# Lower Shannon Sediment Transport Modelling Note

## Final Report

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## Contract

This report describes work commissioned by the OPW, by a letter dated 21/04/2022. The OPW's representative for the contract was Fiona Smith of the OPW. Orla Hannon and Emily Rick of JBA Consulting carried out this work.

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## Abbreviations

| | |
|---|---|
| 1D | One Dimensional (modelling) |
| 2D | Two Dimensional (modelling) |
| AEP | Annual Exceedance Probability. The probability, typically expressed as a percentage, of a flood event of a given magnitude being equalled or exceeded in any given year. For example, a 1% AEP flood event has a 1%, or 1 in a 100 year, chance of occurring or being exceeded in any given year. |
| AquaUoS Study | Lower Shannon Hydro-Geomorphology Study completed by AquaUoS University of Salford |
| CFRAM | Catchment Flood Risk Assessment and Management |
| CWTP | Clareville Water Treatment Plant |
| DDF | Depth Duration Frequency. DDF Model using by Met Eireann to estimate return period rainfall depths. |
| DoEHLG | Department of the Environment, Heritage and Local Government |
| FARL | FEH index of flood attenuation due to reservoirs and lakes |
| FRS | Flood Relief Scheme |
| GSI | Geological Survey of Ireland |
| HEFS | High-End Future Scenario |
| HYMO | Hydromorphology Report |
| IFSAR | Interferometric Synthetic Aperture Radar |
| LiDAR | Light Detection and Ranging |
| mOD | Meters above Ordnance Datum |
| MRFS | Mid-Range Future Scenario |
| OPW | Office of Public Works |
| RMSE | Root Mean Square Error |
| RR | Rainfall-Runoff |
| SAAR | Standard Average Annual Rainfall (mm) |
| SBP | Sub bottom profiling |

## Definitions

| | |
|---|---|
| Normal Flow | Relates to lower flows expressed as daily exceedance probability, such as the $Q_{10}$, which is equalled or exceeded for 10% of the year. |
| Reach | Section of the Old Shannon River for which this study is the focus. Extends from the Shannon Rowing Club Annacotty (upstream of the confluence with the Mulkear) to downstream of the UL rowing club |
| $Q_x$ | Normal flow event, i.e. $Q_{10}$ (which is the flow which is equalled or exceeded for 10% of the year) |
| QX | Flood flow events, i.e., Q10 (which is the 10% AEP flood event with a 1 in 10year chance of the event occurring or being exceeded) |

# 1 Introduction

## 1.1 Terms of Reference and Scope

The OPW, on behalf of the Shannon Flood Risk State Agency Co-ordination Working Group commissioned a Project in the lower River Shannon and Mulkear catchment in Q1 2022. The purpose of this project is to identify feasible options for the management of sediment and vegetation to prevent further reduction in, and if possible, increase, conveyance and/or channel capacity of the Old Shannon between Clareville Water Treatment Plant and St Thomas Island.

## 1.2 Background

As part of the National CFRAM Programme, major excavation to remove sediment and re-widen the river channel along the full length of the River Shannon was examined and was found not to be economically or environmentally sustainable. Therefore, the OPW, on behalf of the Shannon Flood Risk State Agency Co-ordination Working Group, are pursuing a more targeted approach to fully explore the feasibility of preventing further reduction in, and if possible increasing, channel conveyance/capacity along the Shannon. This commission looks specifically at the sediment accumulation and deposition in the Lower Shannon and the Mulkear downstream of Annacotty Weir. It also looks at sediment yields in the Mulkear catchment.

## 1.3 About this report

This document details the method and findings from the sedimentation modelling study, including the hydrology, hydrodynamic modelling and the scenarios tested. This report will form the baseline for the subsequent testing of measures to manage sediment within the Mulkear catchment and the Old River Shannon..

This document is one of a suite of reports in the Lower Shannon modelling study. Chapter 2 describes the study objectives. Chapter 3 details the available information for this study, including previous assessments and new survey information. Chapter 4 discusses the River Shannon hydrodynamic model while Chapter 5 outlines the hydrology for the River Shannon model. The sensitivity tests on the River Shannon model are provided in Chapter 6 and the Sediment Modelling Scenarios are presented and discussed in Chapter 7. Chapter 8 contains the details of the Mulkear Catchment Model.

This report should be read in conjunction with the Hydromorphology Report also completed by JBA as part of this study (IAY-JBAI-XX-XX-RP-HM-0020-S3-P01-Hydromorphology_Study). This report is also referred to as the 'Hydromorphological assessment' throughout this report.

## 1.4 Method Development

The study has produced two new Telemac models; one broadscale model of the Mulkear catchment and one detailed model of the River Shannon. The Mulkear Catchment model is a source pathway model whereas the River Shannon model is a receptor model. The models have been built in ITM / IRENET95.

Insufficient sediment data is available to ground truth sediment load-based modelling approaches. A monitoring programme over the required timescales to achieve this sediment information is not achievable in this project timelines. Therefore, it was agreed to development a hydrodynamic model whereby the quantifications will be based on the island growth rates from the AquaUoS study.

# 2 Study Objective

The objectives of this Project as identified in the Scope of Services are as follows:

- Project Objective 1: Identify feasible options for the management of sediment and vegetation to prevent further reduction in, and if possible, increase conveyance and/or channel capacity of the Old Shannon between Clareville Water Treatment Plant and St Thomas Island, (refer to 'Reach' in Figure 1.1). The Project Area for these options shall include the Mulkear catchment and the Reach (Figure 1.3).
- Project Objective 2: Identify opportunities to bring wider benefits to the Project Area (Figure 1.3), e.g. environmental, water quality, amenity.

All potential positive and negative impacts associated with the delivery of Project Objectives 1 and 2 will be considered and documented.

It is noted that 'The Reach' illustrated with Figure 2-1 is an extract from the documented Scope of Services and does not extend the full length from St Thomas' Island to Clareville Water Treatment Plant (CWTP) as described in text. The methodology presented within this document includes hydrodynamic modelling of the full length of watercourse from CWTP to St Thomas' Island, however 'The Reach' as illustrated in Figure 2-1 will be the focus of the study.


**Figure 2-1: The Old Shannon between Parteen Weir and St Thomas's Island**

(Source: Lower Shannon Options Scope of Services)

# 3 Available Information

## 3.1 Previous Studies

### 3.1.1 AquaUoS Study

The AquaUoS Study (Lower Shannon Hydro-Geomorphology Study) was completed in 2020. The key objectives of that study are set out below:

- Identify the degree and temporal rate of flow restriction, due to sedimentation and subsequent vegetative growth
- Identify the possible or likely causes/influences of variable sedimentation and subsequent vegetative growth
- Predict the probability and rate of further ongoing restriction for the affected channels.

The study covered the River Shannon between Parteen Weir and Limerick City and extended up the Mulkear River from the confluence with the River Shannon to Annacotty Weir. That study also looked at the impacts of removing sediment and vegetation. However, the method of removing the sediment and vegetation was not considered.

Some of the main findings of the report are summarised below. These key findings indicated that the main source of sediment in the Old River Shannon is from the Mulkear River which lead to the objectives of this current study.

- The sediment poor reach above the Mulkear River confluence persists due to the very low supply of sediment from upstream due to the impounding influence of Parteen Weir and Lough Derg trapping sediment behind and encouraging settlement on the bed of the lake.
- Elevated fine sediment inputs from the Mulkear River are being deposited downstream of the confluence. This is principally as low berms and bars in the main channel where it is becoming consolidated and vegetated. These deposits are unlikely to be eroded under the contemporary post-scheme flow regime of the Old River Shannon.
- Channel hydraulics suggest that the reaches down from the Mulkear confluence are prone to aggradation as this material is stored.
- Only limited deposits are seen through the University of Limerick reach as this is influenced by bedrock, is steeper and as a result has a higher sediment transport competence.
- Future depositional rates and key zones will continue to be influenced by inputs from the Mulkear River. This includes mainly Reaches 4 and 5 that will continue to aggrade at rates of between 3 to 25mm per year (based on average depositional depths calculated in Section 2.7 based on data back to 1920) unless fine sediment inputs are reduced from the Mulkear River by wider catchment works.
- Before the Shannon Hydro-Electric Scheme, there would generally be sequenced flows from the Mulkear and the River Shannon, hence a Bankfull flow in the Mulkear would occur in combination with a Bankfull flow on the Shannon. More frequent lower order floods that are currently removed from the Old River Shannon as a result of Parteen weir would definitely assist with mobilisation of finer sediments further downstream.

Recommendations from the study:

- Any future study commissioned to examine sediment/vegetation management options should include an in-depth, assessment of the wider Mulkear catchment,

given the findings as set out in this report on the sources, pathways and sinks for mixed sediment that is being delivered to the Old River Shannon.

- Monitoring of the suspended and bedload transport along the lower Mulkear River and Old River Shannon after the confluence to confirm volumetric inputs and throughputs.
- A repeat ADCP bathymetric survey of the bed sediment below the Mulkear River confluence in the Old River Shannon to quantify any change to the sediment storage measured prior to the extreme flood flow of February 2020. This could then be incorporated into a re-run of the current model.
- A survey of the tree community age structure across the wet woodland islands to determine their robustness to withstand flood flows.
- A detailed program of auguring to ascertain an accurate measure of the volume of cohesive sediment stored in the University of Limerick reach. A similar exercise around Castleconnell could also quantify stored volumes but it is anticipated from this study that this will be very small.
- Dating of the island sediment deposits around the University of Limerick to determine their age and robustness to flood erosion.
- The Shannon fish pass study is currently considering options for improving fish passage along the Old River Shannon, any future studies with regards to optioneering should take into consideration the outcomes of this ongoing study.

### 3.1.2 ST9 Sand and gravel trap Bilbao River Hydromorphological Review

This is a report completed by JBA Consulting on behalf of the OPW which assess the hydromorphological impacts of a sand and gravel trap, named ST9, located at the Blackboy Bridge, near Cappamore Co. Limerick. ST9 is on the Bilboa River which is a tributary of the Mulkear River. The study was completed in 2019.

### 3.1.3 Mulkear River (Ballymackeogh) Certified Drainage Scheme

The OPW scheme on the Newport/Annagh/Killeenagariff Rivers, was completed in 1996. The primary objective of the scheme was to alleviation flooding of domestic and commercial properties in the vicinity of the rivers aforementioned. These rivers are tributaries of the Mulkear River.

### 3.1.4 MulkearLIFE

This report details the restoration of the Lower Shannon SAC for Sea Lamprey, Atlantic Salmon and the European Otter, as completed in 2014.

## 3.2 Previous Models

### 3.2.1 CFRAM

Model built for the Shannon CFRAM Study. This study was completed in 2016, using survey captured in 2012. The hydraulic model covers the River Shannon along the area of interest and also the Mulkear River, although the flood maps on the Mulkear are currently under review (as per the OPW floodinfo.ie website). Figure 3-1 shows the flood extents produced for Limerick City and the surrounding area.

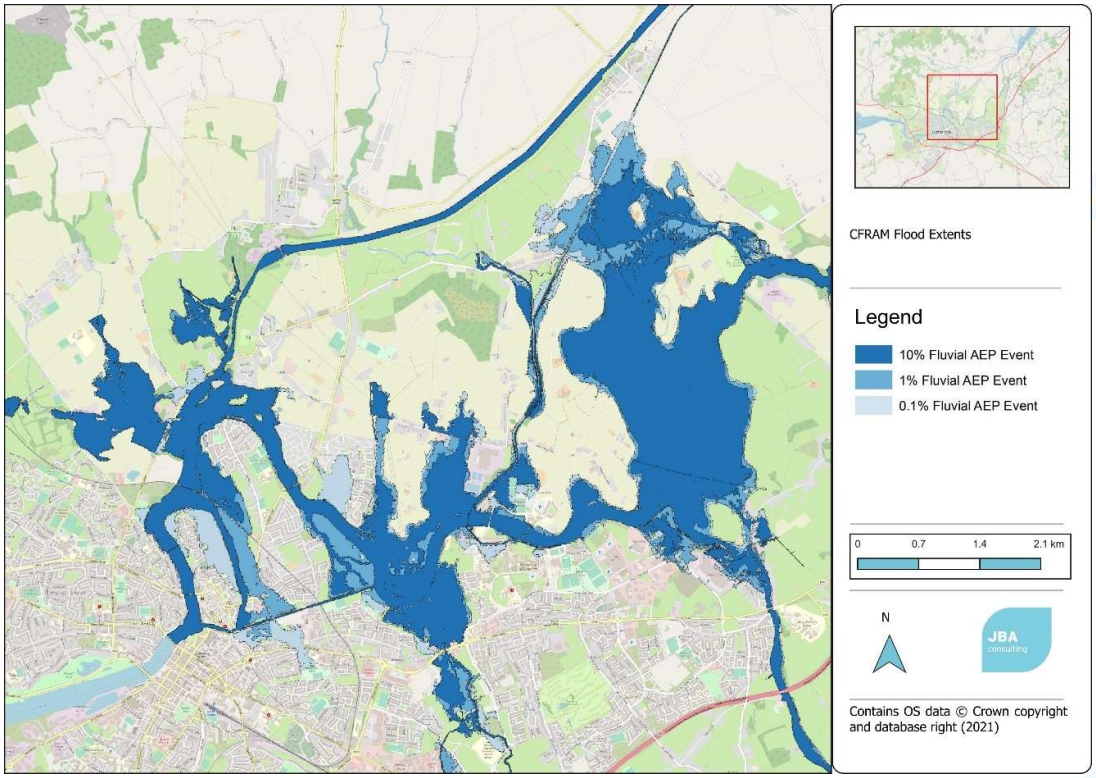



**Figure 3-1: CFRAM Flood Extents**

### 3.2.2 AquaUoS

A model was developed as part of the AquaUoS study (refer to Section 3.1.1 above for more detail) to help to understand the flow and sediment regime for the reach of the Shannon and Mulkear and the potential implications on removal of sediment and/or vegetation from the channel and the broad impacts on flooding:

This study developed a 2D TUFLOW model of the reach of the River Shannon from Parteen Weir to Limerick City and the Mulkear River, using the existing River Shannon model provided by OPW, LIDAR data and new survey commissioned by OPW for this study (refer to Section 3.4.2).

### 3.2.3 Castleconnell FRS

A hydraulic model of the River Shannon from Parteen Weir to Castletroy has been developed by JBA Consulting as part of the Castleconnell FRS. Hydraulic modelling of the River Shannon downstream of the Parteen Weir was developed to assess design flood levels and potential defence options. The model extent is shown in Figure 3-2 below. Further details of the hydraulics and hydrology of the study are included in Appendix A.

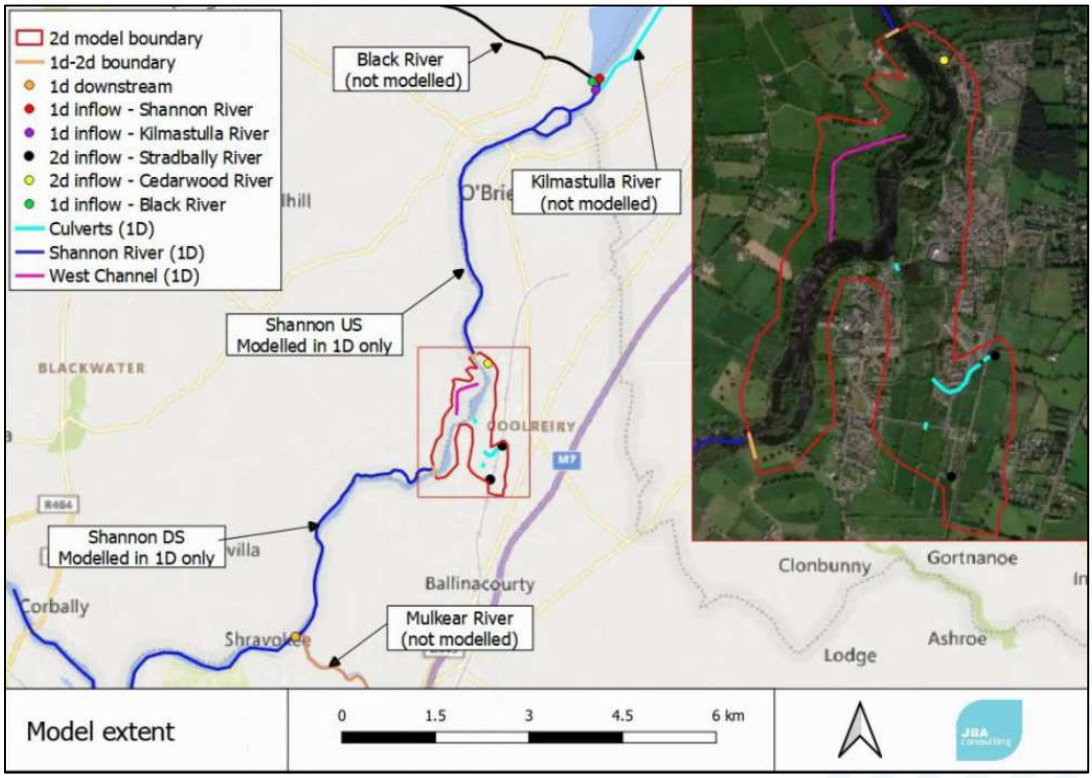



**Figure 3-2: Castleconnell FRS Model Extent (Extract from Hydraulics Report)**

## 3.3 DTM

### 3.3.1 LiDAR

2m resolution LIDAR flown in 2011-2012 has been provided by the OPW. The RMSE of the LiDAR is less than 0.2m, with 99% of all points falling within 2RMSE. The dataset covers the entire area of interest for the River Shannon from the Clareville Water Treatment Plant to St. Thomas Island. The Mulkear River is also covered by the dataset upstream past Annacotty Weir.

