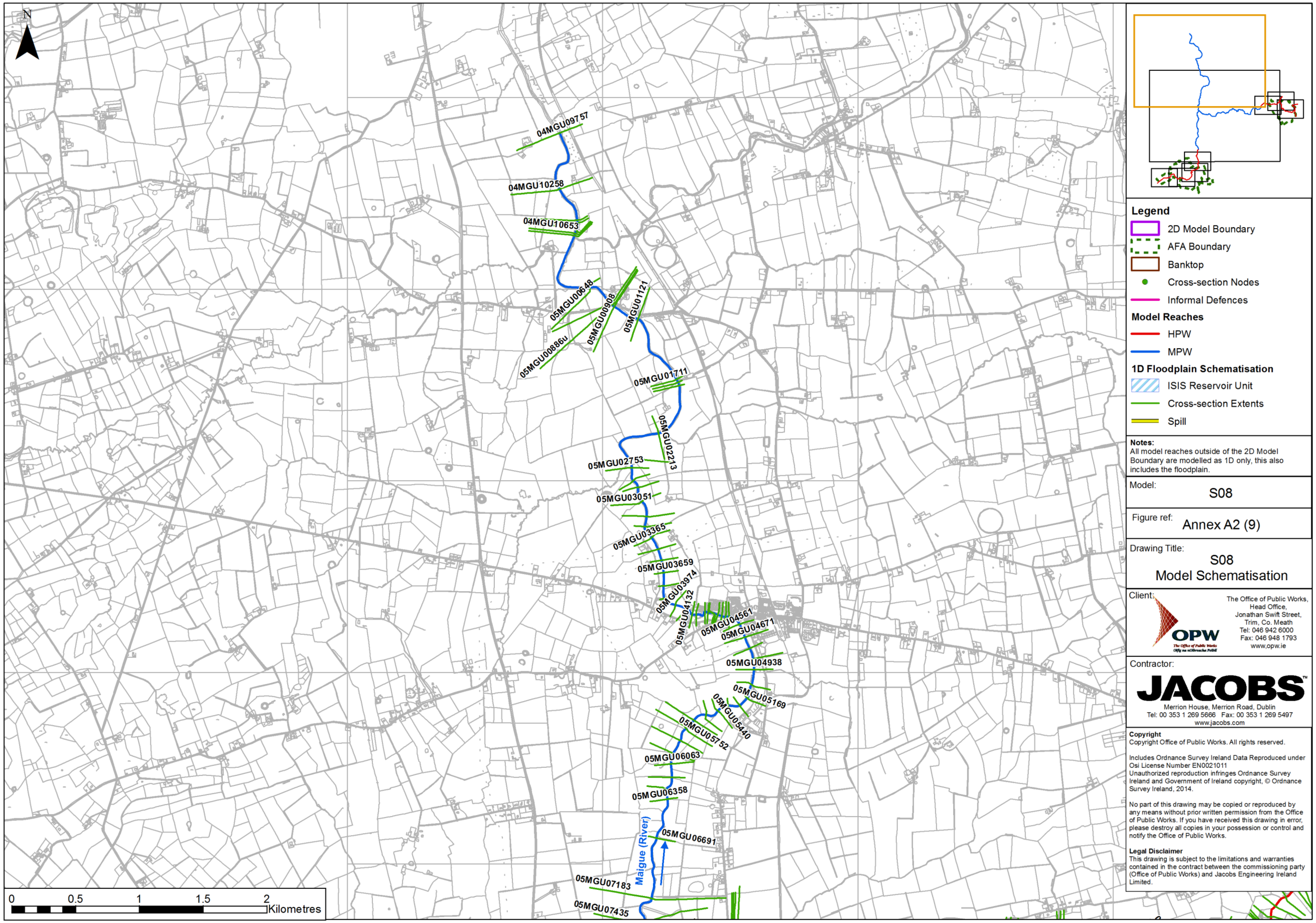
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05MGU04561
05MGU04671
05MGU04938
05MGU05169
05MGU05440
05MGU05752
05MGU06063
05MGU06358
05MGU06691
Maigue (River)
05MGU07183
05MGU07435
0 0.5 1 1.5 2
Kilometres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Informal Defences
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Spill
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S08
Figure ref:
Annex A2 (9)
Drawing Title:
S08
Model Schematisation
Client:
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Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for River Glen

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24MAIG04541D	01GLE09431	3.43m wide Bridge	Orifice + Spill	Y
24MAIG04532D	01GLE09334	1.16m dia. and 8.86m long twin culvert	Orifice + Spill	Y
24MAIG04496D	01GLE08974	8.48m wide Bridge	Rectangular conduit + Spill	Y
24MAIG04444D	01GLE08429	2.15m dia. and 8.23m wide Bridge	Arch sprung conduit + Spill	Y
24MAIG04400D	01GLE07964	7.89m wide Bridge	Arch bridge + Spill	Y
24MAIG04330D	01GLE07218	2.73m wide Bridge	Orifice + Spill	Y
24MAIG04323D	01GLE07145	2.15m dia. and 13.23m long culvert	Circular conduit + Spill	Y
24MAIG04273D	01GLE06637	14.34m wide Bridge	Arch bridge + Spill	Y
24MAIG04257D	01GLE06472	22.58m long culvert	Full arch conduits	Y
24MAIG04240I	01GLE06301u	67m long culvert	Rectangular conduits	Y
24MAIG04228I	01GLE06183u	1.19m dia. and 63.12m long culvert	Three Circular conduits	Y
24MAIG04189I	01GLE05719u	47.6m long culvert	Rectangular conduit + Bend Unit	Y
24MAIG04183I	01GLE05651u	22.2m long culvert	Rectangular conduit	Y
24MAIG04175I	01GLE05572u	25.2m long culvert	Rectangular conduit + Spill	Y
24MAIG04170D	01GLE05517u	Footbridge	Orifice + Spill	Y
24MAIG04166W	01GLE05477u	Weir	General Purpose Weir + Inline spill	Y
24MAIG04139I & 24MAIG04132J	01GLE05210u	67.03m long culvert	Rectangular conduit	Y
24MAIG04101D	01GLE04812u	3.74m wide Footbridge	Arch bridge + Spill	Y
24MAIG04086D	01GLE04642d	3.86m wide Bridge	Arch bridge +spill	Y

24MAIG04067I & 24MAIG04066J	01GLE04455u	6.07m long culvert	Orifice +spill	Y
24MAIG04052D	01GLE04314u	8.27m wide Bridge	Culvert + Rectangular Conduit + Spill	Y
24MAIG04039I & 24MAIG04039J	01GLE04177d	0.38m dia. and 4.44m long culvert	Circular conduit + Spill	Y
24MAIG04014D	01GLE03932u	4.17m wide Bridge	Orifice + Spill	Y
24MAIG03972D	01GLE03499u	0.76m dia. and 4.2m long twin culvert	Orifice + Spill	Y
24MAIG03926D	01GLE02999	4.68m wide Bridge	Arch bridge + Spill	N**

Schedule A.2 - Structure Schedule for River Maigue

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24MAIG03261D	05MGU04426u	7.22m wide Bridge	Arch bridge + Spill	Y
24MAIG03249W	05MGU04316	Weir	Oblique weir + Spill	Y
24MAIG03018D	05MGU01737	3.69m wide Bridge	Arch bridge + Spill	N*
24MAIG02936D	05MGU00886u	7.57m wide Bridge	Arch bridge + Spill	Y
24MAIG02827W	04MGU10589wu	Weir	Oblique weir + Spill	Y

Schedule A.3 - Structure Schedule for Ahatrishnaun Stream

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24LOOB00828D	01AHT00252u	4.72m wide Bridge	Orifice + Spill	Y
24LOOB00821D	01AHT00181u	4.73m wide Bridge	Orifice + Spill	Y

24LOOB000809D	01AHT00062u	6.82m wide Bridge	Arch Sprung culvert + Spill	Y

Schedule A.4 - Structure Schedule for River Loobagh

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24LOOB000797D	01LOO08338u	8.42m wide Bridge	Arch bridge + Spill	Y
24LOOB000625D	01LOO06557u	4.15m wide Bridge	Arch bridge + Spill	Y
24LOOB000601D	01LOO06322	5.75m wide Bridge	Arch bridge + Spill	N*
24LOOB000418D	01LOO04180u	6.76m wide Bridge	Arch bridge + Spill	Y
24LOOB000309D	01LOO03517	3.63m wide Bridge	Arch bridge + Spill	N*
GAR01.0007	01LOO00802u	6.3m wide Bridge	Arch bridge + Spill	Y
GAR01.0003	01LOO00197	Accommodation bridge	Arch bridge + Spill	N*
24LOOD00182W	03LOO00041u	Weir	Oblique weir + Spill	Y
24LOOD00114D	02LOO01211u	11.32m wide Bridge	Arch bridge + Spill	Y
24LOOD00085D	02LOO00922u	7.42m wide Bridge	Arch bridge + Spill	Y
24LOOD00060D	02LOO00646	1.82m wide Footbridge	Arch bridge + Spill	N*

*** Considering the size of the structure relative to the watercourse it was determined that the structure would have little or no hydraulic impact on the model.**
**** Structure will not be hydraulically significant during peak flood flows.**

Schedule A5 - Structure Schedule for River Ahnagluggin Stream

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24LOOE00052D	01COE00558u	4.67m wide Bridge	Orifice + Spill	Y
24LOOE00020D	01COE00215u	4.61m wide Railway Bridge	Orifice + Spill	Y
24LOOE00010D	01COE00111w	8.6m wide Bridge	Box culvert + Spill	Y

Schedule B.1 – Manning's 'n' for HPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
Glen River	01GLE09766 to 01GLE09410	0.047	Determined on a case by case basis using photos, videos and survey drawings	2d Domain : based on OSi NTF land use polygons 1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
	01GLE09347 to 01GLE08948	0.042		
	01GLE08793 to 01GLE06386	0.047		
	01GLE06313 to 01GLE05765	0.041		
	01GLE05719u to 01GLE05143d	0.032		
	01GLE05129 to 01GLE03482	0.042		
	01LOO08373 to 01LOO06538	0.038		
	03LOO00478 to 03LOO00012u	0.038		
Ahatrishnaun Stream	01AHT00596 to 01AHT00005	0.043		
Ahnagluggin Stream	01COE01070 to 01COE00012	0.043		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6

Schedule B.2 – Manning's 'n' for MPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Loobagh	02LOO001879 to 01LOO00000	0.042	Determined on a case by case basis using photos, videos and survey drawing	Land use EPA data has been used for assigning the floodplain roughness.
Glen River	01GLE03015 to 01GLE00000	0.045		
River Maigue	05MGU07709 to 04MGU09757	0.045		

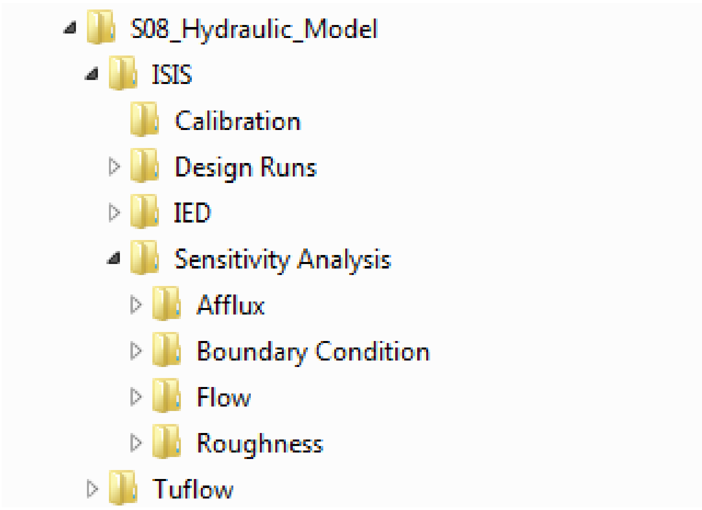
Annex C - Model Calibration Summary Note

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report. It should be noted that it was not possible to calibrate this model for any flood event. One potential flood event (1946) was identified for calibration, however the observational data was neither reliable nor specific. One gauging station at Garroose Bridge (24003) lies within the model extent. The gauging station is verified to 0.69 QMED and is classified as a “B” in the FSU.

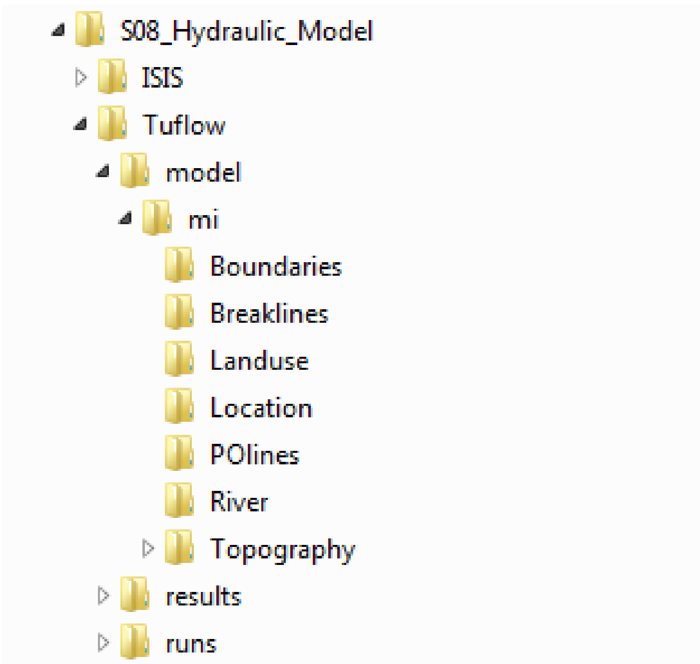
Annex D - Hydraulic Model Files

Model Files Folders Structure

ISIS



TUFLOW



ISIS Files

Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Design Runs – Current Scenario:** **Main Stream Model** S08_Q10_FLU_C_DES_MAIN_8M_1D2D_IssV1.DAT S08_Q100_FLU_C_DES_MAIN_8M_1D2D_IssV1.DAT S08_Q1000_FLU_C_DES_MAIN_8M_1D2D_IssV1.DAT **Tributary 2 Model** S08_Q10_FLU_C_DES_TRIB2_IssV1.DAT S08_Q100_FLU_C_DES_TRIB2_IssV1.DAT S08_Q1000_FLU_C_DES_TRIB2_IssV1.DAT

	Tributary 3 Model S08_Q10_FLU_C_DES_TRIB3_IssV1.DAT S08_Q10_FLU_C_DES_TRIB3_IssV1.DAT S08_Q1000_FLU_C_DES_TRIB3_IssV1.DAT **Sensitivity Runs – Current Scenario** **Main Stream Model** S08_Q100_FLU_C_Sen_Afflux_In_Main_IssV1..DAT S08_Q100_FLU_C_Sen_Afflux_De_Main_IssV1..DAT S08_Q100_FLU_C_Sen_Bdy_In_Main_IssV11.DAT S08_Q100_FLU_C_Sen_Bdy_De_Main_IssV11.DAT S08_Q100_FLU_C_Sen_20FlDe_Main_IssV1.DAT S08_Q100_FLU_C_Sen_20FlIn_Main_IssV1.DAT S08_Q100_FLU_C_Sen_20RoDe_Main_IssV1.DAT S08_Q100_FLU_C_Sen_20RoIn_Main_IssV1.DAT **Tributary 2 Model** S08_Q100_FLU_C_Sen_20FlDe_TRIB2_IssV1.DAT S08_Q100_FLU_C_Sen_20FlIn_TRIB2_IssV1.DAT S08_Q100_FLU_C_Sen_20RoIn_Trib2_IssV1.DAT S08_Q100_FLU_C_Sen_20RoDe_Trib2_IssV1.DAT **Tributary 3 Model** S08_Q100_FLU_C_Sen_20FlDe_TRIB3_IssV1.DAT S08_Q100_FLU_C_Sen_20FlIn_TRIB3_IssV1.DAT S08_Q100_FLU_C_Sen_20RoDe_TRIB3_IssV1.DAT S08_Q100_FLU_C_Sen_20RoIn_TRIB3_IssV1.DAT
Hydrological Inflow Files	**Design Runs – Current Scenario:** **Main Stream Model** Q10_DesignR_Main.IED Q100_DesignR_Main.IED Q1000_DesignR_Main.IED **Tributary 2 Model** Q10_DesignR_Trib2.IED Q100_DesignR_Trib2.IED Q1000_DesignR_Trib2.IED **Tributary 3 Model** Q10_DesignR_Trib3.IED Q100_DesignR_Trib3.IED Q1000_DesignR_Trib3.IED **Sensitivity Runs – Current Scenario** **Main Stream Model** S08_Q100_Sen_Main_20FlDe_IssV1.IED S08_Q100_Sen_Main_20FlIn_IssV1.IED

	Tributary 2 Model S08_Q100_Sen_Trib2_20FlDe_IssV1.IED S08_Q100_Sen_Trib2_20FlIn_IssV1.IED **Tributary 3 Model** S08_Q100_Sen_Trib3_20FlDe_IssV1.IED S08_Q100_Sen_Trib3_20FlIn_IssV1.IED

TUFLOW Files	
TUFLOW Control Files (.tcf) and Associated Files (e.g.: ecf, tgc, tbc)	**Design Runs – Current Scenario:** **Main Stream Model** S08_Q10_MAIN_FLU_C_DES_Iss1.tcf S08_Q100_MAIN_FLU_C_DES_Iss1.tcf S08_Q1000_MAIN_FLU_C_DES_Iss1.tcf **Sensitivity Runs – Current Scenario** **Main Stream Model** S08_Q100_Main_Sen_20FlDe_IssV1.tcf S08_Q100_Main_Sen_20FlIn_IssV1.tcf S08_Q100_Main_Sen_Afflux_De_IssV1.tcf S08_Q100_Main_Sen_Afflux_In_IssV1.tcf S08_Q100_Main_Sen_Bdy_De_IssV1.tcf S08_Q100_Main_Sen_Bdy_In_IssV1.tcf } 2d_8m_S08_CHAR.tbc, 2d_8m_S08_CHAR.tgc, S08_CHAR_Landuse.tmf S08_Q100_Main_Sen_RoDe_IssV1.tcf } 2d_8m_S08_CHAR.tbc, 2d_8m_S08_CHAR.tgc, S08_CHAR_Landuse_RODE.tmf S08_Q100_Main_Sen_RoIn_IssV1.tcf } 2d_8m_S08_CHAR.tbc, 2d_8m_S08_CHAR.tgc, S08_CHAR_Landuse_ROIN.tmf
Grid Orientation File	2d_loc_S08.MIF
Material Files	2d_mat_Buildings_S08_CHAR.MIF 2d_mat_General_S08_CHAR.MIF 2d_mat_GeneralRural_S08_CHAR.MIF 2d_mat_GeneralUrban_S08_CHAR.MIF 2d_mat_Roads_S08_CHAR.MIF 2d_mat_S08_CHAR.MIF 2d_mat_Waterbodies_S08_CHAR.MIF
Zpt Files, Model DTM (.asc)	S08_CHAR_dtm_2mLidar.asc
Breaklines Files	2d_zln_unsurv_banktop_S08_CHAR.MIF 2d_zln_Drains_S08_8m_CHAR.MIF 2d_zln_Parapets_S08_8m_CHAR.MIF 2d_zln_surv_banktop_S08_CHAR.MIF 2d_zln_Parapets_S08_8m_CHAR.MIF 2d_zln_walls_S08_8m_CHAR.MIF 2d_zln_walls_S08_8m_CHAR.MIF
Boundary Files	2d_bc_hxe_CHAR_8m.MIF 2d_bc_hxi_CHAR_8m.MIF
Flow/Head Files in bc_dbase	No Flow/Head boundaries provided in 2D domain.
Initial Water Level Files	No initial water level files provided to the 2d domain.

Time Series Files	No time series files provided to the 2d domain.
One Dimensional Network Files	1d_ISIS_nodes_S08_char.MIF
Available 2D Result Files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs – Current scenario						
	S08_Q10_FLU_C_DES_MAIN_8M_1D 2D_IssV1.DAT	2	65	1 sec 1D 1 sec 2D	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.
2	S08_Q100_FLU_C_DES_MAIN_8M_1 D2D_IssV1.DAT	2	65	1 sec 1D 1 sec 2D	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.
4	S08_Q1000_FLU_C_DES_MAIN_8M_1 D2D_IssV1.DAT	2	66	1 sec 1D 1 sec 2D	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.
5	S08_Q10_FLU_C_DES_TRIB2_IssV1. DAT	0	60	1 sec	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.
6	S08_Q100_FLU_C_DES_TRIB2_IssV1. DAT	0	65	1 sec	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.
7	S08_Q1000_FLU_C_DES_TRIB2_IssV 1.DAT	0	65	1 sec	Automated Preissmann Slot for River Sections” is checked, “minitr” value is set to 2 and “maxitr” value is set to 10, ISIS Flow Engine Version “Double Precision” is checked.	Convergence within manufacturer tolerance.

8	S08_Q10_FLU_C_DES_TRIB3_IssV1.DAT	0	65	1 sec	Automated Preissmann Slot for River Sections" is checked, "minitr" value is set to 2 and "maxitr" value is set to 10, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
9	S08_Q100_FLU_C_DES_TRIB3_IssV1.DAT	0	65	1 sec	Automated Preissmann Slot for River Sections" is checked, "minitr" value is set to 2 and "maxitr" value is set to 10, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
10	S08_Q1000_FLU_C_DES_TRIB3_IssV1.DAT	0	65	1 sec	Automated Preissmann Slot for River Sections" is checked, "minitr" value is set to 2 and "maxitr" value is set to 10, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
Sensitivity Analysis						
11	S08_Q100_FLU_C_Sen_Afflux_In_Main_IssV1..DAT	0	65	1 sec 1D 1 sec 2D	The "coefficient of discharge" is changed to 1.2 in Weir unit (ISIS Node: 01GLE5477s1u)	Convergence within manufacturer tolerance.
12	S08_Q100_FLU_C_Sen_Afflux_De_Main_IssV1..DAT	0	65	1 sec 1D 1 sec 2D	The "coefficient of discharge" is changed to 0.8 in Weir unit (ISIS Node: 01GLE5477s1u)	Convergence within manufacturer tolerance.
13	S08_Q100_FLU_C_Sen_Bdy_In_Main_IssV11.DAT	0	65	1 sec 1D 1 sec 2D	The slope used in the Normal Depth boundary is doubled.	Convergence within manufacturer tolerance.
14	S08_Q100_FLU_C_Sen_Bdy_De_Main_IssV11.DAT	0	65	1 sec 1D 1 sec 2D	The slope used in the Normal Depth boundary is halved.	Convergence within manufacturer tolerance.
15	S08_Q100_FLU_C_Sen_20FlDe_Main_IssV1.DAT	0	65	1 sec 1D 1 sec 2D	The flow in Main stream has been decreased by 20%	Convergence within manufacturer tolerance.

16	S08_Q100_FLU_C_Sen_20FlIn_Main_IssV1.DAT	0	65	1 sec 1D 1 sec 2D	The flow in Main stream has been increased by 20%	Convergence within manufacturer tolerance.
17	S08_Q100_FLU_C_Sen_20RoDe_Main_IssV1.DAT	0	65	1 sec 1D 1 sec 2D	The roughness has been decreased by 20% in 1D and 2D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.
18	S08_Q100_FLU_C_Sen_20RoIn_Main_IssV1.DAT	0	65	1 sec 1D 1 sec 2D	The roughness has been decreased by 20% in 1D and 2D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.
19	S08_Q100_FLU_C_Sen_20FlDe_TRIB2_IssV1.DAT	0	65	1 sec	The flow in Tributary 2 has been decreased by 20%	Convergence within manufacturer tolerance.
20	S08_Q100_FLU_C_Sen_20FlIn_TRIB2_IssV1.DAT	0	65	1 sec	The flow in Tributary 2 has been increased by 20%	Convergence within manufacturer tolerance.
21	S08_Q100_FLU_C_Sen_20RoIn_Trib2_IssV1.DAT	0	65	1 sec	The roughness has been increased by 20% in 1D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.
22	S08_Q100_FLU_C_Sen_20RoDe_Trib2_IssV1.DAT	0	65	1 sec	The roughness has been decreased by 20% in 1D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.
23	S08_Q100_FLU_C_Sen_20FlDe_TRIB3_IssV1.DAT	0	65	1 sec	The flow in Tributary 3 has been decreased by 20%	Convergence within manufacturer tolerance.
24	S08_Q100_FLU_C_Sen_20FlIn_TRIB3_IssV1.DAT	0	65	1 sec	The flow in Tributary 3 has been increased by 20%	Convergence within manufacturer tolerance.
25	S08_Q100_FLU_C_Sen_20RoDe_TRIB3_IssV1.DAT	0	65	1 sec	The roughness has been decreased by 20% in 1D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.

26	S08_Q100_FLU_C_Sen_20RoIn_TRIB3_IssV1.DAT	0	65	1 sec	The roughness has been increased by 20% in 1D model. The Preissmann slot width has been increased to 0.25	Convergence within manufacturer tolerance.

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 10 to improve model stability.*
ISIS Flow Engine Version – Double Precision	Used to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Fluvial Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S11
Unit of Management	24
AFA included in the Model	Newcastle West
Primary Watercourses / Water Bodies	River Deel River Ehernagh River Daar River Arra River Doally River Killeline River Knockane
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A3.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B8 – Figure B8.2

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k OS1212_D
2.2 DTM for 2D Model Domains:	**Within AFA:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFA: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 369
2.4 Defence Asset Survey Data	The defence asset database has been completed for this Model Area. The defence asset database indicates that there are approximately 700m of formal defences in the model area. These defences are along the left and right bank of the River Doally and are illustrated in Annex A2.

2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:**	ISIS Version 3.6.0.156 (32 bit - Double Precision)
	2D Domain(s):	TUFLOW Version: 2012-05-AE-iDP-w32
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.	

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary
2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included.**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
River Deel	05DEL	05DEL08104	05DEL00000
	04DEL	04DEL06520	04DEL00000
River Ehernagh	01EHR	01EHR01341	01EHR00000
River Daar	01CPR	01DAR04394	01DAR00000
River Arra	01APR	01APR00381	01APR00000
River Doally	04DLY	04DLY00690	04DLY00000
	03DLY	03DLY00517	03DLY00000
	02DLY	02DLY02528	02DLY00000
	01DLY	01DLY00182	01DLY00000
River Killeline	01CNG	01CNG00827	01CNG00000
	01SHG	01SHG00980	01SHG00000
River Knockane	02SHG	02SHG00805	02SHG00000

Total model HPW length (km):	12.4	**Total model MPW length (km):**	16.2

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	05
Bridges:	☒	How many?	22
Fixed crest weirs:	☒	How many?	04
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation

S11 comprises two models; the first one, the main model, including the HPW and MPW reaches of the River Deel and the other, the tributary model, including the tributaries of the River Deel which flow through the Newcastle West AFA.

Out-of-bank areas for the main model have been modelled following a 1D

<table>
<tr><td></td><td colspan="3">approach using ISIS and by extending the river channel cross-sections in the model.
In the tributary model, out-of-bank areas for the most part of the HPW reaches have been modelled using a 2D approach using TUFLOW. In some places a 1D approach has been taken using ISIS and by extending the river channel cross-sections in the model.
Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple. 1D-2D modelling is required where HPWs flow through urban areas where out-of-bank flows will form complex flow paths.
An overview of the floodplain schematisation is available in the maps shown in Annex A.</td></tr>
<tr><td rowspan="4">3.6 2D Domain Grid Size:</td><td colspan="3">The number of 2D domains defined and the grid sizes of each 2D model domain are as follows:</td></tr>
<tr><td colspan="3">Number of 2D domains: 1</td></tr>
<tr><td>Domain 1: Newcastle West</td><td>Grid cell size (m): 5</td><td>Area (km^2): 3.42</td></tr>
<tr><td colspan="3">2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.</td></tr>
<tr><td>3.7 Model Breaklines in the 2D Domain:</td><td colspan="3">Bank tops, embanked roads, drains and bridge parapets are represented as breaklines in the 2D domain.</td></tr>
<tr><td>3.8 Floodplain Structures in the 2D Domain</td><td colspan="3">No floodplain structures have been included in the 2D model.</td></tr>
<tr><td>3.9 Hydraulic Roughness</td><td colspan="3">Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:</td></tr>
<tr><td rowspan="2">MPW in-bank</td><td>Minimum 'n' value:</td><td colspan="2">0.040</td></tr>
<tr><td>Maximum 'n' value:</td><td colspan="2">0.052</td></tr>
<tr><td rowspan="2">HPW in-bank</td><td>Minimum 'n' value:</td><td colspan="2">0.045</td></tr>
<tr><td>Maximum 'n' value:</td><td colspan="2">0.055</td></tr>
<tr><td rowspan="6">Floodplain (ISIS Model)</td><td colspan="3">Manning's 'n' for out-of-bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:</td></tr>
<tr><td>Land Use</td><td colspan="2">Manning's 'n' Value</td></tr>
<tr><td>Pastures</td><td colspan="2">0.035</td></tr>
<tr><td>Dense Vegetation</td><td colspan="2">0.080</td></tr>
<tr><td>Road Network</td><td colspan="2">0.025</td></tr>
<tr><td>Buildings</td><td colspan="2">0.100</td></tr>
<tr><td>Floodplain (TUFLOW Model)</td><td colspan="3">Manning's 'n' for out-of-bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:</td></tr>
</table>

	Land Use		Manning's 'n' Value						
	Buildings		0.100						
	Short grass, parks		0.035						
	General Urban		0.060						
	General Rural		0.045						
	Dense Vegetation		0.080						
	Roads		0.025						
	Railways		0.050						
	Water bodies		0.020						
3.10 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain).Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.								
3.11 Model Boundaries - Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report relevant to Unit of Management 24. Peak inflows (m3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2)								
(a) Current Situation									
HEP Reference Name	**Input Node in the Hydraulic Model**	**Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
(a) Main Model									
24_860_1	05DEL08104	70.3	86.5	96.4	104.8	116.1	124.5	132.2	149.8
24_860_2	05DEL07703	2.6	3.2	3.6	3.9	4.3	4.6	4.9	5.6
24_1602_3	05DEL07277	15.6	19.2	21.4	23.3	25.8	27.6	29.4	33.3
24_863_2	05DEL06364	17.9	22.0	24.5	26.6	29.5	31.6	33.6	38.1
24_1511_1	05DEL06098	7.9	9.7	10.9	11.8	13.1	14.0	14.9	16.9
24_688_2	05DEL00000	19.8	24.3	27.1	29.5	32.6	35.0	37.2	42.1
(a) Tributary 2 Model									
24_1605_6	01DAR04394	12.7	16.1	18.2	20.4	23.2	25.2	27.3	32.0
24_872_2	04DLY00690	9.5	12.0	13.6	15.2	17.3	18.8	20.3	23.8
24_866_1	02DLY02494JU	1.1	1.4	1.6	1.8	2.0	2.2	2.4	2.8
24_866_3	02DLY01559	1.0	1.3	1.4	1.6	1.8	2.0	2.2	2.5
24_937_6	01EHR00033	14.4	18.2	20.6	23.1	26.2	28.5	30.8	36.2
24_1273_3	01APR00123	4.8	6.1	6.9	7.8	8.8	9.6	10.4	12.2
24_1156_3	01SHG00060	12.7	16.1	18.2	20.4	23.2	25.2	27.3	32.0

(a) Tributary 3 Model									
24_937_3	01EHR01341	18.2	23.0	26.1	29.2	33.2	36.1	39.0	45.8
24_1273_2	01APR00381	6.1	7.7	8.7	9.7	11.1	12.1	13.0	15.3
24_1265_1	01CNG00827	4.3	5.4	6.1	6.9	7.8	8.5	9.2	10.8
24_877_1	02SHG00805	10.8	13.6	15.4	17.2	19.6	21.3	23.1	27.0
(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.								
HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
(a) Main Model									
24_860_1	05DEL08104	84.4	103.8	115.6	125.8	139.3	149.4	158.7	179.8
24_860_2	05DEL07703	3.1	3.9	4.3	4.7	5.2	5.5	5.9	6.7
24_1602_3	05DEL07277	18.7	23.0	25.7	27.9	30.9	33.2	35.2	39.9
24_863_2	05DEL06364	21.4	26.4	29.4	32.0	35.4	38.0	40.3	45.7
24_1511_1	05DEL06098	9.5	11.7	13.0	14.2	15.7	16.8	17.9	20.2
24_688_2	05DEL00000	23.7	29.2	32.5	35.3	39.1	42.0	44.6	50.5
(a) Tributary 2 Model									
24_1605_6	01DAR04394	15.2	19.3	21.8	24.5	27.8	30.2	32.8	38.4
24_872_2	04DLY00690	11.4	14.4	16.3	18.2	20.8	22.6	24.4	28.6
24_866_1	02DLY02494JU	1.3	1.7	1.9	2.2	2.4	2.6	2.9	3.4
24_866_3	02DLY01559	1.2	1.6	1.7	1.9	2.2	2.4	2.6	3.0
24_937_6	01EHR00033	17.3	21.8	24.7	27.7	31.4	34.2	37.0	43.4
24_1273_3	01APR00123	5.8	7.3	8.3	9.4	10.6	11.5	12.5	14.6
24_1156_3	01SHG00060	15.2	19.3	21.8	24.5	27.8	30.2	32.8	38.4
(a) Tributary 3 Model									
24_937_3	01EHR01341	21.9	27.6	31.3	35.0	39.8	43.3	46.8	54.9
24_1273_2	01APR00381	7.3	9.2	10.4	11.7	13.3	14.5	15.6	18.3
24_1265_1	01CNG00827	5.1	6.5	7.4	8.2	9.4	10.2	11.0	12.9
24_877_1	02SHG00805	12.9	16.3	18.5	20.7	23.5	25.6	27.7	32.4
(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.								

HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
(a) Main Model				
24_860_1	05DEL08104	125.3	161.9	194.8

24_860_2	05DEL07703	4.7	6.0	7.3
24_1602_3	05DEL07277	27.8	35.9	43.2
24_863_2	05DEL06364	31.8	41.1	49.5
24_1511_1	05DEL06098	14.1	18.2	22.0
24_688_2	05DEL00000	35.2	45.5	54.7
(a) Tributary 2 Model				
24_1605_6	01DAR04394	23.7	32.8	41.6
24_872_2	04DLY00690	17.7	24.4	30.9
24_866_1	02DLY02494JU	2.1	2.9	3.6
24_866_3	02DLY01559	1.8	2.6	3.3
24_937_6	01EHR00033	26.8	37.1	47.1
24_1273_3	01APR00123	9.0	12.5	15.9
24_1156_3	01SHG00060	23.7	32.8	41.6
(a) Tributary 3 Model				
24_937_3	01EHR01341	33.9	46.9	59.5
24_1273_2	01APR00381	11.3	15.7	19.9
24_1265_1	01CNG00827	8.0	11.0	14.0
24_877_1	02SHG00805	20.0	27.7	35.2

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:
	A normal depth boundary was chosen to provide a free flow condition at the downstream end of the model. The slope parameter was taken from the local river bed slope. Sensitivity to this assumption is discussed in the relevant section below.

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events

The approach to model calibration is documented in the main Hydraulics Report.

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report.

A full account of the model calibration results is provided in Annex C

A summary of the calibration and verification events along with associated model calibration results is as follows:

Catchment Gauging

Is modelled catchment: Gauged ☒ Ungauged ☐

Station Number	Watercourse	Location	ISIS Node Reference
24030	River Deel (MPW)	Danganbeg Bridge	05DEL00211JU
24011	River Deel (HPW)	Dell Bridge	05DEL05624JU

Calibration Event	Event Date	Station Number	Difference between Modelled and Observed Water Level (mm)	Root Mean Square Error	
				HPW	MPW
Event 1	March 2006	24011	- 220	220	Not Applicable
Event 2	January 2005	24011	- 300	300	Not Applicable
Event 3	January 2002	24011	+ 120	120	Not Applicable

Verification Event	Event Date	Station Number	Difference between Modelled and Observed Water Level (mm)	Root Mean Square Error	
				HPW	MPW
Event 1	November 2000	24011	+ 150	150	Not Applicable

Conclusion

It was possible to calibrate the model, for two in-bank historical events and one out-of-bank historical event, and to verify the model, for one out-of-bank event, along a MPW and HPW reach of the River Deel.

The results suggest that the model calibrates well for the out-of-bank historical event. Calibration to the in-bank event is less conclusive with the modelled peak water levels under predicting the observed water levels outside the acceptable range of +/-0.2m for a HPW. As the discrepancy between the modelled and observed flood peak stages are not consistent for all events the issue is unlikely to be associated with the hydraulic model but with the uncertainties on the volume of the lateral inflow hydrographs input to the model.

The model results for the verification event showed good agreement with the observed event and differences are within the acceptable range of +/-0.2m for a HPW.

	Although hydrometric data was not available to calibrate the model along reaches of the Rivers which flow through the Newcastle West AFA, anecdotal evidence of maximum water levels from the August 2008 event, along the River Doally, were available for a broad verification of the model outputs. The levels predicted by the model in the 1% AEP and the 0.1% AEP events were generally found to be lower than the levels recorded during the 2008 event. A blockage assessment was carried out on the model and the model outputs were found to be sensitive to blockage with an average increase in maximum water level of 920mm directly upstream of the structures. The predicted maximum stage in the 0.1%AEP event with blockage was found to be comparable to the recorded stage from the 2008 event at two locations. The maximum water levels from the August 2008 event were visually recorded therefore there is some doubt over the accuracy of the levels and due to the lack of hydrometric data an AEP has not been assigned to the August 2008 event. Therefore verification of the model using the 2008 maximum water levels was inconclusive.
4.2 Calibration to HEP	Calibration of the hydraulic model to the HEP target flows has been carried out for all design events simulated. Section 2.7.2 of the Hydrology Report for UoM24 provides a summary of the calibration to HEP process. Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincide with the peak time of the propagating flood wave as it is routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Where required, inflows to the hydraulic model were scaled up/down to ensure that the modelled total peak flows remain within ±10% of the HEP target flows. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. The flows at the following HEP nodes were increased by varying amounts: 24_1265_1, 24_877_1. The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: 3.2%, 3.2% and 2.9% for the 10%, 1% and 0.1% AEP events respectively.

HEP Reference Name	**Node in the Hydraulic Model**	**Annual Exceedance Probability**							
		Percentage Difference (%)							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
24_1605_9	01DAR02766	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.8	-0.5
24_1605_14	01DAR00130	0.6	0.7	0.4	0.2	0.4	0.5	0.4	0.5
24_1605_15	01DAR00000	0.7	0.6	0.4	0.1	-0.4	-2.5	-5.9	-2.5
24_872_2	04DLY00690	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
24_872_3	04DLY00251JU	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
24_871_1	03DLY00517	7.0	4.9	4.1	3.7	3.5	1.2	1.0	1.2
24_871_2	03DLY00069	6.1	3.9	3.6	3.4	3.1	0.7	0.2	0.7

24_866_1	02DLY02494JU	12.6	9.6	8.7	7.9	7.1	5.6	4.9	5.6
24_866_3	02DLY01559	12.4	9.6	7.8	6.9	4.6	4.5	3.9	4.5
24_897_1	01DLY00182	10.7	7.4	5.5	4.8	6.6	8.4	8.7	8.4
24_897_2	01DLY00097	10.7	7.4	5.4	4.2	2.6	2.0	0.9	2.0
24_860_1	05DEL08104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_860_2	05DEL07703	-0.1	0.1	0.0	-0.1	-0.1	0.0	0.0	0.0
24_1602_3	05DEL07277	0.2	0.1	0.1	0.0	0.1	-4.6	0.2	0.1
24_863_2	05DEL06364	1.0	0.5	0.3	0.3	0.5	0.5	0.6	0.4
24_1511_1	05DEL06098	1.2	0.7	0.4	0.5	0.6	0.6	0.8	0.4
24_1525_1	05DEL05832JU	-0.4	-1.0	-1.2	-1.1	-1.0	-1.0	-0.8	-1.2
24_1435_7	05DEL01151JU	-7.7	-8.2	-8.6	-8.4	-8.3	-8.4	-8.2	-8.6
24_869_2	05DEL00098	1.3	0.9	0.7	0.8	0.9	0.8	1.0	0.7
24_688_2	05DEL00000	6.0	5.6	5.4	5.5	5.6	5.5	5.7	5.3
24_211_2	04DEL05970	2.1	1.8	1.2	1.6	1.7	1.3	1.8	1.0
24_208_1	04DEL03712	2.2	1.9	1.3	1.7	1.8	1.4	1.8	1.1
24_206_2	04DEL00000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_937_3	01EHR01341	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
24_937_6	01EHR00033	15.6	14.5	9.5	4.7	-0.1	-2.7	-5.9	11.3
24_1273_2	01APR00381	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
24_1273_3	01APR00123	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
24_1265_1	01CNG00827	1.8	1.7	1.8	1.8	1.8	1.8	1.8	0.2
24_1265_3	01CNG00230	2.2	2.9	4.1	4.3	4.4	5.7	4.3	7.2
24_1156_1	01SHG00891	-12.9	-2.7	-1.4	-0.3	0.3	0.5	0.2	1.2
24_1156_3	01SHG00060	-14.5	-6.6	-4.9	-4.4	-4.1	17.8	-5.8	-5.4
24_877_1	02SHG00805	3.8	4.0	6.2	7.7	9.0	9.8	9.5	11.8
24_877_2	02SHG00320	-2.9	-6.2	-3.8	-3.0	-2.3	-2.1	-2.6	-1.1
24_877_3	02SHG00118	-17.9	-8.6	-6.6	-4.6	-3.5	-3.2	-2.8	-1.9

4.3 Model Sensitivity

Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. In each case the sensitivity run was carried out for the 1% AEP fluvial event. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work. Sensitivity test results are provided in the following tables:

+20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section / Reach where the Maximum Difference occurs
River Deel	0.15	0.24	05DEL01958LU
River Ehernagh	0.09	0.17	01EHR00137BD

	River Daar	0.14	0.25	01DAR04105
	River Doally	0.15	0.37	02DLY02273JU
	River Arra	0.10	0.13	01APR00381
	River Knockane	0.05	0.09	02SHG00805
	River Killeline	0.12	0.26	01SHG00095
-20% Manning's 'n'	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	-0.16	-0.28	04DEL05058
	River Ehernagh	-0.11	-0.191	01EHR00137BD
	River Daar	-0.15	-0.29	01DAR02416
	River Doally	-0.15	-0.33	02DLY1926CDL
	River Arra	-0.12	-0.18	01APR00123u
	River Knockane	-0.10	-0.16	02SHG00000
	River Killeline	-0.16	-0.34	01SHG00691SD
+20% inflows	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	0.17	0.39	05DEL02893JU
	River Ehernagh	0.09	0.12	01EHR00867
	River Daar	0.17	0.33	01DAR00951
	River Doally	0.19	0.60	02DLY02239JU
	River Arra	0.08	0.12	01APR00123u
	River Knockane	0.05	0.12	02SHG00805
	River Killeline	0.16	0.41	01SHG00095
-20% inflows	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	-0.20	-0.46	05DEL02893JU
	River Ehernagh	-0.15	-0.25	01EHR00867
	River Daar	-0.19	-0.33	01DAR02454
	River Doally	-0.20	-0.37	02DLY02239JU
	River Arra	-0.10	-0.16	01APR00011

	River Knockane	-0.10	-0.17	02SHG00000
	River Killeline	-0.20	-0.33	01SHG00774
Afflux at Key Structure	Two structures within the Newcastle AFA have a significant head loss during a 1% AEP flood event. One weir located at 02DLY02494WU and another at 02DLY02273WU.			
Afflux at Key Structure 02DLY02273WU: Coefficient of velocity increased by 20%	The coefficient of velocity was decreased by 20% and resulted in a decrease of 115 mm (maximum water level) immediately upstream of the weir. This reduction in stage had the effect of reducing the flood outline and removing 2 properties from the 1% AEP flood outline.			
Afflux at Key Structure 02DLY02273WU: Coefficient of velocity decreased by 20%	The coefficient of velocity was decreased by 20% and resulted in an increase of 137 mm in maximum water level immediately upstream of the weir. This increase of stage had the effect of increasing the flood outline and including 6 additional properties to the 1% AEP flood outline.			
Afflux at Key Structure 02DLY02494WU: Calibration coefficient increased by 20%	The calibration coefficient was increased by 20% and resulted in a decrease of 77 mm in maximum water level immediately upstream of the weir. However the increase in water level did not impact on the predicted flood risk as the floodplain is quite steep in the area.			
Afflux at Key Structure 02DLY02494WU: Calibration coefficient decreased by 20%	The calibration coefficient was decreased by 20% and resulted in an increase of 86 mm in maximum water level immediately upstream of the weir. The increase in water level did not impact on the predicted flood risk as the floodplain is quite steep in the area.			
Downstream Conditions Normal Depth downstream boundary slope doubled	The change to the downstream boundary condition has resulted in a decrease in maximum water level by 193 mm at the downstream limit of the model (ISIS node 04DEL00000). The diminishing effects can be seen 1.5 km upstream of downstream mode limit on the River Deel. The change in the boundary condition has no impact on the water level in the Newcastle West AFA.			
Downstream Conditions Normal Depth downstream boundary slope halved	The change to the downstream boundary condition has resulted in an increase in maximum water level by 140 mm at the downstream limit of the model (ISIS node 04DEL00000). The diminishing effects can be seen 1.5 km upstream of downstream mode limit on the River Deel. The change in the boundary condition has no impact on the water level in the Newcastle West AFA.			
4.4 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D			

5. Hydraulic Model Outputs

5.1 Mapping	Model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard All of the maps contain the maximum extent, depth, velocity and flood hazard for the combined main stream inflows and the tributaries inflows. An explanation for the main stream inflows and the tributaries inflows is provided in Section 6. Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP flood events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

S11 comprises two models; the first one, the main model, including the HPW and MPW reaches of the River Deel and the other, the tributary model, including the tributaries of the River Deel which flow through the Newcastle West AFA. The main model schematisation and tributary model extents are illustrated in Annex A1; S11(Main) and S11(Trib) respectively.

- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. Inflow hydrographs were purposely produced for three model runs. The first run containing only the main stream inflows (Main model run), the second containing only the River Daar, River Doally and River Arra tributary inflows (Tributary 2 model run), and the third containing flows for the River Ehernagh, River Knockane and River Killeline (Tributary 3 model run). The main model was used for the first main model runs while the tributary model was used for the tributary runs. The tributary models share exactly the same geometry (structures and topography). The model outputs from all models were then merged picking up the maximum flood depths and extents to create the flood maps.

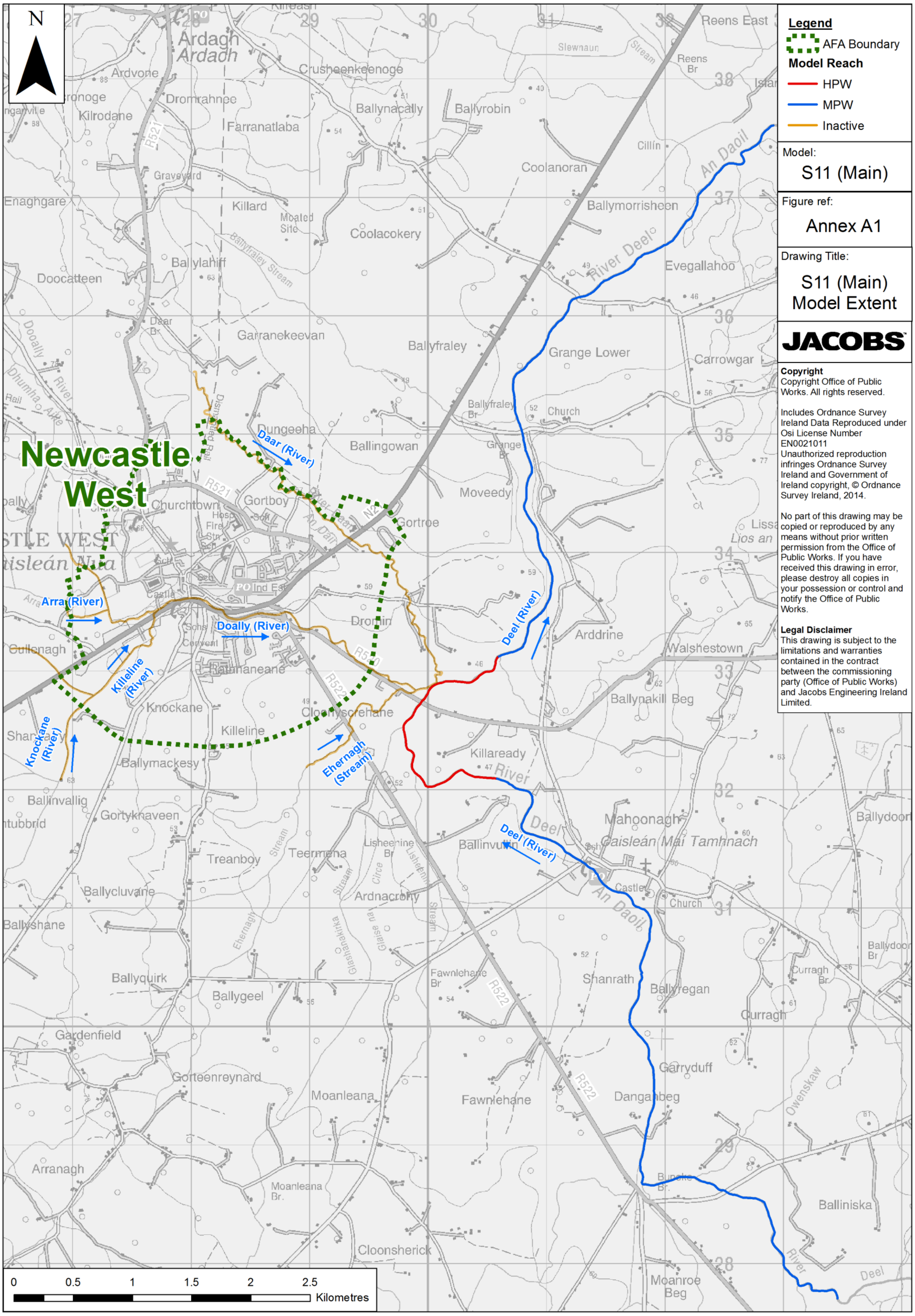
- There is approximately 700m of formal flood defences within the model extent. These formal flood defences comprise flood defence walls and are located on the left and right bank of the River Doally in Annex A2(3) S11(Trib). The defences have been represented in the model; therefore the model and outputs presented in this report represent a defended scenario.

- At the downstream extent of the River Ehernagh a hydrology input was specified (24_866_7). During the tributary 2 model run the River Ehernagh was deactivated. To prevent backflow in the River Ehernagh the flow intended to be input at the downstream extent of the River Ehernagh was distributed along the reach.

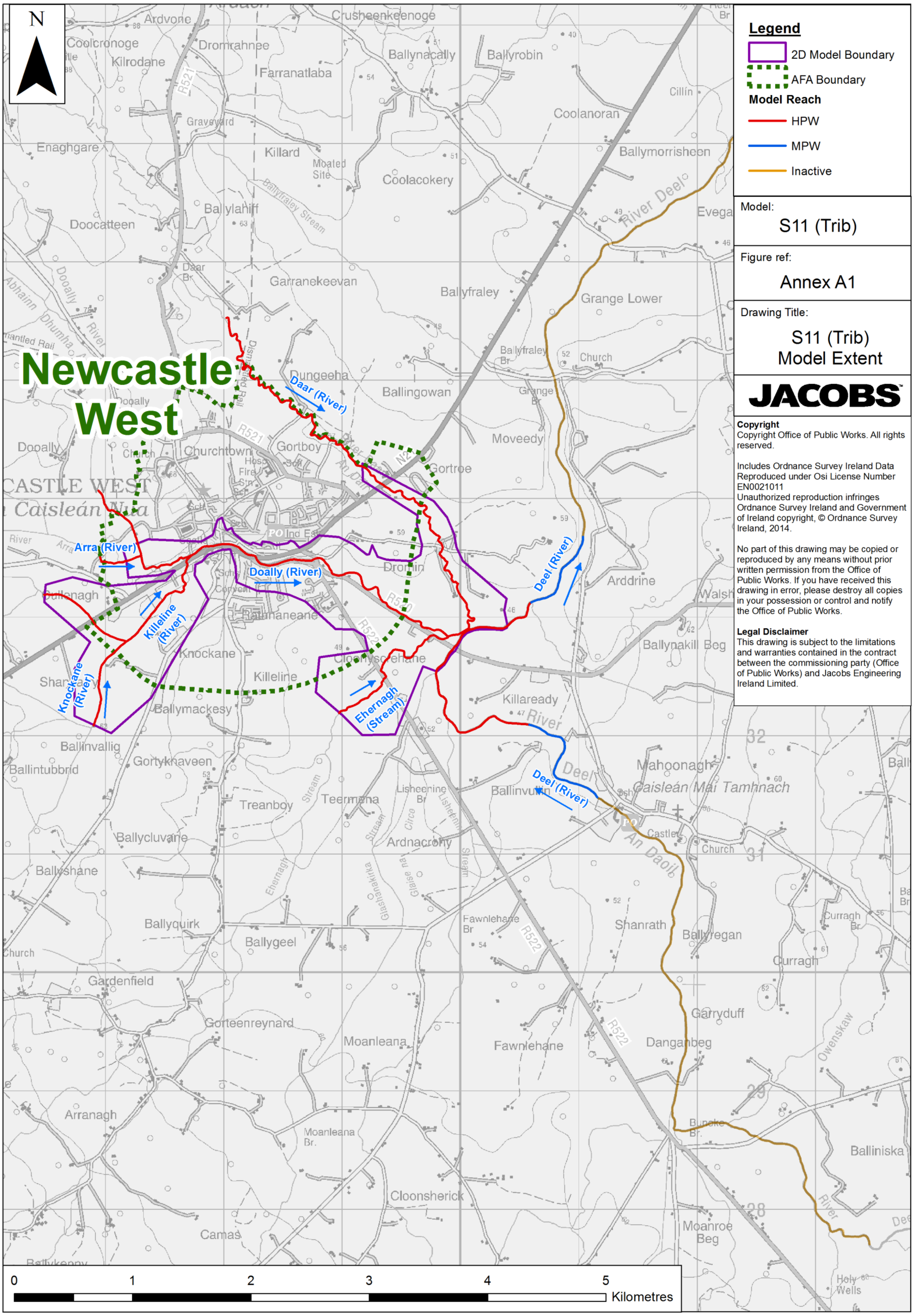
- As detailed in Section 4, the model calibrates well for an out-of-bank historical event. Calibration to the in-bank event is less conclusive with the modelled peak water levels under predicting the observed water levels outside the acceptable range of +/-0.2m for a HPW. High level verification was achieved by comparing water levels to surveyed wrack marks from the 2008. It was identified that water levels were sensitive to blockage assessment within the AFA.

Annex A – Model Extent and Schematisation Maps

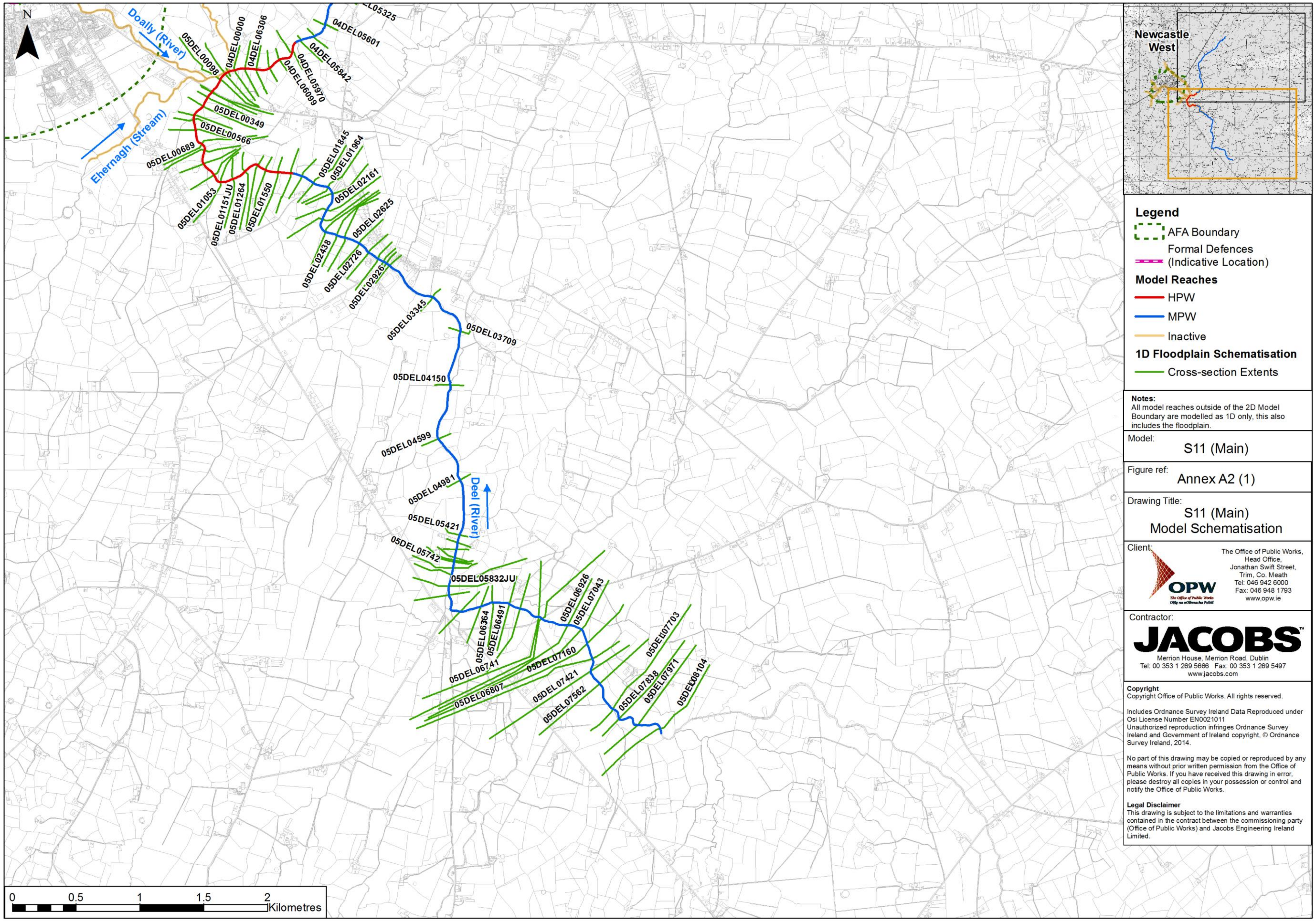
Annex A1 – Model Extent



As described in section 6 there are two models, one main model and one tributary model. Therefore we have provided two model schematisations; one for the main model and one for the tributary model. In the main model schematisation we have shown the tributary watercourses which are inactive in this model.



As described in section 6 there are two models, one main model and one tributary model. Therefore we have provided two model schematisations; one for the main model and one for the tributary model. In the tributary model schematisation above we have shown the main watercourses which are inactive in this model.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Ehernagh (Stream)
Deel (River)
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05DEL00349
05DEL00566
05DEL00689
05DEL01053
05DEL01151JU
05DEL01264
05DEL01550
05DEL01845
05DEL01964
05DEL02161
05DEL02625
05DEL02438
05DEL02726
05DEL02926
05DEL03345
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05DEL06807
05DEL06926
05DEL07043
05DEL07160
05DEL07421
05DEL07562
05DEL07703
05DEL07838
05DEL07971
05DEL08104
0 0.5 1 1.5 2 Kilometres
Newcastle West
Legend
AFA Boundary
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S11 (Main)
Figure ref: Annex A2 (1)
Drawing Title: S11 (Main) Model Schematisation
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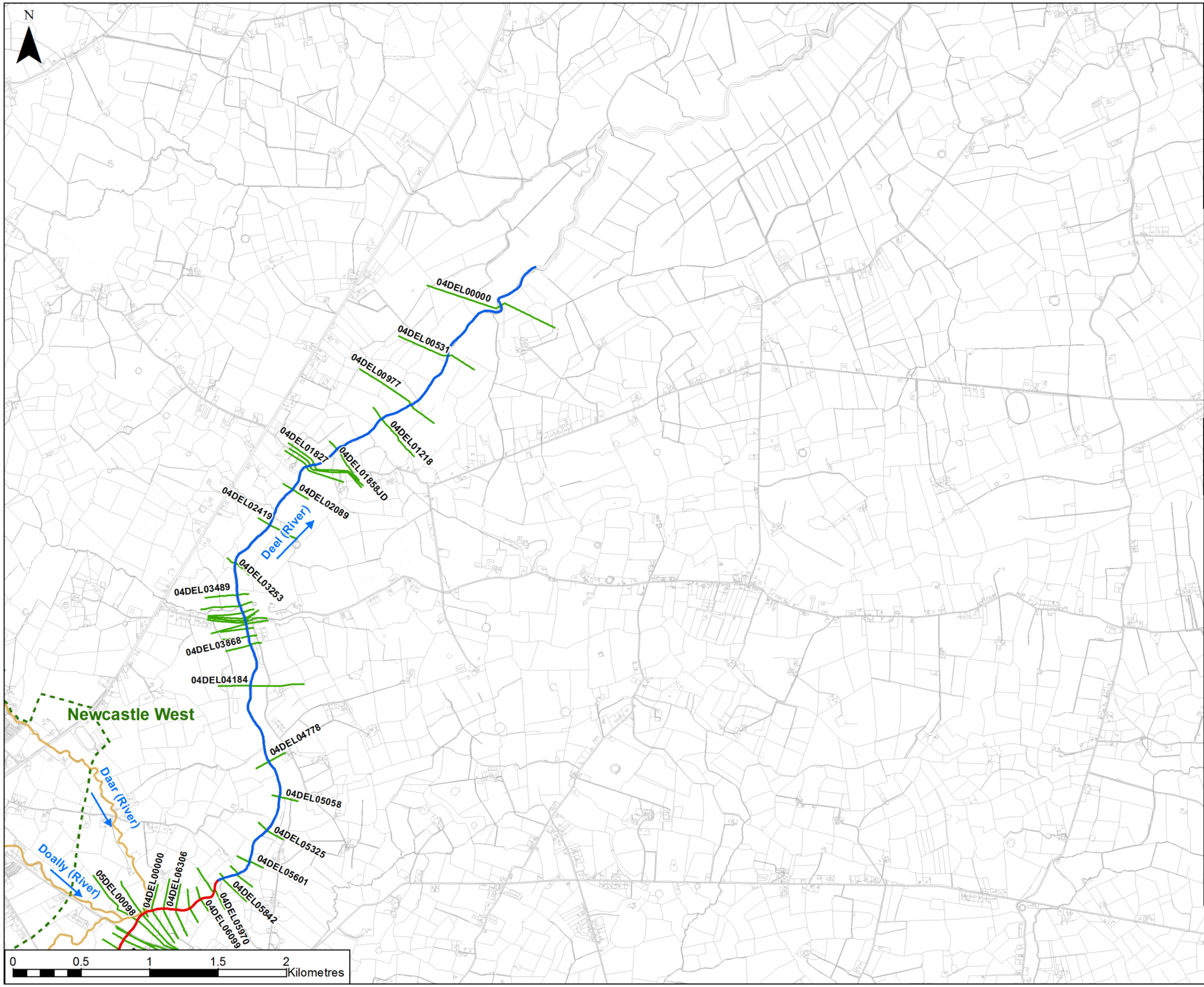

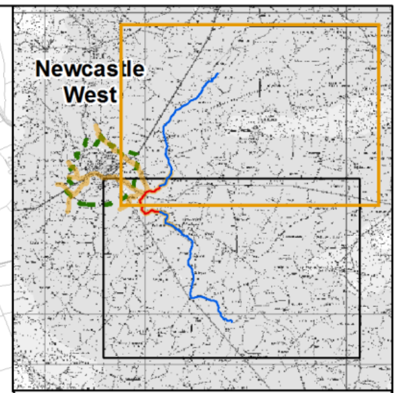

Legend

- AFA Boundary
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW
- Inactive

1D Floodplain Schematisation

- Cross-section Extents

Notes:
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Model: S11 (Main)

Figure ref: Annex A2 (2)

Drawing Title: S11 (Main) Model Schematisation

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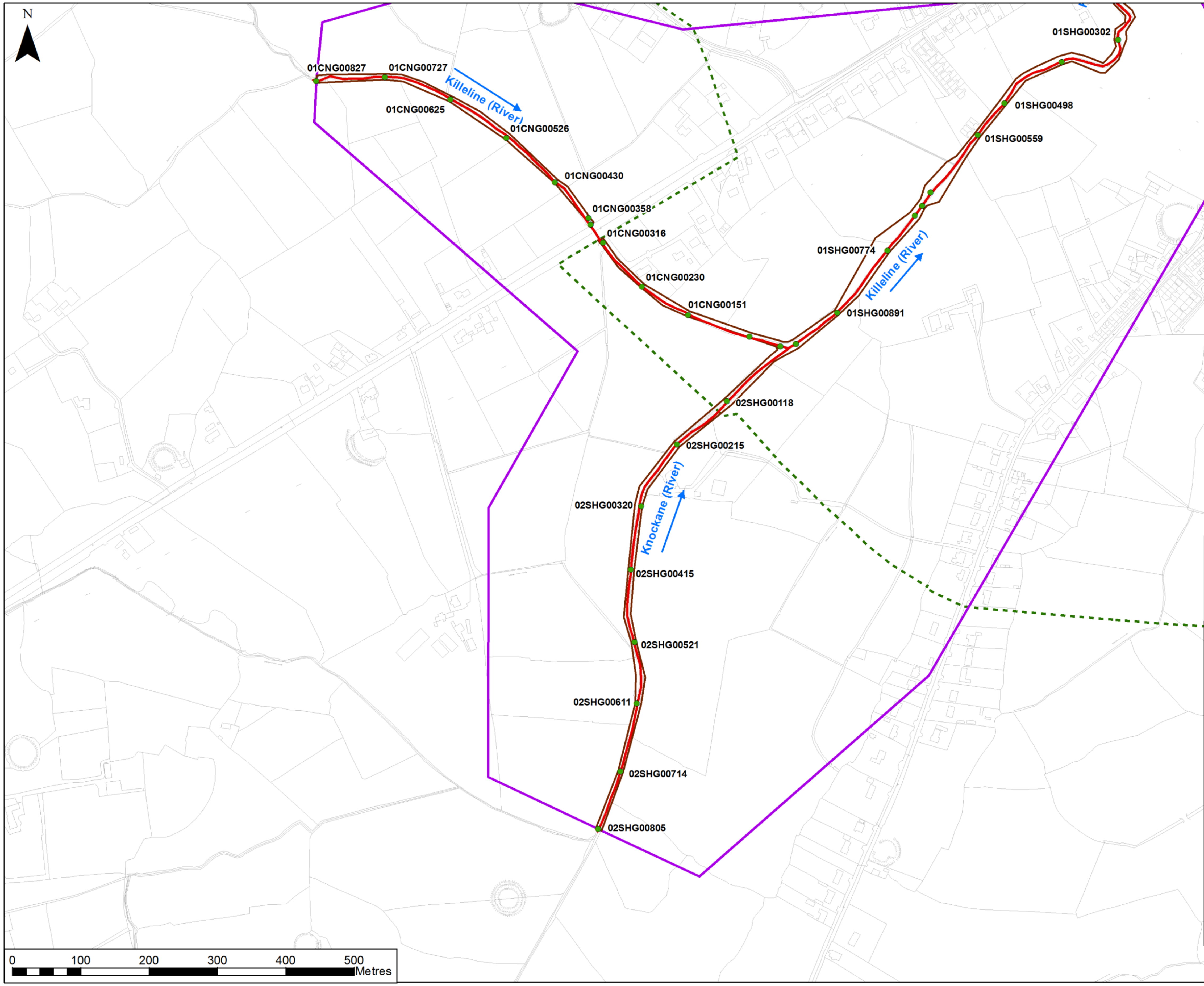

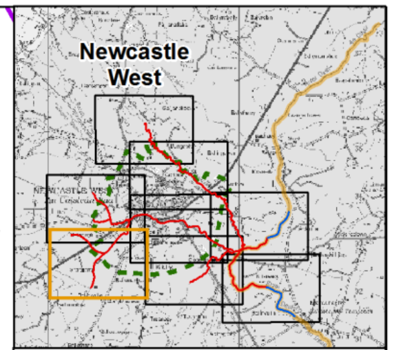

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW
- Inactive

1D Floodplain Schematisation

- Cross-section Extents

Notes:
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Model: S11 (Trib)

Figure ref: Annex A2 (1)

Drawing Title: S11 (Trib) Model Schematisation

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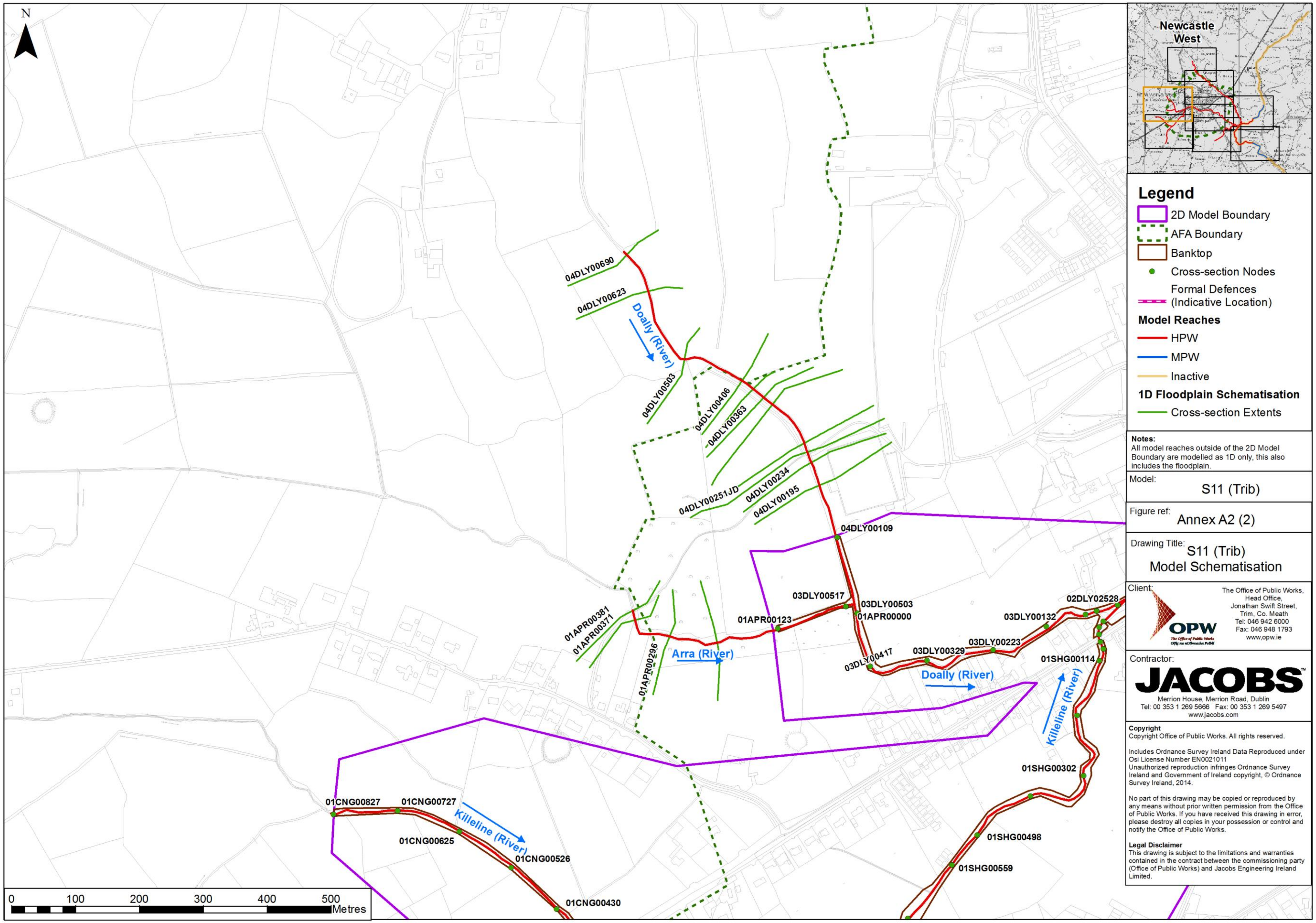
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03DLY00503
01APR00000
01APR00123
01APR00381
01APR00371
01APR00296
Arra (River)
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02DLY02528
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Doally (River)
Killeline (River)
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0 100 200 300 400 500
Metres
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S11 (Trib)
Figure ref:
Annex A2 (2)
Drawing Title:
S11 (Trib)
Model Schematisation
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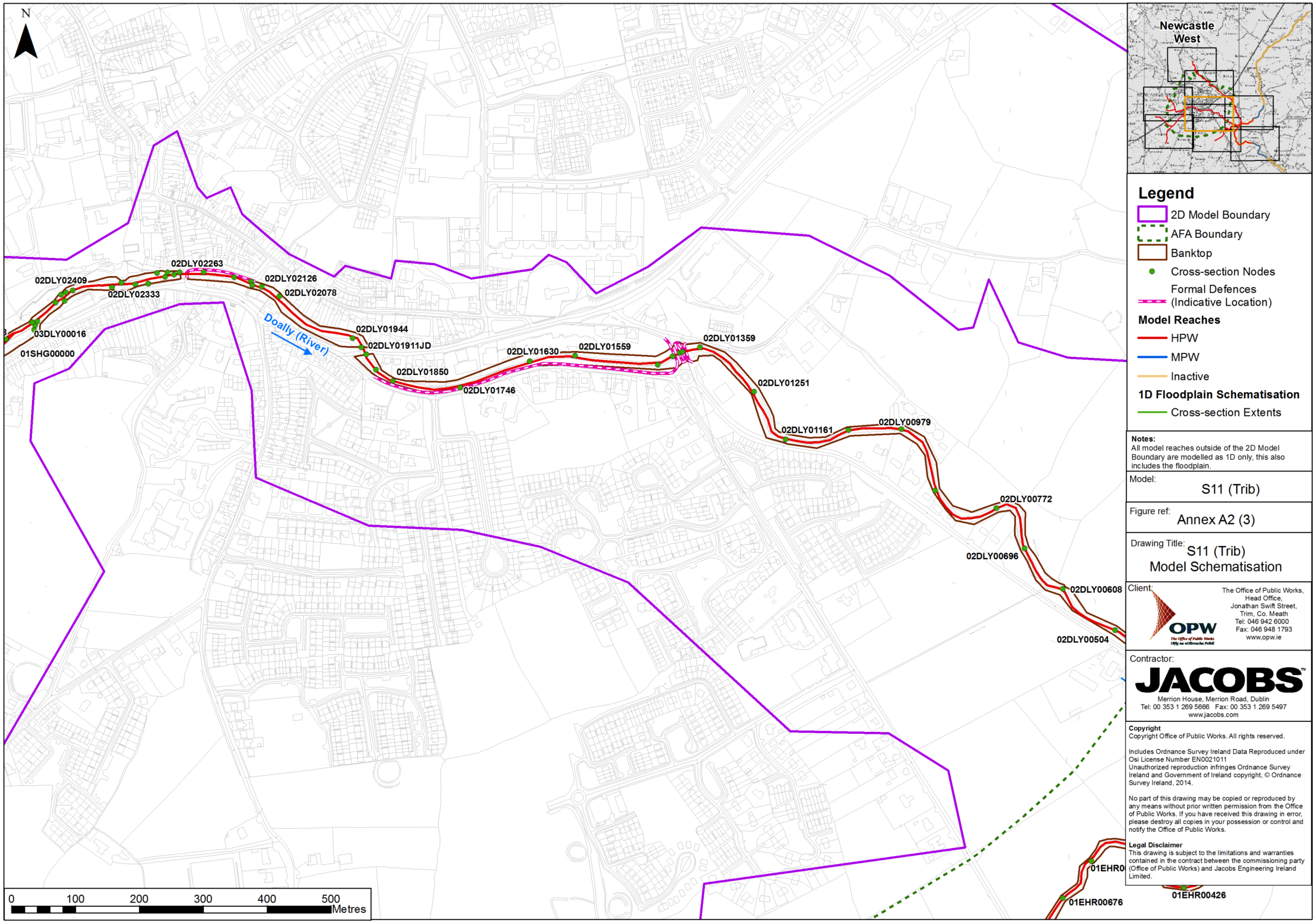
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02DLY00772
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02DLY00608
02DLY00504
01EHR00676
01EHR00426
0 100 200 300 400 500
Metres
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S11 (Trib)
Figure ref: Annex A2 (3)
Drawing Title: S11 (Trib) Model Schematisation
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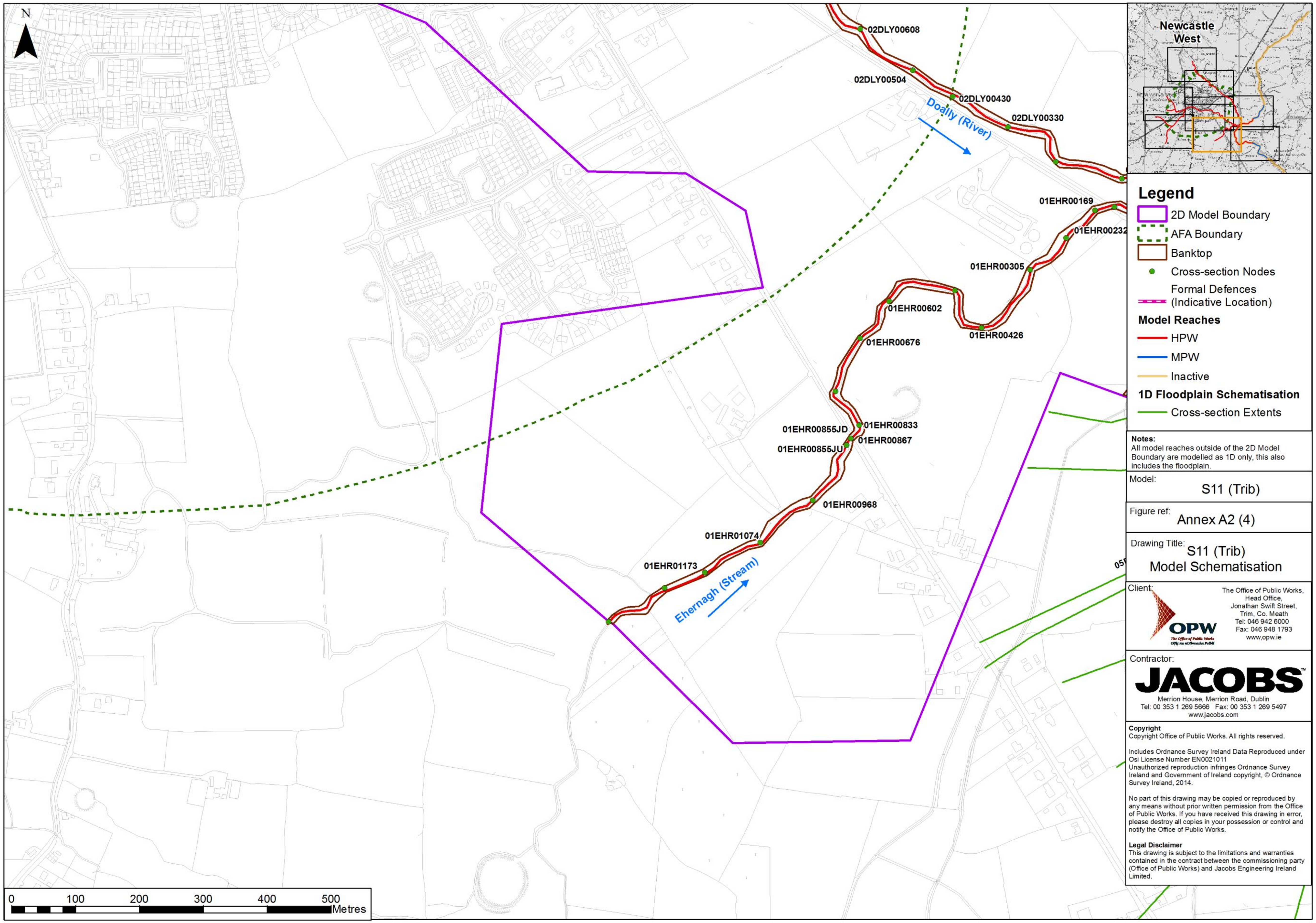
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01EHR00867
01EHR00855JU
01EHR00968
01EHR01074
01EHR01173
Ehernagh (Stream)
0 100 200 300 400 500 Metres
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
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Model:
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Figure ref:
Annex A2 (4)
Drawing Title:
S11 (Trib)
Model Schematisation
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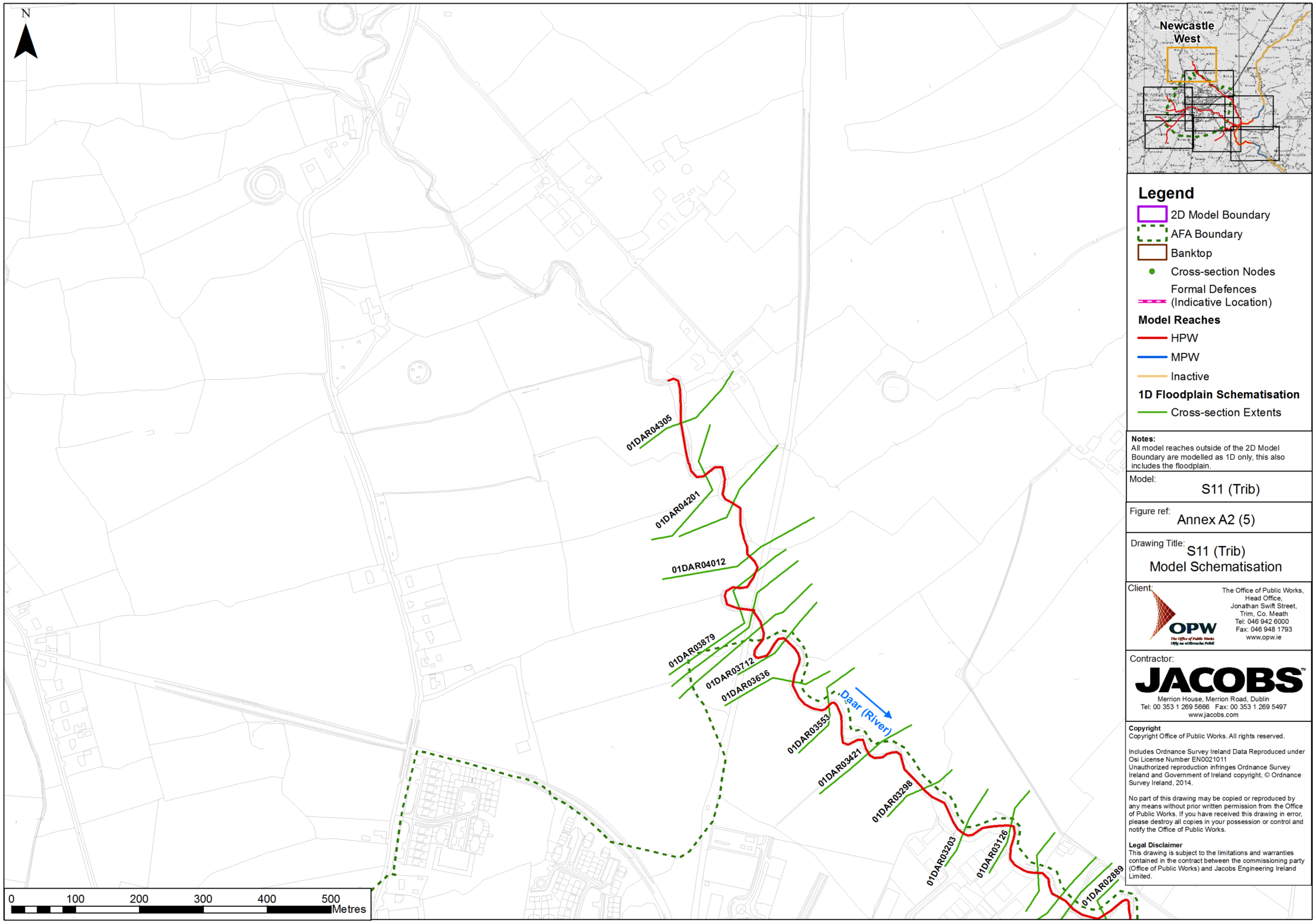
N
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S11 (Trib)
Figure ref:
Annex A2 (5)
Drawing Title:
S11 (Trib)
Model Schematisation
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01DAR04305
01DAR04201
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01DAR03879
01DAR03712
01DAR03636
Daar (River)
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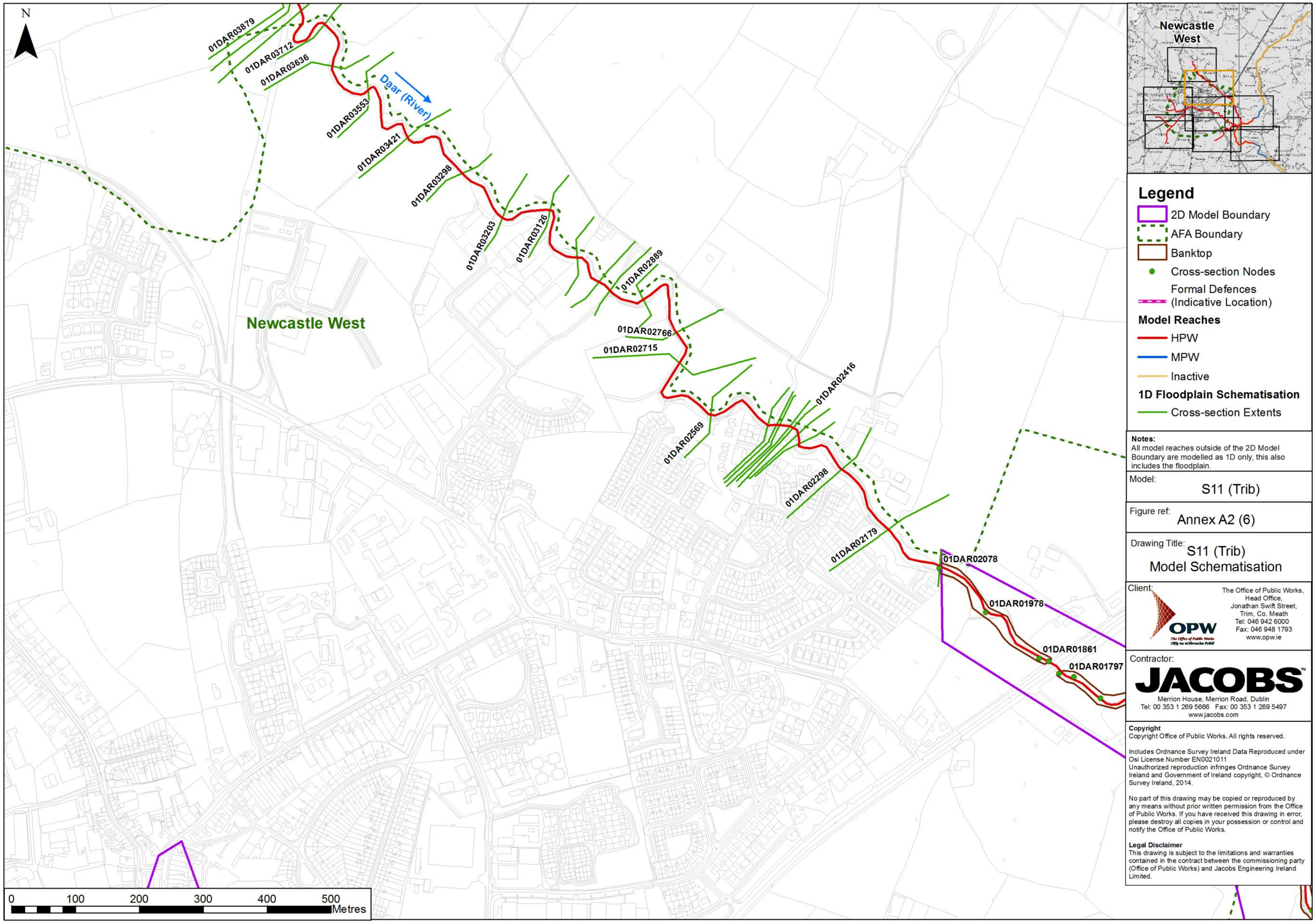
0
100
200
300
400
500
Metres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Newcastle West
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0 100 200 300 400 500
Metres
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S11 (Trib)
Figure ref:
Annex A2 (6)
Drawing Title:
S11 (Trib)
Model Schematisation
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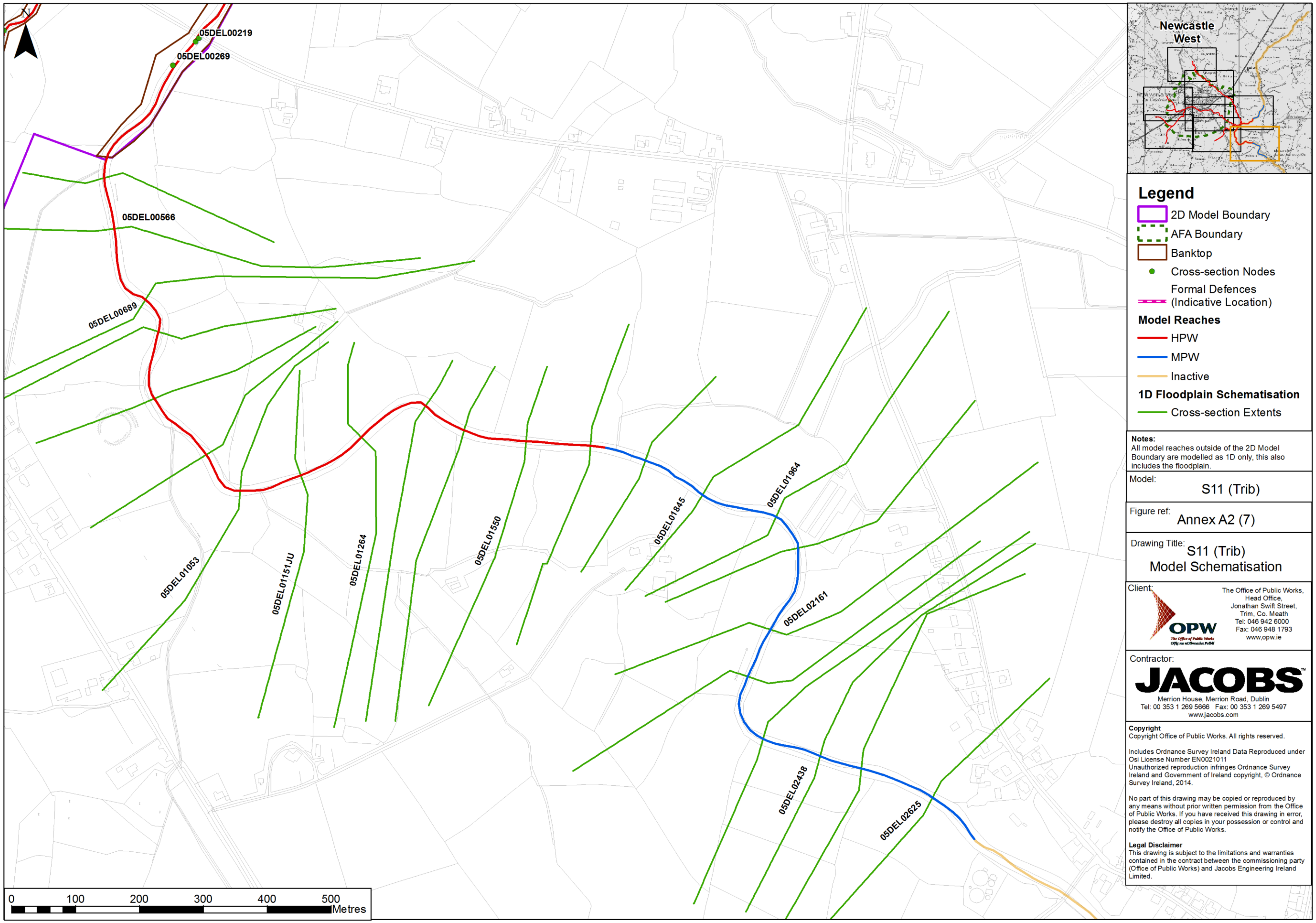