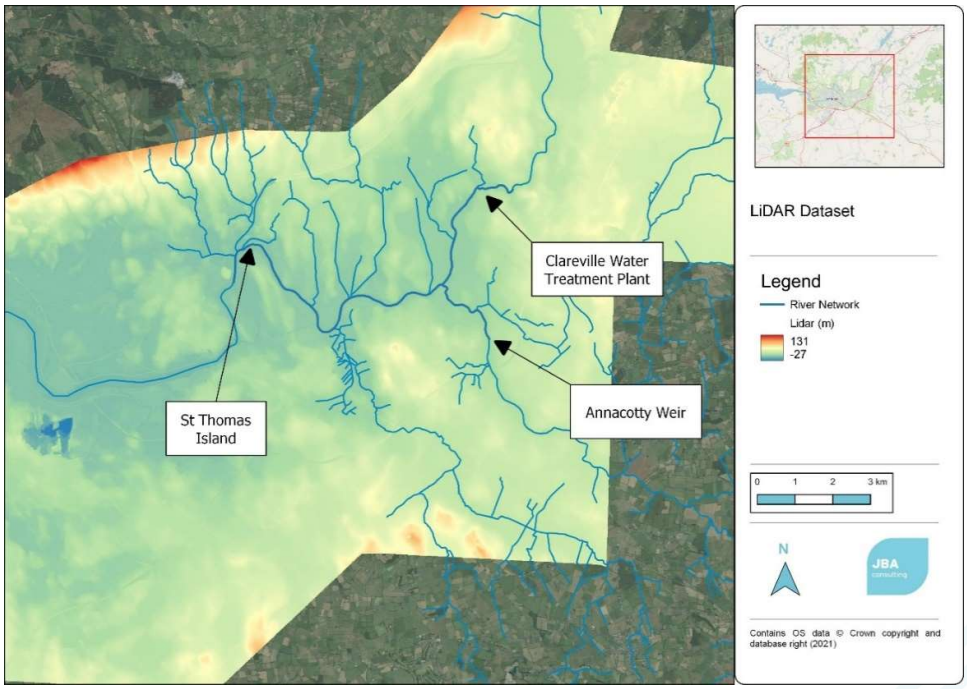



**Figure 3-3: LiDAR Dataset**

### 3.3.2 IFSAR

A 5m Intermap DTM flown in 2007 was also provided by the OPW. It has an RMSE of +/-0.7m on slopes <20 degrees. The dataset covers the entire Mulkear catchment.

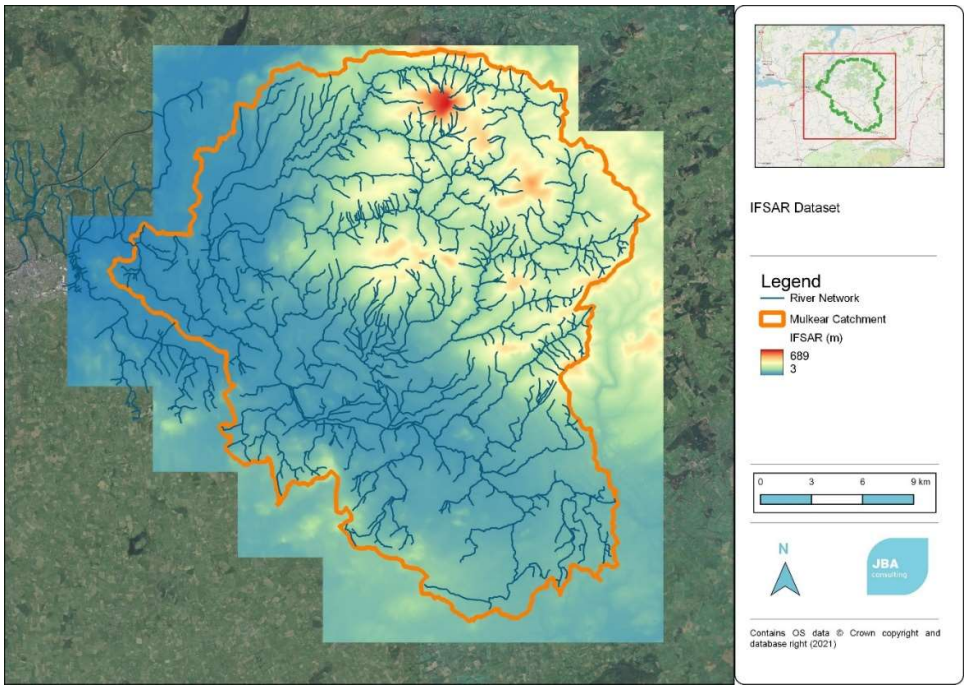



**Figure 3-4: IFSAR Dataset**

## 3.4 Available Survey

### 3.4.1 OPW CFRAM Survey

Cross sections of the River Shannon and the Mulkear were captured in 2012 as part of the CFRAM study. Cross sections cover the River Shannon along the area of interest and also upstream on the Mulkear to the M7 motorway. Refer to Figure 3-5 for the survey cross section locations. This survey was limited in its ability to capture elevation of the in-channel islands due to vegetation and accessibility. The CFRAM modelling therefore included elevation adjustments of these cross-sections to represent the islands. These adjustments maintain a high level of uncertainty to which modelling results and predicted flood levels were highly sensitive to these adjustments.

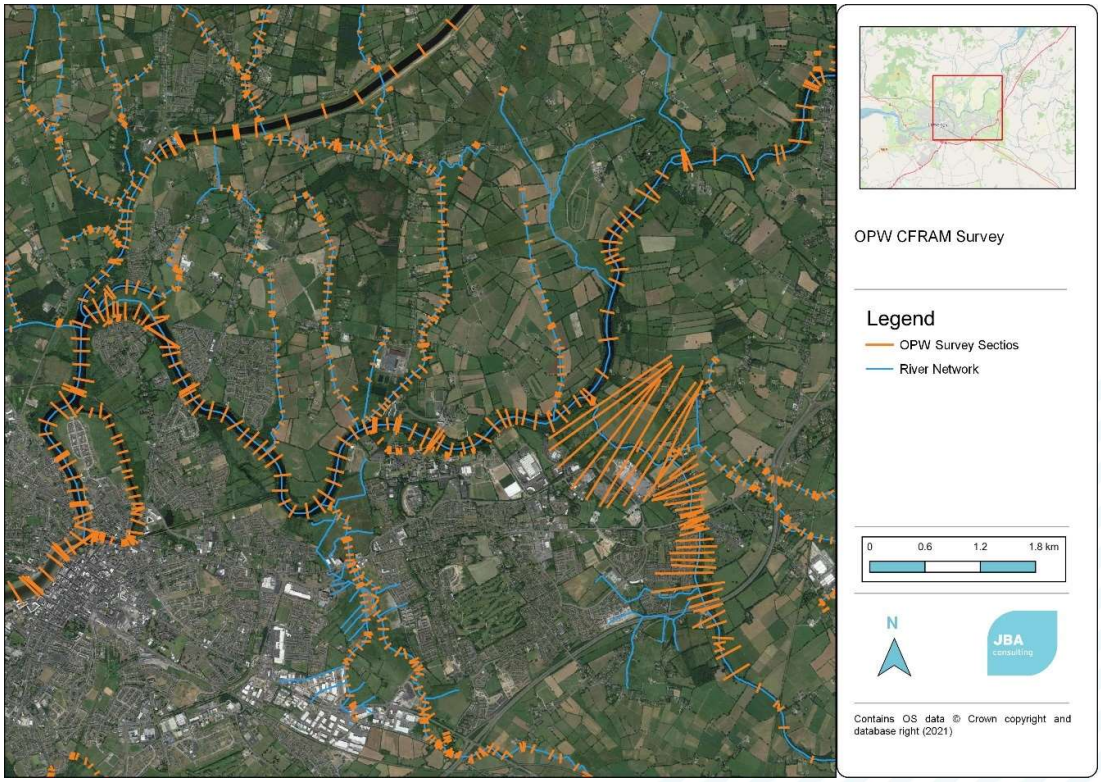



**Figure 3-5: OPW CFRAM Survey**

### 3.4.2 AquaUoS

Aerial (drone) and ADCP survey of the Lower Shannon study reach was commissioned as part of the AquaUoS study. The survey was undertaken to gain a more detailed understanding of the morphology along the reach and to allow comparison to existing OPW survey and hydraulic model data to determine how this has changed over time. This was used to delineate the river and island extents. Figure 3-6 shows a section of the river delineation while the overall drone coverage is shown in the inset.

Bathymetry of the study reach was generated using an Acoustic Doppler Current Profiler (ADCP) facilitated through a fixed mounting behind a kayak and paddled across and down the Lower Shannon River channel by a two-man team. This survey, along with the Drone mapping took place between November 2019 and March 2020. Refer to Figure 3-7 for a clip of the digital elevation model of the lower Shannon.

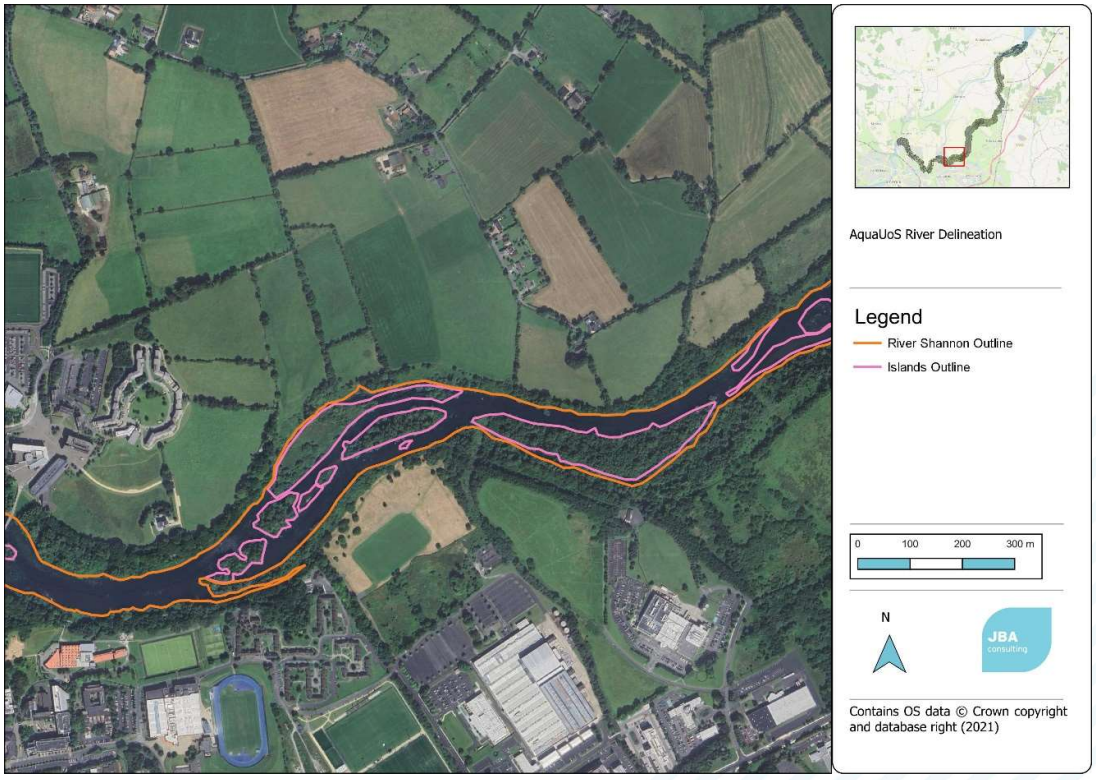
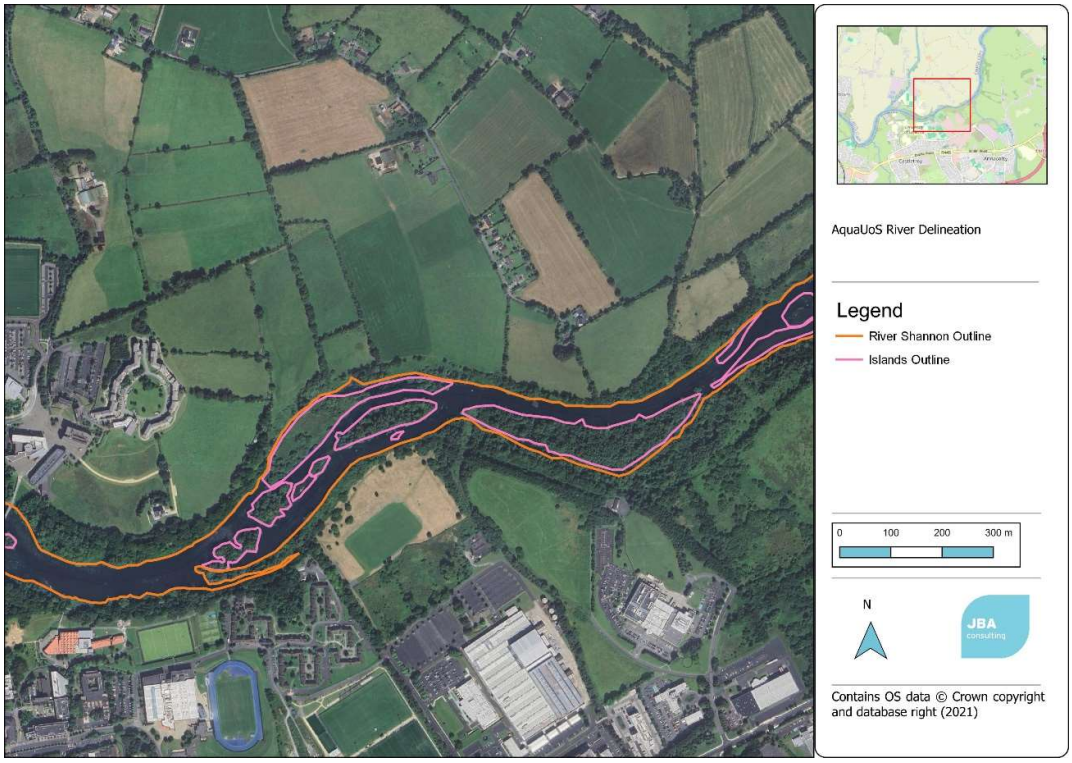



**Figure 3-6: AquaUoS Aerial Drone Survey Coverage**



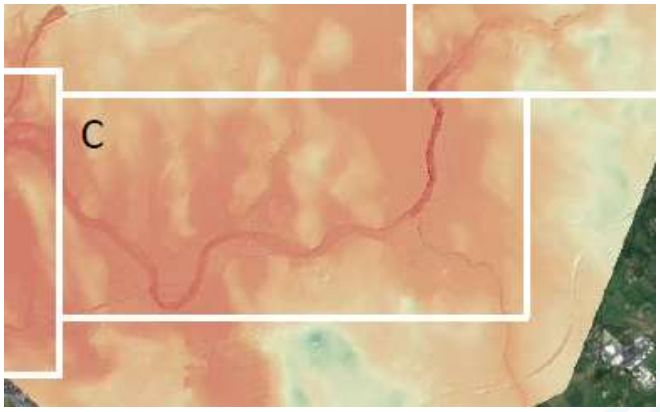




**Figure 3-7: AquaUoS DEM clip**

As part of the AquaUoS Study, drone footage of February 2020 flood event was also captured. The flood survey dates were March 2 to March 4 2020. The drone footage was on the Shannon showing the maximum flood extents reached during this flood event, refer to Figure 3-8.

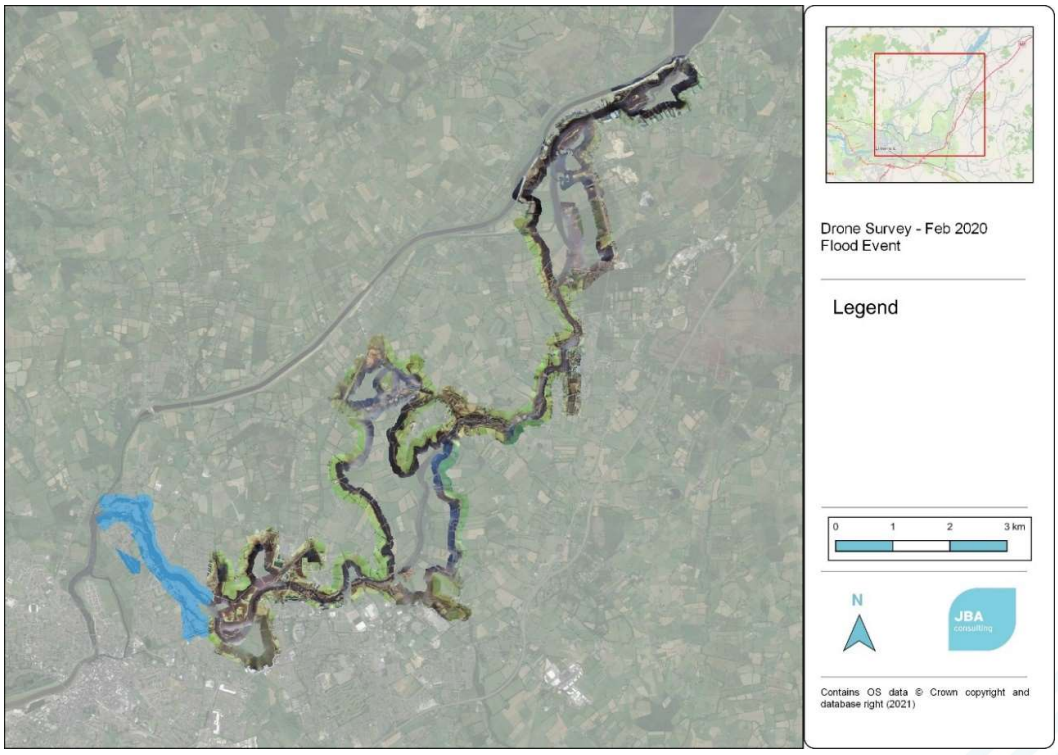



**Figure 3-8: Drone Flood Survey Extent - Feb 2020**

### 3.4.3 Bathymetric & Sediment 2021

This survey was completed by Hydrographic Survey Ltd in 2021. Bathy on the River Shannon was captured from the Clareville Water Treatment Plant to downstream of the Canal. The Mulkear was also surveyed for approx. 700m upstream of the confluence with the River Shannon. Bathymetric survey was undertaken using a water vessel in a zig-zag pattern rather than full coverage. The zig-zag pattern also included the alignment of the CFRAM cross sections with the survey reach. Refer to Figure 3-9 for the survey area and a clip of the surveyed zig-zag points. This method may not have appropriately identify necessary features in channel due to the zig-zag nature of the survey, rather than full coverage. It is also noted that a key area of the Reach from below to junction with the Mulkear River to UL was not accessible at the time of survey.

Sub bottom profiling (SBP) was carried out to determine sediment depths across all designated survey and underwater photo-imagery of the riverbed was captured to identify the sediment types, refer to Figure 3-10.

Additional bathymetric survey was collected as part of this JBA study which is described in Section 3.5

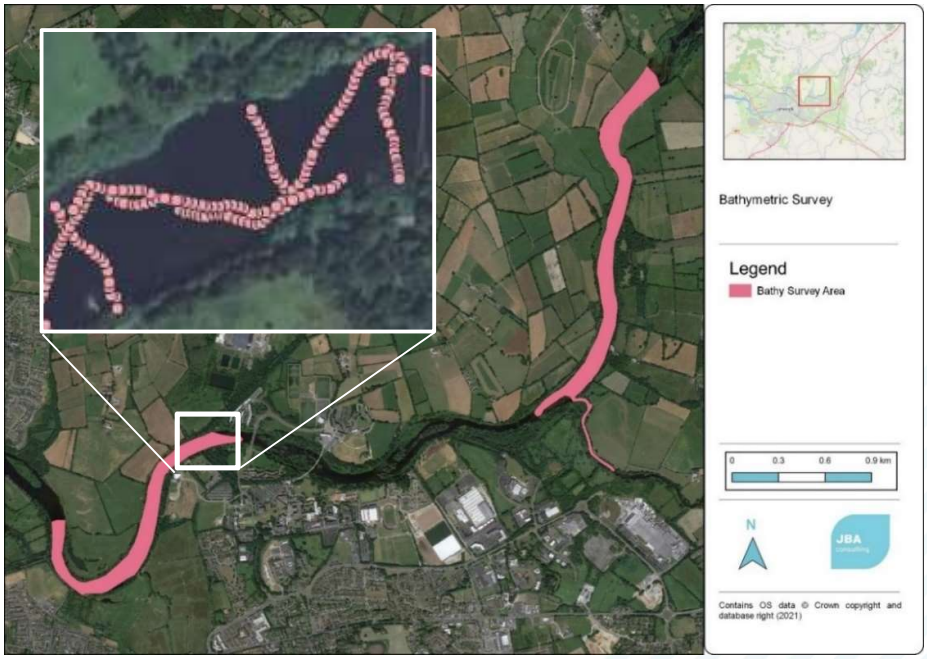



**Figure 3-9: Bathymetric Survey Area**

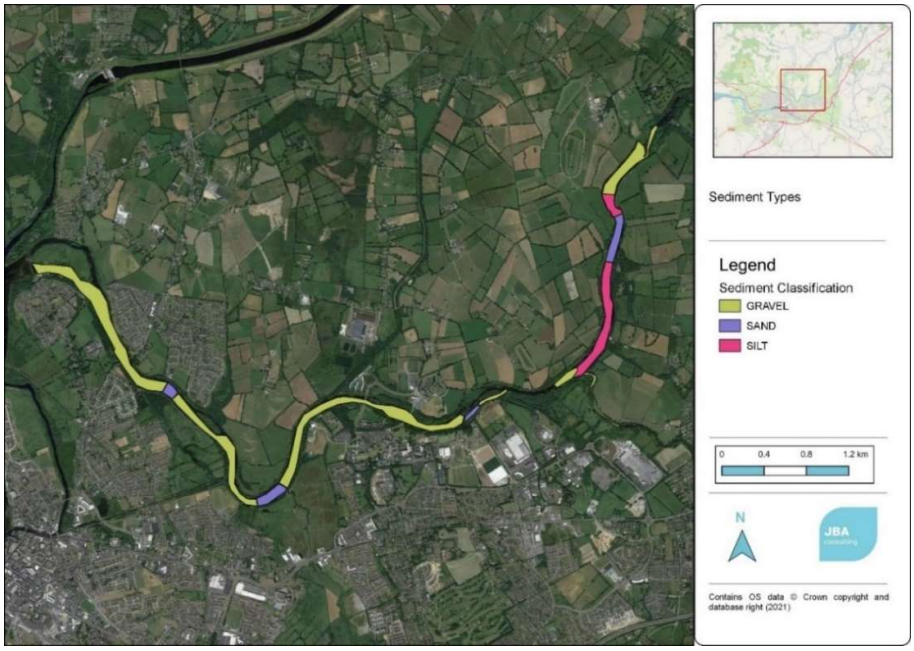



**Figure 3-10: Surveyed Sediment Types**

### 3.4.4 Waterways Ireland

Long and cross sections of the Old Shannon downstream of Mulkear confluence surveyed in 1840. Refer to Figure 3-11 for approximate survey extents and locations.


**Figure 3-11: Indicative locations and extent of Waterways Ireland cross sections**

(Image Source: Lower Shannon Options Scope of Services)

### 3.4.5 ESBI Survey 2007

ESBI survey and modelling for UL development (downstream of Plassey Bridge) completed in 2007. Cross section locations are shown in Figure 3-12 below.

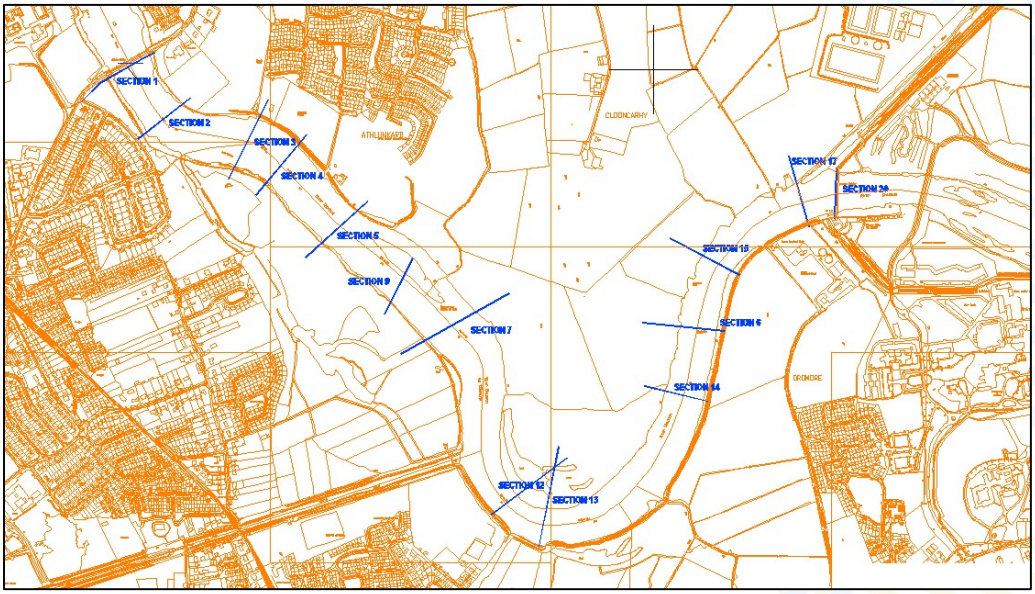


**Figure 3-12: ESB July 2007 survey**

## 3.5 Survey Commissioned for the Project

### 3.5.1 Requirement for additional survey

Bathymetry Survey was completed by Hydrographic Survey Ltd in 2021 (refer to Section 3.4.3). However, this survey did not extend to the 'Reach' as it was not accessible at the time of study. In order to accurately represent the 'Reach' in a hydrodynamic model, the section would need to be resurveyed. As discussed in Section 3.4.3, there are also concerns over the collection method of the existing Bathymetry survey and that it may not have appropriately identified necessary features in channel. Therefore, in addition to the areas which were not surveyed, a more 'feature-targeted' survey was collected to ensure an accurate representation of the riverbed.

### 3.5.2 Survey Brief

The Scope of Works for the survey was to capture the topography and bathymetry of the River Shannon and River Mulkear as outlined in the drawings provided to surveyors.

The purpose of the river survey was to obtain detailed levels of the river bed and in-channel features. This was primarily through a spatial coverage of data points that represent the bedform of the channel both in width and length of the channel which could be used to input into a 2-dimenstional hydraulic flood model.

The survey consists of three components;

1. Cross section survey at the location of the previous CFRAM cross section locations.
2. Infill cross sections at approx. 10m spacing (long stream)
3. Infill cross sections at approx. 25m spacing (long stream)

For the infill cross sections, several points were to be collected along each infill transect such that a representative cross section was captured. These points included the top and toe of banks, top and toe of islands (if islands were within the transect) and any other features such as weirs.

In addition to the survey described above, photographs were required at the confluence of the Mulkear with the River Shannon of the condition and composition of the bed and island feature substrate.

### 3.5.3 Survey Deliverables

The survey was completed by Murphys Surveys and took place from March to July 2023. The cross section and bathymetric ('infill') survey were completed as requested, with additional points collected in the bathymetric survey (approx. 3m infill spacing rather than 10-25m spacing). The cross sections collected at the location of the previous CFRAM cross sections are shown in Figure 3-13 along with the bathymetric survey coverage. Figure 3-14 shows a detailed view of the bathymetric survey collected on the River Shannon. Survey points could not be collected in some areas such as on the islands and along banks where there was dense vegetation, particularly on the left bank of the River Shannon downstream of the confluence with the Mulkear, refer to Figure 3-15. In the figure, the orange hatched area identifies the requested survey area and the green points represent the survey collected.

Photographs of bed of the river along the Shannon and Mulkear catchment were requested. While some photographs were collected, video footage of the bed was collected using an ROV. The ROV footage is analysed in the Hydromorphology Report in Section 3.2.4.

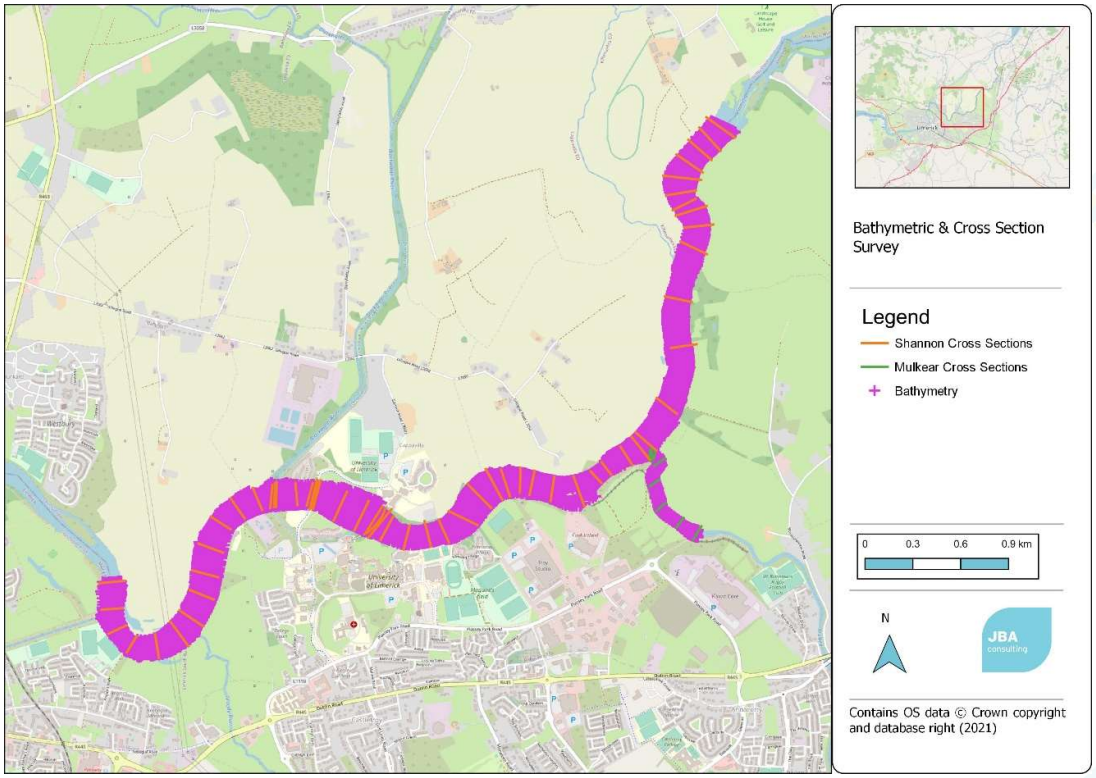



**Figure 3-13: Bathymetric and Cross Section Survey**

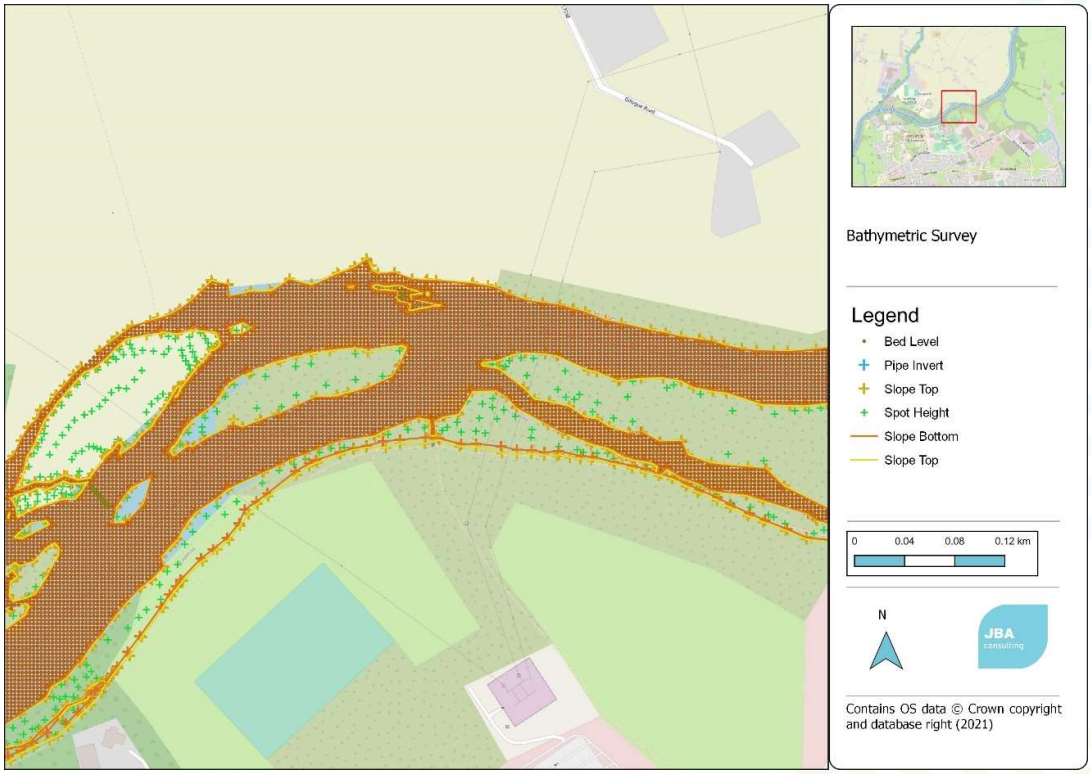



**Figure 3-14: Bathymetric Survey**

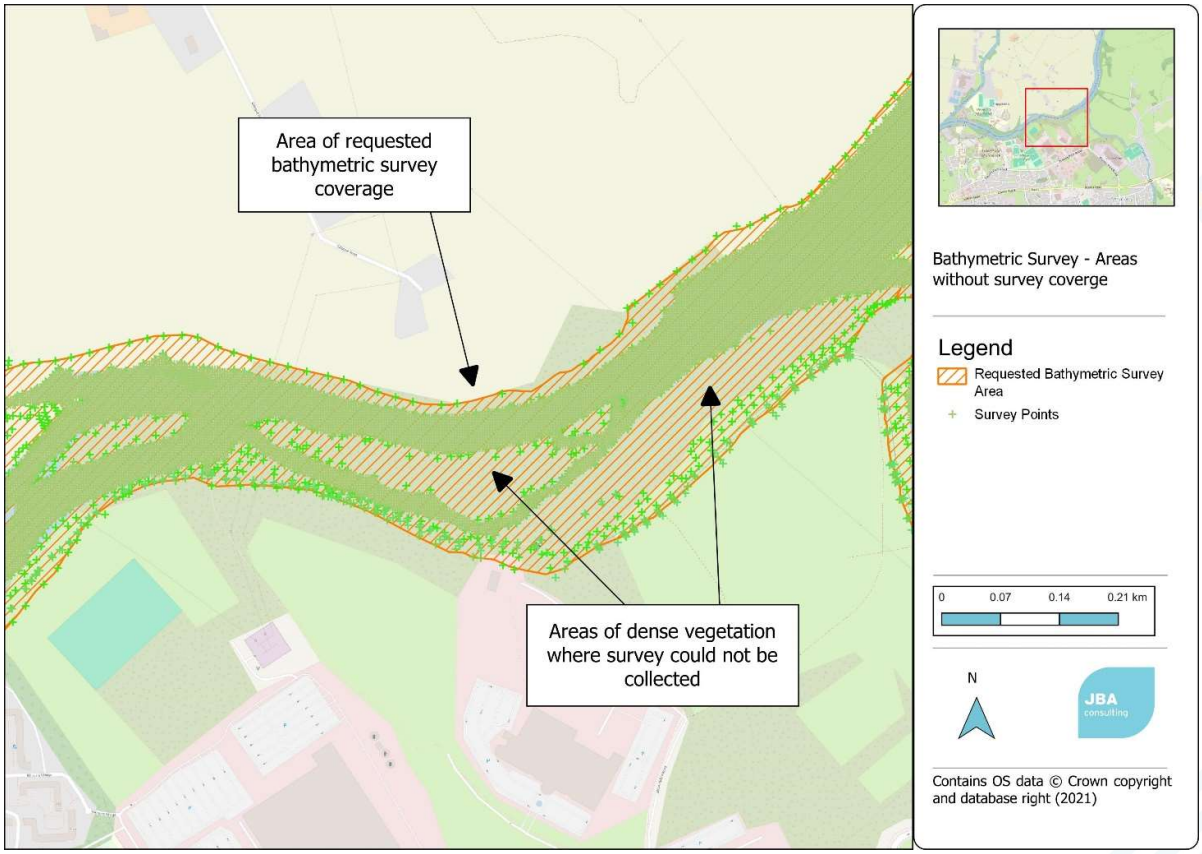



**Figure 3-15: Areas where bathymetric survey could not be collected**

## 3.6 Cross Section Analysis

The AquaUoS Study completed in 2020 (as described in Section 3.1.1) carried out analysis on the historic channel change (both erosion and deposition) using archival cross section survey, historic mapping and aerial photography to develop a developmental sequence dating back to the early 1800s. The study estimated a maximum rate of accumulation of 3cm per year along on the River Shannon directly downstream of the junction with the Mulkear. This accumulation rate was estimated by reconstructing the approximate bedrock profile beneath the current alluvial material using the contemporary cross sections along the Old River Shannon. These bedrock profiles were used to create a bedrock surface of the river and this was subtracted from the contemporary sections to determine average and maximum depths of deposition. It was also estimated that further downstream by the University of Limerick, the maximum rate of accumulation would be reduced to less than 1cm per year. The Aqua UoS study also caveats that this estimated growth rate assumes that no sediment removal has occurred since 1920 (when the hydropower plant at Ardnacrusha was constructed) and it also assumes that no silt was present in 1920.