N
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05DEL02438
05DEL02625
0 100 200 300 400 500
Metres
Newcastle West
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
Inactive
1D Floodplain Schematisation
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S11 (Trib)
Figure ref:
Annex A2 (7)
Drawing Title:
S11 (Trib)
Model Schematisation
Client:
OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
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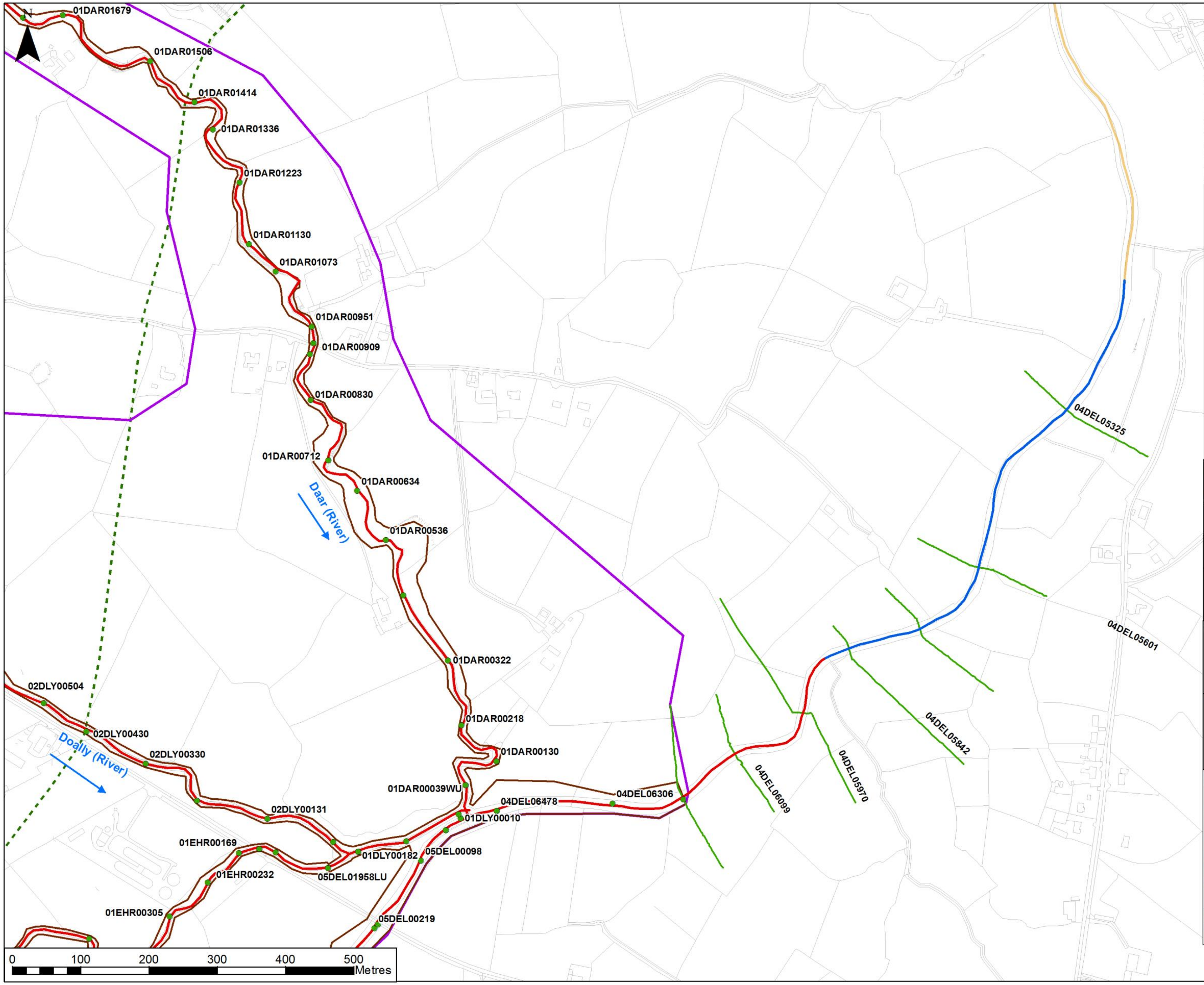

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW
- Inactive

1D Floodplain Schematisation

- Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S11 (Trib)

Figure ref: Annex A2 (8)

Drawing Title: S11 (Trib) Model Schematisation

Client:
OPW
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
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Merrion House, Merrion Road, Dublin
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www.jacobs.com

Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for River Dooally

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24ARRA00277D	03DLY00051JU	Bridge of 3.80 m wide	Arch Bridge + Spill	Y
24DOAL00036D	04DLY00363JU	Bridge of 1.60 m wide	Arch Bridge with one opening + Spill	N*
24DOAL00025D	04DLY00251JU	Bridge of 4.26 m wide	Arch Bridge with one opening + Spill	Y
24ARRA00268W & 24ARRA00268X	02DLY02494JU	Weir	Sharp crested weir + Spill	Y
24ARRA00261W & 24ARRA00261X	02DLY02422JU	Weir	Labyrinth weir + Spill	Y
24ARRA00252D	02DLY02333JU	Bridge of 1.85 m wide	Arch Bridge + Spill	N*
24ARRA00246W & 24ARRA00246X	02DLY02273JU	Weir	Round nosed weir + Spill	Y
24ARRA00245W & 24ARRA00245X	02DLY02263	Weir	Labyrinth weir + Spill	Y
24ARRA00242D	02DLY02239JU	Bridge of 10.87 m wide	Arch Bridge with three openings + Spill	Y
24ARRA00231D	02DLY02126JU	Bridge of 1.20 m wide	Arch Bridge + Spill	N*
24ARRA00230D & 24ARRA00229E	02DLY02122JU	Bridge of 14.09 m wide	Bridge with two rectangular Openings + Spill	Y
24ARRA00211D & 24ARRA00211E	02DLY01926JU	Bridge of 14.20 m wide	Rectangular opening at u/s and arch opening at d/s + Spill	Y
24ARRA00159D	02DLY01403JU	Bridge of 5.29 m wide	Arch Bridge + Spill	Y
24ARRA00157D	02DLY01386JU	Bridge of 9.60 m wide	Arch Bridge + Spill	Y

*** Considering the size of the structure relative to the watercourse it was determined that the structure would have little or no hydraulic impact on the model.**

Schedule A.2 - Structure Schedule for River Killeline

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24ARRB00035D	01CNG00348JU	Culvert of 24.16 m wide	Rectangular conduit + Spill	Y

Schedule A.3 - Structure Schedule for River Deel

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEL03468D	05DEL06773JU	Arch Bridge of 5.75 m wide	Arch Bridge with rectangular opening + Spill	Y
DEEL01_1914u	05DEL05624JU	Bridge of 13.6 m wide	Arch Bridge with two rectangular opening + Spill	Y
24DEEL03138D	05DEL02893JU	Arch Bridge of 6.70 m wide	Bridge with 5 arch openings + Spill	Y
DLBR01_1958	05DEL00211JU	Bridge of 12.5 m wide	Bridge with 3 arch openings + Spill	Y
DEEL01_2476u	04DEL03695JU	Bridge of 14 m wide	Arch Bridge with one rectangular opening + Spill	Y
DEEL01_0639u	04DEL01858JU	Bridge of 13.5 m wide	Arch Bridge with one rectangular opening + Spill	Y

Schedule A.4 - Structure Schedule for River Daar

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DAAR00328D	01DAR03856JU	Bridge of 3.05 m wide	Arch Bridge with rectangular opening + Spill	Y
24DAAR00254D	01DAR02944JU	Bridge of 4.03 m wide	Arch Bridge with one opening + Spill	Y
24DAAR00217D	01DAR02447JU	Bridge of 4.68 m wide	Arch Bridge with Rectangular opening + Spill	Y
24DAAR00212D	01DAR02403JU	Bridge of 7.20 m wide	Arch Bridge with Rectangular opening + Spill	Y
24DAAR00159D & 24DAAR00156E	01DAR01846JU	Culvert of 25.74 m wide	Sprung arch conduit + Spill	Y
24DAAR00079D	01DAR00927JU	Bridge of 4.27 m wide	Arch Bridge with two openings + Spill	Y

Schedule A.5 - Structure Schedule for River Ehernagh

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24EHER00086D	01EHR00855JU	Culvert of 7.70 m wide	Sprung arch conduit + Spill	Y
24EHER00014E	01EHR00137JU	Culvert of 7.10 m wide	Sprung arch conduit + Spill	Y

Schedule A.6 - Structure Schedule for River Knockane

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24RRAA00069D	01SHG00691JU	Arch Bridge of 3.60 m wide	Bridge with rectangular opening + Spill	Y
24RRAA00008D & 24RRAA00007E	01SHG00084JU	Culvert of 12.11m wide	Culvert with rectangular opening at u/s and arch opening at d/s + Spill	Y
24RRAA00005D	01SHG00048JU	Arch Bridge of 3.92 m wide	Bridge with one arch opening + Spill	Y

Schedule B.1 – Manning's 'n' for HPW Network

River Name	ISIS Node Reference	In-bank Roughness*	Estimated Floodplain Roughness
River Arra	01APR00381 to 01APR00000	0.050	2d Domain : based on OSi NTF land use polygons 1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
River Killeline	01CNG00827 to 01CNG00000	0.050	
River Deel	05DEL01651 to 05DEL00485	0.050	
River Deel	05DEL00485 to 04DEL05970	0.052	
River Daar	01DAR04394 to 01DAR00000	0.045	
River Doally	04DLY00690 to 01DLY00000	0.045	
River Ehernagh	01EHR01341 to 01EHR00000	0.045	
River Knockane	02SHG00805 to 01SHG00000	0.050	

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Schedule B.2 – Manning's 'n' for MPW Network

River Name	ISIS Node Reference	In-bank Roughness*	Estimated Floodplain Roughness
River Deel	05DEL08104 to 05DEL01740	0.045	Land use EPA data has been used for assigning the floodplain roughness.
	04DEL05970 to 04DEL04184	0.052	
	04DEL03868 to 04DEL00000	0.040	

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Annex C - Model Calibration Summary Note

The aim of this technical note is to describe the calibration methodology applied to the S11 model and report on the results.

Calibration Methodology:

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report (Appendix F). The results of this analysis concluded that no calibration or verification could be undertaken within the Newcastle West AFA. It should be noted that anecdotal evidence of flooding was collected after the August 2008 event. This evidence is in the form of wrack marks. The elevations of these wrack marks have been used to verify the model outputs.

Outside of the Newcastle West AFA, hydrometric data recorded at two gauging stations on the River Deel (Dangenbeg Bridge, station no. 24030 and Dell Bridge, station no.24011) for four historical events were found to be suitable for calibrating the S11 model along the section of the model shown in Figure C.1. Although the watercourse along this section is, for the most part, classified as MPW the gauging station at Deel Bridge is located on a section of HPW as shown in Figure C.1. The model has been calibrated using two in-bank events (March 2006 and January 2005) and one out-of-bank event (January 2002). The model has been verified using an out-of bank-event that occurred in November 2000.

The S11 main model was used for the calibration process and was truncated to cover the River Deel reach from station 24030 to its original downstream limit.

The rating curves for both gauging stations 24030 and 24011 have been updated as part of the CFRAM study. The flows used as inputs to the model were estimated from the recorded stage at these stations using the updated rating equation. The gauged flows at station 24030 were increased by 9% to take into consideration additional lateral inflows between stations 24030 and 24011. The resulting flow was inserted at the upstream extent of the truncated model.

Peak water levels predicted by the hydraulic model were then compared against the observed water levels at gauging station 24011.

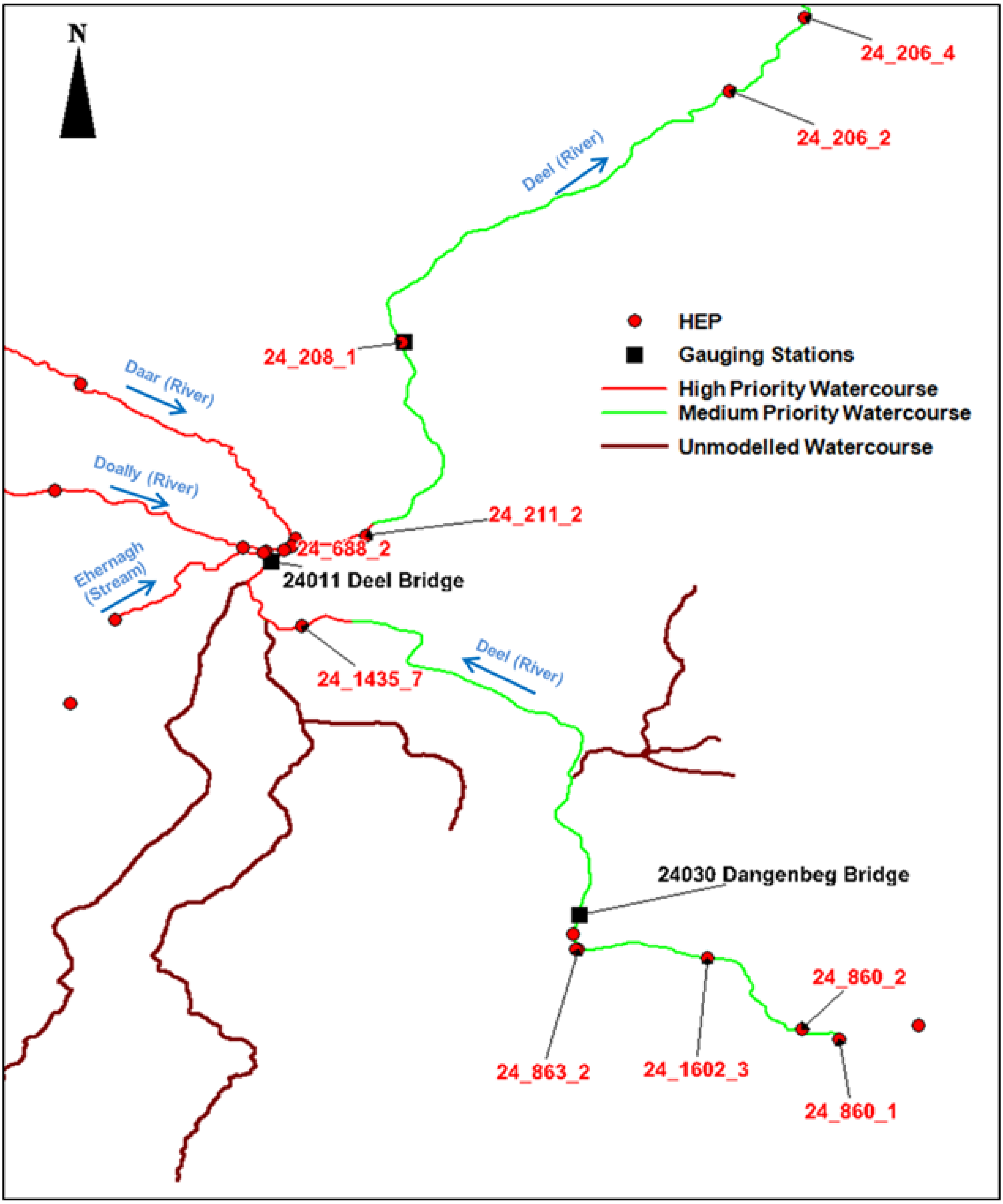


Figure C.1: S11 – Calibration map

Calibration of the model

The River Deel was calibrated to three historic events, two in bank events that occurred in January 2005 and March 2006 and one out of bank event that occurred in January 2002.

The modelled and observed water levels for all events simulated are reported in Table C.1.

Table C.1: Historical Flood Events at Gauging Station 24011 (Deel Bridge)

Event	Historical Flood Event	Model Maximum Stage (mAOD*)	Observed Maximum Stage (mAOD*)	Difference (mm)
In-bank	March 2006	43.90	44.12	-220
In-bank	January 2005	43.98	44.28	-300
Out-of-bank	January 2002	44.06	43.94	+120

(* Datum relates to Malin Head)

The stage results in Table C.1 indicate that the predicted peak water levels, without making any changes to the model schematisation/parameters, under predicts the observed water levels for the in-bank events and over predicts the observed water levels for the out-of-bank event.

From the stage hydrographs in Figures C.2, C.3 and C.4 below it can be seen that the model results over predicts the time to peak for all events. There is a difference between the timing of the peaks of 0.8hr, 2.8hrs and 0.8hr for the March 2006, January 2005 and January 2002 events respectively. Increasing the Manning's 'n' values in channel was considered; however, whilst this may reduce the difference in stage for the in-bank events this would also have a negative effect on the difference in stage for the out-of-bank event and on the difference in time to peak for all events. Therefore no changes were made to the Manning's n values in the hydraulic model. The inconsistent nature of the discrepancies between the observed stage and modelled stage would suggest an issue with the inflows to the model rather than the hydraulic model itself.

The Dangenbeg Bridge (24030) gauging station is over 5 km downstream of the Deel Bridge (24011) gauging station and there are three tributaries identified in the river network along this reach (see Figure C.1). Although, the flow at station no 24001 was increased by 9% to account for lateral inflows for all events, this is an assumption and the actual flows from these tributaries are specific to each historic event simulated. The difference in fit between the in bank and out of bank event may be a result of an underestimation of the lateral inflows for the in bank events.

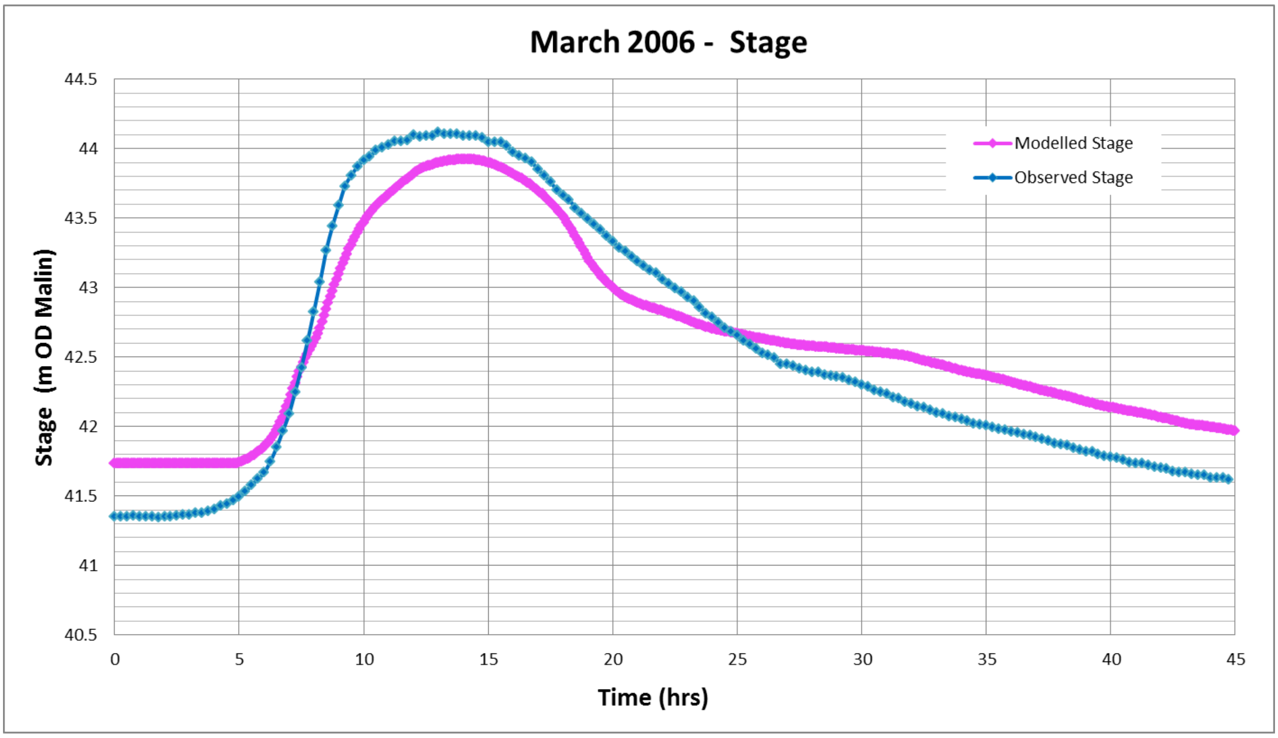


Figure C.2 - Modelled and observed water levels at Deel Bridge GS for the March 2006 event.

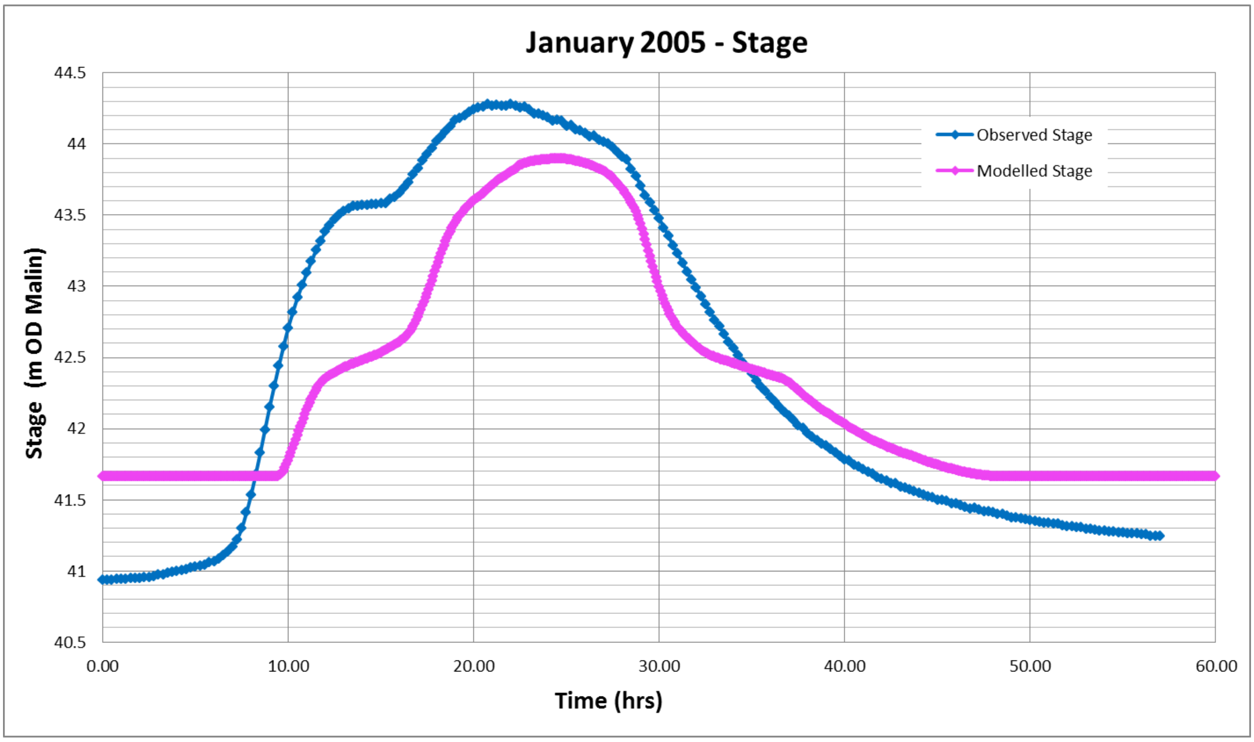


Figure C.3 - Modelled and observed water levels at Deel Bridge GS for the January 2005 event.

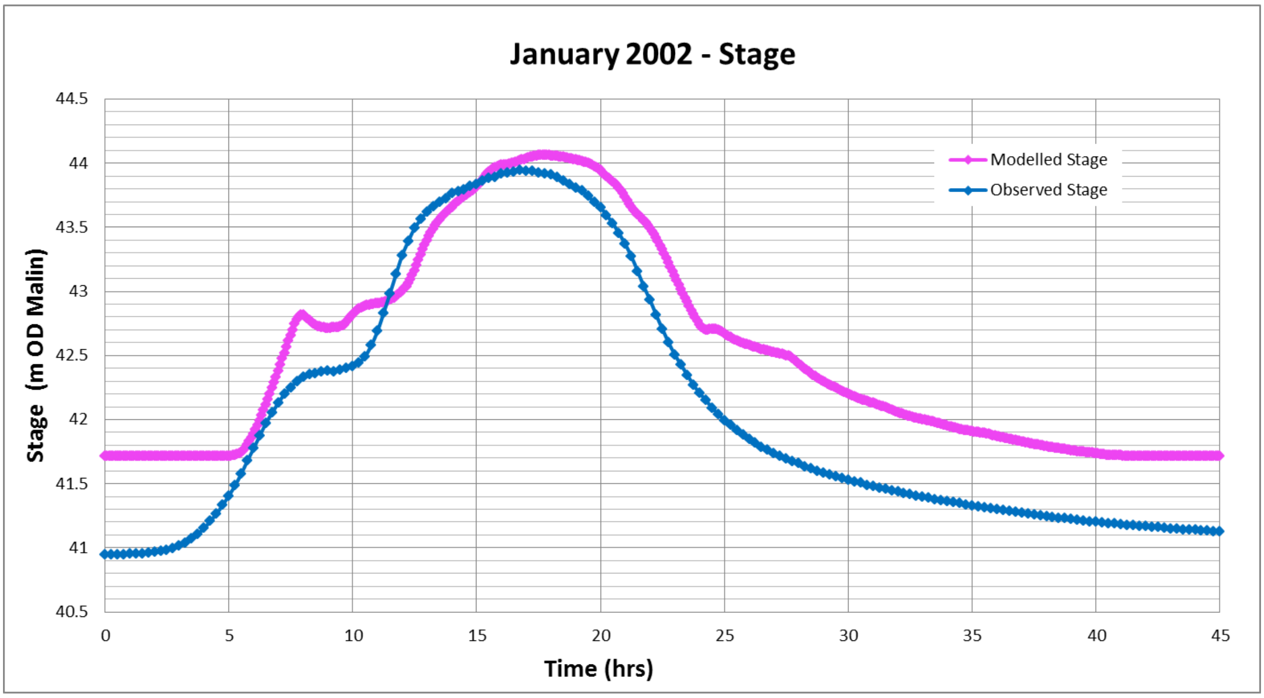


Figure C.4 - Modelled and observed water levels at Deel Bridge GS for the January 2002 event.

Verification of the model

An out of bank event that occurred in November 2000 was used to verify the model. The methodology used for the verification is the same as for the calibration events.

The modelled and observed water levels for the November 2000 event are reported in Table C.4.The result suggest that the model replicates the November 2000 flood event successfully with the difference between modelled stage and observed stage of 150mm and difference between the times to peak of 1hr.

Table C.4: Verification Flood Event at Gauging Station 24011

Event	Historical Flood Event	Model Maximum Stage (mAOD*)	Observed Maximum Stage (mAOD*)	Difference (mm)
Out-of-bank	November 2000	44.21	44.06	+150

(*Datum is taken from Malin Head)

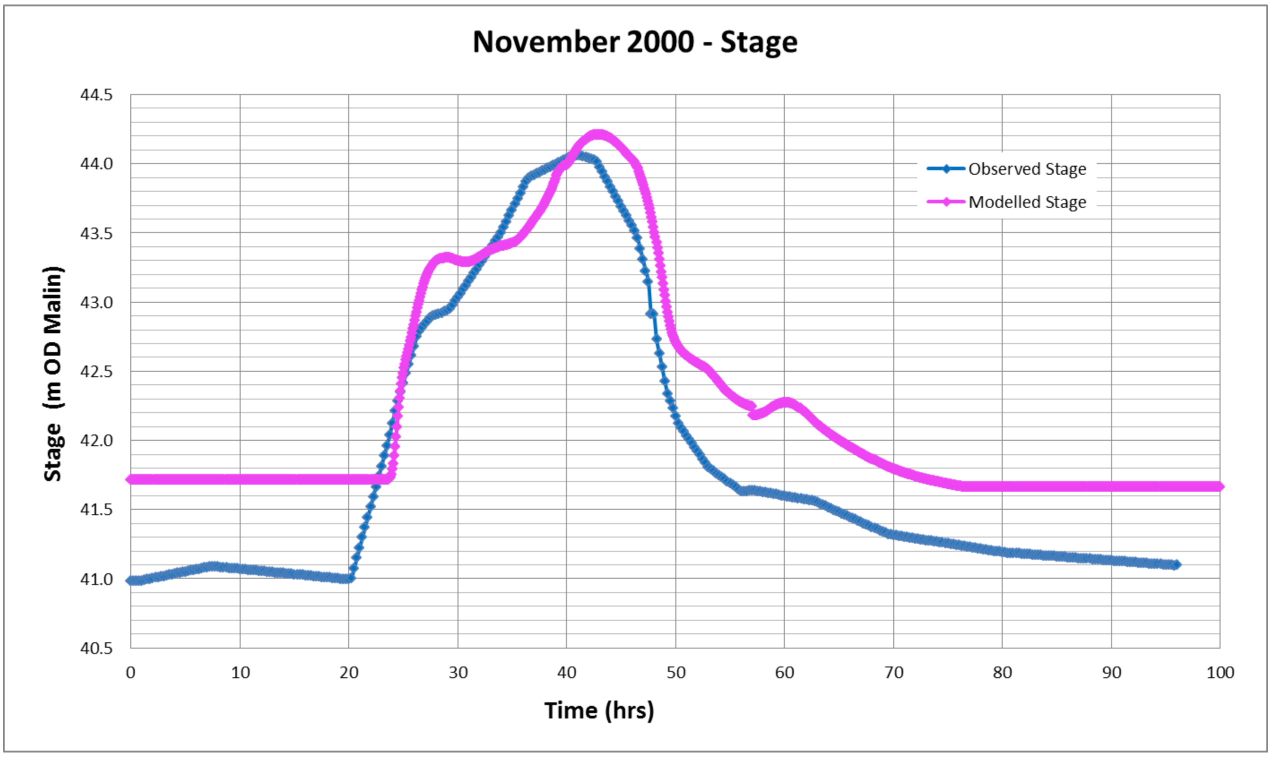


Figure C.6 - Modelled and observed water levels at Deel Bridge GS for the November 2000 event.

Verification of the model using anecdotal evidence collected during the August 2008 historical event in Newcastle West

A report was commissioned by Limerick County Council and completed by JBA consulting in the wake of a significant flood event in Newcastle West on the 1st August 2008[1]. The report identified root causes of the flooding and made recommendations for future analysis and areas of investigation. The report highlighted that the capacity of the channel and its bridges needed further analysis. The report also noted a number of recorded water levels from wrack marks indicating the maximum stage at various locations (see Figure C.7) along the River Doally during the 1st of August 2008 event. These wrack marks were visually recorded by JBA consulting and have not been surveyed. These water levels have been compared to the water levels predicted by the model in the 1% AEP, and 0.1% AEP events.

[1] Newcastle West Flood Severity and Impact Report: Report on flooding in Newcastle West, Co. Limerick, July 2008. JBA Consulting.

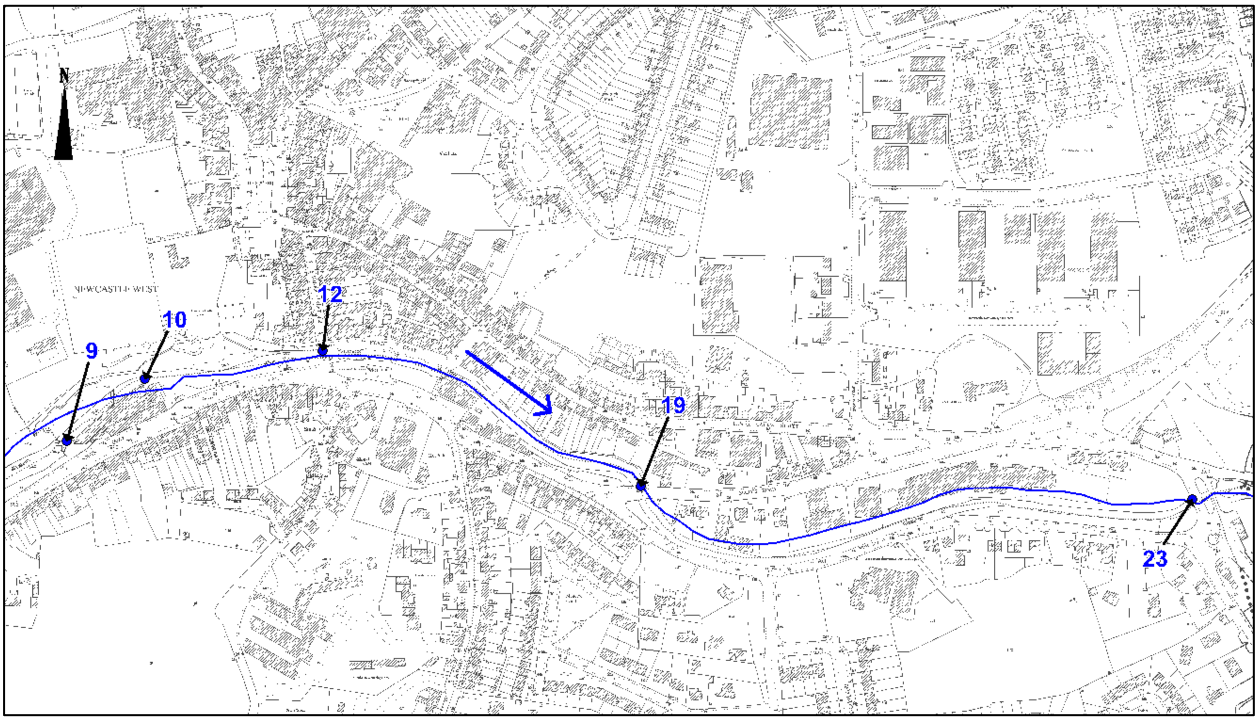


Figure C.7 – Wrack mark locations

Table C.5: Comparison of predicted model stage with JBA wrack mark levels.

JBA Reference Points (see figure)	ISIS Cross-section	Observed Maximum Stage (m AOD*)	Modelled Maximum Stage 1% AEP (m AOD*)	Modelled Maximum Stage 0.1% AEP (m AOD*)
9	02DLY02494	56.28	56.35	56.50
10	02DLY2347JU	55.39	54.32	54.54
12	02DLY02239JU	54.53	52.98	53.80
19	02DLY01926JU	52.09	50.82	51.24
70 m u/s of 23	02DLY01559	49.59	49.25	49.55
23	02DLY01403JD	48.71	48.52	48.84
70 m d/s of 23	02DLY01359	49.52	48.07	48.38

(*Datum is taken from Malin Head)

As can be seen from Table C.5 above, the predicted maximum water levels for the 1% AEP event and the 0.1% AEP event are in most cases below the recorded maximum stage during the 2008 event.

The JBA report includes photographs of various structures during the 2008 flood event. These photographs indicate blockage of some structures by trees, debris and a car. Blockage of structures and reports of debris falling into the channel are also mentioned in the report. Based on these observations a blockage assessment has been carried out on the model. A 50% blockage was applied to 3 structures along the River Doally, shown in Figure C.8 in an attempt to reproduce flood mechanisms observed during the 2008 event and get model results more in line with the wrack mark levels.

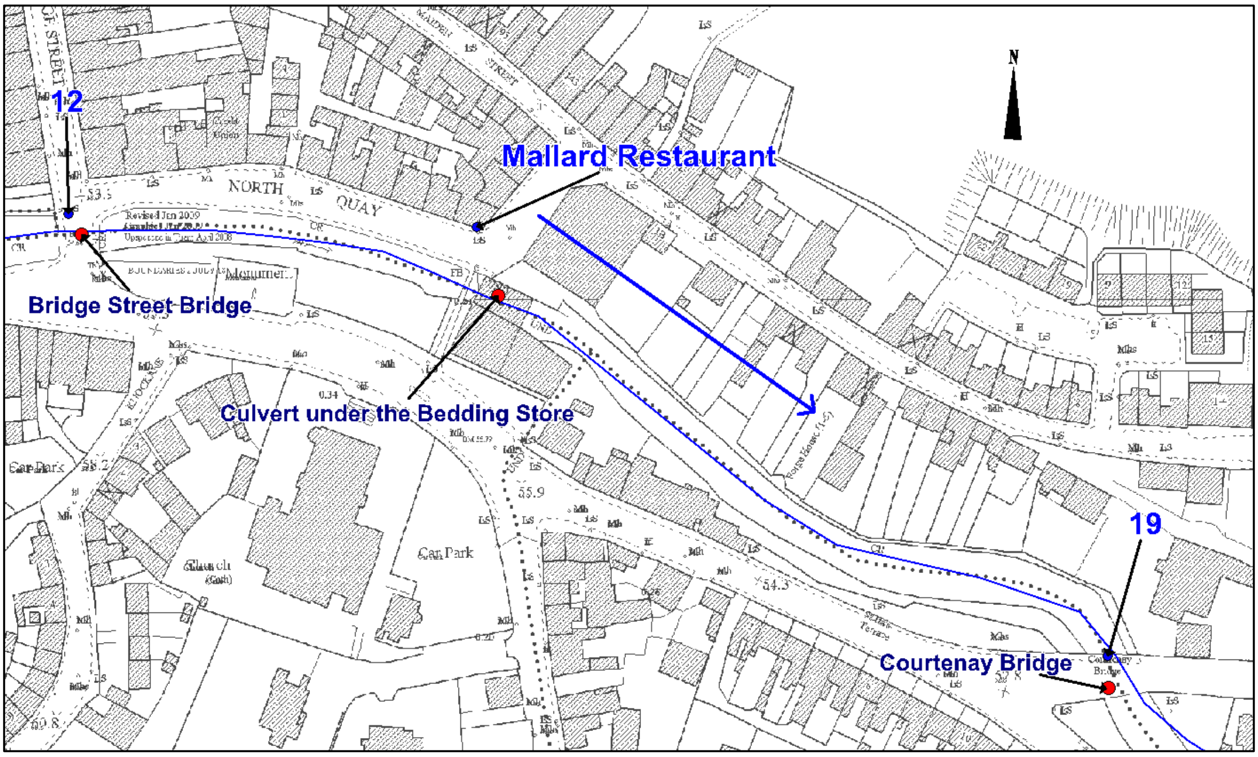


Figure C.8 – Location of structure included in the blockage assessment.

Table C.6: Comparison of predicted model stage from the blockage analysis with JBA wrack mark levels.

Location (see figure)	ISIS Cross-section	Observed Maximum Stage (m AOD*)	Modelled Maximum Stage 1% AEP (m AOD*)	Modelled Maximum Stage 0.1% AEP (m AOD*)	Modelled Maximum Stage 1% AEP (m AOD*) With Blockage	Modelled Maximum Stage 0.1% AEP (m AOD*) With Blockage
12	02DLY02239JU	54.53	52.98	53.80	54.40	54.61
19	02DLY01926JU	52.09	50.82	51.24	51.69	52.25
Mallard Restaurant	02DLY02126	53.90**	52.39	52.82	52.85	53.26

(*Datum is taken from Malin Head)
(**Water level estimated by adding the depth of flooding given at this location to the LiDAR elevation)

Blockage was applied to the Bridge street bridge, downstream of point 12, the Courtenay Bridge, downstream of point 19 and the culvert under the bedding store downstream of the Mallard restaurant. Although a water level relative to Malin was not provided at the Mallard restaurant an estimated depth of flooding of 1.8m at this location was given in the report. The water level at this location was estimated by adding the depth of flooding to the LiDAR elevation at this location. The results of the blockage assessment shown in Table C.6, indicate that the predicted maximum stage, at points 12 and 19 in the 0.1% AEP event with blockage, are comparable to the recorded stage from the 2008 event, with the difference in water level less than +200mm. The predicted maximum stage in the 0.1% AEP event with blockage at the Mallard Restaurant is 640mm less than the estimated stage from the 2008 event.

The maximum stage upstream of the structures, on average, increased by 920mm in the 1% AEP event. This indicates the model results are sensitive to blockage.

Conclusions

It was possible to calibrate the model, for two in-bank historical events and one out-of-bank historical event, and to verify the model, for one event out-of-bank event, along MPW and HPW reaches of the River Deel.

The results suggest that the model calibrates well for the out-of-bank historical event. Calibration to the in-bank events is less conclusive with the modelled peak water levels under predicting the observed water levels outside the acceptable range of +/-0.2m for a HPW. As the discrepancy between the modelled and observed flood peak stages are not consistent for all events the issue is unlikely to be associated with the hydraulic model but with the uncertainties on the volume of the lateral inflow hydrographs input to the model. These are specific to each historic event simulated and cannot be accurately estimated due to lack of hydrometric data. Based on this conclusion no changes were made to the hydraulic model.

The model results for the verification event showed good agreement with the observed event and differences in stage are within the acceptable range of +/-0.2m for a HPW.

Although hydrometric data was not available to calibrate the model along reaches of the rivers which flow through the Newcastle West AFA, anecdotal evidence of maximum water levels from the August 2008 event, along the River Doally, was available for a broad verification of the model outputs. The levels predicted by the model in the 1% AEP and the 0.1% AEP events are generally found to be lower than the levels recorded during the 2008 event. A blockage assessment was carried out on the model. The model results were found to be sensitive to blockage with an average increase in stage of 920mm directly upstream of the structures. The predicted maximum stage in the 0.1% AEP event with blockage was found to be comparable to the recorded stage from the 2008 event at two locations. The maximum water levels from the August 2008 event were visually recorded therefore there is some doubt over the accuracy of the levels and due to the lack of hydrometric data an AEP has not been assigned to the August 2008 event. Therefore verification of the model using the 2008 maximum water levels was inconclusive.

Annex D - Hydraulic Model Files

Model Files Folders Structure	
ISIS	S11 Hydraulic Model ISIS Calibration Historic Design Runs Defended Current Scenario IED Sensitivity Analysis Afflux Boundary Condition Flow Roughness Tuflow
TUFLOW	S11 Hydraulic Model ISIS Tuflow bc_dbase check Checks model bg cs mi Boundaries Breaklines empty Landuse Location POlines River Topography SS xs results runs

ISIS Files	
Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Calibration Runs** S11_Mar06_Flu_C_Cal_His_v1.DAT S11_Jan05_Flu_C_Cal_His_v1.DAT S11_Jan02_Flu_C_Cal_His_v1.DAT S11_Nov00_Flu_C_Ver_His_v1.DAT

	Design Runs – Current Scenario: S11_Q10_FLU_C_DES_MAIN_ISSV1.DAT S11_Q100_FLU_C_DES_MAIN_ISSV1.DAT S11_Q1000_FLU_C_DES_MAIN_ISSV1.DAT S11_Q10_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q100_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q1000_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q10_FLU_C_DES_TRIB3_ISSV1.DAT S11_Q100_FLU_C_DES_TRIB3_ISSV1.DAT S11_Q1000_FLU_C_DES_TRIB3_ISSV1.DAT **Sensitivity Runs – Current Scenario** S11_Q100_FLU_C_Sen_Afflux_De1_TRIB2_IssV1.DAT S11_Q100_FLU_C_Sen_Afflux_In1_TRIB2_IssV1.DAT S11_Q100_FLU_C_Sen_Afflux_De2_TRIB2_IssV1.DAT S11_Q100_FLU_C_Sen_Afflux_In2_TRIB2_IssV1.DAT S11_Q100_FLU_C_SEN_BDY_IN_MAIN_ISSV1.DAT S11_Q100_FLU_C_SEN_BDY_DE_MAIN_ISSV1.DAT S11_Q100_FLU_C_Sen_20FlDe_Main_IssV1.DAT S11_Q100_FLU_C_Sen_20FlIn_Main_IssV1.DAT S11_Q100_FLU_C_Sen_20FlDe_TRIB2_IssV1.DAT S11_Q100_FLU_C_Sen_20FlIn_TRIB2_IssV1.DAT S11_Q100_FLU_C_Sen_20FlDe_TRIB3_IssV1.DAT S11_Q100_FLU_C_Sen_20FlIn_TRIB3_IssV1.DAT S11_Q100_FLU_C_Sen_20RoDe_Main_IssV1.DAT S11_Q100_FLU_C_Sen_20RoIn_Main_IssV1.DAT S11_Q100_FLU_C_Sen_20RoDe_Trib2_IssV1.DAT S11_Q100_FLU_C_Sen_20RoIn_Trib2_IssV1.DAT S11_Q100_FLU_C_Sen_20RoDe_Trib3_IssV1.DAT S11_Q100_FLU_C_Sen_20RoIn_Trib3_IssV1.DAT
Hydrological Inflow Files	**Calibration Runs** S11_March_2006_Cal.IED S11_January_2005_Cal.IED S11_January_2002_Cal.IED S11_November_2000_Ver.IED **Design Runs – Current Scenario:** Q10_DesignR_Main.ied Q100_DesignR_Main.ied Q1000_DesignR_Main.ied Q10_DesignR_Trib2.ied Q100_DesignR_Trib2.ied Q1000_DesignR_Trib2.ied Q10_DesignR_Trib3.ied

	Q100_DesignR_Trib3.ied Q1000_DesignR_Trib3.ied **Sensitivity Runs – Current Scenario** Q100_Sens_Main_De.ied Q100_Sens_Main_In.ied Q100_Sens_Trib2_De.ied Q100_Sens_Trib2_In.ied Q100_Sen_Trib3_De.ied Q100_Sen_Trib3_In.ied
TUFLOW Files	
TUFLOW Control Files (.tcf) and Associated Files (e.g.: ecf, tgc, tbc)	**Design Runs – Current Scenario:** **Tributary 2 Model** S11_Q10_TRIB2_FLU_C_DES_ISSV1.tcf S11_Q100_TRIB2_FLU_C_DES_ISSV1.tcf S11_Q1000_TRIB2_FLU_C_DES_ISSV1.tcf **Tributary 3 Model** S11_Q10_TRIB3_FLU_C_DES_ISSV1.tcf S11_Q100_TRIB3_FLU_C_DES_ISSV1.tcf S11_Q1000_TRIB3_FLU_C_DES_ISSV1.tcf **Sensitivity Runs – Current Scenario** **Tributary 2 Model** S11_Q100_TRIB2_SEN_20FlDe_ISSV1.tcf S11_Q100_TRIB2_SEN_20FlIn_ISSV1.tcf S11_Q100_TRIB2_SEN_AfIn1_ISSV1.tcf S11_Q100_TRIB2_SEN_AfIn2_ISSV1.tcf S11_Q100_TRIB2_SEN_AfDe1_ISSV1.tcf S11_Q100_TRIB2_SEN_AfDe2_ISSV1.tcf S11_Q100_TRIB2_SEN_RoDe_ISSV1.tcf S11_Q100_TRIB2_SEN_RoIn_ISSV1.tcf **Tributary 3 Model** S11_Q100_TRIB3_SEN_20FlDe_ISSV1.tcf S11_Q100_TRIB3_SEN_20FlIn_ISSV1.tcf S11_Q100_TRIB3_SEN_RoDe_ISSV1.tcf S11_Q100_TRIB3_SEN_RoIn_ISSV1.tcf
Grid Orientation File	2d_loc_S11_5m_NEWC.MIF
Material Files	**Design Runs – Current Scenario:** S11_NEWC_Landuse.tmf **Sensitivity Runs – Current Scenario** S11_NEWC_Landuse_RoDe.tmf S11_NEWC_Landuse_RoIn.tmf

	For Newcastle West 2d Domain: 2d_mat_Gen_S11_5m_NEWC.MIF 2d_mat_WaterBodies_S11_5m_NEWC.MIF 2d_mat_Roads_S11_5m_NEWC.MIF 2d_mat_Buildings_S11_5m_NEWC.MIF
Zpt Files, Model DTM (.asc)	Newcastlewest_2m_dtm.asc
Breaklines Files	2d_zln_walls_S11_5m_NEWC.MIF 2d_zln_parapets_S11_5m_NEWC.MIF 2d_zln_surv_banktop_S11_5m_NEWC.MIF 2d_zln_unsurv_banktop_S11_5m_NEWC.MIF
Boundary Files	2d_bc_Hxe_S11_5m_NEWC.MIF 2d_bc_hxi_ S11_5m_NEWC.MIF 2d_bc_SX_ S11_5m_NEWC.MIF
Flow/Head Files in bc_dbase	No Flow/Head boundaries provided in 2d domain.
Initial Water Level Files	No IWL files provided in 2D domain
Time Series Files	No time series files provided to the 2d domain.
One Dimensional Network Files	1d_ISIS_Nodes_S11_5m_NEWC.MIF
Available 2D Result Files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Historic Events						
1	S11_Mar06_Flu_C_Cal_His_v1.DAT	0	50	1 sec 1D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
2	S11_Jan05_Flu_C_Cal_His_v1.DAT	0	50	1 sec 1D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
3	S11_Jan02_Flu_C_Cal_His_v1.DAT	0	50	1 sec 1D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
4	S11_Nov00_Flu_C_Ver_His_v1.DAT	0	50	1 sec 1D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
Design Runs						
1	S11_Q10_FLU_C_DES_MAIN_ISSV1.DAT	0	50	1 sec 1D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 12.	Convergence within manufacturer tolerance.
2	S11_Q10_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q10_TRIB2_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
3	S11_Q10_FLU_C_DES_TRIB3_ISSV1.DAT S11_Q10_TRIB3_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.

4	S11_Q100_FLU_C_DES_MAIN_ISSV1.DAT	0	50	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 12.	Convergence within manufacturer tolerance.
5	S11_Q100_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q100_TRIB2_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
6	S11_Q100_FLU_C_DES_TRIB3_ISSV1.DAT S11_Q100_TRIB3_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
7	S11_Q1000_FLU_C_DES_MAIN_ISSV1.DAT	0	50	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 12.	Convergence within manufacturer tolerance.
8	S11_Q1000_FLU_C_DES_TRIB2_ISSV1.DAT S11_Q1000_TRIB2_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
9	S11_Q1000_FLU_C_DES_TRIB3_ISSV1.DAT S11_Q1000_TRIB3_FLU_C_DES_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 17.	Convergence within manufacturer tolerance.
Sensitivity Analysis						
1	S11_Q100_FLU_C_Sen_Afflux_De1_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_AfDe1_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The coefficient of velocity is changed to 0.8 at ISIS node 02DLY02373	Convergence within manufacturer tolerance.
2	S11_Q100_FLU_C_Sen_Afflux_In1_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_AfIn1_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The coefficient of velocity is changed to 1.2 at ISIS node 02DLY02373	Convergence within manufacturer tolerance.
3	S11_Q100_FLU_C_Sen_Afflux_De2_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_AfDe2_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The coefficient of velocity is changed to 0.8 at ISIS node 02DLY02494	Convergence within manufacturer tolerance.

4	S11_Q100_FLU_C_Sen_Afflux_In2_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_AfIn2_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The coefficient of velocity is changed to 1.2 at ISIS node 02DLY02494	Convergence within manufacturer tolerance.
5	S11_Q100_FLU_C_SEN_BDY_IN_MAIN_ISSV1.DAT	0	50	1 sec 1D	The slope in the downstream boundary is doubled.	Convergence within manufacturer tolerance.
6	S11_Q100_FLU_C_SEN_BDY_DE_MAIN_ISSV1.DAT	0	50	1 sec 1D	The slope in the downstream boundary is halved.	Convergence within manufacturer tolerance.
7	S11_Q100_FLU_C_Sen_20FlDe_Main_IssV1.DAT	0	50	1 sec 1D	The flow in the main stem of the model has been decreased by 20%	Convergence within manufacturer tolerance.
8	S11_Q100_FLU_C_Sen_20FlIn_Main_IssV1.DAT	0	50	1 sec 1D	The flow in the main stem of the model has been increased by 20%	Convergence within manufacturer tolerance.
9	S11_Q100_FLU_C_Sen_20FlDe_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_20FlDe_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The flow in the tributary has been decreased by 20%.	Convergence within manufacturer tolerance.
10	S11_Q100_FLU_C_Sen_20FlIn_TRIB2_IssV1.DAT S11_Q100_TRIB2_SEN_20FlIn_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The flow in the tributary has been increased by 20%.	Convergence within manufacturer tolerance.
11	S11_Q100_FLU_C_Sen_20FlDe_TRIB3_IssV1.DAT	0	40	1 sec 1D 2 sec 2D	The flow in the tributary has been decreased by 20%.	Convergence within manufacturer tolerance.
12	S11_Q100_FLU_C_Sen_20FlIn_TRIB3_IssV1.DAT	0	40	1 sec 1D 2 sec 2D	The flow in the tributary has been increased by 20%.	Convergence within manufacturer tolerance.
13	S11_Q100_FLU_C_Sen_20RoDe_Main_IssV1.DAT	0	50	1 sec 1D	The roughness has been decreased by 20%.	Convergence within manufacturer tolerance.
14	S11_Q100_FLU_C_Sen_20RoIn_Main_IssV1.DAT	0	50	1 sec 1D	The roughness has been increased by 20%.	Convergence within manufacturer tolerance.
15	S11_Q100_FLU_C_Sen_20RoDe_Trib2_IssV1.DAT S11_Q100_TRIB2_SEN_RoDe_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The roughness has been decreased by 20%.	Convergence within manufacturer tolerance.
16	S11_Q100_FLU_C_Sen_20RoIn_Trib2_IssV1.DAT S11_Q100_TRIB2_SEN_RoIn_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	The roughness has been increased by 20%.	Convergence within manufacturer tolerance.

17	S11_Q100_FLU_C_Sen_20RoDe_Trib3_IssV1.DAT	0	40	1 sec 1D 2 sec 2D	The roughness has been decreased by 20%.	Convergence within manufacturer tolerance.
18	S11_Q100_FLU_C_Sen_20RoIn_Trib3_IssV1.DAT	0	40	1 sec 1D 2 sec 2D	The roughness has been increased by 20%.	Convergence within manufacturer tolerance.

Blockage Analysis						
1	S11_Q100_FLU_C_Sen_Bloc_Trib2_IssV1.DAT S11_Q100_TRIB2_SEN_Bloc_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	50% Blockage applied to three structures.	Convergence within manufacturer tolerance.
2	S11_Q1000_FLU_C_Sen_Bloc_Trib2_IssV1.DAT S11_Q1000_TRIB2_SEN_Bloc_ISSV1.tcf	0	40	1 sec 1D 2 sec 2D	50% Blockage applied to three structures.	Convergence within manufacturer tolerance.

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 17/12 to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Fluvial Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S12
Unit of Management	24
AFAs included in the model	Dromcolliher & Milford
Primary Watercourses / Water Bodies	River Deel Ahavarragh Stream Upper Ballyhane Gardenfield South
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A3.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B7 – Figure B7.7

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k Reference: OS1412D & OS1212D
2.2 DTM for 1D Model Domains:	**Within AFAs:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFAs: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 246
2.4 Defence Asset Survey Data	No defences have been identified within the model area in the defence asset database. However, a recently constructed defence along the Ahavarragh Stream has been included with further detail provided in section 6. The defence is labelled as 'defacto defence' in Annex A2 (3) and (4).
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Softwares	**1D Domain:** ISIS Version 3.6.0.156 (32 bit – Double Precision)
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - AFA boundary
2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
Ahavarragh Stream	01AHV	01AHV08190	01AHV00000
River Deel	09DEL	09DEL00600	09DEL00000
	08DEL	08DEL00716	08DEL00000
	07DEL	07DEL07921	07DEL00000
	06DEL	06DEL04857	06DEL00000
Upper Ballyhane	01MLF	01MLF00279	01MLF00000
Gardenfield South	01DRO	01DRO01050	01DRO00000

Total model HPW length (km):	5.39km	**Total model MPW length (km):**	17.87km

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	13
Bridges:	☒	How many?	13
Fixed crest weirs:	☒	How many?	4
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation

Out-of-bank areas for MPW reaches have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections.

Out-of-bank areas for HPW reaches have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections and an ISIS reservoirs unit.

Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple. 1D-2D modelling is required where HPWs flow through urban areas where out of bank flows will form complex flow paths.

An overview of the floodplain schematisation is available in the maps shown in Annex A.

3.6 2D Domain Grid Size:	N/A
	Number of 2D domains: 0
3.7 Model Breaklines in the 2D Domain:	N/A
3.8 Floodplain Structures in the 2D Domain	N/A
3.9 Hydraulic Roughness	Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:

MPW in-bank **Bed and bank sides**	Minimum 'n' value:	0.05
	Maximum 'n' value:	0.05
HPW in-bank	Minimum 'n' value:	0.03
	Maximum 'n' value:	0.055

Floodplain (ISIS Model)	Manning's 'n' for out of bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:	
	Land use	**Manning's 'n' value**
	Pastures	0.035
	Dense Vegetation	0.080
	Road Network	0.025
	Buildings	0.100

3.10 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.
3.11 Model Boundaries - Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report relevant to Unit of Management 24.
(a) Current Situation	Peak inflows (m^3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2).

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
(a) Main Model									
24_1552_3	09DEL00600	42.0	51.6	58.3	64.6	72.6	78.5	84.8	98.6
24_913_2	08DEL00196	0.4	0.4	0.4	0.4	0.4	0.6	0.69	0.74
24_912_2	07DEL07430	7.0	8.0	11.5	13.0	15.0	16.1	17.0	19.4
24_1623_2	06DEL04453	8.8	11.9	14.7	15.7	17.2	20.0	20.1	22.8
24_918_1	06DEL00491	8.1	10.0	11.1	12.1	13.4	14.3	15.2	17.2

Added_Inflow	06DEL04846	5	11	4.5	5.0	5.5	6.1	6.8	7.7
(a) Tributary Model									
24_1552_3	09DEL00600	2.1	2.1	2.1	2.8	2.8	2.8	3.0	3.5
24_1483_2	01AHV08190	2.0	2.5	3.0	3.4	3.9	4.4	4.8	5.8
24_1483_5	01AHV06672	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6
24_1483_6	01AHV06140d	0.2	0.3	0.4	0.5	0.5	0.6	0.6	0.8
24_1483_8	01AHV05140	0.7	0.9	1.1	1.3	1.5	1.6	1.8	2.1
24_1484_2	01AHV03979	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
24_1484_3	01AHV03453	0.8	1.2	1.4	1.6	1.8	2.0	2.2	2.7
24_293_2	01AHV02555	0.5	0.7	0.9	1.0	1.1	1.3	1.4	1.7
24_293_3	01AHV02066	2.3	3.2	3.7	4.3	4.9	5.5	4.9	7.2
24_199_2	01AHV01130	1.6	2.2	2.6	3.0	3.4	3.8	4.2	5.0
24_1621_2	01AHV00927	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4
24_370_1	01MLF00279	0.5	0.7	0.8	0.8	0.9	1	1.1	1.3
24_347_2	01DRO01050	1.9	2.3	2.7	2.9	3.3	3.6	3.9	4.5

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.

HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
(b) Main Model									
24_1552_3	09DEL00600	50.4	61.9	70.0	77.5	87.1	94.2	101.8	118.3
24_913_2	08DEL00196	0.5	0.5	0.5	0.5	0.5	0.7	0.8	0.9
24_912_2	07DEL07430	8.4	9.6	13.8	15.6	18.0	19.3	20.4	23.3
24_1623_2	06DEL04453	10.6	14.3	17.6	18.8	20.6	24.0	24.1	27.4
24_918_1	06DEL00491	9.7	12.0	13.3	14.5	16.1	17.2	18.2	20.6
Added_Inflow	06DEL04846	6.0	13.2	5.4	6.0	6.6	7.3	8.2	9.2
(b) Tributary Model									
24_1552_3	09DEL00600	2.5	2.5	2.5	3.4	3.4	3.4	3.6	4.2
24_1483_2	01AHV08190	2.4	3.0	3.6	4.1	4.7	5.3	5.8	7.0
24_1483_5	01AHV06672	0.2	0.4	0.4	0.5	0.5	0.6	0.6	0.7
24_1483_6	01AHV06140d	0.2	0.4	0.5	0.6	0.6	0.7	0.7	1.0
24_1483_8	01AHV05140	0.8	1.1	1.3	1.6	1.8	1.9	2.2	2.5
24_1484_2	01AHV03979	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
24_1484_3	01AHV03453	1.0	1.4	1.7	1.9	2.2	2.4	2.6	3.2
24_293_2	01AHV02555	0.6	0.8	1.1	1.2	1.3	1.6	1.7	2.0
24_293_3	01AHV02066	2.8	3.8	4.4	5.2	5.9	6.6	5.9	8.6
24_199_2	01AHV01130	1.9	2.6	3.1	3.6	4.1	4.6	5.0	6.0

24_1621_2	01AHV00927	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.5
24_370_1	01MLF00279	0.6	0.8	1.0	1.0	1.1	1.2	1.3	1.6
24_347_2	01DRO01050	2.3	2.8	3.2	3.5	4.0	4.3	4.7	5.4

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.

HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
(b) Main Model				
24_1552_3	09DEL00600	75.8	102.1	128.2
24_913_2	08DEL00196	0.5	0.8	1.0
24_912_2	07DEL07430	15.0	20.9	25.2
24_1623_2	06DEL04453	19.1	26.0	29.6
24_918_1	06DEL00491	14.4	18.6	22.4
Added_Inflow	06DEL04846	5.9	7.9	10.0
(b) Tributary Model				
24_1552_3	09DEL00600	2.7	3.6	4.6
24_1483_2	01AHV08190	3.9	5.7	7.5
24_1483_5	01AHV06672	0.4	0.7	0.8
24_1483_6	01AHV06140d	0.5	0.8	1.0
24_1483_8	01AHV05140	1.4	2.1	2.7
24_1484_2	01AHV03979	0.1	0.1	0.3
24_1484_3	01AHV03453	1.8	2.6	3.5
24_293_2	01AHV02555	1.2	1.7	2.2
24_293_3	01AHV02066	4.8	7.2	9.4
24_199_2	01AHV01130	3.4	4.9	6.5
24_1621_2	01AHV00927	0.3	0.4	0.5
24_370_1	01MLF00279	1.0	1.3	1.7
24_347_2	01DRO01050	3.5	4.7	5.9

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:
	A normal depth boundary was chosen to provide a free flow condition at the downstream end of the model. The slope parameter was taken from the local river bed slope. Sensitivity to this assumption is discussed in the relevant section below.

<table>
<tr><th colspan="6">4. Hydraulic Model Calibration and Sensitivity</th></tr>
<tr><td>4.1 Model Calibration and Verification to Historical Events</td><td colspan="5">The approach to model calibration is documented in the main Hydraulics Report.
The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report.
A summary of the calibration and verification events along with associated model calibration results is as follows:
No historical information was available to allow calibration.</td></tr>
<tr><td>Catchment Gauging</td><td colspan="5">Is modelled catchment: Gauged ☒ Ungauged ☐</td></tr>
<tr><td rowspan="3">Gauging Stations</td><td colspan="5">If the modelled part of the catchment is gauged, list gauging stations:</td></tr>
<tr><td>Station Number</td><td>Watercourse</td><td>Location</td><td colspan="2">ISIS Node Reference</td></tr>
<tr><td>24015</td><td>River Ahavarragh</td><td>Dromcolliher</td><td colspan="2">01AHV06790u</td></tr>
<tr><td rowspan="2">Calibration Event</td><td rowspan="2">Event Date</td><td rowspan="2">Station Number</td><td rowspan="2">Difference between Modelled and Observed Water Level (mm)</td><td colspan="2">Root Mean Square Error</td></tr>
<tr><td>HPW</td><td>MPW</td></tr>
<tr><td></td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Conclusion</td><td colspan="5">It was not possible to calibrate this model for any flood event.</td></tr>
<tr><td>4.2 Calibration to HEP</td><td colspan="5">Calibration of the hydraulic model to the HEP target flows has been carried out for all design events simulated. Section 2.7.2 of the Hydrology Report for UoM 24 provides a summary of the calibration to HEP process.
Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincide with the peak time of the propagating flood wave as it is routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Where required, inflows to the hydraulic model were scaled up/down to ensure that the modelled total peak flows remain within ±10% of the HEP target flows. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. The flows at the following HEP nodes were increased by varying amounts: 24_912_2 & 24_1623_2, while an additional inflow was added at cross-section 06DEL04846.
During the 20% tributary event, the peak flow was not within the 10% target flow at the 24_293_2. As this area is isolated and only occurs in one return period it was not deemed necessary to add additional flows on this occasion.
The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for the HEP nodes are as follows: 5.11%, 5.29%, and 3.61% for the 10%, 1% and 0.1% main model AEP events respectively.
0.74%, 0.44% and 0.46% for the 10%, 1% and 0.1% tributary model events respectively.</td></tr>
</table>

HEP Reference Name	Node in the Hydraulic Model	Annual Exceedance Probability Percentage Difference (%)							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
Main									
24_1552_4	09DEL00012u	-1.1	-2	2.4	-3.1	-3.2	2.6	-2.3	1.8
24_913_2	08DEL00233	-2	-2.9	3.6	-4.6	-2.1	3.1	-3	2.3
24_912_1	07DEL07874	-4.2	-5.6	6.2	-7.3	-5.8	6	-6.4	5
24_912_2	07DEL07430	-4.9	-6.6	7.3	-9.4	-8.1	4.4	-7.9	5.8
24_908_2	07DEL05006	8.5	6.5	-9.5	7.9	8.4	-4.8	7.9	-9.2
24_1622_1	07DEL00598	-3.9	-6.3	3.1	-4	-3.8	7.4	-3.9	3.3
24_1622_2	07DEL00027	-3.3	-5.8	2.9	-3.8	-3.8	7.3	-3.7	3.2
24_1623_2	06DEL04453	-7.4	-2.3	8.7	-8.5	-7.6	9.7	-4.8	2.3
24_918_1	06DEL01046	-2.3	2.2	2.6	-2	-1.2	2.9	0.5	-0.1
24_860_1	06DEL00000	-6.2	-0.7	4.8	-4.1	-3.5	4.7	-1.8	3.1
Tributaries									
24_370_2	01MLF00040	0	0.1	0.4	0	0.1	0	0	-0.2
24_347_4	01DRO00145	-0.1	-0.1	1.9	0	0	-0.8	0	-0.4
24_1483_5	01AHV06691	7.9	-0.1	-1	0	0	-0.7	0	0.9
24_1483_6	01AHV06154u	7.4	0.1	-0.6	0.2	0.2	0.6	0.2	-0.6
24_1483_8	01AHV05140	6.5	-0.1	-0.3	0.1	0	0.6	0	0.6
24_1484_2	01AHV04223	5	-0.2	-0.4	0	-0.2	0.6	-0.2	-0.3
24_1484_3	01AHV03453	4.7	0.8	-0.4	-0.4	-0.5	-0.3	-0.4	0.5
24_293_2	01AHV03058	3.5	11.6	0.8	-0.7	-0.8	0	-0.8	0.1
24_293_3	01AHV02091	2.9	2.9	0	-0.9	-0.9	0.5	-0.9	0.4
24_199_2	01AHV01620	1.5	1.3	0.2	-1.4	-1.2	0.2	-7.8	0.3
24_1621_2	01AHV00927	1.1	0.7	0.7	-1.5	-1.3	0.1	-6.5	0.2
24_1621_4	01AHV00011	1.1	0.5	0.7	-1.5	-1.3	0	-6.4	0.1

4.3 Model Sensitivity

Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's n), fluvial flow, afflux at key structures and downstream conditions. In each case the sensitivity run was carried out for the 1% AEP fluvial event Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work. Sensitivity test results are provided in the following tables:

+20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section / Reach where the Maximum Difference occurs
River Deel	+0.13	+0.54	06DEL01091
Ahavarragh Stream	+0.01	+0.23	01AHV06195u

	Upper Ballyhane	+0.07	+0.40	01MLF00000u
	Gardenfield South	+0.01	+0.06	01DRO00000
-20% Manning's 'n'	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	-0.17	-0.60	08DEL00112
	Ahavarragh Stream	-0.07	-0.42	01AHV00145
	Upper Ballyhane	-0.05	-0.09	01MLF00103u
	Gardenfield South	-0.07	-0.13	01DRO00688d
+20% inflows	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	+0.17	+0.70	06DEL01091
	Ahavarragh Stream	+0.11	+0.27	01AHV00000
	Upper Ballyhane	+0.05	+0.09	01MLF00000u
	Gardenfield South	+0.12	+0.43	01DRO00207u
-20% inflows	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Deel	-0.20	-0.37	09DEL00030
	Ahavarragh Stream	-0.12	-0.28	01AHV00145
	Upper Ballyhane	-0.06	-0.09	01MLF00141su
	Gardenfield South	-0.12	-0.29	01DRO00207u
Afflux at Key Structure Orifice discharge coefficient increased by 20%	There is one structure in the model which has significant head loss during a 1% AEP flood event. This is a bridge which is located in the centre of Milford, where the R515 crosses the River Deel (09DEL00012bu). The orifice discharge coefficient was increased by 20% (to a value of 1.2). This resulted in a decrease of 79mm to the maximum water level immediately upstream of the bridge. The diminishing effects can be seen to the most upstream node of the model, ~0.6km upstream of the structure. This decrease in stage caused an insignificant reduction of the predicted flood extent upstream of the bridge.			
Afflux at Key Structure Orifice discharge coefficient decreased by 20%	The orifice discharge was decreased by 20% (to a value of 0.8). This resulted in an increase of 124mm to the maximum water level immediately upstream of the bridge. Similarly to the case above, the diminishing effects can be seen to the most upstream node of the model,~ 0.6km upstream of			

	the structure. This increase in stage caused an insignificant increase in the predicted flood extent upstream of the bridge with no additional properties impacted.
Downstream Conditions Normal Depth downstream boundary slope doubled	The change to the downstream boundary condition resulted in a decrease in the maximum water level by 89mm at the downstream limit of the model (ISIS node 06DEL00000). The diminishing effects can be seen ~0.6km upstream of the downstream model limit on the River Deel. The change in the boundary condition has no impact on the water level along the HPW reaches within model S12.
Downstream Conditions Normal Depth downstream boundary slope halved	The change to the downstream boundary condition has resulted in an increase in the maximum water level by 83mm at the downstream model limit (ISIS node 06DEL00000). The diminishing effects can be seen ~0.6km upstream of the downstream model limit on the River Deel. The change in the boundary condition has no impact on the water level along the HPW reaches within model S12.
4.4 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D

5. Hydraulic Model Outputs	
5.1 Mapping	Model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP flood events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

- As detailed in the Hydrology Report and Appendix B7 of the Hydrology Report , the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. The River Deel was classified as main stream, whilst the Ahavarragh Stream, Upper Ballyhane and Gardenfield South rivers were considered as tributaries. Inflow hydrographs were purposely produced for both the main stream and tributaries and two models were run, the first containing only the main stream inflows and then the second containing only the tributary inflows. Both Main Stream and Tributary models share exactly the same geometry (structures and topography). The model outputs for both runs (Main and Tributary) were then merged, picking up the maximum flood depths and extents to create the flood maps.
- A number of inline spills were included in the model to improve stability. These are located at 08DEL00710, 01MLF00000, 01DRO00433 and 01AHV06195.
- An additional defence along the Ahavarragh Stream was included in the model between cross-sections 01AHV06204 and 01AHV06032. This defence has been recently constructed and provides protection to a nursing home (under the management of the Dromcollogher and District Respite Care Centre Ltd). The elevation of the top of this wall was not available at every cross-section. Therefore, interpolation was used between the cross-sections where the surveyors captured the elevation of the top of the wall. This model and outputs presented in this report therefore represent a defended scenario.
- There is one gauging station within the model (Dromcolliher on the Ahavarragh). This gauging station is operated by EPA and has only been in operation since 2009. Prior to 2009 it was a gaugeboard only site. Although the gauging station model has been calibrated, there were no medium or high flow gaugings available for the calibration.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent

Legend

2D Model Boundary

AFA Boundary

Model Reaches

HPW

MPW

Model:

S12

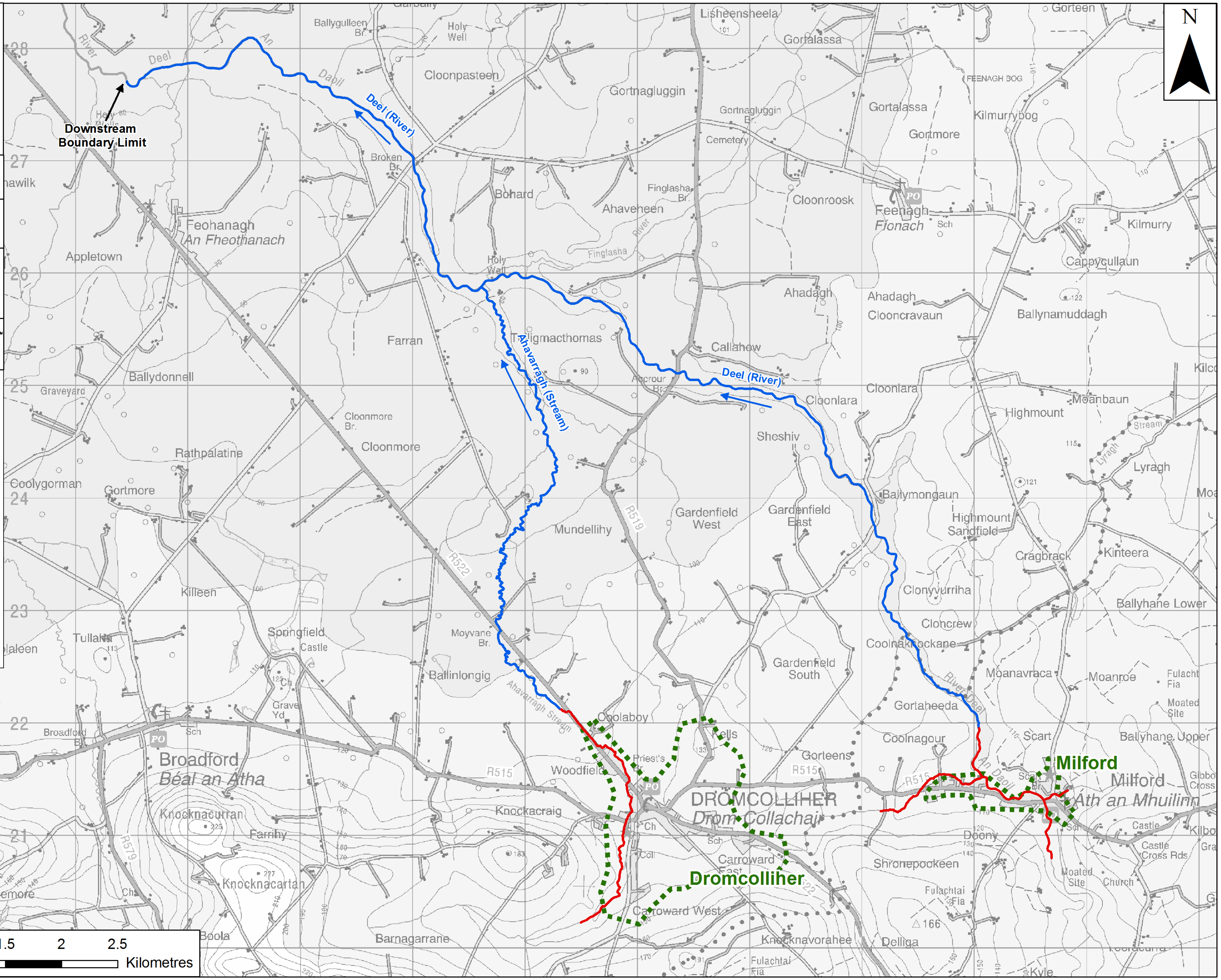
Figure ref:

Annex A1

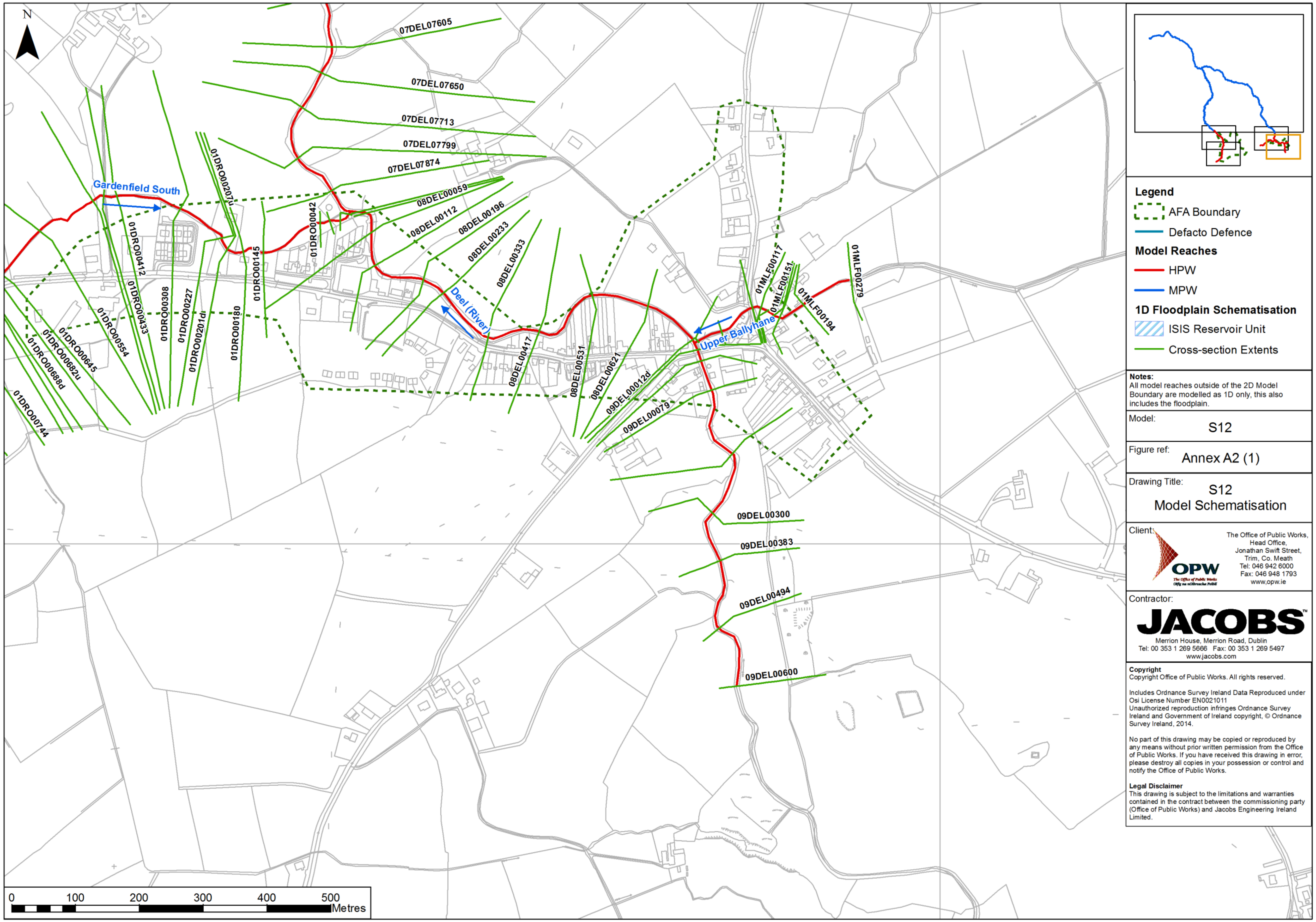
Drawing Title:

S12
Model Extent

JACOBS



Annex A2 – Schematisation Maps



N
07DEL07605
07DEL07650
07DEL07713
07DEL07799
07DEL07874
08DEL00059
08DEL00112
08DEL00196
08DEL00233
08DEL00333
08DEL00417
08DEL00531
08DEL00621
09DEL00012d
09DEL00079
09DEL00300
09DEL00383
09DEL00494
09DEL00600
Gardenfield South
Deel (River)
Upper Ballyhane
01DRO00207u
01DRO00412
01DRO00433
01DRO00308
01DRO00227
01DRO00201dr
01DRO00180
01DRO00145
01DRO00042
01DRO00554
01DRO00645
01DRO00682u
01DRO00688d
01DRO00744
01MLF00117
01MLF00151
01MLF00194
01MLF00279
0
100
200
300
400
500
Metres
Legend
AFA Boundary
Defacto Defence
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S12
Figure ref:
Annex A2 (1)
Drawing Title:
S12
Model Schematisation
Client:
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
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Contractor:
Merrion House, Merrion Road, Dublin
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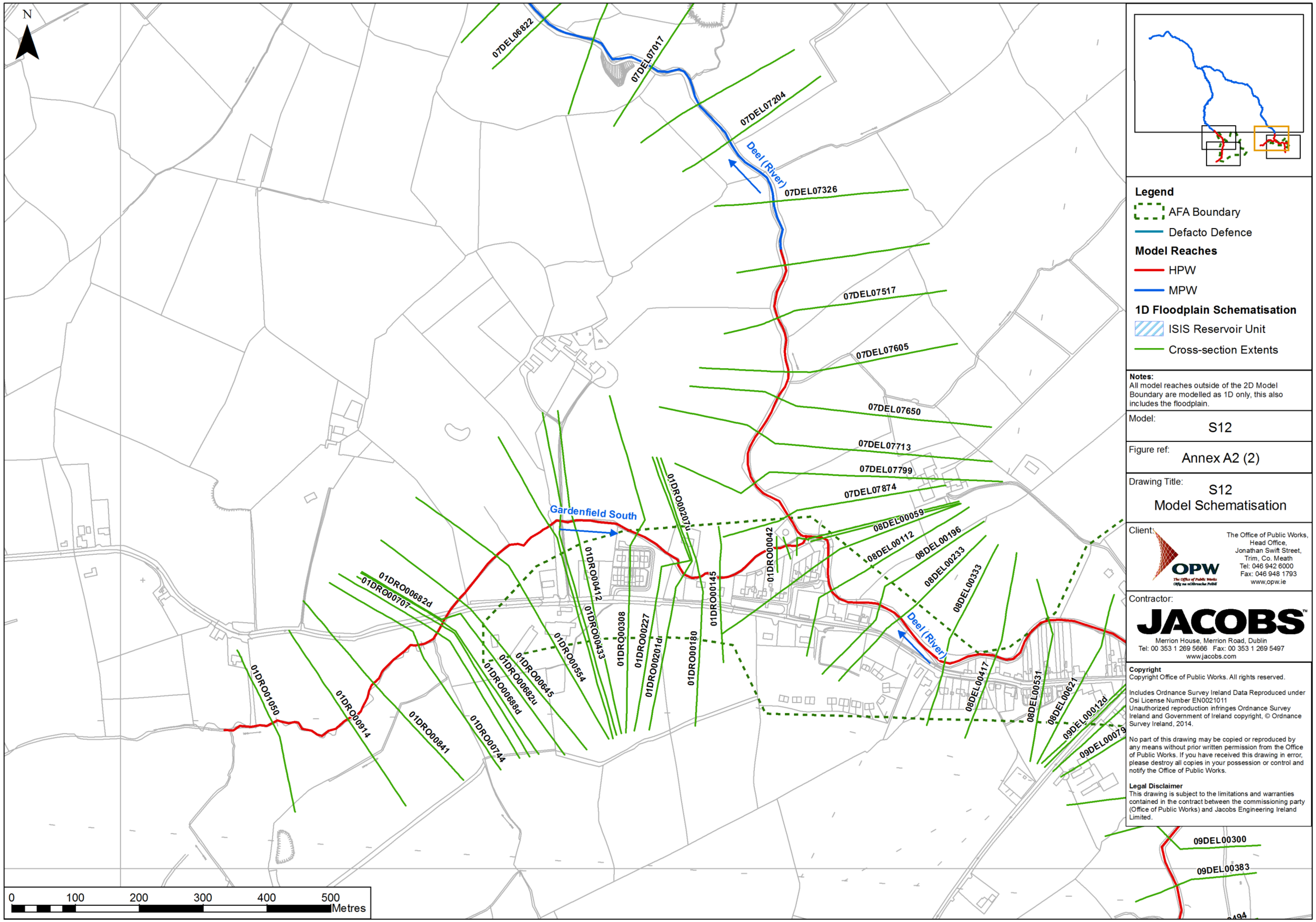
N
07DEL06822
07DEL07017
07DEL07204
Deel (River)
07DEL07326
07DEL07517
07DEL07605
07DEL07650
07DEL07713
07DEL07799
07DEL07874
08DEL00059
08DEL00112
08DEL00196
08DEL00233
08DEL00333
08DEL00417
08DEL00531
08DEL00621
09DEL00012d
09DEL00079
09DEL00300
09DEL00383
Gardenfield South
01DRO00207u
01DRO00042
01DRO00412
01DRO00433
01DRO00308
01DRO00227
01DRO00201d
01DRO00180
01DRO00145
01DRO00554
01DRO00645
01DRO00682u
01DRO00682d
01DRO00688d
01DRO00707
01DRO00744
01DRO00841
01DRO00914
01DRO01050
0 100 200 300 400 500 Metres
Legend
AFA Boundary
Defacto Defence
Model Reaches
HPW
MPW
1D Floodplain Schematisation
ISIS Reservoir Unit
Cross-section Extents
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S12
Figure ref: Annex A2 (2)
Drawing Title: S12 Model Schematisation
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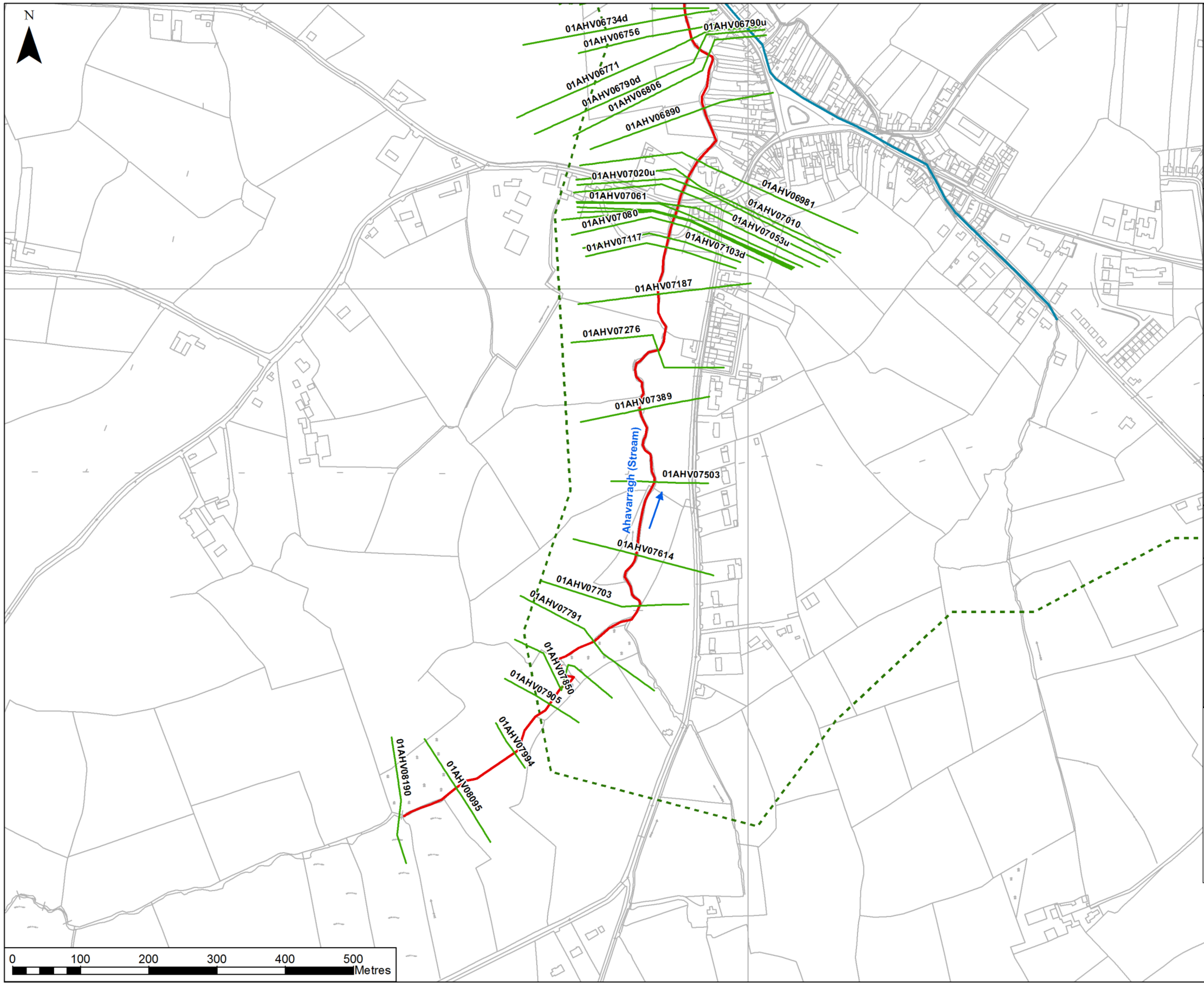

Legend

AFA Boundary

Defacto Defence

Model Reaches

HPW

MPW

1D Floodplain Schematisation

ISIS Reservoir Unit

Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S12

Figure ref: Annex A2 (3)

Drawing Title: S12 Model Schematisation

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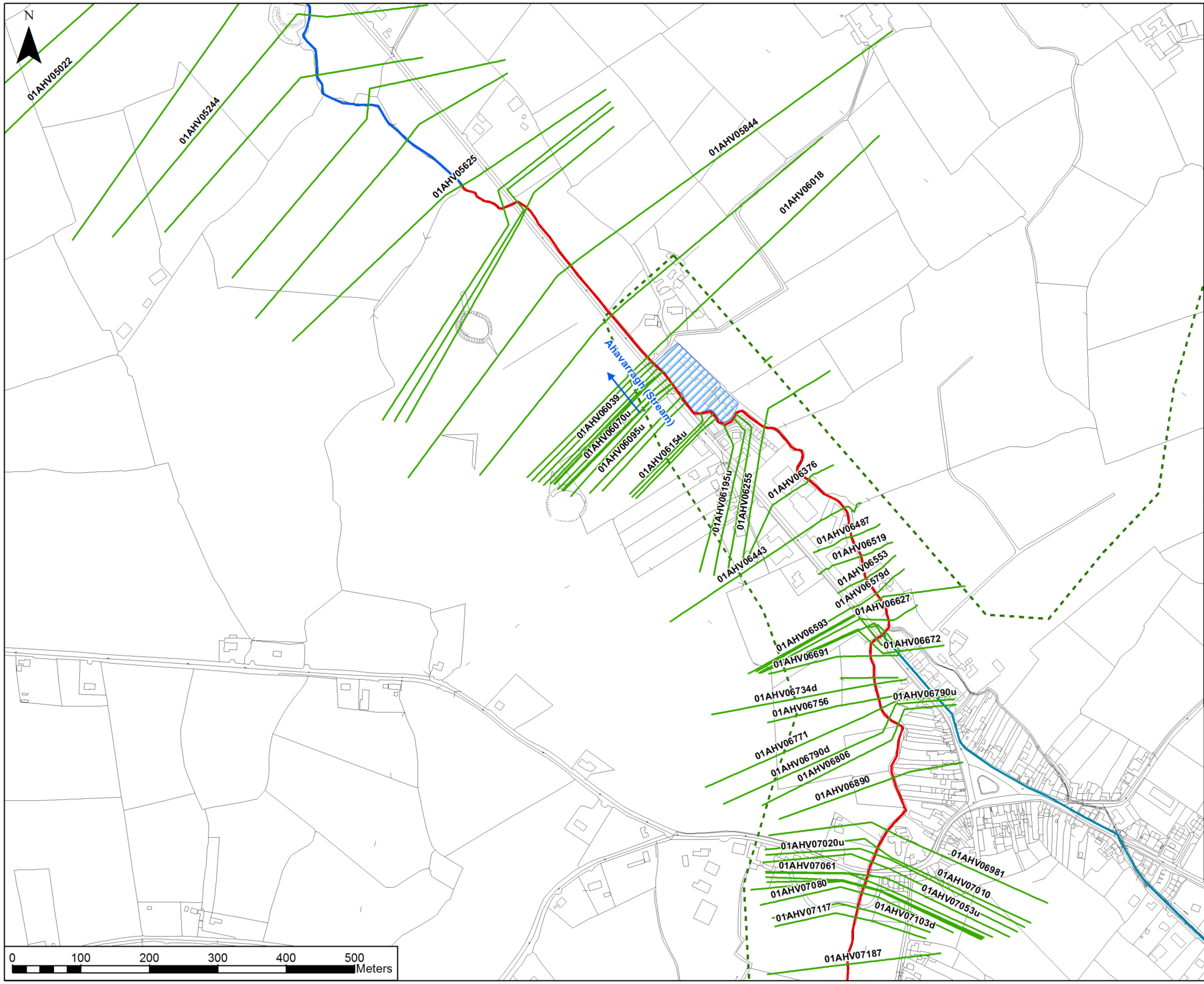

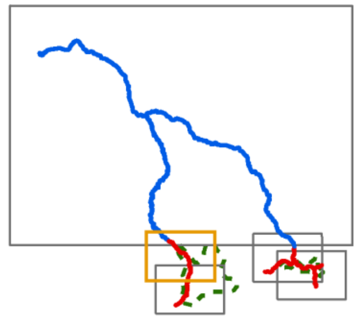

Legend

AFA Boundary

Defacto Defence

Model Reaches

HPW

MPW

1D Floodplain Schematisation

ISIS Reservoir Unit

Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S12

Figure ref: Annex A2 (4)

Drawing Title: S12 Model Schematisation

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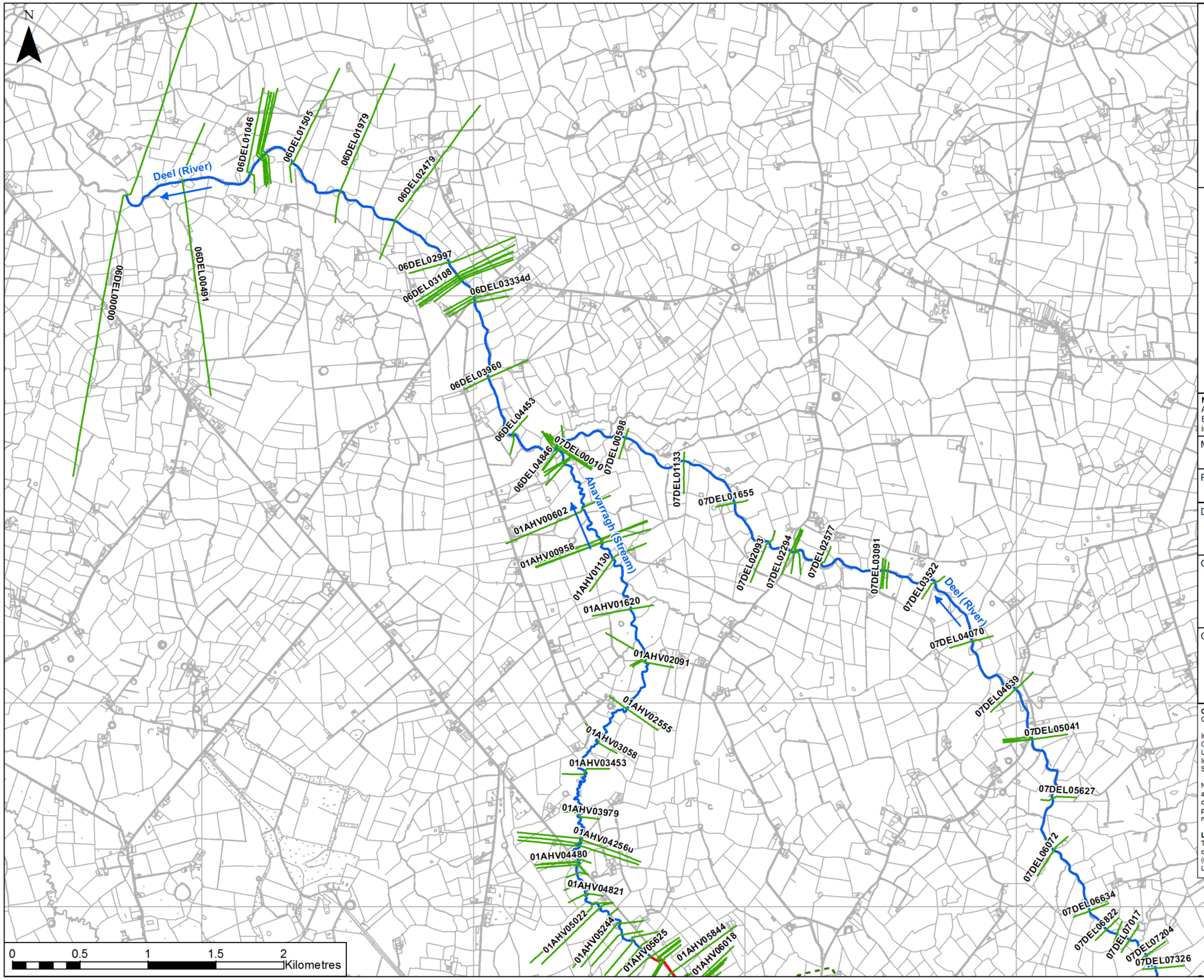

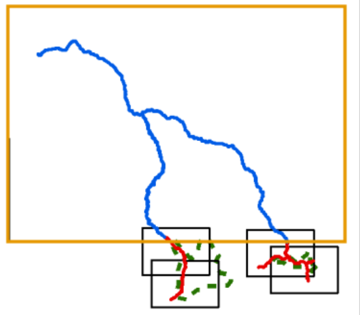

Legend

- AFA Boundary
- Defacto Defence

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- ISIS Reservoir Unit
- Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S12

Figure ref: Annex A2 (5)

Drawing Title: S12 Model Schematisation

Client: The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
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Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for Ahavarragh Stream

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24AHAV00571D	01AHV07103u	Bridge 5.25m wide	Arch Bridge + Spill	Y
24AHAV00568W	01AHV07070u	Weir	Inline Spill for river channel and spill for floodplain	Y
24AHAV00566D	01AHV07053u	Bridge 8.66m wide	Two sprung arch culverts and spill	Y
24AHAV00562D	01AHV07020u	Bridge 2.42m wide	Arch Bridge and Spill	Y
24AHAV00542D	01AHV06790u	Bridge 3.82m wide	Orifice and Spill	Y
Drom01.0014	01AHV06734u	Bridge	Arch Bridge and Spill	Y
24AHAV00529D	01AHV06662u	Bridge of 10.65m wide	Two Rectangular Culvert	Y
Drom01.0005	01AHV06583u	Bridge	Orifice and Spill	Y
24AHAV00487D	01AHV06196u	Bridge 2.71m wide	Arch Bridge and Spill	Y
24AHAV00483D	01AHV06154u	Bridge 4.39m wide	Arch Bridge and Spill	Y
24AHAV00477D	01AHV06095u	Bridge 7.9m wide	Rectangular Culvert and Spill	Y
24AHAV00474W	01AHV06070u	Weir	Inline Spill for river channel and spill for floodplain	Y
24AHAV00472W	01AHV06048u	Weir	Inline Spill for river channel and spill for floodplain	Y
24AHAV00470D	01AHV06032u	Bridge 6.49m wide	Sprung Arch Culvert and Spill	Y
24AHAV00439D	01AHV05721u	Bridge 8.64m wide	Two rectangular Culverts and Spill	Y
24AHAV00337D	01AHV04512u	Bridge 9.72m wide	Sprung Arch and Culvert	Y
24AHAV00320D	01AHV04256u	Bridge 4.67m wide	Arch Bridge and Spill	Y
24AHAV00013D	01AHV00119u	Bridge 3.63m wide	Arch Bridge and Spill	Y

Schedule A.2 - Structure Schedule for River Deel

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEL05064E	09DEL00012u	Bridge 7.51m wide	Arch Bridge and Spill	Y
24DEEL04734E	07DEL05017u	Bridge 8.23m wide	Arch Bridge and Spill	Y
24DEEL04561W	07DEL03123	Weir	Round Nose Weir and Spill for Floodplain	Y
24DEEL04490D	07DEL02322u	Bridge 7.86m wide	Arch Bridge and Spill	Y
24DEEL04244W	07DEL00027	Weir	Round Nose Weir and Spill for Floodplain	Y
24DEEL04101D	06DEL03334u	Bridge 10.3m wide	Arch Bridge and Spill	Y
24DEEL04083W	06DEL03146	Weir	Round Nose Weir and Spill for Floodplain	Y
24DEEL03908W	06DEL01214	Weir	Round Nose Weir and Spill for Floodplain	Y

Schedule A.3 - Structure Schedule for River Upper Ballyhane

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEK00015I	01MLF00141u	Culvert 12.23m wide	Sprung Arch Culvert and Spill	Y
24DEEK00011D	01MLF00103u	Bridge 7.63m wide	Sprung Arch Culvert and Spill	Y

Schedule A.4 - Structure Schedule for River Gardenfield South

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEH00069I	01DRO00694u	Culvert 5.11m wide	Orifice and Spill	Y
24DEEH00068D	01DRO00682u	Bridge 10.6m wide	Arch Bridge and Spill	Y
24DEEH00044D	01DRO00433	Bridge 5.14m wide	Arch Bridge and Spill	Y
24DEEH00022D	01DRO00207u	Bridge 5.33m wide	Circular Culvert and Spill	Y
24DEEH00004I	01DRO00027u	Bridge 16.7m wide	Circular Culvert and Spill	Y

Schedule B.1 – Manning's 'n' for HPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
Ahavarragh Stream	01AHV08190 to 01AHV06771	0.055	Determined on a case by case basis using photos, videos and survey drawings	1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
	01AHV06756 to 01AHV06376	0.035		
	01AHV06255 to 01AHV06204	0.038		
	01AHV06196u to 01AHV06095u	0.036		
	01AHV06087d to 01AHV06039	0.030		
	01AHV06032u to 01AHV05625	0.40		
River Deel	09DEL00600 to 07DEL07430	0.05		
Deel K (MLF)	01MLF00279 to 01MLF00000u	0.050		
Deel H (DRO)	01DRO001050 to 01DRO00000	0.050		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Schedule B.2 – Manning's 'n' for MPW Network

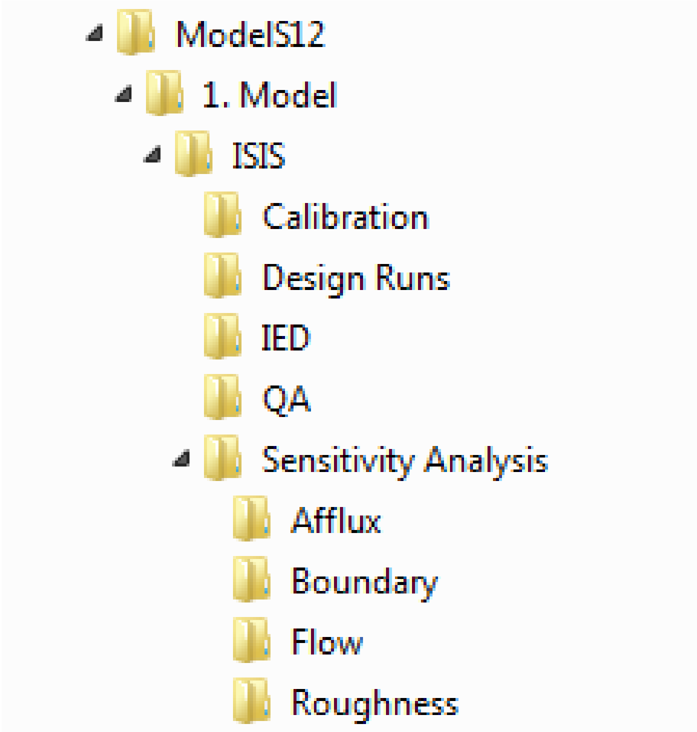
River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
Ahavarragh Stream	01AHV05521 to 01AHV00000	0.05	Determined on a case by case basis using photos, videos and survey drawing	Land use EPA data has been used for assigning the floodplain roughness.
River Deel	07DEL07326 to 06DEL00000	0.05		

Annex C - Model Calibration Summary Note

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report. It should be noted that it was not possible to calibrate this model for any flood event. This was due to insufficient flow data upstream of Danganbeg Gauging Station. Although the Ahavarragh tributary within this model area has a gauging station at Dromcolliher, the larger tributary (River Deel) has no continuous recorder data and is therefore essentially ungauged. Calibration locally at Dromcolliher using historic event data was dismissed as the gauging station in Dromcolliher has only been in operation since 2009, and the historic event observations are all from before 2009.

Following this, no historical calibration has been carried out for the AFA.

Annex D - Hydraulic Model Files

<table>
<tr><th colspan="2">Model Files Folders Structure</th></tr>
<tr><td>ISIS</td><td>
</td></tr>
</table>

<table>
<tr><th colspan="2">ISIS Files</th></tr>
<tr><td>Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)</td><td>Calibration Runs

Design Runs – Current Scenario:S12_Q10_Main_Flu_C_Des_Iss1.DAT
S12_Q10_Trib_Flu_C_Des_Iss1.DAT
S12_Q100_Main_Flu_C_Des_Iss1.DAT
S12_Q100_Trib_Flu_C_Des_Iss1.DATS12_Q1000_Main_Flu_C_Des_Iss1.DAT
S12_Q1000_Trib_Flu_C_Des_Iss1.DAT

Sensitivity Runs – Current Scenario
S12_Q100_Main_Flu_C_Sen_AflDe_v1.DAT
S12_Q100_Main_Flu_C_Sen_AflIn_v1.DAT
S12_Q100_Main_Flu_C_Sen_BoDo_v1.DAT
S12_Q100_Main_Flu_C_Sen_BoHlf_v1.DAT
S12_Q100_Trib_Flu_C_Sen_FlIn_v1.DAT
S12_Q100_Trib_Flu_C_Sen_FlDe_v1.DAT
S12_Q100_Main_Flu_C_Sen_FlIn_v1.DAT
S12_Q100_Main_Flu_C_Sen_FlDe_v1.DAT
S12_Q100_Trib_Flu_C_Sen_RoIn_v1.DAT
S12_Q100_Trib_Flu_C_Sen_RoDe_v1.DAT
S12_Q100_Main_Flu_C_Sen_RoIn_v1.DAT
S12_Q100_Main_Flu_C_Sen_RoDe_v1.DAT</td></tr>
</table>

Hydrological Inflow Files	**Design Runs – Current Scenario:** S12_Main_10yr.IED S12_Main_100yr.IED S12_Main_1000yr.IED S12_Trib_10yr.IED S12_Trib_100yr.IED S12_Trib_1000yr.IED **Sensitivity Runs – Current Scenario** S12_Main_100yr_FlDe.IED S12_Main_100yr_FlIn.IED S12_Trib_100yr_FlDe.IED S12_Trib_100yr_FlIn.IED

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs – Current scenario						
1	S12_Q10_Main_Flu_C_Des_Iss1.DAT	0	16	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
2	S12_Q10_Trib_Flu_C_Des_Iss1.DAT	0	40	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
3	S12_Q100_Main_Flu_C_Des_Iss1.DAT	0	16	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
4	S12_Q100_Trib_Flu_C_Des_Iss1.DAT	0	40	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
5	S12_Q1000_Main_Flu_C_Des_Iss1.DAT	0	16	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
6	S12_Q1000_Trib_Flu_C_Des_Iss1.DAT	0	40	1s	"Automated Preissmann Slot for River Sections" is checked, "maxitr" value is set to 13, ISIS Flow Engine Version "Double Precision" is checked.	Convergence within manufacturer tolerance.
Sensitivity Analysis						
7	S12_Q100_Trib_Flu_C_Sen_RoDe_v1.DAT	0	40	1s	The roughness decreased by 20% in the Tributary model. Preissmann slot increased from 1m to 1.2m deep	Convergence within manufacturer tolerance.
8	S12_Q100_Trib_Flu_C_Sen_RoIn_v1.DAT	0	40	1s	The roughness increased by 20% in the Tributary model. Preissmann slot increased from 1m to 1.3m deep	Convergence within manufacturer tolerance.
9	S12_Q100_Main_Flu_C_Sen_RoDe_v1.DAT	0	16	1s	The roughness decreased by 20% in the Main model. Preissmann slot increased from 1m to 1.1m deep	Convergence within manufacturer tolerance.

10	S12_Q100_Main_Flu_C_Sen_RoIn_v1.DAT	0	16	1s	The roughness increased by 20% in the Main model. Preissmann slot increased from 1m to 1.3m deep	Convergence within manufacturer tolerance.
11	S12_Q100_Trib_Flu_C_Sen_FlDe_v1.DAT	0	40	1s	The flow decreased by 20% in the Tributary model	Convergence within manufacturer tolerance.
12	S12_Q100_Trib_Flu_C_Sen_FlIn_v1.DAT	0	40	1s	The flow increased by 20% in the Tributary model	Convergence within manufacturer tolerance.
13	S12_Q100_Main_Flu_C_Sen_FlDe_v1.DAT	0	16	1s	The flow decreased by 20% in the Main stream model	Convergence within manufacturer tolerance.
14	S12_Q100_Main_Flu_C_Sen_FlIn_v1.DAT	0	16	1s	The flow increased by 20% in the Main stream model	Convergence within manufacturer tolerance.
15	S12_Q100_Main_Flu_C_Sen_BoDo_v1.DAT	0	16	1s	The slope at the downstream boundary was doubled.	Convergence within manufacturer tolerance.
16	S12_Q100_Main_Flu_C_Sen_BoHlf_v1.DAT	0	16	1s	The slope at the downstream boundary was halved.	Convergence within manufacturer tolerance.
17	S12_Q100_Main_Flu_C_Sen_AflDe_v1.DAT	0	16	1s	The orifice discharge coefficient is changed from 1 to 0.8 in weir (ISIS node label 09DEL00012bu)	Convergence within manufacturer tolerance.
18	S12_Q100_Main_Flu_C_Sen_AflIn_v1.DAT	0	16	1s	The orifice discharge coefficient is changed from 1 to 1.2 in weir (ISIS node label 09DEL00012bu)	Convergence within manufacturer tolerance.

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 13 to improve model stability.*
Flow Engine Version “Double Precision” is checked	Used to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

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Appendix C Fluvial/Coastal Hydraulic Model Appendices

Fluvial and Coastal Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S05
Unit of Management	24
AFA included in the Model	Ballylongford
Primary Watercourses / Water Bodies	River Ballyline River Rusheen Park River Lower Aghanagran River Lislaughtin River Well Tributary River Ballyline East River Ballyline West
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A4.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B1 – Figure B1.1

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k OS1014D & OS0814D
2.2 DTM for 2D Model Domains:	**Within AFA:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFA: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 110
2.4 Defence Asset Survey Data	There are no defences within the S05 model area.
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:**	ISIS Version 3.6.0.156
	2D Domain(s):	TUFLOW Version: 2012-05-AE-iSP-w32
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.	

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary
2. **Maps showing a detailed model schematic of the HPW reached are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
River Ballyline	BALY03	BALY03_2740	BALY03_2142u
	BALY02	BALY02_2142d	BALY02_0000
	BALY01	BALY01_2017	BALY01_0000
River Rusheen Park	AGHA01	AGHA01_0436	AGHA01_0000U
River Lover Aghanagran	AGHA02	AGHA02_0261	AGHA02_0000
River Lislaughtin	LISL01	LISL01_0423	LISL01_0000U
River Well Tributary	WELL01	WELL01_0298	WELL01_0000U
River Ballyline East	BALM01	BALM01_0358D	BALM01_0000U
	BALM02	BALM02_0315	BALM02_0000U
River Ballyline West	BALM03	BALM03_0512	BALM03_0000U
Total model HPW length (km):	7.5	**Total model MPW length (km):**	0

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	4
Bridges:	☒	How many?	3
Fixed crest weirs:	☐	How many?	0
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation	All reaches have been modelled using 1D – 2D approach except at the downstream extent of the model where a 1D approach was deemed appropriate. Out-of-bank areas for the tributaries and the upstream extent of the River Ballyline have been modelled using a 2D approach using TuFLOW. Out-of-bank areas of the downstream extent of the River Ballyline have been modelled following a 1D approach using ISIS and by extending the river channel cross-sections in the model. Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple (e.g., parallel to river flow). 1D-2D modelling is required where HPWs flow through urban areas and out-of-bank flows will form complex flow paths. An overview of the floodplain schematisation is available in the maps shown in Annex A.
3.6 2D Domain Grid Size:	The number of 2D domains defined and the grid sizes of each 2D model domain are as follows: **Number of 2D domains: 1** **Domain 1:** Ballylongford — Grid cell size (m): 5 — Area (km^2): 1.34 2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.
3.7 Model Breaklines in the 2D Domain:	Bank tops and bridge parapets are represented as breaklines in the 2D domain.
3.8 Floodplain Structures in the 2D Domain	No floodplain structures have been included in the 2D model as no structures exist.
3.9 Hydraulic Roughness	Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:
HPW in-bank	Minimum 'n' value: 0.020 Maximum 'n' value: 0.060
Floodplain (ISIS mMdel)	Manning's 'n' for out-of-bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:

Land Use	Manning's 'n' Value
Pastures	0.035
Dense Vegetation	0.080
Road Network	0.025
Buildings	0.100

Floodplain (TUFLOW Model)	Manning's 'n' for out-of-bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:

Land Use	Manning's 'n' Value
Buildings	0.100
Short grass, parks	0.035
General Urban	0.060
General Rural	0.045
Dense Vegetation	0.080
Roads	0.025
Railways	0.050
Water bodies	0.020

3.10 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.
3.11 Model Boundaries – Fluvial Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report relevant to Unit of Management 24. Peak inflows (m^3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2)
(a) Current Situation (Main Model Run)	Peak inflows (m3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2)

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1193_1	BALY03_2740	13.0	17.2	20.0	22.7	26.2	28.8	31.4	37.4
24_1195_3e	BALY02_2142d	1.3	1.7	2.0	2.3	2.6	2.9	3.1	3.7
24_1169_1a	WELL01_0298	1.3	1.7	2.0	2.3	2.6	2.9	3.1	3.7
24_1187_3	LISL01_0423	1.9	2.5	2.9	3.2	3.7	4.1	4.5	5.3
24_1024_3	AGHA01_0436	2.3	3.1	3.6	4.1	4.7	5.1	5.6	6.7

(a) Current Situation (Tributary Model Run)

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1195_3	BALM03_0512	1.7	2.2	2.6	3.0	3.4	3.8	4.1	4.9
24_1195_3b	BALM02_0315	2.3	3.0	3.5	3.9	4.5	5.0	5.4	6.5

(b) Future Scenarios (Main Model Run)	The peak inflows (m³/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.

HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5 %**	**0.1%**
24_1193_1	BALY03_2740	15.6	20.6	24.0	27.2	31.4	34.5	37.6	44.8
24_1195_3e	BALY02_2142d	1.5	2.1	2.4	2.7	3.1	3.4	3.7	4.4
24_1169_1a	WELL01_0298	1.5	2.1	2.4	2.7	3.1	3.4	3.7	4.4
24_1187_3	LISL01_0423	2.2	3.0	3.4	3.9	4.5	4.9	5.4	6.4
24_1024_3	AGHA01_0436	2.8	3.7	4.3	4.9	5.6	6.2	6.7	8.0

(a) Future Scenarios (Tributary Model Run)

HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
24_1195_3	BALM03_0512	2.0	2.7	3.1	3.6	4.1	4.5	4.9	5.9
24_1195_3b	BALM02_0315	2.7	3.6	4.2	4.7	5.4	6.0	6.5	7.8

(b) Future Scenarios (Main Model Run)	The peak inflows (m³/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.

HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
24_1193_1	BALY03_2740	26.0	37.4	48.6
24_1195_3e	BALY02_2142d	2.6	3.7	4.8
24_1169_1a	WELL01_0298	2.6	3.7	4.8
24_1187_3	LISL01_0423	3.7	5.3	6.9
24_1024_3	AGHA01_0436	4.6	6.7	8.7

(b) Future Scenarios (Tributary Model Run)

HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
24_1195_3	BALM03_0512	3.4	4.9	6.3
24_1195_3b	BALM02_0315	4.5	6.5	8.4

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:
	Tidal level hydrographs at the outlet of the River Ballyline were produced for a series of design events using the Irish Coastal Protection Strategy Study (ICPSS) extreme tidal peak levels data. The time series were set up as boundary conditions for the ISIS hydraulic model. Full details of how these tidal level hydrographs were derived are provided in Appendix D of the main Hydraulics Report. Peak tidal levels are summarised in the table below for the current and future situations.

	Current Annual Exceedance Probability							
Peak Tidal Levels (mOD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	2.79	2.91	3.00	3.09	3.20	3.29	3.37	3.57
	MRFS Annual Exceedance Probability							
Peak Tidal Levels (mOD)	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**
	3.3	3.5	3.6	3.6	3.8	3.8	3.9	4.1

	HEFS Annual Exceedance Probability		
Peak Tidal Levels (mOD)	**10%**	**0.5%**	**0.1%**
	4.1	4.4	4.6

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F). The results of this analysis concluded that no calibration or verification could be performed within the modelled area. A broad verification was possible using anecdotal evidence from the January and February 2014 events. This is outlined in greater detail in Annex C.

4.2 Calibration to HEP

Calibration of the hydraulic model to the HEP target flows has been carried out for all design events simulated. Section 2.7.2 of the Hydrology Report for UoM24 provides a summary of the calibration to HEP process. This exercise was carried out at normal depth boundary at the downstream extent. Only fluvial flows were modelled for this exercise and it was carried out on the tributaries and the main model.

Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincide with the peak time of the propagating flood wave as it is routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Modelled total peak flows at most HEP locations were found to be within ±10% of the HEP target flows.

At HEP 24_1024_4 the difference between the modelled peak flow and the target flow was greater than 10% for the 10% AEP event. This percentage difference equates to flow of 0.5m^3/s. This difference in flow has been considered negligible and no additional flow was added.

At HEP 24_1195_3d the difference between the modelled peak flow and the target flow was greater than 10% for the 1% and 0.1% AEP event. This HEP is located at the downstream extent of the Ballylline West tributary. There is some bypassing of flow at this location. Modelled peak flow at the HEP point 24_1195_3e further downstream is within tolerance. Topping up of flow upstream of 24_1195_3d would have a negative impact of the difference between the modelled peak flow and the HEP target flow at 24_1195_3e. Therefore no additional flow was added upstream of 24_1195_3d.

The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: -1.5%, 1.63%, 2.69% for the 10%, 1% and 0.1% AEP events respectively.

HEP Reference Name	Node in the Hydraulic Model	Annual Exceedance Probability							
		Percentage Difference (%)							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1193_1	BALY03_2740	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1194_2	BALY02_2060	3.4	2.6	2.3	2.0	1.9	1.7	1.7	1.8
24_1169_1a	WELL01_0298	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1169_1b	WELL01_0000u	0.0	0.1	-0.2	0.3	0.0	-0.1	0.4	1.3
24_1187_3	LISL01_0423	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1187_4	LISL01_0000u	0.0	0.3	0.2	0.4	0.0	0.4	0.2	-0.1

24_1024_3	AGHA01_0436	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1024_4	AGHA01_0000u	2.0	8.0	13.9	11.9	8.5	5.9	5	9.1
24_1195_3	BALM03_0512	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1195_3b	BALM02_0315	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1195_3c	BALM02_0000u	0.1	0.2	0.1	-0.2	0.2	0.1	0.2	0.0
24_1195_3d	BALM03_0040	-0.1	2	4.1	15	31.1	-27.6	-33.2	-43.0
24_1195_3e	BALM01_0025	-0.5	-0.3	-0.1	0.4	-0.6	-1.7	-3.0	-5.1

4.3 Fluvial and Tidal Events Simulated

The River Ballyline is influenced by the tidal levels along the Shannon Estuary. As such, a joint probability analysis of the coincidence of fluvial flood flows and coastal flood levels was carried out to determine the appropriate combination of flows and sea levels to be used for the design probability events, as required under Section 6.5.6 of the Stage 1 Project Brief.

Methodology and outcomes of this analysis are detailed in the main Hydraulic Report and the Hydrology Report. A summary of the joint probability of fluvial and tidal conditions used for the hydraulic modelling in the Ballylongford AFA is reported in the table overleaf.

Combination of Fluvial and Tidal Events

	Joint Probability Design Event	**AEP adopted for Fluvial Flows and Tidal Levels**	
Scenario	**Overall AEP**	**Fluvial**	**Tidal**
1	50%	50%	500%
2	50%	50%	50%
3	20%	20%	500%
4	20%	50%	20%
5	10%	10%	200%
6	10%	50%	10%
7	5%	5%	100%
8	5%	50%	5%
9	2%	2%	50%
10	2%	50%	2%
11	1%	1%	20%
12	1%	20%	1%
13	0.5%	0.5%	10%
14	0.5%	10%	0.5%
15	0.1%	0.1%	2%
16	0.1%	2%	0.1%

4.4 Model Sensitivity	Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. The sensitivity runs were carried out for the 1% AEP fluvial dominated event with the corresponding tidal event from the joint probability study in all cases with the only exception of the tests on the downstream boundary conditions, which were carried out for the 0.5% AEP tidal dominated events with the corresponding fluvial event. (see Section 4.3) Sensitivity test results are provided in the following tables. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work.

+20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section / Reach where the Maximum Difference occurs
River Ballyline	0.01	0.21	BALY03_2740
River Rusheen Park	-0.01	0.02	AGHA01_0436
River Lower Aghanagran	-0.01	-0.01	AGHA2_0123c2
River Lislaughtin	0.02	0.13	LISL01_0423
River Well Tributary	0.02	0.09	WELL01_0177
River Ballyline East	0.05	0.15	BALM01_0205
River Ballyline West	0.06	0.09	BALM03_0296

-20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
River Ballyline	-0.01	-0.26	BALY03_2740
River Rusheen Park	0.01	0.03	AGHA01_0199u
River Lower Aghanagran	0.02	0.02	AGHA2_0139c1
River Lislaughtin	-0.02	-0.15	LISL01_0423
River Well Tributary	0.07	0.16	WELL01_0127
River Ballyline East	-0.07	-0.21	BALM01_0205
River Ballyline West	-0.07	-0.10	BALM03_0296

+20% inflows	Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
	River Ballyline	0.021	0.193	BALY03_2740
	River Rusheen Park	0.004	0.014	AGHA01_0436
	River Lower Aghanagran	0.006	0.010	AGHA02_0198
	River Lislaughtin	0.030	0.134	LISL01_0423
	River Well Tributary	0.025	0.069	WELL01_0177
	River Ballyline East	0.050	0.109	BALM01_0263
	River Ballyline West	0.070	0.094	BALM03_0362
-20% inflows	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section where the Maximum Difference occurs**
	River Ballyline	-0.018	-0.155	BALY03_2740
	River Rusheen Park	-0.005	-0.016	AGHA01_0436
	River Lower Aghanagran	-0.004	-0.007	AGHA2_0261sd
	River Lislaughtin	-0.032	-0.147	LISL01_0423
	River Well Tributary	-0.015	-0.080	WELL01_0177
	River Ballyline East	-0.073	-0.173	BALM01_0263
	River Ballyline West	-0.081	-0.101	BALM03_0362
Afflux at Key Structure	No structures were identified with significant afflux within the AFA.			
Downstream Conditions Duration of surge component of tidal boundary is increased by 100%	The change to the downstream conditions causes increase in peak stage of between 0.001 m and 0.005m. This is considered to be a negligible increase.			
Downstream Conditions Duration of surge component of tidal boundary is decreased by 50%	The change to the downstream conditions causes decrease in peak stage of between -0.002 m and -0.001m. This is considered to be a negligible decrease.			
4.5 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D			

5. Hydraulic Model Outputs	
5.1 Mapping	Model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard All of the maps contain the maximum extent, depth, velocity and flood hazard for the combined main stream inflows and the tributaries inflows. An explanation for the main stream inflows and the tributaries inflows is provided in Section 6. Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP fluvial dominated flood events with the corresponding tidal boundary conditions and to the defended current scenario for the 10%, 0.5% and 0.1% AEP tidal dominated events with the corresponding fluvial events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

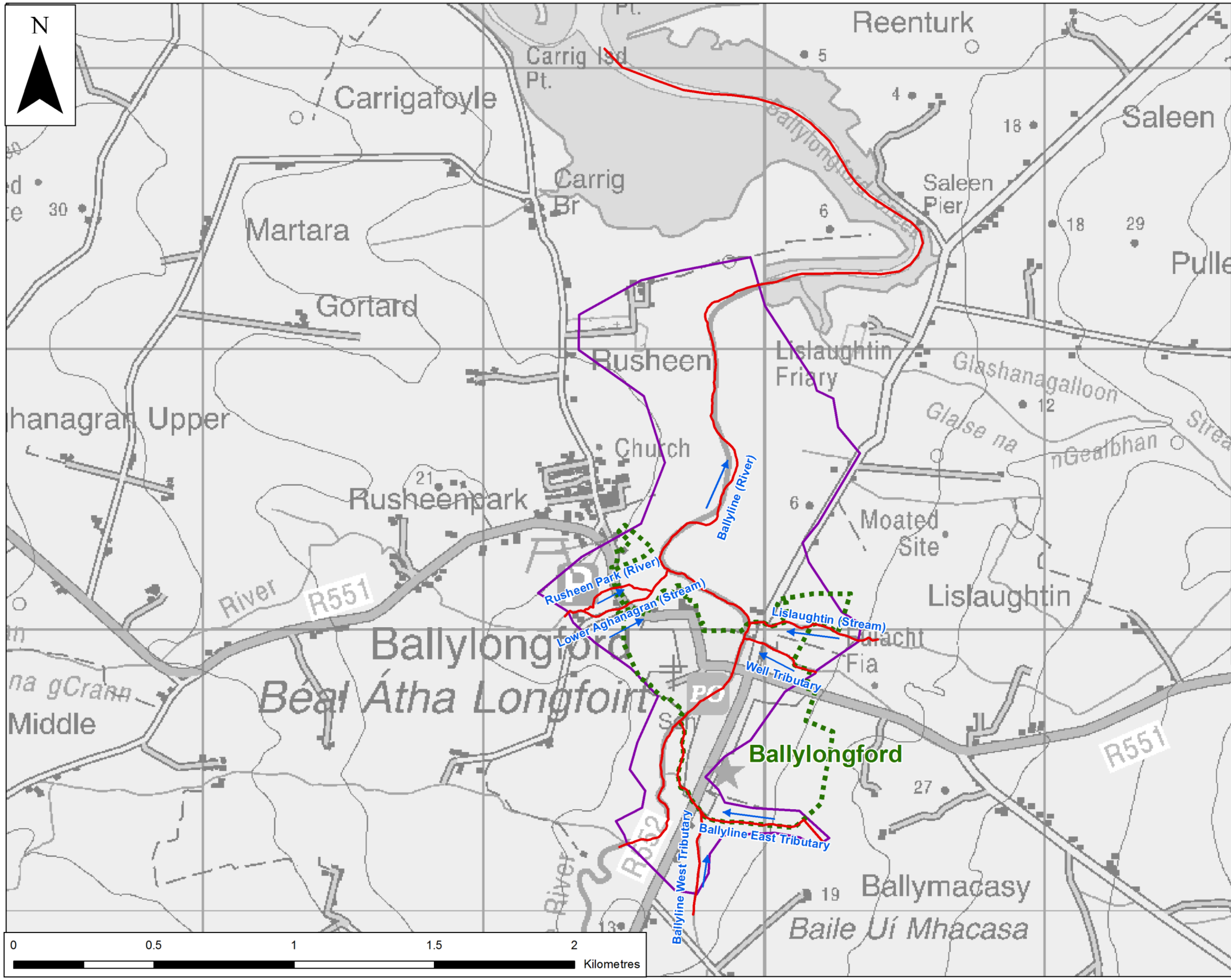
- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and some of its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. Inflow hydrographs were purposely produced for two model runs. The first run, the main model run, contains inflows for the River Ballyline, River Lower Aghanagran, River Rusheen Park, River Lislaughtin and the River Well Tributary. The second run, the tributary model run, contains inflows for only the Ballyline West Tributary and Ballylin East Tributary. The main model and tributary model share exactly the same geometry (structures and topography). The model outputs from all models were then merged picking up the maximum flood depths and extents to create the flood maps.

- Tidal level hydrographs at the downstream boundary of the model have been adjusted in time so that the highest tidal level coincides with the fluvial peak flow at the downstream extent of the model.

- Due to the absence of hydrometric data, hydraulic calibration of model S05 was not possible.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent



Legend

- 2D Model Boundary
- AFA Boundary

Model Reaches

- HPW
- MPW

Model: S05

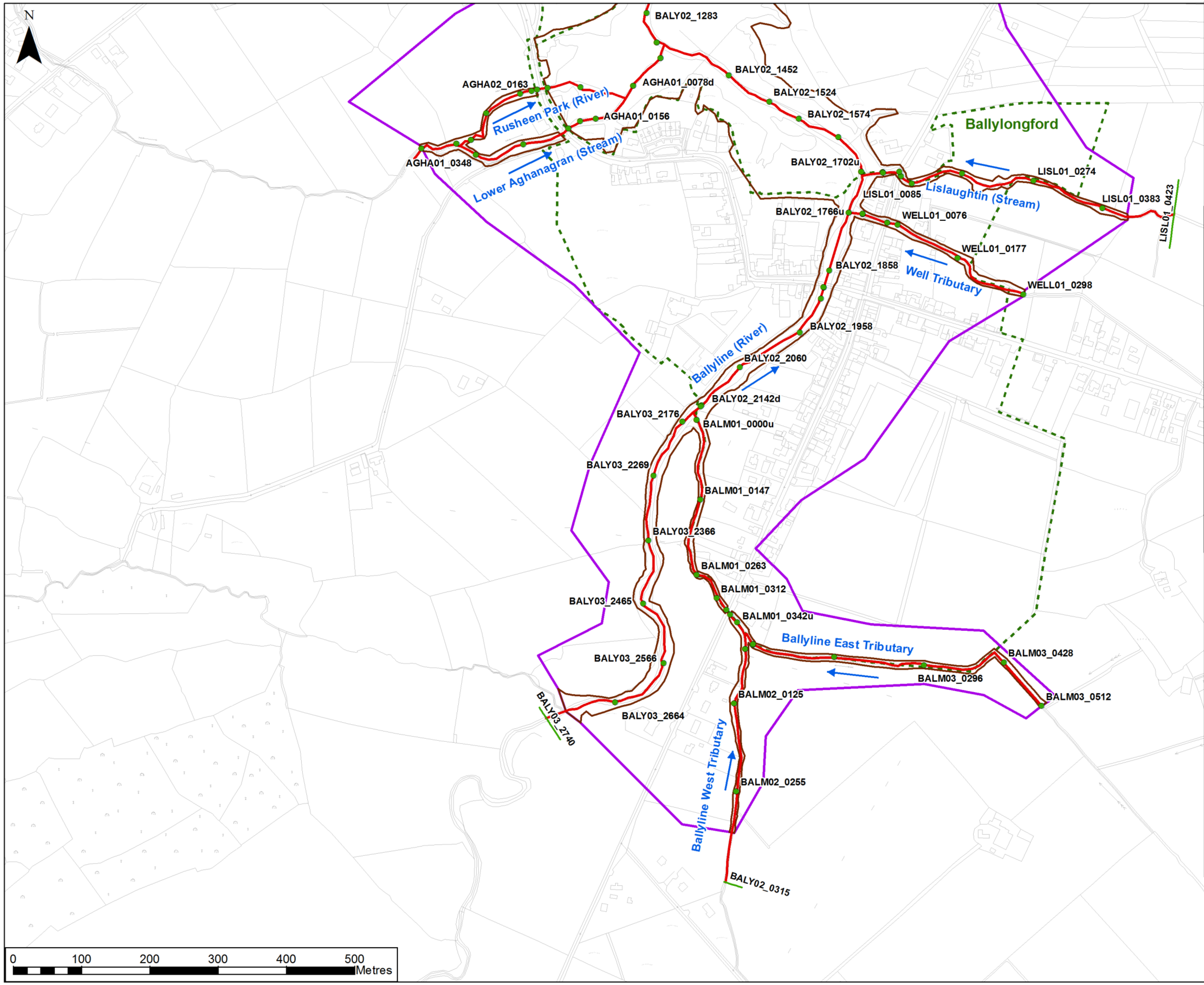
Figure ref: Annex A1

Drawing Title: S05 Model Extent

Annex A2 – Model Schematisation

OPW

JACOBS



Legend

2D Model Boundary

AFA Boundary

Banktop

Cross-section Nodes

Model Reaches

HPW

MPW

1D Floodplain Schematisation

Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

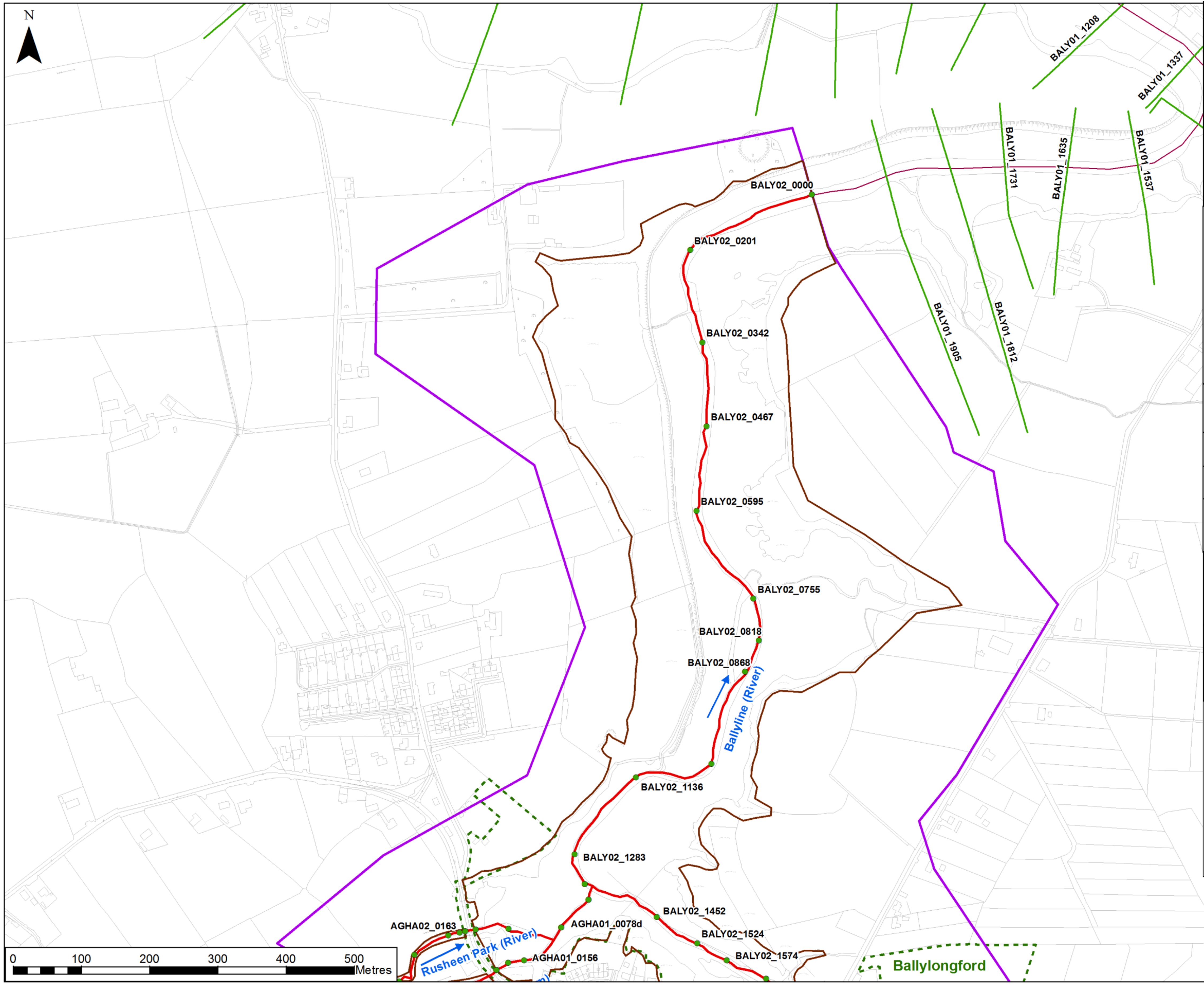
Model: S05

Figure ref: Annex A2 (1)

Drawing Title: S05 Model Schematisation

Client: OPW The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath Tel: 046 942 6000 Fax: 046 948 1793 www.opw.ie

Contractor: JACOBS Merrion House, Merrion Road, Dublin Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497 www.jacobs.com



Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes

Model Reaches

- HPW
- MPW

1D Floodplain Schematisation

- Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

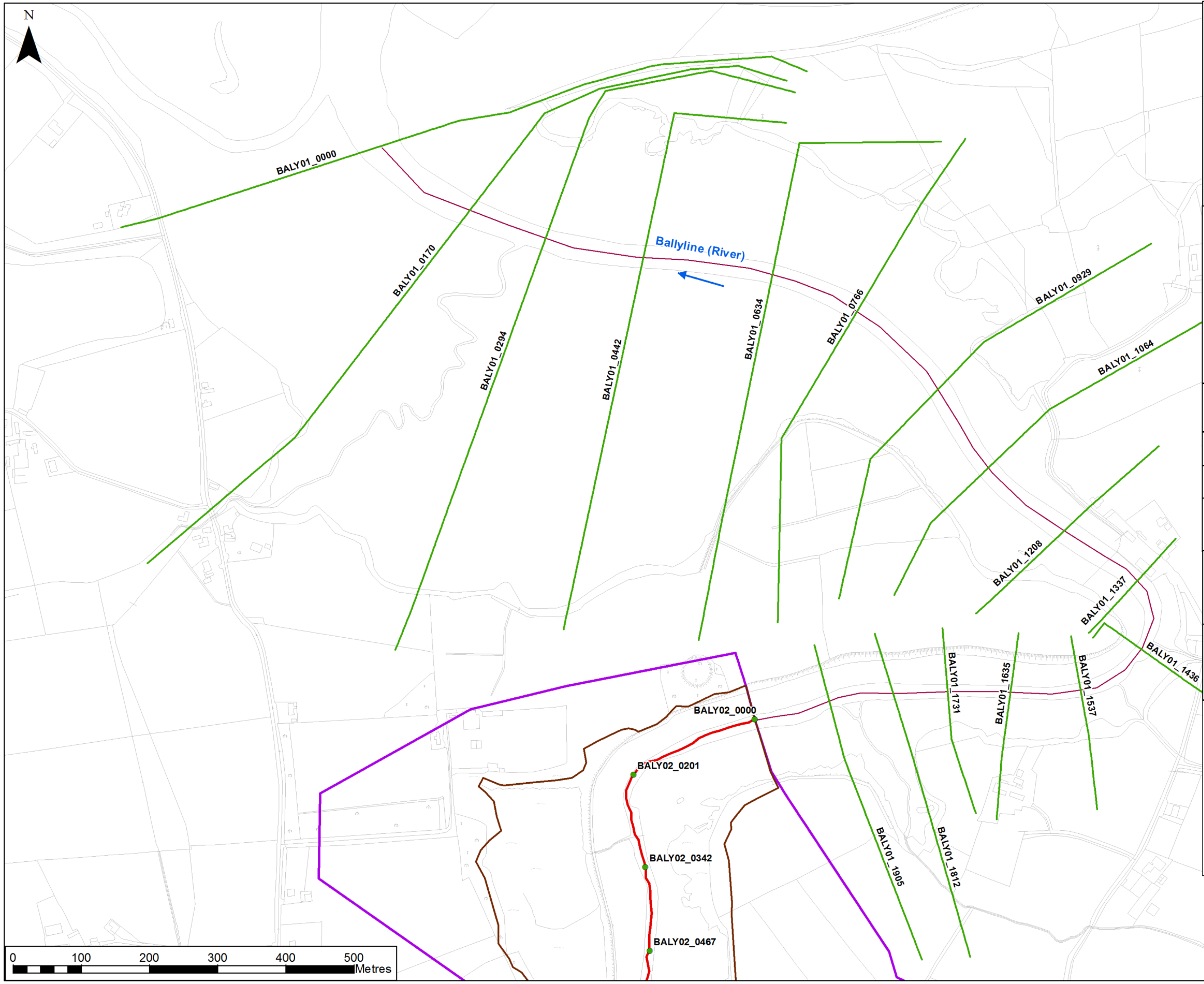
Model: S05

Figure ref: Annex A2 (2)

Drawing Title: S05 Model Schematisation

Client:
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie

Contractor:
JACOBS
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com



Legend
- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes

Model Reaches
- HPW
- MPW

1D Floodplain Schematisation
- Cross-section Extents

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S05

Figure ref: Annex A2 (3)

Drawing Title: S05 Model Schematisation

Client:
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie

Contractor:
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com

Legal Disclaimer
This drawing is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and Jacobs Engineering Ireland Limited.

Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for River Ballyline

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
BL 5/BL 6	BALY01_1883u	Bridge	USBPR bridge with spill	Y

Schedule A.2 - Structure Schedule for River Rusheen Park

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
RUSP4/RUSP5	AGHA01_1100u	Arch Bridge	Arch Bridge with spill	N***
RUSP19	AGHA01_0199u	Arch Bridge	Arch Bridge with spill	Y

Schedule A.3 - Structure Schedule for River Lower Aghanagran

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
RUSP N5D	AGHA02_0139c 1	Culvert	Rectangular culvert with spill	Y

Schedule A.4 - Structure Schedule for River Lislaughtin

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
LIS3/LIS4	LS01_1041ou	0.9m Circular Culvert	Orifice + Spill	N***
LIS9/LIS10	LS01_0765ou	Box Culvert	Orifice + Spill	N***
LIS18A/LIS18B	LS01_0069c1	Twin Box Culvert	Twin Rectangular Culvert + Spill	Y

Schedule A.5 - Structure Schedule for River Well Tributary

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
WELL_BRG1_U/ WELL_BRG1_D	WL01_0840ou	0.5m circular culvert	Orifice unit + spill	N***
WELL_BRG2_U	WL01_0796c	0.8m circular culvert	Circular unit + spill	N***

WELL_BRG3_U/ WELL_BRG3_D	WL01_0491c1	0.6m twin circular culverts	Circular units + spill	N***
WELL_BRG4_U/ WELL_BRG4_D	WL01_0352ou	0.6m circular culvert	Orifice unit + spill	N***
WELL_BRG5_U/ WELL_BRG5_D	WL01_0315ou	0.8m circular culvert	Orifice unit + spill	N***
WELL_BRG7_U	WL01_0059c	Arch culvert	Symmetrical culvert + spill	Y

Schedule A.6 - Structure Schedule for River Ballyline East

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
BL_E_TR4/5	BM02_0600c	Box culvert under road	Rectangular culvert +spill	N***
BL_E2/3	BM01_0342c1	Arch Bridge with flood relief culvert	In parallel, circular culvert + sprung arch culvert + spill on top	Y

*** Considering the size of the structure relative to the watercourse it was determined that the structure would have little or no hydraulic impact on the model.**
**** Structure will not be hydraulically significant during peak flood flows.**
***** Structure outside of model extent.**

Schedule B.1 – Manning's n for HPW Network

<table>
<tr><th>River Name</th><th>ISIS Node Reference</th><th>In-bank Roughness*</th><th>Bank-side Roughness*</th><th>Estimated Floodplain Roughness</th></tr>
<tr><td rowspan="4">River Ballyline</td><td>BALY03_2740 – BALY03_2176</td><td>0.035</td><td>0.06</td><td rowspan="15"><u>2d Domain</u> : based on OSi NTF land use polygons</td></tr>
<tr><td>BALY03_2142u - BALY03_2142u</td><td>0.03</td><td>0.06</td></tr>
<tr><td>BALY02_2142d – BALY02_1639</td><td>0.03</td><td>0.02</td></tr>
<tr><td>BALY02_1574 – BALY02_0000</td><td>0.02</td><td>0.02</td></tr>
<tr><td>River Rusheen Park</td><td>AGHA01_0436 – AGHA01_0000u</td><td>0.04</td><td>0.06</td></tr>
<tr><td rowspan="2">River Lower Aghanagran</td><td>AGHA02_0261 – AGHA02_0064</td><td>0.06</td><td>0.06</td></tr>
<tr><td>AGHA02_0000 - AGHA02_0000</td><td>0.02</td><td>0.02</td></tr>
<tr><td rowspan="2">River Lislaughtin</td><td>LISL01_0423 – LISL01_0069u</td><td>0.04</td><td>0.06</td></tr>
<tr><td>LISL01_0059d – LISL01_0000u</td><td>0.035</td><td>0.035</td></tr>
<tr><td rowspan="3">River Well Tributary</td><td>WELL01_0298 – WELL01_0177</td><td>0.05</td><td>0.05</td></tr>
<tr><td>WELL01_0076 – WELL01_0053d</td><td>0.045</td><td>0.045</td></tr>
<tr><td>WELL01_0022 – WELL01_0000u</td><td>0.03</td><td>0.05</td></tr>
<tr><td rowspan="2">River Ballyline East</td><td>BALM01_0358d – BALM01_0000u</td><td>0.04</td><td>0.06</td></tr>
<tr><td>BALM02_0315 – BALM02_0000u</td><td>0.04</td><td>0.06</td></tr>
<tr><td>River Ballyline West</td><td>BALM03_0512 – BALM03_0000u</td><td>0.04</td><td>0.06</td></tr>
</table>

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections).

Annex C - Model Calibration Summary Note

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F).). The results of this analysis concluded that no calibration or verification could be performed within the modelled area. A broad verification was possible using anecdotal evidence from the January and February 2014 events.

Verification of the model using anecdotal evidence collected after the 3rd of January 2014 and the 1st of February 2014 historical flood event.

A report was compiled by Jacobs Engineering in the wake of two significant flood events in Ballylongford on 3rd of January 2014 and the 1st of February 2014 providing high level verification of the model. In the absence of prior event data this provided confidence in the model. The report identified the source of both flood events to be tidal. Figure C.1 and C.2 below are taken from the Flood event reports and illustrate the location and extent of flooding and the properties affected during these events.

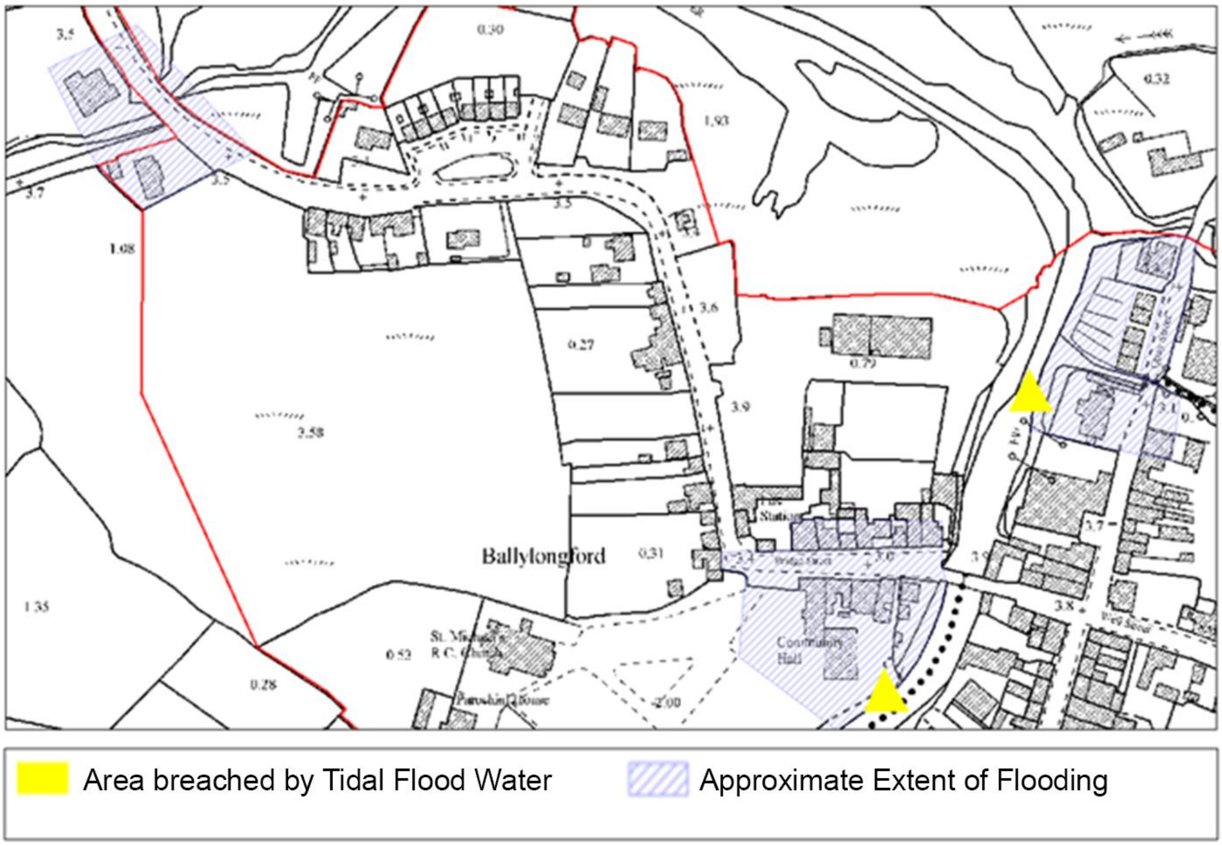


Figure C.1 – Map of Location and Extent of Flooding in Ballylongford on 3rd January 2014.

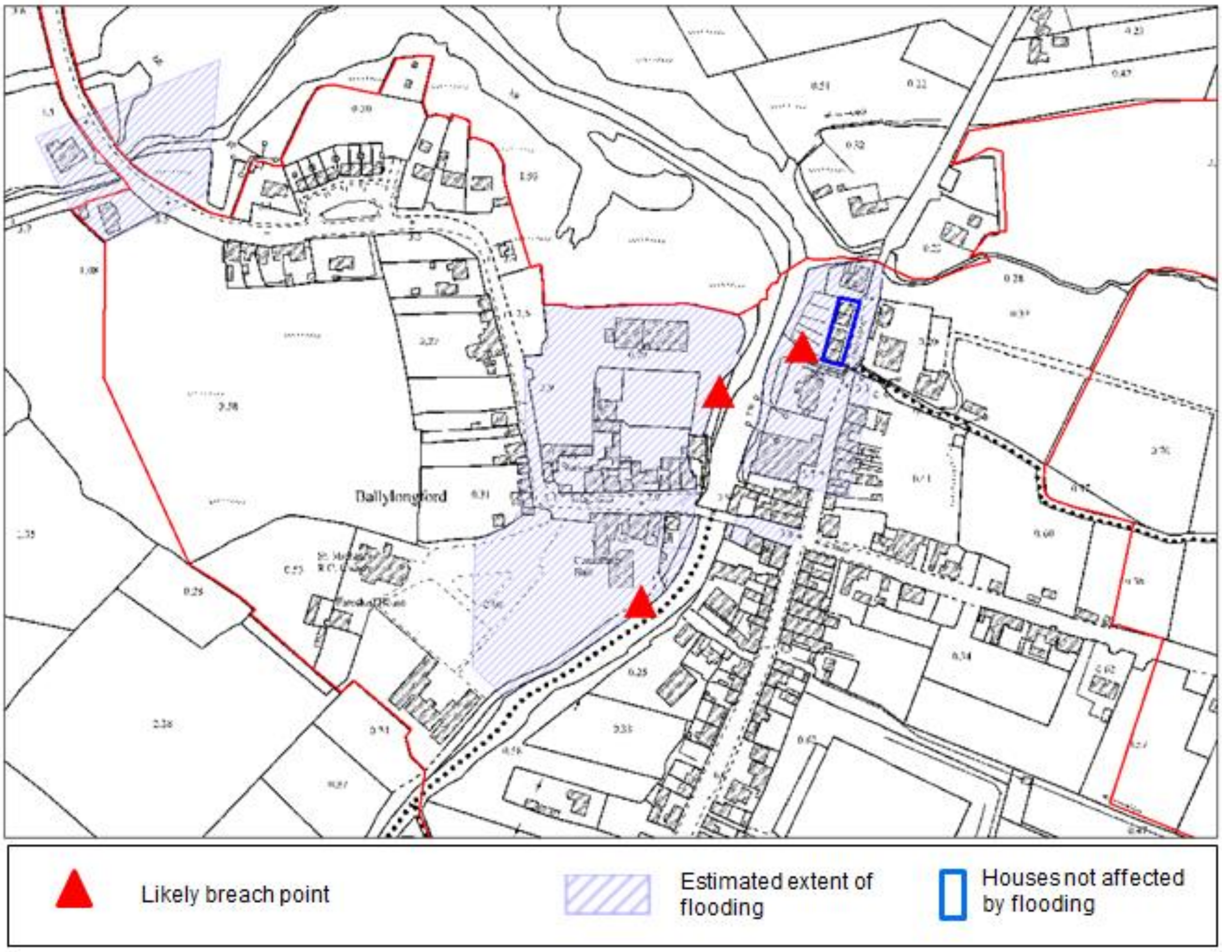


Figure C.2 – Map of Location and Extent of Flooding in Ballylongford on 4th February 2014.

Figure C.3 below show the flood outlines predicted by the model for the 10%, 0.5% and 0.1% tidally dominated AEP events. The properties flooded in the 3rd of January 2014 and the 1st of February 2014 event are included in the 10% tidally dominated AEP indicating that the 2014 events lie somewhere between the 10% AEP event and the 0.5% AEP event.

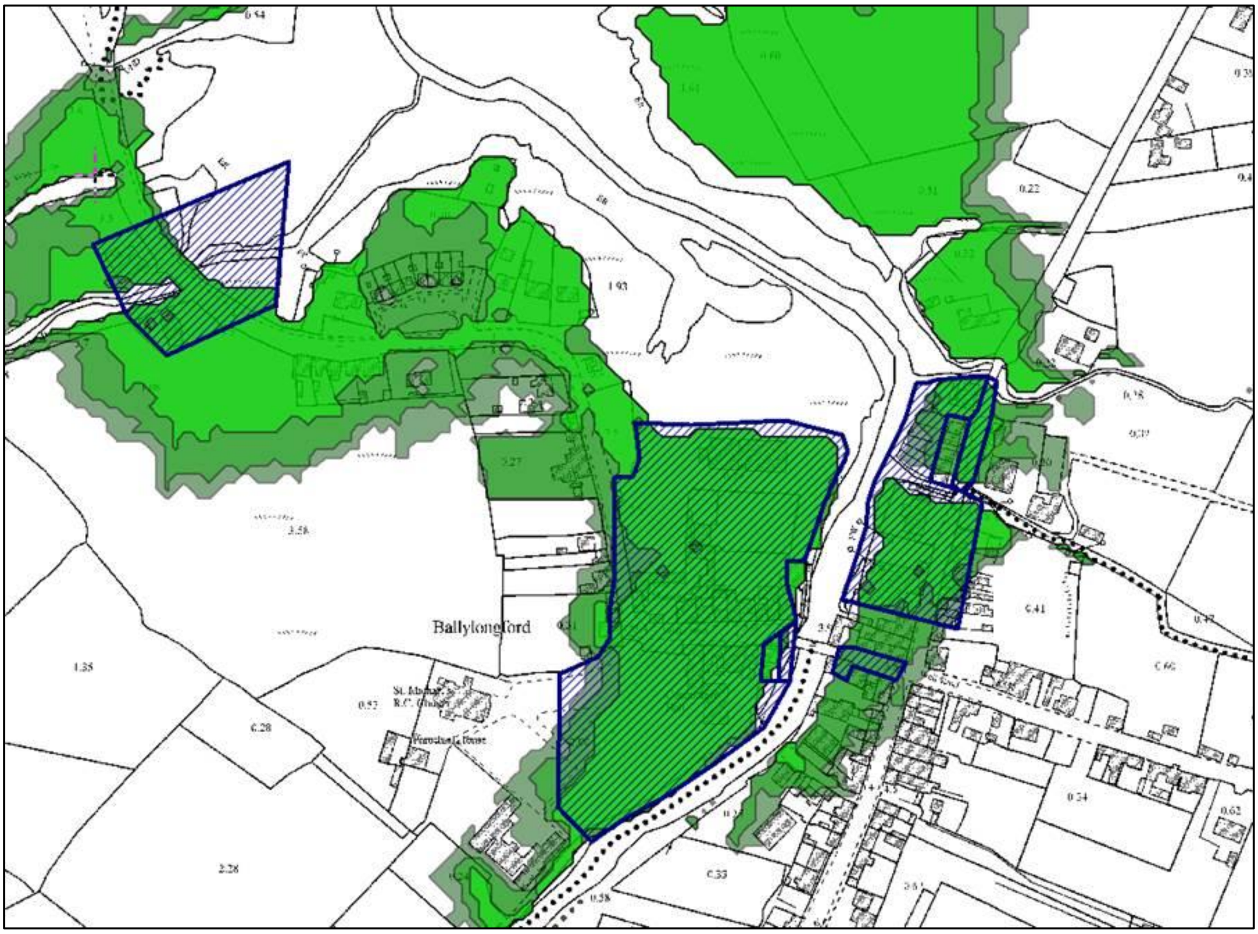
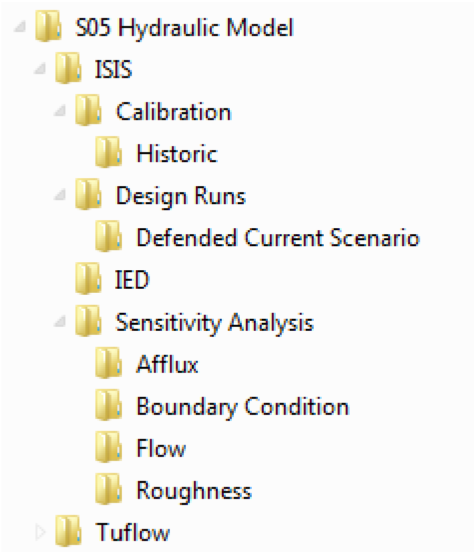


Figure C.3 – Predicted flood extents for the 10%, 0.5% and 0.1% tidally dominated AEP events with the outline indicating properties flooded during the February event.

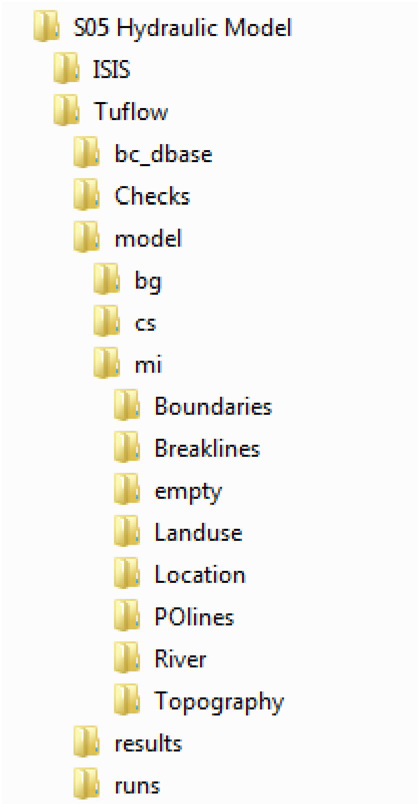
Annex D - Hydraulic Model Files

Model Files Folders Structure

ISIS



TUFLOW



ISIS Files	
Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Design Runs – Fluvial Scenario:** **Main Stream Model** S05_Q1000_FluMi_C_DES_Iss1.DAT S05_Q100_FluMi_C_DES_Iss1.DAT S05_Q10_FluMi_C_DES_Iss1.DAT **Tributary Model** S05_Trib_Q1000_Flu_C_Des_Iss1.DAT S05_ Trib_Q100_Flu_C_Des_Iss1.DAT S05_ Trib_Q10_Flu_C_Des_Iss1.DAT **Design Runs – Tidal Scenario:** S05_Q1000_CoMi_C_DES_Iss1.DAT S05_Q200_CoMi_C_DES_Iss1.DAT S05_Q10_CoMi_C_DES_Iss1.DAT
Hydrological Inflow Files	**Design Runs – Current Fluvial Scenario:** **Main Stream Model** S05_Q1000_FluMi.IED S05_Q100_FluMi.IED S05_Q10_FluMi.IED **Tributary Model** S05_Trib_Q1000_Flu.IED S05_Trib_Q100_Flu.IED S05_ Trib_Q10_Flu.IED **Design Runs – Current Tidal Scenario:** S05_Q1000_CoMi.IED S05_Q200_CoMi.IED S05_Q10_CoMi.IED

TUFLOW Files	
TUFLOW Control Files (.tcf) and Associated Files (e.g.: ecf, tgc, tbc)	**Design Runs – Current Fluvial Scenario:** **Main Model** S05_Q1000_FluMi_C_DES_Iss1.tcf S05_Q100_FluMi_C_DES_Iss1.tcf S05_Q10_FluMi_C_DES_Iss1.tcf **Trib Model** S05_Trib_Q1000_Flu_C_Des_Iss1.tcf S05_Trib_Q100_Flu_C_Des_Iss1.tcf S05_Trib_Q10_Flu_C_Des_Iss1.tcf **Design Runs – Current Tidal Scenario:** S05_Q1000_CoMi_C_DES_Iss1.tcf S05_Q200_CoMi_C_DES_Iss1.tcf S05_Q10_CoMi_C_DES_Iss1.tcf
Grid Orientation File	2d_loc_Bally.MIF
Material Files	2d_mat_Bally.MIF
Zpt Files, Model DTM (.asc)	2d_zpt_5m_Baly.MIF
Breaklines Files	2d_zln_Banktops_LiDAR_Bally.MIF 2d_zln_Banktops_LiDAR_Bally_estuary.MIF 2d_zln_Banktops_Survey_Bally.MIF 2d_zln_BridgeParapets_Bally.MIF
Boundary Files	2d_bc_hxe_Bally.MIF 2d_bc_hxi_ Bally.MIF
Flow/Head Files in bc_dbase	No Flow/Head boundaries provided in 2d domain.
Initial Water Level Files	No IWL files provided in 2D domain
Time Series Files	No time series files provided to the 2d domain.
One Dimensional Network Files	1d_isis_node_Ballylongford_v3.MIF
Available 2D Result Files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs						
1	S05_Q1000_FluMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
3	S05_Q100_FluMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
6	S05_Q10_FluMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary.
9	S05_Q1000_CoMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
10	S05_Q200_CoMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
14	S05_Q10_CoMi_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary.

17	S05_Trib_Q1000_Flu_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
19	S05_ Trib_Q100_Flu_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary
22	S05_ Trib_Q10_Flu_C_Des_Iss1.DAT	-5	40	1	Automated Preissmann slot for River Cross Sections used with width of 0.1m and depth of 1m. Maxitr increased to 26.	Some spikes of poor convergence associated with Tidal Boundary

Parameters changed from Default	**Justification**
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 26 to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Fluvial and Coastal Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S06
Unit of Management	24
AFA included in the Model	Clarina and Adare
Primary Watercourses / Water Bodies	River Maigue Adare River Barnakyle River
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A1.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.2
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B2 – Figure B2.1

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k Reference: OS_1212_D, OS_1214_D, OS_1412_D, OS_1414_D
2.2 DTM for 2D Model Domain:	**Within AFA:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary and wider HPW extents. **MPW reach:** SAR data has been used to inform the hydraulic model with ground elevation in the floodplain areas covered by the downstream MPW reach.
2.3 River Channel/Structures Survey	General information on the topographic survey of the river channel and structures are included in the main Hydraulics Report. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 307
2.4 Defence Asset Survey Data	The defence asset database has been completed for this model area and is provided as a separate deliverable to this report. There is a continuous flood defence (raised embankment) running alongside the left bank of the River Maigue within the modelled extent, providing protection against fluvial and tidal flooding from the River Maigue. The location of the defence is shown in the model schematisation provided in Annex A, and further details of the defence are contained in the defence asset database. The raised embankment on the right bank of the River Maigue is not shown on the model schematisation maps as this defence has a standard of protection of less than 10% AEP.
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D domain:** ISIS Version 3.6.0.156 (64 bit)	
	2D domain(s): TUFLOW Version: 2012-05-AE-iSP-w64	
3.2 Model Area / Extent:	The areal extent of the model and its schematisation are shown in Annex A.	

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary
2. **Maps showing a detailed model schematic of the HPW reaches are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the ISIS model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
Barnakyle River	02BAR	02BAR08103	02BAR00008
Barnakyle River	01BAR	01BAR03237	02BAR00000
River Maigue (upper)	02MGU	02MGU03199	02MGU00093
River Maigue (middle)	01MGU	01MGU15970	01MGU00072d
River Maigue (lower)	00MGU	00MGU07512	00MGU00000
Adare River	01ADA	01ADA02671	01ADA00000

Total model HPW length(km):	9.69	**Total model MPW length (km):**	28.8

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below:

Culverts:	☒	How many?	12
Bridges:	☒	How many?	21
Fixed crest weirs:	☒	How many?	7
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☒	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0

3.5 Floodplain Schematisation

Out-of-bank areas across the entire floodplain of the HPW reaches were modelled using a 2D approach using TUFLOW.

The same 2D approach and 2D domain have been used to represent the coastal floodplain.

Out-of-bank areas for MPW reaches have been modelled using a 1D approach in the ISIS model by extending the river channel cross-sections.

Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple (e.g, parallel to river flow). 1D-2D modelling is required where HPWs flow through urban areas and out-of-bank flows will form complex flow paths.

<table>
<tr><td></td><td colspan="3">An overview of the floodplain schematisation is available in the maps shown in Annex A.</td></tr>
<tr><td rowspan="5">3.6 2D Domain Grid Size:</td><td colspan="3">The number of 2D domains defined and the grid sizes of each 2D domain are as follows:</td></tr>
<tr><td colspan="3">Number of 2D domains: 2</td></tr>
<tr><td>Domain 1:</td><td>Grid cell size: 5m</td><td>Area: 1.95 km^2</td></tr>
<tr><td>Domain 2:</td><td>Grid cell size: 10m</td><td>Area: 110.01 km^2</td></tr>
<tr><td colspan="3">2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.</td></tr>
<tr><td>3.7 Model Breaklines in the 2D Domain:</td><td colspan="3">Bank tops and flood defence walls are represented as breaklines in the 2D domain. Bridge parapets are represented either as spill units in the 1D model or as breaklines in the 2D domain.</td></tr>
<tr><td>3.8 Floodplain Structures in the 2D Domain</td><td colspan="3">None</td></tr>
<tr><td>3.9 Hydraulic Roughness</td><td colspan="3">Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:</td></tr>
<tr><td rowspan="2">HPW in-bank</td><td>Minimum 'n' value:</td><td colspan="2">0.038</td></tr>
<tr><td>Maximum 'n' value:</td><td colspan="2">0.055</td></tr>
<tr><td rowspan="10">Floodplain (TUFLOW Model)</td><td colspan="3">Manning's 'n' for out of bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics. Floodplain land uses and adopted roughness values in TUFLOW are as follows:</td></tr>
<tr><td>Land Use</td><td colspan="2">Manning's 'n' Value</td></tr>
<tr><td>Buildings</td><td colspan="2">0.100</td></tr>
<tr><td>Short grass, parks</td><td colspan="2">0.035</td></tr>
<tr><td>General Urban</td><td colspan="2">0.060</td></tr>
<tr><td>General Rural</td><td colspan="2">0.045</td></tr>
<tr><td>Dense Vegetation</td><td colspan="2">0.080</td></tr>
<tr><td>Roads</td><td colspan="2">0.025</td></tr>
<tr><td>Railways</td><td colspan="2">0.050</td></tr>
<tr><td>Water bodies</td><td colspan="2">0.020</td></tr>
<tr><td>3.10 Spill Units</td><td colspan="3">Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR.
Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.</td></tr>
</table>

3.11 Model Boundaries – Fluvial Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report for Unit of Management 24, appendices A1 and B2.
(a) Current Situation	Peak inflows (m3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2)

Main Model

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		*50%	20%	10%	5%	*2%	1%	0.5%	0.1%
24_1594_8	02MGU03199	132	169	191	211	236	255	274	317

Tributary Model

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		*50%	20%	10%	5%	*2%	1%	0.5%	0.1%
24_1438_1a	01ADA02671	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5
24_1438_1	01ADA01454u	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.7
24_271_2	02BAR07524u	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4
24_1113_3	02BAR06575u	2.6	3.4	3.8	4.2	4.7	5.1	5.5	6.3
24_41_1	02BAR06575	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7
24_538_2	02BAR05421u	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5
24_538_5	02BAR03924u	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.2
24_1480_1	02BAR02747u	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
24_1480_5	02BAR00265u	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8
24_1597_1	02BAR03167	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.7
24_1597_3	02BAR02188u	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.6

*50% and 2% fluvial flows were utilised for the joint tidal and fluvial event simulation.

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.

HEP Reference Name	Input Node in the Hydraulic Model	MRFS Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
Main Model									
24_1594_8	02MGU03199	158	203	229	253	283	306	329	380
Tributary Model									
24_1438_1a	01ADA02671	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6
24_1438_1	01ADA01454u	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9
24_271_2	02BAR07524u	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.6
24_1113_3	02BAR06575u	3.2	4.1	4.6	5.1	5.6	6.1	6.6	7.6
24_41_1	02BAR06575	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9
24_538_2	02BAR05421u	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.7
24_538_5	02BAR03924u	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5

24_1480_1	02BAR02747u	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
24_1480_5	02BAR00265u	0.4	0.5	0.6	0.6	0.7	0.8	0.8	1.0
24_1597_1	02BAR03167	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8
24_1597_3	02BAR02188u	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.7

(b) Future Scenarios

The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.

HEP Reference Name	Input Node in the Hydraulic Model	HEFS Annual Exceedance Probability		
		10%	1%	0.1%
Main Model				
24_1594_8	02MGU03199	248.3	331.5	412.1
Tributary Model				
24_1438_1a	01ADA02671	0.4	0.6	0.7
24_1438_1	01ADA01454u	0.6	0.8	0.9
24_271_2	02BAR07524u	1.1	1.4	1.8
24_1113_3	02BAR06575u	5.0	6.6	8.2
24_41_1	02BAR06575	0.6	0.8	0.9
24_538_2	02BAR05421u	0.4	0.6	0.7
24_538_5	02BAR03924u	0.9	1.3	1.6
24_1480_1	02BAR02747u	0.1	0.1	0.2
24_1480_5	02BAR00265u	0.6	0.8	1.0
24_1597_1	02BAR03167	0.5	0.7	0.9
24_1597_3	02BAR02188u	0.4	0.6	0.7

3.12 Model Boundaries – Downstream Conditions

Downstream boundary conditions adopted in the model are as follows:

Tidal level hydrographs at the River Maigue downstream boundary were produced for a series of design events using the Irish Coastal Protection Strategy Study (ICPSS) extreme tidal peak levels data. The time series were set up as boundary conditions for the hydraulic model along the coastal boundary of the 2D model and also at the downstream extents of the HPW reaches in the ISIS model. Full details on how these tidal level hydrographs were derived are provided in Appendix D of the main Hydraulics Report. Peak tidal levels are summarised in the table below for the current and future situations.

	Current Annual Exceedance Probability							
Peak Tidal Levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.7

	MRFS Annual Exceedance Probability							
Peak Tidal Levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.9	4.1	4.3	4.4	4.6	4.8	4.9	5.3

	HEFS Annual Exceedance Probability		
Peak tidal levels (m OD)	**10%**	**0.5%**	**0.1%**
	4.8	5.4	5.8

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events	The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F). The results of this analysis concluded that the model could be calibrated and verified, along a reach of the River Maigue within the Adare AFA, to two historical events. A full account of the model calibration approach and results is provided in Annex C. A summary of the calibration and verification events along with associated model calibration results is as follows:
Catchment Gauging	Is modelled catchment: Gauged ☒ Ungauged ☐ *check one box only*
4.2 Calibration to HEP	Calibration of the hydraulic model to the HEP target flows has been carried out for the 10%, 1% and 0.1% AEP fluvial events. Section 2.7.2 of the Hydrology Report for UoM24 provides a summary of the calibration to HEP process. Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincide with the peak time of the propagating flood wave as it is routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Inflows at HEP node 24_538_2 to 24_1704_2 were increased by varying amounts to ensure that the modelled total peak flows downstream of this location achieved an average of ±10% of the HEP target flows. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: -4.64%, -5.09%, -4.45%, -5.55%, -6.18%, -7.55%, -6.09 and -6.00% for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP events respectively. Locations 02BAR05421u and 02BAR02188u were impacted by structures upstream of the check location for higher return period, hence returning some values just outside of the target ±10%. However, the magnitude of error was small at these locations and is considered suitable. Other locations show some return periods where peak flows are -11 0r -12%, however these are on the Barnakyle River and so the magnitude of the error at less than 1m^3/s was deemed acceptable for use in this study.