As there is no real sediment information available to verify this estimation a comparison has been completed between the CFRAM cross sections (surveyed in 2012, refer to Section 3.4.1) and the cross sections surveyed as part of the survey completed in 2023 as part of this JBA study along the location of the CFRAM survey sections (Section 3.5). The sections compared are shown in Figure 3-16. The

approximate changes in cross sectional area are provided in Table 3-1. Is should be noted that the exact location of each survey point could not be replicated hence an exact comparison of cross sectional areas cannot be determined. The comparison only allows for observing the general tends in accumulation along the Reach when no other sediment information is available.

The analysis indicates that there is decrease in cross sectional area downstream of the confluence at cross section 25SHAN008826 and 25SHAN008772. Over the past 11 years, the cross sections appear to have been eroded in some locations, with deposition occurring in other sections with the overall trend being the volume increase in sediment is greater than the volume eroded. Figure 3-17 below shows a section of the erosion vs deposition on the left bank of the section.

Upstream of the confluence at cross section 25SHAN008869 there is an increase in cross sectional area, meaning the rate of erosion over the last 11 years has been greater than the rate of deposition.

At section 25SHAN008632, while there has been a change in the cross sectional shape, there has been an almost equal amount of erosion as there has been sedimentation. This roughly fits with the analysis in the Aqua UoS study which indicated that the rate of accumulation would decrease around the University of Limerick to a maximum increase of <1cm per year.

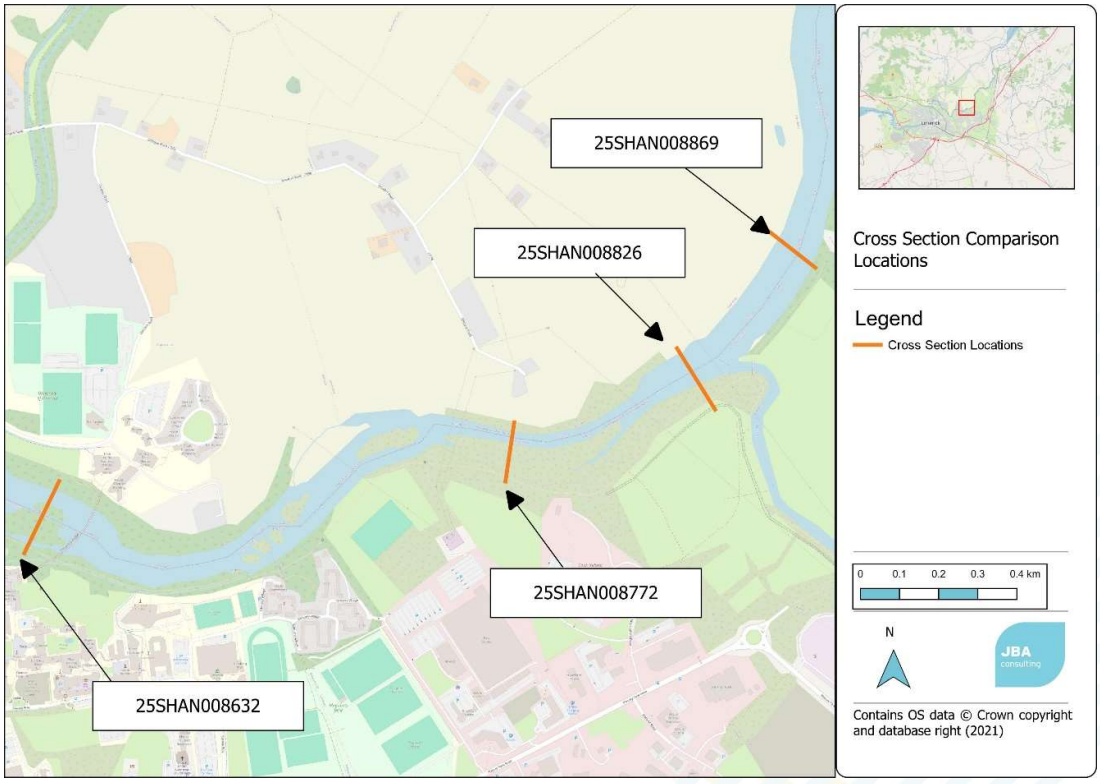



**Figure 3-16: Cross Section Comparison Locations**

**Table 3-1: Approximate changes in cross sectional area**

| | Decrease in CSA | Increase in CSA | Change in CSA |
|---|---|---|---|
| 25SHAN008869 | 57 | 6 | -51m2 |
| 25SHAN008826 | 19 | 31 | +12m2 |
| 25SHAN008772 | 45 | 77 | +32m2 |
| 25SHAN008632 | 22 | 15 | -7m2 |

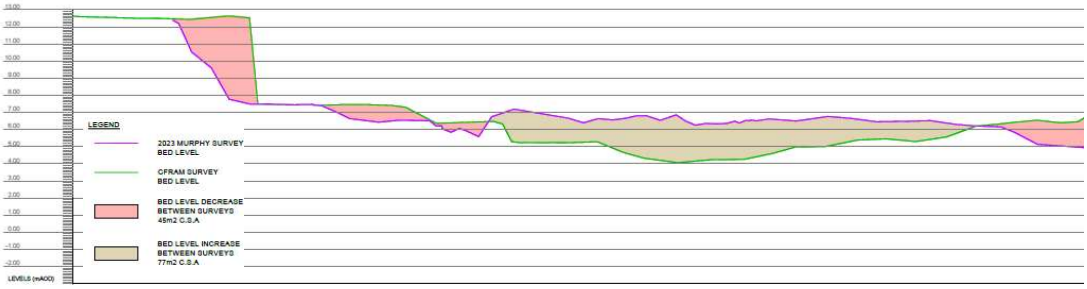



**Figure 3-17: Cross Section Comparison - 25SHAN008772 (Left Bank)**

## 3.7 Corine Landcover 2018

The Corine Land Cover 2018 is the 2018 update of the COPERNICUS pan-European landcover data series. The dataset defines the land use types in the Republic of Ireland as shown in Figure 3-18, along with the model domains.

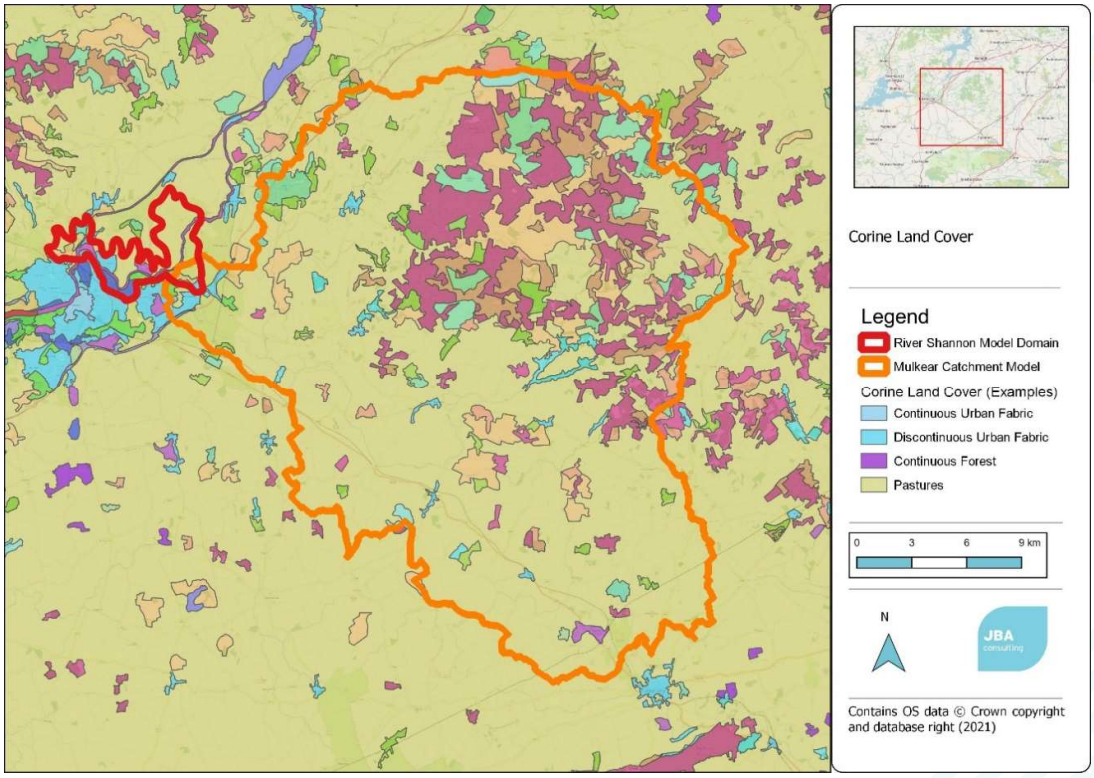



**Figure 3-18: Corine Land Cover Map**

## 3.8 IFS Soils

The IFS soils categories are shown in Figure 3-19 along with the model domains. The IFS soils layer was obtained from the EPA geoportal website[1].

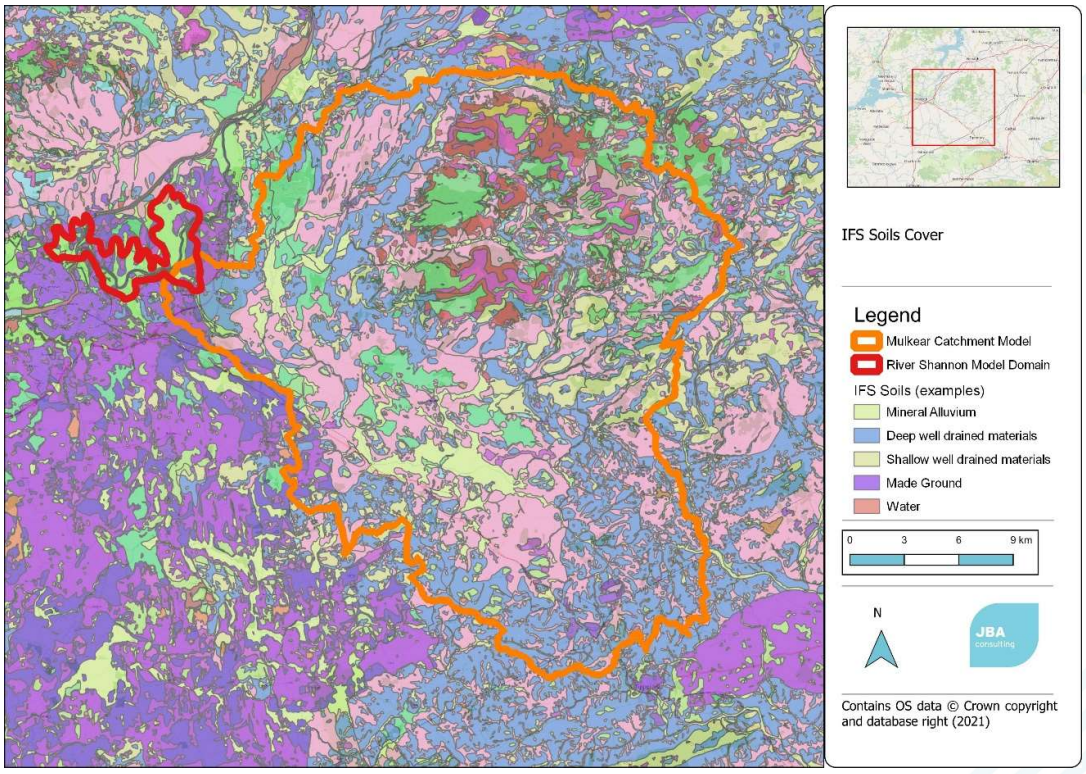



**Figure 3-19: IFI Soils Map**

1 https://gis.epa.ie/GetData/Download

## 3.9 Hydrometric Data

The Old River Shannon is gauged at Parteen Weir and at Ardnacrusha while the Mulkear River is gauged at Annacotty Weir and at Abington further upstream, refer to Figure 3-20. These are the key hydrometric stations required as part of the hydrological analysis. While other gauge information is available on other watercourses entering the River Shannon catchment, such as the River Groody, gauge information is not required on these watercourses as specific inflows at these points are not required.

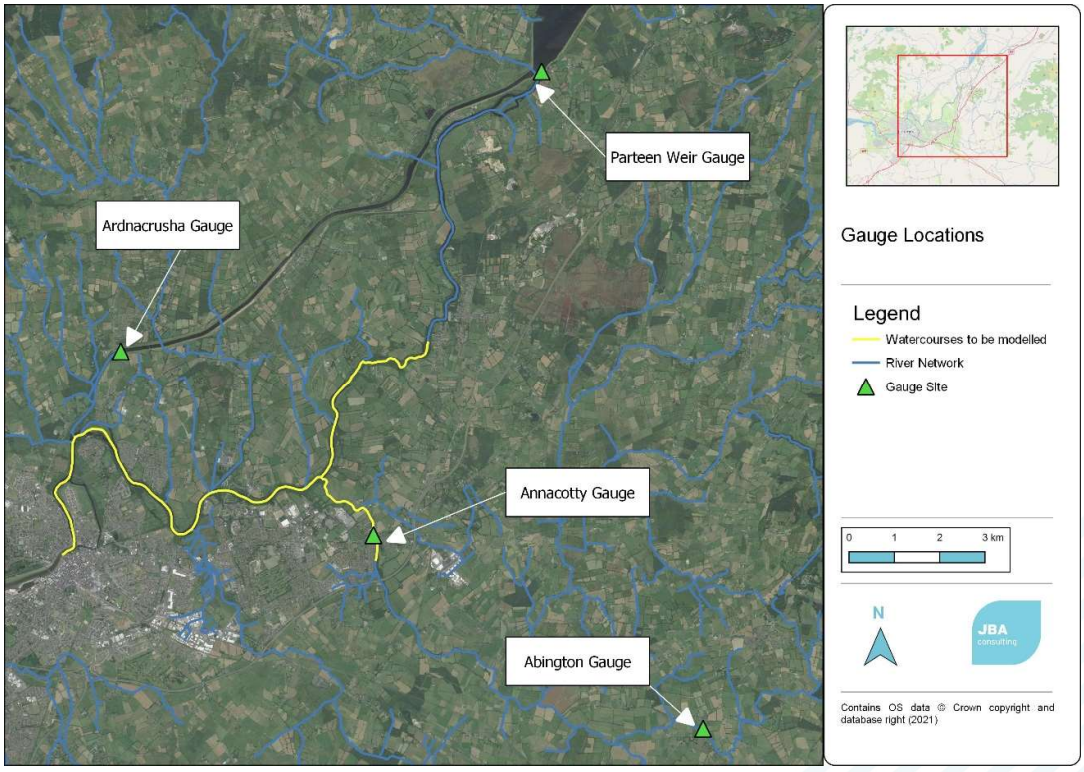



**Figure 3-20: Gauge Locations**

**Table 3-2: Gauge Information**

| Gauge | Watercourse | Record Length |
|---|---|---|
| Parteen Weir | River Shannon | 1993 - Current |
| Ardnacrusha | Headrace | 1993 - Current |
| Annacotty | Mulkear | 1972 - Current |

## 3.10 MET Eireann DDF

The Depth Duration Frequency (DDF) model is provided by Met Eireann. The data is based on the calculations from Fitzgerald (2007). The data estimates the return period rainfall depths for a number of durations at a number of points. The points cover the country in a 2km grid spacing. Figure 3-21 below shows the DDF points available for the Mulkear catchment.

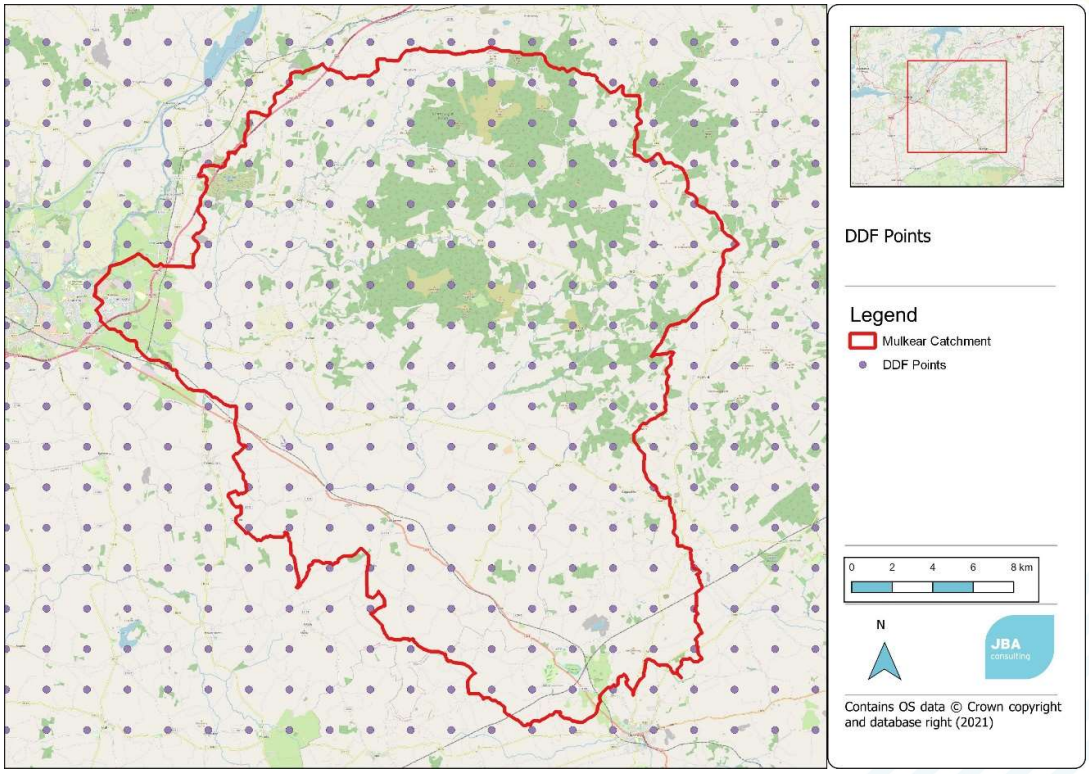



**Figure 3-21: DDF Point Locations**

# 4 River Shannon Hydrodynamic Model

A new detailed 2D Telemac model of the River Shannon has been developed. The model extends from Clareville Water Treatment Plant to St Thomas Island in Limerick City. The model also extends up the Mulkear River to Annacotty weir. The extent of the River Shannon both upstream and downstream allow the impacts of each scenario to be quantified in Springfield, Annacotty and Limerick City, as a requirement of the Scope of Services. Figure 4-1 shows the 2D model domain extent.

The model is a 2D (horizontal) hydrodynamic model, based on the depth-averaged non-linear shallow water (NLSW) equations, which has been tested for a range of flows. A variable resolution, unstructured Delaunay triangular, mesh has been constructed to represent the islands along the Reach with appropriate detail to represent the longitudinal and lateral movements of the islands. Details of the model mesh are provided in Section 4.3 below. With this high level of in channel detail, the model provides an insight into the velocity patterns within the Reach and areas of bed shear stress which would encourage erosion and/or deposition.

This detailed model has then been used in the sediment modelling scenarios as discussed in Sections 6.1 to 6.4 below. In these scenarios, future forecast conditions have been created, some of which are based on manual adjustments to the bed level. The outputs of the baseline model and the Hydromorphological assessment informed the areas prone to deposition. The bed level has been adjusted in these areas based on the growth rates as estimated in the AquaUoS study. Historic mapping and aerial imagery such as on Google Earth have also been used as visual confirmation of the growth patterns.

The model has also been utilised to accurately define any floodplain flow routes within the model study area and how each of the scenarios tested impact these flow routes.

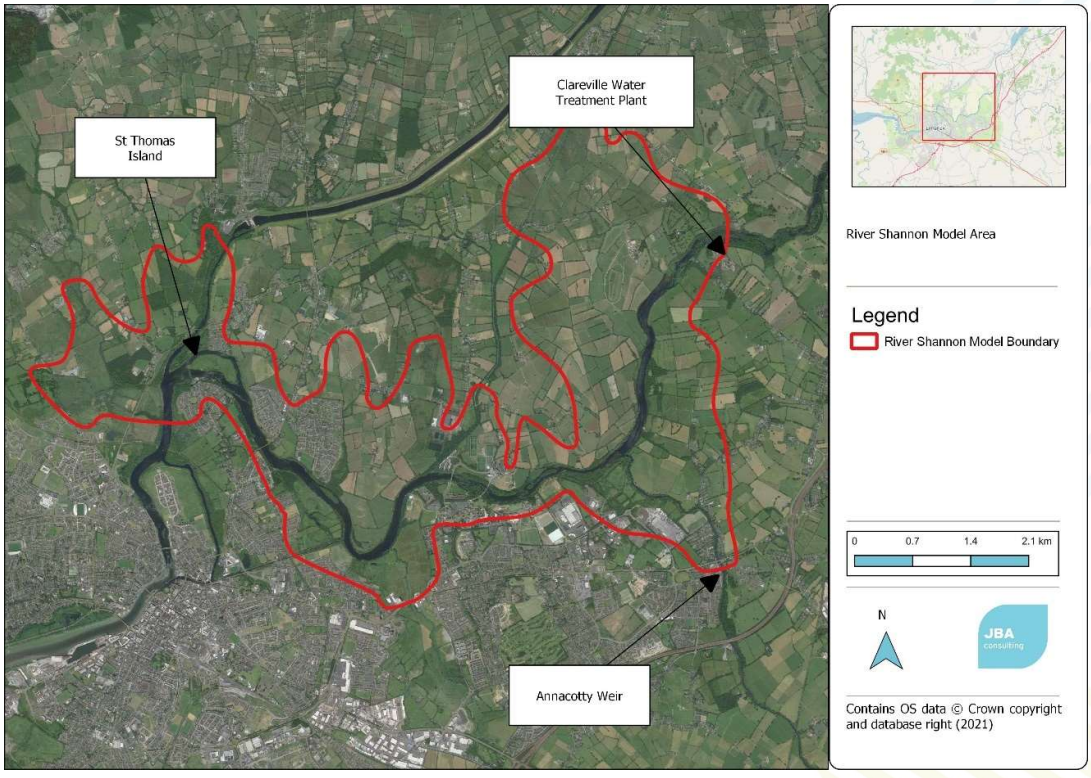



**Figure 4-1: River Shannon Model Domain**

## 4.1 Model Build

A variable resolution unstructured triangular mesh was utilised for the model, with high-resolution in the channel to appropriately assess and demonstrate in-channel flow behaviour at feature scale and lower definition in the floodplain and in areas of lower sensitivity / less variable geometry. The set-up provides a good compromise of model accuracy against modelling expense (in terms of CPU time).

Figure 4-2 shows a sub-domain of the mesh for the model at the River Shannon and Mulkear confluence illustrating the variable resolution unstructured mesh employed by the hydrodynamic model. The mesh is discussed further in Section 4.3.

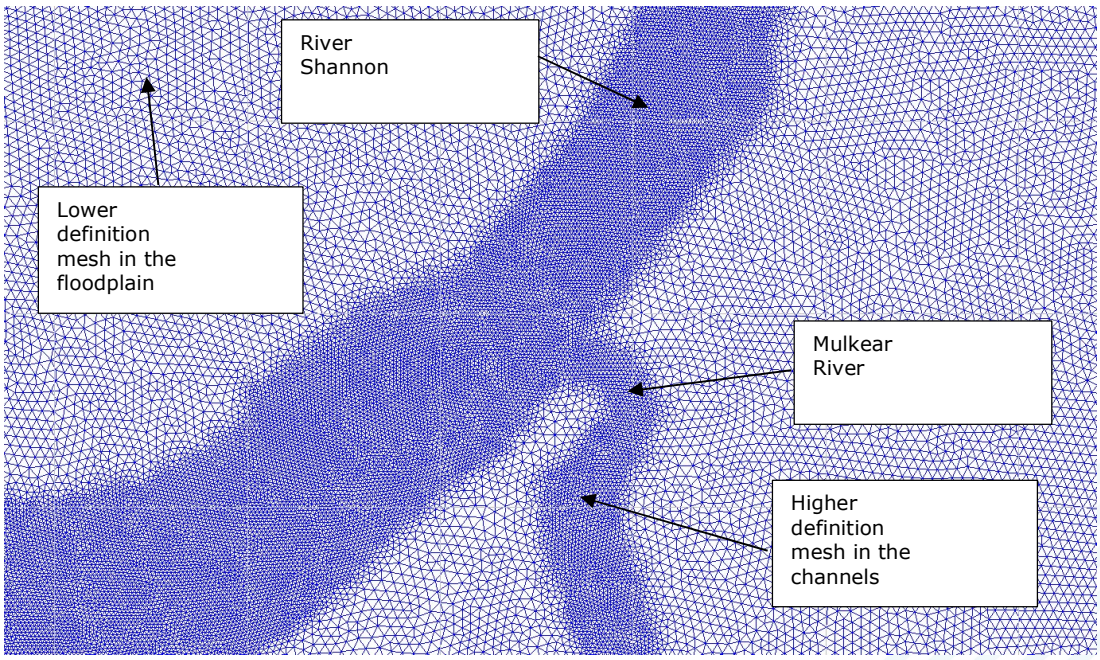



**Figure 4-2: River Shannon Mesh**

## 4.2 Topography

The River Shannon and the River Mulkear have been defined using a combination of bathymetric survey data collected on the river channel supplemented with cross sectional survey data. The survey used in the model is identified in Figure 4-3. 2m LiDAR data, as provided by the OPW, defines the topography in the floodplain. Figure 4-4 shows the final topography read into the model using the combined bathymetry data, cross section and LiDAR data. The various sources of bathymetry were combined onto the model mesh nodes via bilinear interpolation.

## 4.3 Model Mesh

For flexibility and computational efficiency reasons, the model employs an unstructured mesh comprising a Delaunay triangulation of the model domain. The mesh is high resolution within the rivers and areas of importance (flood plains etc.) and is of lower resolution where accuracy is not paramount, as seen in Figure 4-2. The mesh comprises 360245 computational nodes (~716500 computational elements). The mesh edge length ranges from a minimum edge length of 2.4m to a maximum edge length of 17.6m; the mean interior edge length is 7.6m.

It is noted that due to the lower model mesh in the floodplain, field drains have not been reinforced with actual and therefore are not represented. Such locations include in the vicinity of the Springfield area.

## 4.4 Numerical Parameters

The finite element (FE) version of TELEMAC 2D is utilized which is based on the depth-averaged, non-linear shallow water equations. The model employed a fixed time-step of 1.5s. Based on the cell sizes and water depths in the model, for certain smaller cells this corresponds to a Courant number in excess of unity; this is possible as TELEMAC employs an implicit scheme for time-matching. The use of a high Courant number provides both computational efficiency and minimises numerical diffusion. The wave equation approach is employed to treat the linear system for the continuity equation. Advection is achieved via a distributive (fluctuation-splitting) scheme. A constant viscosity turbulence model is used, and default values are employed for the horizontal turbulent viscosity coefficients. Sensitivity testing complete in previous modelling studies with available validation data showed that these values provided the best results.

## 4.5 Boundary Conditions

The 2D River Shannon model is driven through boundary conditions that are provided at the three open boundaries. Tidal water levels are prescribed on the downstream boundary as a time series of water levels via absorbing generating boundary conditions on the water depth (based on the use of Riemann invariants). For the upstream, river discharge, boundary conditions (for both the Shannon and Mulkear), the model employed Dirichlet conditions on both the water discharge rate and the water level. The discharge values and the tidal signals that were employed to drive the mode are given in detail in the relevant sections below.

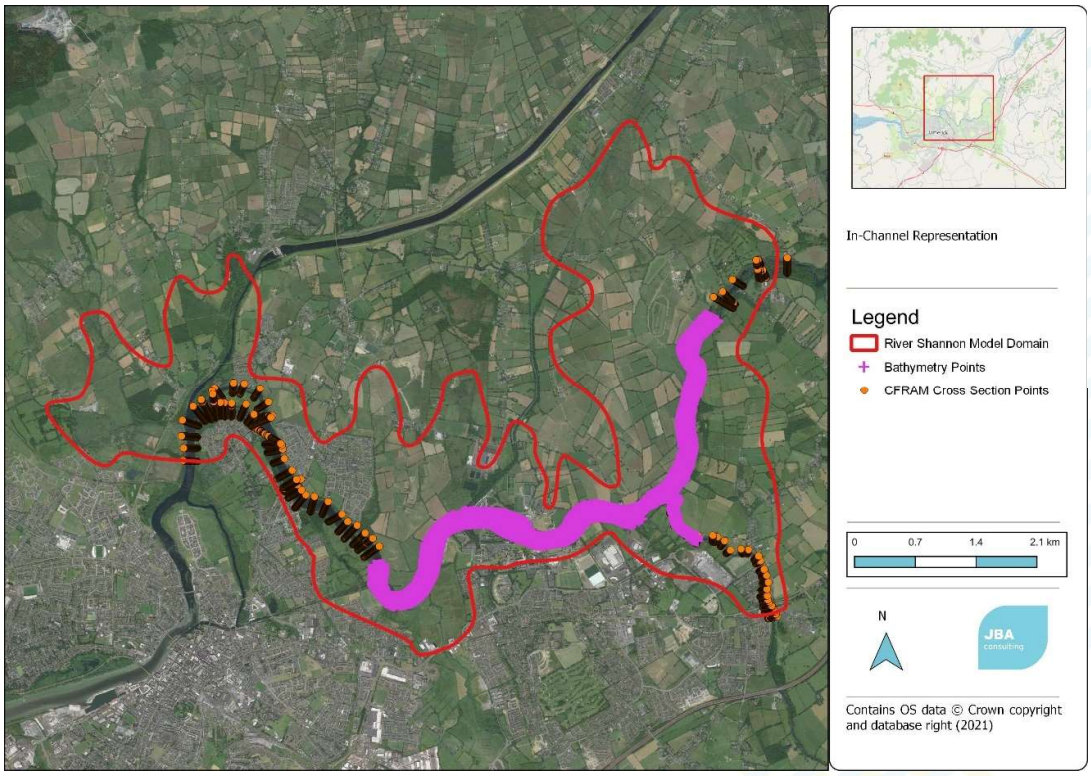



**Figure 4-3: In-Channel Representation**

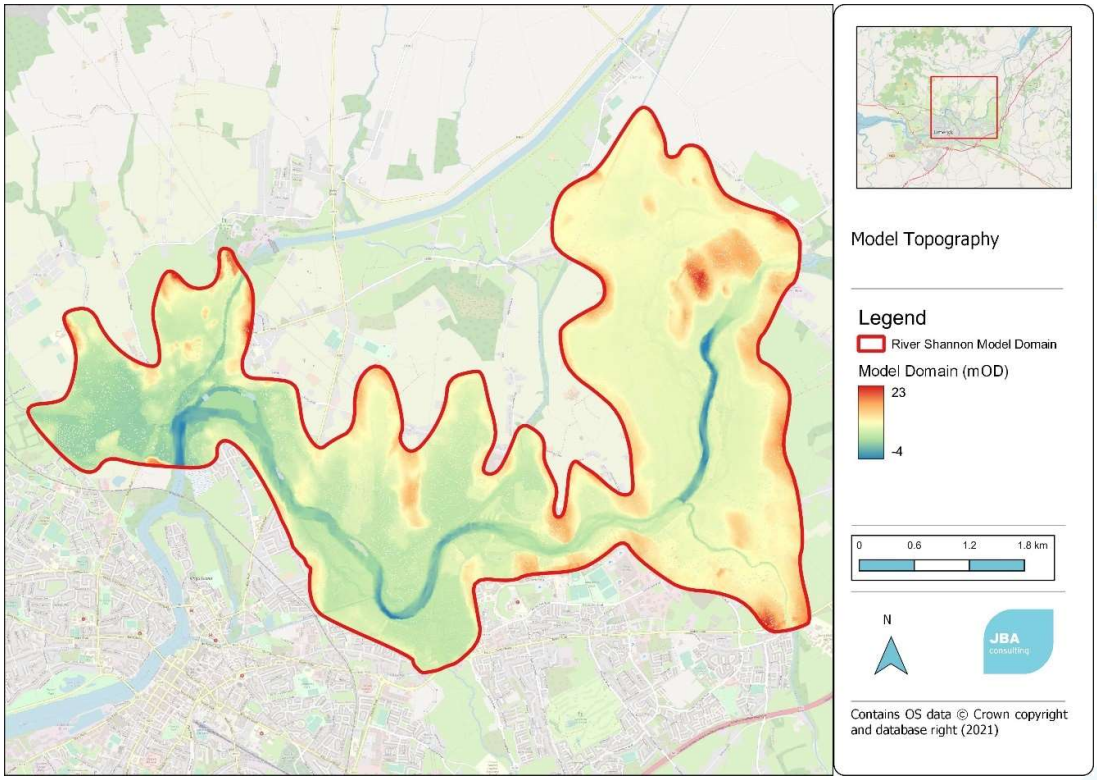



**Figure 4-4: Model Topography**

## 4.6 Roughness

Manning's *n* roughness value coefficients are required for 2D channels and model domain.

Google Satellite Imagery was used to provide a reasonable representation of key floodplain features, such as roads, vegetation, and buildings. The model's material file layer was compared to Google Maps ™ Aerial Imagery to ensure the accuracy of the data was fit for purpose across the study region. Assigned Manning's *n* values were reviewed and, if necessary, altered as part of the calibration process. 2D Manning's *n* roughness coefficients have been selected based on previous modelling experience and internal JBA guidance.

Figure 4-5 below shows the land use types across the model domain and Table 4-1 shows the Mannings *n* Value assigned to each land use type.

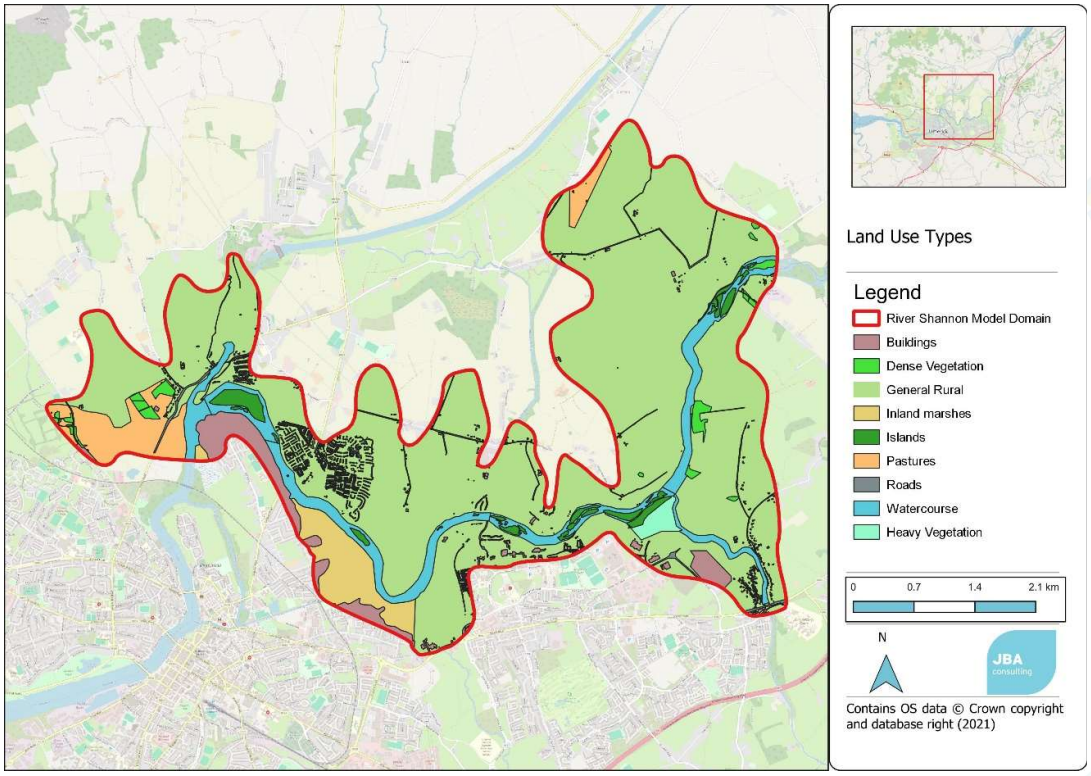



**Figure 4-5: Land Use Types**

**Table 4-1: Land Use Values**

| Land Use Type | Mannings *n* Value |
|---|---|
| Roads | 0.015 |
| Pastures | 0.033 |
| Short Grass | 0.035 |
| General Rural | 0.04 |
| Watercourse | 0.045 – 0.05 |
| Heavy Vegetation | 0.06 |
| Dense Vegetation / Islands | 0.08 |
| Buildings | 0.1 |

# 5 River Shannon Model Hydrology

The River Shannon model has been tested for 8 different flow events with an emphasis on Normal Flows. Five Normal Flow, or daily flow events were simulated along with three Flood events. These 8 events are discussed in detail below.