HEP Reference Name	Node in the Hydraulic Model	Annual Exceedance Probability							
		Percentage Difference (%)							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1675_3	02MGU01472	-10	-8	-4	-8	-9	-11	-8	-9
24_1676_2	02MGU00500	-10	-7	-9	-8	-8	-7	-8	-6
24_1438_1a	01ADA02671	-7	-6	-6	-5	-5	-2	-2	0
24_1438_1	01ADA01454u	-7	-6	-6	-7	-9	-11	0	1
24_271_2	02BAR07524u	-4	-5	0	-5	-6	-12	-10	-10
24_1113_3	02BAR06575u	-3	-1	0	-5	-7	-12	-9	-7
24_41_1	02BAR06575	5	8	9	8	7	5	7	7
24_538_2	02BAR05421u	-10	-10	-10	-11	-11	-12	-11	-12

24_1597_1	02BAR03167	-4	-6	-6	-8	-8	-11	-10	-10
24_1597_3	02BAR02188u	-6	-7	-9	-5	-5	-4	-11	-14
24_1704_2	02BAR00633	--5	-8	-8	-7	-7	-6	-5	-6

24_538_5 and 24_815_2 are situated downstream of a large natural area of floodplain storage. Consequently, these locations were deemed unsuitable for flow comparison as scaling of inflows upstream resulted in only reduced impact at these locations.

24_1480_2, 24_1480_5 and 24_1480_1 were affected by structures in the vicinity of the check point. These locations were also deemed unsuitable for flow comparison.

4.3 Fluvial and Tidal Events Simulated

The watercourses in the model reach are influenced by the tidal levels in the River Shannon at its confluence with the River Maigue. As such, a joint probability analysis of the coincidence of fluvial flood flows and coastal flood levels was carried out to determine the appropriate combinations of flows and sea levels to be used for the design probability events, as required under Section 6.5.6 of the Stage I Project Brief.

Methodology and outcomes of this analysis are detailed in the main Hydraulic Report and in the main Hydrology Report. A summary of the joint probability of fluvial and tidal conditions used for the hydraulic modelling in this reach is reported in the table below.

Combination of Fluvial and Tidal Events

	Joint Probability Design Event	AEP adopted for Fluvial Flows and Tidal Levels	
Scenario	**Overall AEP**	**Fluvial**	**Tidal**
1	50%	50%	500%
2	50%	50%	50%
3	20%	20%	500%
4	20%	50%	20%
5	10%	10%	200%
6	10%	50%	10%
7	5%	5%	100%
8	5%	50%	5%
9	2%	2%	50%
10	2%	50%	2%
11	1%	1%	20%
12	1%	20%	1%
13	0.5%	0.5%	10%
14	0.5%	10%	0.5%
15	0.1%	0.1%	2%
16	0.1%	2%	0.1%

4.4 Model Sensitivity

This stage of analysis and reporting is to be completed following delivery of initial model deliverables.

+20% Manning's 'n'

Watercourse	Average Water level difference (m)	Maximum water level difference (m)	Cross-section / reach where the maximum difference occurs
Barnakyle	0.091	0.254	01BAR02209

	Maigue	0.067	0.203	02MGU02160
-20% Manning's 'n'	**Watercourse**	**Average Water level difference (m)**	**Maximum water level difference (m)**	**Cross-section / reach where the maximum difference occurs**
	Barnakyle	-0.066	-0.127	02BAR06290
	Maigue	-0.062	-0.270	02MGU02769i
+20% inflows	**Watercourse**	**Average Water level difference (m)**	**Maximum water level difference (m)**	**Cross-section / reach where the maximum difference occurs**
	Barnakyle	0.127	0.282	01BAR02688
	Maigue	0.130	0.363	01MGU15774
-20% inflows	**Watercourse**	**Average Water level difference (m)**	**Maximum water level difference (m)**	**Cross-section / reach where the maximum difference occurs**
	Barnakyle	-0.056	-0.128	02BAR06448
	Maigue	-0.078	-0.279	02MGU02711
Afflux at Key Structure Inlet coefficients of culverts and discharge coefficients of bridge and orifice increased by 20%	This sensitivity test has been undertaken with variations as described below: - Weir coefficients increased by 20% at key structures on the Maigue and Barnakyle Water levels were compared at the upstream and downstream of the structures. Model results show that the increases of coefficients have insignificant impacts on water levels and the maximum observed increase is 29mm. This is located upstream of the bridge crossing on the Maigue at 02MGU02531 and is controlled by spill over the structure deck. However, the changes in water level are localised and are shown to have no significant influence on the predicted flood extent for the test event. Significantly, the weir and bridge structures adjacent to Adare on the Maigue show limited to sensitivity to this test, with a maximum increase in flood levels of 5mm shown for this test event.			
Afflux at Key Structure Inlet coefficients of culverts and discharge coefficients of bridge and orifice decreased by 20%	This sensitivity test has been undertaken with variations as described below: - Weir coefficients decreased by 20% at key structures on the Maigue and Barnakyle Water levels were compared at the upstream and downstream of the structures. Model results show that the increases of coefficients have insignificant impacts on water levels and the maximum observed decrease is 26mm. This is located upstream of the bridge crossing on the Maigue at 02MGU02531 and is caused by the impact of the spill over the structure deck. However, the changes in water level are localised and are shown to have no significant influence on the predicted flood extent for the test event. Significantly, the weir and bridge structures adjacent to Adare on the Maigue show limited to sensitivity to this test, with a maximum decrease in flood levels of 4mm shown for this test event.			
Downstream Conditions Duration of surge component of tidal boundary is increased by 100% (i.e. 30hours)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was increased by 100% (i.e. 30 hours). Model results show that due to increase in tidal surge duration, the water level increases along the downstream reach of the Maigue, with the			

	maximum observed increase at the cross section 01MGU00000. The water level response extends upstream to cross section 02MGU00468. Analysis of outputs demonstrates that water levels and extents within AFAs are not impacted by the changes to downstream boundary.
Downstream Conditions Duration of surge component of tidal boundary is decreased by 100% (i.e. 15hours)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was decreased by 100% (i.e. 15 hours). Model results show that due to increase in tidal surge duration, the water level increases along the downstream reach of the Maigue, with the maximum observed decrease at cross section 01MGU00509. The water level response extends upstream to cross section 01MGU15706. Analysis of outputs demonstrates that water levels and extents within AFAs are not impacted by the changes to downstream boundary.
4.5 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D.

5. Hydraulic Model Outputs

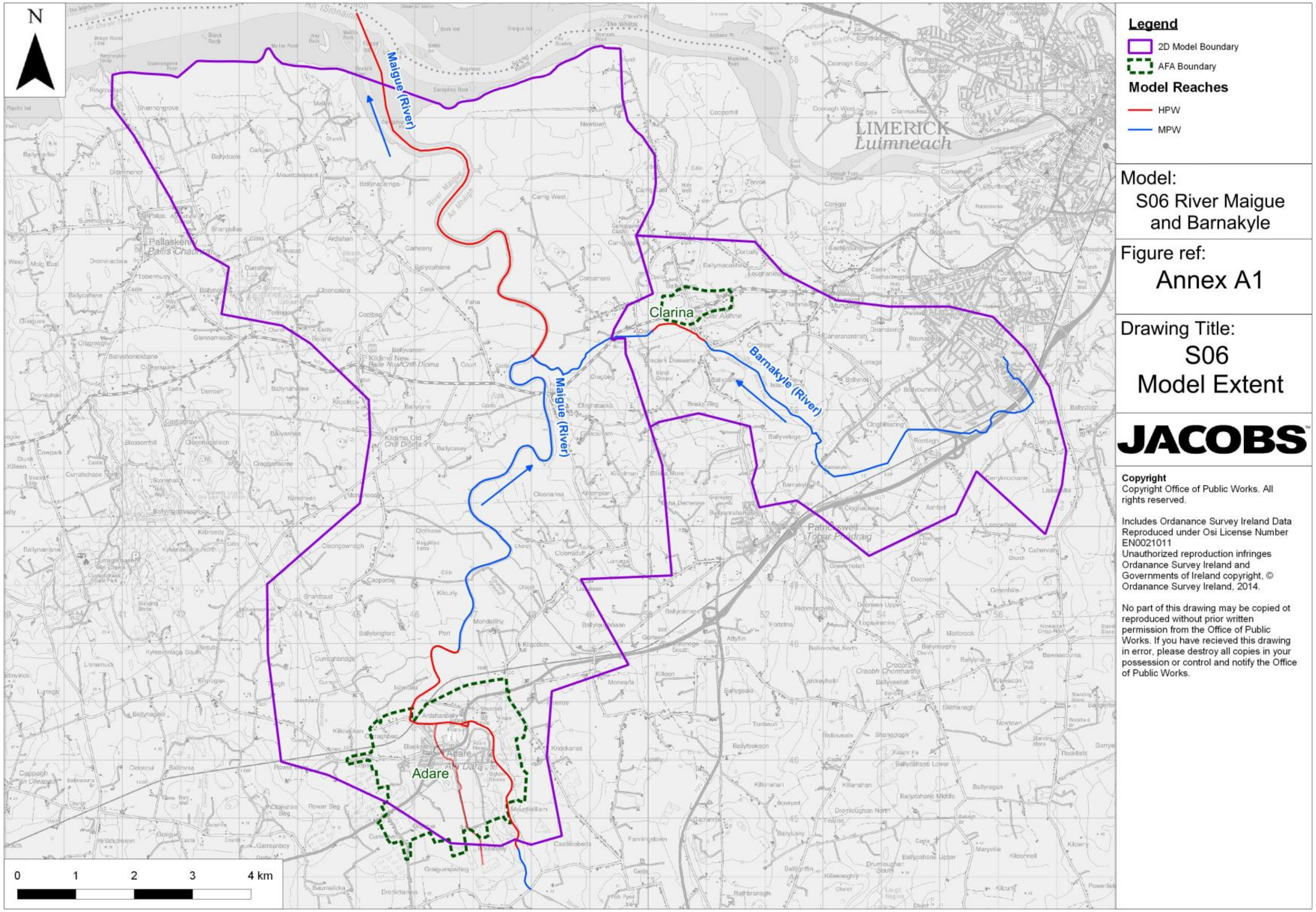
5.1 Mapping	The model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2 and, more specifically, under Section 7.5.2.1, with both AFAs in the model reach being an area where flooding is subject to both tidal and fluvial influence (see Section 6). These include mapping outputs covering: • Flood extent • Flood depth and velocity • Flood hazard Flood mapping outputs corresponding to the **defended** current scenario for the 10%, 1% and 0.1% AEP fluvial dominated flood events with the corresponding tidal boundary conditions and to the **defended** current scenario for the 10%, 0.5% and 0.1% AEP tidal dominated events with the corresponding fluvial events are shown in Annex E for flood extent and depth only.

6. Key Model Assumption and Limitations

- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. The River Maigue and its tributaries are classified as the main channel and the River Barnakyle and the Adare River are classified as tributaries.
- Where topographic survey exists for defences these have been applied as surveyed using geometry modification features in TUFLOW. Where defences are known to exist and survey was not available, crest elevations have been taken from LiDAR or SAR (where LiDAR was not available).
- The embankment along the right bank of the River Maigue and the estuary has been modelled as one complete flood defence and the SOP relates to the full embankment. Furthermore the SOP applied to the embankment is generated in relation to when a first breach of the embankment occurs at a point along the full length at a set AEP (the AEP is stepped back where appropriate to give the applied SOP.
- At a number of structures, cross sections at upstream or downstream faces were missing from the channel survey. These have been copied from the nearest location up or downstream, with elevations amended if appropriate to represent local channel geometry gradients. Where this has been carried out, clear comments are provided in the ISIS datafile.
- Along the Adare reach there is some interaction between the watercourse and a series of lakes. It is unclear whether these are online, or whether the watercourse runs alongside these. Schematisation has been undertaken based upon careful review of aerial photography and Google streetview coverage. A site visit has been subsequently undertaken which justified the initial schematisation of the model.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent


N
Legend
2D Model Boundary
AFA Boundary
Model Reaches
HPW
MPW
Model:
S06 River Maigue and Barnakyle
Figure ref:
Annex A1
Drawing Title:
S06
Model Extent
JACOBS
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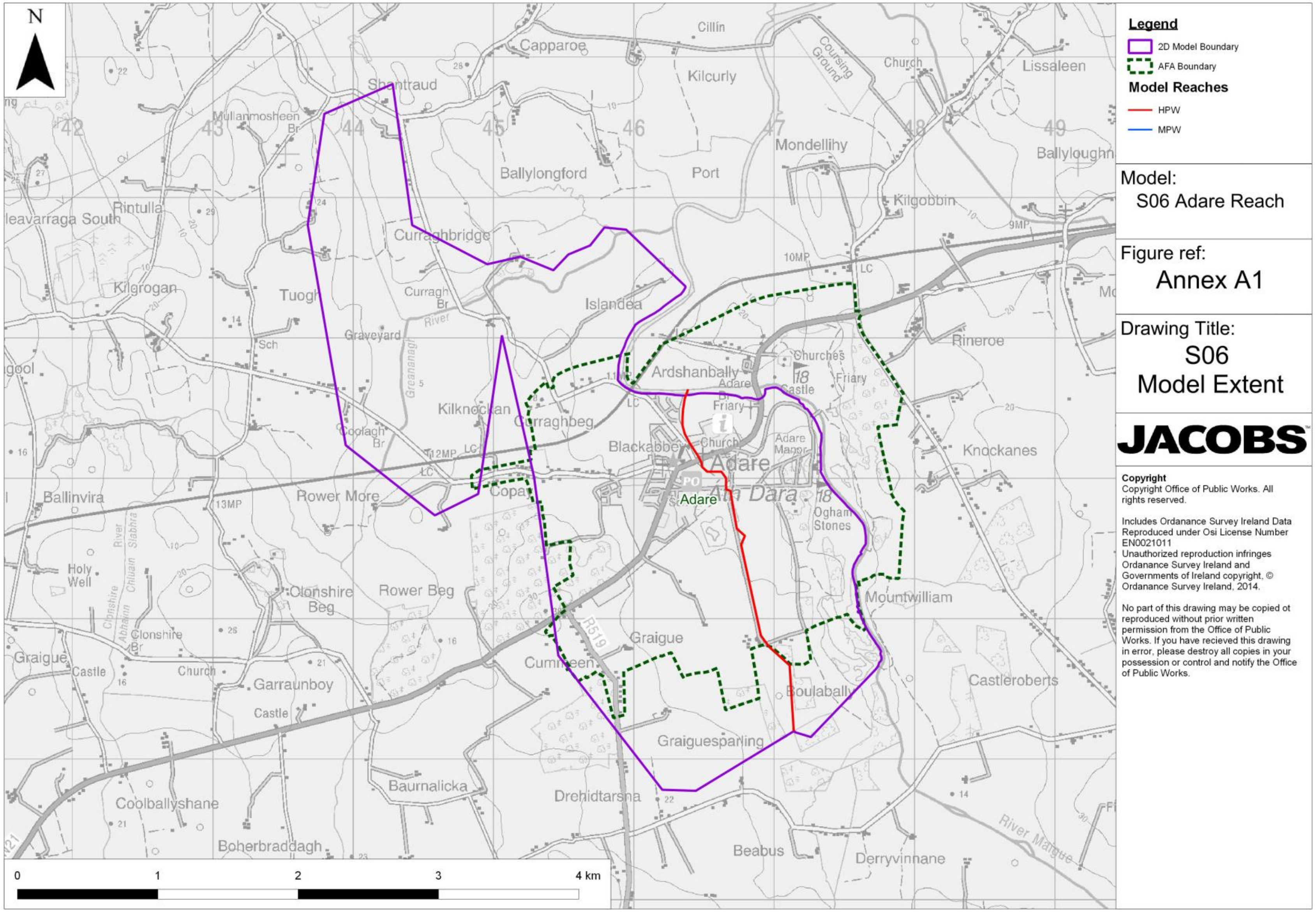
Maigue (River)
Barnakyle (River)
Clarina
Adare
LIMERICK
Luimneach
0
1
2
3
4 km



N
Legend
2D Model Boundary
AFA Boundary
Model Reaches
HPW
MPW
Model:
S06 Adare Reach
Figure ref:
Annex A1
Drawing Title:
S06
Model Extent
JACOBS
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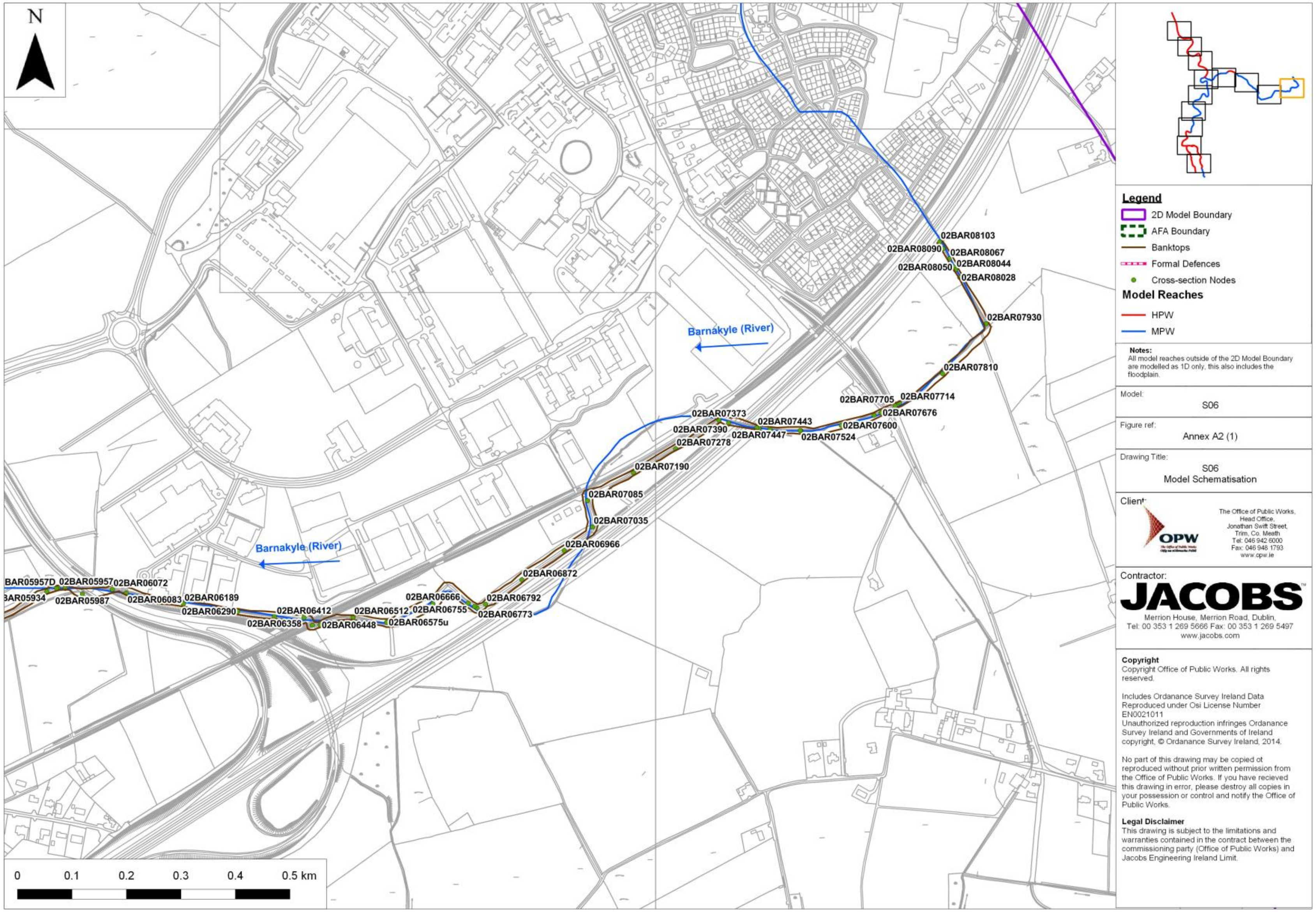
0
1
2
3
4 km
Cillin
Capparoe
Kilcurly
Shanntraud
Mullanmosheen Br
Ballylongford
Port
Mondellihy
Lissaleen
Ballyloughn
Kilgobbin
Rintulla
Curraghbridge
Kilgrogan
Tuogh
Curragh Br
Islandea
Graveyard
Rineroe
Ardshanbally
Adare
Kilknockan
Curraghbeg
Blackabbey
Knockanes
Ballinvira
Rower More
Copa
Adare
Áth Dara
Ogham Stones
Holy Well
Clonshire Beg
Rower Beg
Mountwilliam
Clonshire Br
Graigue
Graigue
Castle
Church
Garraunboy
Cummeen
Boulabally
Castleroberts
Castle
Graiguesparling
Baurnalicka
Coolballyshane
Drehidtarsna
Boherbraddagh
Beabus
Derryvinnane
River Maigue
R519

Annex A2 – Schematisation Maps


N
Barnakyle (River)
Barnakyle (River)
02BAR08103
02BAR08090
02BAR08067
02BAR08050
02BAR08044
02BAR08028
02BAR07930
02BAR07810
02BAR07705
02BAR07714
02BAR07676
02BAR07600
02BAR07373
02BAR07443
02BAR07390
02BAR07447
02BAR07524
02BAR07278
02BAR07190
02BAR07085
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02BAR06666
02BAR06755
02BAR06512
02BAR06575u
02BAR06448
02BAR06412
02BAR06358
02BAR06290
02BAR06189
02BAR06083
02BAR06072
02BAR05957D
02BAR05957
02BAR05987
BAR05934
0
0.1
0.2
0.3
0.4
0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (1)
Drawing Title:
S06
Model Schematisation
Client:
OPW
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie
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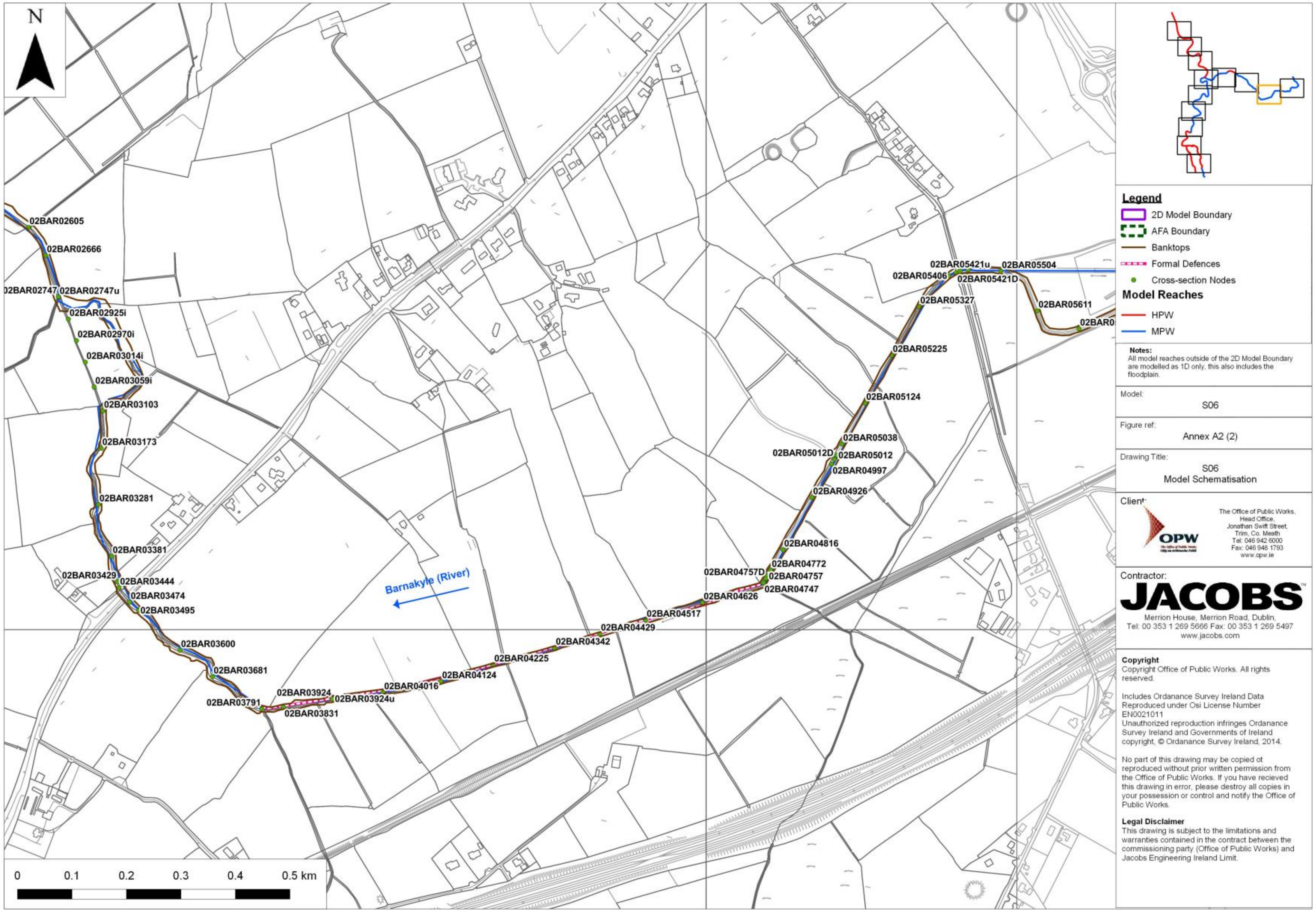

N
02BAR02605
02BAR02666
02BAR02747
02BAR02747u
02BAR02925i
02BAR02970i
02BAR03014i
02BAR03059i
02BAR03103
02BAR03173
02BAR03281
02BAR03381
02BAR03429
02BAR03444
02BAR03474
02BAR03495
02BAR03600
02BAR03681
02BAR03791
02BAR03924
02BAR03924u
02BAR03831
02BAR04016
02BAR04124
02BAR04225
02BAR04342
02BAR04429
02BAR04517
02BAR04626
02BAR04747
02BAR04757D
02BAR04757
02BAR04772
02BAR04816
02BAR04926
02BAR04997
02BAR05012D
02BAR05012
02BAR05038
02BAR05124
02BAR05225
02BAR05327
02BAR05406
02BAR05421u
02BAR05421D
02BAR05504
02BAR05611
Barnakyle (River)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (2)
Drawing Title:
S06
Model Schematisation
Client:
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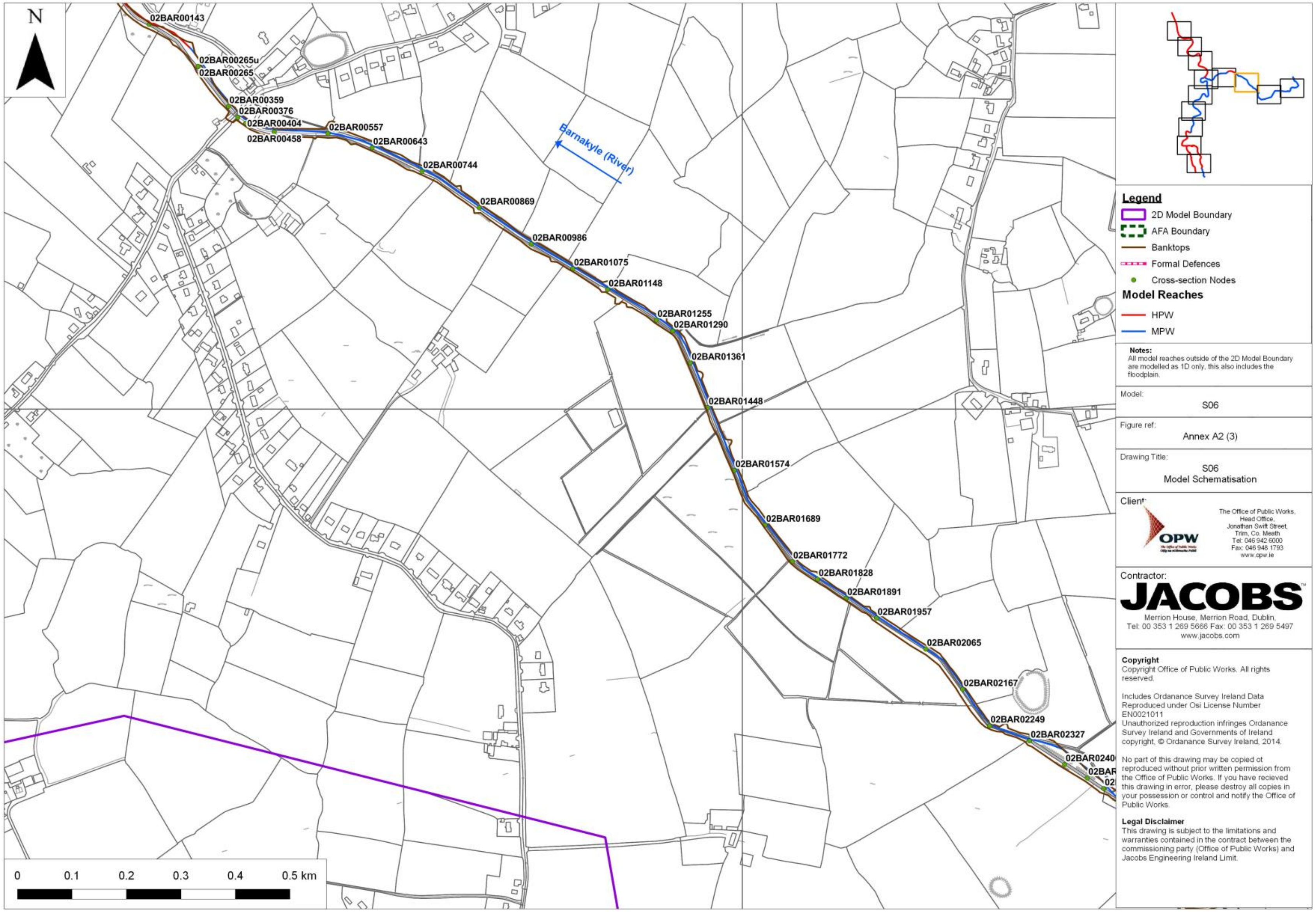
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02BAR00265
02BAR00359
02BAR00376
02BAR00404
02BAR00458
02BAR00557
02BAR00643
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02BAR00986
02BAR01075
02BAR01148
02BAR01255
02BAR01290
02BAR01361
02BAR01448
02BAR01574
02BAR01689
02BAR01772
02BAR01828
02BAR01891
02BAR01957
02BAR02065
02BAR02167
02BAR02249
02BAR02327
Barnakyle (River)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (3)
Drawing Title:
S06
Model Schematisation
Client:
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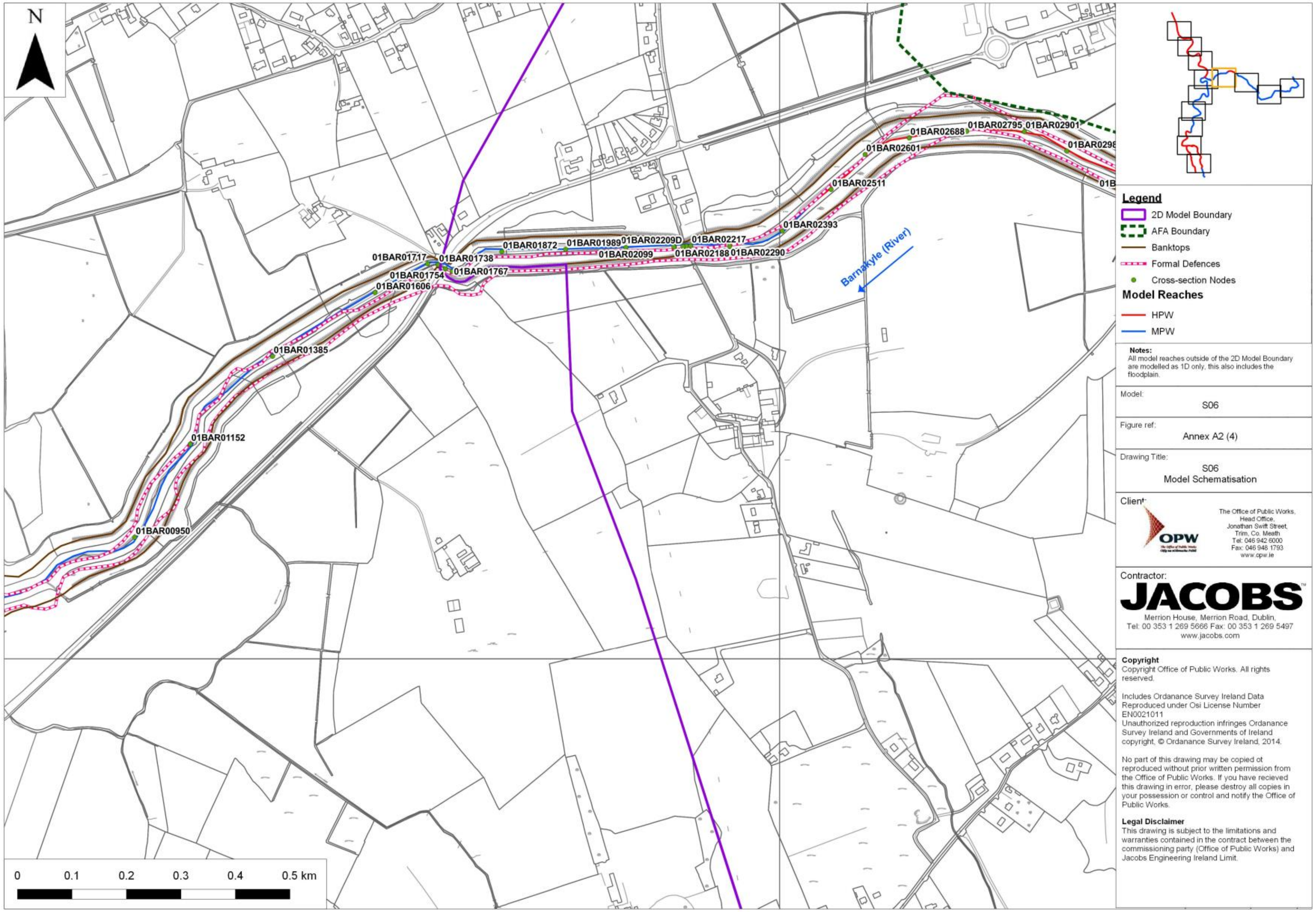
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01BAR00950
01BAR01152
01BAR01385
01BAR01606
01BAR01717
01BAR01738
01BAR01754
01BAR01767
01BAR01872
01BAR01989
01BAR02099
01BAR02209D
01BAR02217
01BAR02188
01BAR02290
01BAR02393
01BAR02511
01BAR02601
01BAR02688
01BAR02795
01BAR02901
Barnakyle (River)
0
0.1
0.2
0.3
0.4
0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (4)
Drawing Title:
S06
Model Schematisation
Client:
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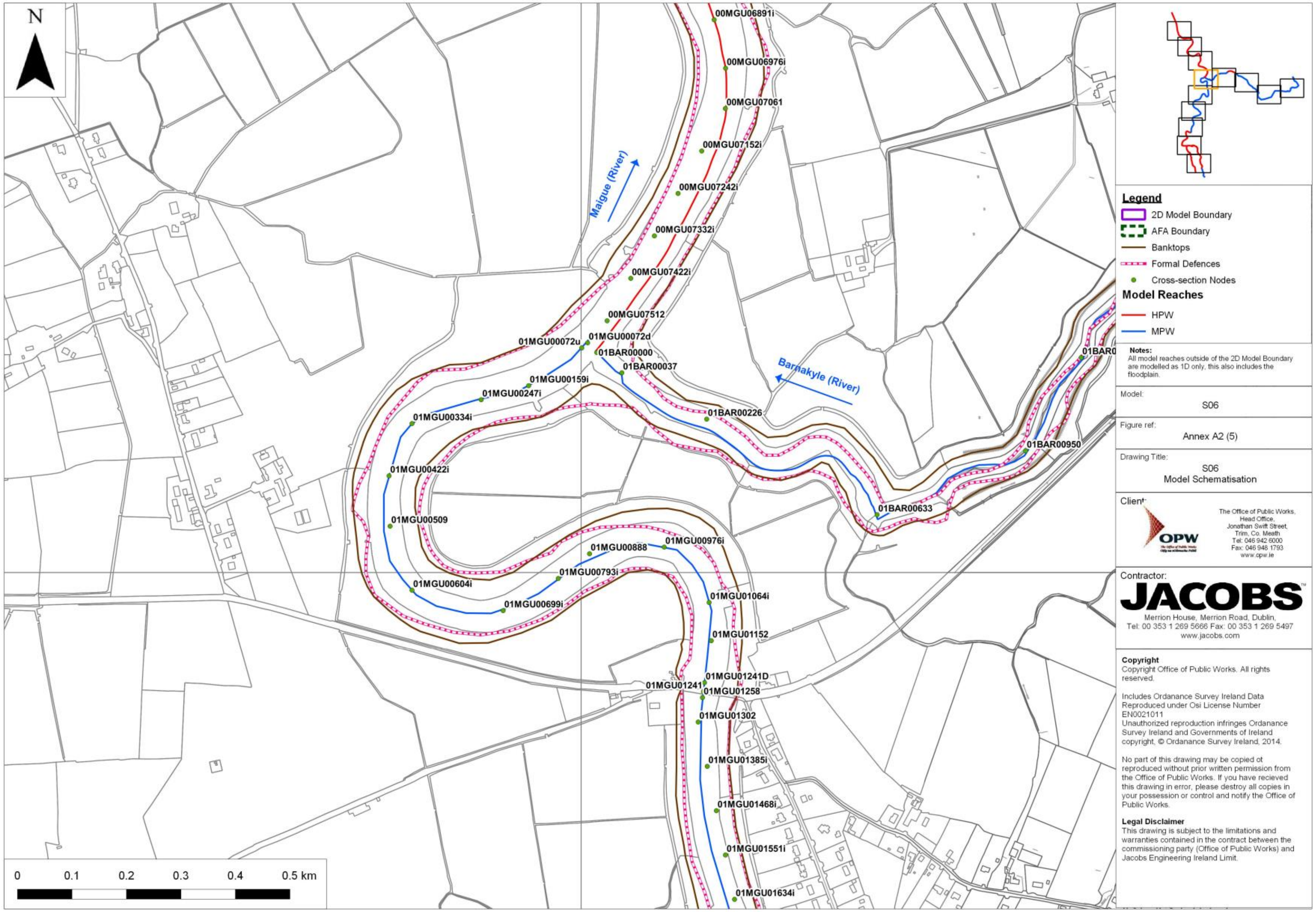
N
Maigue (River)
Barnakyle (River)
00MGU06891i
00MGU06976i
00MGU07061
00MGU07152i
00MGU07242i
00MGU07332i
00MGU07422i
00MGU07512
01MGU00072u
01MGU00072d
01BAR00000
01BAR00037
01MGU00159i
01MGU00247i
01MGU00334i
01BAR00226
01BAR00950
01BAR00633
01MGU00422i
01MGU00509
01MGU00888
01MGU00976i
01MGU00793i
01MGU00604i
01MGU00699i
01MGU01064i
01MGU01152
01MGU01241D
01MGU01241
01MGU01258
01MGU01302
01MGU01385i
01MGU01468i
01MGU01551i
01MGU01634i
0
0.1
0.2
0.3
0.4
0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (5)
Drawing Title:
S06
Model Schematisation
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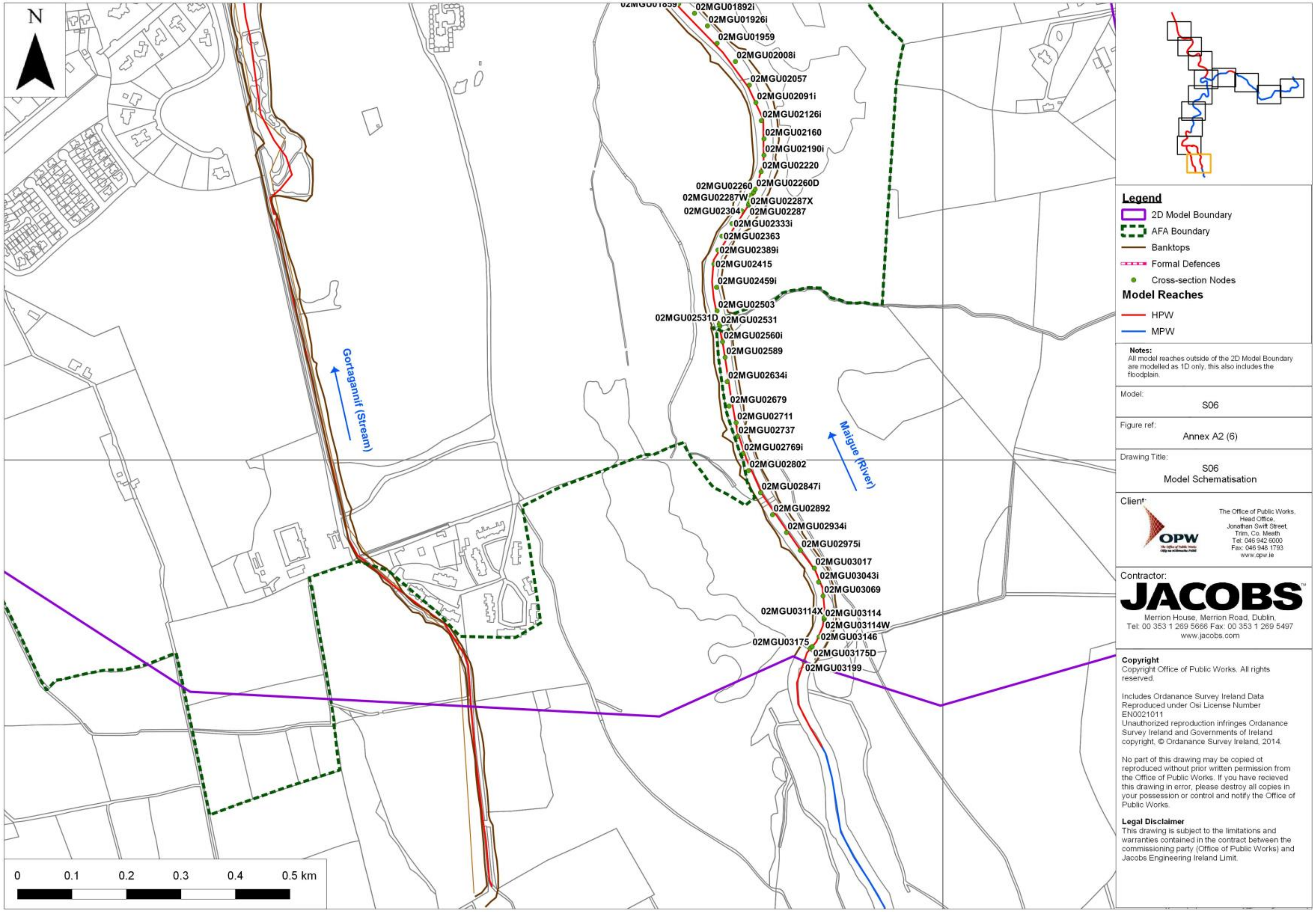

N
02MGU01892i
02MGU01926i
02MGU01959
02MGU02008i
02MGU02057
02MGU02091i
02MGU02126i
02MGU02160
02MGU02190i
02MGU02220
02MGU02260
02MGU02260D
02MGU02287W
02MGU02287X
02MGU02304
02MGU02287
02MGU02333i
02MGU02363
02MGU02389i
02MGU02415
02MGU02459i
02MGU02503
02MGU02531D
02MGU02531
02MGU02560i
02MGU02589
02MGU02634i
02MGU02679
02MGU02711
02MGU02737
02MGU02769i
02MGU02802
02MGU02847i
02MGU02892
02MGU02934i
02MGU02975i
02MGU03017
02MGU03043i
02MGU03069
02MGU03114X
02MGU03114
02MGU03114W
02MGU03146
02MGU03175
02MGU03175D
02MGU03199
Gortagannif (Stream)
Maigue (River)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (6)
Drawing Title:
S06
Model Schematisation
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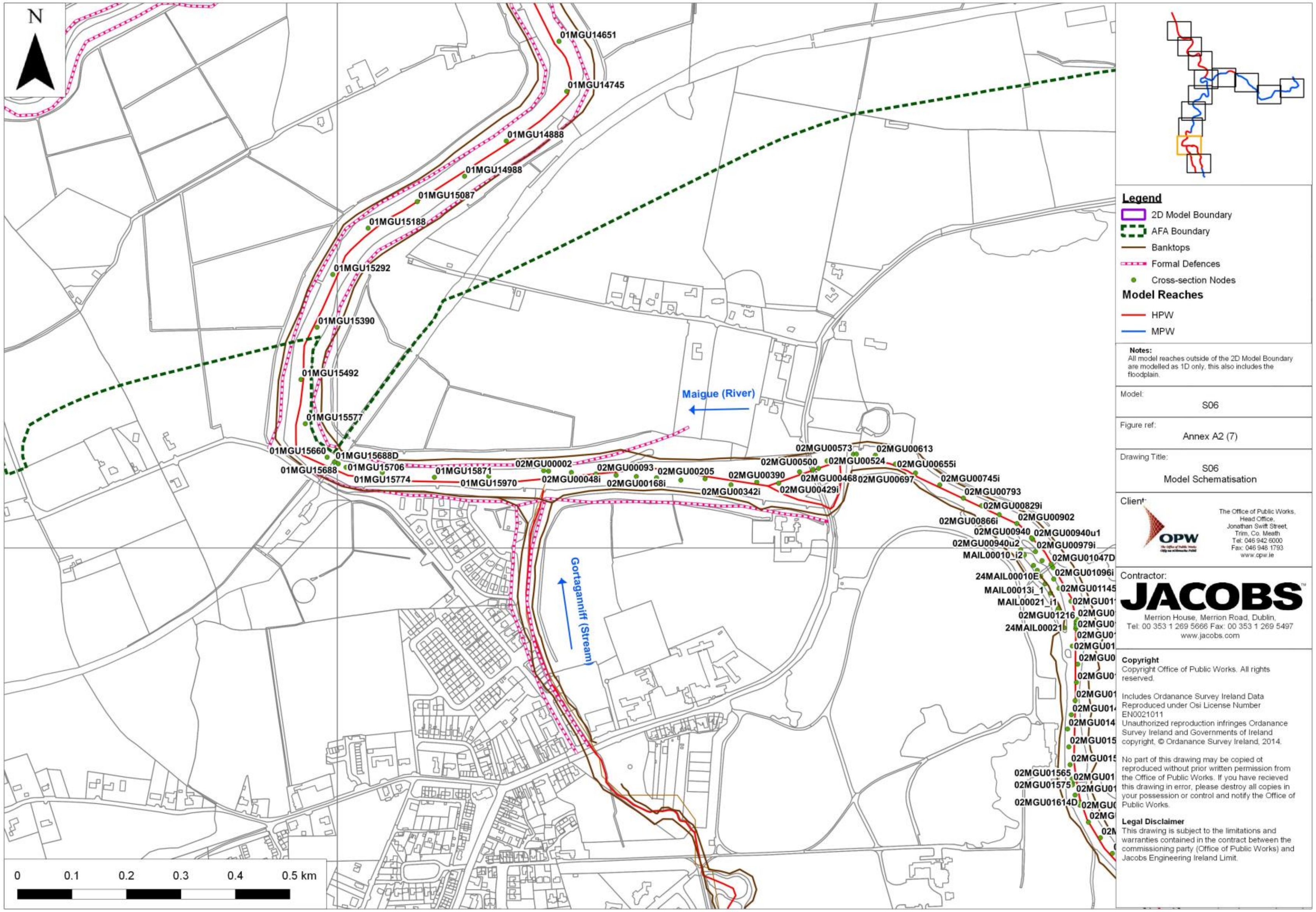

N
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01MGU14745
01MGU14888
01MGU14988
01MGU15087
01MGU15188
01MGU15292
01MGU15390
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01MGU15577
01MGU15660
01MGU15688D
01MGU15688
01MGU15706
01MGU15774
01MGU15871
01MGU15970
02MGU00002
02MGU00048i
02MGU00093
02MGU00168i
02MGU00205
02MGU00342i
02MGU00390
02MGU00429i
02MGU00468
02MGU00500
02MGU00524
02MGU00573
02MGU00613
02MGU00655i
02MGU00697
02MGU00745i
02MGU00793
02MGU00829i
02MGU00866i
02MGU00902
02MGU00940
02MGU00940u1
02MGU00940u2
02MGU00979i
MAIL00010_i2
02MGU01047D
24MAIL00010E
02MGU01096i
MAIL00013i_1
02MGU01145
MAIL00021_i1
02MGU01216
24MAIL00021
02MGU01565
02MGU01575
02MGU01614D
Maigue (River)
Gortaganniff (Stream)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (7)
Drawing Title:
S06
Model Schematisation
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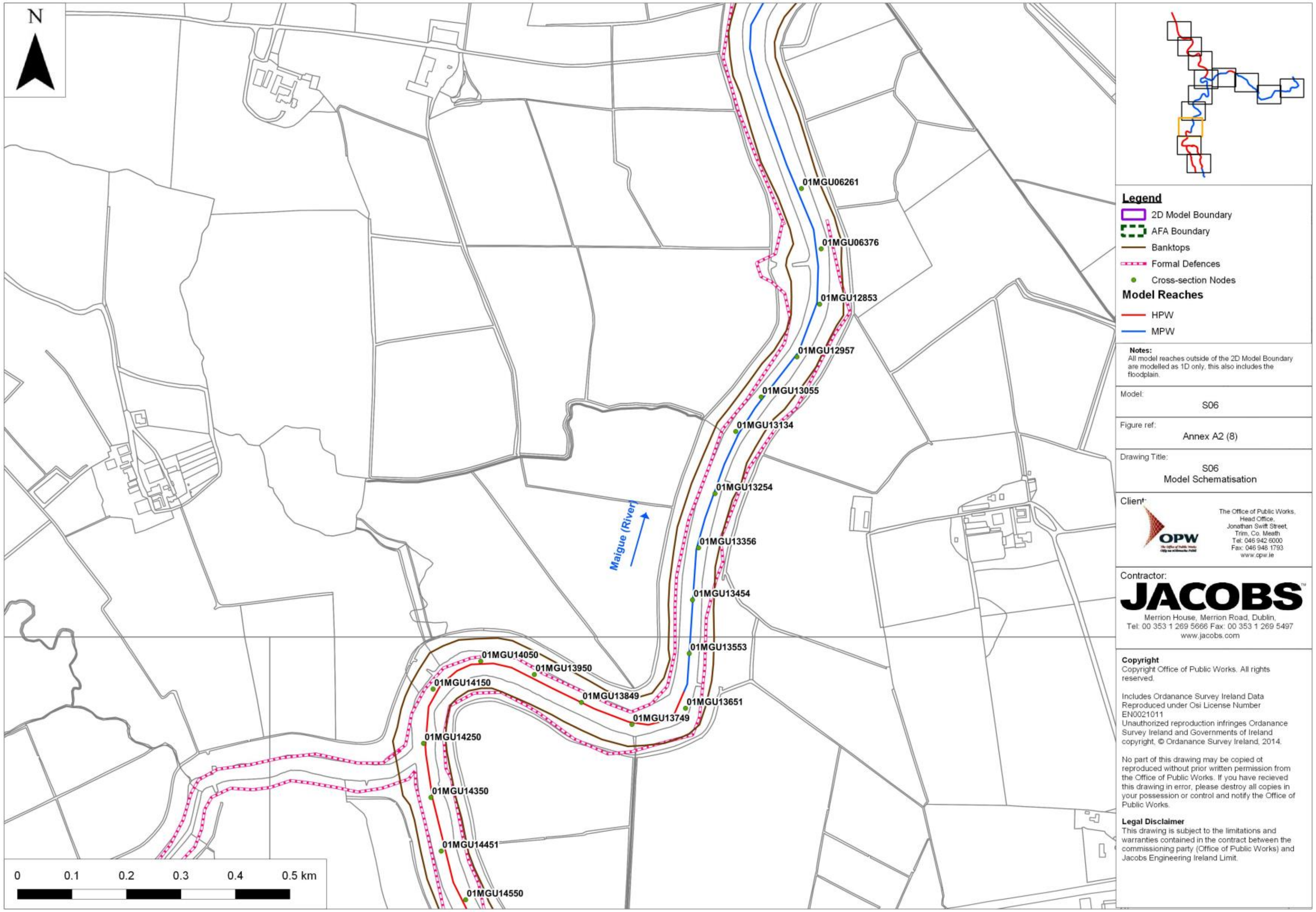

N
01MGU06261
01MGU06376
01MGU12853
01MGU12957
01MGU13055
01MGU13134
01MGU13254
01MGU13356
01MGU13454
01MGU13553
01MGU13651
01MGU13749
01MGU13849
01MGU13950
01MGU14050
01MGU14150
01MGU14250
01MGU14350
01MGU14451
01MGU14550
Maigue (River)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (8)
Drawing Title:
S06
Model Schematisation
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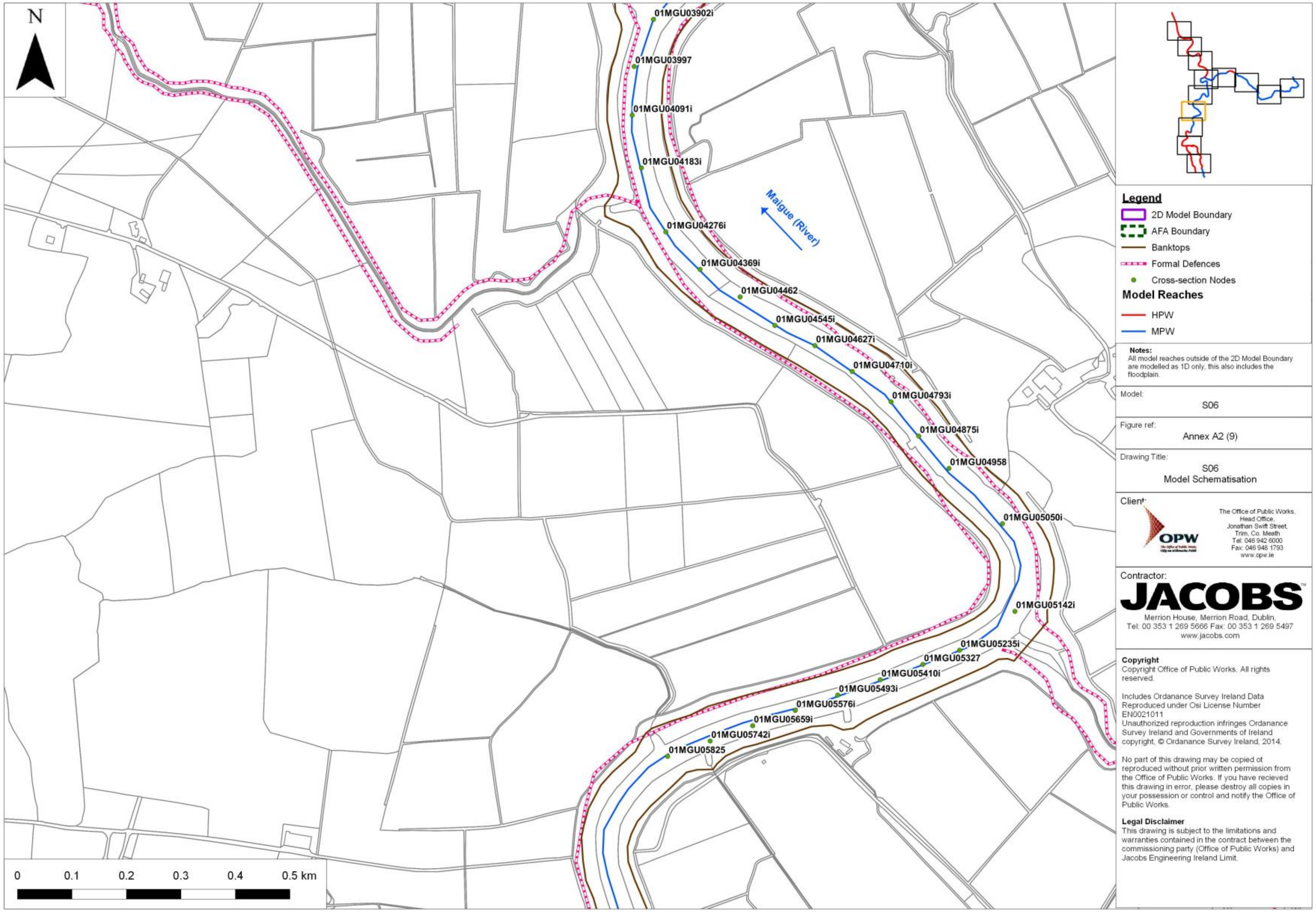

N
Maigue (River)
01MGU03902i
01MGU03997
01MGU04091i
01MGU04183i
01MGU04276i
01MGU04369i
01MGU04462
01MGU04545i
01MGU04627i
01MGU04710i
01MGU04793i
01MGU04875i
01MGU04958
01MGU05050i
01MGU05142i
01MGU05235i
01MGU05327
01MGU05410i
01MGU05493i
01MGU05576i
01MGU05659i
01MGU05742i
01MGU05825
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S06
Figure ref: Annex A2 (9)
Drawing Title: S06 Model Schematisation
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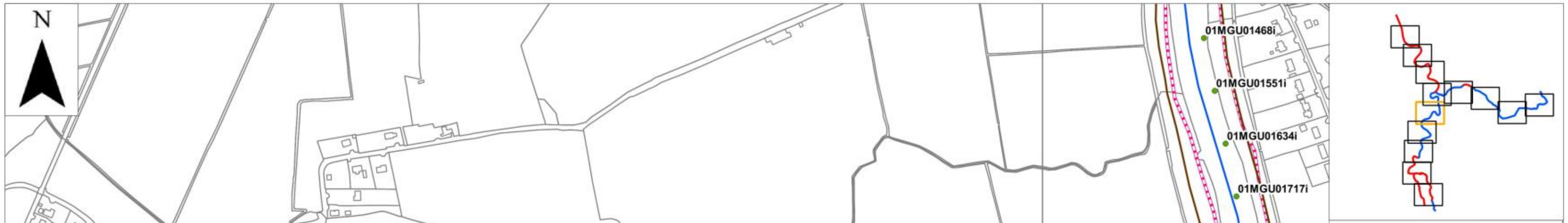

Legend

- 2D Model Boundary
- AFA Boundary
- Banktops
- Formal Defences
- Cross-section Nodes

Model Reaches

- HPW
- MPW

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model:
S06

Figure ref:
Annex A2 (10)

Drawing Title:
S06
Model Schematisation

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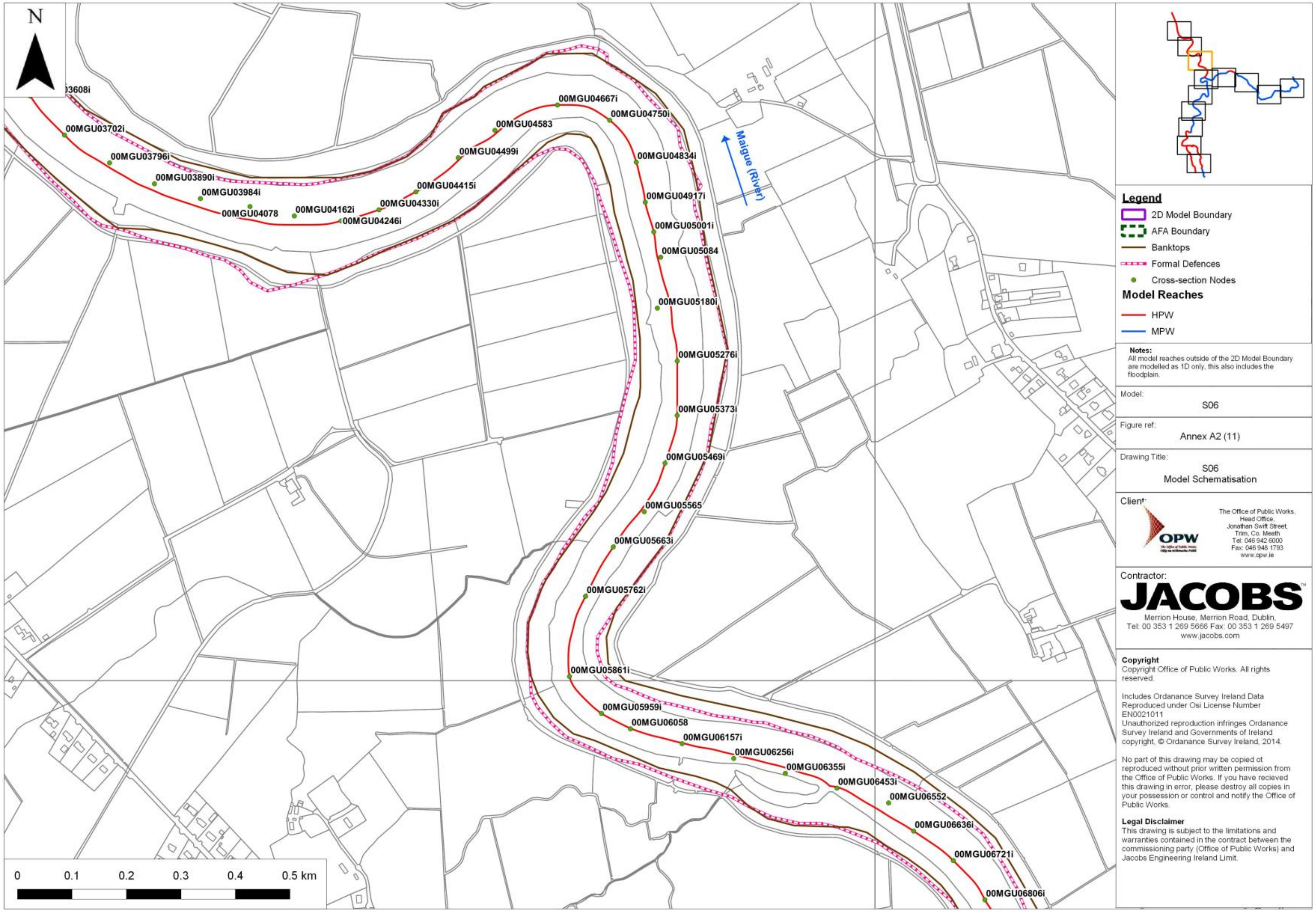
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03608i
00MGU03702i
00MGU03796i
00MGU03890i
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00MGU04078
00MGU04162i
00MGU04246i
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00MGU04415i
00MGU04499i
00MGU04583
00MGU04667i
00MGU04750i
00MGU04834i
00MGU04917i
00MGU05001i
00MGU05084
00MGU05180i
00MGU05276i
00MGU05373i
00MGU05469i
00MGU05565
00MGU05663i
00MGU05762i
00MGU05861i
00MGU05959i
00MGU06058
00MGU06157i
00MGU06256i
00MGU06355i
00MGU06453i
00MGU06552
00MGU06636i
00MGU06721i
00MGU06806i
Maigue (River)
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (11)
Drawing Title:
S06
Model Schematisation
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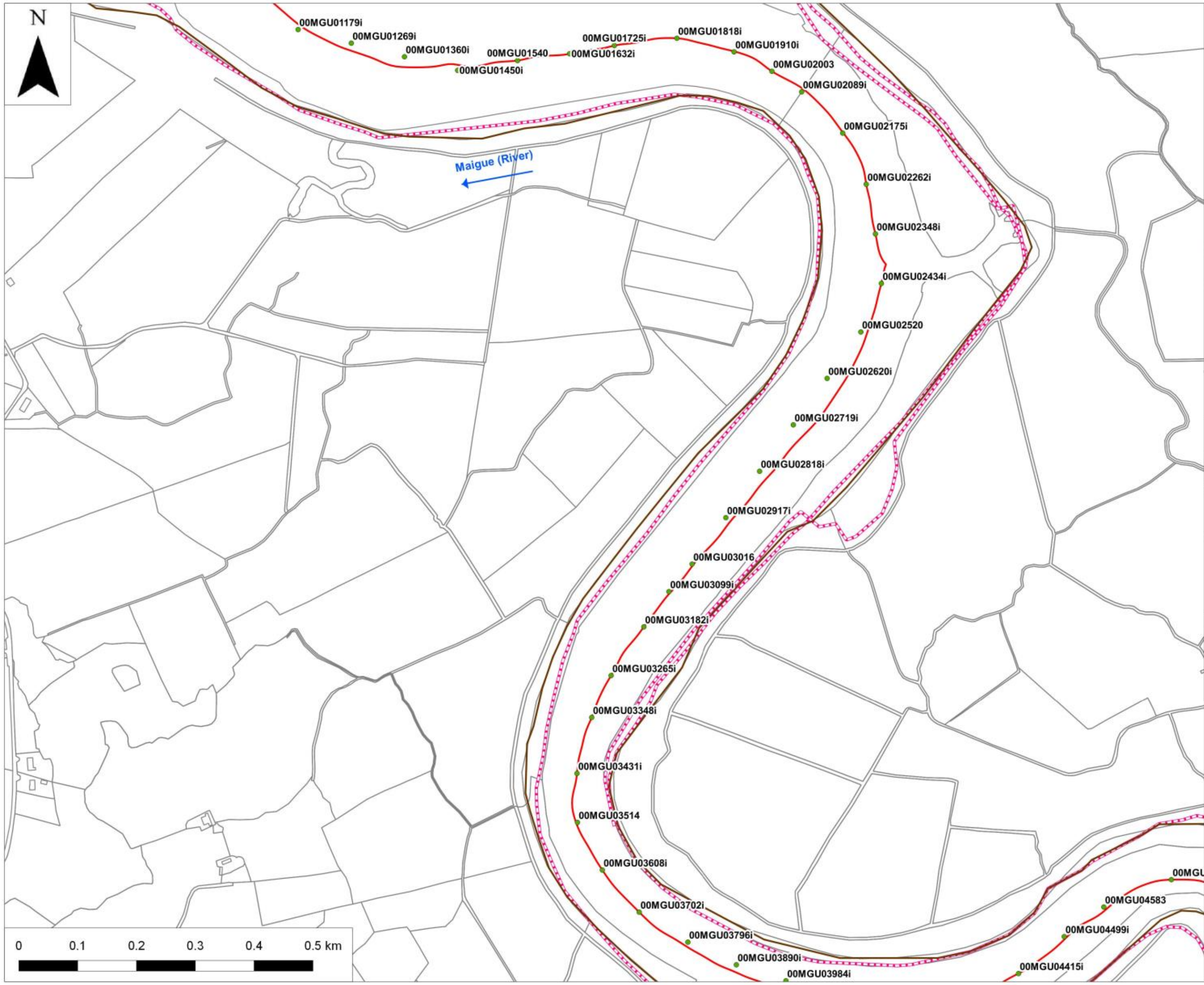

Legend

- 2D Model Boundary
- AFA Boundary
- Banktops
- Formal Defences
- Cross-section Nodes

Model Reaches

- HPW
- MPW

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S06

Figure ref: Annex A2 (12)

Drawing Title: S06 Model Schematisation

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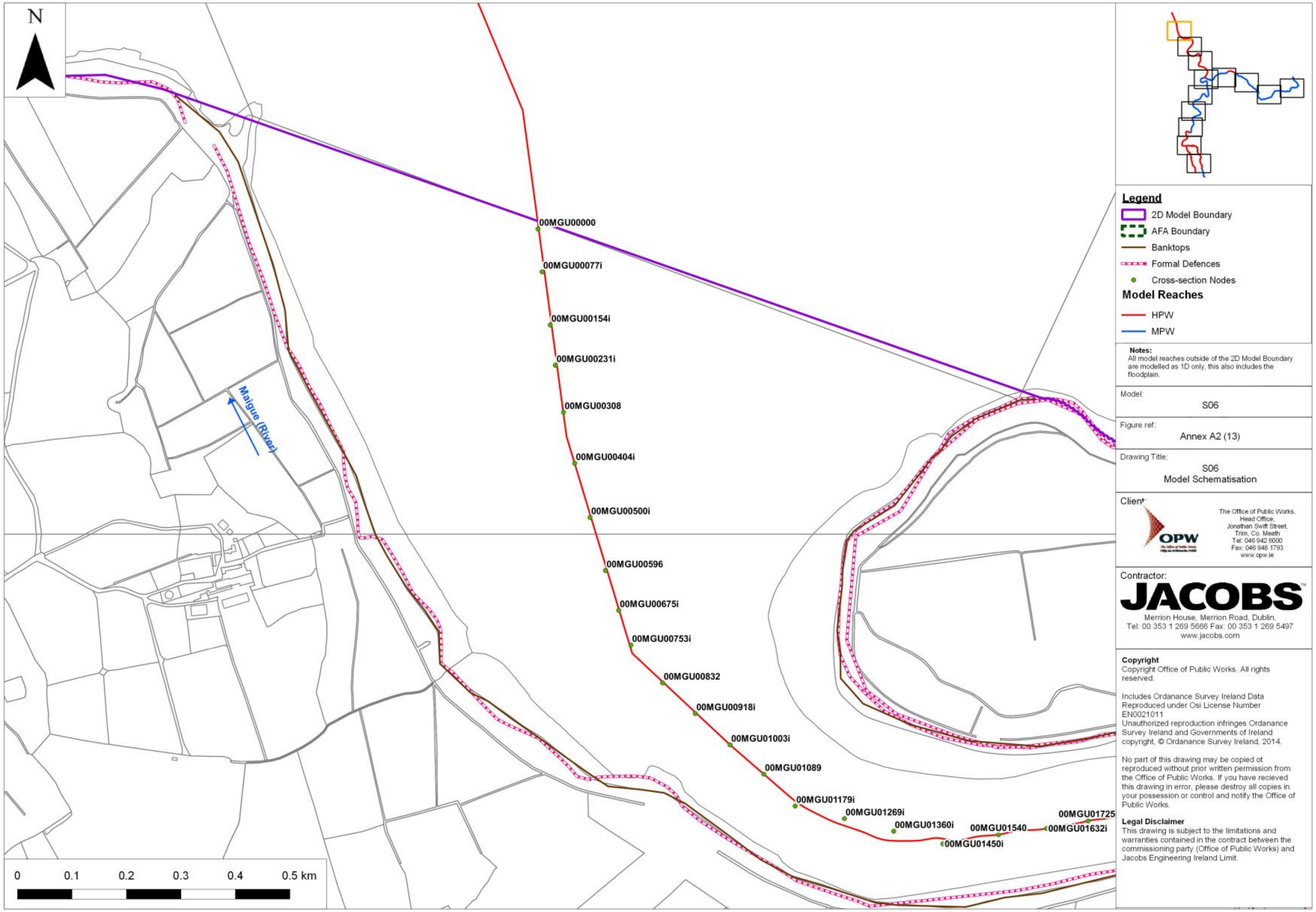
N
Maigue (River)
00MGU00000
00MGU00077i
00MGU00154i
00MGU00231i
00MGU00308
00MGU00404i
00MGU00500i
00MGU00596
00MGU00675i
00MGU00753i
00MGU00832
00MGU00918i
00MGU01003i
00MGU01089
00MGU01179i
00MGU01269i
00MGU01360i
00MGU01450i
00MGU01540
00MGU01632i
00MGU01725
0 0.1 0.2 0.3 0.4 0.5 km
Legend
2D Model Boundary
AFA Boundary
Banktops
Formal Defences
Cross-section Nodes
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model:
S06
Figure ref:
Annex A2 (13)
Drawing Title:
S06
Model Schematisation
Client:
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie
Contractor:
Merrion House, Merrion Road, Dublin,
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com
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Annex B – Structure and Hydraulic Roughness schedules

Schedule A.1 - Structure Schedule for S06

Survey Reference	ISIS Node ref	Type of structure	Modelling approach	Structure included in Model (Y/N)
24BARN01141J	02BAR08103	Bridge of unknown m wide	Rectangular conduit + Spill	N
24BARN01134I	02BAR08050	Culvert of 5.85 m wide	Circular conduit + Spill	Y
24BARN01101I	02BAR07705	Culvert of 29.14 m wide	Circular conduit at u/s and rectangular at d/s+ Spill	Y
24BARN01075W	02BAR07447	Weir	Spill	Y
24BARN01075I	02BAR07443	Culvert of 52.56 m wide	Rectangular conduit + Spill	Y
24BARN01000I	02BAR06773	Culvert of 5.29 m wide	Circular conduit + Spill	Y
24BARN00966E	02BAR06429	Bridge of 5.56 m wide.	Sprung arch conduit + Spill	Y
24BARN00931I	02BAR06072	Culvert of 85.80 m wide	Rectangular conduit + Spill	Y
24BARN00918D	02BAR05957	Arch Bridge of 3.73 m wide	Arch bridge with Rectangular opening + Spill	Y
24BARN00874E	02BAR05421	Arch Bridge of 7.81 m wide	Arch bridge + Spill	Y
24BARN00834D	02BAR05012	Arch Bridge of 3.59 m wide	Arch bridge with Rectangular opening + Spill	Y
24BARN00808D	02BAR04757	Arch Bridge of 3.54 m wide	Arch bridge with Rectangular opening + Spill	Y
24BARN00680I	02BAR03474	Culvert of 30.72 m wide	Circular conduit at u/s and rectangular at d/s+ Spill	Y
24BARN00325D	02BAR03229	Bridge of 5.66 m wide	Arch bridge + Spill	Y
24BARN00223D	02BAR02209	Bridge of 3.18 m wide	Arch bridge + Spill	Y
24BARN00178D	02BAR01754	Bridge of 16.33 m wide	Arch bridge with rectangular opening + Spill	Y
24MAIG01287D	02MGU03175	Arch Bridge of 4.68 m wide.	Bridge with three rectangular openings + Spill	Y
24MAIG01281W	02MGU03114	Weir	3 Round nosed broad crested weirs	Y
24MAIG01241W	02MGU02718	Weir	Round nosed broad crested weir	Y
24MAIG01223D	02MGU02531	Arch Bridge of 1.54 m wide.	Bridge with arch opening + Spill	Y

Survey Reference	ISIS Node ref	Type of structure	Modelling approach	Structure included in Model (Y/N)
24MAIG01198W	02MGU02287	Weir	Round nosed broad crested weir	Y
24MAIG01196D	02MGU02260	Arch Bridge of 4.74 m wide.	Arch Bridge + Spill	Y
24MAIG01131D	02MGU01614	Arch Bridge of 3.87 m wide.	Arch Bridge + Spill	Y
24MAIG01127W	02MGU01575	Weir	Round nosed broad crested weir+ Spill	Y
24MAIG01091W	02MGU01216	Weir	Spill	Y
24MAIG01074D	02MGU01047	USBPR Bridge of 4.66 m wide.	Bridge with five arch openings+ Spill	Y
24MAIG01027W	02MGU00577	Weir	Spill	Y
24MAIG01020D	02MGU00500	USBPR Bridge of 8.92 m wide.	Bridge with 10 arch openings+ Spill	Y
24MAIG00931D	01MGU15688	Arch Bridge of 7.91 m wide.	Bridge with three rectangular openings + Spill	Y
24MAIG00124E	01MGU01241	USBPR Bridge of 8.53 m wide.	Bridge with three arch openings+ Spill	Y

Schedule A.2 - Structure Schedule for Adare Reach

Survey Reference	ISIS Node ref	Type of structure	Modelling approach	Structure included in Model (Y/N)
24MAIA00256D	01ADA02539	Bridge of 4.90 m wide	Arch bridge with rectangular opening + Spill	Y
24MAIA00208D	01ADA02055	Culvert of 9.09 m wide	Circular conduit + Spill	Y
24MAIA00199D	01ADA01972	Culvert of 7.39 m wide	Circular conduit + Spill	Y
24MAIA00190D	01ADA01881	Bridge of 4.53 m wide	Arch bridge with rectangular opening + Spill	Y
24MAIA00135D	01ADA01324	Culvert of 10.84 m wide	Circular conduit + Spill	Y
24MAIA00087I	01ADA00846	Culvert of 85.61 m wide	Rectangular conduit + Spill	Y
24MAIA00072D	01ADA00696	Bridge of 4.40 m wide	Circular conduit + Spill	Y
24MAIA00059D	01ADA00570	Arch Bridge of 5.34 m wide	Bridge with Arch opening + Spill	Y
24MAIA00054D	01ADA00516	Culvert of 24.47 m wide	Sprung arch conduits + Spill	Y
24MAIA00006I	01ADA00034	Culvert of 23.70 m wide	Circular conduit + Spill	Y

Schedule B.1 – In-bank Manning's 'n' for HPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Maigue	02MGU03199 to 01MGU13451	0.031	Determined on a case by case basis using photos, videos and survey drawings	2d Domain : based on OSi NTF land use polygons 1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
River Maigue - end of river	01MGU00072 to 00MGU00000	0.030		
Adare River	01ADA02671 to 01ADA00000	0.065		
Barnakyle River	02BAR00265 to 02BAR00008 and 01BAR02393 to 01 BAR02511	0.051		
Barnakyle River	02BAR00008 to 01BAR02393	0.037		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Schedule B.1 – In-bank Manning's 'n' for MPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Maigue	01MGU13451 to 01MGU00072	0.030	Determined on a case by case basis using photos, videos and survey drawing	Land use EPA data has been used for assigning the floodplain roughness.
Barnakyle River	02BAR08103 to 02BAR00265 and 02BAR02511 to 01BAR00000	0.051		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Annex C – Model Calibration Summary Note

The aim of this technical note is to describe the calibration methodology applied to the S06 model and report on the results.

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F).

The results of this analysis concluded that the model could be calibrated and verified, along a reach of the River Maigue within the Adare AFA, to two historical events.

Calibration and verification of the model along a reach of the River Maigue within the Adare AFA to two historical events

Calibration Methodology:

Calibration and verification of the model was found to be possible using hydrometric data recorded at a three gauging stations on the River Maigue (Castleroberts U_S 24008, Adare Manor 24009 and Adare Quay D_S 24062) for two historical events (November 2009 and January 2008). The gauging stations are illustrated in Figure C1 below.

To facilitate the calibration process, the S06 hydraulic model was truncated to only cover the reach of River Maigue within the Adare AFA. All historical calibration runs were carried out using this truncated model. As both events were out of bank, the models were run in 1D/2D. Out-of-bank main stem calibration between stations 24008 and 24009 was completed using the November 2009 historical event by inputting the gauged flows at 24008 (for HEP node number see calibration spreadsheet) and comparing the modelled water levels with the gauging station level at station 24009. As this reach is tidally influenced, the downstream boundary of the model was taken from the November 2009 measured stage at 24062.

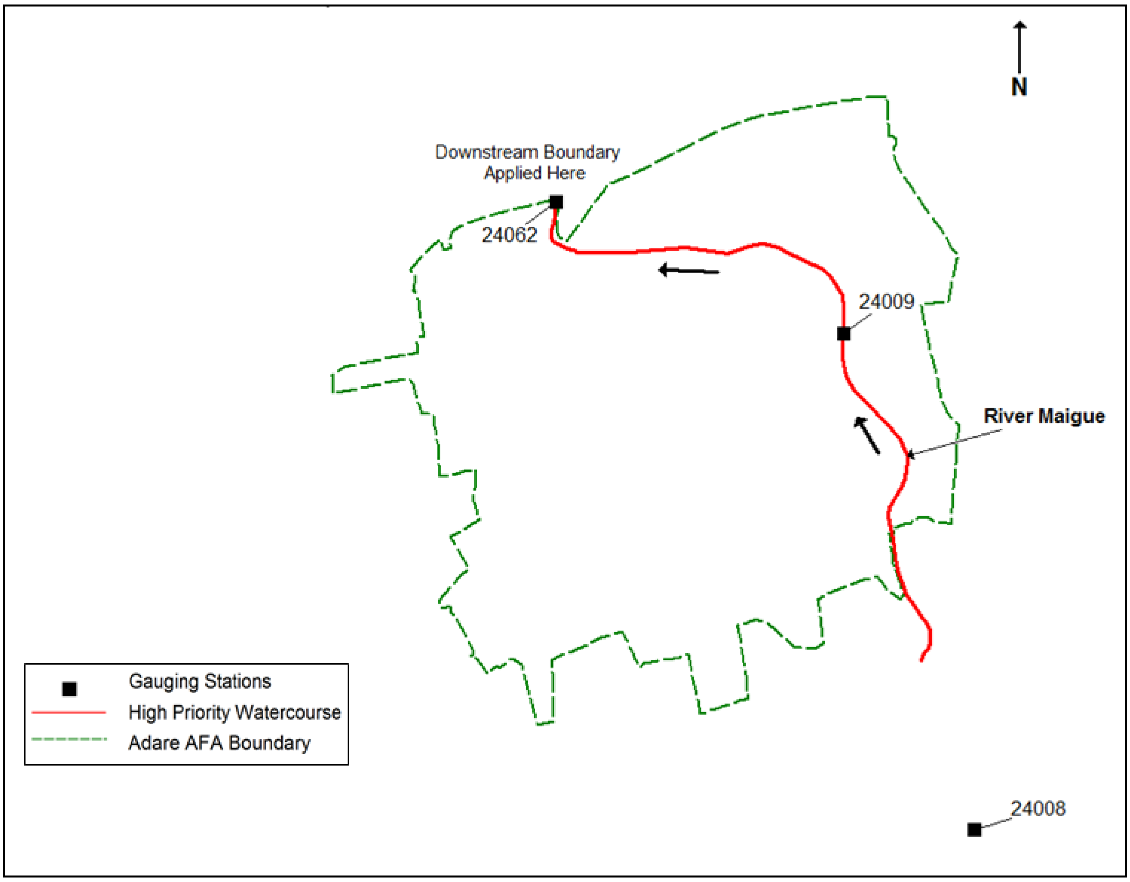


Fig C.1: S06 – Calibration Map

Calibration of the model to one historical event

The results of the calibration can be seen in Table C.1 for peak levels and in Figure C.2 for the stage hydrographs.

Table C.1: Historical Flood Events at Gauging Station 24009

Event	Historical Flood Event	Model maximum stage (m OD*)	Observed maximum stage (m OD*)	Difference (mm)
Out-of-bank	November 2009	4.080	3.896	+184

(* Datum is taken for Malin Head)

The stage results in Table C.1 indicate that the predicted peak water level replicate the November 2009 event within the acceptable range. There is a difference of 184mm between the modelled and observed water levels. The results would suggest that the channel cross section geometry and roughness parameters set in the model provide a reasonable representation of the hydraulics in the river channel along this reach. There is also a good fit on the times to peak with no time difference between the observed time to peak and the modelled time to peak as illustrated in Figure C.2.

As can be seen from Figure C.2, the lower range of the tidal curve of the predicted stage is distorted. This distortion originates from data provided for the downstream boundary. This data was recorded at GS 24062 which is upstream of a number of structures. The structures have a dampening effect on the recorded levels at the lower range of the tidal curve. Therefore a comparison of levels was only made on the peaks.

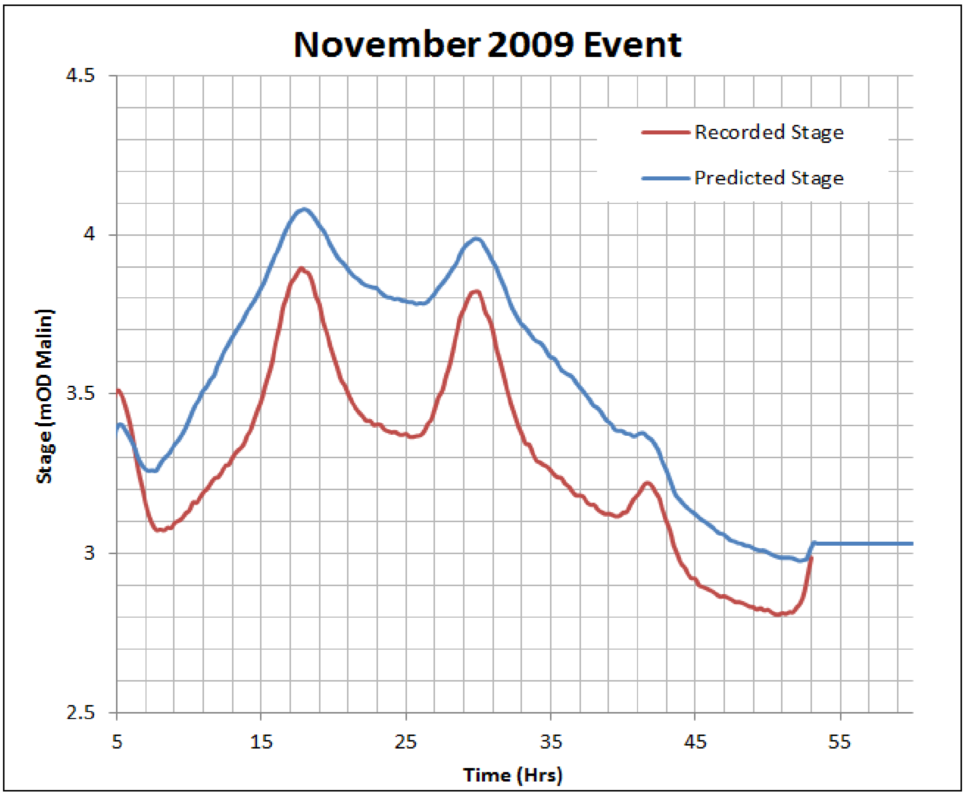


Figure C.2 - Modelled and observed water levels at gauging station 24009 for the 2009 event

Verification of the model to one historical event

An event that occurred in January 2008 was used to verify the model calibration. The methodology used for the verification is the same as for the calibration event.

The modelled and observed water levels for the January 2008 event are reported in Table C.2.The results suggest that the model replicates the January 2008 flood event successfully with the difference between modelled stage and observed stage of 170mm.

Table C.2: Historical Flood Events at Gauging Station 24009

Event	Historical Flood Event	Model maximum stage (m AD*)	Observed maximum stage (m AD*)	Difference (mm)
Out-of-bank	January 2008	4.342	4.165	+170

(* Datum is taken for Malin Head)

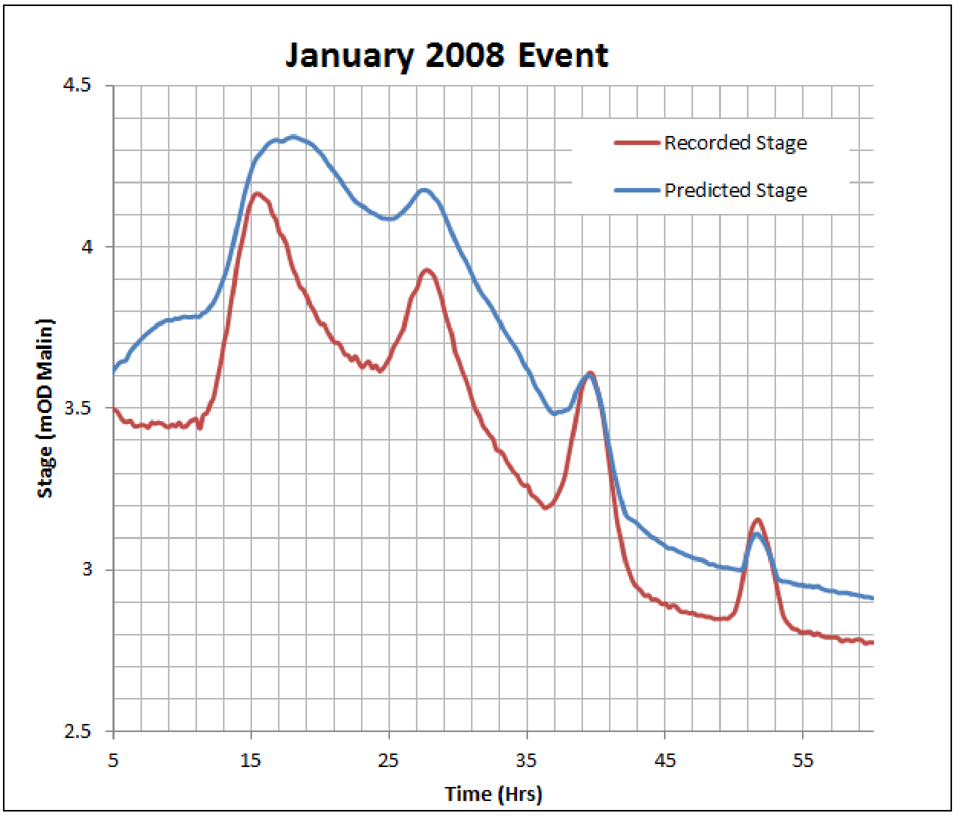


Figure C.2 - Modelled and observed water levels at gauging station 24009 for the 2008 event

Conclusions

It was possible to calibrate the model along the reach of the River Maigue within the Adare AFA for one out-of-bank historical event and to verify the model for one historical out-of-bank event.