## 5.1 Normal Flows

For the Sediment Modelling, which is described in Section 6, the impacts of each of the scenarios are tested using normal flows, or daily percentage exceedance events. Normal flow events range from $Q_1$ to $Q_{99}$. The $Q_1$ refers to the daily maximum flow which was equalled or exceeded for 1% of an average year, while the $Q_{99}$ refers to the daily maximum flow which was equalled or exceeded for 99% of an average year.

The Normal Flow events which were selected for testing and agreed with the OPW are the $Q_{10}$, $Q_{30}$, $Q_{50}$, $Q_{70}$ and $Q_{90}$.

For the Normal Flow events, the model was run in a steady state condition. As these flows are based on daily percentage exceedance events the same event is used on both watercourses, unlike for the Flood Events where joint probability needs to be considered.

### 5.1.1 River Shannon

There are no flow gauging stations downstream of Parteen and so the records at Parteen have been used to assess the low flow hydrology on the Shannon (downstream of Parteen Weir). The daily flow data (up to May 2023) was provided by the ESB. The data was rearranged from the highest to lowest daily flow. Once the data was reordered, the Normal Flow events were extracted. Refer to Figure 5-1 for the daily flows on the River Shannon ordered from highest flow to lowest and where the normal flow events fit on the plot, the flow values were extracted. Refer to Table 5-1 for the Normal Flow estimation on the River Shannon.

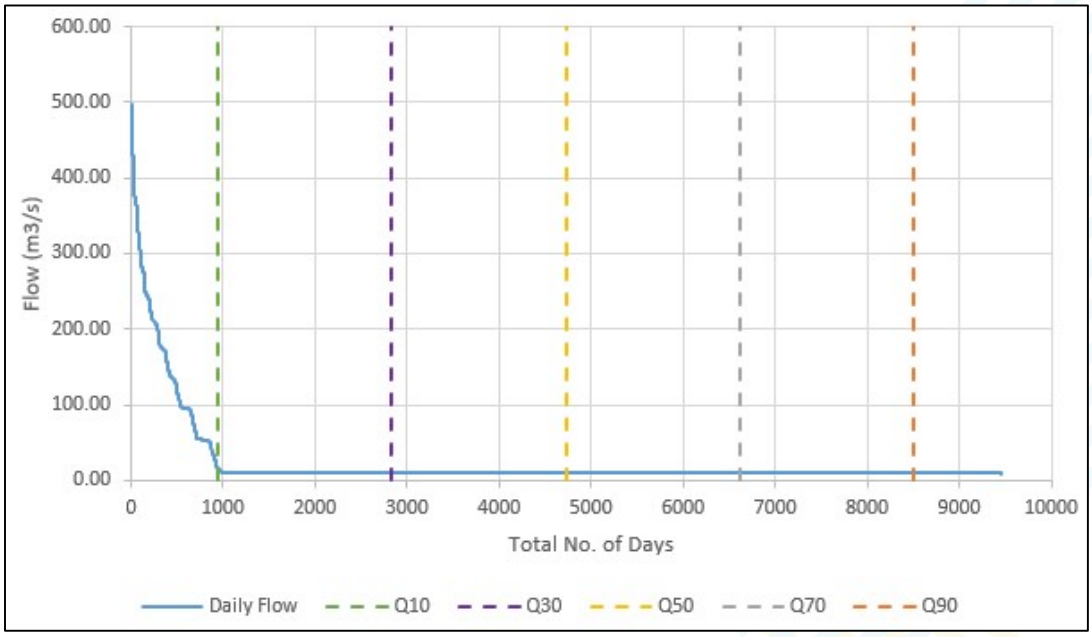



**Figure 5-1: River Shannon Daily Flows (Ordered from highest to lowest)**

### 5.1.2 Mulkear

On the Mulkear River, the Annacotty Gauging Station (25001) is located downstream of the Dublin Road bridge which has been used to estimate the flow percentiles on the Mulkear. The same approach was applied to the Mulkear River data set as the River Shannon, whereby the daily flows were ordered from highest to lowest and each of the normal flow values could then be extracted from the plot, refer to Figure 5-2 below.

The Normal Flows estimated on the Mulkear River are shown in Table 5-1 below.

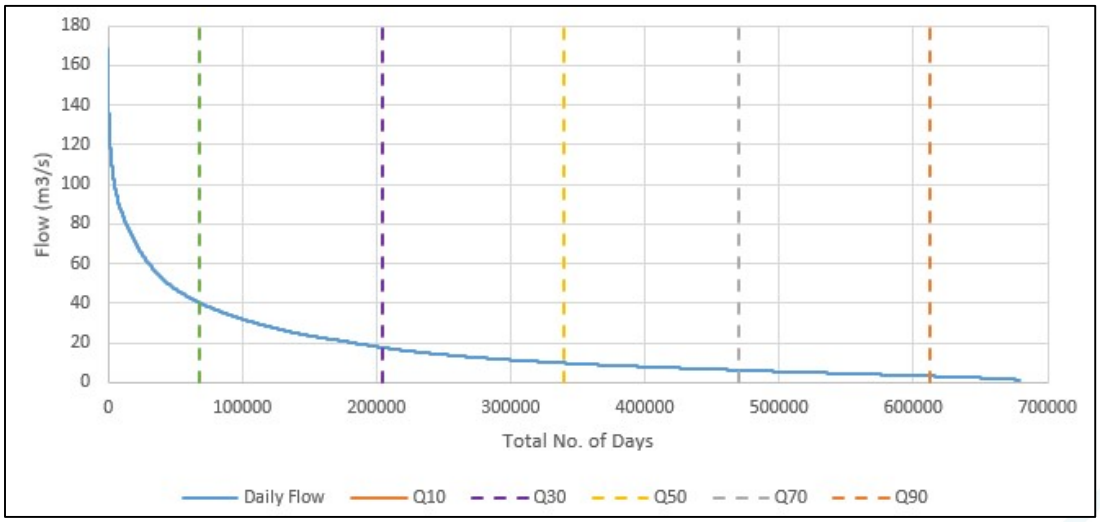



**Figure 5-2: Mulkear River Daily Flows (Ordered from highest to lowest)**

### 5.1.3 Tributaries

For the Kilmastulla and the Black River, hydrometric data is not available. For these watercourses, the HydroTool on the EPA website[2] was used to estimate the normal flows, refer to Table 5-1. These watercourses are tributaries of the River Shannon, which join upstream of the model domain and downstream of Parteen Weir, refer to Figure 5-3. Therefore, the Normal Flows for these tributaries shown in Table 5-1 were added to the River Shannon Normal Flows as the upstream inflows to the model.

It is noted that flows between Mulkear and Downstream boundary are not included in the model (including those from Ardnacrusha) and so the impact on defences in Limerick have not been quantified under this study, although a qualitative assessment has been undertaken.

**Table 5-1: Normal Flows**

| | Shannon | Mulkear | Kilmastulla | Blackriver |
|---|---|---|---|---|
| $Q_{10}$ | 15.08 | 40.01 | 4.16 | 1.04 |
| $Q_{30}$ | 9.69 | 17.71 | 2.16 | 0.51 |
| $Q_{50}$ | 9.30 | 9.71 | 1.31 | 0.31 |
| $Q_{70}$ | 9.30 | 6.02 | 0.77 | 0.20 |
| $Q_{90}$ | 9.30 | 3.26 | 0.38 | 0.11 |

2 https://gis.epa.ie/EPAMaps/water

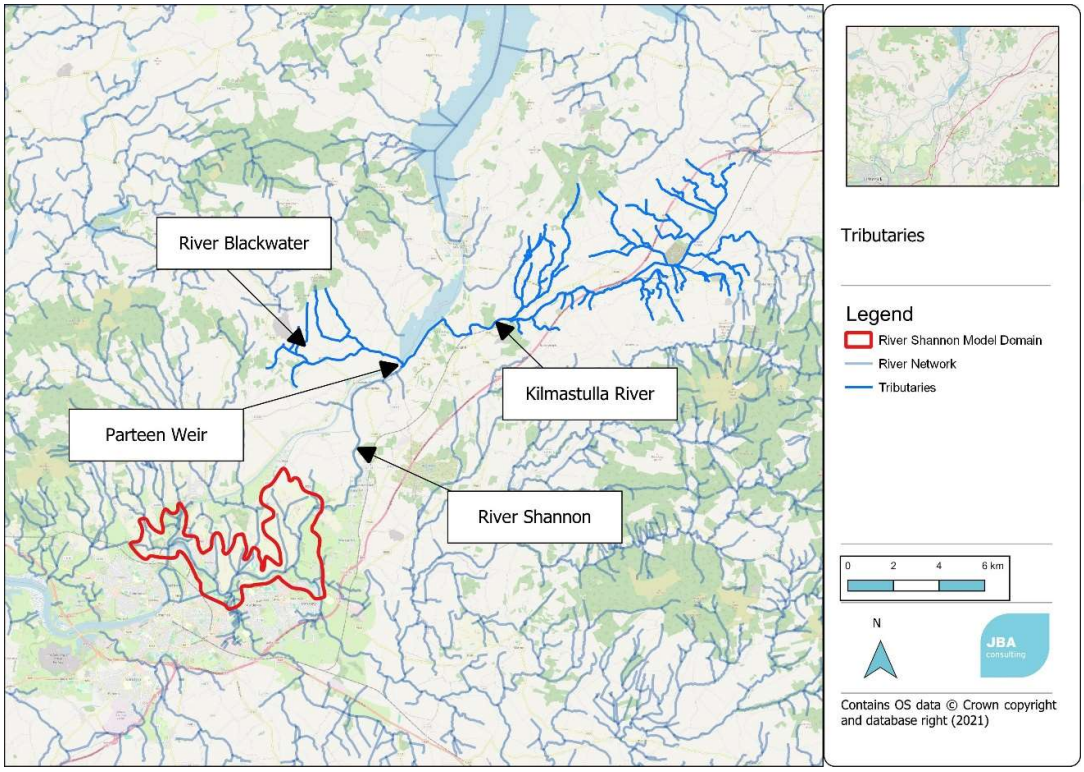



**Figure 5-3: Tributaries**

## 5.2 Flood Events

The flood events recommended by JBA to be tested in the model are the 50%, 10% and 1% AEP events. Two climate change scenarios will also be tested for each of the flood events;

- Mid-Range Future Scenario (MRFS) - 20% increase in flow value
- High-End Future Scenario (HEFS) - 30% increase in flow value

### 5.2.1 River Shannon

Extensive work on the River Shannon flows were completed as part of the Castleconnell Flood Relief Scheme which is described in detail in Appendix A.2. There is an overlap between the downstream extent of the Castleconnell FRS model and the River Shannon Model. Therefore, it was possible to extract inflow hydrographs from the Castleconnell FRS model and use them as the inflows for the River Shannon model.

Table 5-2 below shows the Flood flows extracted from the Castleconnell FRS model and Figure 5-4 shows the 1% AEP event hydrograph which is used in the model.

**Table 5-2: River Shannon Flood Flows**

| Flood Event (AEP) | Flow (m3/s) |
|---|---|
| 50% | 210 |
| 10% | 365 |
| 1% | 521 |

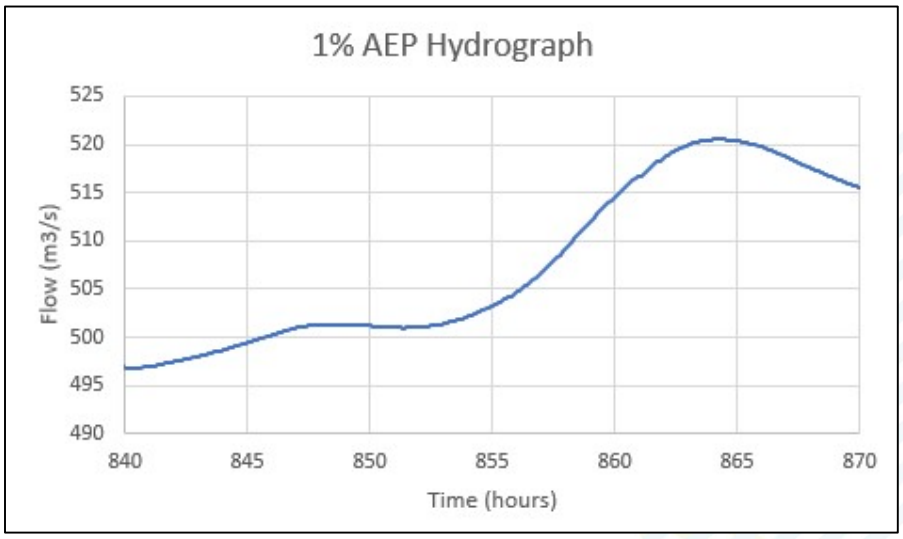



**Figure 5-4: 1% AEP Shannon Hydrograph**

### 5.2.2 Mulkear

Flow and rating information was not available from the Limerick City FRS, and so the CFRAM Study flows on the Mulkear were reviewed as part of the study. Annacotty Gauging Station (25001) is located downstream of the Dublin Road bridge on Reach 5, refer to Figure 5-5. The rating at this station was reviewed as part of the CFRAM. Only AMAX data from 1977 is recommended to be used for flood estimation, giving 33 years of data. Low confidence was given in the rating above QMED. Abington Gauging Station (25003) is located c. 10km upstream of the Annacotty station on

Reach 2. It has 56 years of AMAX data and the CFRAM modelled rating shows a good fit with the check gaugings. Both returned a relatively flat growth curve. Pooled analysis was also carried out as the 56 years of the AMAX series for the Abington Gauge only offers robust estimates up to 28 years. The pooled growth curves gave more conservative results than the at site growth curves. To acknowledge the important of local observations, the growth curve closest to the plotted AMAX data at the Abington gauge was adopted by the CFRAM for use along Reach 2 and 5.

The final inflows used in the model for the Mulkear River are shown in Table 5-3 below.

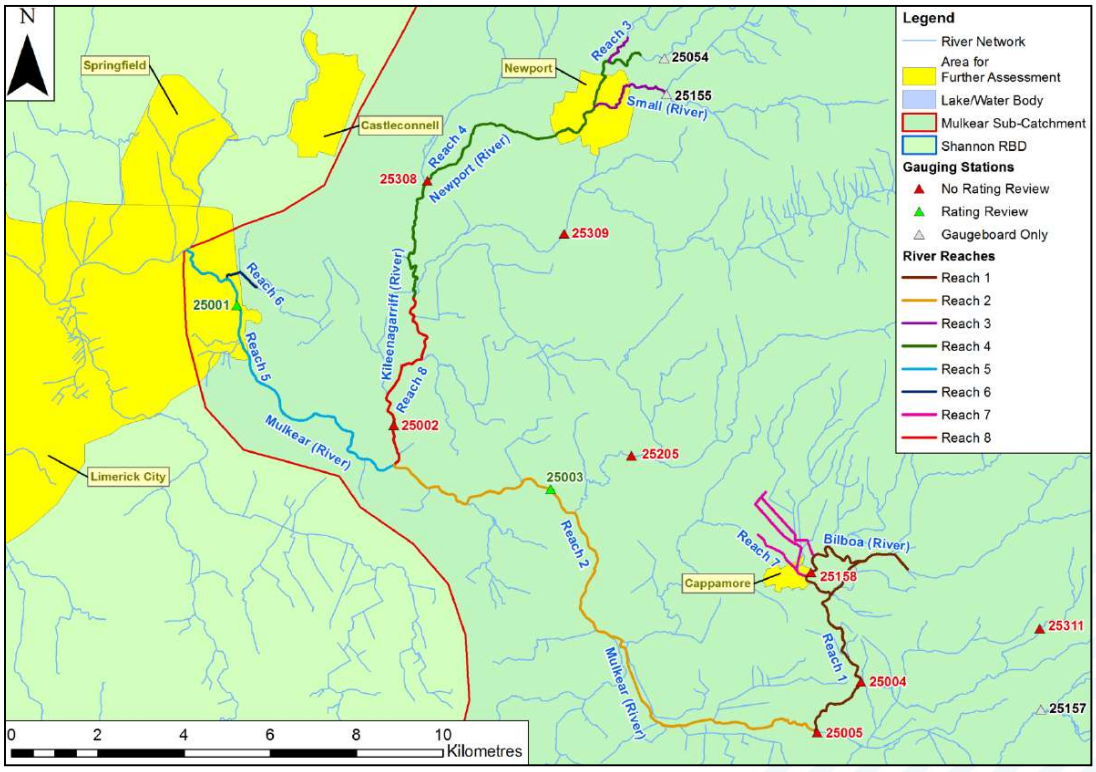



**Figure 5-5: CFRAM River Reaches**

**Table 5-3: Mulkear Flows**

| Flood Event (AEP) | Flow (m3/s) |
|---|---|
| 50% | 127 |
| 10% | 163 |
| 1% | 201 |

The hydrograph shape for Mulkear inflows was estimated using the Annacotty gauge. The 10 biggest events recorded on the gauge were analysed. As most of the flood events were over 20 years ago, the Top 4 events post- 2000 were plotted and are shown in Figure 5-6 below. The 2015 flood event was selected as the typical gauge shape and was adopted as the hydrograph shape for each of the flood events.