The results suggest that the model calibrates well with the result within the acceptable range of +/-0.2m for a HPW. The calibration was successfully verified with only 170mm stage difference between the modelled peak water level and observed peak water level. There is also a good fit on the times to peak with no time difference between the observed time to peak and the modelled time to peak in both the calibration and verification events.

Annex D - Hydraulic Model files

Mainstem and Tributary (Barnakyle)

ISIS files	
Model geometry (.dat) and associated files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Design runs – Fluvial and Tidal scenarios:** **Fluvial Mainstream** S06_Q10_Mi_Dsn_Iss2_Final.DAT S06_Q10_FluMainMi_C_Des_IssV6.ief S06_Q100_FluMainMi_C_Des_IssV6.ief S06_Q1000_FluMainMi_C_Des_IssV6.ief **Tributary** S06_Q10_Mi_Dsn_Iss2_Final.DAT S06_Q10_FluTribMi_C_Des_IssV6.ief S06_Q100_FluTribMi_C_Des_IssV6.ief S06_Q1000_FluTribMi_C_Des_IssV6.ief **Tidal** S06_Q10_Mi_Dsn_Iss2_Final.DAT S06_Q10_TiMi_C_Des_IssV6.ief S06_Q1000_TiMi_C_Des_IssV6.ief S06_Q200_TiMi_C_Des_IssV6.ief

Hydrological Inflow files	**Design runs** DS_10yr.IED DS_100yr.IED DS_200yr.IED DS_1000yr.IED S06_S5_R1.IED S06_S5_R2.IED S06_S6_R1.IED S06_S11_R1.IED S06_S11_R2.IED S06_S12_R1.IED S06_S14_R1.IED S06_S15_R1.IED S06_S15_R2.IED S06_S3_R1_1996.IED S06_S3_R1_1999.IED S06_S3_R1_2008_Trunc.IED S06_S3_R1_2009.IED S06_S3_R1_2009_Trunc.IED S06_S3_R2_CAL1.IED

TUFLOW files	
TUFLOW Control Files (.tcf) and associated files (e.g.: ecf, tgc, tbc)	**Design runs – Fluvial and Tidal Scenarios** **Fluvial Mainstream** S06_Q10_FluMainMi_C_Des_IssV6.tcf S06_Q100_FluMainMi_C_Des_IssV6.tcf S06_Q1000_FluMainMi_C_Des_IssV6.tcf **Fluvial Tributary** S06_Q10_FluTribMi_C_Des_IssV6.tcf S06_Q100_FluTribMi_C_Des_IssV6.tcf S06_Q1000_FluTribMi_C_Des_IssV6.tcf **Tidal** S06_Q10_TiMi_C_Des_IssV6.tcf S06_Q100_TiMi_C_Des_IssV6.tcf S06_Q1000_TiMi_C_Des_IssV6.tcf
Grid Orientation file	2d_loc_S06_D1_0-01.TAB
Material files	2d_mat_S06_MPW_0-01.mif 2d_mat_S06_NTF_0-01.mif S06_landuse.tmf
Zpt files, model DTM (.asc)	S06_MPW_SAR.asc S06_splice_LiDAR.asc

Breaklines files	2d_zlr_S06_D2_banksfromLiDAR_0-04.MIF 2d_zlr_S06_banksfromLiDAR_0-01.MIF 2d_zlr_S06_DSdef_0-01.mif 2d_zlr_S06_defencesfromsurvey_0-01.MIF 2d_zsh_LiDARfill_S06_D2_0-01.MIF
Boundary files	2d_bc_hxi_S06_barn_0-03.MIF 2d_bc_hxi_S06_0-03.MIF 2d_bc_hxe_S06_0-01.mif
Flow/Head files in bc_dbase	NA
Initial Water Level files	NA
Time Series Files	NA
One dimensional network files	1d_isis_nodes_S06_combined_0-03.MIF
Available 2D result files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

SR No.	Model file name		Start Time	End Time	Advanced Options /Other information	
			Fluvial Mainstem			
1	S06_Q10_FluMainMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
2	S06_Q100_FluMainMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
3	S06_Q1000_FluMainMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
			Fluvial Tributary			
1	S06_Q10_FluTribMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation

2	S06_Q100_FluTribMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
3	S06_Q1000_FluTribMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
7	S06_Q200_FluTribMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
Tidal:						
8	S06_Q10_TiMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation
10	S06_Q1000_TiMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation

15	S06_Q200_TiMi_C_Des_IssV6.ief	S06_Qxxx_Mi_Dsn_Issv6.DAT	3	60	dflood set to 10. Maxitr set to 21. Automated Priesmann Slots for river sections = "On". All other run parameters = default.	Convergence within manufacturer tolerance for the majority of the simulation

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 21 to improve model stability.*
Dflood	Increased to 10 to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Fluvial and Coastal Hydraulic Modelling Report	
1. Basic Model Information	
1.1 General Information	
Model ID:	S09
Unit of Management	24
AFAs included in the Model	Foynes
Primary Watercourses / Water Bodies	River Foynes Ardineer Ardaneer Durnish Corgrig Coolnavee
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A2.1
Model Location	Hydraulics Report Unit of Management 24 – Figure 2
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B5 – Figure B5.1

2. Survey Data and Base Mapping	
2.1 Base Mapping:	OSi data base mapping at scale 1:50k Reference: OS1214_D_BW
2.2 DTM for 2D Model Domain:	**Within AFAs:** LiDAR with 2m resolution (horizontal) and 200mm accuracy (vertical) has been used for the 2D domain of the hydraulic model.
	Outside AFAs: The supplied LiDAR data covers the area to be modelled outside the AFA. Therefore this has been used instead of SAR, given the much greater accuracy.
2.3 River Channel/Structures Survey	The modelling methodology for all structures within the modelled reaches is detailed in Annex B, and the variety of structures is detailed in Section 3.4. Number of cross sections in the model: 173
2.4 Defence Asset Survey Data	There is one formal defence scheme present in the Foynes area along the Robertstown River to the east. This river does not form part of this study but these defences stop tidal overtopping into the Foynes AFA and the channels of Durnish and Ardaneer. These defences have been represented in the model. Further details on the defences are available in the defence asset database.
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D domain : ISIS v3.7.0.223**
	2D domain(s): TUFLOW Build 2013-12-AB-iDP-w64
3.2 Model Area / Extent:	The areal extent of the model and its schematisation are shown in Annex A.

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary
2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
River Foynes	03FOY	03FOY00560	03FOY00000
River Foynes	02FOY	02FOY00532	02FOY00000
River Foynes	01FOY	01FOY00342	01FOY00000
Ardineer	01ANC	01ANC00540a	01ANC00000
Ardaneer	01ARD	01ARD00928	01ARD00000
Durnish	01DUR	01DUR00969	01DUR00000
Coolnavee	01CLN	01CLN00910	01CLN00000
Corgrig	01CRG	01CRG01708	01CRG00000
Flood Relief Channel	01FRC	01FRC00282a	01FRC00000

Total model HPW length (km):	**7.82**	**Total model MPW length (km):**	**0.0**

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Structure	Included		Number
Culverts:	☒	How many?	16
Bridges:	☒	How many?	5
Fixed crest weirs:	☒	How many?	1
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☐	How many?	0
Locks:	☐	How many?	0
Dams:	☐	How many?	0

Other (describe):

Orifice x 8 (2 x flapped at tidal outfalls)

3.5 Floodplain Schematisation: The model is a single 2D domain, covering all of the watercourses, all of which are classed as HPW. Therefore the 2D domain out-of-bank areas have been modelled using TUFLOW with a grid size of 5m.

<table>
<tr><td rowspan="4">3.6 2D Domain Grid Size:</td><td colspan="3">The number of 2D domains defined and the grid sizes of each 2D model domain are as follows:</td></tr>
<tr><td colspan="3">Number of 2D domains: 1</td></tr>
<tr><td>Domain 1:</td><td>Grid cell size (m) 5</td><td>Area (km^2) 3.730</td></tr>
<tr><td colspan="3">2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.</td></tr>
<tr><td>3.7 Model Breaklines in the 2D Domain:</td><td colspan="3">Banktops were included on one channel, the Coolnavee, to stabilise the model.</td></tr>
<tr><td>3.8 Floodplain Structures in the 2D Domain</td><td colspan="3">All structures are represented in the 1D domain.</td></tr>
<tr><td>3.9 Hydraulic Roughness</td><td colspan="3">Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:</td></tr>
<tr><td rowspan="2">HPW in-bank</td><td>Minimum 'n' value:</td><td colspan="2">0.040</td></tr>
<tr><td>Maximum 'n' value:</td><td colspan="2">0.060</td></tr>
<tr><td rowspan="10">Floodplain (TUFLOW Model)</td><td colspan="3">Manning's 'n' for out of bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:</td></tr>
<tr><td>Land use</td><td colspan="2">Manning's 'n' value</td></tr>
<tr><td>Buildings</td><td colspan="2">0.100</td></tr>
<tr><td>Short grass, parks</td><td colspan="2">0.035</td></tr>
<tr><td>General Urban</td><td colspan="2">0.060</td></tr>
<tr><td>General Rural</td><td colspan="2">0.045</td></tr>
<tr><td>Pastures</td><td colspan="2">0.035</td></tr>
<tr><td>Dense Vegetation</td><td colspan="2">0.080</td></tr>
<tr><td>Roads</td><td colspan="2">0.025</td></tr>
<tr><td>Water bodies</td><td colspan="2">0.020</td></tr>
<tr><td>3.10 Spill Units</td><td colspan="3">Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain).
Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR.
Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.
Spill units have not been applied to structures in 2D areas where flow may not return directly to the channel.</td></tr>
<tr><td>3.11 Model Boundaries - Inflows</td><td colspan="3">Full details of the flow estimates and flow hydrographs are provided in the Hydrology Report appendices B5 and A2.6. Summary details are included within this section.</td></tr>
</table>

(a) Current Situation		The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for the current situation.							
HEP Reference Name	**Input Node in the Hydraulic Model**	**Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
24_001_1	01DUR00969	0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.5
24_001_2	01ARD00928	0.7	0.9	1.0	1.1	1.3	1.4	1.6	1.9
24_1419_1	01CRG01708	0.8	1.1	1.3	1.4	1.6	1.8	2.0	2.3
24_1419_2	01CRG00961	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5
24_1419_3	01CRG00788	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9
24_1419_5	01CRG00069	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
24_1397_1	03FOY00264	0.7	0.9	1.1	1.2	1.4	1.5	1.6	1.9
24_248_1	01CLN00910	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.								
HEP Reference Name	**Input Node in the Hydraulic Model**	**MRFS Annual Exceedance Probability**							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
24_001_1	01DUR00969	0.6	0.8	1.0	1.1	1.2	1.3	1.4	1.8
24_001_2	01ARD00928	0.8	1.1	1.2	1.3	1.6	1.7	1.9	2.3
24_1419_1	01CRG01708	1.0	1.3	1.6	1.7	1.9	2.2	2.4	2.8
24_1419_2	01CRG00961	0.2	0.2	0.4	0.4	0.4	0.5	0.5	0.6
24_1419_3	01CRG00788	0.4	0.5	0.6	0.7	0.8	0.8	1.0	1.1
24_1419_5	01CRG00069	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.4
24_1397_1	03FOY00264	0.8	1.1	1.3	1.4	1.7	1.8	1.9	2.3
24_248_1	01CLN00910	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.5

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.			
HEP Reference Name	**Input Node in the Hydraulic Model**	**HEFS Annual Exceedance Probability**		
		10%	**1%**	**0.1%**
24_001_1	01DUR00969	1.0	1.4	2.0
24_001_2	01ARD00928	1.3	1.8	2.5
24_1419_1	01CRG01708	1.7	2.3	3.0
24_1419_2	01CRG00961	0.4	0.5	0.7
24_1419_3	01CRG00788	0.7	0.9	1.2
24_1419_5	01CRG00069	0.3	0.3	0.4
24_1397_1	03FOY00264	1.4	2.0	2.5
24_248_1	01CLN00910	0.3	0.4	0.5

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:							
	A static low water tidal boundary was used for the HEP calibration. All other models have tidal HTBDY curves as boundary units. Tidal level hydrographs for Foynes were produced for a series of design events using ICPSS extreme tidal peak levels data. The time series were set up as boundary conditions for the hydraulic model along the coastal boundary of the hydraulic model. Full details on how these tidal level hydrographs were derived are provided in Appendix D of the main Hydraulics Report. Peak tidal levels are summarised in the table below for the current and future situations. For the wave overtopping model, wave overtopping hydrographs have been applied directly to the hydraulic model using a flow versus time boundary along the landward side of the flood defences. The hydrographs vary for different points along the defence as shown in Annex F. Full details on how these tidal level hydrographs were derived are provided in section 4.4 of the main Hydraulics Report. The tidal hydrographs applied for wave overtopping are available in Annex F of this report.							
	Current Annual Exceedance Probability							
Peak tidal levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.9
	MRFS Annual Exceedance Probability							
Peak tidal levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.4	3.6	3.7	3.8	4.0	4.1	4.2	4.5
	HEFS Annual Exceedance Probability							
Peak tidal levels (m OD)	**10%**			**0.5%**			**0.1%**	
	4.2			4.7			5.0	

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events	The approach to model calibration is documented in the main Hydraulics Report. The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 Appendix F. A summary of the calibration and verification events along with associated model calibration results is as follows:
Catchment Gauging	Is modelled catchment: Gauged ☐ Ungauged ☒ check one box only
Calibration Events	None are available for this catchment

Verification Events	**Event Date**	**Station Number**	**Difference between Modelled and Observed Water Level (m)**	**Root Mean Square Error**	
				HPW	**MPW**
N/A	N/A	N/A	N/A	N/A	N/A

Conclusion	No calibration or verification to historical events was possible due to their being no historical events recorded.
4.2 Calibration to HEP	It was decided that HEP calibration would not be carried out for this model due to the following reasons: • Catchment is very flat by nature • Uncertainty regarding the flow pattern • Tidally dominated • Presence of interlocking flood relief channels not previously considered in the hydrological analysis The HEP calibration process relies on calibrating to natural watercourses and with hydraulics or tide impacting the hydrology as listed above it was not possible to perform the calibration.
4.3 Fluvial and Tidal Events Simulated	The River Foynes is influenced by the tidal levels along the Shannon Estuary. As such, a joint probability analysis of the coincidence of fluvial flood flows and coastal flood levels was carried out to determine the appropriate combinations of flows and sea levels to be used for the design probability events, as required under Section 6.5.6 of the Stage I Project Brief. Methodology and outcomes of this analysis are detailed in the main Hydraulic Report and in the Hydrology Report. A summary of the joint probability of fluvial and tidal conditions used for the hydraulic modelling in the Foynes AFA is reported in the table below. The fluvial and tidal model runs and results will be the product of both fluvial and tidal elements.

Combination of Fluvial and Tidal Events

	Joint Probability Design Event	**AEP adopted for Fluvial Flows and Tidal Levels**	
Scenario	**Overall AEP**	**Fluvial**	**Tidal**
1	50%	50%	500%
2	50%	50%	50%
3	20%	20%	500%

	4	20%	50%	20%
	5	10%	10%	200%
	6	10%	50%	10%
	7	5%	5%	100%
	8	5%	50%	5%
	9	2%	2%	50%
	10	2%	50%	2%
	11	1%	1%	20%
	12	1%	20%	1%
	13	0.5%	0.5%	10%
	14	0.5%	10%	0.5%
	15	0.1%	0.1%	2%
	16	0.1%	2%	0.1%

4.4 Model Sensitivity	Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. The sensitivity runs were carried out for the 1% AEP fluvial dominated event with the corresponding tidal event from the joint probability study in all cases, with the only exception of the tests on the downstream boundary conditions, which were carried out for the 0.5% AEP tidal dominated events with the corresponding fluvial event (see Section 4.3). Sensitivity test results are provided in the following tables. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work.

+20% Manning's n	**Watercourse**	**Average Water Level Difference (m)**	**Maximum Water Level Difference (m)**	**Cross-section / Reach where the Maximum Difference occurs**
	01CRG	0.02	0.09	01CRG00961
	03FOY	0.00	0.00	N/A
	02FOY	0.05	0.05	Whole reach
	01FOY	0.04	0.05	Whole reach
	01ARD	0.01	0.05	01ARD00928-854
	01ANC	0.06	0.06	Whole reach
	01DUR	0.01	0.06	01DUR00902
	01CLN	0.01	0.04	01CLN00739

-20% Manning's n	**Watercourse**	**Average Water Level Difference**	**Maximum Water Level Difference**	**Cross-section where the Maximum Difference occurs**
	01CRG	0.02	0.09	01CRG00961
	03FOY	0.00	0.00	N/A
	02FOY	0.05	0.05	Whole reach
	01FOY	0.04	0.05	Whole reach
	01ARD	0.01	0.05	01ARD00928-854
	01ANC	0.06	0.06	Whole reach
	01DUR	0.01	0.06	01DUR00902
	01CLN	0.01	0.04	01CLN00739

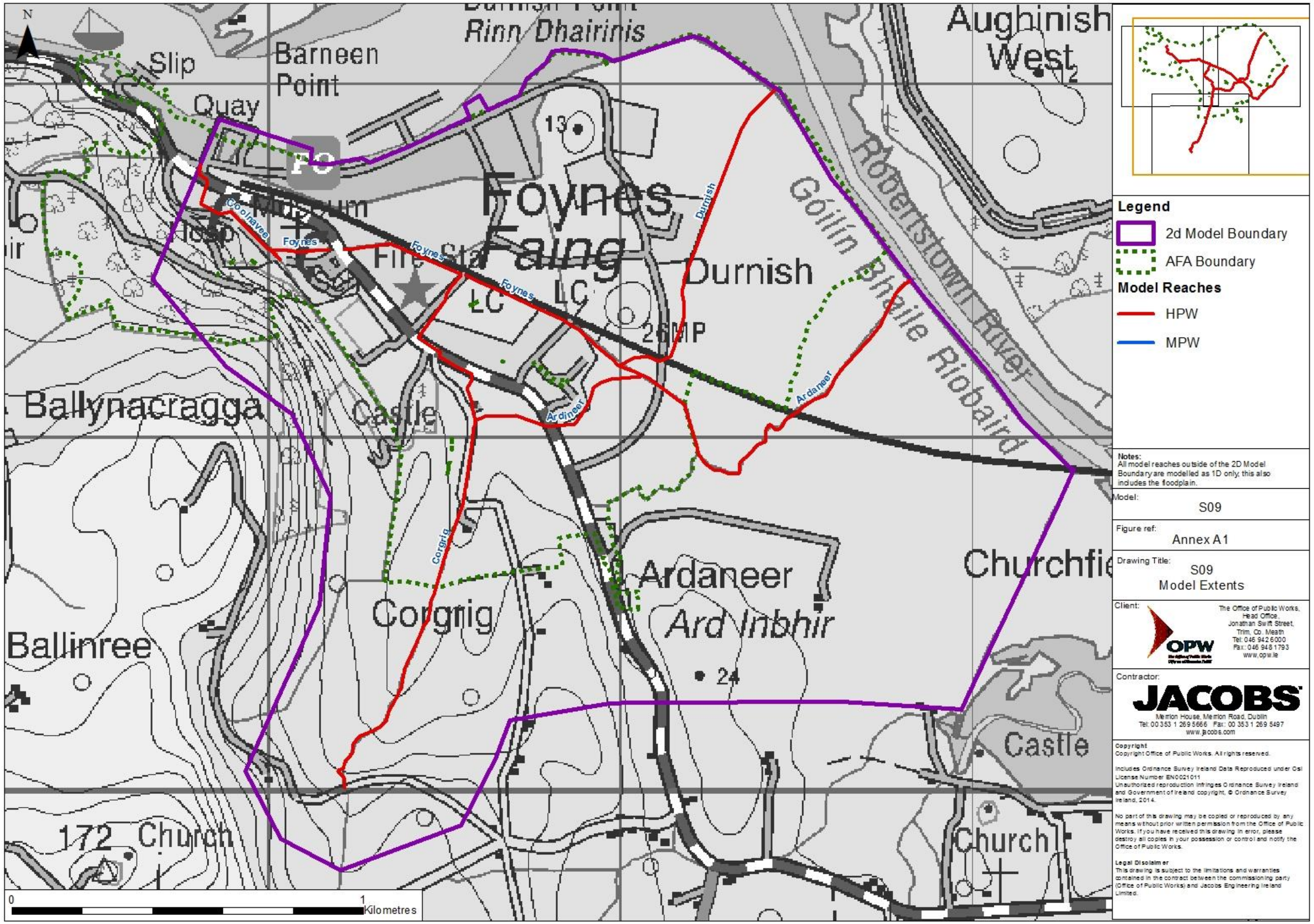
+20% inflows	Watercourse	Average Water Level Difference	Maximum Water Level Difference	Cross-section where the Maximum Difference occurs
	01CRG	0.02	0.09	01CRG00961
	03FOY	0.00	0.00	N/A
	02FOY	0.05	0.05	Whole reach
	01FOY	0.04	0.05	Whole reach
	01ARD	0.01	0.05	01ARD00928-854
	01ANC	0.06	0.06	Whole reach
	01DUR	0.01	0.06	01DUR00902
	01CLN	0.01	0.04	01CLN00739
-20% inflows	**Watercourse**	**Average Water Level Difference**	**Maximum Water Level Difference**	**Cross-section where the Maximum Difference occurs**
	01CRG	-0.02	-0.11	01CRG00961
	03FOY	0.00	0.00	Whole reach
	02FOY	-0.05	-0.05	Whole reach
	01FOY	-0.04	-0.04	Whole reach
	01ARD	-0.01	-0.04	01ARD00928-854
	01ANC	-0.04	-0.04	Whole reach
	01DUR	-0.01	-0.05	01DUR00902
	01CLN	-0.01	-0.04	01CLN00739
Afflux at Key Structure	No structures were identified with significant afflux within the AFA.			
Downstream Conditions Duration of surge component of tidal boundary is increased by 100% (i.e. 33hrs)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was increased by 100% (i.e. 33 hours). Model results show that due to increase in tidal surge duration a water level increase response can be seen up to 1.3 km upstream from the boundary. This is due to the shallow gradient of the River reaches in this AFA. Upstream of Node 01CRG00550 the effect is negligible.			
Downstream Conditions Duration of surge component of tidal boundary is decreased by 50% (i.e. 16.5hrs)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was decreased by 50% (i.e. 16.5 hours). Model results show that water levels are not affected by the 50% decrease in surge duration.			
4.5 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D.			

5. Hydraulic Model Outputs	
5.1 Mapping	Model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. These include mapping outputs covering: • Flood extent • Flood depth and velocity • Flood hazard • Wave overtopping Flood mapping outputs corresponding to the **defended** current scenario for the 10%, 1% and 0.1% AEP fluvial dominated flood events with the corresponding tidal boundary conditions and to the **defended** current scenario for the 10%, 0.5% and 0.1% AEP tidal dominated events with the corresponding fluvial events are shown in Annex E for flood extent and depth only.

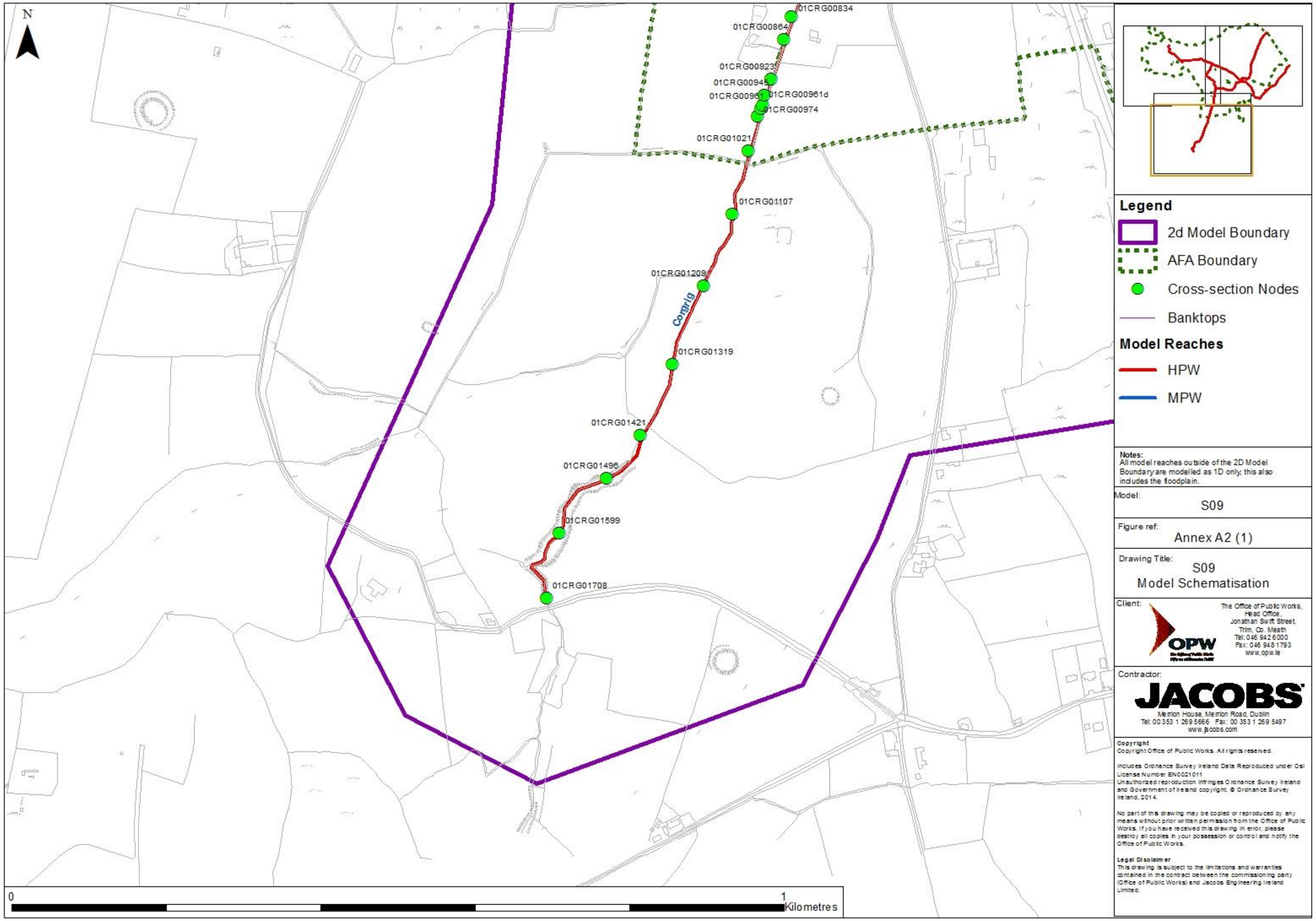
6. Key Model Assumption and Limitations

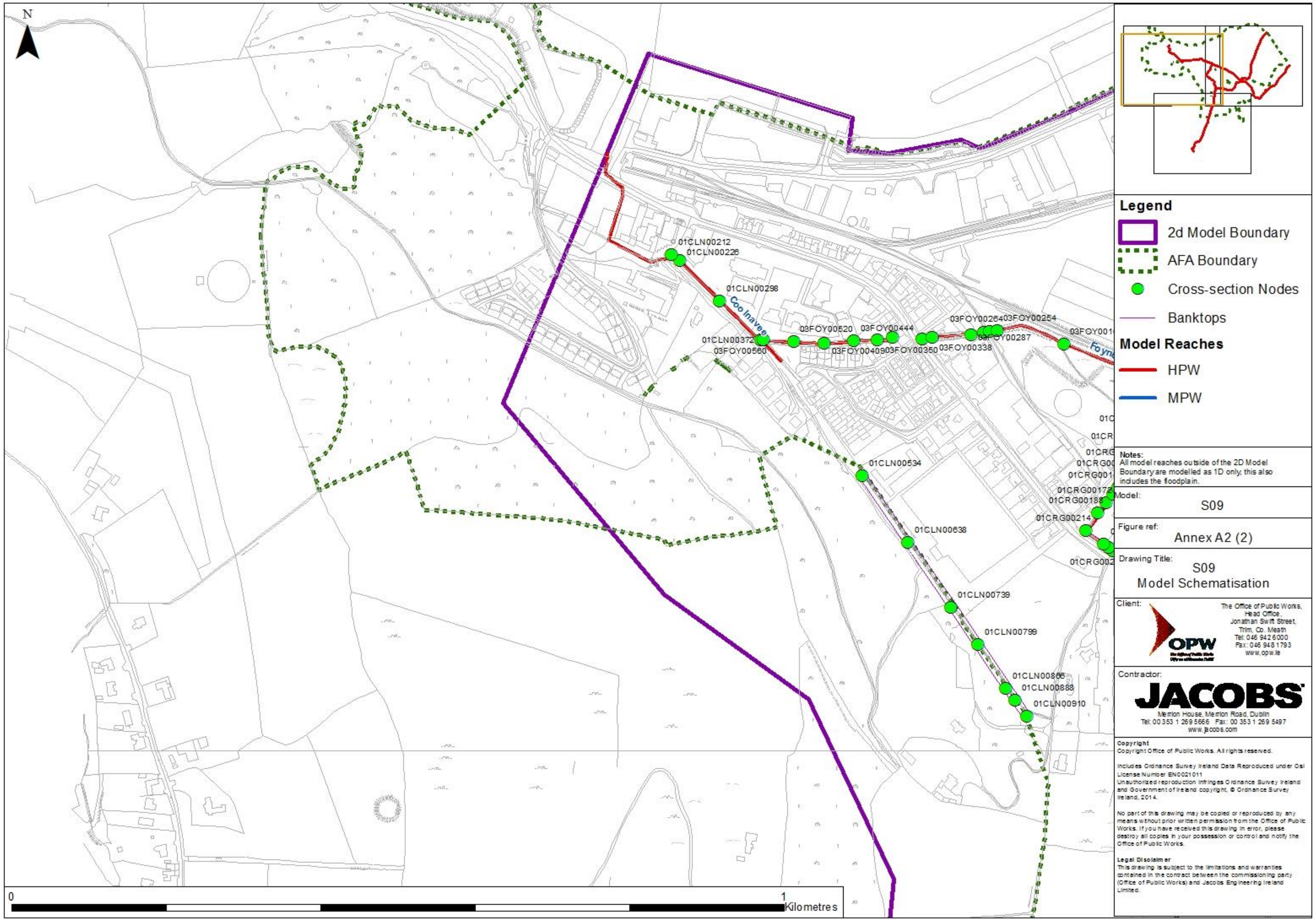
- The watercourses that comprise Model S09 include the four minor streams flowing through the Foynes AFA; two discharging to the Shannon Estuary at Foynes Harbour and two to the Robertstown River.
- Historical calibration has not been completed as no historical records were available to inform such a calibration.
- There is one formal defence scheme present in the Foynes area along the Robertstown River to the east. This river does not form part of this study but these defences stop tidal overtopping into the Foynes AFA and the channels of Durnish and Ardaneer. These defences have not been directly represented in the model. Further details on the defences are available in the defence asset database.
- Spill units have been used to represent culvert inlet and outlet units for some culverts along the Corgrig Reach to improve model stability.

Annex A – Model Extent and Schematisation Maps
Annex A1 – Model Extent



Annex A2 – Schematisation Maps




N
01CLN00212
01CLN00226
01CLN00298
Coolnaveel
01CLN00372
03FOY00560
03FOY00520
03FOY00444
03FOY00409
03FOY00350
03FOY00338
03FOY00264
03FOY00254
03FOY00287
Foyn
01CLN00534
01CLN00638
01CLN00739
01CLN00799
01CLN00866
01CLN00888
01CLN00910
01CRG00172
01CRG00188
01CRG00214
0
1
Kilometres
Legend
2d Model Boundary
AFA Boundary
Cross-section Nodes
Banktops
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only; this also includes the floodplain.
Model:
S09
Figure ref:
Annex A2 (2)
Drawing Title:
S09
Model Schematisation
Client:
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie
Contractor:
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com
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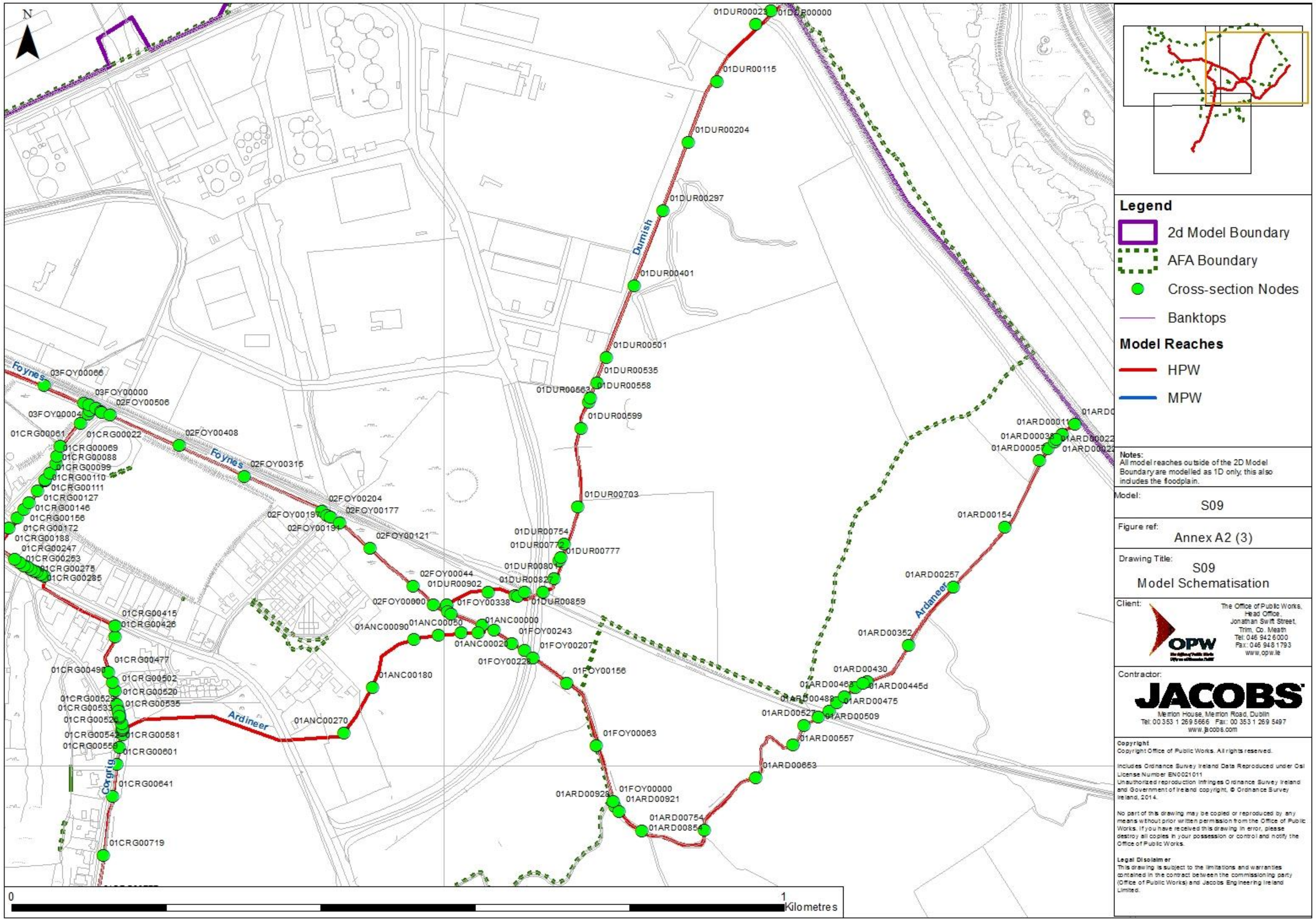
OPW

JACOBS



N
Foynes
Durnish
Ardineer
Ardaneer
Corgrig
Legend
2d Model Boundary
AFA Boundary
Cross-section Nodes
Banktops
Model Reaches
HPW
MPW
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only; this also includes the floodplain.
Model:
S09
Figure ref:
Annex A2 (3)
Drawing Title:
S09
Model Schematisation
Client:
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie
Contractor:
JACOBS
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com
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0
1
Kilometres

Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for Corgrig

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24FOYC00095D	01CRG00961bu	Flat Deck Bridge	USBPR Bridge with spill	Y
24FOYC00078D	01CRG00788bu	Flat Deck Bridge	USBPR Bridge with spill	Y
24FOYC00055X	01CRG00559	Weir	Round Nosed Weir	Y
24FOYC00053J	01CRG00542	Compound culvert structure	Symmetrical conduit units	Y
24FOYC00052D	01CRG00533bu	Flat Deck Bridge	USBPR Bridge with spill	Y
24FOYC00052I	01CRG00526	Culvert	Circular Conduit Units with spill inlet and outlet	Y
24FOYC00049I	01CRG00502	Culvert	Rectangular Conduit Units with spill inlet and outlet	Y
24FOYC00041I	01CRG00415	Culvert	Symmetrical Conduit Units with culvert inlet and outlet	Y
24FOYC00028I	01CRG00279	Culvert	Circular Conduit Units with spill for inlet and a culvert outlet	Y
24FOYC00027D	01CRG00264	Bridge	Modelled as an orifice	Y
24FOYC00025I	01CRG00247	Culvert	Symmetrical Conduit Units with culvert inlet and outlet	Y
24FOYC00018I	01CRG00172	Culvert	Circular Conduit Units with culvert inlet and outlet	Y
24FOYC00012I	01CRG00111	Bridge	Orifice Unit	Y
24FOYC00009I	01CRG00088	Bridge	Orifice Unit	Y

Schedule A.2 - Structure Schedule for Ardaneer

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24FOYF00052I	01ARD00509	Culvert	Rectangular Conduit Units with culvert inlet and outlet	Y
24FOYF00045D	01ARD00445	Bridge	Orifice with spill	Y
24FOYF00004D	01ARD00022	Bridge	Orifice with spill	Y
24FOYF00001I	01ARD00000	Flapped outfall	Modelled as an orifice with a flap	Y

Schedule A.3 - Structure Schedule for Durnish

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24FOYD00085I	01DUR00859, 01DUR00827	Culverts	Orifice units to represent two perpendicular culverts taking flow under railway and motorway	Y
24FOYD00078D	01DUR00777	Culvert	Circular conduit units with culvert inlet and outlet	Y
24FOYD00057D	01DUR00558	Culvert	Circular conduit units with culvert inlet and outlet	Y
24FOYD00001I	01DUR00000	Flapped outfall	Flapped Orifice unit	Y

Schedule A.4 - Structure Schedule for Coolnavee

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24FOYN00054	01CLN00534	Culvert	Modelled as a culvert with inlet unit, and a spill for the outlet.	Y
24FOYN00016I	01CLN00212	Culvert	Modelled as a culvert with spill for the inlet and the outlet.	Y

Schedule A.5 - Structure Schedule for Relief Channels

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
N/A	01ANC00540	Culvert	Modelled as a culvert with a spill for the outlet.	Y
N/A	01FRC00282a	Culvert	Modelled as an orifice	Y

Schedule A.6 - Structure Schedule for River Foynes

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24FOYA00127I	03FOY00391	Culvert	Rectangular Conduit Units with culvert inlet and spill for outlet	Y
24FOYA00114E	03FOY00264	Flat Deck Bridge	USBPR Bridge with spill	Y
24FOYA00087E	02FOY00518	Arch Bridge	Arch Bridge with spill	Y

24FOYA00055D	02FOY00197	Arch Bridge	Arch Bridge	Y
24FOYA00024I	01FOY00228	Culvert	Circular Conduit Units with culvert inlet and outlet	Y

Schedule B.1 – Manning's 'n' for HPW Network

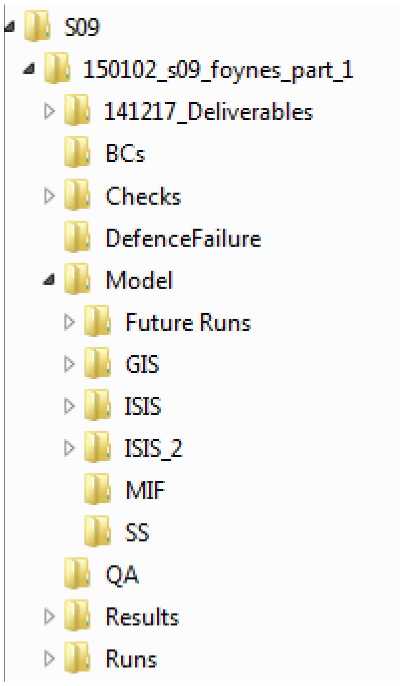
River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
Foynes	03FOY00560-01FOY00000	0.045	Determined on a case by case basis using photos, videos and survey drawing	Based on OSi NTF land use polygons
Corgrig	01CRG01708-01CRG00000	0.04		
Durnish	01DUR00969-01DUR00000	0.04		
Ardaneer	01ARD00928-01ARD00000	0.04		
Coolnavee	01CLN00910-01CLN00000	0.042		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.8

Annex C – Model Calibration

The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report. As there was no gauging station located within the AFA there was no historical data available to calibrate to.

Annex D - Hydraulic Model Files

Model Files Folders Structure	
ISIS/TUFLOW	

ISIS Files	
Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Calibration Runs** N/A **Design Runs – Current Scenario:** S09_Foynes_Mi_C_Des_ISS16.DAT S09_Q10_CoMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD S09_Q10_FluMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD S09_Q200_CoMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD S09_Q1000_CoMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD S09_Q100_FluMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD S09_Q1000_FluMi_C_Des_ISS16.ZZL, ZZU, ZZX, ZZD **Sensitivity Runs – Current Scenario** S09_Q100_FluMi_C_Sen_FlIn_ISS16.IEF S09_Q100_FluMi_C_Sen_FlDe_ISS16.IEF S09_Q100_FluMi_C_Sen_RoIn_ISS16.IEF S09_Q100_FluMi_C_Sen_RoDe_ISS16.IEF S09_Q100_FluMi_C_Sen_SurIn_ISS16.IEF S09_Q100_FluMi_C_Sen_SurDe_ISS16.IEF

Hydrological Inflow Files	**Design Runs – Current Scenario:** Q10_T0.5.IED Q10_T200.IED Q100_T5.IED Q200_T10_v02.IED Q1000_T50.IED **Sensitivity Runs – Current Scenario** Q100_T5_Sen_FlDe.IED Q100_T5_Sen_FlIn.IED Q10_T200_Sen_SurDe_v2.IED Q10_T200_Sen_SurIn_v2.IED
TUFLOW Files	
TUFLOW Control Files (.tcf) and Associated Files (e.g.: ecf, tgc, tbc)	**Design Runs – Current Scenario:** S09_Q10_CoMi_C_Des_ISS16.TCF S09_Q10_FluMi_C_Des_ISS16.TCF S09_Q200_CoMi_C_Des_ISS16.TCF S09_Q1000_CoMi_C_Des_ISS16.TCF S09_Q100_FluMi_C_Des_ISS16.TCF S09_Q1000_FluMi_C_Des_ISS16.TCF S09_Foynes_v14-A.TBC S09_Foynes_14-A.TGC **Sensitivity Runs – Current Scenario** S09_Q100_FluMi_C_Sen_FlIn_ISS16.TCF S09_Q100_FluMi_C_Sen_FlDe_ISS16.TCF S09_Q100_FluMi_C_Sen_RoIn_ISS16.TCF S09_Q100_FluMi_C_Sen_RoDe_ISS16.TCF S09_Q100_FluMi_C_Sen_SurIn_ISS16.TCF S09_Q100_FluMi_C_Sen_SurDe_ISS16.TCF
Grid Orientation Files	2d_loc_S09_L.shp
Material Files	**Design Runs – Current Scenario:** S09_Foynes_MAT.tmf **Sensitivity Runs – Current Scenario** S09_Foynes_MAT+20.tmf S09_Foynes_MAT-20.tmf
Zpt Files, Model DTM (.asc)	Askeato2m_dtm.asc
Breaklines Files	2d_zln_banktop_CLN_L.shp 2d_zln_banktop_CLN_P.shp

Boundary Files	2d_bc_S09_Foynes_v5_L.shp
Flow/Head Files in bc_dbase	2d_bc_S09_Foynes_v28_L.shp 2d_bc_Tide_L.shp
Initial Water Level Files	No initial water level file was used for 2D domain
Time Series Files	No time series files provided to the 2d domain.
One Dimensional Network Files	1d_x1d_ISIS_nodes_S09_Foynes_v17.shp
Available 2D Result Files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs						
1	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the CoMi_Q10 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
2	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the FluMi_Q10 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
3	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the FluMi_Q100 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
4	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the CoMi_Q200 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
5	S09_Foynes_Mi_C_ISS3.DAT	0	30	0.5/1	Running with the CoMi_Q1000 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
6	S09_Foynes_Mi_C_ISS3.DAT	0	30	0.5/1	Running with the FluMi_Q1000 Event	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
Sensitivity Analysis						
7	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the FlIn Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
8	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the FlDe Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking

9	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the RoIn Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
10	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the RoDe Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
11	S09_Foynes_Mi_C_ISS16.DAT	0	60	0.5 sec 1D 1 sec 2D	Running with the SurIn Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking
12	S09_Foynes_Mi_C_ISS16.DAT	0	30	0.5 sec 1D 1 sec 2D	Running with the SurDe Sensitivity	Some minor flow localised non-convergence associated with the abrupt changes in tidal locking

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Htol	Parameter has been changed to 0.005 to aid stability in a tidally dominated model.
Qtol	Parameter has been changed to 0.05 to aid stability in a tidally dominated model.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Annex F - Wave Overtopping tidal hydrographs used as model boundary conditions

Location B

Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000				0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167				0.000	0.000	-2.608	0.000	0.000	-2.596	0.000	0.000	-2.591	0.000	0.000	-2.584	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.574
12.333				0.000	0.000	-1.426	0.000	0.000	-1.333	0.000	0.000	-1.293	0.000	0.000	-1.240	0.000	0.000	-1.199	0.000	0.000	-1.159	0.000	0.000	-1.159
13.500				0.000	0.000	0.157	0.000	0.000	0.323	0.000	0.000	0.394	0.000	0.000	0.489	0.000	0.000	0.561	0.000	0.000	0.633	0.000	0.000	0.633
14.667				0.000	0.000	1.444	0.000	0.000	1.667	0.000	0.000	1.763	0.000	0.000	1.891	0.000	0.000	1.987	0.000	0.000	2.085	0.028	0.012	2.085
15.833				0.002	0.001	2.436	0.008	0.003	2.695	0.066	0.027	2.807	1.287	0.530	2.956	5.809	2.394	3.068	3.869	1.594	3.182	18.720	7.715	3.182
17.000				0.091	0.037	2.833	0.000	0.000	3.105	0.000	0.000	3.222	0.000	0.000	3.378	0.000	0.000	3.496	0.000	0.000	3.615	0.000	0.000	3.615
18.167				0.000	0.000	2.236	0.001	0.001	2.495	0.006	0.002	2.607	0.097	0.040	2.756	0.634	0.261	2.868	3.869	1.594	2.982	18.720	7.715	2.982
19.333				0.000	0.000	0.944	0.000	0.000	1.167	0.000	0.000	1.263	0.000	0.000	1.391	0.000	0.000	1.487	0.000	0.000	1.585	0.000	0.000	1.585
20.500				0.000	0.000	-0.743	0.000	0.000	-0.577	0.000	0.000	-0.506	0.000	0.000	-0.411	0.000	0.000	-0.339	0.000	0.000	-0.267	0.000	0.000	-0.267
21.667				0.000	0.000	-2.226	0.000	0.000	-2.133	0.000	0.000	-2.093	0.000	0.000	-2.040	0.000	0.000	-1.999	0.000	0.000	-1.959	0.000	0.000	-1.959
22.833				0.000	0.000	-2.008	0.000	0.000	-1.996	0.000	0.000	-1.991	0.000	0.000	-1.984	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.974
24.000				0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			1%			0%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.586	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.569	0.000	0.000	-2.562	0.000	0.000	-2.557	0.000	0.000	-2.552	0.000	0.000	-2.552
12.333	0.000	0.000	-1.255	0.000	0.000	-1.203	0.000	0.000	-1.162	0.000	0.000	-1.122	0.000	0.000	-1.069	0.000	0.000	-1.028	0.000	0.000	-0.988	0.000	0.000	-0.988
13.500	0.000	0.000	0.462	0.000	0.000	0.555	0.000	0.000	0.627	0.000	0.000	0.698	0.000	0.000	0.793	0.000	0.000	0.865	0.000	0.000	0.938	0.000	0.000	0.938
14.667	0.000	0.000	1.854	0.000	0.000	1.980	0.000	0.000	2.077	0.000	0.000	2.172	0.000	0.000	2.300	0.004	0.002	2.397	0.015	0.006	2.494	0.635	0.262	2.494
15.833	0.000	0.000	2.913	0.000	0.000	3.060	0.000	0.000	3.172	0.000	0.000	3.284	0.000	0.000	3.433	0.000	0.000	3.545	0.000	0.000	3.659	0.000	0.000	3.659
17.000	0.000	0.000	3.333	0.000	0.000	3.487	0.000	0.000	3.605	0.000	0.000	3.722	0.000	0.000	3.878	0.000	0.000	3.996	0.000	0.000	4.115	0.000	0.000	4.115
18.167	0.000	0.000	2.713	0.000	0.000	2.860	0.000	0.000	2.972	0.000	0.000	3.084	0.000	0.000	3.233	0.000	0.000	3.345	0.000	0.000	3.459	0.000	0.000	3.459
19.333	0.000	0.000	1.354	0.000	0.000	1.480	0.000	0.000	1.577	0.000	0.000	1.672	0.000	0.000	1.800	0.004	0.002	1.897	0.015	0.006	1.994	0.635	0.262	1.994
20.500	0.000	0.000	-0.438	0.000	0.000	-0.345	0.000	0.000	-0.273	0.000	0.000	-0.202	0.000	0.000	-0.107	0.000	0.000	-0.035	0.000	0.000	0.038	0.000	0.000	0.038
21.667	0.000	0.000	-2.055	0.000	0.000	-2.003	0.000	0.000	-1.962	0.000	0.000	-1.922	0.000	0.000	-1.869	0.000	0.000	-1.828	0.000	0.000	-1.788	0.000	0.000	-1.788
22.833	0.000	0.000	-1.986	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.969	0.000	0.000	-1.962	0.000	0.000	-1.957	0.000	0.000	-1.952	0.000	0.000	-1.952
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	AEP								
	10%			1%			0%		
Time	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.552	0.000	0.000	-2.530	0.000	0.000	-2.530
12.333	0.000	0.000	-0.991	0.000	0.000	-0.817	0.000	0.000	-0.817
13.500	0.000	0.000	0.932	0.000	0.000	1.242	0.000	0.000	1.242
14.667	0.001	0.001	2.486	2.955	1.218	2.904	14.850	6.120	2.904
15.833	0.000	0.000	3.649	0.000	0.000	4.135	0.000	0.000	4.135
17.000	0.000	0.000	4.105	0.000	0.000	4.615	0.000	0.000	4.615
18.167	0.000	0.000	3.449	0.000	0.000	3.935	0.000	0.000	3.935
19.333	0.001	0.001	1.986	0.018	0.007	2.404	0.335	0.138	2.404
20.500	0.000	0.000	0.032	0.000	0.000	0.342	0.000	0.000	0.342
21.667	0.000	0.000	-1.791	0.000	0.000	-1.617	0.000	0.000	-1.617
22.833	0.000	0.000	-1.952	0.000	0.000	-1.930	0.000	0.000	-1.930
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Location C1

Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000				0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167				0.000	0.000	-2.601	0.000	0.000	-2.596	0.000	0.000	-2.591	0.000	0.000	-2.584	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.574
12.333				0.000	0.000	-1.374	0.000	0.000	-1.333	0.000	0.000	-1.293	0.000	0.000	-1.240	0.000	0.000	-1.199	0.000	0.000	-1.159	0.000	0.000	-1.159
13.500				0.000	0.000	0.251	0.000	0.000	0.323	0.000	0.000	0.394	0.000	0.000	0.489	0.000	0.000	0.561	0.000	0.000	0.633	0.000	0.000	0.633
14.667				0.000	0.000	1.570	0.000	0.000	1.667	0.000	0.000	1.763	0.000	0.000	1.891	0.000	0.000	1.987	0.000	0.000	2.085	0.032	0.002	2.085
15.833				0.003	0.000	2.583	0.006	0.000	2.695	0.031	0.002	2.807	0.297	0.020	2.956	1.162	0.080	3.068	2.376	0.164	3.182	0.000	0.000	3.182
17.000				0.136	0.009	2.987	0.719	0.050	3.105	3.052	0.211	3.222	0.000	0.000	3.378	0.000	0.000	3.496	0.000	0.000	3.615	0.000	0.000	3.615
18.167				0.000	0.000	2.383	0.003	0.000	2.495	0.005	0.000	2.607	0.030	0.002	2.756	0.150	0.010	2.868	2.376	0.164	2.982	2.222	0.154	2.982
19.333				0.000	0.000	1.070	0.000	0.000	1.167	0.000	0.000	1.263	0.000	0.000	1.391	0.000	0.000	1.487	0.000	0.000	1.585	0.017	0.001	1.585
20.500				0.000	0.000	-0.649	0.000	0.000	-0.577	0.000	0.000	-0.506	0.000	0.000	-0.411	0.000	0.000	-0.339	0.000	0.000	-0.267	0.000	0.000	-0.267
21.667				0.000	0.000	-2.174	0.000	0.000	-2.133	0.000	0.000	-2.093	0.000	0.000	-2.040	0.000	0.000	-1.999	0.000	0.000	-1.959	0.000	0.000	-1.959
22.833				0.000	0.000	-2.001	0.000	0.000	-1.996	0.000	0.000	-1.991	0.000	0.000	-1.984	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.974
24.000				0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.586	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.569	0.000	0.000	-2.562	0.000	0.000	-2.557	0.000	0.000	-2.552	0.000	0.000	-2.552
12.333	0.000	0.000	-1.255	0.000	0.000	-1.203	0.000	0.000	-1.162	0.000	0.000	-1.122	0.000	0.000	-1.069	0.000	0.000	-1.028	0.000	0.000	-0.988	0.000	0.000	-0.988
13.500	0.000	0.000	0.462	0.000	0.000	0.555	0.000	0.000	0.627	0.000	0.000	0.698	0.000	0.000	0.793	0.000	0.000	0.865	0.000	0.000	0.938	0.000	0.000	0.938
14.667	0.000	0.000	1.854	0.000	0.000	1.980	0.000	0.000	2.077	0.000	0.000	2.172	0.004	0.000	2.300	0.004	0.000	2.397	0.007	0.000	2.494	0.071	0.005	2.494
15.833	0.008	0.001	2.913	0.362	0.025	3.060	1.526	0.105	3.172	0.000	0.000	3.284	0.000	0.000	3.433	0.000	0.000	3.545	0.000	0.000	3.659	0.000	0.000	3.659
17.000	0.000	0.000	3.333	0.000	0.000	3.487	0.000	0.000	3.605	0.000	0.000	3.722	0.000	0.000	3.878	0.000	0.000	3.996	0.000	0.000	4.115	0.000	0.000	4.115
18.167	0.001	0.000	2.713	0.027	0.002	2.860	0.172	0.012	2.972	0.739	0.051	3.084	4.412	0.305	3.233	0.000	0.000	3.345	0.000	0.000	3.459	0.000	0.000	3.459
19.333	0.000	0.000	1.354	0.000	0.000	1.480	0.000	0.000	1.577	0.000	0.000	1.672	0.000	0.000	1.800	0.000	0.000	1.897	0.000	0.000	1.994	0.028	0.002	1.994
20.500	0.000	0.000	-0.438	0.000	0.000	-0.345	0.000	0.000	-0.273	0.000	0.000	-0.202	0.000	0.000	-0.107	0.000	0.000	-0.035	0.000	0.000	0.038	0.000	0.000	0.038
21.667	0.000	0.000	-2.055	0.000	0.000	-2.003	0.000	0.000	-1.962	0.000	0.000	-1.922	0.000	0.000	-1.869	0.000	0.000	-1.828	0.000	0.000	-1.788	0.000	0.000	-1.788
22.833	0.000	0.000	-1.986	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.969	0.000	0.000	-1.962	0.000	0.000	-1.957	0.000	0.000	-1.952	0.000	0.000	-1.952
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	10%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.552	0.000	0.000	-2.530	0.000	0.000	-2.530
12.333	0.000	0.000	-0.991	0.000	0.000	-0.817	0.000	0.000	-0.817
13.500	0.000	0.000	0.932	0.000	0.000	1.242	0.000	0.000	1.242
14.667	0.002	0.000	2.486	0.307	0.021	2.904	1.426	0.099	2.904
15.833	0.000	0.000	3.649	0.000	0.000	4.135	0.000	0.000	4.135
17.000	0.000	0.000	4.105	0.000	0.000	4.615	0.000	0.000	4.615
18.167	0.000	0.000	3.449	0.000	0.000	3.935	0.000	0.000	3.935
19.333	0.000	0.000	1.986	0.007	0.000	2.404	0.075	0.005	2.404
20.500	0.000	0.000	0.032	0.000	0.000	0.342	0.000	0.000	0.342
21.667	0.000	0.000	-1.791	0.000	0.000	-1.617	0.000	0.000	-1.617
22.833	0.000	0.000	-1.952	0.000	0.000	-1.930	0.000	0.000	-1.930
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Location C2

Current Scenario

AEP

	50%			20%			10%			5%			2%			1%			0.5%			0.1%		
Time	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**
10.000							0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405
11.167							0.000	0.00000	-2.618	0.000	0.00000	-2.613	0.000	0.00000	-2.618	0.000	0.00000	-2.579	0.000	0.00000	-2.579	0.000	0.00000	-2.574
12.333							0.000	0.00000	-1.506	0.000	0.00000	-1.466	0.000	0.00000	-1.506	0.000	0.00000	-1.199	0.000	0.00000	-1.199	0.000	0.00000	-1.159
13.500							0.000	0.00000	0.015	0.000	0.00000	0.086	0.000	0.00000	0.015	0.000	0.00000	0.561	0.000	0.00000	0.561	0.000	0.00000	0.633
14.667							0.000	0.00000	1.253	0.000	0.00000	1.348	0.000	0.00000	1.253	0.000	0.00000	1.987	0.000	0.00000	1.987	0.013	0.00223	2.085
15.833							0.012	0.00200	2.213	0.023	0.00384	2.324	0.014	0.00236	2.213	0.058	0.00977	3.068	0.255	0.04330	3.068	3.694	0.62719	3.182
17.000							0.040	0.00687	2.599	0.111	0.01880	2.716	0.770	0.13065	2.599	3.617	0.61412	3.496	8.963	1.52180	3.496	0.000	0.00000	3.615
18.167							0.012	0.00200	2.013	0.012	0.00211	2.124	0.006	0.00102	2.013	0.013	0.00224	2.868	0.048	0.00820	2.868	3.694	0.62719	2.982
19.333							0.000	0.00000	0.753	0.000	0.00000	0.848	0.000	0.00000	0.753	0.000	0.00000	1.487	0.000	0.00000	1.487	0.000	0.00000	1.585
20.500							0.000	0.00000	-0.885	0.000	0.00000	-0.814	0.000	0.00000	-0.885	0.000	0.00000	-0.339	0.000	0.00000	-0.339	0.000	0.00000	-0.267
21.667							0.000	0.00000	-2.306	0.000	0.00000	-2.266	0.000	0.00000	-2.306	0.000	0.00000	-1.999	0.000	0.00000	-1.999	0.000	0.00000	-1.959
22.833							0.000	0.00000	-2.018	0.000	0.00000	-2.013	0.000	0.00000	-2.018	0.000	0.00000	-1.979	0.000	0.00000	-1.979	0.000	0.00000	-1.974
24.000							0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405

Mid Range Future Scenario

AEP

	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m^3/s)**	**Water Level (mOD)**
10.000	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405
11.167	0.000	0.00000	-2.608	0.000	0.00000	-2.579	0.000	0.00000	-2.574	0.000	0.00000	-2.569	0.000	0.00000	-2.562	0.000	0.00000	-2.557	0.000	0.00000	-2.552	0.000	0.00000	-2.552
12.333	0.000	0.00000	-1.428	0.000	0.00000	-1.203	0.000	0.00000	-1.162	0.000	0.00000	-1.122	0.000	0.00000	-1.069	0.000	0.00000	-1.028	0.000	0.00000	-0.988	0.000	0.00000	-0.988
13.500	0.000	0.00000	0.155	0.000	0.00000	0.555	0.000	0.00000	0.627	0.000	0.00000	0.698	0.000	0.00000	0.793	0.000	0.00000	0.865	0.000	0.00000	0.938	0.000	0.00000	0.938
14.667	0.000	0.00000	1.441	0.000	0.00000	1.980	0.000	0.00000	2.077	0.000	0.00000	2.172	0.000	0.00000	2.300	0.000	0.00000	2.397	0.006	0.00108	2.494	0.047	0.00797	2.494
15.833	0.012	0.00209	2.432	0.005	0.00089	3.060	0.023	0.00394	3.172	0.112	0.01902	3.284	1.281	0.21750	3.433	4.647	0.78900	3.545	0.000	0.00000	3.659	0.000	0.00000	3.659
17.000	0.055	0.00941	2.829	0.521	0.08839	3.487	2.933	0.49799	3.605	0.000	0.00000	3.722	0.000	0.00000	3.878	0.000	0.00000	3.996	0.000	0.00000	4.115	0.000	0.00000	4.115
18.167	0.000	0.00000	2.232	0.002	0.00037	2.860	0.005	0.00080	2.972	0.015	0.00260	3.084	0.166	0.02812	3.233	0.681	0.11564	3.345	3.533	0.59986	3.459	18.650	3.16653	3.459
19.333	0.000	0.00000	0.941	0.000	0.00000	1.480	0.000	0.00000	1.577	0.000	0.00000	1.672	0.000	0.00000	1.800	0.000	0.00000	1.897	0.000	0.00000	1.994	0.009	0.00158	1.994
20.500	0.000	0.00000	-0.745	0.000	0.00000	-0.345	0.000	0.00000	-0.273	0.000	0.00000	-0.202	0.000	0.00000	-0.107	0.000	0.00000	-0.035	0.000	0.00000	0.038	0.000	0.00000	0.038
21.667	0.000	0.00000	-2.228	0.000	0.00000	-2.003	0.000	0.00000	-1.962	0.000	0.00000	-1.922	0.000	0.00000	-1.869	0.000	0.00000	-1.828	0.000	0.00000	-1.788	0.000	0.00000	-1.788
22.833	0.000	0.00000	-2.008	0.000	0.00000	-1.979	0.000	0.00000	-1.974	0.000	0.00000	-1.969	0.000	0.00000	-1.962	0.000	0.00000	-1.957	0.000	0.00000	-1.952	0.000	0.00000	-1.952
24.000	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405

High End Future Scenario

AEP

	10%			0.50%			0.10%		
Time	**q (l/m/s)**	**q (m3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m3/s)**	**Water Level (mOD)**	**q (l/m/s)**	**q (m3/s)**	**Water Level (mOD)**
10.000	0.000	0.00000	-1.405	0.000	0.00000	-1.405	0.000	0.00000	-1.405
11.167	0.000	0.00000	-2.552	0.000	0.00000	-2.530	0.000	0.00000	-2.530
12.333	0.000	0.00000	-0.991	0.000	0.00000	-0.817	0.000	0.00000	-0.817
13.500	0.000	0.00000	0.932	0.000	0.00000	1.242	0.000	0.00000	1.242
14.667	0.000	0.00000	2.486	0.030	0.00502	2.904	0.703	0.11929	2.904
15.833	0.000	0.00000	3.649	0.000	0.00000	4.135	0.000	0.00000	4.135
17.000	0.000	0.00000	4.105	0.000	0.00000	4.615	0.000	0.00000	4.615
18.167	0.310	0.05260	3.449	0.000	0.00000	3.935	0.000	0.00000	3.935
19.333	0.000	0.00000	1.986	0.000	0.00000	2.404	0.050	0.00843	2.404
20.500	0.000	0.00000	0.032	0.000	0.00000	0.342	0.000	0.00000	0.342
21.667	0.000	0.00000	-1.791	0.000	0.00000	-1.617	0.000	0.00000	-1.617
22.833	0.000	0.00000	-1.952	0.000	0.00000	-1.930	0.000	0.00000	-1.930
24.000	0.000	0.00000	-0.405	0.000	0.00000	-0.405	0.000	0.00000	-0.405

Location D
Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.608	0.000	0.000	-2.608	0.000	0.000	-2.596	0.000	0.000	-2.591	0.000	0.000	-2.584	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.574
12.333	0.000	0.000	-1.426	0.000	0.000	-1.426	0.000	0.000	-1.333	0.000	0.000	-1.293	0.000	0.000	-1.240	0.000	0.000	-1.199	0.000	0.000	-1.159	0.000	0.000	-1.159
13.500	0.000	0.000	0.157	0.000	0.000	0.157	0.000	0.000	0.323	0.000	0.000	0.394	0.000	0.000	0.489	0.000	0.000	0.561	0.000	0.000	0.633	0.000	0.000	0.633
14.667	0.000	0.000	1.444	0.000	0.000	1.444	0.000	0.000	1.667	0.000	0.000	1.763	0.000	0.000	1.891	0.001	0.001	1.987	0.001	0.001	2.085	0.023	0.015	2.085
15.833	0.002	0.001	2.436	0.009	0.006	2.436	0.045	0.029	2.695	0.265	0.173	2.807	2.109	1.383	2.956	7.786	5.107	3.068	16.670	10.934	3.182	14.100	9.249	3.182
17.000	0.085	0.056	2.833	0.653	0.428	2.833	6.260	4.106	3.105	18.270	11.984	3.222	0.000	0.000	3.378	0.000	0.000	3.496	0.000	0.000	3.615	0.000	0.000	3.615
18.167	0.000	0.000	2.236	0.002	0.001	2.236	0.006	0.004	2.495	0.026	0.017	2.607	0.212	0.139	2.756	1.481	0.971	2.868	16.670	10.934	2.982	14.100	9.249	2.982
19.333	0.000	0.000	0.944	0.000	0.000	0.944	0.000	0.000	1.167	0.000	0.000	1.263	0.000	0.000	1.391	0.000	0.000	1.487	0.000	0.000	1.585	0.002	0.001	1.585
20.500	0.000	0.000	-0.743	0.000	0.000	-0.743	0.000	0.000	-0.577	0.000	0.000	-0.506	0.000	0.000	-0.411	0.000	0.000	-0.339	0.000	0.000	-0.267	0.000	0.000	-0.267
21.667	0.000	0.000	-2.226	0.000	0.000	-2.226	0.000	0.000	-2.133	0.000	0.000	-2.093	0.000	0.000	-2.040	0.000	0.000	-1.999	0.000	0.000	-1.959	0.000	0.000	-1.959
22.833	0.000	0.000	-2.008	0.000	0.000	-2.008	0.000	0.000	-1.996	0.000	0.000	-1.991	0.000	0.000	-1.984	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.974
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.586	0.000	0.000	-2.579	0.000	0.000	-2.574	0.000	0.000	-2.569	0.000	0.000	-2.562	0.000	0.000	-2.557	0.000	0.000	-2.552	0.000	0.000	-2.552
12.333	0.000	0.000	-1.255	0.000	0.000	-1.203	0.000	0.000	-1.162	0.000	0.000	-1.122	0.000	0.000	-1.069	0.000	0.000	-1.028	0.000	0.000	-0.988	0.000	0.000	-0.988
13.500	0.000	0.000	0.462	0.000	0.000	0.555	0.000	0.000	0.627	0.000	0.000	0.698	0.000	0.000	0.793	0.000	0.000	0.865	0.000	0.000	0.938	0.000	0.000	0.938
14.667	0.000	0.000	1.854	0.000	0.000	1.980	0.000	0.000	2.077	0.000	0.000	2.172	0.000	0.000	2.300	0.005	0.003	2.397	0.058	0.038	2.494	0.732	0.480	2.494
15.833	0.122	0.080	2.913	4.189	2.748	3.060	11.010	7.222	3.172	0.000	0.000	3.284	0.000	0.000	3.433	0.000	0.000	3.545	0.000	0.000	3.659	0.000	0.000	3.659
17.000	0.000	0.000	3.333	0.000	0.000	3.487	0.000	0.000	3.605	0.000	0.000	3.722	0.000	0.000	3.878	0.000	0.000	3.996	0.000	0.000	4.115	0.000	0.000	4.115
18.167	0.007	0.005	2.713	0.415	0.272	2.860	1.413	0.927	2.972	2.518	1.652	3.084	0.000	0.000	3.233	0.000	0.000	3.345	0.000	0.000	3.459	0.000	0.000	3.459
19.333	0.000	0.000	1.354	0.000	0.000	1.480	0.000	0.000	1.577	0.000	0.000	1.672	0.000	0.000	1.800	0.000	0.000	1.897	0.002	0.001	1.994	0.015	0.010	1.994
20.500	0.000	0.000	-0.438	0.000	0.000	-0.345	0.000	0.000	-0.273	0.000	0.000	-0.202	0.000	0.000	-0.107	0.000	0.000	-0.035	0.000	0.000	0.038	0.000	0.000	0.038
21.667	0.000	0.000	-2.055	0.000	0.000	-2.003	0.000	0.000	-1.962	0.000	0.000	-1.922	0.000	0.000	-1.869	0.000	0.000	-1.828	0.000	0.000	-1.788	0.000	0.000	-1.788
22.833	0.000	0.000	-1.986	0.000	0.000	-1.979	0.000	0.000	-1.974	0.000	0.000	-1.969	0.000	0.000	-1.962	0.000	0.000	-1.957	0.000	0.000	-1.952	0.000	0.000	-1.952
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	AEP								
	10%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.552	0.000	0.000	-2.530	0.000	0.000	-2.530
12.333	0.000	0.000	-0.991	0.000	0.000	-0.817	0.000	0.000	-0.817
13.500	0.000	0.000	0.932	0.000	0.000	1.242	0.000	0.000	1.242
14.667	0.002	0.002	2.486	3.678	2.413	2.904	13.990	9.177	2.904
15.833	0.000	0.000	3.649	0.000	0.000	4.135	0.000	0.000	4.135
17.000	0.000	0.000	4.105	0.000	0.000	4.615	0.000	0.000	4.615
18.167	0.000	0.000	3.449	0.000	0.000	3.935	0.000	0.000	3.935
19.333	0.000	0.000	1.986	0.037	0.024	2.404	0.758	0.497	2.404
20.500	0.000	0.000	0.032	0.000	0.000	0.342	0.000	0.000	0.342
21.667	0.000	0.000	-1.791	0.000	0.000	-1.617	0.000	0.000	-1.617
22.833	0.000	0.000	-1.952	0.000	0.000	-1.930	0.000	0.000	-1.930
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Location E

Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000																0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167																0.000	0.000	-2.608	0.000	0.000	-2.591	0.000	0.000	-2.584
12.333																0.000	0.000	-1.426	0.000	0.000	-1.293	0.000	0.000	-1.240
13.500																0.000	0.000	0.157	0.000	0.000	0.394	0.000	0.000	0.489
14.667																0.000	0.000	1.444	0.000	0.000	1.763	0.000	0.000	1.891
15.833																0.000	0.000	2.436	0.025	0.008	2.807	0.232	0.073	2.956
17.000																0.091	0.029	2.833	0.240	0.075	3.222	2.409	0.755	3.378
18.167																0.000	0.000	2.236	0.025	0.008	2.607	0.081	0.025	2.756
19.333																0.000	0.000	0.944	0.000	0.000	1.263	0.000	0.000	1.391
20.500																0.000	0.000	-0.743	0.000	0.000	-0.506	0.000	0.000	-0.411
21.667																0.000	0.000	-2.226	0.000	0.000	-2.093	0.000	0.000	-2.040
22.833																0.000	0.000	-2.008	0.000	0.000	-1.991	0.000	0.000	-1.984
24.000																0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
10.000										0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167										0.000	0.000	-2.603	0.000	0.000	-2.579	0.000	0.000	-2.569	0.000	0.000	-2.552	0.000	0.000	-2.552
12.333										0.000	0.000	-1.388	0.000	0.000	-1.203	0.000	0.000	-1.122	0.000	0.000	-0.988	0.000	0.000	-0.988
13.500										0.000	0.000	0.225	0.000	0.000	0.555	0.000	0.000	0.698	0.000	0.000	0.938	0.000	0.000	0.938
14.667										0.000	0.000	1.536	0.000	0.000	1.980	0.000	0.000	2.172	0.000	0.000	2.494	0.000	0.000	2.494
15.833										0.000	0.000	2.543	0.039	0.012	3.060	0.109	0.034	3.284	0.304	0.095	3.659	4.732	1.483	3.659
17.000										0.187	0.058	2.945	0.763	0.239	3.487	2.577	0.807	3.722	8.611	2.698	4.115	36.200	11.341	4.115
18.167										0.000	0.000	2.343	0.017	0.005	2.860	0.031	0.010	3.084	0.055	0.017	3.459	1.628	0.510	3.459
19.333										0.000	0.000	1.036	0.000	0.000	1.480	0.000	0.000	1.672	0.000	0.000	1.994	0.000	0.000	1.994
20.500										0.000	0.000	-0.675	0.000	0.000	-0.345	0.000	0.000	-0.202	0.000	0.000	0.038	0.000	0.000	0.038
21.667										0.000	0.000	-2.188	0.000	0.000	-2.003	0.000	0.000	-1.922	0.000	0.000	-1.788	0.000	0.000	-1.788
22.833										0.000	0.000	-2.003	0.000	0.000	-1.979	0.000	0.000	-1.969	0.000	0.000	-1.952	0.000	0.000	-1.952
24.000										0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	10%			0.5%			0%		
Time	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)	q (l/m/s)	q (m3/s)	Water Level (mOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.552	0.000	0.000	-2.530	0.000	0.000	-2.530
12.333	0.000	0.000	-0.991	0.000	0.000	-0.817	0.000	0.000	-0.817
13.500	0.000	0.000	0.932	0.000	0.000	1.242	0.000	0.000	1.242
14.667	0.000	0.000	2.486	0.004	0.001	2.904	0.065	0.020	2.904
15.833	0.025	0.008	3.649	10.780	3.377	4.135	41.910	13.130	4.135
17.000	2.314	0.725	4.105	0.000	0.000	4.615	0.000	0.000	4.615
18.167	0.007	0.002	3.449	2.830	0.887	3.935	17.670	5.536	3.935
19.333	0.000	0.000	1.986	0.000	0.000	2.404	0.000	0.000	2.404
20.500	0.000	0.000	0.032	0.000	0.000	0.342	0.000	0.000	0.342
21.667	0.000	0.000	-1.791	0.000	0.000	-1.617	0.000	0.000	-1.617
22.833	0.000	0.000	-1.952	0.000	0.000	-1.930	0.000	0.000	-1.930
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Location F
Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)
10.000													0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167													0.000	0.000	-2.618	0.000	0.000	-2.618	0.000	0.000	-2.601	0.000	0.000	-2.591
12.333													0.000	0.000	-1.506	0.000	0.000	-1.506	0.000	0.000	-1.374	0.000	0.000	-1.293
13.500													0.000	0.000	0.015	0.000	0.000	0.015	0.000	0.000	0.251	0.000	0.000	0.394
14.667													0.000	0.000	1.253	0.000	0.000	1.253	0.000	0.000	1.570	0.000	0.000	1.763
15.833													0.000	0.000	2.213	0.000	0.000	2.213	0.064	0.016	2.583	0.109	0.027	2.807
17.000													0.063	0.016	2.599	0.088	0.022	2.599	0.071	0.018	2.987	0.115	0.029	3.222
18.167													0.000	0.000	2.013	0.000	0.000	2.013	0.064	0.016	2.383	0.103	0.026	2.607
19.333													0.000	0.000	0.753	0.000	0.000	0.753	0.000	0.000	1.070	0.000	0.000	1.263
20.500													0.000	0.000	-0.885	0.000	0.000	-0.885	0.000	0.000	-0.649	0.000	0.000	-0.506
21.667													0.000	0.000	-2.306	0.000	0.000	-2.306	0.000	0.000	-2.174	0.000	0.000	-2.093
22.833													0.000	0.000	-2.018	0.000	0.000	-2.018	0.000	0.000	-2.001	0.000	0.000	-1.991
24.000													0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000										0.000	0.000	-1.405	0.000	0.000	-0.705	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167										0.000	0.000	-2.603	0.000	0.000	0.795	0.000	0.000	-2.596	0.000	0.000	-2.579	0.000	0.000	-2.569
12.333										0.000	0.000	-1.388	0.000	0.000	1.995	0.000	0.000	-1.335	0.000	0.000	-1.203	0.000	0.000	-1.122
13.500										0.000	0.000	0.225	0.000	0.000	2.795	0.000	0.000	0.319	0.000	0.000	0.555	0.000	0.000	0.698
14.667										0.000	0.000	1.536	0.000	0.000	2.795	0.000	0.000	1.662	0.000	0.000	1.980	0.000	0.000	2.172
15.833										0.000	0.000	2.543	0.079	0.020	1.795	0.120	0.030	2.690	0.087	0.022	3.060	0.122	0.031	3.284
17.000										0.070	0.018	2.945	0.085	0.021	0.295	0.132	0.033	3.099	0.082	0.021	3.487	0.124	0.031	3.722
18.167										0.000	0.000	2.343	0.075	0.019	-1.405	0.113	0.028	2.490	0.084	0.021	2.860	0.122	0.031	3.084
19.333										0.000	0.000	1.036	0.000	0.000	-2.591	0.000	0.000	1.162	0.000	0.000	1.480	0.000	0.000	1.672
20.500										0.000	0.000	-0.675	0.000	0.000	-1.293	0.000	0.000	-0.581	0.000	0.000	-0.345	0.000	0.000	-0.202
21.667										0.000	0.000	-2.188	0.000	0.000	0.394	0.000	0.000	-2.135	0.000	0.000	-2.003	0.000	0.000	-1.922
22.833										0.000	0.000	-2.003	0.000	0.000	1.763	0.000	0.000	-1.996	0.000	0.000	-1.979	0.000	0.000	-1.969
24.000										0.000	0.000	-0.405	0.000	0.000	2.807	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	10%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.581	0.000	0.000	-2.557	0.000	0.000	-2.547
12.333	0.000	0.000	-1.217	0.000	0.000	-1.032	0.000	0.000	-0.951
13.500	0.000	0.000	0.530	0.000	0.000	0.860	0.000	0.000	1.003
14.667	0.000	0.000	1.946	0.088	0.022	2.390	0.136	0.034	2.582
15.833	0.051	0.013	3.020	0.100	0.025	3.536	0.186	0.047	3.761
17.000	0.047	0.012	3.445	0.145	0.036	3.987	0.865	0.217	4.222
18.167	0.000	0.000	2.820	0.103	0.026	3.336	0.164	0.041	3.561
19.333	0.000	0.000	1.446	0.000	0.000	1.890	0.000	0.000	2.082
20.500	0.000	0.000	-0.370	0.000	0.000	-0.040	0.000	0.000	0.103
21.667	0.000	0.000	-2.017	0.000	0.000	-1.832	0.000	0.000	-1.751
22.833	0.000	0.000	-1.981	0.000	0.000	-1.957	0.000	0.000	-1.947
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Location G
Current Scenario

AEP

	50%			20%			10.00%			5.00%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)
10.000													0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167													0.000	0.000	-2.608	0.000	0.000	-2.596	0.000	0.000	-2.591	0.000	0.000	-2.579
12.333													0.000	0.000	-1.426	0.000	0.000	-1.333	0.000	0.000	-1.293	0.000	0.000	-1.199
13.500													0.000	0.000	0.157	0.000	0.000	0.323	0.000	0.000	0.394	0.000	0.000	0.561
14.667													0.000	0.000	1.444	0.000	0.000	1.667	0.000	0.000	1.763	0.000	0.000	1.987
15.833													0.000	0.000	2.436	0.041	0.013	2.695	0.045	0.014	2.807	0.047	0.015	3.068
17.000													0.040	0.013	2.833	0.037	0.012	3.105	0.041	0.013	3.222	0.041	0.013	3.496
18.167													0.000	0.000	2.236	0.000	0.000	2.495	0.046	0.015	2.607	0.049	0.016	2.868
19.333													0.000	0.000	0.944	0.000	0.000	1.167	0.000	0.000	1.263	0.000	0.000	1.487
20.500													0.000	0.000	-0.743	0.000	0.000	-0.577	0.000	0.000	-0.506	0.000	0.000	-0.339
21.667													0.000	0.000	-2.226	0.000	0.000	-2.133	0.000	0.000	-2.093	0.000	0.000	-1.999
22.833													0.000	0.000	-2.008	0.000	0.000	-1.996	0.000	0.000	-1.991	0.000	0.000	-1.979
24.000													0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Mid Range Future Scenario

	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m^3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000				0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405				0.000	0.000	-1.405	0.000	0.000	-1.405
11.167				0.000	0.000	-2.608	0.000	0.000	-2.603	0.000	0.000	-2.591	0.000	0.000	-2.586				0.000	0.000	-2.569	0.000	0.000	-2.557
12.333				0.000	0.000	-1.428	0.000	0.000	-1.388	0.000	0.000	-1.295	0.000	0.000	-1.255				0.000	0.000	-1.122	0.000	0.000	-1.028
13.500				0.000	0.000	0.155	0.000	0.000	0.225	0.000	0.000	0.390	0.000	0.000	0.462				0.000	0.000	0.698	0.000	0.000	0.865
14.667				0.000	0.000	1.441	0.000	0.000	1.536	0.000	0.000	1.758	0.000	0.000	1.854				0.000	0.000	2.172	0.063	0.020	2.397
15.833				0.000	0.000	2.432	0.045	0.014	2.543	0.035	0.011	2.801	0.044	0.014	2.913				0.033	0.011	3.284	0.057	0.018	3.545
17.000				0.038	0.012	2.829	0.043	0.014	2.945	0.031	0.010	3.216	0.038	0.012	3.333				0.032	0.010	3.722	0.171	0.055	3.996
18.167				0.000	0.000	2.232	0.000	0.000	2.343	0.000	0.000	2.601	0.045	0.014	2.713				0.036	0.011	3.084	0.056	0.018	3.345
19.333				0.000	0.000	0.941	0.000	0.000	1.036	0.000	0.000	1.258	0.000	0.000	1.354				0.000	0.000	1.672	0.000	0.000	1.897
20.500				0.000	0.000	-0.745	0.000	0.000	-0.675	0.000	0.000	-0.510	0.000	0.000	-0.438				0.000	0.000	-0.202	0.000	0.000	-0.035
21.667				0.000	0.000	-2.228	0.000	0.000	-2.188	0.000	0.000	-2.095	0.000	0.000	-2.055				0.000	0.000	-1.922	0.000	0.000	-1.828
22.833				0.000	0.000	-2.008	0.000	0.000	-2.003	0.000	0.000	-1.991	0.000	0.000	-1.986				0.000	0.000	-1.969	0.000	0.000	-1.957
24.000				0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405				0.000	0.000	-0.405	0.000	0.000	-0.405

High End Future Scenario

	10.00%			0.50%			0.10%		
Time	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)	q (l/m/s)	q (m3/s)	Water Level (mAOD)
10.000	0.000	0.000	-1.405	0.000	0.000	-1.405	0.000	0.000	-1.405
11.167	0.000	0.000	-2.581	0.000	0.000	-2.547	0.000	0.000	-2.535
12.333	0.000	0.000	-1.217	0.000	0.000	-0.951	0.000	0.000	-0.857
13.500	0.000	0.000	0.530	0.000	0.000	1.003	0.000	0.000	1.170
14.667	0.000	0.000	1.946	0.054	0.017	2.582	0.066	0.021	2.806
15.833	0.046	0.015	3.020	0.059	0.019	3.761	0.213	0.068	4.022
17.000	0.040	0.013	3.445	0.380	0.122	4.222	1.614	0.516	4.496
18.167	0.048	0.015	2.820	0.047	0.015	3.561	0.096	0.031	3.822
19.333	0.000	0.000	1.446	0.000	0.000	2.082	0.065	0.021	2.306
20.500	0.000	0.000	-0.370	0.000	0.000	0.103	0.000	0.000	0.270
21.667	0.000	0.000	-2.017	0.000	0.000	-1.751	0.000	0.000	-1.657
22.833	0.000	0.000	-1.981	0.000	0.000	-1.947	0.000	0.000	-1.935
24.000	0.000	0.000	-0.405	0.000	0.000	-0.405	0.000	0.000	-0.405

Fluvial Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	S10
Unit of Management	24
AFA included in the model	Askeaton & Rathkeale
Primary Watercourses / Water Bodies	River Deel Mill Race (Askeaton) Unnamed River River Deegerty
1.2 Reference to other Relevant Reports	
Catchment Description	Hydrology Report Unit of Management 24 – Appendix A3.1
Model Location	Hydraulics Report Unit of Management 24 – Section 3.4.12
HEP Schematisation	Hydrology Report Unit of Management 24 – Appendix B6 – Figure B6.1

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k OS1214_D & OS1212_D
2.2 DTM for 2D Model Domains:	**Within AFAs:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the AFA boundary.
	Outside AFAs: IFSAR data with 5m horizontal resolution and approximately 500mm-1000mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas outside the AFA boundary. **Note:** In general, there is overlap between the AFA area and area outside the AFA with regard to the availability of LiDAR data. Therefore, some areas outside the AFA are covered by LiDAR to the same resolution as that for the AFA.
2.3 River Channel/Structures Survey	Details of the topographic survey of the river channel and structures are included in the main Hydraulics Report. This includes longitudinal sections and channel cross-sections. Full details of the survey outputs are provided in the topographic survey deliverables, as required under Section 5.2 of the Stage I Project Brief. Number of cross-sections included in this model: 295
2.4 Defence Asset Survey Data	No defences have been identified within the model area in the defence asset database. However, The OPW constructed an embankment in recent years approximately 2km upstream of Askeaton. This structure was identified in the Flood Risk Review, and has been included in the model with the elevations taken from LiDAR. The location of this embankment is shown in Annex A2, and further details on the defences are available in the defence asset database.

2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:**	ISIS Version 3.6.0.156
	2D Domain(s):	TUFLOW Version: 2012-05-AE-iSP-w32
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.	

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
   - River centre lines, HPW/MPW extents, names of watercourses
   - 2D domain area
   - AFA boundary

2. **Maps showing a detailed model schematic of the HPW/MPW reaches are also included**

3.3 Model Reaches: The following model reaches as shown on the maps referred above have been defined in the model:

Watercourse Name	Reach	Upstream Model Node	Downstream Model Node
River Deel	03DEL	03DEL18279	03DEL00000
	02DEL	02DEL00846	02DEL00000
	01DEL	01DEL03945	01DEL00000
Mill Race	01DEX	01DEX00473	01DEX0002c2o
Unnamed River	01STN	01STN00958	01STN00009co
River Deegerty	01MOI	01MOI01235	01MOI00000sd
Total model HPW length (km):	9.38	**Total model MPW length (km):**	16.45

3.4 Model Structures: A full schedule of structures included in the model is provided in Schedule A in Annex B. A summary of the structures included is given below

Culverts:	☒	How many?	7
Bridges:	☒	How many?	10
Fixed crest weirs:	☒	How many?	9
Adjustable crest weirs:	☐	How many?	0
Sluice / Gate structures:	☒	How many?	1
Locks:	☐	How many?	0
Dams:	☐	How many?	0
Other (describe):			

3.5 Floodplain Schematisation

Out-of-bank areas for MPW reaches have been modelled following a 1D approach using ISIS and by extending the river channel cross-sections in the model, and by using a 2D approach using TuFLOW. Further detail on these approaches is outlined in Section 5.3.1 of the Hydraulics Report for Unit of Management 24.

Out-of-bank areas for HPW reaches, within the Askeaton AFA, have been modelled using a 2D approach using TuFLOW.

Out-of-bank areas for HPW reaches, within the Rathkeale AFA, have been modelled following a 1D approach using ISIS and by extending the river channel cross-sections in the model.

Extended 1D sections are considered appropriate for HPW extents where floodplain flow paths are simple. 1D-2D modelling is required where HPWs

	flow through urban areas where out of bank flows will form complex flow paths. An overview of the floodplain schematisation is available in the maps shown in Annex A.
3.6 2D Domain Grid Size:	The number of 2D domains defined and the grid sizes of each 2D model domain are as follows:

Number of 2D domains: 3

Domain 1: Askeaton	Grid cell size (m): 5	Area (km^2): 5.873
Domain 2: River Deel	Grid cell size (m): 20	Area (km^2): 18.55
Domain 3: Inchirourke	Grid cell size (m): 20	Area (km^2): 12.85

2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.