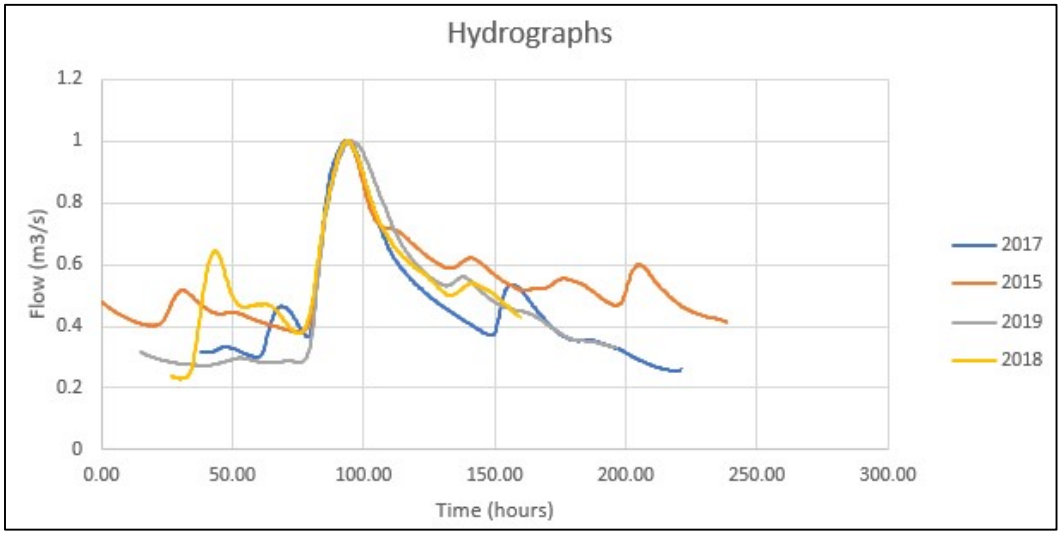



**Figure 5-6: Annacotty Flood Hydrograph Shapes**

### 5.2.3 Joint Probability

The Mulkear River and other tributaries in the model area have significantly smaller catchments than the River Shannon. Flood events in the Shannon can last for prolonged periods so it is possible that during a flood event on the Shannon when the water levels are high, a flood event could also occur on the smaller tributaries. This was the case during the 2015 flood event when the peak flow on the Mulkear River occurred on the 12th December while the peak flow recorded over Parteen Weir to the Old Shannon was from approximately the 12th - 16th December, refer to Figure 5-7. The flow data in Figure 5-7 was extracted from the Annacotty gauge on the Mulkear and the Parten Weir gauge for flows down the Old River Shannon.

The joint probability (JP) of flow events on the Shannon and the tributaries was assessed using the FSU Guidance for River Basin Modelling work package. Figure 5-8 is an example of the work package which indicates that during a 1% AEP event on the Shannon, a 14% AEP event is estimated for the Mulkear. As these AEP events are not the standard flood events for which the flows on the Mulkear have been calculated, the flood events on the Mulkear have been adjusted based on the nearest (and most conservative) available flow AEP event, i.e., where the 14% AEP event has been estimated from the FSU guidance with a 1% AEP event on the Shannon, the 10% AEP event on the Mulkear has been adopted. The estimate flood events on the Mulkear from the FSU guidance and the final flow events used in the model are shown in Table 5-4.

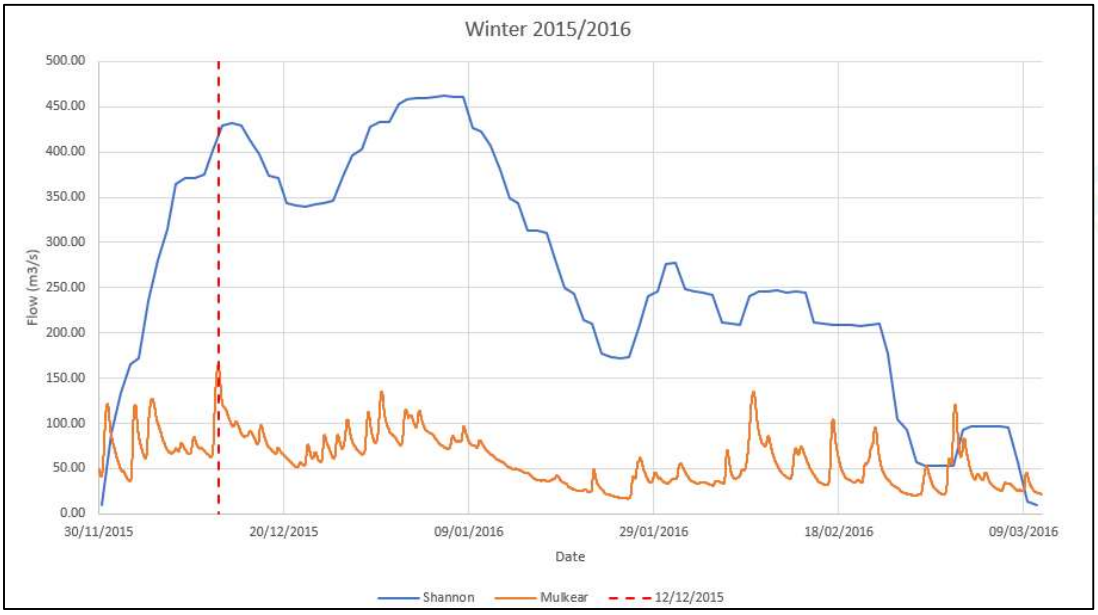



**Figure 5-7: Winter 2015 flows on the River Shannon and Mulkear**

| AEP at conditioning site: 0.01<br>Equivalent return period: 100 years | | | Table C-1: Dependence model results for different classes of pairwise catchment descriptors | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Connected | Difference of BFI within 0.3 | Centroids within 25 km | Ratio of AREA within a factor of 2.7 | Difference of FARL within 0.07 | 5%ile AEP | 25%ile AEP | Median AEP period at dependent site | 75%ile AEP | 95%ile AEP | No. of pairs in data | Interpretation of site configuration |
| TRUE | FALSE | FALSE | FALSE | FALSE | 1.000 | 1.000 | 0.989 | 0.732 | 0.102 | 4 | *Not enough data |
| TRUE | FALSE | FALSE | FALSE | TRUE | NA | NA | NA | NA | NA | 0 | * |
| TRUE | FALSE | FALSE | TRUE | FALSE | 0.972 | 0.480 | 0.188 | 0.052 | 0.002 | 4 | *Not enough data |
| TRUE | FALSE | FALSE | TRUE | TRUE | NA | NA | NA | NA | NA | 0 | * |
| TRUE | FALSE | TRUE | FALSE | FALSE | NA | NA | NA | NA | NA | 0 | |
| TRUE | FALSE | TRUE | FALSE | TRUE | NA | NA | NA | NA | NA | 0 | * |
| TRUE | FALSE | TRUE | TRUE | FALSE | NA | NA | NA | NA | NA | 0 | * |
| TRUE | FALSE | TRUE | TRUE | TRUE | NA | NA | NA | NA | NA | 0 | * |
| TRUE | TRUE | FALSE | FALSE | FALSE | 0.596 | 0.295 | 0.140 | 0.054 | 0.006 | 2 | Not enough data |

**Figure 5-8: FSU Guidance for River Basin Modelling work package – 1% Example**

**Table 5-4: FSU Guidance - Mulkear Flows**

| Flood Event on the Shannon (AEP%) | Flood Event at Mulkear (FSU Guidance) (AEP%) | Flood Event Used in Model (AEP%) |
|---|---|---|
| 50% | 70% | 50% |
| 10% | 47% | 50% |
| 1% | 14% | 10% |

## 5.3 Downstream Boundary

The downstream boundary of the model is based on the Mean Spring Tide abstracted from the ICPSS model used within the King's Island FRS study. The tidal data is shown in Figure 5-9 below. Extensive work was completed on the downstream boundary application as part of the Kings Island Flood Relief Scheme which is why it was adopted for this study. This downstream boundary is more appropriate than extracting information for any of the gauges in Limerick City as only the tidal plot is considered rather than the tidal and fluvial impacts which would be observed at the gauges in Limerick City. The model area is outside of the zone of tidal influence, nevertheless sensitivity testing was undertaken, refer to Section 7.3 below.

Since the King's Island FRS study has been completed, the ICPSS has been superseded by the ICWWS. Sensitivity testing has been completed on the downstream boundary in Section 7.3. The model was shown not be sensitive to the downstream boundary condition, so the ICPSS information was not updated.

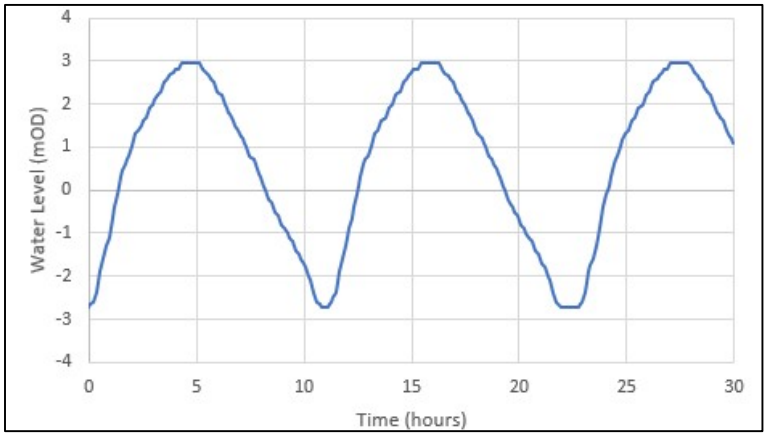



**Figure 5-9: Mean Spring Tide Plot**

# 6 Sediment Modelling

This section details the different scenarios that were considered as part of the study to help understand the flow and sediment regime in the Mulkear River and what happens when it enters the Shannon, and the impacts of each of the options considered.

## 6.1 Baseline Model

The existing condition of the Mulkear and the Shannon was first modelled using the River Shannon Telemac model (described in Section 4) to set the baseline for which to compare the results of each of the different scenarios listed below. As discussed in Section 5, 5No. of the modelled flows are Normal Flow events and 3No. are Flood Events.

Model validation and sensitivity testing has been completed on the baseline model to ensure the model accurately represents the existing condition to the best of our knowledge based on the available information, refer to Section 7.

The model uses the Normal Flows and Flood Flows to assist in refining the areas, spatially, which have the potential for deposition and erosion by identifying the velocity patterns within the channel.

The baseline model results are discussed in the sections below. While the flood extents for all the assessed events are provided in the figures below, the in-depth analysis on the water depths and velocities has focused on the $Q_{10}$ Normal Flow and the 50% AEP Flood Event based on the following rationale:

- The $Q_{10}$ Normal Flow is considered representative of a typical winter flow. It is commonly examined in hydromorphological studies because it is key to flushing (i.e. eroding and transporting) fine sediment such as silts and fine sands that may be deposited during low to average normal flow conditions. These flows are expected to remain in-channel.
- The 50% AEP is often used as a proxy for bankfull conditions and is assumed to represent the maximum energy condition of the river channel during flood conditions. Under these conditions, maximum shear stress is exerted on the bed and banks and therefore examining these hydraulic conditions builds an understanding of the maximum erosion and transportation capacity of the river.

These flows represent the flushing dynamics of the river system. By interpreting the hydraulic conditions associated with these flows, an understanding can be developed of: i) whether the river system can sustainably manage the sediment supply that might be deposited under normal flow conditions, and ii) what might be mobilised, transported, and deposited during flood conditions. Together this builds a conceptual understanding of the prevailing sediment dynamics under the current flow regime.

The baseline hydraulic model results show that flow begins to spill out of bank in a 50% AEP event into the surrounding floodplain. This implies that there is the potential for significant morphological change and associated transport competence to occur during both $Q_{10}$ and 50% AEP conditions, given they represent high flow scenarios where flow is largely contained in-channel ($Q_{10}$) and where flow is beginning to overtop the banks (50% AEP). This supports the rationale that both flow events are appropriate for investigating the geomorphological function of both the Mulkear River and the Old Shannon.

### 6.1.1 Baseline Model Flood Extents

The modelled extents for the Normal Flow events are shown in Figure 6-1. The Flood Events which were modelled are shown in Figure 6-2.

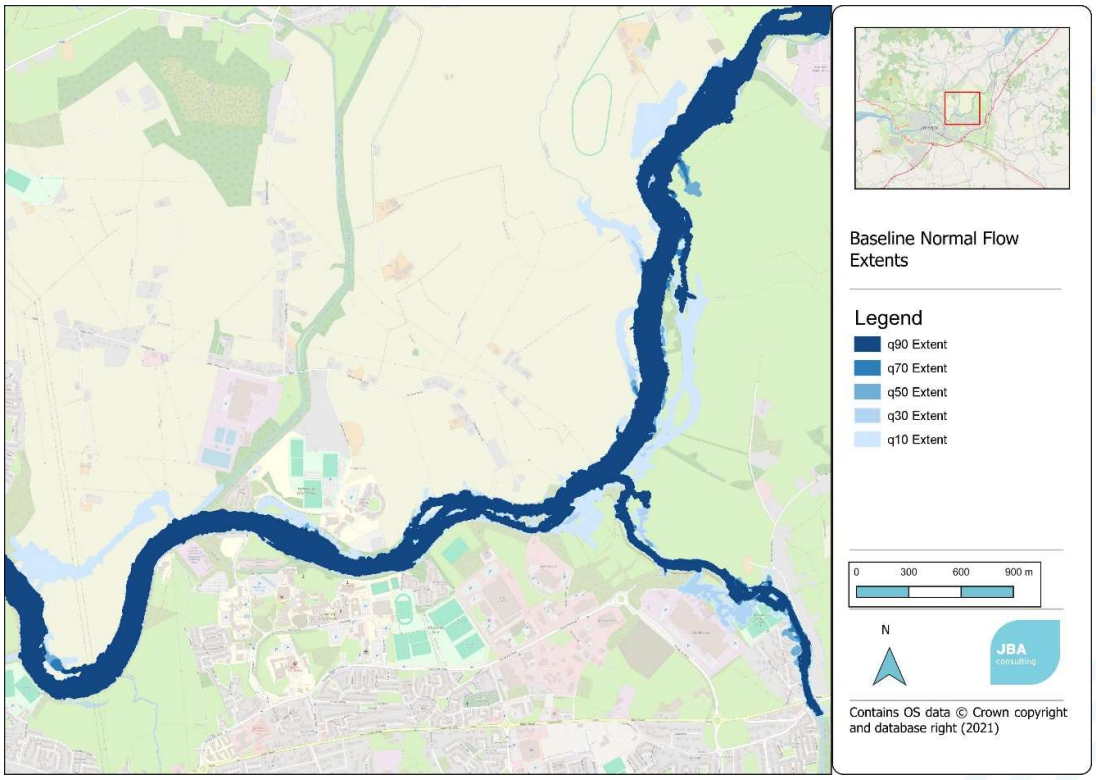



**Figure 6-1: Baseline Normal Flow Extents**

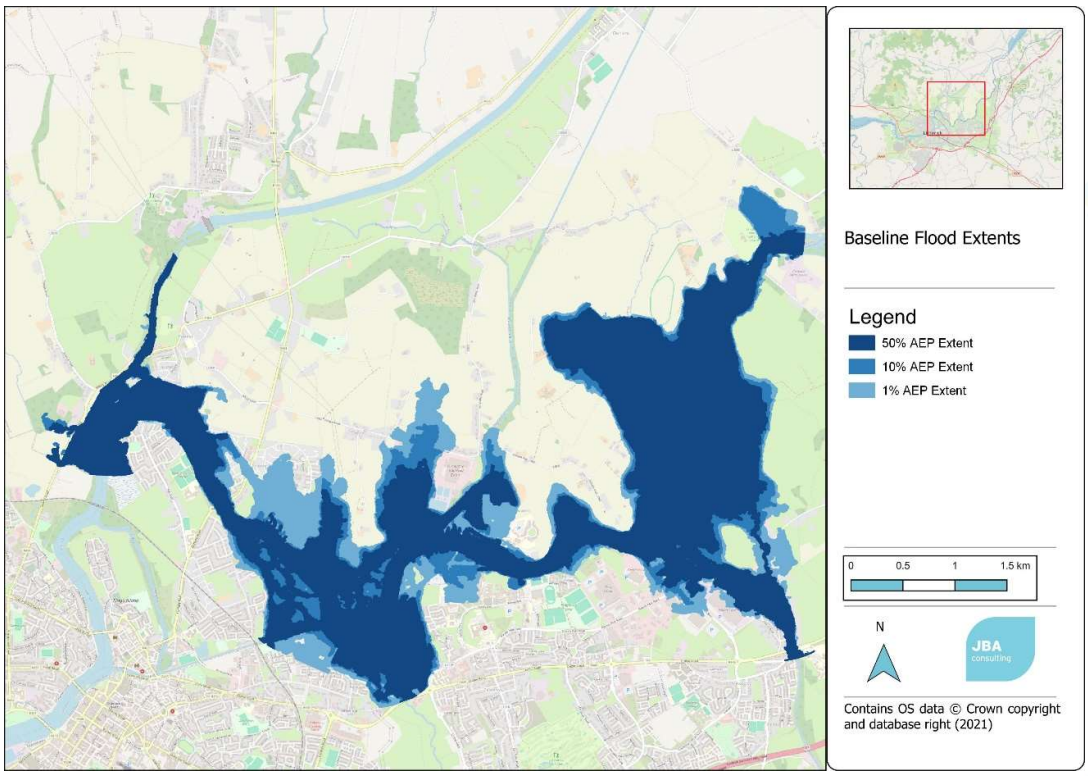



**Figure 6-2: Baseline Flood Flow Extents**

### 6.1.2 Baseline Model Water Depths

The water depths for the $Q_{10}$ Normal Flow and the 50% AEP Event are shown in Figure 6-3 and Figure 6-4, respectively. For both events, the flood depths in the channel are significantly greater upstream of the confluence on the River Shannon, with depths of up to 8m in the $Q_{10}$ Normal Flow events and up to 9.5m in the 50% AEP Event. Downstream of the confluence, depths decrease to approx. 3m in the $Q_{10}$ Normal Flow event and 4.5m in the 50% AEP Event. This difference in water depth between upstream and downstream of the confluence with the Mulkear is due to the topography of the river bed, which significantly increases in bed level from -0.8mOD upstream of the confluence to 1.37mOD downstream of the confluence