3.7 Model Breaklines in the 2D Domain:	Bank tops and bridge parapets are represented as breaklines in the 2D domain.
3.8 Floodplain Structures in the 2D Domain	No floodplain structures have been included in the 2D model as none were required.
3.9 Hydraulic Roughness	Hydraulic roughness (Manning's 'n') has been defined in accordance with the approaches described in the main Hydraulics Report. Details of the values adopted for this model are included in Schedule B in Annex B. A summary of Manning's 'n' for the model as a whole is as follows:

MPW In-bank **Bed and Bank Sides**	Minimum 'n' value:	0.03
	Maximum 'n' value:	0.04
HPW In-bank	Minimum 'n' value:	0.02
	Maximum 'n' value:	0.055

Floodplain (ISIS Model)

Manning's 'n' for out-of-bank areas represented in the ISIS model are as defined by EPA land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in ISIS are as follows:

Land Use	**Manning's 'n' Value**
Pastures	0.035
Dense Vegetation	0.080
Road Network	0.025
Buildings	0.100

Floodplain (TUFLOW Model)

Manning's 'n' for out of bank areas represented in the TUFLOW model are as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:

Land Use	**Manning's 'n' Value**
Buildings	0.100
Short grass, parks	0.035
General Urban	0.060

	General Rural	0.045
	Dense Vegetation	0.080
	Roads	0.025
	Railways	0.050
	Water bodies	0.020

3.10 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.
3.11 Model Boundaries – Fluvial Inflows	Hydrological flow hydrographs were input to the model at key model locations as indicated in the tables below. The production of peak flow estimates and flow hydrograph shapes is fully explained in the Hydrology Report relevant to Unit of Management 24. Peak inflows (m3/s) are summarised in the tables below for the current situation and the design event simulated. These are the final inflows as obtained following calibration to HEPs (see Section 4.2). It should be noted that the inflows at Node 24_1670_6 are negative. Negative flows are required to represent the loss of flow to karstic features between HEP 24_1553_2 and 24_1670_6. This is outlined in more detail in section 4.2
(a) Current Situation (Main Model)	

HEP Reference Name	Input Node in the Hydraulic Model	Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_206_2	03DEL18279	130.7	161.4	181.0	196.0	217.0	233.9	247.1	282.3
24_1501_3	03DEL12858	9.1	11.2	12.5	18.1	20.1	27.0	30.4	36.5
24_1670_6	03DEL001315	-23.5	-31.3	-28.1	-23.4	-21.1	-17.6	-11.2	-5.1
Tributary Model									
24_1671_2a	01STN00958	1.1	1.4	1.5	1.7	1.8	2.0	2.1	2.4
24_1673_1	01MOI01235	5.3	6.6	7.3	8.0	8.8	9.4	10.0	11.4
24_1673_2	01MOI00754	0.3	0.4	0.4	0.4	0.5	0.5	0.5	2.5

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for all return periods for the MRFS. These events are selected as these are the MRFS that are to be mapped.

HEP Reference Name	Input Node in the Hydraulic Model	MRFS Annual Exceedance Probability							
		50%	20%	10%	5%	2%	1%	0.5%	0.1%
Main Model									
24_206_2	03DEL18279	156.9	193.7	217.2	235.2	260.4	280.6	296.6	338.8
24_1501_3	03DEL12858	10.9	13.5	15.0	21.7	24.1	32.4	36.4	43.8
24_1670_6	03DEL001315	-28.2	-37.6	-33.7	-28.0	-25.3	-21.1	-13.4	-6.1
Tributary Model									
24_1671_2a	01STN00958	1.3	1.6	1.8	2.0	2.2	2.4	2.5	2.8

24_1673_1	01MOI01235	6.4	7.9	8.8	9.5	10.6	11.3	12.0	13.6
24_1673_2	01MOI00754	0.3	0.4	0.5	0.5	0.6	0.6	0.6	3.0

(b) Future Scenarios	The peak inflows (m^3/s) used as inputs to the model at key model locations are summarised in the table below for 10%, 1% and 0.1% events for the HEFS. These events are selected as these are the HEFS that are to be mapped.

HEP Reference Name	Input Node in the Hydraulic Model	HEFS Annual Exceedance Probability		
		10%	**1%**	**0.1%**
Main Model				
24_206_2	03DEL18279	235.3	304.0	367.0
24_1501_3	03DEL12858	16.3	35.0	47.4
24_1670_6	03DEL001315	-36.5	-22.9	-6.6
Tributary Model				
24_1671_2a	01STN00958	2.0	2.6	3.1
24_1673_1	01MOI01235	9.5	12.3	14.8
24_1673_2	01MOI00754	0.5	0.7	3.3

3.12 Model Boundaries – Downstream Conditions	Downstream boundary conditions adopted in the model are as follows:
	Tidal level hydrographs at the outlet of the river Shannon were produced for a series of design events using the Irish Coastal Protection Strategy Study (ICPSS) extreme tidal peak levels data. The time series were set up as boundary conditions for the ISIS hydraulic model. Full details on how these tidal level hydrographs were derived are provided in Appendix D of the main Hydraulics Report. Peak tidal levels are summarised in the table below for the current and future situations.

	Current Annual Exceedance Probability							
Peak Tidal Levels (mOD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.0	3.2	3.3	3.5	3.6	3.7	3.9	4.2
	MRFS Annual Exceedance Probability							
Peak Tidal Levels (mOD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.7

	HEFS Annual Exceedance Probability		
Peak Tidal Levels (mOD)	**10%**	**0.5%**	**0.1%**
	4.4	4.9	5.2

<table>
<tr><th colspan="5">4. Hydraulic Model Calibration and Sensitivity</th></tr>
<tr><td>4.1 Model Calibration and Verification to Historical Events</td><td colspan="4">The approach to model calibration is documented in the main Hydraulics Report.
The analysis of available flood event data and high flow data for possible consideration as calibration and verification events is covered in detail in the Hydrology Report for UoM24 (Appendix F).
A full account of the model calibration approach and results is provided in Annex C.
A summary of the calibration and verification events along with associated model calibration results is as follows:</td></tr>
<tr><td rowspan="4">Catchment Gauging</td><td colspan="4">Is modelled catchment: Gauged ☒ Ungauged ☐</td></tr>
<tr><td>Station Number</td><td>Watercourse</td><td>Location</td><td>ISIS Node Reference</td></tr>
<tr><td>24029</td><td>River Deel</td><td>Inchirourke</td><td>03DEL01008</td></tr>
<tr><td>24013</td><td>River Deel</td><td>Rathkeale</td><td>03DEL11383</td></tr>
<tr><td>Summary of Findings</td><td colspan="4">Hydrometric data was available for possible calibration of the model for a reach of the River Deel between Inchirourke gauging station 24029 & Rathkeale gauging station 24013.
However, it was observed from the gauged flow data that the peak flow decreases in the downstream direction from gauging station 24013 to 24019. This has been attributed to water losses within the catchment due to permeable underlying soil conditions and karstic features and it was not possible to replicate such losses in the hydraulic model.
Therefore it was not possible to calibrate this model for any flood event.</td></tr>
<tr><td>4.2 Calibration to HEP</td><td colspan="4">The lower Deel model, S10, hydrological analysis identified a reduction in observed flood flows between the gauging stations at Rathkeale and Inchirouke More (near Askeaton), resulting in a reduction of QMED and other return period design peak flows between these stations. Hydraulic modelling using the combined 1D-2D model has shown that floodplain storage occurs but that this storage is only a minor contribution to the reduction of peak flows. It is believed that losses to the highly permeable soils and underlying karstified aquifer may be the main contributors.

It was possible to reliably estimate target flows at the gauging stations where the design peak flows were established from good estimates of the AMAX flow series (based on the rating reviews at Rathkeale and Inchirourke More, refer to Appendix C of the UoM 24.

It was not possible to provide target flow estimates of HEP nodes along the River Deel away from the gauging stations, as the rate of loss of floodwater along the watercourse is unknown. The losses could occur gradually along the watercourse or in discrete geological features (e.g karstic conduits or rock fissures), the locations of which are not known. The uncertainty in water levels in the MPW between Rathkeale and Askeaton due to these losses have been confirmed by the hydraulic modelling to be on average less than 400mm for the 100-year flood, which is within the acceptable calibration range for MPWs. The flows between Rathkeale and Askeaton used for the hydraulic modelling of that model section are informed by the higher Rathkeale design flows, which is a conservative approach. This should give realistic design flows and water levels in the Rathkeale AFA, but may overestimate flood flows and levels downstream of Rathkeale. This discrepancy would increase moving along the watercourse towards Askeaton. At Askeaton AFA the Inchirourke More design flows are used,</td></tr>
</table>

	which should provide realistic flows and levels for the AFA. Therefore calibration of the hydraulic model to the HEP target flows, for all design events simulated (10%, 1% and 0.1% AEP), has only been carried out along the tributaries and on the River Deel at the locations of the gauging stations and at the most upstream extent, HEPs 24_206_, 24_1553_2, 24_1670_6. Preliminary inflow hydrographs derived from the hydrological analysis and input to the model were adjusted in time so that their respective peak flows coincided with the peak time of the propagating flood wave as it was routed down the model. Total peak flows predicted by the hydraulic model at HEP locations were then compared to the HEP target flows estimated during the hydrological analysis. Where required, inflows to the hydraulic model were scaled up/down to ensure that the modelled total peak flows remain within ±10% of the HEP target flows. This ±10% target allows for good agreement between the hydrological estimates and the hydraulic results without the addition/removal of unrealistic volumes of flow from the model. The robustness of this has been verified by the agreement of the design flood maps. The flows at the following HEP nodes were increased by varying amounts: 24_1501_3, 24_1673_2. The flow at the HEP node 24_1670_6 was reduced by varying amounts to represent the loss of flow to karstic features between HEP 24_1553_2 and 24_1670_6. The table below shows the percentage difference between the modelled and target flows at each HEP location. The average percentage differences for all of the HEP nodes are as follows: 1%, 1%, and 0.7% for the 10%, 1% and 0.1% AEP events respectively.

HEP Reference Name	**Node in the Hydraulic Model**	**Annual Exceedance Probability**							
		Percentage Difference (%)							
		50%	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
24_206_2	03DEL18279	-3	-2	0.0	-2	-2	0.0	-2	0.0
24_1553_2	**03DEL11413**	-12	2	0.9	1	0	0.3	0	0.2
24_1670_6	03DEL001315	-13	-1	-0.3	2	-3	-1.6	-3	-2.4
24_1671_2a	01STN00958	**0.1**	**0.2**	-0.4	**0.0**	**0.1**	-0.2	**-0.4**	-0.2
24_1673_1	01MOI01235	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24_1673_2	01MOI00754	**-3.2**	**-1.5**	-1.0	**-0.7**	**-1.0**	-1.3	**-4.6**	-7.2
24_1673_4	**01MOI00119u**	**-7.4**	**-6.2**	-5.4	**-7.0**	**-7.5**	-7.8	**-8.5**	-9.5

4.3 Fluvial and Tidal Events Simulated

The River Deel is influenced by the tidal levels along the Shannon Estuary. As such, a joint probability analysis of the coincidence of fluvial flood flows and coastal flood levels was carried out to determine the appropriate combination of flows and sea levels to be used for the design probability events, as required under Section 6.5.6 of the Stage 1 Project Brief.

The methodology and outcomes of this analysis are detailed in the main Hydraulic Report and the Hydrology Report. A summary of the joint probability of fluvial and tidal conditions used for the hydraulic modelling in the S10 is reported in the table overleaf.

Combination of Fluvial and Tidal Events

	Joint Probability Design Event	AEP adopted for Fluvial Flows and Tidal Levels	
Scenario	**Overall AEP**	**Fluvial**	**Tidal**
1	50%	50%	500%
2	50%	50%	50%
3	20%	20%	500%
4	20%	50%	20%
5	10%	10%	200%
6	10%	50%	10%
7	5%	5%	100%
8	5%	50%	5%
9	2%	2%	50%
10	2%	50%	2%
11	1%	1%	20%
12	1%	20%	1%
13	0.5%	0.5%	10%
14	0.5%	10%	0.5%
15	0.1%	0.1%	2%
16	0.1%	2%	0.1%

4.4 Model Sensitivity

Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), fluvial flow, afflux at key structures and downstream conditions. The sensitivity runs were carried out for the 1% AEP fluvial dominated event with the corresponding tidal event from the joint probability study in all cases with the only exception of the tests on the downstream boundary conditions, which were carried out for the 0.5%AEP tidal dominated events with the corresponding fluvial event. (see Section 4.3)

Sensitivity test results are provided in the following tables. Uncertainty maps illustrating the results of the sensitivity analysis will be delivered as part of the final stage of this work.

+20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section / Reach where the Maximum Difference occurs
River Deel	0.023	0.241	03DEL09763
Mill Race	-0.074	-0.331	01DEX00430
Unnamed River	0.02	0.09	01STN00958
River Deegerty	0.03	0.07	01MOI00056dc

-20% Manning's 'n'

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
River Deel	-0.099	-0.444	03DEL10250
Mill Race	0.026	0.221	01DEX00278u
Unnamed River	-0.04	-0.163	01STN00530
River Deegerty	0.00	0.05	01MOI00112u

+20% inflows

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
River Deel	0.141	0.410	03DEL11187
Mill Race	0.128	0.238	01DEX00010u
Unnamed River	0.08	0.19	01STN00958
River Deegerty	0.01	0.08	01MOI00033

-20% inflows

Watercourse	Average Water Level Difference (m)	Maximum Water Level Difference (m)	Cross-section where the Maximum Difference occurs
River Deel	-0.172	-0.511	03DEL11499
Mill Race	-0.212	-0.378	01DEX00430
Unnamed River	-0.21	-0.34	01STN00215
River Deegerty	-0.01	-0.07	01MOI00000c1

Afflux at Key Structure Coefficients of approach velocity increased by 20% at vertical sluice at ISIS node 01DEX00278gu	There are 4 structures in the model within the AFAs which encounter significant head loss during the 1% AEP flood event. A vertical sluice gate is located on the mill race between the Aerobord factory and the River Deel. The coefficients of approach velocity were increased by 20% (to a value of 1.2). This produced a decrease of 139mm to the maximum water level immediately upstream of the structure, diminishing to zero within 180m. This decrease in stage caused a negligible reduction in the predicted flood extent upstream of the sluice gate.
Afflux at Key Structure Coefficients of approach velocity decreased by 20% at vertical sluice at ISIS node 01DEX00278gu	The coefficients of approach velocity at the vertical sluice gate were decreased by 20% (to a value of 0.8). This resulted in an increase of 18mm to the maximum water level immediately upstream of the structure, with the impact diminishing to zero within 110m. This increase in stage caused an insignificant increase in the predicted flood extent upstream of the structure.
Afflux at Key Structure Calibration coefficient and weir coefficient increased by 20% at ISIS node 02DEL00315u	An arch bridge is modelled immediately north of the Desmond Castle in Askeaton, crossing the River Deel. The calibration coefficient of the bridge unit was increased by 20% (to a value of 1.2) and the weir coefficient of the spill unit was also increased by 20% (to a value of 1.560). This resulted in a decrease of 3mm to the maximum water level immediately upstream of the bridge, diminishing to zero within 300m of the structure. This decrease in stage caused a negligible reduction in the predicted flood extent upstream of the bridge.
Afflux at Key Structure Calibration coefficient and weir coefficient decreased by 20% at ISIS node 02DEL00315u	The calibration coefficient of the bridge unit was decreased by 20% (to a value of 0.8) and the weir coefficient of the spill unit was also decreased by 20% (to a value of 1.083). This resulted in an increase of 2mm to the maximum water level upstream of the bridge, diminishing to zero within 160m of the structure. This increase in stage caused a negligible increase in the predicted flood extent upstream of the bridge.
Afflux at Key Structure Coefficient of velocity and weir coefficient increased by 20% at ISIS node 02DEL00719.	A round nosed weir is modelled on the Deel River, just downstream of Desmond Castle, prior to the mill race and the River Deel merging. The coefficient of velocity of the weir was increased by 20% (to a value of 1.2) as well as the weir coefficient of the spill unit (to a value of 1.8). This resulted in a decrease of 330mm to the maximum water level immediately upstream of the structure, diminishing to zero within 230m of the weir. This decrease in stage caused a negligible reduction in the predicted flood extent upstream of the weir given the reach of its influence.
Afflux at Key Structure Coefficient of velocity and weir coefficient decreased by 20% at ISIS node 02DEL00719.	The coefficient of velocity of the weir was decreased by 20% (to a value of 0.8) as well as the weir coefficient of the spill unit (to a value of 1.2). This resulted in an increase of 229mm to the maximum water level immediately upstream of the structure, diminishing to zero within 125m of the weir. This increase in stage caused a negligible increase in the predicted flood extent upstream of the weir given the reach of its influence.
Afflux at Key Structure Coefficient of velocity and weir coefficient increased by 20% at ISIS node 03DEL00103	A round nosed weir is located on the River Deel, adjacent to the most southerly Aerobord building leaving Askeaton. The coefficient of velocity of the weir unit was increased by 20% (to a value of 1.2) whist the weir coefficient of the spill unit was also increased by 20% (to a value of 1.8). This resulted in a decrease of 185mm to the maximum water level immediately upstream of the structure, diminishing to zero within 445m of the weir. This decrease in stage caused a negligible reduction in the predicted flood extent upstream of the weir given the reach of its influence.

Afflux at Key Structure Coefficient of velocity and weir coefficient decreased by 20% at ISIS node 03DEL00103	The coefficient of velocity of the weir unit was decreased by 20% (to a value of 0.8) whist the weir coefficient of the spill unit was also decreased by 20% (to a value of 1.2). This resulted in an increase of 229mm to the maximum water level immediately upstream of the structure, diminishing to zero within 445m of the weir. This increase in stage caused a negligible increase in the predicted flood extent upstream of the weir given the reach of its influence.
Downstream Conditions Duration of surge component of tidal boundary is increased by 100% (i.e. 22hours)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was increased by 100% (i.e. 22 hours). Model results also show that water levels are not affected by the increase in surge duration.
Downstream Conditions Duration of surge component of tidal boundary is decreased by 50% (i.e. 11hours)	To investigate the impact of the duration of high tide levels for a given upstream flood flow condition, the duration of the surge component of the 0.5% AEP tidal boundary was decreased by 100% (i.e. 11 hours). Model results also show that water levels are not affected by the decrease in surge duration.
4.5 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D.

5. Hydraulic Model Outputs

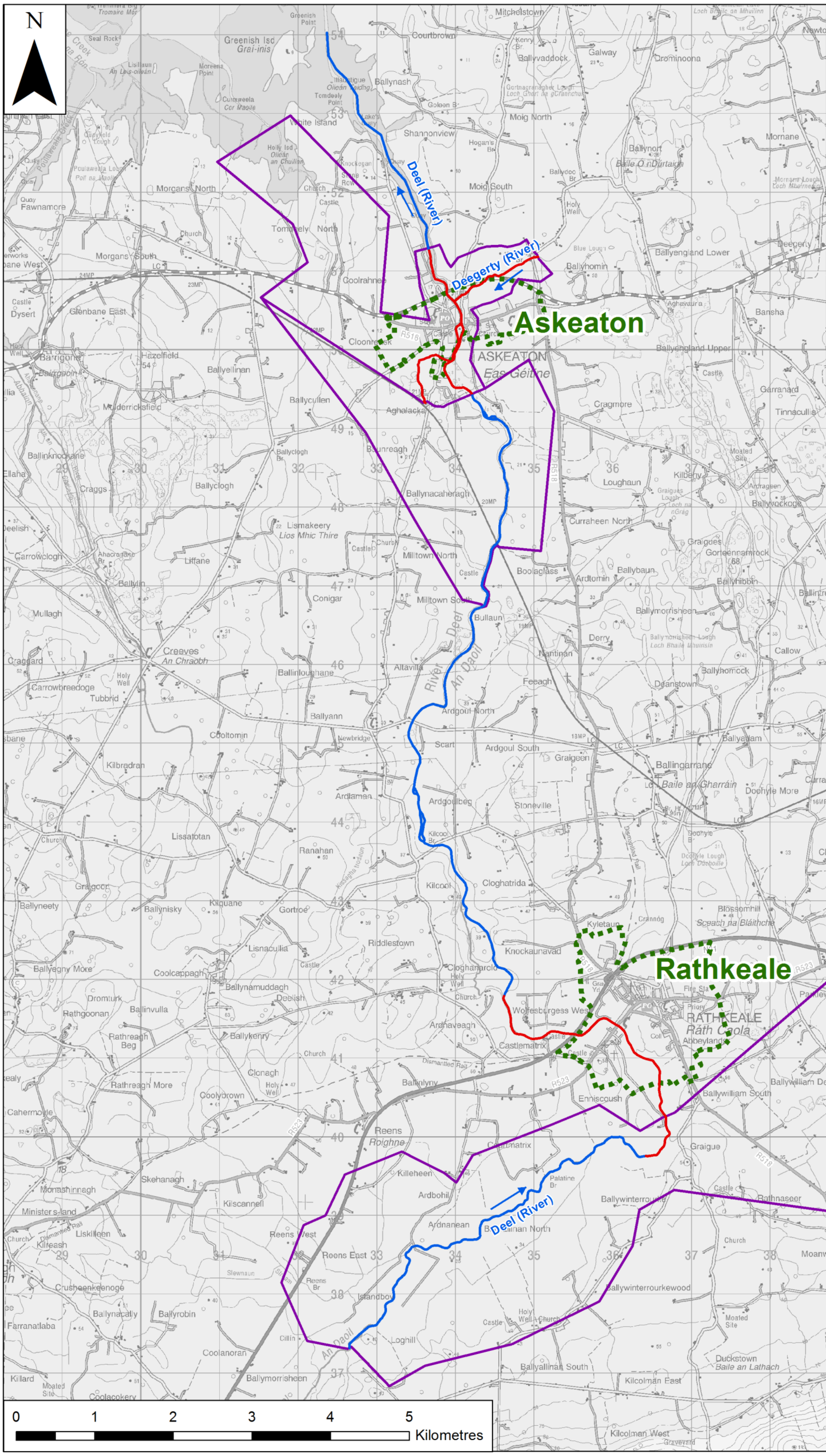
5.1 Mapping	Model outputs have been processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth and velocity • Flood hazard All of the maps contain the maximum extent, depth, velocity and flood hazard for the combined main stream inflows and the tributary inflows. An explanation for the main stream inflows and the tributary inflows is provided in Section 6. Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 1% and 0.1% AEP fluvial dominated flood events with the corresponding tidal boundary conditions and to the defended current scenario for the 10%, 0.5% and 0.1% AEP tidal dominated events with the corresponding fluvial events are shown in Annex E for flood extent and depth only. The flood extents for the fluvial extents are shown in the areas upstream of the tidal extent.

6. Key Model Assumption and Limitations

- As detailed in the Hydrology Report, the hydrological approach to the study catchment requires the main river and its tributaries to be treated separately in order to produce flood extents for the design events considered in this study. The River Deel (including the mill race) is classified as the main channel. The River Deegerty and Unknown River are classified as tributaries. Inflow hydrographs were purposely produced for both the main channel and tributaries and two models were run. The first containing only the main channel inflows, and the second containing only the tributary inflows. The main stem model and tributary models share exactly the same geometry (structures and topography). The model outputs from all models were then merged picking up the maximum flood depths and extents to create the flood maps.
- Although no defences have been identified within the model area in the defence asset database, a number of structures have been included in the model as they will have an impact on predicted flow routes. The OPW constructed an embankment in recent years approximately 2km upstream of Askeaton. This structure was identified in the Flood Risk Review, and has been included in the model with the elevations taken from LiDAR. There are also four structures within Askeaton AFA which have been included in the model, the locations of these structures are illustrated in Annex A2. These structures have been represented in the model as they will have an impact on predicted flow routes and connectivity between the river and floodplain.
- In the absence of survey data at the downstream extent of the River Deegerty, where it joins the River Deel through a culvert, the dimensions of the culvert were estimated using photographs.
- Tidal level hydrographs at the downstream boundary of the model have been adjusted in time so that the highest tidal level coincides with the fluvial peak flow at the downstream extent of the model.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent



Legend

- 2D Model Boundary
- AFA Boundary

Model Reaches

- HPW
- MPW

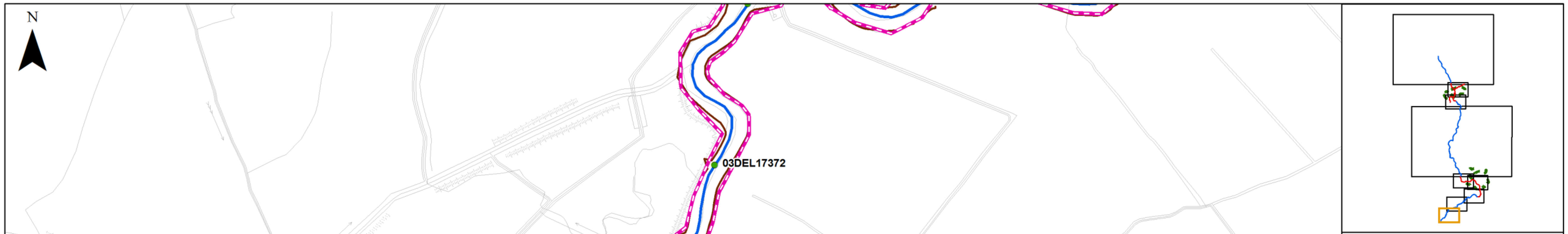
Model: S10

Figure ref: Annex A1

Drawing Title: S10 Model Extent

JACOBS

Annex A2 – Schematisation Maps



Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW

1D Model Schematisation

- Cross-section Extents
- Spills

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (1)

Drawing Title: S10 Model Schematisation

Client:
OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works,
Head Office,
Jonathan Swift Street,
Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie

Contractor:
JACOBS
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
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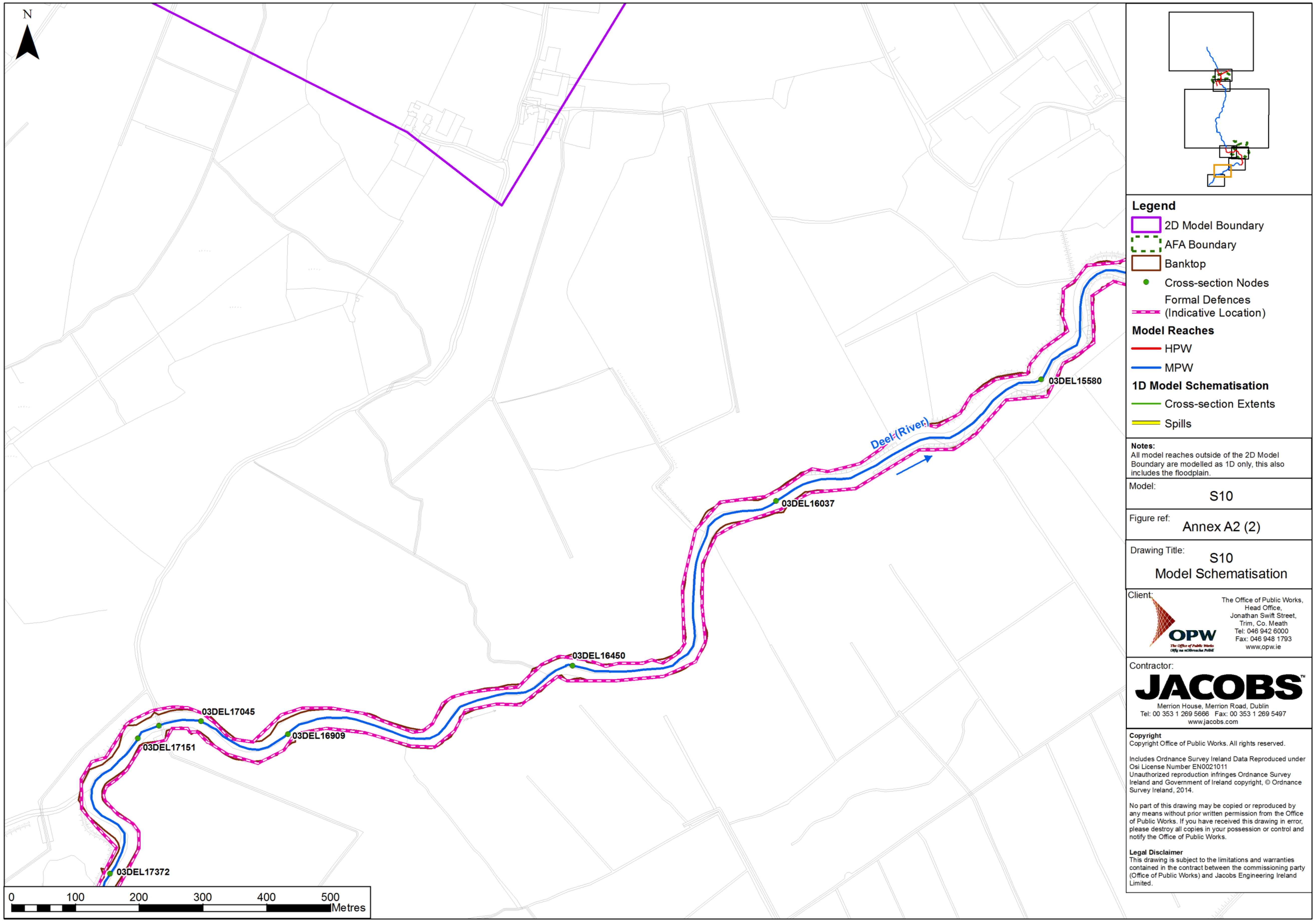

Legend

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (2)

Drawing Title: S10 Model Schematisation

Client: The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www,opw.ie

Contractor: JACOBS
Merrion House, Merrion Road, Dublin
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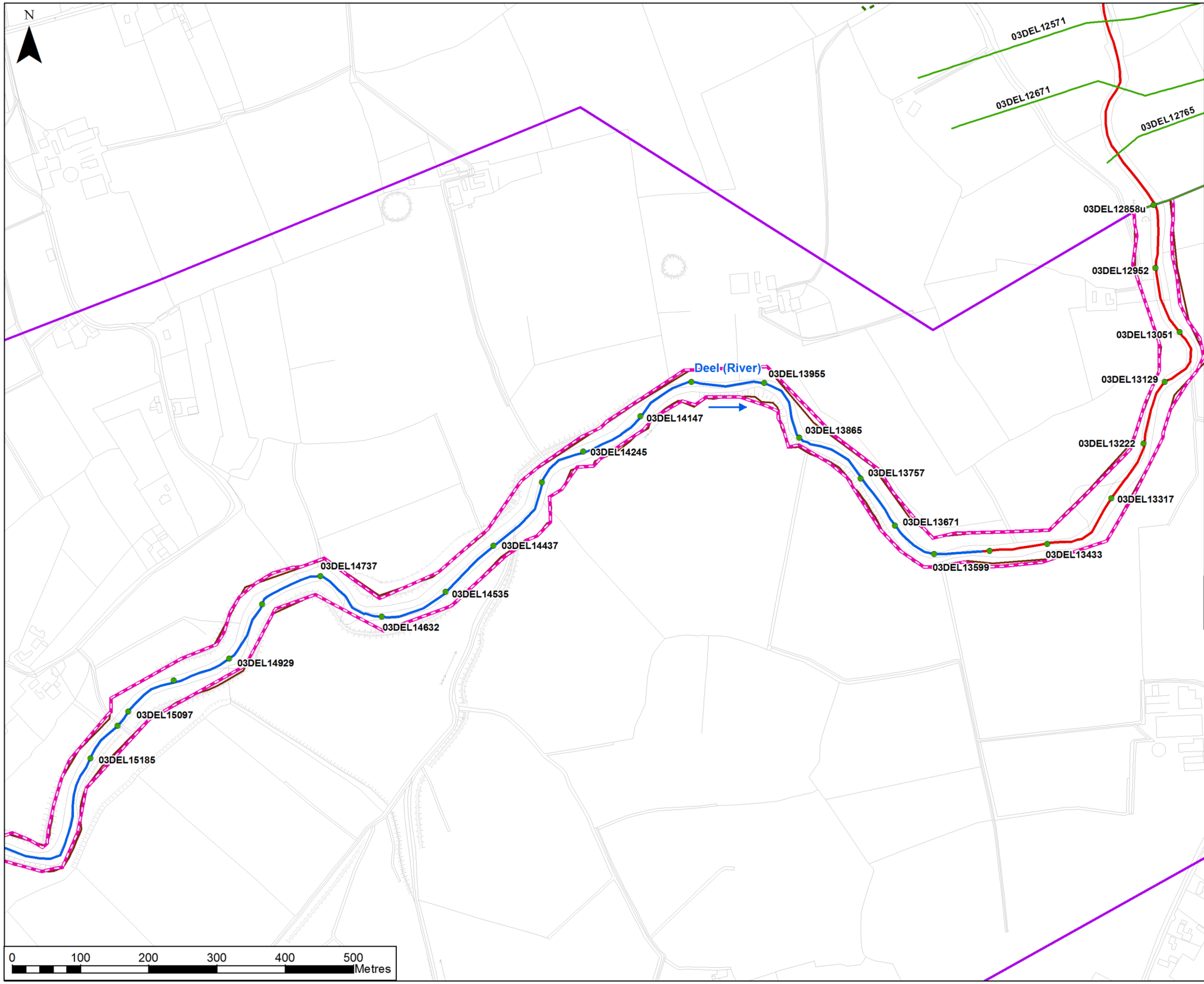

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW

1D Model Schematisation

- Cross-section Extents
- Spills

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (3)

Drawing Title: S10 Model Schematisation

Client:
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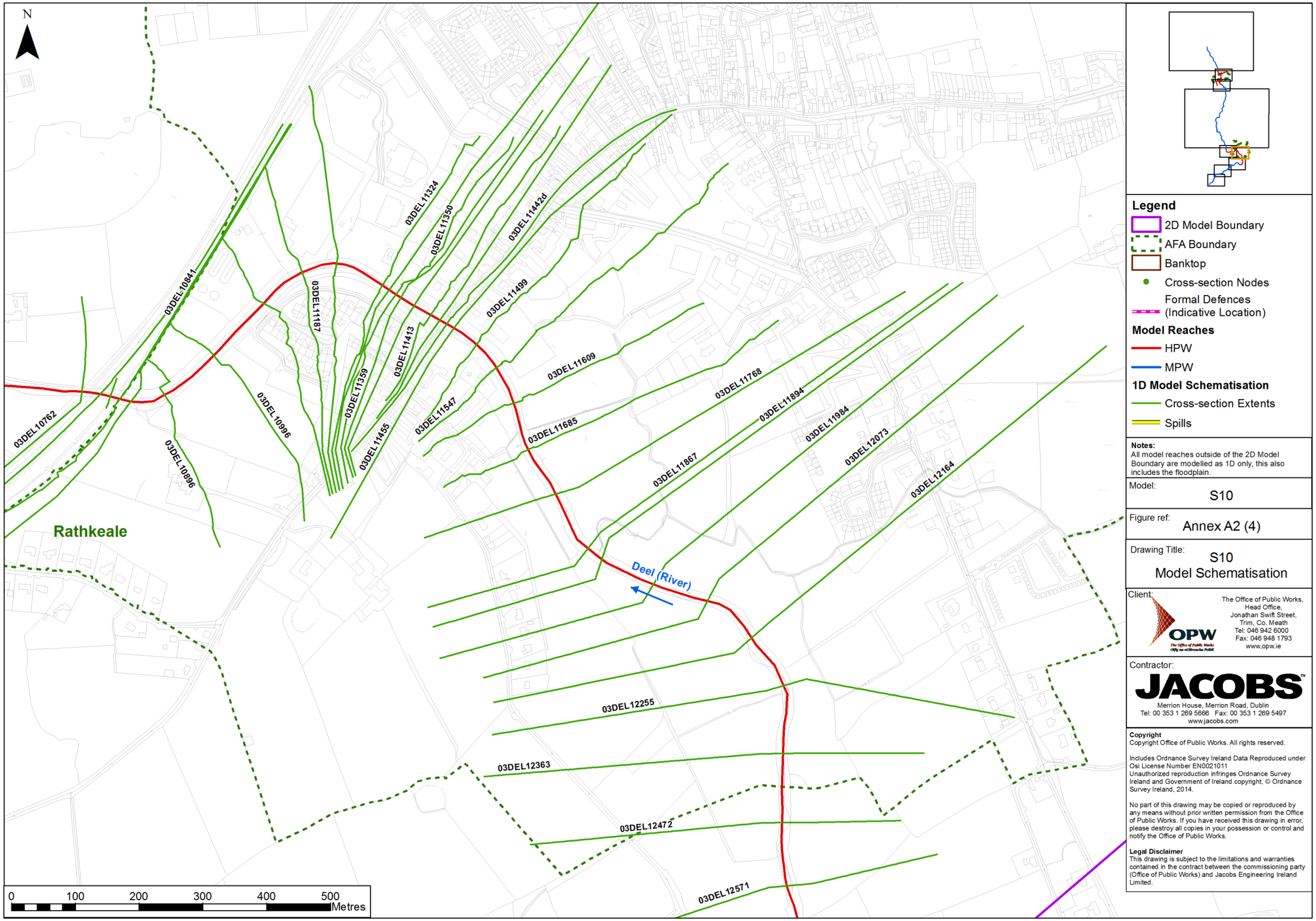
N
Rathkeale
Deel (River)
03DEL10762
03DEL10841
03DEL10896
03DEL10996
03DEL11187
03DEL11324
03DEL11350
03DEL11359
03DEL11413
03DEL11442d
03DEL11455
03DEL11499
03DEL11547
03DEL11609
03DEL11685
03DEL11768
03DEL11867
03DEL11894
03DEL11984
03DEL12073
03DEL12164
03DEL12255
03DEL12363
03DEL12472
03DEL12571
0 100 200 300 400 500 Metres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
1D Model Schematisation
Cross-section Extents
Spills
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S10
Figure ref: Annex A2 (4)
Drawing Title: S10 Model Schematisation
Client:
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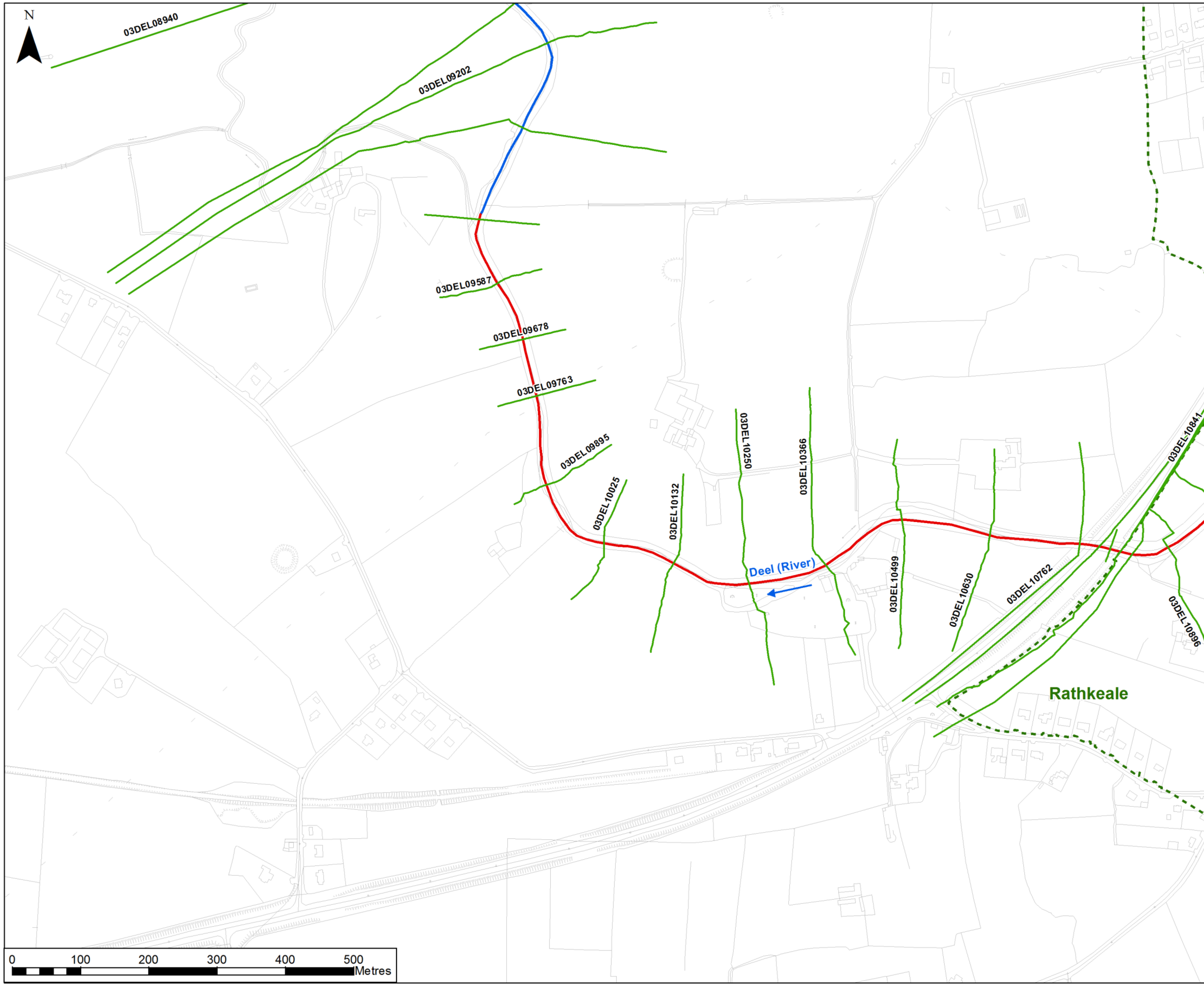

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW

1D Model Schematisation

- Cross-section Extents
- Spills

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (5)

Drawing Title: S10 Model Schematisation

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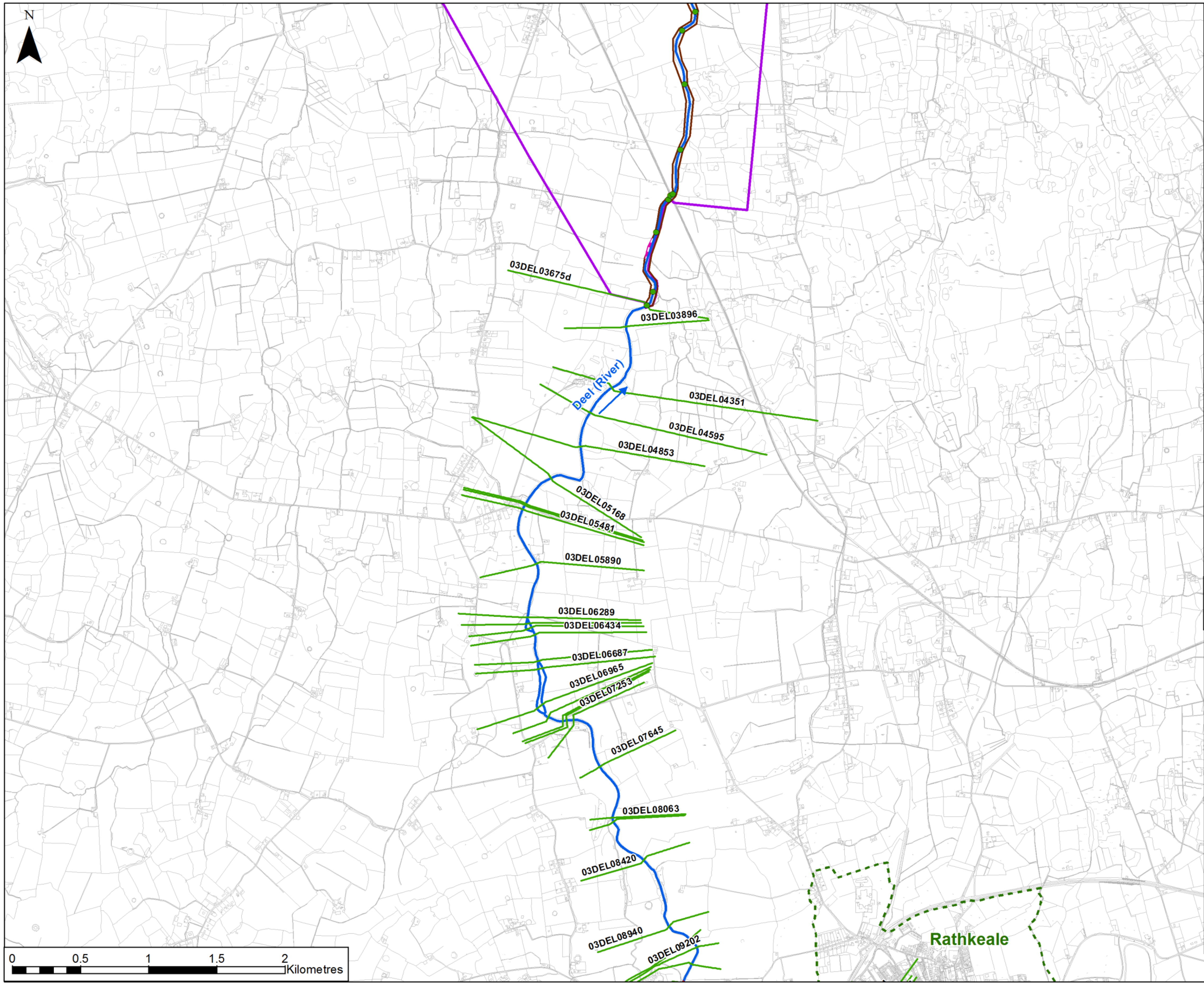

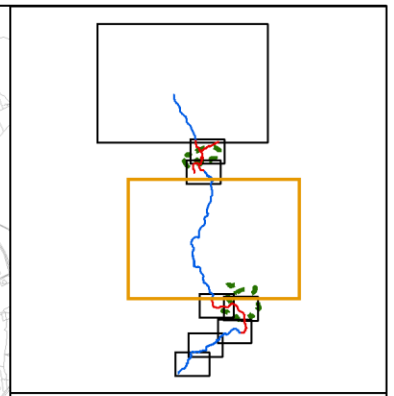

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW

1D Model Schematisation

- Cross-section Extents
- Spills

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (6)

Drawing Title: S10 Model Schematisation

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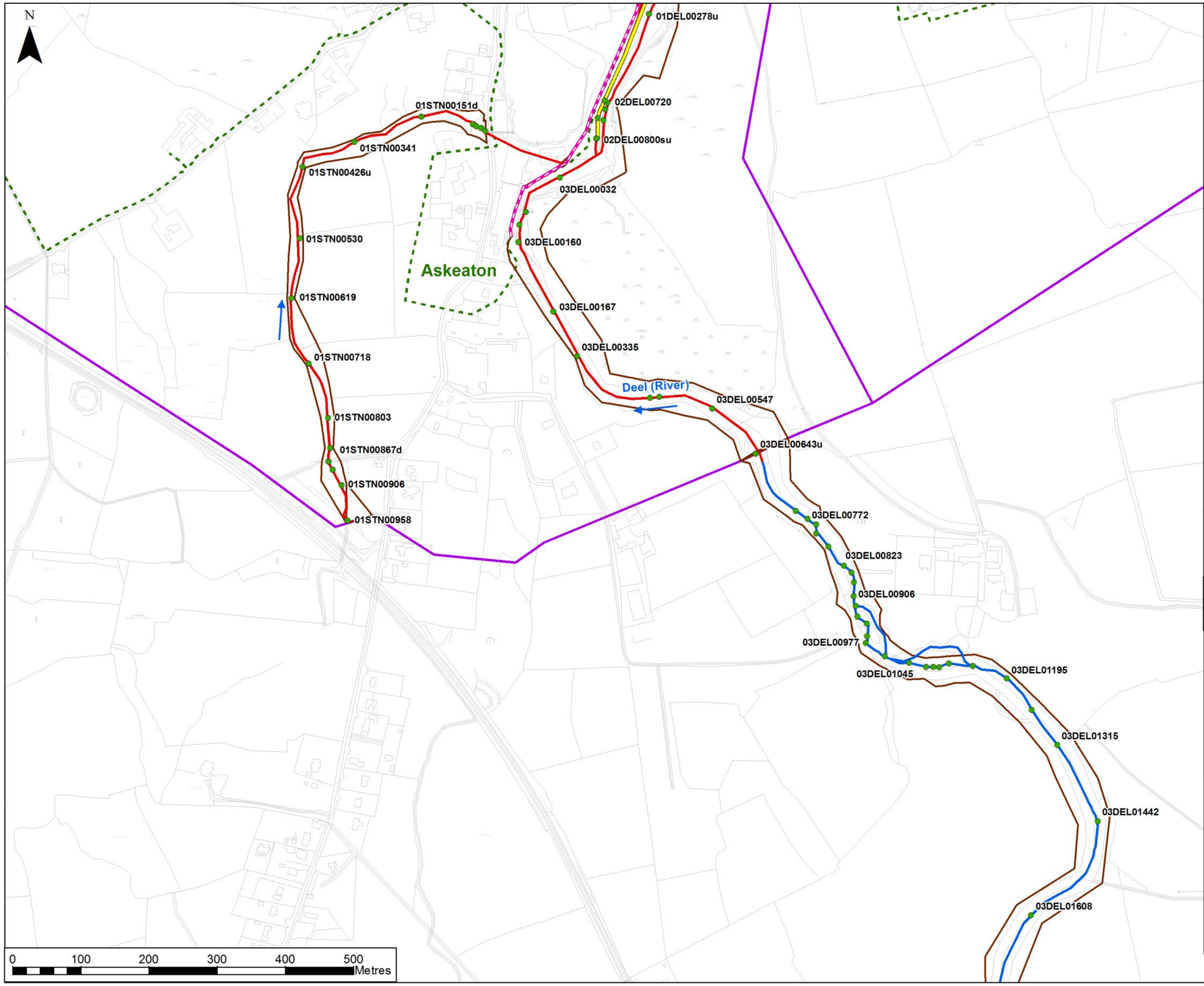

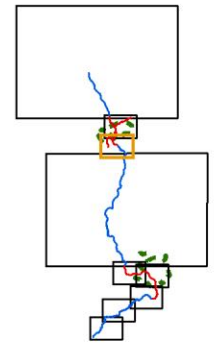

Legend

- 2D Model Boundary
- AFA Boundary
- Banktop
- Cross-section Nodes
- Formal Defences (Indicative Location)

Model Reaches

- HPW
- MPW

1D Model Schematisation

- Cross-section Extents
- Spills

Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.

Model: S10

Figure ref: Annex A2 (7)

Drawing Title: S10 Model Schematisation

Client:
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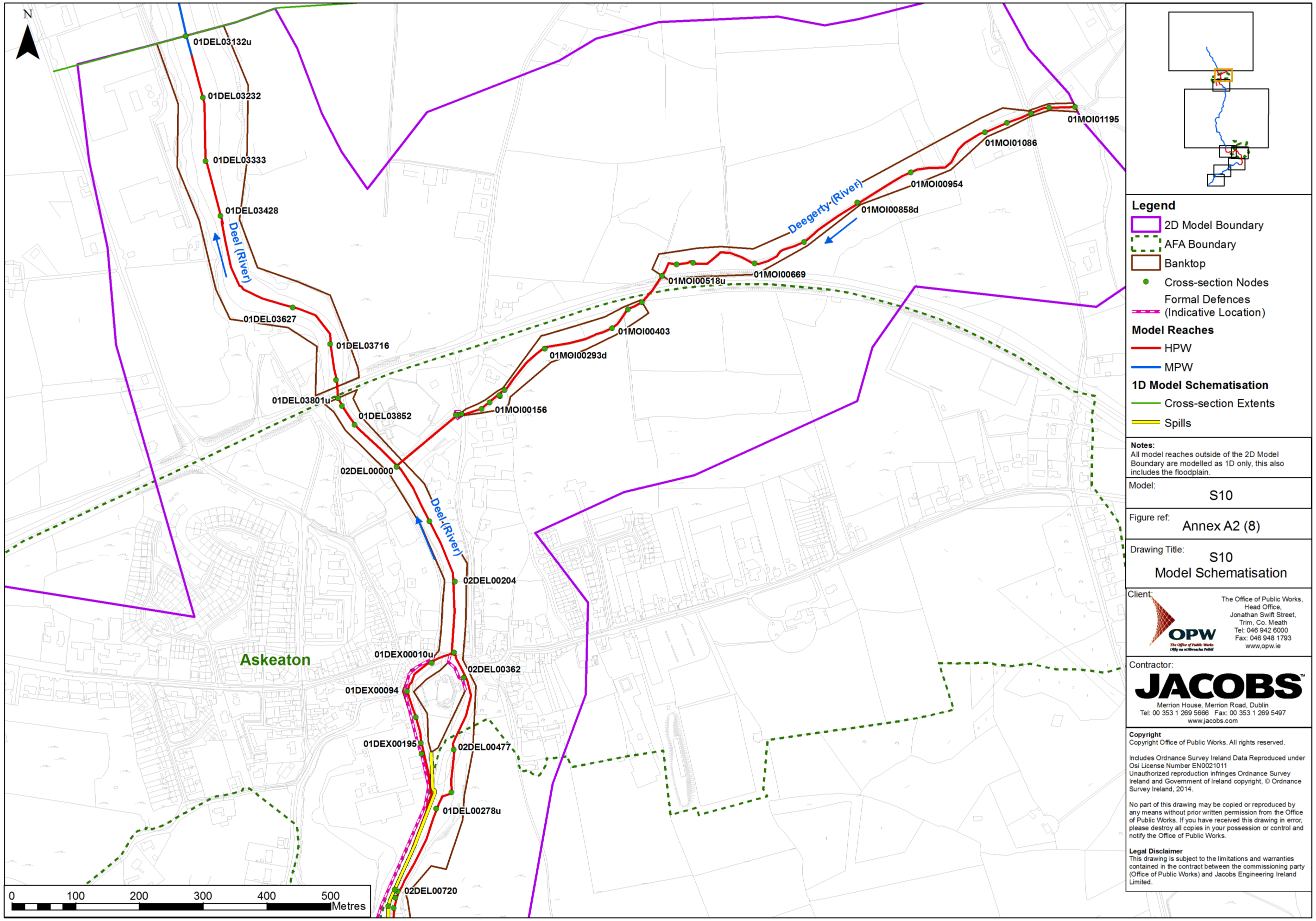
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01DEL03132u
01DEL03232
01DEL03333
01DEL03428
Deel (River)
01DEL03627
01DEL03716
01DEL03801u
01DEL03852
02DEL00000
Deel (River)
02DEL00204
01DEX00010u
02DEL00362
01DEX00094
01DEX00195
02DEL00477
01DEL00278u
02DEL00720
Askeaton
01MOI00156
01MOI00293d
01MOI00403
01MOI00518u
01MOI00669
Deegerty (River)
01MOI00858d
01MOI00954
01MOI01086
01MOI01195
0 100 200 300 400 500
Metres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
1D Model Schematisation
Cross-section Extents
Spills
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S10
Figure ref: Annex A2 (8)
Drawing Title: S10 Model Schematisation
Client:
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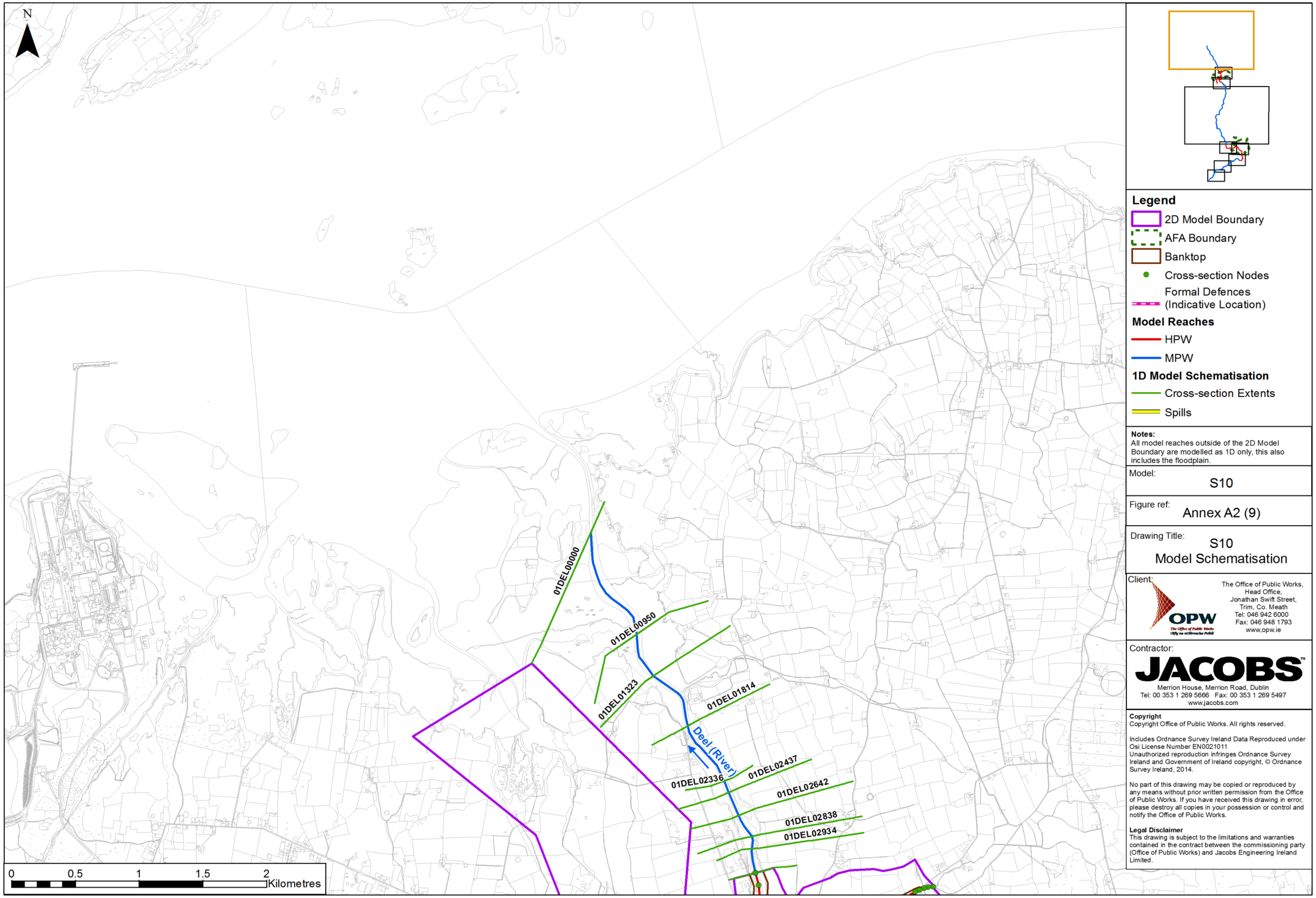

N
01DEL00000
01DEL00950
01DEL01323
01DEL01814
Deel (River)
01DEL02336
01DEL02437
01DEL02642
01DEL02838
01DEL02934
0
0.5
1
1.5
2
Kilometres
Legend
2D Model Boundary
AFA Boundary
Banktop
Cross-section Nodes
Formal Defences (Indicative Location)
Model Reaches
HPW
MPW
1D Model Schematisation
Cross-section Extents
Spills
Notes:
All model reaches outside of the 2D Model Boundary are modelled as 1D only, this also includes the floodplain.
Model: S10
Figure ref: Annex A2 (9)
Drawing Title: S10 Model Schematisation
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Annex B – Structure and Hydraulic Roughness Schedules

Schedule A.1 - Structure Schedule for River Deel

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEL01971D	03DEL17111	4.43m wide Bridge	Arch Bridge + Spill	N*
24DEEL01772D	03DEL15123	4.43m wide Bridge	Arch Bridge + Spill	N*
DEEL01_2317u	03DEL11442	7.25m wide Bridge	Arch Bridge + Spill	Y
DEEL01_2225	03DEL11350	Weir	Spill Unit	Y
DEEL01_1716	03DEL10823	5.65m wide Bridge	Arch Bridge + Spill	Y
DEEL01_1666u	03DEL10791	17.6m wide Bridge	Arch Bridge + Spill	Y
24DEEL01061D	03DEL07202	5.68m wide bridge	Arch Bridge + Spill	Y
24DEEL00886E	03DEL05446	5.23m wide bridge	Arch Bridge + Spill	Y
24DEEL00625D	03DEL02845	4.43m wide Bridge	Arch Bridge + Spill	Y
DEER01_0200u	03DEL00951	Weir	Round Nose Weir	Y
24DEEL00363W	03DEL00161	Weir	Labyrinth Weir + Spill	Y
24DEEL00357W	03DEL00102	Weir	Round Nose Weir	Y
24DEEL00342W	02DEL00797	Weir	Round nosed weir + Spill	Y
24DEEL00334W	02DEL00719	Weir	Round nosed weir + Spill	Y
24DEEL00294E	02DEL00315	7.45m wide bridge	Arch Bridge + Spill	Y
24DEEL00283W	02DEL00206	Weir	Round nosed weir + Spill	Y
24DEEL00248D	01DEL03801	13.83m wide bridge	USBPR unit**	Y

* Considering the size of the structure relative to the watercourse it was determined that the structure would have little or no hydraulic impact on the model.

Schedule A.2 - Structure Schedule for Mill Race

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEED00028W	01DEX00278	Sluice Gate	Sluice Gate	Y
24DEED00002E	01DEX00010	7.65m wide bridge	Two culverts + Spill	Y

Schedule A.3 - Structure Schedule for Deel E

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEE00087D	01STN00867	4.60m wide bridge	Orifice + Spill	Y
24DEEE00015D	01STN00154	0.8m dia. & 3.70m long twin culvert	Two circular conduits + Spill	Y
24DEEE00014I & 24DEEE00009J	01STN00140	130.5m long culvert	Circular & rectangular conduit at inlet and single circular conduit at outlet + Bend unit	Y

Schedule A.4 - Structure Schedule for River Deegerty

Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
24DEEA00118D	01MOI01164	8.40m wide Bridge	Arch Bridge + Spill	Y
24DEEA00054I & 24DEEA00048J	01MOI00518	1.0m dia. & 52.15m long circular culvert	Circular conduit	Y
24DEEA00021D	01MOI00191	1.5m wide footbridge	Arch Bridge + Spill	Y
24DEEA00014E	01MOI00123	6.68m wide bridge	Orifice + Spill	Y
24DEEA00014W	01MOI00119	Weir	General purpose weir + Spill	Y
24DEEA00013I	01MOI00112	111.5m long culvert	Full arch conduit at inlet and rectangular conduit at outlet + Bend unit	Y

Schedule B.1 – Manning’s ‘n’ for HPW Network

River Name	ISIS Node Reference	Bed Roughness*	Estimated Bank Side Roughness	Estimated Floodplain Roughness
River Deel	03DEL13518 to 03DEL11768	0.04	Determined on a case by case basis using photos, videos and survey drawings	2d Domain : based on OSi NTF land use polygons 1d Domain: Land use EPA data has been used for assigning the floodplain roughness.
	(Rathkeale GS) 03DEL11685 to 03DEL11455	0.04		
	(Rathkeale GS) 03DEL11442u to 03DEL11442d	0.02		
	(Rathkeale GS) 03DEL11430 to 03DEL10841	0.04		
	(Rathkeale GS) 03DEL10823u to 03DEL10823d	0.02		
	(Rathkeale GS) 03DEL10808 to 03DEL09125	0.04		
	03DEL00643 to 02DEL00797	0.04		
	02DEL00797 to 02DEL00362	0.045		
	02DEL00315 to 01DEL03801	0.04		
	01DEL03773 to 01DEL03232	0.04		
River Deegerty	01MOI01235 to 01MOI00112u	0.05		
Mill Race	01DEX00473 to 01DEX00010u	0.045		
Deel E	01STN00958 to 01STN00140u	0.055		

*In some cross-sections a different bed roughness coefficient may have been used to represent specific bed material (e.g. engineered concrete sections). All of the altered cross sections are within the roughness bounds defined in Section 3.6.

Schedule B.2 – Manning's 'n' for MPW Network

<table>
<tr><th>River Name</th><th>ISIS Node Reference</th><th>Bed Roughness*</th><th>Estimated Bank Side Roughness</th><th>Estimated Floodplain Roughness</th></tr>
<tr><td rowspan="5">River Deel</td><td>04DEL00000 to 03DEL13599</td><td>0.04</td><td rowspan="5">Determined on a case by case basis using photos, videos and survey drawing</td><td rowspan="5">Land use EPA data has been used for assigning the floodplain roughness.</td></tr>
<tr><td>03DEL08940 to 03DEL01315</td><td>0.035</td></tr>
<tr><td>(Inchirourke GS) 03DEL01253 to 03DEL00951u</td><td>0.03</td></tr>
<tr><td>(Inchirourke GS) 03DEL00950d to 03DEL00751</td><td>0.035</td></tr>
<tr><td>01DEL00181 to 01DEL00000</td><td>0.035</td></tr>
</table>

Annex C - Model Calibration Summary Note

Hydrometric data was available for possible calibration of the model for a reach of the River Deel between Inchirourke gauging station 24029 & Rathkeale gauging station 24013.

However, it was observed from the gauged flow data that the peak flow decreases in the downstream direction from gauging station 24013 to 24019. This has been attributed to water losses within the catchment due to permeable underlying soil conditions and karstic features and it was not be possible to replicate such losses in the hydraulic model.

Therefore it was not possible to calibrate this model for any flood event.

Annex D - Hydraulic Model Files

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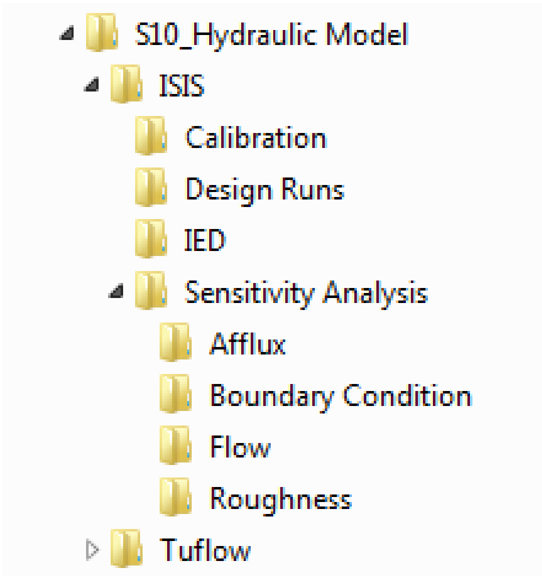
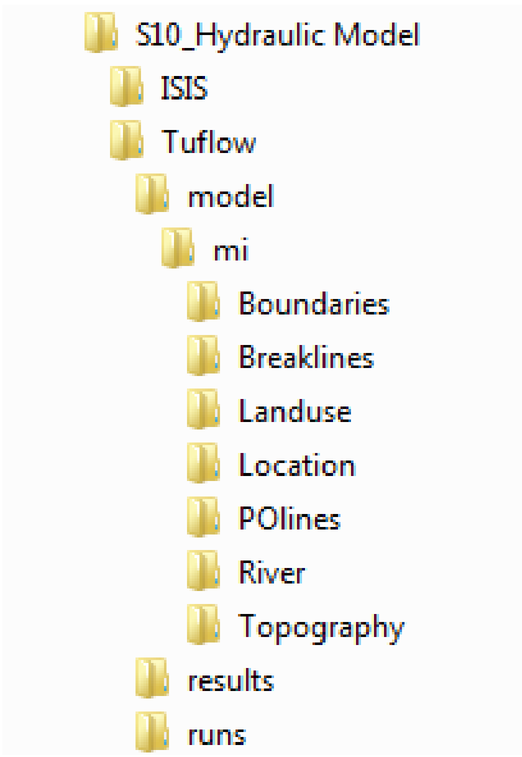
<tr><td>ISIS</td><td>
</td></tr>
<tr><td>TUFLOW</td><td>
</td></tr>
</table>

ISIS Files	
Model Geometry (.dat) and Associated Files (e.g.: .ief, .zzl, .zzd, .zzu,.zzx)	**Design Runs – Current Fluvial Scenario:** **Main Stream Model** S10_Q1000_FluMi_C_Des_Iss2.DAT S10_Q200_FluMi_C_Des_Iss2.DAT S10_Q100_FluMi_C_Des_Iss2.DAT S10_Q50_FluMi_C_Des_Iss2.DAT S10_Q20_FluMi_C_Des_Iss2.DAT S10_Q10_FluMi_C_Des_Iss2.DAT S10_Q5_FluMi_C_Des_Iss2.DAT S10_Q2_FluMi_C_Des_Iss2.DAT **Tributary Model** S10_Trib_Q1000_Flu_C_Des_Iss1.DAT S10_ Trib_Q200_Flu_C_Des_Iss1.DAT S10_ Trib_Q100_Flu_C_Des_Iss1.DAT S10_ Trib_Q50_Flu_C_Des_Iss1.DAT S10_ Trib_Q20_Flu_C_Des_Iss1.DAT S10_ Trib_Q10_Flu_C_Des_Iss1.DAT S10_ Trib_Q5_Flu_C_Des_Iss1.DAT S10_ Trib_Q2_Flu_C_Des_Iss1.DAT **Design Runs – Current Tidal Scenarios:** S10_Q1000_CoMi_C_Des_Iss2.DAT S10_Q200_CoMi_C_Des_Iss2.DAT S10_Q100_CoMi_C_Des_Iss2.DAT S10_Q50_CoMi_C_Des_Iss2.DAT S10_Q20_CoMi_C_Des_Iss2.DAT S10_Q10_CoMi_C_Des_Iss2.DAT S10_Q5_CoMi_C_Des_Iss2.DAT S10_Q2_CoMi_C_Des_Iss2.DAT
Hydrological Inflow Files	**Design Runs – Current Fluvial Scenario:** **Main Stream Model** S10_Q1000_FluMi.IED S10_Q200_FluMi.IED S10_Q100_FluMi.IED S10_Q50_FluMi.IED S10_Q10_FluMi.IED S10_Q5_FluMi.IED S10_Q2_FluMi.IED **Tributary Model** S10_Trib_Q1000_Flu.IED S10_Trib_Q200_Flu.IED S10_Trib_Q100_Flu.IED S10_Trib_Q50_Flu.IED S10_ Trib_Q10_Flu.IED

	S10_ Trib_Q5_Flu.IED S10_ Trib_Q2_Flu.IED **Design Runs – Current Tidal Scenario:** **Main Stream Model** S10_Q1000_CoMi.IED S10_Q200_CoMi.IED S10_Q100_CoMi.IED S10_Q50_CoMi.IED S10_Q10_CoMi.IED S10_Q5_CoMi.IED S10_Q2_CoMi.IED

TUFLOW files	
TUFLOW Control Files (.tcf) and Associated Files (e.g.: ecf, tgc, tbc)	**<u>Design Runs – Current Fluvial Scenario</u>:** **Main Model** S10_Q1000_FluMi_C_Des_Iss2.tcf S10_Q200_FluMi_C_Des_Iss2.tcf S10_Q100_FluMi_C_Des_Iss2.tcf S10_Q50_FluMi_C_Des_Iss2.tcf S10_Q20_FluMi_C_Des_Iss2.tcf S10_Q10_FluMi_C_Des_Iss2.tcf S10_Q5_FluMi_C_Des_Iss2.tcf S10_Q2_FluMi_C_Des_Iss2.tcf } 2d_5m_S10_Aske.tbc 2d_20m_S10_Deel.tbc 2d_20m_S10_Inch.tbc 2d_5m_S10_Aske.tgc 2d_20m_S10_Deel.tgc 2d_20m_S10_Inch.tgc S10_Landuse.tmf **Trib Model** S10_Trib_Q1000_Flu_C_Des_Iss1.tcf S10_Trib_Q200_Flu_C_Des_Iss1.tcf S10_Trib_Q100_Flu_C_Des_Iss1.tcf S10_Trib_Q50_Flu_C_Des_Iss1.tcf S10_Trib_Q20_Flu_C_Des_Iss1.tcf S10_Trib_Q10_Flu_C_Des_Iss1.tcf S10_Trib_Q5_Flu_C_Des_Iss1.tcf S10_Trib_Q2_Flu_C_Des_Iss1.tcf } 2d_5m_S10_Aske_Tribs.tbc 2d_5m_S10_Aske_Tribs.tgc S10_Landuse_Aske.tmf **<u>Design Runs – Current Tidal Scenario:</u>** S10_Q1000_CoMi_C_Des_Iss2.tcf S10_Q200_CoMi_C_Des_Iss2.tcf S10_Q100_CoMi_C_Des_Iss2.tcf S10_Q50_CoMi_C_Des_Iss2.tcf S10_Q20_CoMi_C_Des_Iss2.tcf S10_Q10_CoMi_C_Des_Iss2.tcf S10_Q5_CoMi_C_Des_Iss2.tcf S10_Q2_CoMi_C_Des_Iss2.tcf } 2d_5m_S10_Aske.tbc 2d_20m_S10_Deel.tbc 2d_20m_S10_Inch.tbc 2d_5m_S10_Aske.tgc 2d_20m_S10_Deel.tgc 2d_20m_S10_Inch.tgc S10_Landuse.tmf
Grid Orientation File	2d_loc_S08.MIF
Material Files	2d_mat_5m_S10_Aske.MIF 2d_mat_5m_S10_Aske_outside.MIF 2d_mat_5m_S10_Aske_rural.MIF 2d_mat_5m_S10_Inch_rural.MIF 2d_mat_5m_S10_Deel.MIF
Zpt Files, Model DTM (.asc)	Askeato2m_dtm.asc S10_SAR.asc
Breaklines Files	2d_zln_surv_banktop_S10_Deel.MIF 2d_zln_surv_banktop_S10_Inch.MIF 2d_zln_surv_banktop_S10_Aske.MIF 2d_zln_unsurv_banktop_5m_S10.MIF 2d_zln_unsurv_banktop_20m_S10_Deel.MIF 2d_zln_surv_embankments_20m_S10.MIF

Boundary Files	2d_bc_hxe_5m_S10_Aske.MIF 2d_bc_hxe_5m_S10_Deel.MIF 2d_bc_hxe_5m_S10_Inch.MIF 2d_bc_hxi_5m_S10_Aske.MIF 2d_bc_hxi_5m_S10_Deel.MIF 2d_bc_hxi_5m_S10_Inch.MIF 2d_2d_bc_S10.MIF 2d_bc_hq_20m_S10_Deel.MIF 2d_bc_HT_5m_S10_Aske.MIF 2d_bc_SX_S10_5m_Aske.MIF 2d_bc_SX_wall_gap.MIF
Flow/Head Files in bc_dbase	**Design runs:** S10_bc_dbase Q1000.csv Q200.csv Q100.csv Q50.csv Q20.csv Q10.csv Q5.csv Q2.csv
Initial Water Level Files	No initial water level files provided to the 2d domain.
Time Series Files	No time series files provided to the 2d domain.
One Dimensional Network Files	1d_ISIS_nodes_5m_S10_Aske.MIF 1d_ISIS_nodes_20m_S10_Deel.MIF 1d_ISIS_nodes_20m_S10_Inch.MIF
Available 2D Result Files	Depth, stage, hazard and velocity 2d results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time Step	Advanced Options /Other Information	Comments on Model Stability
Design Runs – Current scenario						
1	S10_Q1000_FluMi_C_Des_Iss2.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary
2	S10_Q100_FluMi_C_Des_Iss2.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary.
3	S10_Q10_FluMi_C_Des_Iss2.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary
	S10_Trib_Q1000_Flu_C_Des_Iss1.DAT	-1	85	1	"Automated Preissmann Slot for River Sections" is checked, Maxitr set at 10 and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary
10	S10_ Trib_Q100_Flu_C_Des_Iss1.DAT	-1	85	1	"Automated Preissmann Slot for River Sections" is checked, Maxitr set at 10 and perform corrective 1d timestep" is checked. All other run parameters = default	Convergence within manufacturer tolerance.
11	S10_ Trib_Q10_Flu_C_Des_Iss1.DAT	-1	85	1	"Automated Preissmann Slot for River Sections" is checked, Maxitr set at 10 and perform corrective 1d timestep" is checked. All other run parameters = default	Convergence within manufacturer tolerance.

	S10_Q1000_CoMi_C_Des_Iss1.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary
18	S10_Q200_CoMi_C_Des_Iss1.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary
22	S10_Q10_CoMi_C_Des_Iss1.DAT	-1	60	1	"Automated Preissmann Slot for River Sections" is checked and perform corrective 1d timestep" is checked. All other run parameters = default	Some spikes of poor convergence associated with Tidal Boundary

Parameters changed from Default	Justification
Automated Preismann slot for River Sections turned on.	Automated Preismann slot are a standard parameter used to aid model stability particularly in low flows. These Preismann slots have negligible to no impact on the water levels during flood events.
Maxitr	Increased to 10 to improve model stability.*
Perform Corrective 1D Timestep	Used to improve model stability.*

*Stage and Flow profiles at all cross sections have been checked to ensure results are sensible and to ensure any changes to the default model run parameters has not impacted on the model results.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Coastal Hydraulic Modelling Report

1. Basic Model Information

1.1 General Information	
Model ID:	IRR4
Unit of Management	24
IRRs included in the model	Tarbert Power Station
Primary Watercourses / Water Bodies	Not applicable – No watercourses in this model
1.2 Reference to other Relevant Reports	
Catchment Description	Hydraulics Report Unit of Management 24 – Section 2.5
Model Location	Hydraulics Report Unit of Management 24 – Figure 1
HEP Schematisation	N/A

2. Survey Data and Base Mapping

2.1 Base Mapping:	OSi data base mapping at scale 1:50k Reference: OS1014_D
2.2 DTM for 2D Model Domains:	**Within and outside IRR:** LiDAR data with 2m horizontal resolution and approximately 200mm vertical accuracy has been used to inform the hydraulic model with ground elevation in the floodplain areas included in the IRR boundary and also outside the IRR.
2.3 Defence Asset Survey Data	The defence asset database has been completed for this IRR. IRR Tarbert Power Station has one formal effective defence within the IRR boundary to the north of the Power Station site. The approximate length of formal defences in IRR4 is 0.27km. The maximum crest level for the formal defences is 4.61mOD. A formal defence also exists, to the south of the Power station, outside of the IRR boundary. This defence and another discrete embankment have been represented in the hydraulic model. The locations of the defences are shown in the figures presented in Annex A2.
2.5 Survey interaction	The Lidar, IFSAR and topographic survey were checked for anomalies, and to ensure that interactions between were within expected tolerances. No issues were identified in this model.

3. Hydraulic Model Construction and Schematisation

3.1 Software:	**1D Domain:** NA		
	2D Domain(s): TUFLOW Version: 2013-12-AA-iSP-w64		
3.2 Model Area / Extent:	The extent of the model and its schematisation are shown in Annex A.		

The mapping details for the model extent included in Annex A are as follows:

1. **Full modelled area showing**:
    - IRR extent
    - 2D domain area
2. **Maps showing a detailed model schematic of the floodplain are also included**

3.3 Floodplain Schematisation	The floodplain area within and outside the IRR boundary has been modelled using a 2D approach as set out in the TUFLOW model. An overview of the floodplain schematisation is available in the maps shown in Annex A.		
3.4 2D Domain Grid Size:	A single 2D domain was defined and the grid size of the 2D model domain is as follows:		
	Number of 2D domains: 1		
	Domain 1: Tarbert	Grid cell size (m): 2	Area (km^2): 2.286
	2D domains are defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas where there are multiple features that could not be suitably represented in, say, a 10m grid. The model grid is orientated in the main direction of the floodplain flow.		
3.5 Model Breaklines in the 2D Domain:	Formal flood defence walls, an embankment to the west of the site and a drain discharging into the main lagoon were represented as breaklines in the 2D domain.		
3.6 Floodplain Structures in the 2D Domain	1D elements have been included in the 2D model to represent: • 4 x 1m diameter circular culverts linking the main tidal lagoon to a secondary lagoon located south of the power station site • One access bridge across a drain discharging into the main lagoon The above structures were not surveyed, their dimensions were obtained through SSE (Scottish and Southern Energy) Plc. which owns the Power Station. It should be noted that SSE confirmed that no tidal flaps are fitted on both structures. SSE has also confirmed that there is no weir or tidal gate at the outlet from the main lagoon to the Shannon estuary. There is a pedestrian bridge above what is left of a fish screen structure (screen is no longer there). The footbridge structure was not represented in the model as it was considered it would not have a significant impact on the tidal waters in and out of the structure. To broadly represent the effect of the fish screen structure, hydraulic roughness has been increased locally.		
3.7 Hydraulic Roughness	Hydraulic roughness (Manning's 'n') for the areas represented in the TUFLOW model were as defined by OSi NTF land use characteristics, as described in the main Hydraulics Report. Floodplain land uses and adopted roughness values in TUFLOW are as follows:		
	Land Use	**Manning's 'n' Value**	
	Rural areas on/off site	0.045	

	Default value covering the power plant site	0.060
	Dense Vegetation on/off site	0.080
	Water bodies	0.020
	Flat Rock	0.025
	Roads	0.025
	Fish screen	0.05
	Buildings	0.100
3.8 Spill Units	Spill units are used for a number of different purposes (e.g. irregular weir, lateral spilling in the floodplain). Spill profile geometry is defined using topographic survey data and LiDAR/IfSAR. Spill coefficients used generally vary between 0.9 and 1.5 depending on the type of ground conditions (e.g. rough vegetated, smooth concrete) over which flood flows are spilling. Lower coefficients (<1.0) can be also found to account for lateral spilling perpendicular to the main direction of flow.	
3.9 Model Boundaries	Tidal level hydrographs for Tarbert Power Station were produced for a series of design events using ICPSS extreme tidal peak levels data. The time series were set up as boundary conditions for the hydraulic model along the coastal boundary of the hydraulic model. Full details on how these tidal level hydrographs were derived are provided in Appendix D of the main Hydraulics Report. Peak tidal levels are summarised in the table below for the current and future situations. For the wave overtopping model, wave overtopping hydrographs have been applied directly to the hydraulic model using a flow versus time boundary along the landward side of the flood defences. The hydrographs vary for different points along the defence as shown in Annex F. Full details on how these tidal level hydrographs were derived are provided in section 4.4 of the main Hydraulics Report. The tidal hydrographs applied for wave overtopping are available in Annex F of this report.	

	Current Annual Exceedance Probability							
Peak tidal levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.5

	MRFS Annual Exceedance Probability							
Peak tidal levels (m OD)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1

	HEFS Annual Exceedance Probability		
Peak tidal levels (m OD)	**10%**	**0.5%**	**0.1%**
	4.0	4.4	4.6

4. Hydraulic Model Calibration and Sensitivity

4.1 Model Calibration and Verification to Historical Events	Model calibration and verification was not possible due to lack of information available.
4.2 Model Sensitivity	Sensitivity tests have been carried out in order to assess the sensitivity of the predicted peak water levels to alterations in roughness (Manning's 'n'), and Downstream Conditions. In each case the sensitivity run was carried out for the 0.5% AEP tidal event (defended scenario only). Sensitivity test results are provided in the section below:
4.2.1 Hydraulic Roughness	Model outputs show that increasing or decreasing the roughness has a marginal effect on the predicted flood extents and flood depths. When compared to the baseline situation, maximum flood depths predicted by the model vary from approximately 0 to +/-9mm. The table below provides examples of flood depths variation at several key locations across the model domain.

	Location			Maximum Flood Depth (m)		
	Description	Grid reference		Existing	+20%	-20%
		X	Y			
1	Northern formal flood defence	107609	149623	0.106	0.097	0.114
2	Access Road: outside west perimeter of power station	107505	149630	0.075	0.069	0.085
3	Buildings: west of main power station building	107443	149631	0.080	0.080	0.080
4	Behind buildings south of main drain	107459	149192	0.057	0.049	0.063
5	Green area south of lagoon	107304	149202	0.135	0.133	0.139

4.2.2 Downstream Conditions	Model outputs show that increasing or decreasing the duration of the surge component of the tidal boundary has a marginal effect on the predicted flood extents and flood depths. When compared to the baseline situation, maximum flood depths predicted by the model vary from approximately 0 to +/-6mm. The table below provides examples of flood depths variation at several key locations across the model domain.

	Location			Maximum Flood Depth (m)		
	Description	Grid reference		Existing	+100%	-50%
		X	Y			
1	Northern formal flood defence	107609	149623	0.106	0.107	0.101
2	Access Road: outside west perimeter of power station	107505	149630	0.075	0.076	0.070
3	Buildings: west of main power station building	107443	149631	0.080	0.080	0.080
4	Behind buildings south of main drain	107459	149192	0.057	0.061	0.051
5	Green area south of lagoon	107304	149202	0.135	0.137	0.133

4.3 Model Files	The hydraulic model files associated with this model are provided as a separate deliverable under the contract, as required under Sections 7.8 and 13 of the Stage I Project Brief. The model files included are detailed in Annex D and refer to the defended scenario only.

5. Hydraulic Model Outputs

5.1 Mapping	Model outputs were processed to produce a series of flood maps according to the requirements stated in the Stage I Project Brief under Section 7.5.2. This includes mapping outputs covering: • Flood extents • Flood depth • Wave Overtopping Mapping outputs corresponding to the **defended**, **current** scenario for the 10%, 0.5% and 0.1% AEP flood events are shown in Annex E for flood extent and depth only.

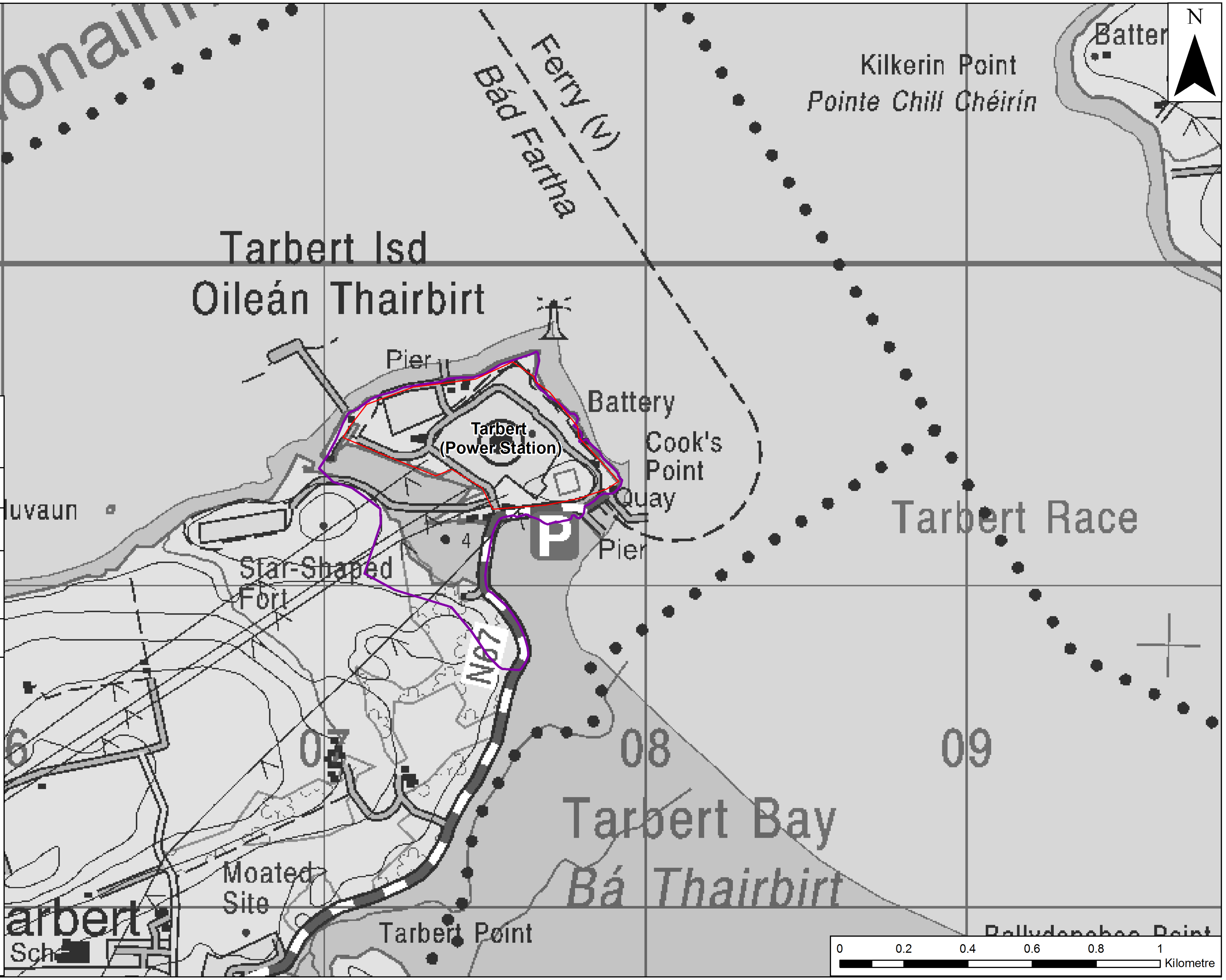
6. Key Model Assumption and Limitations

- Due to lack of survey information, a drain channel located to the south of the main power station building was represented in a coarse manner (using a breakline) in the hydraulic model. It should also be noted that the upstream end of the drain is not connected to any underground pipe system that might outfall into the drain at this location. Such underground system if it exists is not represented in the hydraulic model. For the 0.1% AEP extreme event, the model predicts that tidal water engulfing into the drain via the main lagoon would lead to overtopping of the channel and eventually flooding of the electrical main station (south west of the main power station building) would occur. It should be noted that in reality further damages and flooding might occur elsewhere as tidal water would also backup into the pipe system.

- Model grid manipulations were required to smooth out anomalous ground levels given by the LiDAR data over the main power station building footprint. An average elevation of 4.2mAD based on surrounding ground levels was assigned to this area.

Annex A – Model Extent and Schematisation Maps

Annex A1 – Model Extent



Legend

2D Model Boundary

IRR Boundary

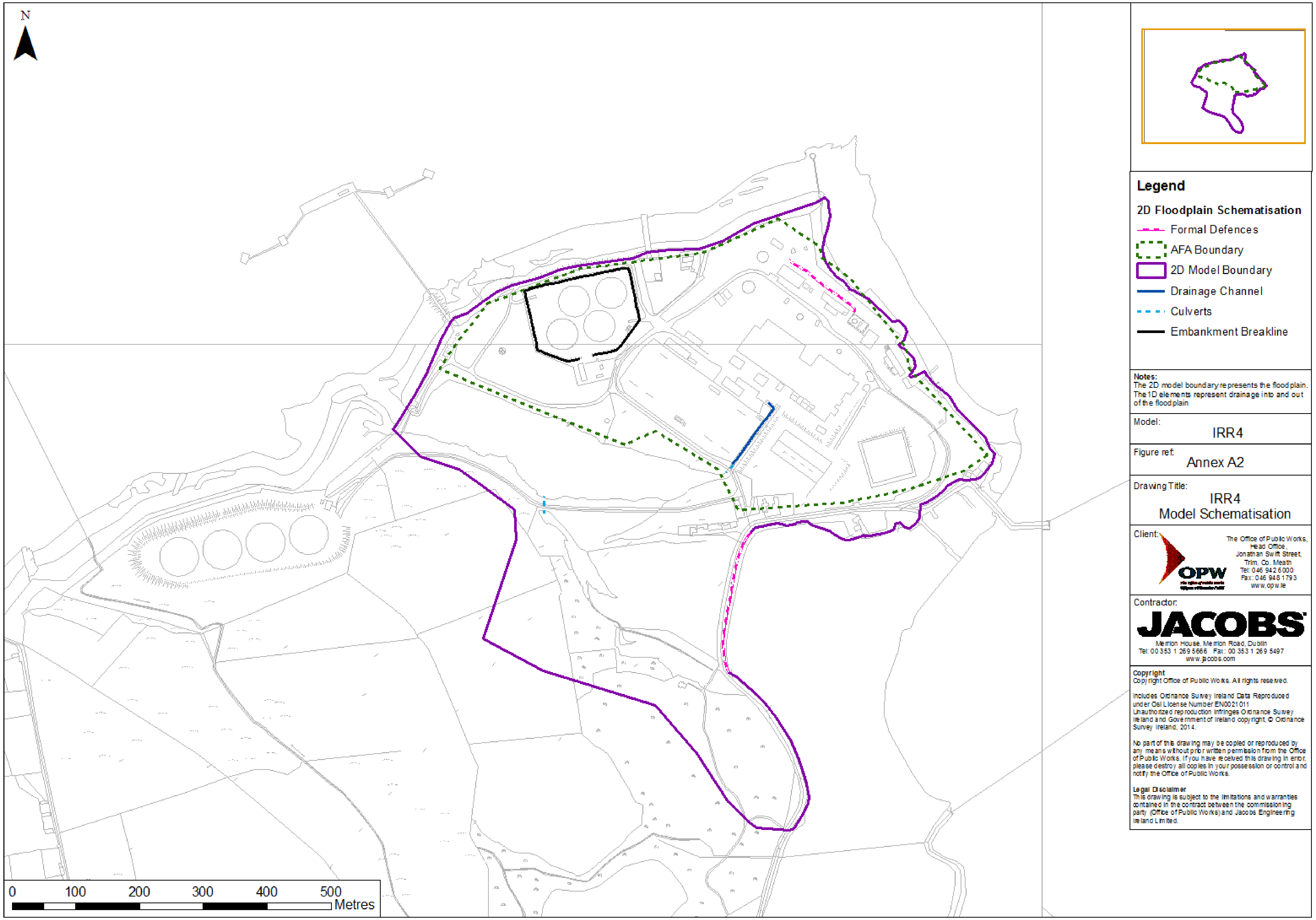
Model:
IRR4

Figure ref:
Annex A1

Drawing Title:
IRR4
Model Extent

JACOBS

Annex A2 – Schematisation Maps


N
0
100
200
300
400
500
Metres
Legend
2D Floodplain Schematisation
Formal Defences
AFA Boundary
2D Model Boundary
Drainage Channel
Culverts
Embankment Breakline
Notes:
The 2D model boundary represents the floodplain. The 1D elements represent drainage into and out of the floodplain
Model:
IRR4
Figure ref:
Annex A2
Drawing Title:
IRR4
Model Schematisation
Client:
The Office of Public Works, Head Office, Jonathan Swift Street, Trim, Co. Meath
Tel: 046 942 6000
Fax: 046 948 1793
www.opw.ie
Contractor:
Merrion House, Merrion Road, Dublin
Tel: 00 353 1 269 5666 Fax: 00 353 1 269 5497
www.jacobs.com
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Annex B - Structure Schedule

Schedule A.1 - Structure Schedule for IRR Tarbert

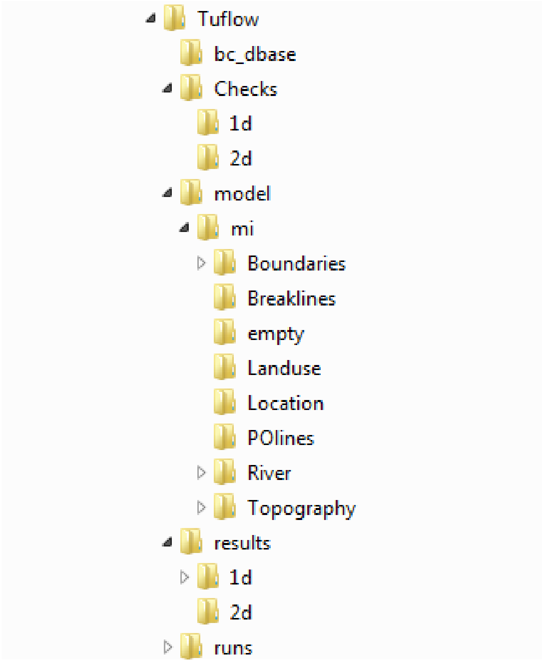
Survey Reference	ISIS Node Reference	Type of Structure	Modelling Approach	Structure included in Model (Y/N)
N/A	N/A	4 x 1m diameter circular culverts linking main tidal lagoon to a secondary lagoon located south of the power station site	TUFLOW ESTRY	Y
N/A	N/A	Access Bridge across a drain discharging into main lagoon	TUFLOW ESTRY	Y
N/A	N/A	Pedestrian bridge	Arch Bridge + Spill	N*
N/A	N/A	Fish Screen Structure	Local Roughness Increased	Y

*** Considering the size of the structure, it was determined that it would not have a significant impact on the tidal waters.**

Annex C – Model Calibration

Not used as calibration was not possible.

Annex D - Hydraulic Model Files

Model files folders structure	
TUFLOW	

TUFLOW files	
TUFLOW Control Files (.tcf) and associated files (e.g.: ecf, tgc, tbc)	**Design runs – Current scenario:** IRR4_Q2_Co_C_Des_Iss1.tcf IRR4_Q5_Co_C_Des_Iss1.tcf IRR4_Q10_Co_C_Des_Iss1.tcf IRR4_Q20_Co_C_Des_Iss1.tcf IRR4_Q50_Co_C_Des_Iss1.tcf IRR4_Q100_Co_C_Des_Iss1.tcf IRR4_Q200_Co_C_Des_Iss1.tcf IRR4_Q1000_Co_C_Des_Iss1.tcf **Sensitivity runs – Current scenario** IRR4_Q200_Co_C_Sen_RoIn.tcf IRR4_Q200_Co_C_Sen_RoDe.tcf IRR4_Tarb.tgc IRR4_Tarb.tbc
Grid Orientation file	2d_loc_Tarb.MIF
Material files	**Design runs – Current scenario:** IRR4_Tarb_Landuse.tmf **Sensitivity runs – Current scenario** IRR4_Tarb_Landuse_RoIn.tmf

	IRR4_Tarb_Landuse_RoDe.tmf 2d_mat_rural_Tarb_v1.MIF 2d_mat_ind_Tarb.MIF 2d_mat_vegetation_Tarb.MIF 2d_mat_fishscreen_walkway_Tarb.MIF 2d_mat_water_Tarb_v1.MIF 2d_mat_roads_Tarb.MIF 2d_mat_buildings_Tarb.MIF 2d_mat_flatrock_Tarb.MIF
Zpt files, model DTM (.asc)	Tarbert_2m_DTM.asc 2d_zsh_buildings_Tarb.MIF
Breakline files	2d_zln_defence_v2_Tarb.MIF 2d_zln_embankment_Tarb.MIF 2d_zln_drain_Tarb.MIF
Boundary files	2d_bc_HT_Tarb.MIF 2d_bc_hxe_Tarb.MIF 2d_bc_SX_Culverts_Tarb_v1.MIF 1d_nwk_drain_Tarb_v1.MIF
1D elements files	bc_dbase_50AEP_Tarb.csv bc_dbase_20AEP_Tarb.csv bc_dbase_10AEP_Tarb.csv bc_dbase_5AEP_Tarb.csv bc_dbase_2AEP_Tarb.csv bc_dbase_1AEP_Tarb.csv bc_dbase_0.1AEP_Tarb.csv
Files in bc_dbase	Tarbert_2m_DTM.asc 2d_zsh_buildings_Tarb.MIF
Initial Water Level files	NA
Time Series Files	HT_Tarb.csv
Available 2D result files	Depth, stage, hazard and velocity 2D results in ASCII file format for all available design return periods.

Model Run Log

Sr. No.	Model File Name	Start Time	End Time	Time step	Advanced Options /Other information	Comments on model stability
Design Runs – Current scenario						
1	IRR4_Q2_Co_C_des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
2	IRR4_Q5_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
3	IRR4_Q10_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
4	IRR4_Q20_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
5	IRR4_Q50_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
6	IRR4_Q100_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
7	IRR4_Q200_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
8	IRR4_Q1000_Co_C_Des_Iss1.tcf	3	36	0.25 sec 1D 0.5 sec 2D		Convergence within manufacturer tolerance.
Sensitivity Analysis						
9	IRR4_Q200_Co_C_Sen_RoIn.tcf	3	36	0.25 sec 1D 0.5 sec 2D	The roughness is increased by 20% in the model	Convergence within manufacturer tolerance.
10	IRR4_Q200_Co_C_Sen_RoDe.tcf	3	36	0.25 sec 1D 0.5 sec 2D	The roughness is decreased by 20% in the model	Convergence within manufacturer tolerance.

Annex E - Flood Mapping

Flood Maps are available through the OPW flood mapping website; http://maps.opw.ie/fhrm/

Annex F– Wave Overtopping tidal hydrographs used as model boundary conditions

Location A

Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.322	-	0.000	-2.310	-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.241	-	0.000	-2.189	-	0.000	-2.189
13.0	-	0.000	-1.916	-	0.000	-1.891	-	0.000	-1.858	-	0.000	-1.810	-	0.000	-1.777	-	0.000	-1.754	-	0.000	-1.652	-	0.000	-1.652
13.5	-	0.000	-1.376	-	0.000	-1.339	-	0.000	-1.291	-	0.000	-1.219	-	0.000	-1.171	-	0.000	-1.136	-	0.000	-0.986	-	0.000	-0.986
14.0	-	0.000	-0.793	-	0.000	-0.745	-	0.000	-0.682	-	0.000	-0.588	-	0.000	-0.526	-	0.000	-0.480	-	0.000	-0.284	-	0.000	-0.284
14.5	-	0.000	-0.213	-	0.000	-0.155	-	0.000	-0.078	-	0.000	0.036	-	0.000	0.112	-	0.000	0.168	0.029	0.004	0.407	0.118	0.018	0.407
15.0	0.022	0.003	0.362	0.037	0.006	0.430	0.050	0.007	0.519	0.062	0.009	0.652	0.097	0.014	0.741	0.135	0.020	0.806	0.067	0.010	1.083	0.325	0.049	1.083
15.5	0.040	0.006	0.889	0.074	0.011	0.965	0.106	0.016	1.065	0.144	0.022	1.214	0.245	0.037	1.313	0.363	0.054	1.386	0.201	0.030	1.697	1.049	0.157	1.697
16.0	0.082	0.012	1.365	0.168	0.025	1.448	0.259	0.039	1.557	0.387	0.058	1.720	0.704	0.106	1.829	1.072	0.161	1.908	0.704	0.106	2.248	3.355	0.503	2.248
16.5	0.189	0.028	1.791	0.418	0.063	1.880	0.675	0.101	1.996	1.066	0.160	2.170	1.972	0.296	2.286	2.999	0.450	2.371	2.308	0.346	2.733	8.927	1.339	2.733
17.0	0.361	0.054	2.077	0.816	0.122	2.169	1.348	0.202	2.291	2.171	0.326	2.473	3.917	0.588	2.593	5.839	0.876	2.682	5.157	0.774	3.061	-	0.000	3.061
17.5	0.638	0.096	2.311	1.450	0.218	2.406	2.371	0.356	2.531	3.794	0.569	2.717	6.648	0.997	2.841	9.654	1.448	2.933	-	0.000	3.321	-	0.000	3.321
18.0	0.720	0.108	2.359	1.631	0.245	2.455	2.663	0.399	2.581	4.264	0.640	2.769	7.414	1.112	2.894	10.680	1.602	2.986	-	0.000	3.378	-	0.000	3.378
18.5	0.638	0.096	2.311	1.450	0.218	2.406	2.371	0.356	2.531	3.794	0.569	2.717	6.648	0.997	2.841	9.654	1.448	2.933	-	0.000	3.321	-	0.000	3.321
19.0	0.325	0.049	2.032	0.733	0.110	2.124	1.211	0.182	2.246	1.956	0.293	2.428	3.548	0.532	2.548	5.315	0.797	2.637	4.625	0.694	3.016	14.910	2.237	3.016
19.5	0.141	0.021	1.656	0.310	0.046	1.745	0.498	0.075	1.861	0.779	0.117	2.035	1.449	0.217	2.151	2.225	0.334	2.236	1.656	0.248	2.598	6.862	1.029	2.598
20.0	0.057	0.009	1.140	0.112	0.017	1.223	0.167	0.025	1.332	0.243	0.036	1.495	0.436	0.065	1.604	0.662	0.099	1.683	0.414	0.062	2.023	2.081	0.312	2.023
20.5	0.027	0.004	0.574	0.048	0.007	0.650	0.067	0.010	0.750	0.087	0.013	0.899	0.142	0.021	0.998	0.205	0.031	1.071	0.109	0.016	1.382	0.561	0.084	1.382
21.0	0.015	0.002	0.002	0.025	0.004	0.070	0.033	0.005	0.159	0.041	0.006	0.292	0.061	0.009	0.381	0.082	0.012	0.446	0.041	0.006	0.723	0.183	0.027	0.723
21.5	-	0.000	-0.618	-	0.000	-0.560	-	0.000	-0.483	-	0.000	-0.369	-	0.000	-0.293	-	0.000	-0.237	-	0.000	0.002	-	0.000	0.002
22.0	-	0.000	-1.153	-	0.000	-1.105	-	0.000	-1.042	-	0.000	-0.948	-	0.000	-0.886	-	0.000	-0.840	-	0.000	-0.644	-	0.000	-0.644
22.5	-	0.000	-1.646	-	0.000	-1.609	-	0.000	-1.561	-	0.000	-1.489	-	0.000	-1.441	-	0.000	-1.406	-	0.000	-1.256	-	0.000	-1.256
23.0	-	0.000	-2.051	-	0.000	-2.026	-	0.000	-1.993	-	0.000	-1.945	-	0.000	-1.912	-	0.000	-1.889	-	0.000	-1.787	-	0.000	-1.787
23.5	-	0.000	-2.322	-	0.000	-2.310	-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.241	-	0.000	-2.189	-	0.000	-2.189
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Mid Range Future Scenario

	50% Mid Range			20% Mid Range			10% Mid Range			5% Mid Range			2% Mid Range			1% Mid Range			0.5% Mid Range			0.1% Mid Range		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	-2.505	-0.078	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.257	-	-2.245	0.519	-	0.000	-2.175	-	0.000	-2.163	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
13.0	-	0.000	-1.786	-	-1.762	1.065	-	0.000	-1.624	-	0.000	-1.600	-	0.000	-1.569	-	0.000	-1.546	-	0.000	-1.523	-	0.000	-1.523
13.5	-	0.000	-1.184	-	-1.148	1.557	-	0.000	-0.944	-	0.000	-0.909	-	0.000	-0.863	-	0.000	-0.829	-	0.000	-0.794	-	0.000	-0.794
14.0	-	0.000	-0.543	-	-0.495	1.996	-	0.000	-0.230	-	0.000	-0.184	-	0.000	-0.124	-	0.000	-0.079	-	0.000	-0.034	-	0.000	-0.034
14.5	0.028	0.004	0.091	0.044	0.149	2.291	0.011	0.002	0.473	0.016	0.002	0.529	0.025	0.004	0.602	0.033	0.005	0.657	0.043	0.006	0.711	0.231	0.035	0.711
15.0	0.057	0.009	0.716	0.096	0.784	2.531	0.025	0.004	1.159	0.037	0.006	1.224	0.064	0.010	1.309	0.092	0.014	1.373	0.128	0.019	1.436	0.801	0.120	1.436
15.5	0.135	0.020	1.285	0.251	1.362	2.581	0.066	0.010	1.783	0.113	0.017	1.856	0.227	0.034	1.951	0.353	0.053	2.022	0.518	0.078	2.094	3.033	0.455	2.094
16.0	0.376	0.056	1.798	0.736	1.881	2.531	0.233	0.035	2.341	0.431	0.065	2.421	0.916	0.137	2.525	1.452	0.218	2.603	2.138	0.321	2.681	9.684	1.453	2.681
16.5	1.070	0.161	2.253	2.097	2.342	2.246	0.960	0.144	2.833	1.735	0.260	2.918	3.469	0.520	3.028	5.252	0.788	3.112	-	0.000	3.195	-	0.000	3.195
17.0	2.218	0.333	2.560	4.192	2.652	1.861	2.878	0.432	3.165	4.818	0.723	3.254	-	0.000	3.370	-	0.000	3.457	-	0.000	3.544	-	0.000	3.544
17.5	3.945	0.592	2.807	7.132	2.902	1.332	-	0.000	3.428	-	0.000	3.519	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
18.0	4.445	0.667	2.859	7.950	2.955	0.750	-	0.000	3.486	-	0.000	3.578	-	0.000	3.698	-	0.000	3.788	-	0.000	3.878	-	0.000	3.878
18.5	3.945	0.592	2.807	7.132	2.902	0.159	-	0.000	3.428	-	0.000	3.519	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
19.0	1.996	0.299	2.515	3.798	2.607	-0.483	2.474	0.371	3.120	4.204	0.631	3.209	-	0.000	3.325	-	0.000	3.412	-	0.000	3.499	-	0.000	3.499
19.5	0.776	0.116	2.118	1.539	2.207	-1.042	0.634	0.095	2.698	1.166	0.175	2.783	2.409	0.361	2.893	3.739	0.561	2.977	5.347	0.802	3.060	-	0.000	3.060
20.0	0.233	0.035	1.573	0.453	1.656	-1.561	0.135	0.020	2.116	0.244	0.037	2.196	0.518	0.078	2.300	0.831	0.125	2.378	1.239	0.186	2.456	6.290	0.944	2.456
20.5	0.081	0.012	0.970	0.144	1.047	-1.993	0.038	0.006	1.468	0.061	0.009	1.541	0.115	0.017	1.636	0.176	0.026	1.707	0.255	0.038	1.779	1.582	0.237	1.779
21.0	0.037	0.006	0.356	0.061	0.424	-2.294	0.016	0.002	0.799	0.023	0.003	0.864	0.038	0.006	0.949	0.053	0.008	1.013	0.070	0.010	1.076	0.415	0.062	1.076
21.5	-	0.000	-0.314	-	-0.256	-2.505	0.007	0.001	0.068	0.010	0.002	0.124	0.016	0.002	0.197	0.021	0.003	0.252	0.027	0.004	0.306	-	0.000	0.306
22.0	-	0.000	-0.903	-	-0.855	-2.505	-	0.000	-0.590	-	0.000	-0.544	-	0.000	-0.484	-	0.000	-0.439	-	0.000	-0.394	-	0.000	-0.394
22.5	-	0.000	-1.454	-	-1.418	-2.269	-	0.000	-1.214	-	0.000	-1.179	-	0.000	-1.133	-	0.000	-1.099	-	0.000	-1.064	-	0.000	-1.064
23.0	-	0.000	-1.921	-	-1.897	-1.810	-	0.000	-1.759	-	0.000	-1.735	-	0.000	-1.704	-	0.000	-1.681	-	0.000	-1.658	-	0.000	-1.658
23.5	-	0.000	-2.257	-	-2.245	-1.219	-	0.000	-2.175	-	0.000	-2.163	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
24.0	-	0.000	-2.505	-	-2.505	-0.588	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

High End Future Scenario

	10% High End			0.5% High End			0.1% High End		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.110	-	0.000	-2.059	-	0.000	-2.059
13.0	-	0.000	-1.495	-	0.000	-1.393	-	0.000	-1.393
13.5	-	0.000	-0.753	-	0.000	-0.603	-	0.000	-0.603
14.0	0.006	0.001	0.020	0.027	0.004	0.216	-	0.000	0.216
14.5	0.014	0.002	0.777	0.070	0.010	1.016	0.413	0.062	1.016
15.0	0.036	0.005	1.513	0.288	0.043	1.790	1.765	0.265	1.790
15.5	0.136	0.020	2.180	1.474	0.221	2.491	7.187	1.078	2.491
16.0	0.699	0.105	2.774	6.457	0.969	3.114	-	0.000	3.114
16.5	4.049	0.607	3.294	-	0.000	3.657	-	0.000	3.657
17.0	-	0.000	3.648	-	0.000	4.027	-	0.000	4.027
17.5	-	0.000	3.924	-	0.000	4.313	-	0.000	4.313
18.0	-	0.000	3.986	-	0.000	4.378	-	0.000	4.378
18.5	-	0.000	3.924	-	0.000	4.313	-	0.000	4.313
19.0	-	0.000	3.603	-	0.000	3.982	-	0.000	3.982
19.5	2.545	0.382	3.159	-	0.000	3.522	-	0.000	3.522
20.0	0.357	0.054	2.549	3.816	0.572	2.889	14.800	2.220	2.889
20.5	0.068	0.010	1.865	0.691	0.104	2.176	3.874	0.581	2.176
21.0	0.022	0.003	1.153	0.139	0.021	1.430	0.870	0.131	1.430
21.5	0.009	0.001	0.372	0.041	0.006	0.611	0.220	0.033	0.611
22.0	-	0.000	-0.340	-	0.000	-0.144	-	0.000	-0.144
22.5	-	0.000	-1.023	-	0.000	-0.873	-	0.000	-0.873
23.0	-	0.000	-1.630	-	0.000	-1.528	-	0.000	-1.528
23.5	-	0.000	-2.110	-	0.000	-2.059	-	0.000	-2.059
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Location B

Current Scenario

	AEP											
	50%			20%			10%			5%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.322	-	0.000	-2.322	-	0.000	-2.310	-	0.000	-2.310
13.0	-	0.000	-1.916	-	0.000	-1.916	-	0.000	-1.891	-	0.000	-1.891
13.5	-	0.000	-1.376	-	0.000	-1.376	-	0.000	-1.339	-	0.000	-1.339
14.0	-	0.000	-0.793	-	0.000	-0.793	-	0.000	-0.745	-	0.000	-0.745
14.5	-	0.000	-0.213	-	0.000	-0.213	-	0.000	-0.155	-	0.000	-0.155
15.0	0.010	0.006	0.362	0.020	0.013	0.362	0.027	0.017	0.430	0.042	0.026	0.430
15.5	0.018	0.011	0.889	0.035	0.022	0.889	0.048	0.030	0.965	0.077	0.048	0.965
16.0	0.031	0.019	1.365	0.064	0.040	1.365	0.093	0.058	1.448	0.155	0.097	1.448
16.5	0.057	0.036	1.791	0.126	0.079	1.791	0.196	0.122	1.880	0.337	0.210	1.880
17.0	0.095	0.059	2.077	0.221	0.138	2.077	0.352	0.220	2.169	0.599	0.374	2.169
17.5	0.156	0.097	2.311	0.364	0.227	2.311	0.583	0.364	2.406	0.977	0.610	2.406
18.0	0.173	0.108	2.359	0.404	0.252	2.359	0.648	0.405	2.455	1.084	0.676	2.455
18.5	0.156	0.097	2.311	0.364	0.227	2.311	0.583	0.364	2.406	0.977	0.610	2.406
19.0	0.087	0.054	2.032	0.201	0.126	2.032	0.321	0.200	2.124	0.547	0.341	2.124
19.5	0.046	0.029	1.656	0.100	0.062	1.656	0.152	0.095	1.745	0.261	0.163	1.745
20.0	0.024	0.015	1.140	0.047	0.029	1.140	0.067	0.042	1.223	0.110	0.069	1.223
20.5	0.013	0.008	0.574	0.025	0.016	0.574	0.034	0.021	0.650	0.053	0.033	0.650
21.0	0.007	0.005	0.002	0.014	0.009	0.002	0.019	0.012	0.070	-	0.000	0.070
21.5	-	0.000	-0.618	-	0.000	-0.618	-	0.000	-0.560	-	0.000	-0.560
22.0	-	0.000	-1.153	-	0.000	-1.153	-	0.000	-1.105	-	0.000	-1.105
22.5	-	0.000	-1.646	-	0.000	-1.646	-	0.000	-1.609	-	0.000	-1.609
23.0	-	0.000	-2.051	-	0.000	-2.051	-	0.000	-2.026	-	0.000	-2.026
23.5	-	0.000	-2.322	-	0.000	-2.322	-	0.000	-2.310	-	0.000	-2.310
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

	2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.229
13.0	-	0.000	-1.858	-	0.000	-1.810	-	0.000	-1.777	-	0.000	-1.730
13.5	-	0.000	-1.291	-	0.000	-1.219	-	0.000	-1.171	-	0.000	-1.101
14.0	-	0.000	-0.682	-	0.000	-0.588	-	0.000	-0.526	-	0.000	-0.434
14.5	-	0.000	-0.078	-	0.000	0.036	-	0.000	0.112	-	0.000	0.224
15.0	0.060	0.038	0.519	0.075	0.047	0.652	0.100	0.062	0.741	0.200	0.125	0.871
15.5	0.118	0.073	1.065	0.156	0.098	1.214	0.223	0.139	1.313	0.490	0.306	1.459
16.0	0.254	0.159	1.557	0.365	0.228	1.720	0.547	0.341	1.829	1.245	0.777	1.988
16.5	0.577	0.360	1.996	0.868	0.542	2.170	1.322	0.825	2.286	2.996	1.870	2.456
17.0	1.040	0.649	2.291	1.605	1.002	2.473	2.451	1.529	2.593	5.316	3.317	2.771
17.5	1.710	1.067	2.531	2.638	1.646	2.717	3.956	2.469	2.841	8.212	5.124	3.024
18.0	1.898	1.184	2.581	2.923	1.824	2.769	4.371	2.728	2.894	8.982	5.605	3.078
18.5	1.710	1.067	2.531	2.638	1.646	2.717	3.956	2.469	2.841	8.212	5.124	3.024
19.0	0.950	0.593	2.246	1.462	0.912	2.428	2.241	1.398	2.548	4.908	3.063	2.726
19.5	0.444	0.277	1.861	0.665	0.415	2.035	1.013	0.632	2.151	2.320	1.448	2.321
20.0	0.175	0.109	1.332	0.245	0.153	1.495	0.364	0.227	1.604	0.830	0.518	1.763
20.5	0.078	0.049	0.750	0.101	0.063	0.899	0.140	0.087	0.998	0.297	0.185	1.144
21.0	0.042	0.026	0.159	0.051	0.032	0.292	0.067	0.042	0.381	0.127	0.079	0.511
21.5	-	0.000	-0.483	-	0.000	-0.369	-	0.000	-0.293	-	0.000	-0.181
22.0	-	0.000	-1.042	-	0.000	-0.948	-	0.000	-0.886	-	0.000	-0.794
22.5	-	0.000	-1.561	-	0.000	-1.489	-	0.000	-1.441	-	0.000	-1.371
23.0	-	0.000	-1.993	-	0.000	-1.945	-	0.000	-1.912	-	0.000	-1.865
23.5	-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.229
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Mid Range Future Scenario

	0.500			0.200			0.100			0.050		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.257	-	0.000	-2.257	-	0.000	-2.245	-	0.000	-2.245
13.0	-	0.000	-1.786	-	0.000	-1.786	-	0.000	-1.762	-	0.000	-1.762
13.5	-	0.000	-1.184	-	0.000	-1.184	-	0.000	-1.148	-	0.000	-1.148
14.0	-	0.000	-0.543	-	0.000	-0.543	-	0.000	-0.495	-	0.000	-0.495
14.5	0.010	0.007	0.091	0.021	0.013	0.091	0.028	0.017	0.149	-	0.000	0.149
15.0	0.020	0.012	0.716	0.039	0.025	0.716	0.053	0.033	0.784	0.088	0.055	0.784
15.5	0.037	0.023	1.285	0.079	0.050	1.285	0.114	0.071	1.362	0.198	0.124	1.362
16.0	0.079	0.050	1.798	0.183	0.114	1.798	0.282	0.176	1.881	0.496	0.309	1.881
16.5	0.195	0.121	2.253	0.459	0.286	2.253	0.717	0.448	2.342	1.230	0.768	2.342
17.0	0.385	0.240	2.560	0.886	0.553	2.560	1.393	0.869	2.652	2.321	1.448	2.652
17.5	0.690	0.430	2.807	1.529	0.954	2.807	2.357	1.471	2.902	3.786	2.362	2.902
18.0	0.781	0.487	2.859	1.710	1.067	2.859	2.626	1.639	2.955	4.187	2.613	2.955
18.5	0.690	0.430	2.807	1.529	0.954	2.807	2.357	1.471	2.902	3.786	2.362	2.902
19.0	0.347	0.217	2.515	0.803	0.501	2.515	1.264	0.789	2.607	2.119	1.322	2.607
19.5	0.146	0.091	2.118	0.346	0.216	2.118	0.543	0.339	2.207	0.938	0.585	2.207
20.0	0.055	0.035	1.573	0.123	0.077	1.573	0.185	0.116	1.656	0.327	0.204	1.656
20.5	0.026	0.016	0.970	0.052	0.033	0.970	0.073	0.046	1.047	0.124	0.077	1.047
21.0	0.014	0.008	0.356	0.027	0.017	0.356	0.036	0.023	0.424	0.059	0.037	0.424
21.5	-	0.000	-0.314	-	0.000	-0.314	-	0.000	-0.256	-	0.000	-0.256
22.0	-	0.000	-0.903	-	0.000	-0.903	-	0.000	-0.855	-	0.000	-0.855
22.5	-	0.000	-1.454	-	0.000	-1.454	-	0.000	-1.418	-	0.000	-1.418
23.0	-	0.000	-1.921	-	0.000	-1.921	-	0.000	-1.897	-	0.000	-1.897
23.5	-	0.000	-2.257	-	0.000	-2.257	-	0.000	-2.245	-	0.000	-2.245
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

	0.020			0.010			0.005			0.001		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.228	-	0.000	-2.204	-	0.000	-2.124	-	0.000	-2.124
13.0	-	0.000	-1.729	-	0.000	-1.680	-	0.000	-1.523	-	0.000	-1.523
13.5	-	0.000	-1.099	-	0.000	-1.027	-	0.000	-0.794	-	0.000	-0.794
14.0	-	0.000	-0.432	-	0.000	-0.338	0.007	0.004	-0.034	-	0.000	-0.034
14.5	-	0.000	0.226	0.071	0.044	0.341	0.014	0.009	0.711	0.073	0.045	0.711
15.0	0.129	0.081	0.873	0.158	0.099	1.006	0.033	0.020	1.436	0.200	0.124	1.436
15.5	0.313	0.195	1.462	0.413	0.258	1.611	0.094	0.059	2.094	0.671	0.419	2.094
16.0	0.815	0.509	1.991	1.129	0.704	2.153	0.345	0.215	2.681	2.223	1.387	2.681
16.5	2.032	1.268	2.458	2.897	1.808	2.632	1.236	0.771	3.195	5.955	3.716	3.195
17.0	3.758	2.345	2.774	5.303	3.309	2.956	3.012	1.879	3.544	-	0.000	3.544
17.5	5.978	3.730	3.027	8.314	5.188	3.213	-	0.000	3.817	-	0.000	3.817
18.0	6.575	4.103	3.081	9.142	5.705	3.269	-	0.000	3.878	-	0.000	3.878
18.5	5.978	3.730	3.027	8.314	5.188	3.213	-	0.000	3.817	-	0.000	3.817
19.0	3.452	2.154	2.729	4.887	3.049	2.911	2.677	1.670	3.499	10.170	6.346	3.499
19.5	1.552	0.968	2.323	2.224	1.388	2.497	0.881	0.550	3.060	4.650	2.902	3.060
20.0	0.535	0.334	1.766	0.735	0.459	1.928	0.205	0.128	2.456	1.396	0.871	2.456
20.5	0.190	0.118	1.147	0.244	0.152	1.296	0.054	0.034	1.779	0.365	0.228	1.779
21.0	0.084	0.052	0.513	0.100	0.062	0.646	0.021	0.013	1.076	0.116	0.072	1.076
21.5	-	0.000	-0.179	-	0.000	-0.064	0.010	0.006	0.306	0.047	0.029	0.306
22.0	-	0.000	-0.792	-	0.000	-0.698	-	0.000	-0.394	-	0.000	-0.394
22.5	-	0.000	-1.369	-	0.000	-1.297	-	0.000	-1.064	-	0.000	-1.064
23.0	-	0.000	-1.864	-	0.000	-1.815	-	0.000	-1.658	-	0.000	-1.658
23.5	-	0.000	-2.228	-	0.000	-2.204	-	0.000	-2.124	-	0.000	-2.124
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

High End Future Scenario

	0.100			0.005			0.001		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.110	-	0.000	-2.059	-	0.000	-2.059
13.0	-	0.000	-1.495	-	0.000	-1.393	-	0.000	-1.393
13.5	-	0.000	-0.753	-	0.000	-0.603	-	0.000	-0.603
14.0	-	0.000	0.020	0.010	0.006	0.216	0.048	0.030	0.216
14.5	0.005	0.003	0.777	0.023	0.014	1.016	0.118	0.074	1.016
15.0	0.011	0.007	1.513	0.064	0.040	1.790	0.416	0.259	1.790
15.5	0.027	0.017	2.180	0.265	0.165	2.491	1.655	1.033	2.491
16.0	0.093	0.058	2.774	1.175	0.733	3.114	5.554	3.466	3.114
16.5	0.480	0.300	3.294	4.475	2.792	3.657	-	0.000	3.657
17.0	1.715	1.070	3.648	-	0.000	4.027	-	0.000	4.027
17.5	-	0.000	3.924	-	0.000	4.313	-	0.000	4.313
18.0	-	0.000	3.986	-	0.000	4.378	-	0.000	4.378
18.5	-	0.000	3.924	-	0.000	4.313	-	0.000	4.313
19.0	1.451	0.905	3.603	-	0.000	3.982	-	0.000	3.982
19.5	0.301	0.188	3.159	3.182	1.986	3.522	-	0.000	3.522
20.0	0.054	0.034	2.549	0.680	0.424	2.889	3.654	2.280	2.889
20.5	0.017	0.010	1.865	0.133	0.083	2.176	0.875	0.546	2.176
21.0	0.007	0.005	1.153	0.038	0.024	1.430	0.220	0.138	1.430
21.5	-	0.000	0.372	0.015	0.009	0.611	0.072	0.045	0.611
22.0	-	0.000	-0.340	-	0.000	-0.144	-	0.000	-0.144
22.5	-	0.000	-1.023	-	0.000	-0.873	-	0.000	-0.873
23.0	-	0.000	-1.630	-	0.000	-1.528	-	0.000	-1.528
23.5	-	0.000	-2.110	-	0.000	-2.059	-	0.000	-2.059
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Location C1

Current Scenario

AEP

Time	50% q (l/m/s)	50% q (m^3/s)	50% Water Level (mOD)	20% q (l/m/s)	20% q (m^3/s)	20% Water Level (mOD)	10% q (l/m/s)	10% q (m^3/s)	10% Water Level (mOD)	5% q (l/m/s)	5% q (m^3/s)	5% Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.241	-	0.000	-2.229
13.0	-	0.000	-1.810	-	0.000	-1.777	-	0.000	-1.754	-	0.000	-1.730
13.5	-	0.000	-1.219	-	0.000	-1.171	-	0.000	-1.136	-	0.000	-1.101
14.0	-	0.000	-0.588	-	0.000	-0.526	-	0.000	-0.480	-	0.000	-0.434
14.5	-	0.000	0.036	-	0.000	0.112	-	0.000	0.168	-	0.000	0.224
15.0	-	0.000	0.652	-	0.000	0.741	-	0.000	0.806	-	0.000	0.871
15.5	-	0.000	1.214	-	0.000	1.313	-	0.000	1.386	0.001	0.000	1.459
16.0	-	0.000	1.720	0.001	0.000	1.829	0.001	0.000	1.908	0.002	0.000	1.988
16.5	0.001	0.000	2.170	0.003	0.001	2.286	0.005	0.001	2.371	0.013	0.003	2.456
17.0	0.007	0.001	2.473	0.028	0.006	2.593	0.072	0.014	2.682	0.199	0.040	2.771
17.5	0.071	0.014	2.717	0.333	0.067	2.841	0.879	0.176	2.933	-	0.000	3.024
18.0	0.125	0.025	2.769	0.577	0.115	2.894	1.478	0.296	2.986	-	0.000	3.078
18.5	0.071	0.014	2.717	0.333	0.067	2.841	0.879	0.176	2.933	-	0.000	3.024
19.0	0.005	0.001	2.428	0.018	0.004	2.548	0.047	0.009	2.637	0.130	0.026	2.726
19.5	0.001	0.000	2.035	0.002	0.000	2.151	0.003	0.001	2.236	0.005	0.001	2.321
20.0	-	0.000	1.495	-	0.000	1.604	0.001	0.000	1.683	0.001	0.000	1.763
20.5	-	0.000	0.899	-	0.000	0.998	-	0.000	1.071	-	0.000	1.144
21.0	-	0.000	0.292	-	0.000	0.381	-	0.000	0.446	-	0.000	0.511
21.5	-	0.000	-0.369	-	0.000	-0.293	-	0.000	-0.237	-	0.000	-0.181
22.0	-	0.000	-0.948	-	0.000	-0.886	-	0.000	-0.840	-	0.000	-0.794
22.5	-	0.000	-1.489	-	0.000	-1.441	-	0.000	-1.406	-	0.000	-1.371
23.0	-	0.000	-1.945	-	0.000	-1.912	-	0.000	-1.889	-	0.000	-1.865
23.5	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.241	-	0.000	-2.229
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Time	2% q (l/m/s)	2% q (m^3/s)	2% Water Level (mOD)	1% q (l/m/s)	1% q (m^3/s)	1% Water Level (mOD)	0.50% q (l/m/s)	0.50% q (m^3/s)	0.50% Water Level (mOD)	0.10% q (l/m/s)	0.10% q (m^3/s)	0.10% Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.213	-	0.000	-2.201	-	0.000	-2.189	-	0.000	-2.189
13.0	-	0.000	-1.699	-	0.000	-1.675	-	0.000	-1.652	-	0.000	-1.652
13.5	-	0.000	-1.055	-	0.000	-1.020	-	0.000	-0.986	-	0.000	-0.986
14.0	-	0.000	-0.374	-	0.000	-0.329	-	0.000	-0.284	-	0.000	-0.284
14.5	-	0.000	0.297	-	0.000	0.352	-	0.000	0.407	0.003	0.001	0.407
15.0	-	0.000	0.956	-	0.000	1.019	0.001	0.000	1.083	0.006	0.001	1.083
15.5	0.001	0.000	1.554	0.002	0.000	1.626	0.002	0.000	1.697	0.015	0.003	1.697
16.0	0.003	0.001	2.092	0.005	0.001	2.170	0.010	0.002	2.248	0.073	0.015	2.248
16.5	0.044	0.009	2.566	0.108	0.022	2.650	0.242	0.048	2.733	0.696	0.139	2.733
17.0	0.682	0.136	2.887	-	0.000	2.974	-	0.000	3.061	-	0.000	3.061
17.5	-	0.000	3.143	-	0.000	3.232	-	0.000	3.321	-	0.000	3.321
18.0	-	0.000	3.198	-	0.000	3.288	-	0.000	3.378	-	0.000	3.378
18.5	-	0.000	3.143	-	0.000	3.232	-	0.000	3.321	-	0.000	3.321
19.0	0.462	0.092	2.842	1.046	0.209	2.929	-	0.000	3.016	-	0.000	3.016
19.5	0.016	0.003	2.431	0.038	0.008	2.515	0.086	0.017	2.598	0.357	0.071	2.598
20.0	0.002	0.000	1.867	0.003	0.001	1.945	0.004	0.001	2.023	0.033	0.007	2.023
20.5	-	0.000	1.239	0.001	0.000	1.311	0.002	0.000	1.382	0.009	0.002	1.382
21.0	-	0.000	0.596	-	0.000	0.659	-	0.000	0.723	0.004	0.001	0.723
21.5	-	0.000	-0.108	-	0.000	-0.053	-	0.000	0.002	-	0.000	0.002
22.0	-	0.000	-0.734	-	0.000	-0.689	-	0.000	-0.644	-	0.000	-0.644
22.5	-	0.000	-1.325	-	0.000	-1.290	-	0.000	-1.256	-	0.000	-1.256
23.0	-	0.000	-1.834	-	0.000	-1.810	-	0.000	-1.787	-	0.000	-1.787
23.5	-	0.000	-2.213	-	0.000	-2.201	-	0.000	-2.189	-	0.000	-2.189
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Mid Range Future Scenario

Time	50% Mid Range q (l/m/s)	50% Mid Range q (m^3/s)	50% Mid Range Water Level (mOD)	20% Mid Range q (l/m/s)	20% Mid Range q (m^3/s)	20% Mid Range Water Level (mOD)	10% Mid Range q (l/m/s)	10% Mid Range q (m^3/s)	10% Mid Range Water Level (mOD)	5% Mid Range q (l/m/s)	5% Mid Range q (m^3/s)	5% Mid Range Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.204	-	0.000	-2.187	-	0.000	-2.175	-	0.000	-2.163
13.0	-	0.000	-1.680	-	0.000	-1.648	-	0.000	-1.624	-	0.000	-1.600
13.5	-	0.000	-1.027	-	0.000	-0.980	-	0.000	-0.944	-	0.000	-0.909
14.0	-	0.000	-0.338	-	0.000	-0.276	-	0.000	-0.230	-	0.000	-0.184
14.5	-	0.000	0.341	-	0.000	0.417	-	0.000	0.473	-	0.000	0.529
15.0	-	0.000	1.006	-	0.000	1.094	-	0.000	1.159	-	0.000	1.224
15.5	-	0.000	1.611	0.001	0.000	1.710	0.001	0.000	1.783	0.001	0.000	1.856
16.0	0.001	0.000	2.153	0.003	0.001	2.262	0.005	0.001	2.341	0.011	0.002	2.421
16.5	0.029	0.006	2.632	0.133	0.027	2.748	0.344	0.069	2.833	0.807	0.161	2.918
17.0	0.953	0.191	2.956	-	0.000	3.076	-	0.000	3.165	-	0.000	3.254
17.5	-	0.000	3.213	-	0.000	3.337	-	0.000	3.428	-	0.000	3.519
18.0	-	0.000	3.269	-	0.000	3.394	-	0.000	3.486	-	0.000	3.578
18.5	-	0.000	3.213	-	0.000	3.337	-	0.000	3.428	-	0.000	3.519
19.0	0.588	0.118	2.911	-	0.000	3.031	-	0.000	3.120	-	0.000	3.209
19.5	0.008	0.002	2.497	0.036	0.007	2.613	0.094	0.019	2.698	0.232	0.046	2.783
20.0	0.001	0.000	1.928	0.001	0.000	2.037	0.002	0.000	2.116	0.003	0.001	2.196
20.5	-	0.000	1.296	-	0.000	1.395	-	0.000	1.468	0.001	0.000	1.541
21.0	-	0.000	0.646	-	0.000	0.734	-	0.000	0.799	-	0.000	0.864
21.5	-	0.000	-0.064	-	0.000	0.012	-	0.000	0.068	-	0.000	0.124
22.0	-	0.000	-0.698	-	0.000	-0.636	-	0.000	-0.590	-	0.000	-0.544
22.5	-	0.000	-1.297	-	0.000	-1.250	-	0.000	-1.214	-	0.000	-1.179
23.0	-	0.000	-1.815	-	0.000	-1.783	-	0.000	-1.759	-	0.000	-1.735
23.5	-	0.000	-2.204	-	0.000	-2.187	-	0.000	-2.175	-	0.000	-2.163
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Time	2% Mid Range q (l/m/s)	2% Mid Range q (m^3/s)	2% Mid Range Water Level (mOD)	1% Mid Range q (l/m/s)	1% Mid Range q (m^3/s)	1% Mid Range Water Level (mOD)	0.5% Mid Range q (l/m/s)	0.5% Mid Range q (m^3/s)	0.5% Mid Range Water Level (mOD)	0.1% Mid Range q (l/m/s)	0.1% Mid Range q (m^3/s)	0.1% Mid Range Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
13.0	-	0.000	-1.569	-	0.000	-1.546	-	0.000	-1.523	-	0.000	-1.523
13.5	-	0.000	-0.863	-	0.000	-0.829	-	0.000	-0.794	-	0.000	-0.794
14.0	-	0.000	-0.124	-	0.000	-0.079	-	0.000	-0.034	-	0.000	-0.034
14.5	-	0.000	0.602	-	0.000	0.657	-	0.000	0.711	0.004	0.001	0.711
15.0	0.001	0.000	1.309	0.001	0.000	1.373	0.002	0.000	1.436	0.011	0.002	1.436
15.5	0.002	0.000	1.951	0.003	0.001	2.022	0.004	0.001	2.094	0.049	0.010	2.094
16.0	0.034	0.007	2.525	0.077	0.015	2.603	0.140	0.028	2.681	0.596	0.119	2.681
16.5	-	0.000	3.028	-	0.000	3.112	-	0.000	3.195	-	0.000	3.195
17.0	-	0.000	3.370	-	0.000	3.457	-	0.000	3.544	-	0.000	3.544
17.5	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
18.0	-	0.000	3.698	-	0.000	3.788	-	0.000	3.878	-	0.000	3.878
18.5	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
19.0	-	0.000	3.325	-	0.000	3.412	-	0.000	3.499	-	0.000	3.499
19.5	0.719	0.144	2.893	-	0.000	2.977	-	0.000	3.060	-	0.000	3.060
20.0	0.008	0.002	2.300	0.016	0.003	2.378	0.026	0.005	2.456	0.210	0.042	2.456
20.5	0.001	0.000	1.636	0.002	0.000	1.707	0.002	0.000	1.779	0.021	0.004	1.779
21.0	-	0.000	0.949	-	0.000	1.013	-	0.000	1.076	0.007	0.001	1.076
21.5	-	0.000	0.197	-	0.000	0.252	-	0.000	0.306	0.003	0.001	0.306
22.0	-	0.000	-0.484	-	0.000	-0.439	-	0.000	-0.394	-	0.000	-0.394
22.5	-	0.000	-1.133	-	0.000	-1.099	-	0.000	-1.064	-	0.000	-1.064
23.0	-	0.000	-1.704	-	0.000	-1.681	-	0.000	-1.658	-	0.000	-1.658
23.5	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

High End Future Scenario

Time	10% High End q (l/m/s)	10% High End q (m^3/s)	10% High End Water Level (mOD)	0.5% High End q (l/m/s)	0.5% High End q (m^3/s)	0.5% High End Water Level (mOD)	0.1% High End q (l/m/s)	0.1% High End q (m^3/s)	0.1% High End Water Level (mOD)
12.0	-	0.000	-2.505	-	0.001	-2.505	-	0.000	-2.505
12.5	-	1.000	-2.110	-	1.001	-2.059	-	1.000	-2.059
13.0	-	2.000	-1.495	-	2.001	-1.393	-	2.000	-1.393
13.5	-	3.000	-0.753	-	3.001	-0.603	-	3.000	-0.603
14.0	-	4.000	0.020	-	4.001	0.216	0.003	4.000	0.216
14.5	-	5.000	0.777	0.001	5.001	1.016	0.006	5.000	1.016
15.0	0.001	6.000	1.513	0.003	6.001	1.790	0.023	6.000	1.790
15.5	0.002	7.000	2.180	0.044	7.001	2.491	0.260	7.000	2.491
16.0	0.189	8.000	2.774	-	8.001	3.114	-	8.000	3.114
16.5	-	9.000	3.294	-	9.001	3.657	-	9.000	3.657
17.0	-	10.000	3.648	-	10.001	4.027	-	10.000	4.027
17.5	-	11.000	3.924	-	11.001	4.313	-	11.000	4.313
18.0	-	12.000	3.986	-	12.001	4.378	-	12.000	4.378
18.5	-	13.000	3.924	-	13.001	4.313	-	13.000	4.313
19.0	-	14.000	3.603	-	14.001	3.982	-	14.000	3.982
19.5	-	15.000	3.159	-	15.001	3.522	-	15.000	3.522
20.0	0.024	16.000	2.549	0.812	16.001	2.889	-	16.000	2.889
20.5	0.001	17.000	1.865	0.008	17.001	2.176	0.070	17.000	2.176
21.0	-	18.000	1.153	0.002	18.001	1.430	0.011	18.000	1.430
21.5	-	19.000	0.372	-	19.001	0.611	0.004	19.000	0.611
22.0	-	20.000	-0.340	-	20.001	-0.144	-	20.000	-0.144
22.5	-	21.000	-1.023	-	21.001	-0.873	-	21.000	-0.873
23.0	-	22.000	-1.630	-	22.001	-1.528	-	22.000	-1.528
23.5	-	23.000	-2.110	-	23.001	-2.059	-	23.000	-2.059
24.0	-	24.000	-2.505	-	24.001	-2.505	-	24.000	-2.505

Location C2
Current Scenario

	AEP																							
	50%			20%			10%			5%			2%			1%			0.50%			0.10%		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0													-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5													-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.189
13.0													-	0.000	-1.858	-	0.000	-1.810	-	0.000	-1.777	-	0.000	-1.652
13.5													-	0.000	-1.291	-	0.000	-1.219	-	0.000	-1.171	-	0.000	-0.986
14.0													-	0.000	-0.682	-	0.000	-0.588	-	0.000	-0.526	-	0.000	-0.284
14.5													-	0.000	-0.078	-	0.000	0.036	-	0.000	0.112	-	0.000	0.407
15.0													-	0.000	0.519	-	0.000	0.652	-	0.000	0.741	-	0.000	1.083
15.5													0.002	0.001	1.065	0.002	0.001	1.214	0.003	0.001	1.313	0.002	0.001	1.697
16.0													0.004	0.001	1.557	0.004	0.001	1.720	0.006	0.001	1.829	0.006	0.002	2.248
16.5													0.008	0.002	1.996	0.012	0.003	2.170	0.019	0.005	2.286	0.033	0.008	2.733
17.0													0.018	0.005	2.291	0.032	0.008	2.473	0.058	0.014	2.593	0.198	0.049	3.061
17.5													0.043	0.011	2.531	0.089	0.022	2.717	0.191	0.047	2.841	1.168	0.288	3.321
18.0													0.053	0.013	2.581	0.115	0.028	2.769	0.257	0.063	2.894	1.677	0.414	3.378
18.5													0.043	0.011	2.531	0.089	0.022	2.717	0.191	0.047	2.841	1.168	0.288	3.321
19.0													0.016	0.004	2.246	0.027	0.007	2.428	0.048	0.012	2.548	0.146	0.036	3.016
19.5													0.006	0.001	1.861	0.008	0.002	2.035	0.012	0.003	2.151	0.019	0.005	2.598
20.0													0.003	0.001	1.332	0.003	0.001	1.495	0.004	0.001	1.604	0.004	0.001	2.023
20.5													-	0.000	0.750	0.002	0.000	0.899	0.002	0.001	0.998	0.002	0.000	1.382
21.0													-	0.000	0.159	-	0.000	0.292	-	0.000	0.381	-	0.000	0.723
21.5													-	0.000	-0.483	-	0.000	-0.369	-	0.000	-0.293	-	0.000	0.002
22.0													-	0.000	-1.042	-	0.000	-0.948	-	0.000	-0.886	-	0.000	-0.644
22.5													-	0.000	-1.561	-	0.000	-1.489	-	0.000	-1.441	-	0.000	-1.256
23.0													-	0.000	-1.993	-	0.000	-1.945	-	0.000	-1.912	-	0.000	-1.787
23.5													-	0.000	-2.294	-	0.000	-2.269	-	0.000	-2.253	-	0.000	-2.189
24.0													-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Mid Range Future Scenario

	50% Mid Range			20% Mid Range			10% Mid Range			5% Mid Range			2% Mid Range			1% Mid Range			0.5% Mid Range			0.1% Mid Range		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	0.000	0.000	0.000	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	0.000	0.000	0.000	-	0.000	-2.245	-	0.000	-2.187	-	0.000	-2.163	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
13.0	0.000	0.000	0.000	-	0.000	-1.762	-	0.000	-1.648	-	0.000	-1.600	-	0.000	-1.569	-	0.000	-1.546	-	0.000	-1.523	-	0.000	-1.523
13.5	0.000	0.000	0.000	-	0.000	-1.148	-	0.000	-0.980	-	0.000	-0.909	-	0.000	-0.863	-	0.000	-0.829	-	0.000	-0.794	-	0.000	-0.794
14.0	0.000	0.000	0.000	-	0.000	-0.495	-	0.000	-0.276	-	0.000	-0.184	-	0.000	-0.124	-	0.000	-0.079	-	0.000	-0.034	-	0.000	-0.034
14.5	0.000	0.000	0.000	-	0.000	0.149	-	0.000	0.417	-	0.000	0.529	-	0.000	0.602	-	0.000	0.657	-	0.000	0.711	-	0.000	0.711
15.0	0.000	0.000	0.000	-	0.000	0.784	-	0.000	1.094	-	0.000	1.224	-	0.000	1.309	-	0.000	1.373	-	0.000	1.436	0.002	0.001	1.436
15.5	0.000	0.000	0.000	-	0.000	1.362	-	0.000	1.710	-	0.000	1.856	-	0.000	1.951	-	0.000	2.022	-	0.000	2.094	0.005	0.001	2.094
16.0	0.000	0.000	0.000	0.002	0.001	1.881	-	0.000	2.262	-	0.000	2.421	0.002	0.001	2.525	0.003	0.001	2.603	0.004	0.001	2.681	0.031	0.008	2.681
16.5	0.000	0.000	0.000	0.006	0.001	2.342	0.004	0.001	2.748	0.005	0.001	2.918	0.012	0.003	3.028	0.023	0.006	3.112	0.040	0.010	3.195	0.596	0.147	3.195
17.0	0.000	0.000	0.000	0.016	0.004	2.652	0.016	0.004	3.076	0.029	0.007	3.254	0.117	0.029	3.370	0.359	0.089	3.457	0.797	0.197	3.544	4.957	1.224	3.544
17.5	0.000	0.000	0.000	0.046	0.011	2.902	0.101	0.025	3.337	0.290	0.072	3.519	1.366	0.337	3.638	3.780	0.934	3.728	7.491	1.850	3.817	20.210	4.992	3.817
18.0	0.000	0.000	0.000	0.061	0.015	2.955	0.168	0.042	3.394	0.509	0.126	3.578	2.323	0.574	3.698	6.041	1.492	3.788	11.560	2.855	3.878	26.900	6.644	3.878
18.5	0.000	0.000	0.000	0.046	0.011	2.902	0.101	0.025	3.337	0.290	0.072	3.519	1.366	0.337	3.638	3.780	0.934	3.728	7.491	1.850	3.817	20.210	4.992	3.817
19.0	0.000	0.000	0.000	0.013	0.003	2.607	0.013	0.003	3.031	0.022	0.005	3.209	0.079	0.019	3.325	0.239	0.059	3.412	0.533	0.132	3.499	3.857	0.953	3.499
19.5	0.000	0.000	0.000	0.004	0.001	2.207	0.003	0.001	2.613	0.003	0.001	2.783	0.006	0.002	2.893	0.012	0.003	2.977	0.018	0.004	3.060	0.239	0.059	3.060
20.0	0.000	0.000	0.000	0.002	0.000	1.656	-	0.000	2.037	-	0.000	2.196	-	0.000	2.300	0.002	0.000	2.378	0.002	0.001	2.456	0.014	0.003	2.456
20.5	0.000	0.000	0.000	-	0.000	1.047	-	0.000	1.395	-	0.000	1.541	-	0.000	1.636	-	0.000	1.707	-	0.000	1.779	0.003	0.001	1.779
21.0	0.000	0.000	0.000	-	0.000	0.424	-	0.000	0.734	-	0.000	0.864	-	0.000	0.949	-	0.000	1.013	-	0.000	1.076	-	0.000	1.076
21.5	0.000	0.000	0.000	-	0.000	-0.256	-	0.000	0.012	-	0.000	0.124	-	0.000	0.197	-	0.000	0.252	-	0.000	0.306	-	0.000	0.306
22.0	0.000	0.000	0.000	-	0.000	-0.855	-	0.000	-0.636	-	0.000	-0.544	-	0.000	-0.484	-	0.000	-0.439	-	0.000	-0.394	-	0.000	-0.394
22.5	0.000	0.000	0.000	-	0.000	-1.418	-	0.000	-1.250	-	0.000	-1.179	-	0.000	-1.133	-	0.000	-1.099	-	0.000	-1.064	-	0.000	-1.064
23.0	0.000	0.000	0.000	-	0.000	-1.897	-	0.000	-1.783	-	0.000	-1.735	-	0.000	-1.704	-	0.000	-1.681	-	0.000	-1.658	-	0.000	-1.658
23.5	0.000	0.000	0.000	-	0.000	-2.245	-	0.000	-2.187	-	0.000	-2.163	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
24.0	0.000	0.000	0.000	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

High End Future Scenario

	10% Mid Range			0.5% Mid Range			0.1% Mid Range		
Time	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)	q (l/m/s)	q (m^3/s)	Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.110	-	1.000	-2.059	-	1.000	-2.059
13.0	-	0.000	-1.495	-	2.000	-1.393	-	2.000	-1.393
13.5	-	0.000	-0.753	-	3.000	-0.603	-	3.000	-0.603
14.0	-	0.000	0.020	-	4.000	0.216	-	4.000	0.216
14.5	-	0.000	0.777	-	5.000	1.016	-	5.000	1.016
15.0	-	0.000	1.513	-	6.000	1.790	0.003	6.000	1.790
15.5	-	0.000	2.180	0.003	7.000	2.491	0.017	7.000	2.491
16.0	0.003	0.001	2.774	0.033	8.000	3.114	0.373	8.000	3.114
16.5	0.029	0.007	3.294	2.784	9.000	3.657	9.348	9.000	3.657
17.0	0.711	0.176	3.648	-	10.000	4.027	-	10.000	4.027
17.5	8.610	2.127	3.924	-	11.000	4.313	-	11.000	4.313
18.0	13.710	3.386	3.986	-	12.000	4.378	-	12.000	4.378
18.5	8.610	2.127	3.924	-	13.000	4.313	-	13.000	4.313
19.0	0.461	0.114	3.603	25.760	14.000	3.982	-	14.000	3.982
19.5	0.013	0.003	3.159	0.932	15.000	3.522	4.549	15.000	3.522
20.0	-	0.000	2.549	0.010	16.000	2.889	0.090	16.000	2.889
20.5	-	0.000	1.865	0.002	17.000	2.176	0.006	17.000	2.176
21.0	-	0.000	1.153	-	18.000	1.430	0.002	18.000	1.430
21.5	-	0.000	0.372	-	19.000	0.611	-	19.000	0.611
22.0	-	0.000	-0.340	-	20.000	-0.144	-	20.000	-0.144
22.5	-	0.000	-1.023	-	21.000	-0.873	-	21.000	-0.873
23.0	-	0.000	-1.630	-	22.000	-1.528	-	22.000	-1.528
23.5	-	0.000	-2.110	-	23.000	-2.059	-	23.000	-2.059
24.0	-	0.000	-2.505	-	24.000	-2.505	-	24.000	-2.505

Location D

Current Scenario

AEP

Time	0.500 q (l/m/s)	0.500 q (m^3/s)	0.500 Water Level (mOD)	0.200 q (l/m/s)	0.200 q (m^3/s)	0.200 Water Level (mOD)	0.100 q (l/m/s)	0.100 q (m^3/s)	0.100 Water Level (mOD)	0.050 q (l/m/s)	0.050 q (m^3/s)	0.050 Water Level (mOD)
12.0							-	0.000	-2.505	-	0.000	-2.505
12.5							-	0.000	-2.241	-	0.000	-2.229
13.0							-	0.000	-1.754	-	0.000	-1.730
13.5							-	0.000	-1.136	-	0.000	-1.101
14.0							-	0.000	-0.480	-	0.000	-0.434
14.5							-	0.000	0.168	-	0.000	0.224
15.0							-	0.000	0.806	-	0.000	0.871
15.5							-	0.000	1.386	-	0.000	1.459
16.0							-	0.000	1.908	-	0.000	1.988
16.5							0.001	0.001	2.371	0.001	0.001	2.456
17.0							0.003	0.002	2.682	0.007	0.004	2.771
17.5							0.023	0.015	2.933	0.086	0.055	3.024
18.0							0.042	0.026	2.986	0.161	0.102	3.078
18.5							0.023	0.015	2.933	0.086	0.055	3.024
19.0							0.002	0.001	2.637	0.005	0.003	2.726
19.5							0.001	0.000	2.236	0.001	0.001	2.321
20.0							-	0.000	1.683	-	0.000	1.763
20.5							-	0.000	1.071	-	0.000	1.144
21.0							-	0.000	0.446	-	0.000	0.511
21.5							-	0.000	-0.237	-	0.000	-0.181
22.0							-	0.000	-0.840	-	0.000	-0.794
22.5							-	0.000	-1.406	-	0.000	-1.371
23.0							-	0.000	-1.889	-	0.000	-1.865
23.5							-	0.000	-2.241	-	0.000	-2.229
24.0							-	0.000	-2.505	-	0.000	-2.505

Time	0.020 q (l/m/s)	0.020 q (m^3/s)	0.020 Water Level (mOD)	0.010 q (l/m/s)	0.010 q (m^3/s)	0.010 Water Level (mOD)	0.005 q (l/m/s)	0.005 q (m^3/s)	0.005 Water Level (mOD)	0.001 q (l/m/s)	0.001 q (m^3/s)	0.001 Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.213	-	0.000	-2.201	-	0.000	-2.189	-	0.000	-2.189
13.0	-	0.000	-1.699	-	0.000	-1.675	-	0.000	-1.652	-	0.000	-1.652
13.5	-	0.000	-1.055	-	0.000	-1.020	-	0.000	-0.986	-	0.000	-0.986
14.0	-	0.000	-0.374	-	0.000	-0.329	-	0.000	-0.284	-	0.000	-0.284
14.5	-	0.000	0.297	-	0.000	0.352	-	0.000	0.407	-	0.000	0.407
15.0	-	0.000	0.956	-	0.000	1.019	-	0.000	1.083	0.002	0.001	1.083
15.5	-	0.000	1.554	-	0.000	1.626	-	0.000	1.697	0.003	0.002	1.697
16.0	0.001	0.000	2.092	0.001	0.001	2.170	0.002	0.001	2.248	0.007	0.004	2.248
16.5	0.003	0.002	2.566	0.006	0.004	2.650	0.014	0.009	2.733	0.095	0.060	2.733
17.0	0.031	0.020	2.887	0.105	0.066	2.974	0.333	0.211	3.061	1.336	0.846	3.061
17.5	0.503	0.319	3.143	1.615	1.022	3.232	4.203	2.660	3.321	-	0.000	3.321
18.0	0.919	0.582	3.198	2.770	1.753	3.288	6.743	4.268	3.378	-	0.000	3.378
18.5	0.503	0.319	3.143	1.615	1.022	3.232	4.203	2.660	3.321	-	0.000	3.321
19.0	0.020	0.013	2.842	0.066	0.041	2.929	0.208	0.132	3.016	0.938	0.594	3.016
19.5	0.002	0.001	2.431	0.003	0.002	2.515	0.005	0.003	2.598	0.037	0.023	2.598
20.0	-	0.000	1.867	-	0.000	1.945	0.001	0.001	2.023	0.004	0.003	2.023
20.5	-	0.000	1.239	-	0.000	1.311	-	0.000	1.382	0.003	0.002	1.382
21.0	-	0.000	0.596	-	0.000	0.659	-	0.000	0.723	-	0.000	0.723
21.5	-	0.000	-0.108	-	0.000	-0.053	-	0.000	0.002	-	0.000	0.002
22.0	-	0.000	-0.734	-	0.000	-0.689	-	0.000	-0.644	-	0.000	-0.644
22.5	-	0.000	-1.325	-	0.000	-1.290	-	0.000	-1.256	-	0.000	-1.256
23.0	-	0.000	-1.834	-	0.000	-1.810	-	0.000	-1.787	-	0.000	-1.787
23.5	-	0.000	-2.213	-	0.000	-2.201	-	0.000	-2.189	-	0.000	-2.189
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Mid Range Future Scenario

Time	0.500 q (l/m/s)	0.500 q (m^3/s)	0.500 Water Level (mOD)	0.200 q (l/m/s)	0.200 q (m^3/s)	0.200 Water Level (mOD)	0.100 q (l/m/s)	0.100 q (m^3/s)	0.100 Water Level (mOD)	0.050 q (l/m/s)	0.050 q (m^3/s)	0.050 Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.204	-	0.000	-2.187	-	0.000	-2.175	-	0.000	-2.163
13.0	-	0.000	-1.680	-	0.000	-1.648	-	0.000	-1.624	-	0.000	-1.600
13.5	-	0.000	-1.027	-	0.000	-0.980	-	0.000	-0.944	-	0.000	-0.909
14.0	-	0.000	-0.338	-	0.000	-0.276	-	0.000	-0.230	-	0.000	-0.184
14.5	-	0.000	0.341	-	0.000	0.417	-	0.000	0.473	-	0.000	0.529
15.0	-	0.000	1.006	-	0.000	1.094	-	0.000	1.159	-	0.000	1.224
15.5	-	0.000	1.611	-	0.000	1.710	-	0.000	1.783	-	0.000	1.856
16.0	-	0.000	2.153	0.001	0.000	2.262	0.001	0.001	2.341	0.001	0.001	2.421
16.5	0.001	0.001	2.632	0.004	0.003	2.748	0.010	0.007	2.833	0.031	0.019	2.918
17.0	0.017	0.011	2.956	0.114	0.072	3.076	0.411	0.260	3.165	1.332	0.843	3.254
17.5	0.384	0.243	3.213	2.436	1.542	3.337	-	0.000	3.428	-	0.000	3.519
18.0	0.786	0.498	3.269	4.379	2.772	3.394	-	0.000	3.486	-	0.000	3.578
18.5	0.384	0.243	3.213	2.436	1.542	3.337	-	0.000	3.428	-	0.000	3.519
19.0	0.011	0.007	2.911	0.067	0.042	3.031	0.242	0.153	3.120	0.813	0.515	3.209
19.5	0.001	0.001	2.497	0.002	0.001	2.613	0.004	0.002	2.698	0.008	0.005	2.783
20.0	-	0.000	1.928	-	0.000	2.037	-	0.000	2.116	0.001	0.000	2.196
20.5	-	0.000	1.296	-	0.000	1.395	-	0.000	1.468	-	0.000	1.541
21.0	-	0.000	0.646	-	0.000	0.734	-	0.000	0.799	-	0.000	0.864
21.5	-	0.000	-0.064	-	0.000	0.012	-	0.000	0.068	-	0.000	0.124
22.0	-	0.000	-0.698	-	0.000	-0.636	-	0.000	-0.590	-	0.000	-0.544
22.5	-	0.000	-1.297	-	0.000	-1.250	-	0.000	-1.214	-	0.000	-1.179
23.0	-	0.000	-1.815	-	0.000	-1.783	-	0.000	-1.759	-	0.000	-1.735
23.5	-	0.000	-2.204	-	0.000	-2.187	-	0.000	-2.175	-	0.000	-2.163
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

Time	0.020 q (l/m/s)	0.020 q (m^3/s)	0.020 Water Level (mOD)	0.010 q (l/m/s)	0.010 q (m^3/s)	0.010 Water Level (mOD)	0.005 q (l/m/s)	0.005 q (m^3/s)	0.005 Water Level (mOD)	0.001 q (l/m/s)	0.001 q (m^3/s)	0.001 Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
13.0	-	0.000	-1.569	-	0.000	-1.546	-	0.000	-1.523	-	0.000	-1.523
13.5	-	0.000	-0.863	-	0.000	-0.829	-	0.000	-0.794	-	0.000	-0.794
14.0	-	0.000	-0.124	-	0.000	-0.079	-	0.000	-0.034	-	0.000	-0.034
14.5	-	0.000	0.602	-	0.000	0.657	-	0.000	0.711	-	0.000	0.711
15.0	-	0.000	1.309	-	0.000	1.373	-	0.000	1.436	0.003	0.002	1.436
15.5	-	0.000	1.951	0.001	0.001	2.022	0.001	0.001	2.094	0.006	0.004	2.094
16.0	0.002	0.002	2.525	0.005	0.003	2.603	0.008	0.005	2.681	0.078	0.049	2.681
16.5	0.146	0.092	3.028	0.483	0.306	3.112	1.135	0.718	3.195	3.869	2.449	3.195
17.0	5.117	3.239	3.370	-	0.000	3.457	-	0.000	3.544	-	0.000	3.544
17.5	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
18.0	-	0.000	3.698	-	0.000	3.788	-	0.000	3.878	-	0.000	3.878
18.5	-	0.000	3.638	-	0.000	3.728	-	0.000	3.817	-	0.000	3.817
19.0	3.399	2.152	3.325	-	0.000	3.412	-	0.000	3.499	-	0.000	3.499
19.5	0.034	0.022	2.893	0.114	0.072	2.977	0.274	0.173	3.060	1.465	0.927	3.060
20.0	0.001	0.001	2.300	0.002	0.001	2.378	0.002	0.002	2.456	0.019	0.012	2.456
20.5	-	0.000	1.636	-	0.000	1.707	-	0.000	1.779	0.004	0.003	1.779
21.0	-	0.000	0.949	-	0.000	1.013	-	0.000	1.076	0.002	0.001	1.076
21.5	-	0.000	0.197	-	0.000	0.252	-	0.000	0.306	-	0.000	0.306
22.0	-	0.000	-0.484	-	0.000	-0.439	-	0.000	-0.394	-	0.000	-0.394
22.5	-	0.000	-1.133	-	0.000	-1.099	-	0.000	-1.064	-	0.000	-1.064
23.0	-	0.000	-1.704	-	0.000	-1.681	-	0.000	-1.658	-	0.000	-1.658
23.5	-	0.000	-2.148	-	0.000	-2.136	-	0.000	-2.124	-	0.000	-2.124
24.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505

High End Future Scenario

Time	10% q (l/m/s)	10% q (m^3/s)	10% Water Level (mOD)	0.50% q (l/m/s)	0.50% q (m^3/s)	0.50% Water Level (mOD)	0.10% q (l/m/s)	0.10% q (m^3/s)	0.10% Water Level (mOD)
12.0	-	0.000	-2.505	-	0.000	-2.505	-	0.000	-2.505
12.5	-	1.000	-2.110	-	1.000	-2.059	-	1.000	-2.059
13.0	-	2.000	-1.495	-	2.000	-1.393	-	2.000	-1.393
13.5	-	3.000	-0.753	-	3.000	-0.603	-	3.000	-0.603
14.0	-	4.000	0.020	-	4.000	0.216	-	4.000	0.216
14.5	-	5.000	0.777	-	5.000	1.016	0.002	5.000	1.016
15.0	-	6.000	1.513	-	6.000	1.790	0.004	6.000	1.790
15.5	-	7.000	2.180	0.003	7.000	2.491	0.024	7.000	2.491
16.0	0.006	8.000	2.774	0.602	8.000	3.114	2.172	8.000	3.114
16.5	1.714	9.000	3.294	-	9.000	3.657	-	9.000	3.657
17.0	-	10.000	3.648	-	10.000	4.027	-	10.000	4.027
17.5	-	11.000	3.924	-	11.000	4.313	-	11.000	4.313
18.0	-	12.000	3.986	-	12.000	4.378	-	12.000	4.378
18.5	-	13.000	3.924	-	13.000	4.313	-	13.000	4.313
19.0	-	14.000	3.603	-	14.000	3.982	-	14.000	3.982
19.5	0.366	15.000	3.159	-	15.000	3.522	-	15.000	3.522
20.0	0.002	16.000	2.549	0.060	16.000	2.889	0.386	16.000	2.889
20.5	-	17.000	1.865	0.001	17.000	2.176	0.007	17.000	2.176
21.0	-	18.000	1.153	-	18.000	1.430	0.003	18.000	1.430
21.5	-	19.000	0.372	-	19.000	0.611	-	19.000	0.611
22.0	-	20.000	-0.340	-	20.000	-0.144	-	20.000	-0.144
22.5	-	21.000	-1.023	-	21.000	-0.873	-	21.000	-0.873
23.0	-	22.000	-1.630	-	22.000	-1.528	-	22.000	-1.528
23.5	-	23.000	-2.110	-	23.000	-2.059	-	23.000	-2.059
24.0	-	24.000	-2.505	-	24.000	-2.505	-	24.000	-2.505

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Appendix D Shannon CFRAMS Design Tidal Hydrographs

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Shannon CFRAMS Design Tidal Hydrographs – Technical Note

1 Background and Aims

Following the definition of the model extents in the Shannon RBD (as part of the Shannon CFRAMs Study) several hydraulic models have been identified for which downstream tidal boundary conditions will have to be defined to pilot the downstream levels during the required design event simulations. This note details the approach taken to define the downstream boundary conditions at the model extents (see Figure 1) along the Shannon Estuary using the ICPSS (Irish Coastal Protection Strategy Study) extreme water levels associated with combined tide and surge information provided by the OPW.

2 Data Used

The following available datasets were used to produce the design tidal surge hydrographs as boundary conditions for the models shown on Figure 1. (All the information associated with these files is contained in the appendices of this technical note):

- Predicted Extreme Water Levels (Tide and Surge) [11] for the following design events: 50%AEP, 20%AEP, 10%AEP, 5%AEP, 2%AEP, 1%AEP, 0.5%AEP and 0.1%AEP
- Foynes, Carrigaholt and Limerick Tidal gauge level data (2003-2007) [12]
- Admiralty Tide Tables information for port locations along the Shannon Estuary[13]
- OSi Conversion Graphs (Poolbeg-Malin head) including levelling information for port locations
- Shannon CFRAMS Model Extents for the downstream tidal models

[11] OPW - RPS Irish Coastal Protection Strategy Study Phase IV South West Coast
[12] Shannon – Foynes Port Company
[13] Admiralty Tide Tables, United Kingdom and Ireland, Vol 1 NP 201-06, (2006)

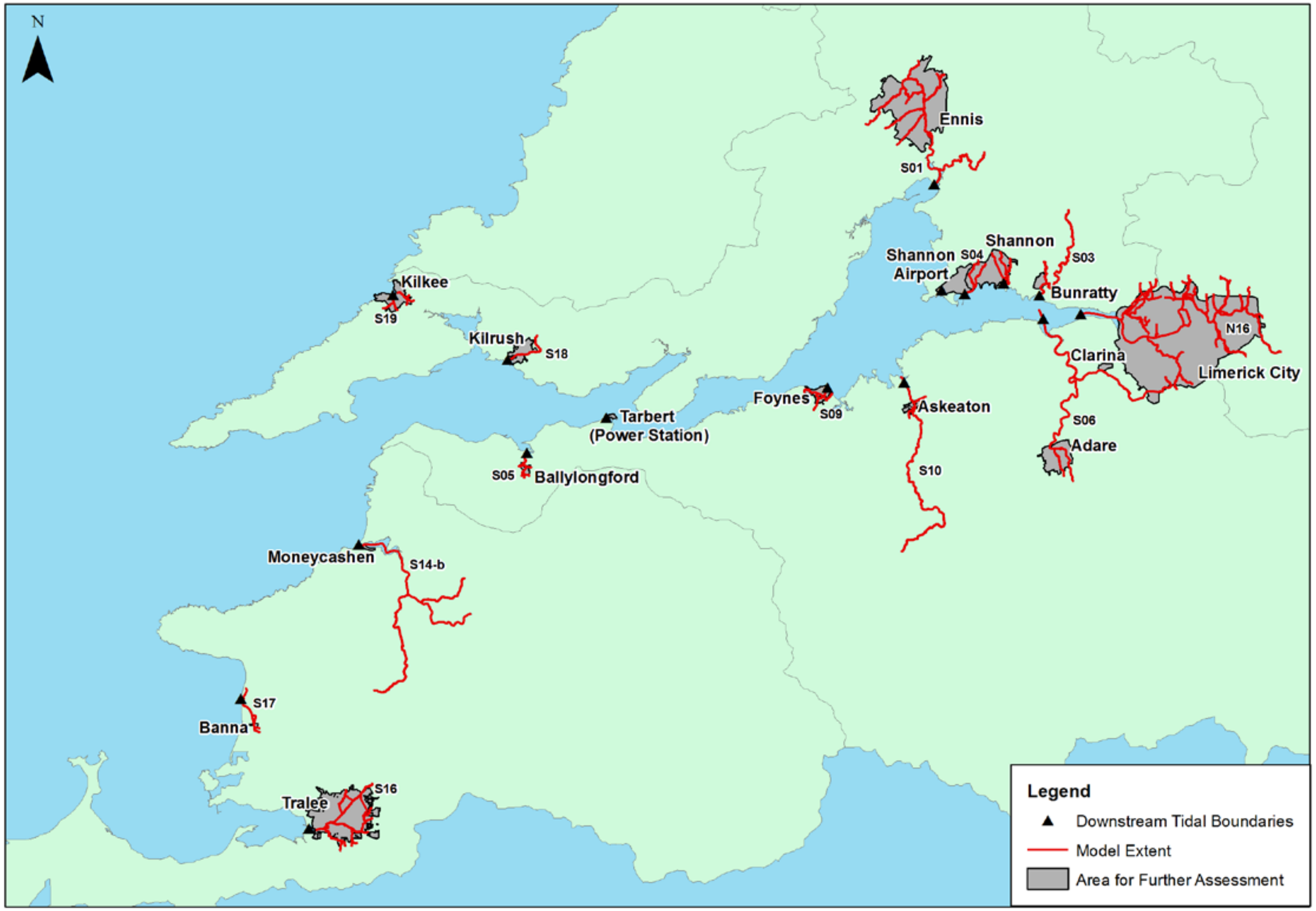


Figure 1: Shannon CFRAM models where tidal boundary conditions are required

3 Methodology

The following section details the different stages followed to develop the downstream tidal hydrographs assigned to each model.

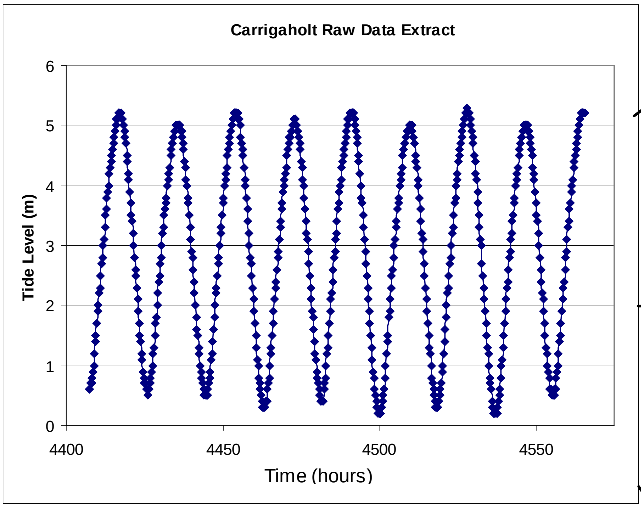
Stage 1

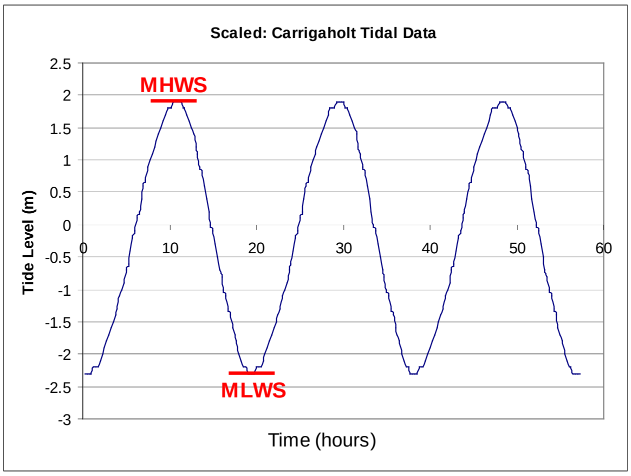
Following a data collection exercise tidal records at port locations: Carrigaholt, Limerick and Foynes (see Figure 2 below) were collated (Please refer to appendix A). These were used to extract tidal profiles which have been subsequently used and scaled to generate mean Spring tide profile ranging from Mean High Water Spring (MHWS) to Mean Low Water Spring (MLWS) levels at the nine port locations (see Figure 3) listed in the Admiralty Tide Tables as standard and secondary ports and located within the Shannon Estuary and Tralee Bay. These locations are Tarbert Island (Standard port), Carrigaholt, Kilrush, Foynes Island, Mellon Point, Limerick Dock, Coney Island and Fenit Pier (Tralee Bay). Details of the calculations carried out to determine MHWS and MLWS levels are provided in Appendix B.

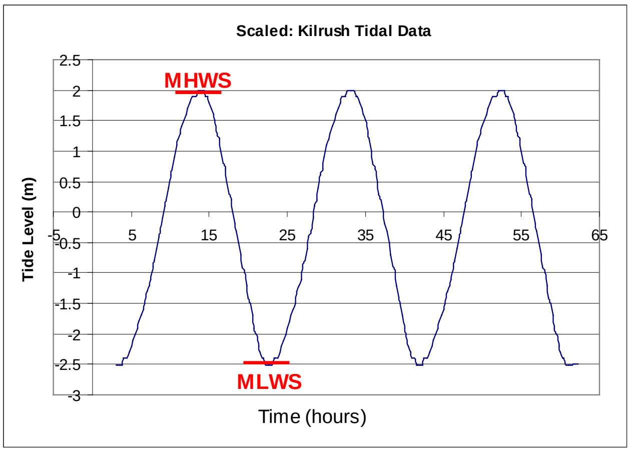
Figure 2: Shannon Estuary

Figure 3: Port locations as listed in the Admiralty Tide Tables

Figure 4 below is an example of how the raw data collected from the tidal gauges at Carrigaholt, Limerick and Foynes have been scaled to produce tidal data for the ports outlined above with the exception of Tarbert Island. The scaling factors that have been used for each port are detailed in Appendix B of Appendix D. The raw data was extracted to define the shape of the hydrograph and scaled based on the MHWS/MLWS levels at each port location. For the case of Tarbert Island, as it is a standard port, a typical Spring tide curve is available in the Admiralty Tide Tables and was therefore used.







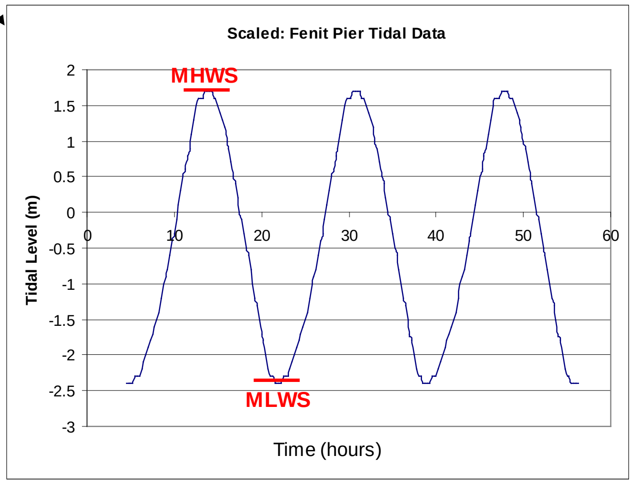


Figure 4: Example of Scaling of Raw Data

Stage 2

One of the outputs of the Irish Coastal Protection Strategy Study (ICPSS) was a series of prediction points for which extreme water levels combining tide and surge have been estimated. Each of the prediction points[14], as shown on Figure 5, has been allocated one of the mean spring profiles described above. This allocation was based on the nearest port location and tidal hydrodynamics within the Shannon Estuary.

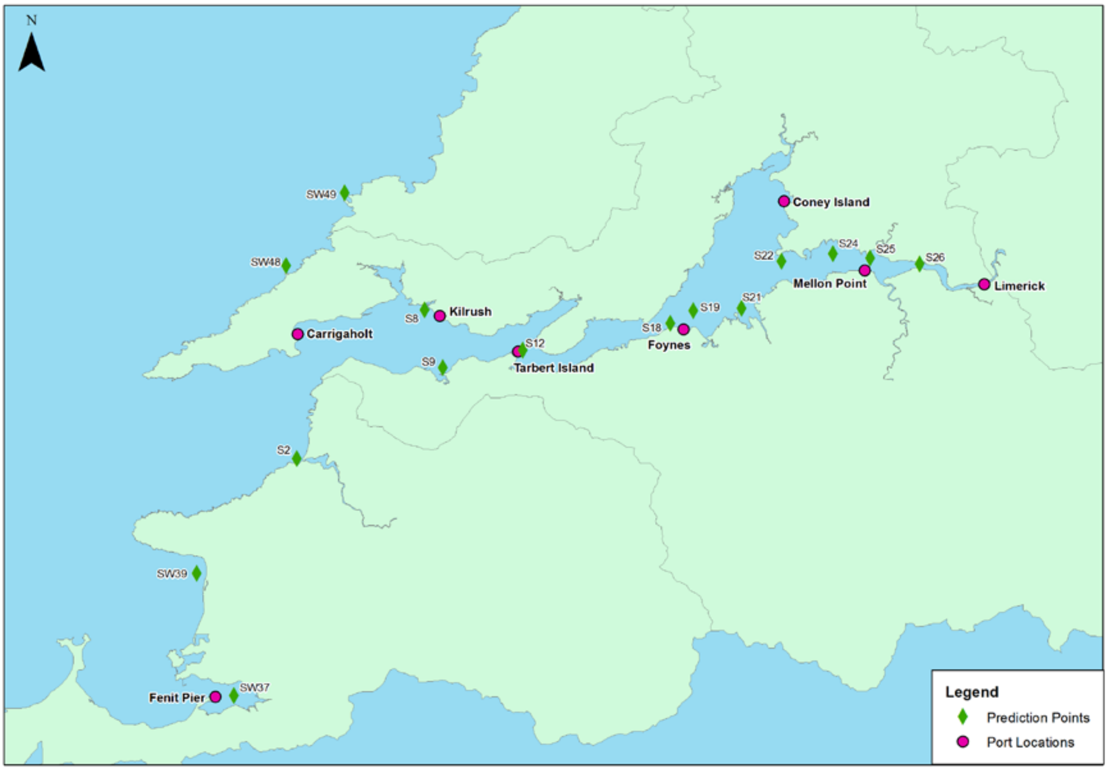


Figure 5: Prediction Point Locations

Table 1 below describes the allocation of the prediction points to each of the associated ports.

Table 1: Allocated of Prediction Points to Ports

Port	ICPSS (Prediction Point Reference)
Mellon Point	S25
	S24
Coney Island	S22
Kilrush	S9
	S8

Table 1: Allocated of Prediction Points to Ports

Port	ICPSS (Prediction Point Reference)
Limerick	S26
Foynes	S18
	S19
	S21
Carrigaholt	S2
	SW48-SW49
Fenit Pier	SW37
	SW39
Tarbert	S12

[14] Prediction point references used in Figure 5 and Table 1 are the ICPSS Prediction point references

Stage 3

Using the spring profiles and the available ICPSS extreme water levels for a range of annual probabilities, a series of design tidal hydrographs have been produced at each prediction point. The tidal hydrographs represent the effect of 30hr meteorological surges of increasing intensity on the mean Spring profile associated with each ICPSS prediction point. The 30hr surge duration means that 3 tide cycles are affected. The surge effect is centred such that middle high tide level matches with the extreme water levels taken from the ICPSS data.

This process is illustrated on Figure 6 below

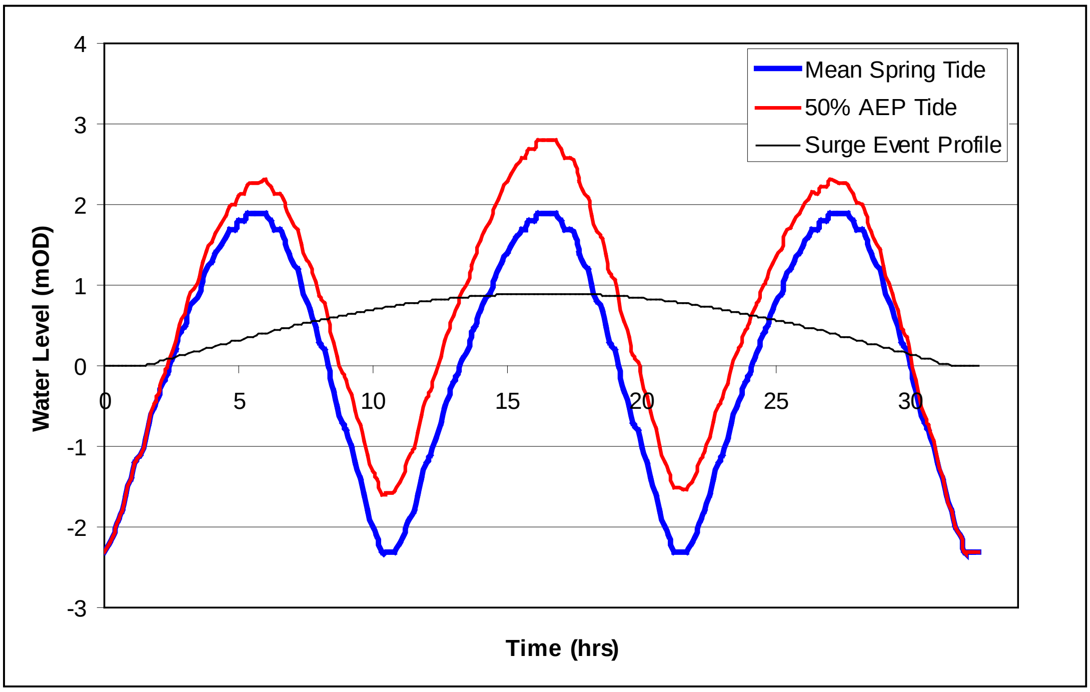


Figure 6: Example showing how an extreme event tide hydrograph has been produced

Stage 4

In the final step, the different model downstream boundaries were assigned to the closest prediction points and their associated design tidal hydrographs. For most of the models direct allocation was deemed appropriate except for the model S19 (AFA Kilkee) and S09 (AFA Foynes) where linear interpolation between two prediction points was carried out. An example of this is shown in Figure 7 below.

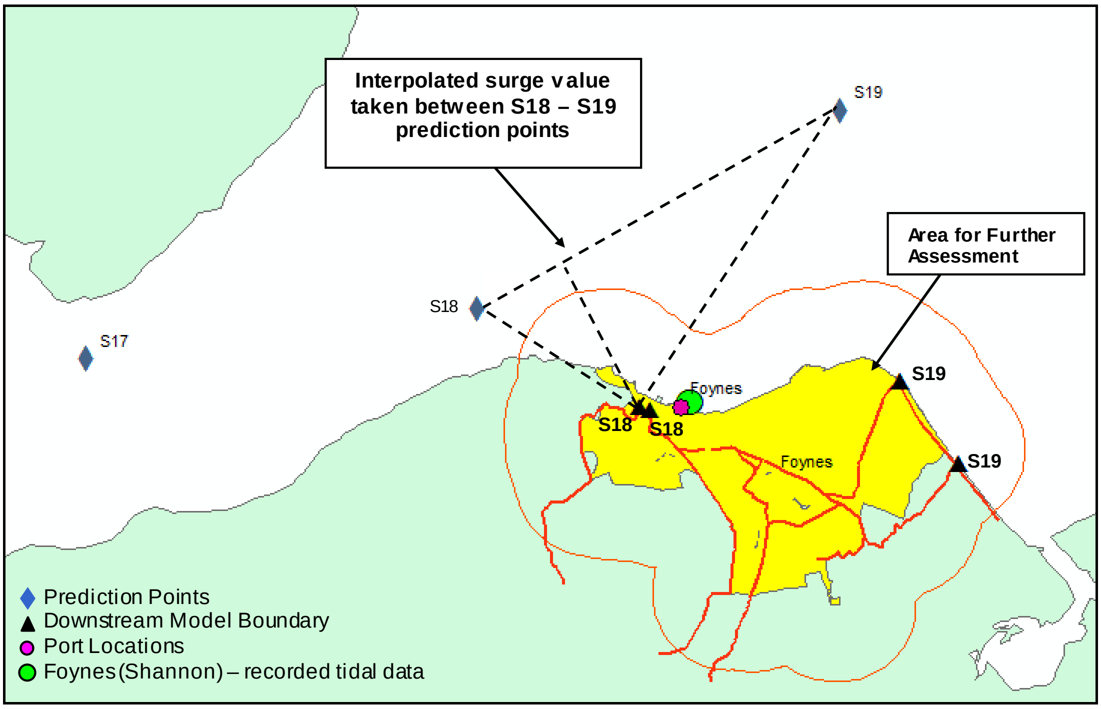


Figure 7: Model downstream boundary assignment for Foynes AFA (model S09)

Table 2 below lists the prediction points assigned to each model downstream boundary

Table 2: Allocation of Prediction Points to Model Downstream Boundaries	
ICPSS (Prediction Point Reference)	**AFAs – Model No**
S25	Adare / Clarina - Model S06
	Bunratty – Model S03
S24	Shannon Airport – IRR3
	Shannon - Model S04
S22	Ennis Model S01[15]

Table 2: Allocation of Prediction Points to Model Downstream Boundaries	
ICPSS (Prediction Point Reference)	**AFAs – Model No**
S9	Ballylongford – S05
S8	Kilrush – S18
S26	Limerick – Model N16
S18 - S19	Foynes - Model S09
S21	Askeaton – Model S10
S2	Moneycashen – Model S14b
SW48-SW49	Kilkee – Model S19
SW37	Tralee – Model S16
SW39	Banna – Model S17
S12	Tarbert – IRR4

Figure 8 shows the predictions points, the model extents and the area affected by the tidal conditions

[15] For the S01 model, the obtained design tidal boundary will be reviewed against the one used in the Ennis Main Drainage and Flood Study, Ennis urban District Council, 2001

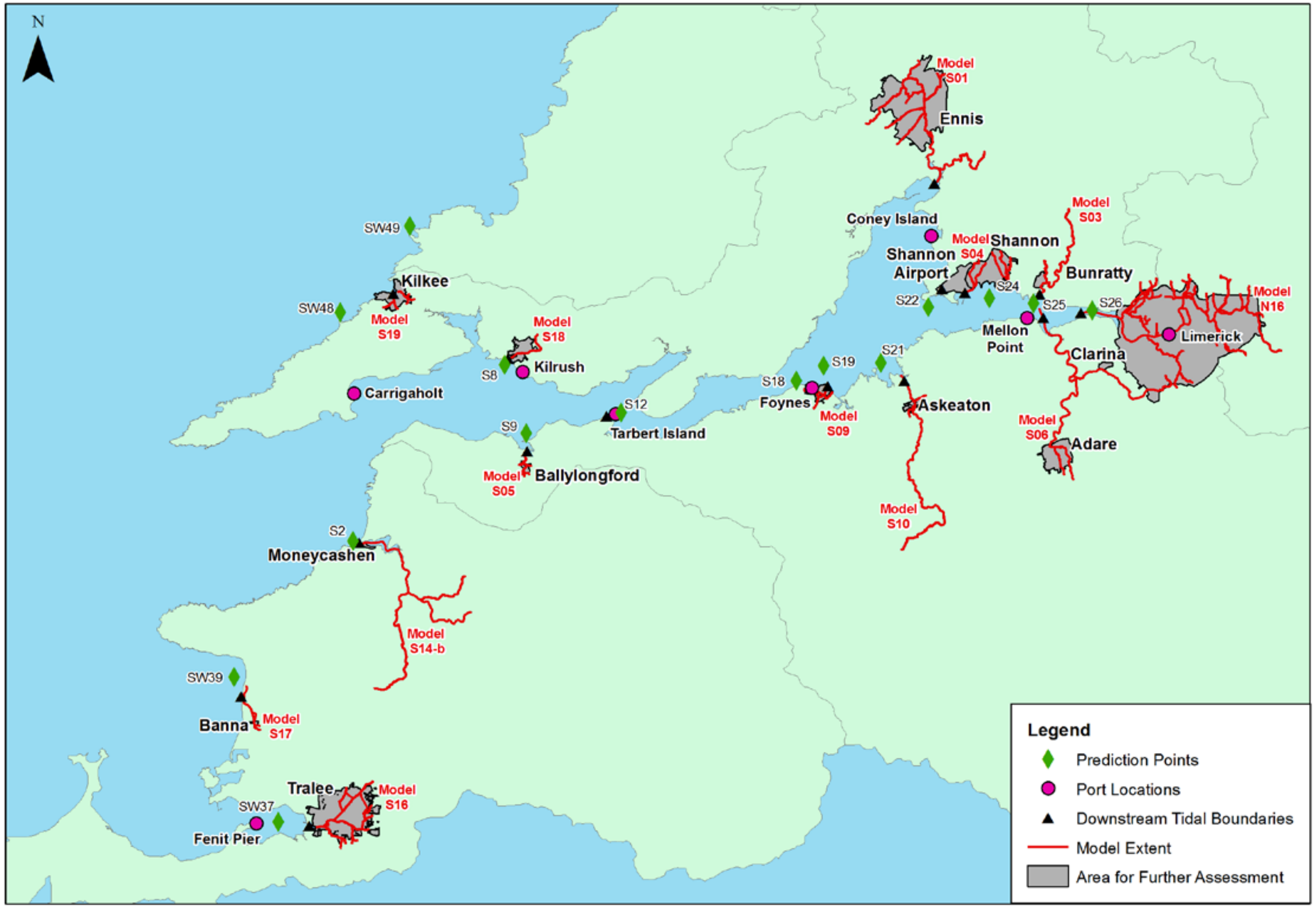


Figure 8 – Prediction point, model extents and AFAs

4 Conclusion

A summary of the methodology described in detail above is shown as a flow chart on Figure 9 below. For each model, a summary table of the assigned prediction point along with the data used to derive the downstream boundary tide profiles is also available in Appendix C.

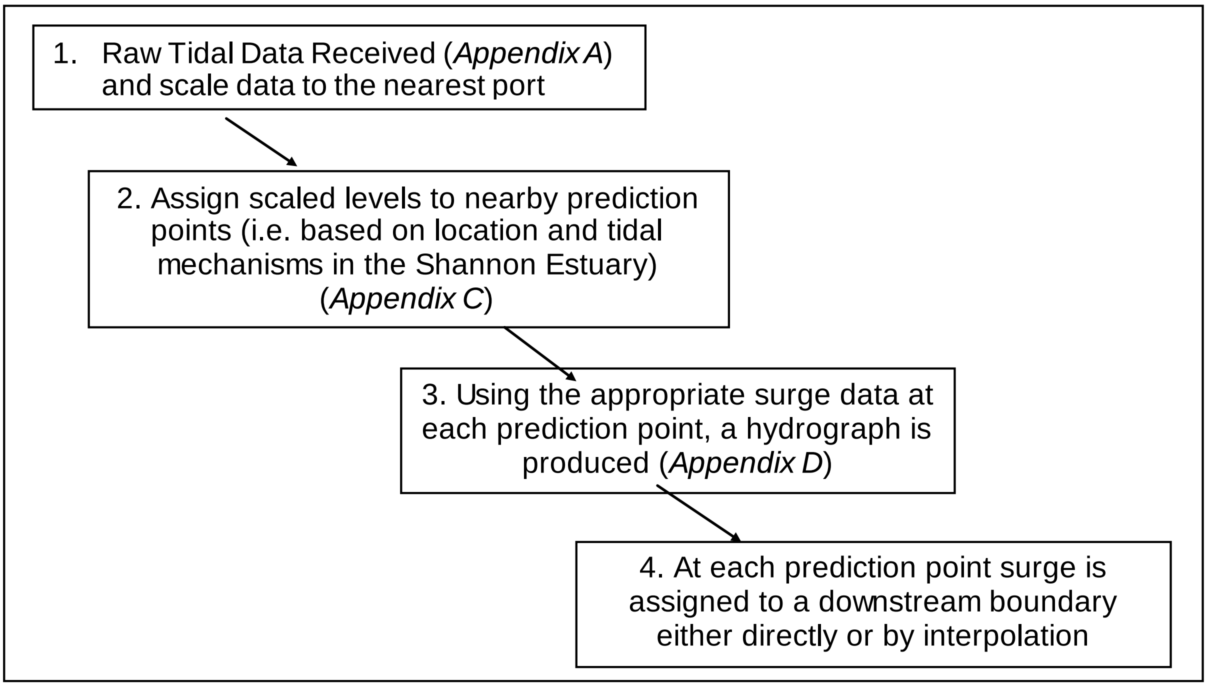
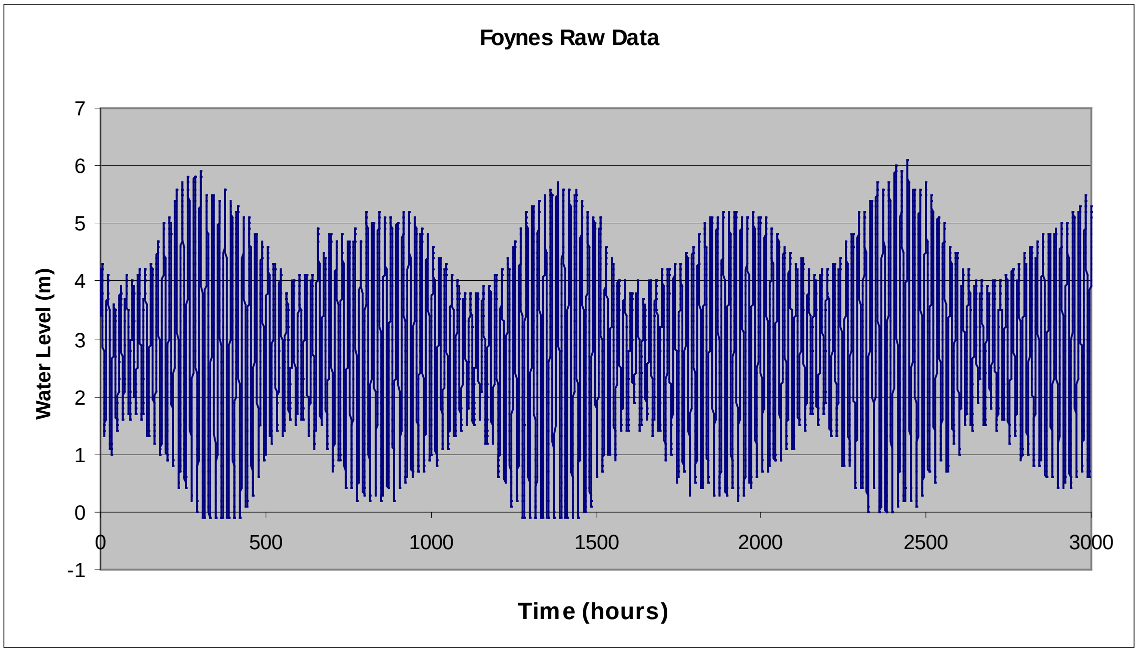
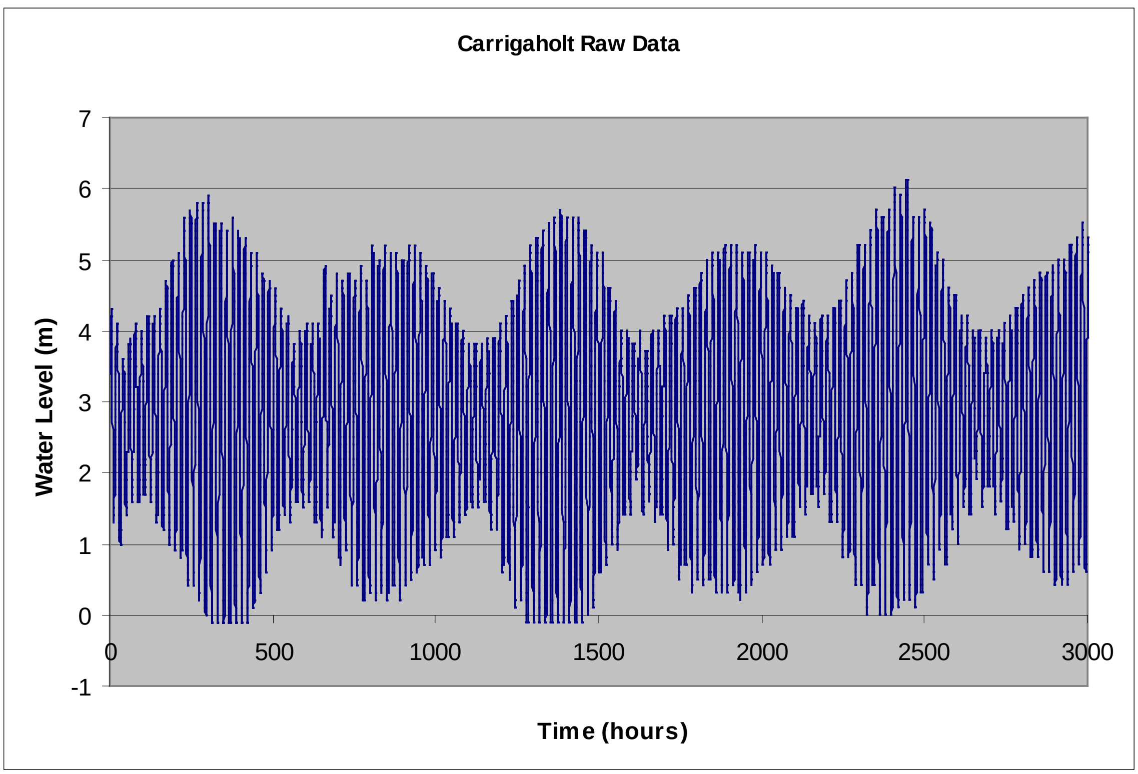
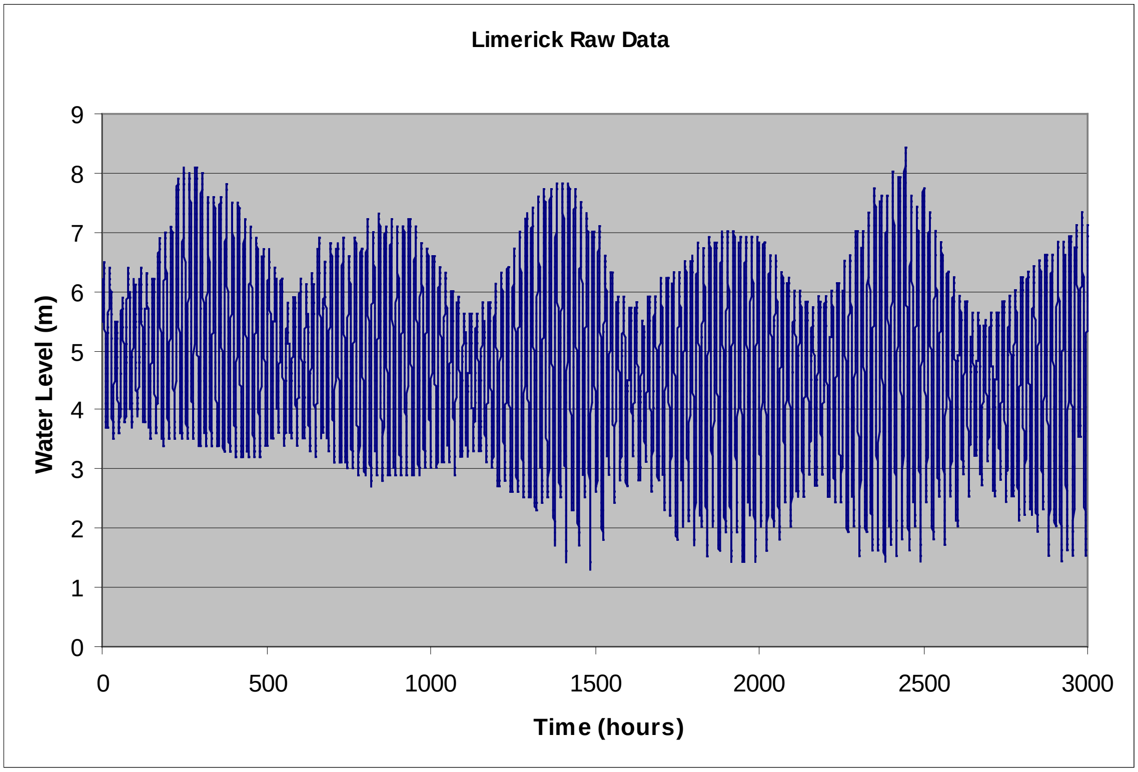


Figure 9: Flow Diagram of the Methodology

Appendix A – Raw Tidal Data Extract







Appendix B – MHWS/MHWL (Port Scaling Table)

Tidal record used to derive tidal hydrograph		Height difference in meters MHWS	MHWN	MLWN	MLWS	ML (m)	Water level in meters (Chart Datum Local) MHWS	MHWN	MLWN	MLWS	ML (m)
(Foynes)	**Tarbert Island (Standard Port)**	5.00	3.80	1.70	0.50	2.77	5.00	3.80	1.70	0.50	2.77
(Carrigaholt)	Carrigaholt	-0.10	-0.10	0.20	0.20		4.90	3.70	1.90	0.70	2.73
(Carrigaholt)	Kilrush	0.00	-0.10	0.00	0.00		5.00	3.70	1.70	0.50	2.64
(Foynes)	Foynes Island	0.20	0.20	0.10	-0.20		5.20	4.00	1.80	0.30	
(Foynes)	Mellon Point	0.90	0.70	0.20	-0.10		5.90	4.50	1.90	0.40	
(Limerick)	Limerick Dock	1.10	0.80	-0.50	-0.10		6.10	4.60	1.20	0.40	
(Foynes)	River Fergus (Coney Island)	0.20	0.10				5.20	3.90			

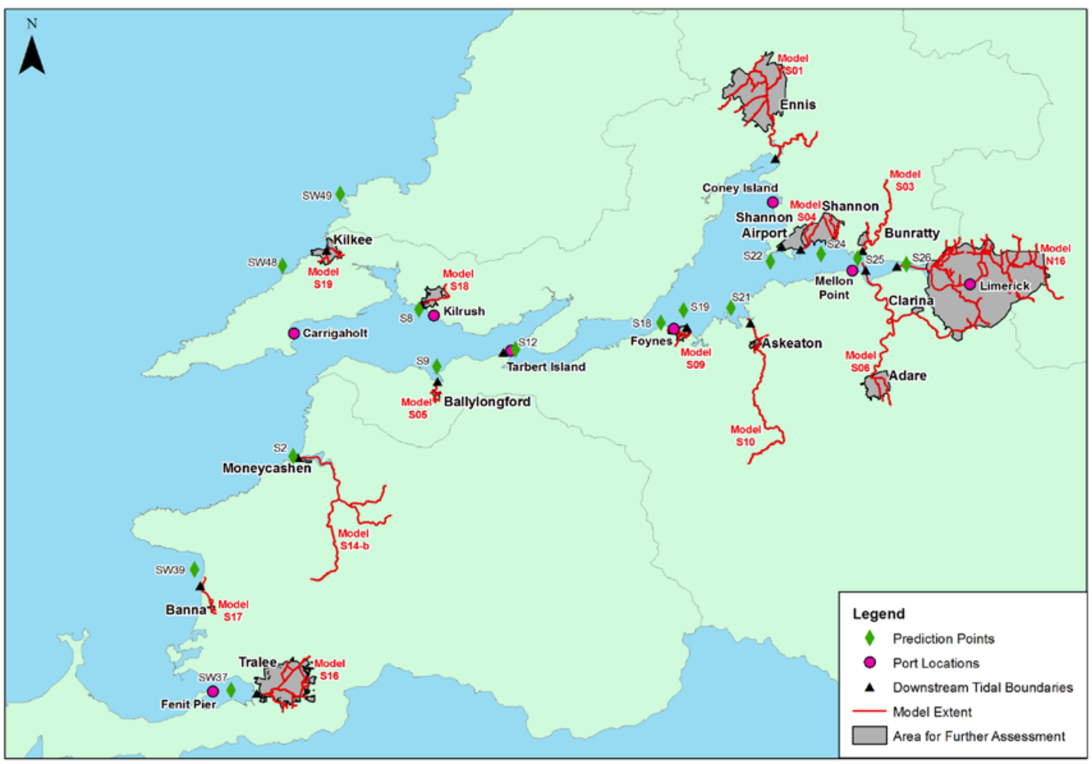
	Height difference in meters MHWS	MHWN	MLWN	MLWS	ML (m)	Water level in meters MHWS	MHWN	MLWN	MLWS	ML (m)
COBH (Standard Port)	4.10	3.20	1.30	0.40	2.25	4.10	3.20	1.30	0.40	2.25
Fenit Pier - Tralee Bay	0.50	0.20	0.30	0.10		4.60	3.40	1.60	0.50	2.53
	4.6	3.4	1.6	0.5	2.525					

	Land Leveling (Height in Meters)	Poolbeg (Datum) - Malin Head Conversion
Tarbert Island	-0.30	
Carrigaholt	-0.30	
Kilrush	-0.30	
Foyes Island	-0.30	
Limerick Dock	-0.46	-2.663
Fenit Pier	-0.21	-2.693

Poolbeg (Datum) - Malin Head Conversion	
-2.705	(Futher refinement Based on Osi data/sheets)

Appendix C – Prediction Point Assignment

AFA Applicable to	ICPSS (Prediction Point Reference)	Method	Port	Tidal_Data
Adare / Clarina	S25	Direct Assignment	Mellon Point	Foynes
Bunratty	S25	Direct Assignment	Mellon Point	Foynes
Shannon Airport	S24	Direct Assignment	Mellon Point	Foynes
Shannon	S24	Direct Assignment	Mellon Point	Foynes
Ennis	S22	Direct Assignment	Coney Island	Foynes
Ballylongford	S9	Direct Assignment	Kilrush	Carrigaholt
Kilrush	S8	Direct Assignment	Kilrush	Carrigaholt
Limerick	S26	Direct Assignment	Limerick	Limerick
Foynes	S18-S19	Interpolated	Foynes	Foynes
Foynes	S19	Direct Assignment	Foynes	Foynes
Askeaton	S21	Direct Assignment	Foynes	Foynes
Moneycashen	S2	Direct Assignment	Carrigaholt	Carrigaholt
Kilkee	SW48-49	Interpolated	Carrigaholt	Carrigaholt
Tralee	SW37	Direct Assignment	Fenit Pier	Carrigaholt
Banna	SW39	Direct Assignment	Fenit Pier	Carrigaholt
Tarbert	S12	Direct Assignment	Tarbert	Foynes



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Appendix D – ICPSS Predicted Extreme Water Levels Associated with Combined Tide and Surge

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RPS

ICPSS PHASE IV - SOUTH WEST COAST

OPW

Predicted Extreme Water Levels Associated with Combined Tide and Surge

PREDICTION	ANNUAL EXCEEDENCE PROBABILITY (AEP)								COORDINATES OF PREDICTION POINTS	
POINT ID	50%	20%	10%	5%	2%	1%	0.5%	0.1%	EASTINGS	NORTHINGS
SW27	2.32	2.42	2.49	2.56	2.65	2.71	2.78	2.93	30635	104299
SW28	2.38	2.48	2.56	2.63	2.73	2.80	2.87	3.04	36361	109676
SW29	2.42	2.53	2.61	2.68	2.78	2.85	2.92	3.09	41593	112847
SW30	2.47	2.58	2.66	2.74	2.84	2.91	2.98	3.15	48882	116516
SW31	2.52	2.63	2.70	2.77	2.86	2.93	3.00	3.16	54279	114238
SW32	2.53	2.64	2.71	2.78	2.87	2.94	3.00	3.16	59207	115106
SW33	2.56	2.67	2.75	2.82	2.92	3.00	3.08	3.25	60950	120616
SW34	2.68	2.79	2.86	2.93	3.01	3.08	3.15	3.30	64289	115512
SW35	2.69	2.79	2.86	2.94	3.03	3.10	3.17	3.33	68777	112162
SW36	2.72	2.83	2.91	2.98	3.08	3.15	3.22	3.39	73381	113155
SW37	2.83	2.94	3.02	3.10	3.21	3.29	3.36	3.55	78171	113613
SW38	2.63	2.74	2.81	2.89	2.98	3.05	3.12	3.29	72867	119737
SW39	2.63	2.74	2.82	2.90	3.00	3.08	3.16	3.33	74265	126382
SW40	2.59	2.71	2.79	2.86	2.97	3.04	3.12	3.29	67371	131016
SW41	2.63	2.74	2.82	2.90	3.00	3.07	3.15	3.32	74926	133602
SW42	2.67	2.79	2.87	2.96	3.07	3.15	3.23	3.42	84187	139720
SW43	2.64	2.77	2.86	2.95	3.07	3.16	3.25	3.45	86181	149471
SW44	2.62	2.75	2.83	2.92	3.03	3.12	3.20	3.40	74602	147527
SW45	2.57	2.69	2.78	2.86	2.97	3.06	3.14	3.33	67807	147150
SW46	2.59	2.71	2.79	2.88	2.98	3.07	3.15	3.33	73800	151815
SW47	2.60	2.72	2.80	2.88	2.99	3.07	3.15	3.34	78108	154787
SW48	2.61	2.73	2.82	2.90	3.01	3.10	3.18	3.37	83599	158464
SW49	2.62	2.74	2.83	2.92	3.03	3.12	3.20	3.40	89719	166059
SW50	2.64	2.77	2.86	2.95	3.06	3.15	3.24	3.44	97955	167774
SW51	2.65	2.78	2.87	2.96	3.08	3.17	3.26	3.46	98414	173525
SW52	2.66	2.79	2.88	2.97	3.08	3.17	3.26	3.46	101090	178980
SW53	2.70	2.83	2.93	3.02	3.15	3.24	3.33	3.55	107926	187640
SW54	2.69	2.82	2.92	3.01	3.13	3.22	3.31	3.52	100223	189240
SW55	2.72	2.85	2.95	3.04	3.16	3.24	3.33	3.54	104725	195829
SW56	2.82	2.97	3.07	3.17	3.30	3.39	3.49	3.72	112752	208923

Notes

All water levels shown are in metres and referenced to Ordnance Datum Malin
Prediction Point Coordinates are referenced to Irish Grid TM65

RPS

ICPSS PHASE IV - SOUTH WEST COAST

OPW

Predicted Extreme Water Levels Associated with Combined Tide and Surge

PREDICTION	ANNUAL EXCEEDENCE PROBABILITY (AEP)								COORDINATES OF PREDICTION POINTS	
POINT ID	50%	20%	10%	5%	2%	1%	0.5%	0.1%	EASTINGS	NORTHINGS
S1	2.64	2.76	2.85	2.94	3.06	3.15	3.23	3.43	82688	148391
S2	2.71	2.82	2.91	2.99	3.10	3.18	3.26	3.44	84845	138260
S3	2.73	2.85	2.93	3.02	3.13	3.22	3.30	3.49	85474	144422
S4	2.71	2.83	2.92	3.01	3.12	3.21	3.30	3.50	86013	151950
S5	2.72	2.84	2.92	3.01	3.12	3.20	3.29	3.48	88695	148419
S6	2.74	2.86	2.95	3.03	3.15	3.24	3.32	3.52	91646	152584
S7	2.77	2.89	2.98	3.07	3.18	3.27	3.35	3.55	95785	147777
S8	2.76	2.89	2.98	3.07	3.19	3.28	3.37	3.58	98052	153862
S9	2.79	2.91	3.00	3.09	3.20	3.29	3.37	3.57	99936	147831
S10	2.75	2.87	2.96	3.05	3.17	3.26	3.35	3.55	103931	150900
S11	2.77	2.89	2.99	3.08	3.20	3.29	3.38	3.59	106638	150798
S12	2.72	2.84	2.93	3.02	3.13	3.21	3.29	3.48	108294	149661
S13	2.70	2.83	2.92	3.01	3.12	3.21	3.30	3.50	109699	148606
S14	2.72	2.85	2.94	3.03	3.15	3.24	3.33	3.53	112483	148567
S15	2.72	2.86	2.96	3.06	3.20	3.30	3.40	3.63	115609	151987
S16	2.75	2.89	3.00	3.10	3.24	3.34	3.45	3.69	118265	150532
S17	2.78	2.93	3.04	3.16	3.30	3.42	3.53	3.79	121126	152131
S18	2.83	2.99	3.11	3.22	3.38	3.50	3.62	3.89	123686	152457
S19	2.89	3.04	3.17	3.29	3.45	3.57	3.69	3.97	126062	153757
S20	2.93	3.09	3.22	3.34	3.51	3.63	3.76	4.05	127363	157071
S21	3.03	3.20	3.32	3.45	3.61	3.74	3.86	4.15	131090	154017
S22	3.12	3.31	3.44	3.58	3.75	3.89	4.02	4.33	135251	158930
S23	3.18	3.37	3.52	3.66	3.86	4.00	4.15	4.48	138731	157900
S24	3.22	3.42	3.57	3.72	3.92	4.07	4.21	4.56	140612	159730
S25	3.29	3.50	3.66	3.81	4.02	4.17	4.33	4.68	144515	159263
S26	3.40	3.64	3.82	4.00	4.24	4.41	4.59	5.00	149662	158626

Notes

All water levels shown are in metres and referenced to Ordnance Datum Malin
Prediction Point Coordinates are referenced to Irish Grid TM65

Appendix E – Ordnance Survey Conversion Tables (Poolbeg-Malin Head)

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POOLBEG:MALIN HEAD DIFFS COUNTRYWIDE

AREA	DIFF (MEAN)	AREA	DIFF (MEAN)
ARTHURSTOWN (WEX)	2.578 mts	DUNDALK	2.640 mts
ATHLONE	2.766 mts	DUNGARVAN	2.697 mts
BALLINA	2.810 mts	DUN LAOGHAIRE	2.722 mts
BALLINACOLLIG	2.739 mts	DUNMORE EAST	2.610 mts
BALLINROBE	2.773 mts	EDENDERRY	2.670 mts
BALLYBOFEY	2.747 mts	EDGEWORTHSTOWI	2.780 mts
BALLYBUNION	2.704 mts	ENNISCORTHY	2.645 mts
BALLYHAUNIS	2.759 mts	FERBANE	2.717 mts
BALLYSADARE (SLIGO)	2.792 mts	GALWAY	2.732 mts
BALLYSHANNON	2.744 mts	GEASHILL	2.784 mts
BANTRY	2.756 mts	GORMANSTOWN-ST	2.716 mts
BLANCHARDSTOWN	2.744 mts	GREENHILLS RD. (D	2.722 mts
BOYLE	2.797 mts	KILKENNY	2.674 mts
CAHIR	2.705 mts	KILLARNEY	2.686 mts
CARLOW	2.713 mts	KINSALE	2.704 mts
CARRICKMACROSS	2.647 mts	LETTERKENNY	2.719 mts
CARRICK-ON-SUIR	2.665 mts	LIMERICK	2.663 mts
CARRIGTOHILL	2.701 mts	LISTOWEL	2.737 mts
CASTLEBAR	2.840 mts	LONGFORD	2.760 mts
CASTLEBLANEY	2.744 mts	LUCAN-LEIXLIP	2.719 mts
CASTLEISLAND	2.689 mts	MACROOM	2.762 mts
CHARLEVILLE	2.669 mts	MALIN HEAD	2.598 mts
CLARA	2.698 mts	MANORHAMILTON	2.781 mts
CLAREMORRIS	2.764 mts	MAYNOOTH	2.746 mts
CLONAKILTY	2.719 mts	MOATE	2.782 mts
CLONEE	2.763 mts	MONASTEBOICE (L(	2.689 mts
CLONES	2.775 mts	MONASTERVIN	2.682 mts
CLONMEL	2.714 mts	MULLINGAR	2.777 mts
COBH	2.690 mts	NAAS	2.685 mts
CORK	2.701 mts	NAVAN	2.732 mts
DONEGAL TOWN	2.700 mts	NENAGH	2.644 mts
DROGHEDA	2.680 mts	NEWCASTLEWEST	2.699 mts

AREA	DIFF (MEAN)
NEW ROSS	2.573 mts
PORT LAOISE	2.703 mts
RATHKEALE	2.695 mts
SHANNON	2.705 mts
SLIGO	2.790 mts
SKERRIES	2.700 mts
SKIBBEREEN	2.737 mts
SWINFORD	2.839 mts
SWORDS	2.694 mts
TEMPLEMORE	2.726 mts
TRALEE	2.693 mts
TRAMORE	2.643 mts
TULLAMORE (CLARA ROAD)	2.701 mts
WATERFORD	2.702 mts
WESTPORT	2.818 mts
WEXFORD TOWN	2.662 mts

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Appendix E National Technical Co-ordination Group (NTCG) Guidance Note no. 23 (GN23)

Technical Note

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Date	**17th June 2013**
To	John Martin, Office of Public Works
From	Peter Smyth, Jacobs
Project	**Shannon CFRAM Study**
Subject	NTCG Guidance Note No.23 (GN23) - Hydraulic Model Calibration
Reference	32103000/TD_HYDO_0330_V2_0_JAC_GN23_Model_Calib_130617

1.0 Introduction

This Guidance Note (GN23) outlines Jacobs' proposed approach for calibrating the fluvial hydraulic models and the tidal inundation models, and the reasoning behind the approach to be adopted. Throughout the Guidance Note any references to "we" implies that it is Jacobs' approach on the Shannon CFRAM Study.

This note only covers calibration of the main hydraulic model deliverables. It excludes the calibration of the hydraulic models required for the Gauging Station Rating Reviews: which are to be calibrated using the recorded check gaugings (spot flows) as deemed reliable, up to the maximum gauged flows.

This Guidance Note has been produced for circulation amongst all CFRAM Study Consultants for information. The approaches outlined in this Guidance Note apply specifically to the Shannon CFRAM Study, although each CFRAM Study Consultant may adopt the approach where the methodology lends itself suitably to application elsewhere. However, it is emphasised that differences in approach, such as the possible application of rainfall-runoff modelling in other CFRAM Studies, will require additional consideration by other CFRAM Study consultants.

2.0 Summary of Stage I Tender Documents

Stage I Tender Documents: Project Brief states:

6. HYDROLOGICAL ANALYSIS

6.1. LEVEL OF DETAIL

The hydrological analysis of the whole Study Area should be comprehensive and taken to a high level of detail, such that no further hydrological analysis should be required after completion of the Project (other than to confirm findings of the Project, assess minor design variations or update the analysis after a number of years or the occurrence of an extreme event) for the OPW or other authorities to have justifiable confidence in the implementation of the strategy and specific measures identified through the Project to manage the flood risk within the APSRs. The hydrological analysis should place particular emphasis on flood flow estimation for the APSRs and HPWs in terms of, for example, statistical flood frequency estimation and the calibration of hydrological models.

6.5. ESTIMATION OF DESIGN FLOOD PARAMETERS

6.5.5. Hydrological Calibration and Validation

The Consultant shall calibrate and validate the estimates of the design flood parameters (other than extreme peak sea levels) to recorded data as far as reasonably possible, based on historic or recorded flood event data.

7. HYDRAULIC ANALYSIS

7.1. LEVEL OF DETAIL

The level of detail of the hydraulic analysis to be undertaken under this Project should be sufficient to enable the Consultant to fully meet the requirements and objectives of the flood mapping, flood risk assessment, development and appraisal of flood risk management actions and measures (and associated assessments) and the preparation of a Flood Risk Management Plan, as set out herein.

Within APSRs, the hydraulic analysis should be comprehensive and taken to a high level of detail, such that no further hydraulic analysis should be required after completion of the Project (other than to confirm findings of the Project, assess minor design variations or for validation and / or re-calibration after the occurrence of an extreme event) for the OPW or other authorities to have justifiable confidence in the implementation of the strategy and specific measures identified through the Project to manage the flood risk within the APSRs. The level of detail of the hydraulic analysis for MPWs does not need to be as high as that required for the APSRs, but nonetheless should be the best achievable within the constraints of the survey specification and available calibration data for MPWs to enable reasonable estimates of flood hazard and risk.

7.2. DEVELOPMENT OF FLUVIAL HYDRAULIC MODELS

7.2.1. Fluvial Model Development

The Consultant shall develop dynamic hydraulic models for the HPWs and MPWs and their associated floodplains, based on the definitions of HPWs and MPWs set out herein, and the APSRs associated with fluvial flood risk, as identified in the tender documentation of the Specific Tender Stage (Stage II), to analyse historic flood events and estimate design and potential future flood levels, depths, velocities and extents.

The Consultant shall develop models to a high level of detail for the HPWs, but to a lower level of detail for MPWs, making full and best use of the survey, calibration and other information captured, provided or developed as specified herein……

7.2.2. Fluvial Model Calibration

The Consultant shall appropriately ensure that the flood flows within the hydraulic models along HPW and MPW reaches are calibrated to the flood flow estimates at the Hydrological Estimation Points to ensure hydrological continuity (taking account of flood attenuation explicitly simulated within the hydraulic modelling) and that the design flood flows for each AEP are maintained along all lengths of relevant watercourses. Such adjustment might, for example, be by the provision of appropriate lateral inflows and ensuring appropriate inflow from tributaries, or by running the hydraulic models for individual reaches.

The Consultant shall calibrate and verify the fluvial hydraulic models against a number of suitable past flood events (not less than four (4) events for each APSR if relevant data is

available). The calibration and verification of the models shall make use of the best available data including, but not limited to, hydrometric data, photographs, videos, press articles and anecdotal information provided by local authority staff and other Stakeholders. The models should be verified to vertical accuracies of not less than 0.2m and 0.4m for HPWs and MPWs respectively, subject to the availability of suitable calibration data.

7.3. DEVELOPMENT OF COASTAL FLOODING MODELS

7.3.1. Coastal Flooding Model Development

The Consultant shall develop models for the APSRs associated with risk of flooding from coastal sources, as identified in the tender documentation of the Specific Tender Stage (Stage II), to analyse the inland propagation of coastal or estuarine flood waters and to analyse historic flood events and estimate design and potential future flood levels, depths, velocities and extents. It is reiterated that the Consultant shall not be required to develop hydrodynamic storm surge models, or off-shore models, under this Project and shall instead use the peak design extreme coastal water levels provided by the OPW as the basis for the inland (overland) propagation modelling of flood waters.

The Consultant shall develop models to a high level of detail making full and best use of the survey and other information captured, provided or developed as specified herein. The modelling shall be undertaken using 2-dimensional modelling or other equivalent types of flood spreading modelling capable of accurately simulating the propagation of coastal floodwaters over tidal cycles and storm surge events inland.

The hydraulic models shall be developed using one of the following modelling software packages:

- *ISIS-2D / Tuflow*
- *Mike 21, Mike Flood*
- *JFlow*

Hydraulic modelling software packages other than those listed above may not be used in undertaking this element of the Project.

7.3.2. Coastal Flooding Model Calibration

The Consultant shall calibrate and verify the coastal flooding models against a number of suitable past flood events (not less than four (4) events for each APSR if relevant data is available). The calibration and verification of the models shall make use of the best available data including, but not limited to, hydrometric data, photographs, videos, press articles and anecdotal information provided by local authority staff and other Stakeholders. The models should be verified to vertical accuracies of not less than 0.2m, subject to the availability of suitable calibration data.

3.0 Proposed Approach

3.1 Technical Requirements for Calibration

Calibration of the hydrological and hydraulic models is required to give confidence in the results of the models.

The calibration and verification of the models will make appropriate use of the available data including, but not necessarily limited to, hydrometric data, photographs, videos, press articles and anecdotal information provided by local authority staff and other Stakeholders. Reliable calibration can only be achieved within the constraints of the available data, taking account of both its relevance and reliability.

The hydraulic models need to be calibrated and verified against a number of suitable past flood events representing both in-bank and out-of-bank events (not less than two of each for each AFA if relevant data is available).

The hydraulic models should be verified to vertical accuracies of 0.2m and 0.4m or less for High Priority Watercourses (HPWs) and Medium Priority Watercourses (MPWs) respectively, subject to the availability of suitable calibration data. This calibration accuracy will be measured based on the RMSE compared to observed levels along HPWs associated with a given AFA, or along a reach of MPW. A degree of flexibility and pragmatism is required with this approach taking account of the reliability of data provided at various locations along a reach. The focus will be on achieving a better calibration against the more reliable data sources, rather than allowing less reliable data points to unreasonably influence the calibration.

In considering the above requirements, the following data must be known in order to give a reliable model calibration:

- **Flow** at the point of interest;
- **Water level** at the point of interest;
- **Channel / hydraulic controls** influencing the water level at the location of interest so that the model is representative of the situation.

Where there is uncertainty in any of these three variables, the accuracy of the calibration is reduced.

3.2 Methodology

3.2.1 General

The dearth of sub-daily rainfall records for the Shannon RBD Study area in particular severely limits the application and accuracy of traditional rainfall-runoff techniques to simulate historical events. The uncertainty arising in the calibration of such models and the subsequent need to adjust the model flood flow predictions, to align with the flood frequencies derived from local flow gauge records, renders rainfall-runoff modelling ineffective. Rainfall-runoff modelling of historical events has therefore been discounted. It is noted that the contract recognises this eventuality and does not require the use of rainfall-runoff modelling for historic events.

Hence a combination of Hydrological Estimation Point calibration and hydraulic calibration is proposed as detailed in the sections below.

3.2.2 Hydrological Estimation Point (HEP) Calibration

Within the broader context of hydraulic model calibration, there is the need consistency and continuity moving downstream through the catchments with regard to flows and flow frequency. This means that, for example, the 2% AEP event at one location as given in the hydraulic model, should be cross-checked against the 2% AEP event derived from the hydrological analysis at the same location, and there should be only a small discrepancy between the estimates. This is explicitly covered in Step 8 below, but is of fundamental importance with regard to the model output – the flood maps themselves.

A sequence of tasks proposed to undertake the HEP calibration is provided below. It is emphasised that this is the proposed approach in the absence of any rainfall-runoff modelling.

1) Undertake gauging station rating reviews to provide increased confidence in high flows gauged at specific gauging stations in the catchment. These gauging station reviews are critical in providing reliable information to be used as pivotal sites for hydrological adjustments to flood estimates at ungauged sites.

2) Rework the annual maxima series of flood flows as required following Step 1 at reviewed gauging stations.

3) Estimate Qmed for key gauging stations (ideally ones that have been subject to a rating review) in or near the model domain from the gauged annual maxima at the site and compare this to the outcome of the FSU regression equation at the gauging station. If no suitable "pivotal" site can be found in or near the model domain, then FSU Guidance on the approach to choosing appropriate pivotal sites based on hydrological similarity (Area, BFI and SAAR) should be followed. Divide the two Qmed estimates at these stations to obtain an adjustment factor ($Qmed_{observed}$/ $Qmed_{synthetic}$)

4) Estimate Qmed at all HEPs using the FSU regression equation and adjust these using the adjustment factor found in Step 3 for the key gauging station in the vicinity of the HEPs. This is done in line with implementation guidance on the FSU with respect to pivotal sites, with the determination of adjustment factors for any model length being guided by the number, quality and similarity of the gauging stations available for selection as pivotal sites.

5) Produce flood frequency estimates at the key gauging stations. This is done by pooling group analysis and single site analysis. The results of these two methods are then compared and a view is taken on the best choice of distribution. Generally the selected distribution will be one of two distributions which come out of the pooling group analysis as the best fits to the pooled data. Pooled analysis is favoured over single site analysis for higher return period (e.g. 100 year) because the single site analysis is not normally based on a sufficiently long record. If the single site analysis is based on sufficiently reliable data (with a relatively long record and a few extreme floods), the pooled distribution which matches closest with the single site growth curve will be favoured as the latter is based on local flood data. The comparison of single site analysis with pooling group analysis allows a check on the validity of the design floods. A combined approach may also be appropriate in some instances, in which a composite growth curve is developed that takes account of both the pooling group and single site growth curves. In the unlikely event that further adjustments to the pooled (or combined) growth factors are deemed appropriate Steps 5 to 7 could be repeated.

6) Estimate hydrograph shape for the watercourse from gauged data or analogue sites.

7) Combine output from Steps 4, 5 and 6 above to estimate design flood hydrographs at each HEP.

8) Run hydraulic models (with appropriate amendments to the models where required) to give consistency of design flows between the hydrological and hydraulic estimates, within a reasonable degree of accuracy.

9) Once calibrated, the timings of the downstream tidal boundary will be adjusted such that the flood peak at the downstream end of the model coincides with the tidal peak, taking account of the Guidance Note on Joint Probability Analysis (GN20).

3.2.3 Hydraulic Model Calibration

As there is insufficient sub-daily raingauge coverage within the Shannon RBD, it will not be possible to reliably calibrate a rainfall-runoff model to supply flood flows to the hydraulic models and run calibration events through the model.

The approach taken will therefore depend on the level of data availability, and its quality. Fundamentally, the critical information required to calibrate a model is:

- **Flow**
- **Level** – this may come from a gauging station record (where available) or a reliable recorded water level at a specific location.
- **Hydraulic controls** – a knowledge of the conditions in the channel at the time / date of the recorded flow and level.

The approach taken for different locations and situations is described below based on four categories.

Category 1 - Gauged locations within AFAs or immediately u/s or d/s of the AFA

Where a flow gauge is located at a suitable location upstream or downstream of an AFA and suitable historic flood data exists, we will select not less than two in-bank events and not less than two out of bank events, obtain the relevant flow hydrographs from the gauging station and apply it to the hydraulic model to allow the gauged reach through (or very close to) the AFA to be calibrated and verified. Intervening ungauged catchments contributing to the watercourse through the AFA will be scaled according to the ratio of the peaks of the gauged calibration event and design event at the gauged location. Clearly, the closer the gauge is to the AFA and the fewer the number of ungauged contributing catchments between the gauge and the AFA, the more successful the calibration is likely to be.

The focus of the calibration must be on locations within the AFAs where there is a reliable estimate of flow, level and hydraulic controls.

- **Flow** – this will come from the gauging station record (using the rating curves as recommended from the rating review or existing rating elsewhere)
- **Level** – this will come from a suitable gauging station record and (where available) a reliable recorded water level at specific locations in the AFA that can be linked to a location on the modelled reach. The water level results from a hydraulic model which uses the direct gauged flow from a given gauging station as input inflow, should not in

turn be directly calibrated against gauged water levels from that gauging station as this would constitute circular calibration.

- **Hydraulic controls** – these will be as constructed in the model to represent conditions in the channel as at present (based on the channel survey). Where specific, reliable information is available with regard to issues such as blocked culverts, blockage at bridges, and changes to hydraulic controls between the event date and conditions now, this will be taken into account. However, it is noted that the availability of such information is likely to be extremely limited.

Where reaches that are suitable for calibration are tidally influenced, and suitable historic tidal hydrographs exist, we will apply these to the models as part of the calibration process. However, this introduces another level of uncertainty to the calibration.

It should also be noted that the accuracy of the information relating to these three factors can be influenced by the size of the river (and its responsiveness) at the gauging station.

Category 2 - Gauged locations significantly outside of the AFA i.e. on MPWs

Where suitable historic flood flow and level data exists on MPWs, i.e. at a gauging station, we will follow the same method outlined for the AFAs (Category 1). The primary difference between the level of information available on these reaches is that there is unlikely to be any reliable information on flood history in the vicinity, or reliable observed levels away from the gauge location.

As for gauged locations within the AFAs, where reaches that are suitable for calibration are tidally influenced, and suitable historic tidal hydrographs exist, we will apply these to the models as part of the calibration process. As noted above, this introduces another level of uncertainty to the calibration.

Category 3 - Ungauged locations within an AFA

Where the gauge is too far removed from an AFA to enable reliable calibration, or in the case of tidally affected reaches where the tidal hydrograph data is unsuitable, we will compare anecdotal and historical flood information (if suitably reliable information is available) to the flood outlines derived from the design events. This can serve as a reality check and help determine whether the frequency of flooding experienced in the past is replicated by the model. It is emphasised that the calibration at these locations is reliant on the same three factors identified for gauged locations, namely: (1) flow, (2) water level, and (3) knowledge of the channel conditions that led to the particular water level at the point of interest. Typically, reliable information of this nature is rare, and by definition, flow is not measured at these locations so at best it can only ever be a "best estimate".

It should also be noted that calibration based on observed flood frequency is highly variable and can only ever be treated as indicative. For example, if there is a reliable flood history over 50 years, and there have been 7 reliably recorded flood events at a specific location e.g. a level on a wall of a house, it is **likely** that the threshold event for flooding at that location is in the range 20% to 10% AEP event (5 year to 10 year return period). It is statistically very unlikely that Qmed would flood the property, and equally, it is very unlikely that the threshold event would be as high as the 5% AEP event (20 year return period). Linking this to the flood mapping, it would be anticipated that the Qmed flood outline would not show the property as being flooded and that the 5% AEP event outline would show it as flooded. Both the 20% and 10% AEP could, not unreasonably, potentially show the property as either flooded or not flooded. Hence this high level assessment does not constitute a calibration –

it is merely a high level indicator of what may be considered reasonable. An alternative example would be a location with a long known history with very few flood events recorded. These can be even more difficult to assign threshold events for flooding, giving a greater range of what might be considered reasonable in terms of the flood outline that shows a location to be flooded.

Category 4 - Ungauged locations outside of the AFA i.e. on MPWs

The approach here is similar in principle to the ungauged locations within an AFA. However, there is likely to be even less usable information on known levels in known events, and hence use of the term "calibration" in these areas would generally be misleading. Consideration of the question "is it believable?" is most appropriate as a reality check (see Section 3.2.5).

Summary of Approaches Considered

The above sections outline what can be considered for each type of location. This is summarised in terms of the focus for hydraulic model calibration in Table 1, and the approach likely to be adopted for different situations.

With regard to data gathering for use within the model calibration exercise, the focus is to draw on data included within www.floodmaps.ie where this provides sufficient information, supplemented with additional data provided by Local Authorities where details are known. To facilitate the data collection and provide an indication of when flooding may have occurred, the dates of the AMAX data for specific gauges have been used as a guide to possible (or likely) high flows within particular AFAs. Clearly, this depends on the size of the catchment and proximity to the AFA and it is quite possible that the dates of the highest ranked AMAX events at nearby gauges do not correspond to flood events. However, it can provide a useful pointer for the Local Authorities as to when there may have been flood events, particularly when coupled with data included from events recorded in the floodmaps.ie database.

Technical Note

1		2	3	4	5	6	7	8
Location description		**Likely accuracy of Flow estimate**	**Likely accuracy of Gauged Level estimate**	**Known hydraulic conditions (1)**	**Supplement-ary known, useful flood levels(2)**	**Reliable flood history (levels, locations, dates) (3)**	**Indicative calibration score (sum of columns 2-6)**	**Calibration comment**
Category 1	Large gauged river within an AFA (HPW)	3	3	2 - 3	2	2	12 - 13	Calibrate main channel to large events on the river. E.g Croom using Station 24001 (Maigue @ Croom)
	Small gauged river within an AFA (HPW)	2	3	2	1	1	9	Calibrate main channel to large events on the river. E.g Dromcolliher using Station 24015 (Ahavarragh @ Dromcolliher). Take note of uncertainties due to channel blockages etc.
Category 3	Large ungauged river within an AFA (HPW)	1 - 2	0	2	2	2	7 - 8	Calibrate main channel to best estimate of flow with known level in AFA (if available). If no dates / levels, then modelled outline to reflect "reasonable" historic flood frequency (if available). Otherwise not calibrated – use reasonable hydraulic parameters.
	Small ungauged river within an AFA (HPW)	0 - 1	0	1 - 2	1	1	3 - 5	Modelled outline to reflect "reasonable" historic flood frequency (if available). Otherwise not calibrated – use reasonable hydraulic parameters
Category 2	Gauged MPW	3	3	2 - 3	0	0	8 – 9	Calibrate main channel to large events on the river – this will have been done for the gauging station review (for those stations included for review).
Category 4	Ungauged MPW	0 - 2	0	0 - 2	0	0	0 - 4	Reach uncalibrated – use reasonable hydraulic parameters. Reliant on better calibration at u/s and d/s AFAs, and other gauged MPW reaches.

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely. Total score in column 7 provides an overall indicative guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

Notes:

(1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.

(2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.

(3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2).

3.2.4 Tidal Inundation Model Calibration

In the event that a suitable tidal hydrograph for a past flood event (and associated details of the resultant flood consequences) exists, we would carry out at least 4 event runs to calibrate and verify the model. However, we would note that to date, we have not found sufficient information relating to a tidal inundation event that could be used as a true calibration event, although sources such as ICPSS or Proudman Oceanographic Laboratory may yield some data.

Where a suitable tidal hydrograph does not exist – which we consider will be the norm for the tidal inundation modelling - we will compare any suitable flood data with the design flood outlines, in a similar way to the fluvial model calibration methodology, outlined in Section 3.2.3 for Categories 3 and 4 – i.e. in an ungauged location. This will serve as a reality check and help determine whether the frequency of flooding experienced in the past is replicated by the model.

It should be noted that all tidal inundation model calibration requires the following fundamental information:

- Tidal hydrograph – as the driving force leading to the tidal inundation
- Water levels – peak flood level recorded on the tidal flood plain
- Tidal flood plain conditions – the ground profile in the model must replicate the situation for the time / date when the tidal inundation occurred.

Given these requirements we anticipate that (as for Category 4 in the fluvial model calibration) the availability of usable information is likely to be very limited and hence the term "calibration" in these areas would generally be misleading. Consideration of the question "is it believable?" is therefore likely to be the level of detail for the calibration, as a reality check against known tidal flooding.

The accuracy of the tidal flooding inundation is likely to be best at locations where the threshold event for inundation is low e.g. events up to around the 20% AEP event tide level, assuming this relatively frequent level of flooding is observed.

3.2.5 Reality Checking of Mapping as and Aid to Calibration

We note that within the Stage I Tender Documents Sections 7.2.2 and 7.3.2 state:

'The calibration and verification of the models shall make use of the best available data including, but not limited to, hydrometric data, photographs, videos, press articles and anecdotal information provided by local authority staff and other Stakeholders.'

Our approach outlined above will do this. However, we do anticipate based on the lack of calibration data available to date through many AFAs, along MPW reaches, and in tidal locations, that a reality check on the flood mapping could add value to the process prior to the formal public consultation on the draft flood mapping. Those with the best local knowledge within the Local Authorities and OPW Regional Staff could be engaged in the process. Typical questions to address will include:

- Are there areas that you (LA and OPW) know flood (i.e. have flooded once or more in the past), which are not shown by the design event extents?
- Are there areas shown as flooded, that you believe are highly unlikely to ever flood? If so, why do you believe they are highly unlikely to ever flood?
- Is there evidence of the range of design event flood profile levels having been met or exceeded? If so, how often?

This type of local review providing a reality check on the mapping could be usefully facilitated through a flood-mapping workshop (or series of workshops) focused on different groupings of AFAs. For example, there could be a mapping workshop for each Local Authority or each UoM. Although these Local Authority / Regional OPW flood mapping workshops are not identified as an activity within the Stage I or Stage II tender documents, the Progress and Steering / Advisory Group meetings may be suitable fora for such workshops, noting that additional workshops with individual Local Authorities, OPW Regional Staff and/or other Stakeholders may need to be considered as well. These meetings / workshops within the context of the Progress and Steering / Advisory Group meetings do not replace the formal requirement for stakeholder workshops for flood mapping.

Appendix F National Technical Co-ordination Group (NTCG) Guidance Note no. 22 (GN22)

GUIDANCE NOTE 22 V5.0

JBA Project Code	2011s5232
Contract	Western CFRAM
Client	OPW
Day, Date and Time	17 February 2014
Author	Sam Willis
Subject	Guidance Note 22 – Sensitivity Analysis and Uncertainty Mapping Guidance Note

1 Overview

This note updates Guidance Note 22 on Sensitivity Analysis and Uncertainty and supersedes all previous guidance notes issued on these topics. The revised Guidance Note 22 now includes alternative recommendations for the representation of uncertainty in the flood maps.

The objective of the proposed approach to representing uncertainty is to incorporate the best available knowledge of the modelling limitations into the analysis without requiring significant additional input from the CFRAM consultants. To do this the approach will use the understanding provided by the sensitivity analyses to determine the level of uncertainty. The proposed approach is an alternative option only and consultants are free to continue to use the approach outlined in the project brief if preferred.

The proposed representation of uncertainty will be through a second flood extent developed for the 10%, and 1% flood extents only. These extents will not be presented on the standard flood maps but will only be provided online as separate uncertainty maps with the relevant best estimate flood extent. There would therefore be no requirements to include the alternative line-type around the design extents as currently outlined in the project brief. This should simplify the presentation of the flood maps whilst allowing uncertainty maps to be made available as required.

The development of the uncertainty bounds will utilise only the results from those sensitivity tests that are found to produce the largest increase in the predicted flood extent. Where two sensitivity tests are producing a comparable increase in the predicted flood extent in an area of interest then further consideration of the appropriate uncertainty bound as described below in Section 3 is required.

The key steps are as follows:

1. Prepare screening assessment from knowledge of model build and its calibration
2. Undertake sensitivity tests on hydrological parameters
3. Undertake sensitivity tests on core hydraulic parameters
4. Undertake additional hydraulic testing where it is scoped in
5. Assess which test or combination is to be displayed on the maps

To minimise the work load associated with the alternative approach it has been agreed to represent uncertainty on the medium priority flood extents using the alternative line-type approach and classify the full medium priority reach as highly uncertain. Similarly it has been agreed that uncertainty mapping will not be required for the Flood Zone maps as there is no guarantee that this information would be utilised if made available.

This note first discusses the required approach to completing the sensitivity analysis before highlighting how the results from this analysis can be incorporated into the uncertainty mapping.

2 Sensitivity Analysis

Section 7.4 of the project brief states that:

The Consultant shall undertake sensitivity tests for each and all forms of modelling as described above as appropriate to determine the robustness and sensitivity of the models and the design flood levels, extents, etc. estimated using the models. Such tests should include, but not necessarily be limited to, variations in roughness parameters, flow values, boundary conditions and (within APSRs) afflux parameters at hydraulically-significant structures.

The nature of the sensitivity analysis and the model parameters assessed means that any analysis will be based on engineering judgement only, however by maximising the hydraulic modellers knowledge of the site, sensitivity assessments can be representative of the limitations of the data availability for the site.

It is not appropriate to adopt a generic approach to the sensitivity analysis, rather a screening judgement should be made as to those tests that are applicable and required for a given AFA. Once decided, analyses should be AFA specific and utilise knowledge of the site. Decisions and justification will need to

be recorded as part of the hydraulics reporting.

Typically, sensitivity analyses will be run for the 1% AEP event, however to support the development of uncertainty bounds described in Section 3 it will also be necessary to run the 10% AEP event. In some instances this will require a variation to the sensitivity tests applied for the 1% AEP event.

The following sections discuss the range of the sensitivity tests required and provide examples of how parameters should be adjusted to reflect known uncertainties. In all cases it is important to consider the sensitivity tests as a sensible shift within the bounds of reasonableness. Therefore, if through the calibration/validation process, parameters have been increased towards the upper limits of reasonableness for a given parameter then the additional shift for a review of sensitivity will be less than if no calibration/validation process has been carried out and default parameters have been applied. Increased confidence in model results will be directly linked to the calibration classifications discussed in Guidance Note 23 and reference to these classifications will support and guide the level of sensitivity tests required.

The following sensitivity tests are outlined for consideration:

Table 2-1: Sensitivity tests for consideration

Mandatory	**Optional tests following Screening Assessment**
Flow (1% AEP Event)	Building representation (1% and 10% AEP Event)
Roughness (1% AEP Event)	Flow volume (1% and 10% AEP Event)
Water level boundaries (1% AEP Event)	Afflux/head loss at key structures (1% and 10% AEP Event)
	Timing of tributaries (1% and 10% AEP Event)
	Flow, roughness and water level boundaries (10% AEP Event)

This list is not exhaustive and where predicted flood risk is dependent on additional parameters or modelling assumptions, these should be highlighted in the model report and investigated through further sensitivity tests.

Sensitivity tests to flow, roughness and water level boundaries should be carried out on all models for the 1% AEP event. Sensitivity tests to building representation, flow volume, afflux at key structures and timing of tributaries for the 1% AEP event and for all tests listed in Table 2-1 for the 10% AEP event should be carried out where a screening exercise has identified that there remains significant uncertainty and models may be underestimating flood risk.

2.1 Flow

As flow is probably the most critical of all the sensitivity tests it will be important to consider the quality of data available in the derivation of the design flows.

Table 2-2 provides a scoring mechanism through which each watercourse is attributed a score from each row of the table reflecting the level of confidence in the hydrology. The resulting scores are summed to provide an overall indication of uncertainty and used to look up in Table 2-3 the uncertainty weighting to apply.

The uncertainty in QMED can be assessed using the equations for SE and FSE provided in the FSU WP2.2 report. These are provided for estimates derived from catchment descriptors, which will give a scaling factor of 1.37, and can be calculated at gauge sites which have been typically found to be around 1.06. Site with donor adjustments will be in between these values and it is recommended an adjustment factor of 1.2 is applied.

This QMED adjustment factor reflects the uncertainty in the index flood but does not reflect the uncertainty in the growth curve, for this reason an additional adjustment factor is included for the 1% AEP

event. A review of single site analyses with greater than 40 years of data produced an uncertainty adjustment factor for the growth curve of approximately 1.2. Use of pooling groups would reduce this uncertainty suggesting an adjustment factor of 1.1 is appropriate. Uncertainty at the upper end is harder to quantify and consultants should review the adjustment factors produced using this scoring system to confirm they are appropriate.

Table 2-2: Flow sensitivity scoring system

Scoring Parameter	Score of 1	Score of 3	Score of 5	Score of 7
Is there a local recording gauge/s that have been used as a donor for the hydrology or to provide confidence in the hydrology by other means?	Within 5km of the AFA and on the same watercourse with no significant other inflows between the gauge and the AFA OR Upstream and downstream of the AFA with no significant other inflows between and routing of flows supports the hydrology	Within 5km of the AFA but not on the same watercourse or with significant other inflows between the gauge and the AFA	Beyond 5km or with significant other inflows between the gauge and the AFA	No useable gauge
What is the length of record of the local gauge?	Greater than 40 years	Between 20 and 40 years	Between 2 and 20 years.	No useable gauge
What quality is the record from the gauge?	Rating review carried out, high confidence	Rating review carried out, moderate confidence or no rating review carried out but gauge is FSU class A	All other sites.	N/A.
What unusual features are there in the catchment hydrology?	None – a rural catchment typical of many in the gauged datasets	Some lakes (0.99>FARL>0.9) or urbanisation (0.05<URBEXT< 0.15)	Some karst or extensive lakes (FARL<0.9) or urbanisation (URBEXT>0.15) or arterial drainage	N/A
What is the size of the catchment	N/A	N/A	<25km	N/A

Table 2-3: Flow sensitivity adjustment factors

	Summed Scores			
Return Period of Event	**Score up to 6**	**Score of between 7 and 14**	**Score of between 15 and 22**	**Score above 23**
10%	No sensitivity test required.	Use QMED uncertainty	Use QMED uncertainty	Use QMED uncertainty
1%*	Use QMED uncertainty then apply adjustment factor of 1.1	Use QMED uncertainty then apply adjustment factor of 1.2	Use QMED uncertainty then apply adjustment factor of 1.3	Use QMED uncertainty then apply adjustment factor of 1.5.
***** Where extensive areas of karst with connections to the surface water system is present then use QMED uncertainty then multiply flows by 2.0 to reflect the uncertainty in the 1% event flow.				

2.2 Roughness

As part of the hydraulic modelling work completed it is expected that channels will have been assessed for typical vegetation cover. Using these descriptions and an understanding of the maintenance regime carried out by the local authorities and OPW it should be possible to determine high and low end roughness values for each channel. The hydraulic modeller should justify the variations to this parameter based on the known conditions on site.

If one or more large events have been observed and sufficient data is available with which to calibrate the roughness within the channel then it will not be necessary to vary Manning's n to the full extent suggested in the tables below. It is also noted that in large events with greater depths the influence of channel roughness will often reduce. Again in these instances a variation to the maximum upper bound may not be applicable.

The following tables provide typical roughness values and upper and lower bounds for various surfaces. These can be used as a guide or, if preferred, alternative data sources can be referenced and applied when determining appropriate sensitivity tests. It is not proposed that upper values are applied with no consideration of local factors as discussed above.

Table 2-4: Typical roughness bounds for river channels

Channel Substrate	**Roughness Values (Manning's n)**		
	Typical Value	**Lower Bound Value**	**Upper Bound Value**
Bedrock	0.025	0.023	0.028
Cobbles (64-256mm)	0.055	0.04	0.07
Coarse Gravel	0.035	0.022	0.04
Gravel (2-64mm)	0.03	0.028	0.035
Sands	0.025	0.023	0.032
Silt	0.022	0.02	0.025
Clay	0.02	0.018	0.023
Concrete	0.02	0.018	0.022

Simplified version of Table 10 from Reducing Uncertainty in River Flood Conveyance. Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA / Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057. July 2003.

Table 2-5: Typical roughness bounds for river banks

Bank Material	Roughness Values (Manning's n)		
	Typical Value	**Lower Bound Value**	**Upper Bound Value**
Scrub/Long Grass	0.04		
Bushes	0.06		
Trees – flood level not reaching branches	0.07	0.05	0.13
Trees – flood level reaching branches	0.15	0.1	0.2

Simplified version of Table 16 and 23 from Reducing Uncertainty in River Flood Conveyance. Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA / Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057. July 2003.

Table 2-6: Typical roughness bounds for rivers to flood stage

General Channel	Roughness Values (Manning's n)		
	Typical Value	**Lower Bound Value**	**Upper Bound Value**
Clean, straight, full stage, no rifts or deep pools	0.030	0.025	0.033
As above but more stones and weeds	0.035	0.030	0.040
Clean, winding, some pools and riffles	0.040	0.033	0.045
As above but some weeds and stones	0.045	0.035	0.050
As above but lower stages, more ineffective slopes and sections	0.048	0.040	0.055
As above but more stones	0.050	0.045	0.060
Sluggish reaches. Weedy deep pools	0.070	0.050	0.080
Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.100	0.075	0.150
Mountainous streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high water levels. Bed: gravels, cobbles and a few boulders.	0.040	0.030	0.050
Mountainous streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high water levels. Bed: cobbles and with large boulders.	0.050	0.040	0.070

Simplified version of Table A1.1 from Culvert design and operation guide, CIRIA C689, 2010.

Floodplain Manning's n values should be adjusted in the same roughness sensitivity test. Digital data on floodplain surface types is generally limited however a suggested range of typical floodplain roughness values are provided below.

Table 2-7: Typical Roughness Values in the Floodplain

Floodplain Material	Roughness Values (Manning's n)		
	Typical Value	**Lower Bound Value**	**Upper Bound Value**
General Natural Surfaces	0.040	0.030	0.050
Buildings	0.300	0.100	1.000
Inland Water	0.035	0.025	0.045
Roads, Tracks and Paths	0.015	0.013	0.017
Non-coniferous Woodland	0.070	0.060	0.100
Coniferous Trees	0.100	0.080	0.120
General Manmade Surfaces	0.017	0.015	0.020
Glasshouses	0.200	0.100	0.300
Rock	0.050	0.040	0.070
Mixed Vegetation	0.080	0.060	0.110

2.3 Building Representation

Buildings in the floodplain can dictate flow paths and some consideration of how the preferred representation of buildings influences the flood extent is required.

The preferred methods for floodplain and building representation appear to be AFA specific. For example, a major conurbation could utilise a generic roughness approach whereas a small AFA outline could be heavily influenced by an individual riverside or floodplain building and hence a bespoke method may be appropriate.

The key aim of the sensitivity tests is to ascertain whether the selected approach is appropriate and whether by changing the level to which buildings dictate flow routes, alternative routes are identified. For example if a generic roughness approach is used full storage within buildings is available from ground level, raising thresholds in the sensitivity would divert low flows around buildings and reduce the storage available in the floodplain and potentially cause flooding elsewhere; modelling buildings as voids would be an extreme example of this where there is no floodplain storage within buildings.

Building representation will be different for different CFRAMs and different AFAs within each CFRAM but the essential approach to this sensitivity should be to;

- increase the influence of buildings where they have a low influence, (i.e. have been modelled as reduced hydraulic conveyance only with full floodplain storage allowed), either by increasing thresholds or modelling buildings as voids in the active floodplain,
- or reduce the influence where they have a high influence (i.e. have been modelled with raised thresholds or as voids) by modelling a bare earth scenario where the influence of buildings is represented by reduced hydraulic conveyance only.

The results of the sensitivity test will determine if the alternate approach needs to be adopted for all model runs for the AFA or if it can remain as a demonstration of sensitivity only.

2.4 Water Level Boundaries

The effect of rising sea levels is being investigated through the climate change scenarios and it is recommended that the change quoted for the MRFS is used to test sensitivity to sea levels.

Requiring further consideration may be the initial conditions in lakes within hydraulic models. Where long term level data from gauges on the lake, or historic data is available, this should be reviewed to determine

levels in a typical year and in an extreme year during winter months. Where no long term or historic data is available an estimate of appropriate changes in water levels is required; an increase in lake levels of 1m is proposed.

Where the water level boundary is situated on a river, the potential implications associated with changes to this boundary should be considered given Section 1.2.2.4 of the project brief requires HPWs to extend a sufficient distance downstream of an AFA to minimise the risk of any downstream boundary uncertainty. For this reason sensitivity tests for downstream boundaries on watercourses will not generally be required. Where there is potential for downstream water levels to impact sites within an AFA (typically on large flat watercourses), then MPW models should be used in conjunction with the flow sensitivity test to determine potential increases in water levels. Where tributaries join larger watercourses, increases in levels can be extracted from these models however care should be taken not to apply unrealistic joint probability events, i.e. coinciding a 1% AEP peak flow on a small tributary with the same event on a larger watercourse.

2.5 Flow Volume

Hydrograph durations will have in some cases been developed from observed data. Where this data consists of multiple hydrographs in excess of the 10% AEP event it is considered a reasonable approximation of the flood duration has been made and a significant increase in flow volume will not be required.

In other cases flood durations may have been developed from single events or from catchment descriptors only, in these cases there will be much more uncertainty in the flood duration applied. Because of the different approaches being used to develop hydrographs across the CFRAM it is not possible to be prescriptive for this sensitivity test. Instead it is assumed that some analysis will have been done comparing hydrographs generated from catchment descriptors at gauge sites and indicative scaling factors can be extracted from this analysis

Table 2-8: Adjustment Factors for Flood Duration

Description of Site	Sensitivity Adjustment Factor applied to Flood Duration
Flood duration has been developed from a single observed event data or multiple events below the 10% AEP.	1.2
Flood duration has been developed from catchment descriptors and there are few or no lakes in the upstream catchment (FARL>0.9)	Adjustment factors to be developed by CFRAM consultants reflecting preferred approach for hydrograph generation.
Flood duration has been developed from catchment descriptors and there are extensive lakes in the upstream catchment (FARL<0.9)	

2.6 Afflux/Head loss at Key Structures

General modelling units and parameters can often not fully represent the head loss that can occur at atypical or complex structures. Whilst it is not realistic to model these structures exactly as observed on site it is feasible to investigate if additional flooding could result from variability in head loss away from the standard representation included in the modelling software. This sensitivity test will review the potential implications of additional head losses at a structure above those predicted through normal modelling methods.

It is recommended that this analysis is completed for those structures that are likely to have an impact on either the scale of flood risk or future flood risk management measures only.

Head losses at a given structure are related to the velocity head and as a preliminary screening

assessment, local flow velocities can be reviewed to determine if the head losses required to cause additional flooding can be realistically achieved.

Where additional flooding appears to be a risk, a review of the maximum potential head loss at peak velocity needs to be completed. Published head loss coefficients describe losses associated with the expansion and contraction of flows at structures. It is therefore proposed that the structure be remodelled using a conservative estimate of head loss based on published values, either as a series of loss units or by adjusting calibration coefficients in the model to reflect the expected head loss calculated using this method.

For example losses across a bridge could be calculated using the typical bridge expansion and contraction coefficients detailed below and then, if these are greater than currently predicted, should be re- modelled by adjusting calibration parameters to deliver this loss at peak velocity. Alternatively losses at an inlet controlled culvert could be calculated using the culvert contraction loss and compared to the modelled representation of the culvert inlet.

Where there are additional complexities within the structure additional losses associated with further contractions and expansions of flows would need to be incorporated.

Table 2-9: Typical Head Loss Coefficents

	K Value
Calculated expansion loss	$K = (1 - \frac{W1}{W2})$ where W1 and W1 are the upstream and downstream widths
Typical bridge expansion	K = 0.5
Culvert contraction	K = 0.44
Abrupt expansion	K = 0.8
Square edged contraction	K = 0.3 (lower bound 0.23, upper bound 0.35)
Round edged contraction	K = 0.15 (lower bound 0.1, upper bound 0.2)
Typical bridge contraction	K = 0.3
Abrupt contraction	K = 0.6

Based on Table 5-2 in the HEC-RAS manual

Note: expansion losses are applied to upstream velocities and contraction losses are applied to downstream velocities.

2.7 Timing of Tributaries

Design events assume a consistent storm falls across a river basin and allow the response and size of each catchment to determine the occurrence of peak flows in the watercourse. Understanding this response is particularly important at the confluence of tributaries where downstream flows are the product of the combined response of two upstream catchments. This sensitivity test aims to understand the potential implications of a different catchment response resulting in higher peak flows downstream of a confluence, i.e. the peak flows on two contributing watercourses occur closer together.

It is not considered realistic to simply adjust inflow hydrographs from separate watercourses so that peak flows coincide, effectively making downstream flows the sum of the maximum flow on each tributary. Instead the timing of the inflow hydrograph peak of the smaller watercourse will be moved closer to peak of the larger watercourse by up to 10% of the overall duration of the smaller watercourse hydrograph. This will prevent moving smaller tributary inflows to 'sit' on the peak of a larger watercourse.

Flows at all confluences should be screened however it will not be necessary to complete this sensitivity test if the increase in flows resulting from the adjusting the timing of tributaries is less than the increase in flows being assessed in the flow sensitivity test.

3 Presentation of uncertainty

3.1 Scope

The objective of any alternative methodology is to deliver more representative uncertainty bounds than are currently produced using the RPS/Halcrow methodology whilst not increasing the work load required to produce these bounds.

This approach is applicable for the representation of uncertainty on flood maps. In determining uncertainty and freeboard in scheme investigations a more detailed site specific analysis will be required.

3.2 Data

The proposed approach will utilise readily available information developed as part of the sensitivity analyses discussed above, thereby limiting the additional work to be completed. Confidence in how these sensitivity assessments are undertaken is therefore an important consideration in the expected accuracy of the confidence bounds. The process requires thought and justification on the part of the hydraulic modeller for the variation in modelling parameters but the reporting of this should provide an auditable trail for the basis of the resulting flood maps.

It is noted that a similar justification would be required for the development of the data quality/confidence parameters that are fed into the RPS/Halcrow tool without the benefit of visualising the implications of any decisions.

3.3 Methodology

In developing an uncertainty bound from the sensitivity tests it is proposed that the sensitivity test resulting in the greatest flood extent for a given location be used as the uncertainty bound in all cases. The final uncertainty bound will therefore be the result of all sensitivity tests overlain using a GIS package to produce a final merged uncertainty bound. This suits the 2d modelling packages being used on the CFRAMs, and avoids extending a random ΔH across cross sections to form an outer outline.

This approach, which applies the single most sensitive parameter adjustment in all locations, is different from a typical sum of squares approach which applies a proportional allowance for each source of uncertainty.

It is noted that in the majority of cases the hydrology sensitivity test will produce the greatest uncertainty extents, reflecting the fact that hydrology is usually the greatest source of uncertainty in modelling. However, in the particular locations where multiple uncertainties are present to equivalent extents, a review should be undertaken, and if necessary an additional model run completed to incorporate a greater worst case scenario by modelling a combination of uncertainties for that specific location.

The approach for combining uncertainties has been developed in response to the unlikely eventuality that multiple sensitivity tests are producing similarly large increases in flood extents. Combinations will not be required where sensitivity test extents are close to the baseline. Only those combinations the consultant considers appropriate will need to be assessed and these can all be included in a single model run if desired. Therefore whilst there are a large number of possible combinations the consultant should attempt to minimise additional runs where possible.

The following points highlight examples where it may be possible to scope out combinations of uncertainties:

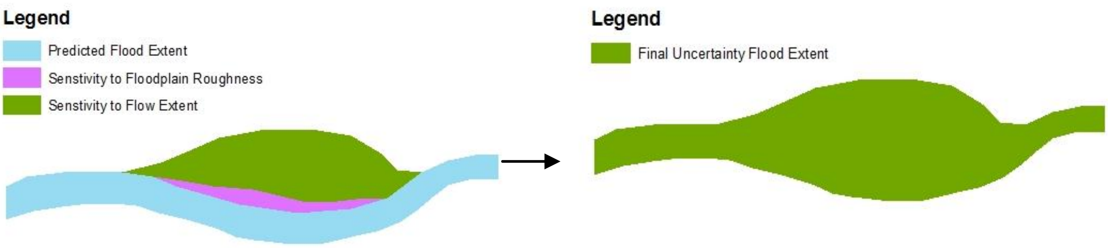
- The sensitivity tests for flow, water level boundary within lakes and timing of tributaries will all have the effect of increasing downstream flows. As such it is likely only the worst of these will be required in any combination event unless the sensitivity tests demonstrate that increases in downstream flows from these are of equivalent magnitude, in which case some combination event will need to be considered.
- Where the combination of flow and tidal boundaries is reviewed in depth in the joint probability analysis this test will not be required.
- Building representation is reviewed to determine the most appropriate method for representing buildings in a given AFA, however if significant variation is apparent between methods and there is cause to justify either approach then a combination of the alternative method with the most significant sensitivity test will likely be required. In this example the uncertainty bound could vary significantly from the best estimate of the extent.

The critical joint sensitivity tests will therefore likely be an increase in flow of one form or another in conjunction with an increase in flow volume and additional losses at structures. If each of these are found to produce similarly large extents in one location it is recommended a worst case combination event is run to provide a conservative uncertainty bound.

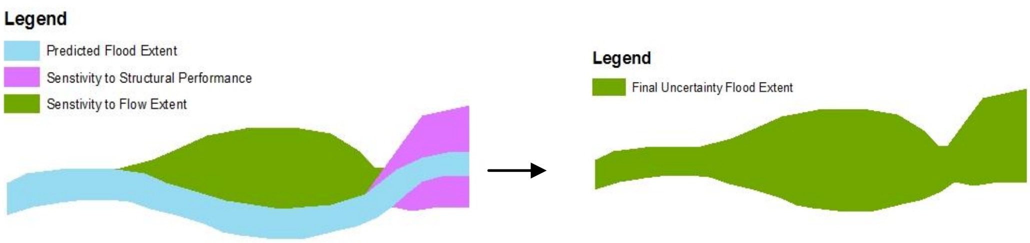
In summary the approach is as follows:

1. Complete hydraulic modeller led sensitivity assessments and document findings
2. Map 2D model results and review extents to identify where multiple sensitivity tests produce similarly extreme outlines.
3. Run extreme sensitivity model run if required.
4. Overlay and merge in GIS to develop a final uncertainty bound.

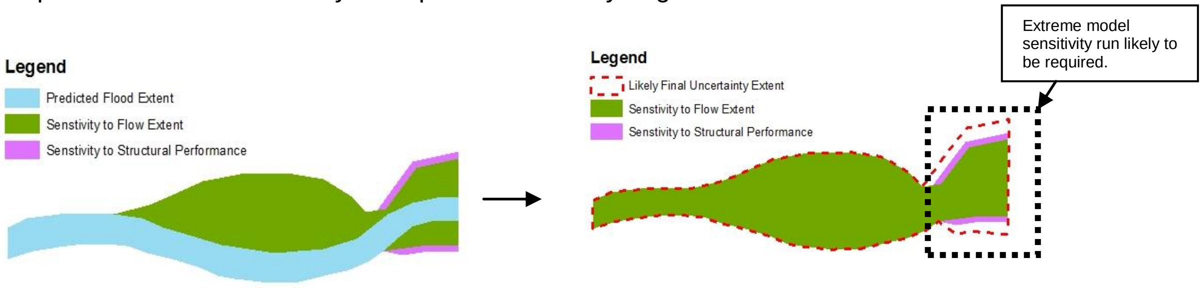
Example 1 – A single sensitivity test produces the greatest bound



Example 2 – Different locations are sensitive to different sensitivity tests



Example 3 – Different sensitivity tests produce similarly large extents in critical areas



3.4 Discussion

The benefits of this approach are as follows:

- The use of the hydraulic modelling outputs effectively allows uncertainty to be assessed in detail at all locations rather than on a reach scale. This is the benefit of the application of 2D modelling in HPW reaches.
- The production of the uncertainty map by building on the sensitivity tests allows modellers/reviewers to see 'behind' the uncertainty bounds in the final map to understand where there are large changes in the extent and why. This compares to the original approach as indicated in the CFRAM Generic Specification that develops an increase in water levels based on an empirical formula derived from a limited number of watercourses.
- Hydraulic modeller input into the sensitivity analysis and the process of the sensitivity testing allows the implications of changes to model assumptions to be better understood and reduces the risk of unwanted outcomes from the current approach, for example a large uncertainty bound where hydraulic modellers feel there is good certainty in the output.
- Less work associated with splitting the watercourse into uncertainty reaches.

The disadvantages of this approach are as follows:

- Potential for inconsistent application between CFRAMS as it relies on professional judgement for suitable parameter shifts. This guidance note attempts to mitigate this risk but it remains a reasonable caveat that different watercourses will be sensitive to different assumptions. This will always be a challenge.
- More work associated with model runs for the Q10 design event where the need for these sensitivity tests have been identified as required as part of the screening assessment.