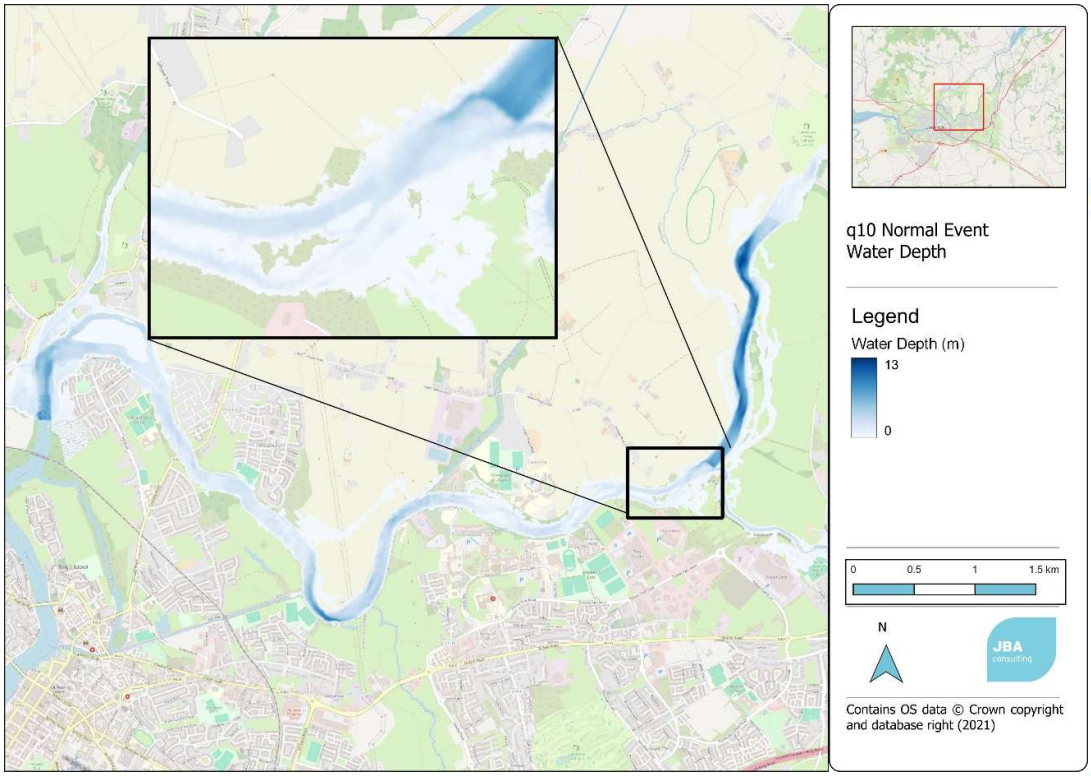



**Figure 6-3: $Q_{10}$ Normal Flow Water Depth**

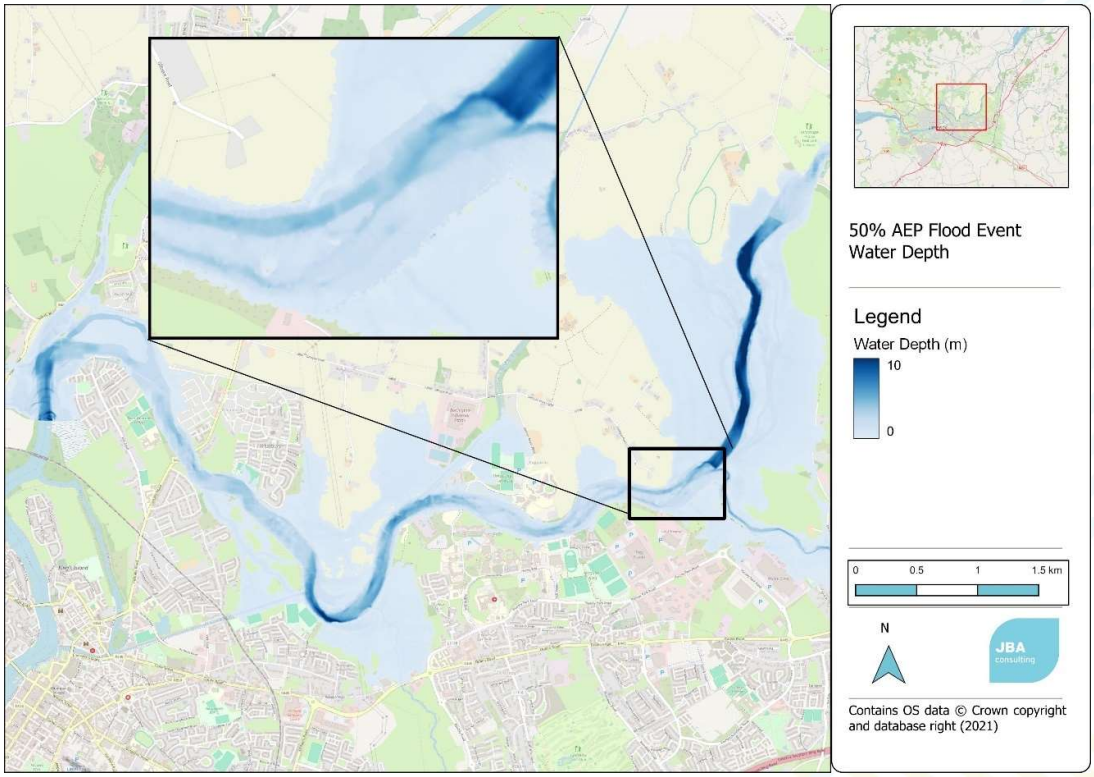



**Figure 6-4: 50% AEP Flood Event Water Depths**

### 6.1.3 Baseline Model Velocities

The velocities for the $Q_{10}$ Normal Flow and the 50% AEP Flood Event are shown in Figure 6-5 to Figure 6-10 below. For the $Q_{10}$ Normal Flow event, Figure 6-5 gives an overview of the maximum depth-averaged velocities across the model, while Figure 6-6 provides a detailed view of velocities at the confluence between the River Shannon and the Mulkear and Figure 6-7 shows the velocities downstream of this location. For the 50% AEP flood event, Figure 6-8 gives an overview of the velocities, Figure 6-9 provides a detailed view of velocities at the confluence and Figure 6-10 shows the velocities downstream.

For both events, velocities are shown to be very low upstream on the River Shannon upstream of the confluence but increase downstream of the confluence with the additional flow inputs from the Mulkear River. Velocities are lower in the out of bank areas compared to the velocities in the channel.

When comparing the two events shown below, the 50% AEP Flood Event indicates higher velocities than $Q_{10}$ Normal Flow event along the length of the Reach. The $Q_{10}$ Normal Flow event estimates an isolated area of very high velocities when the Mulkear enters the River Shannon. This only occurs in the $Q_{10}$ Normal Flow event when the flow remain primarily in channel and is funnelled along the thalweg of the Mulkear River where it joins the River Shannon. While higher velocities may occur along this thalweg, the modelled velocities are possible estimating higher velocities than may actually occur. Without data for which to validate the velocities at this location in the $Q_{10}$ Normal Flow event, the accuracy of these velocities cannot be confirmed. However, throughout the modelling scenarios completed in the Sections below, these potentially higher velocities do not impact any of the overall model findings or conclusions of the scenarios tested.

It is noted that high velocities are estimated at the downstream boundary of the model. These higher velocities are a result of the influence of the tidal boundary at this downstream boundary. These high velocities at the downstream boundary do not impact the velocities along the Reach, as per the sensitivity testing on the downstream boundary in Section 7.3.

It is noted that in some of the lower normal flow events, an isolated section of high velocities is presented in the channel which cannot be verified as the information is not available. As with the high velocity in the thalweg during the $Q_{10}$ Normal Flow event described above, the model results are still useful in providing the overall sediment regime in the channel for each of the flow events tested.

Given repeat bathymetric survey is planned in the future for the confluence zone, there may be an opportunity to investigate whether coincident ADCP flow gauging could offer potential validation of modelled velocities. It is unknown whether ADCP outputs can provide depth-averaged velocities for comparison with the model results.

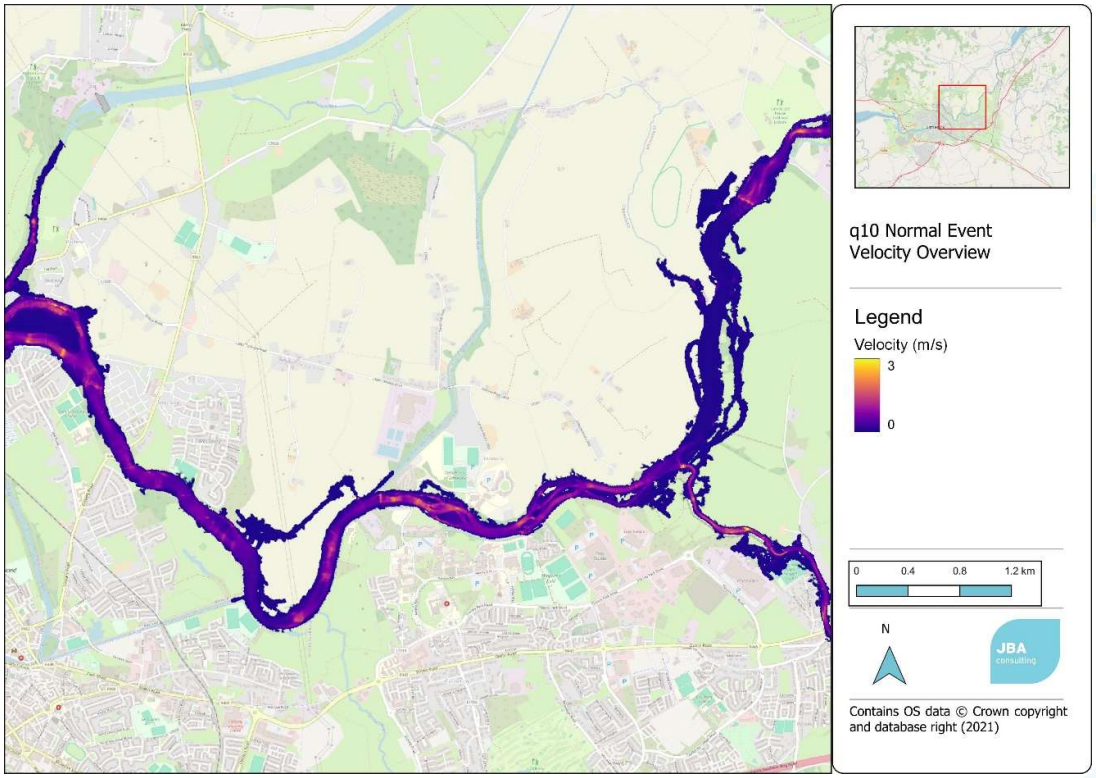



**Figure 6-5: $Q_{10}$ Normal Flow Velocities - Overview**

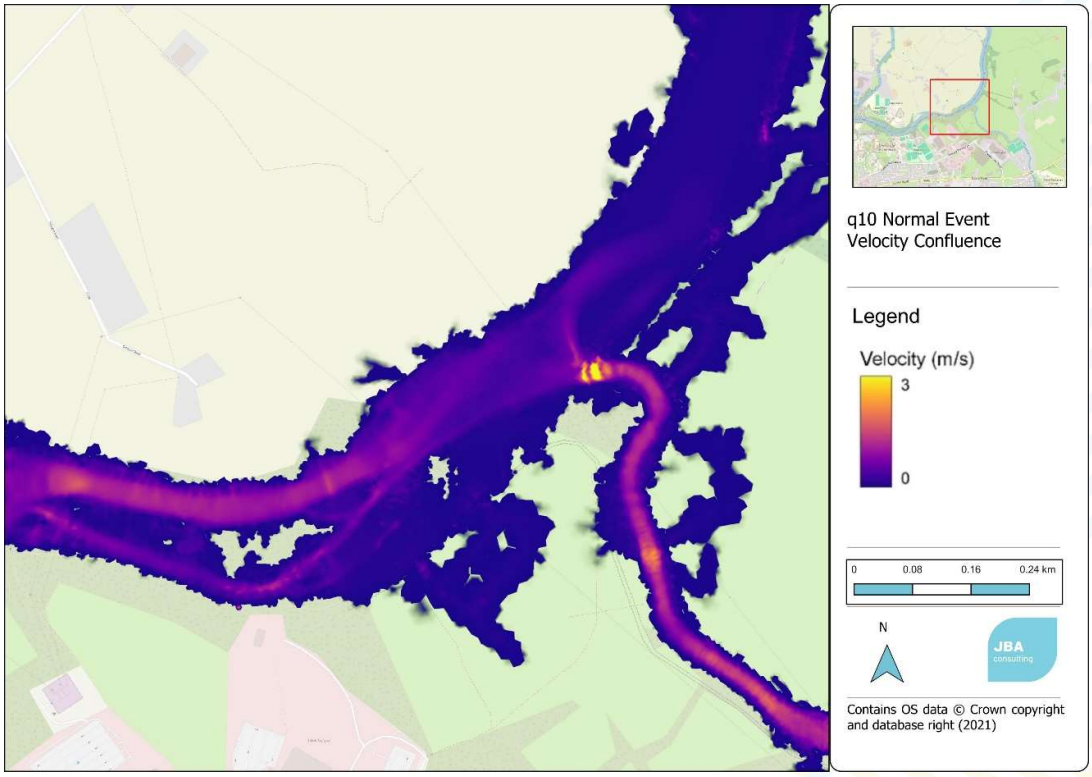



**Figure 6-6: $Q_{10}$ Normal Flow Velocities – River Shannon and Mulkear Confluence**

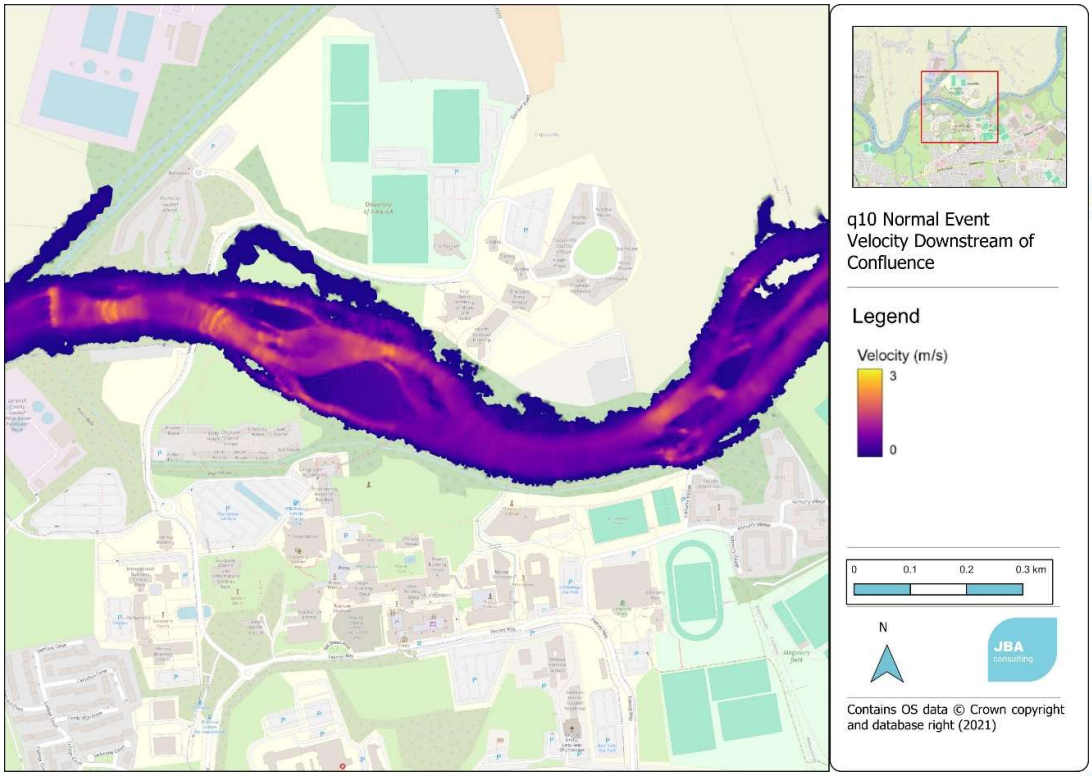



**Figure 6-7: $Q_{10}$ Normal Flow Velocities – Downstream of Confluence**

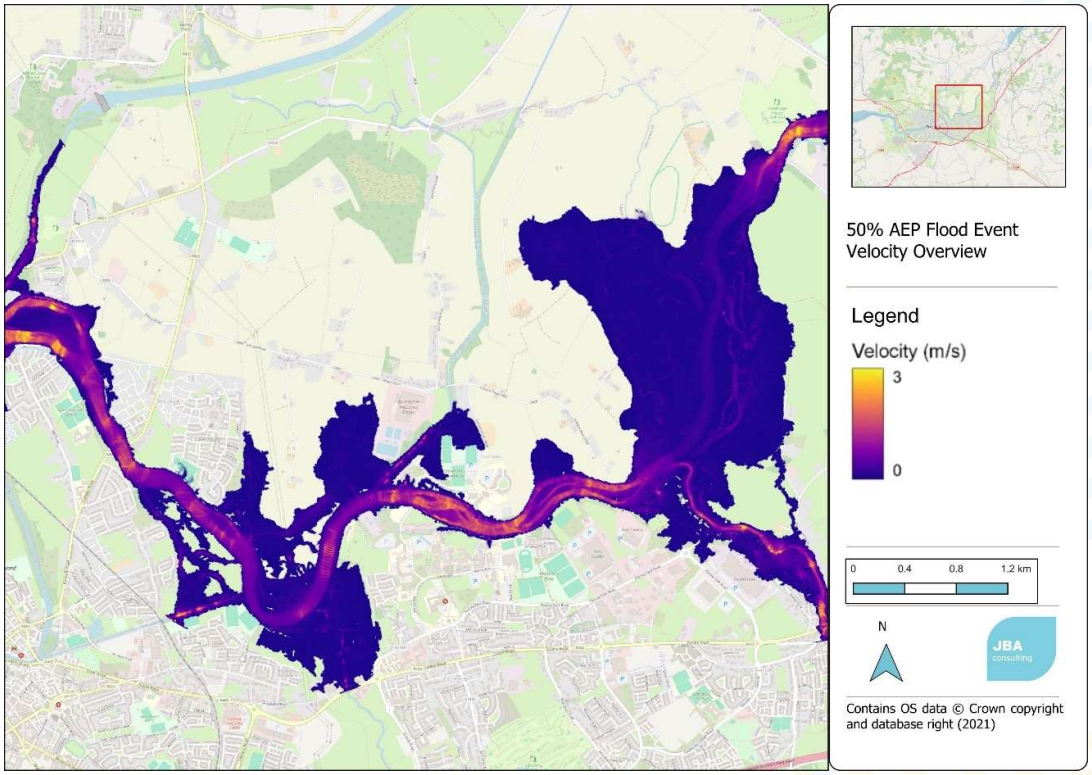



**Figure 6-8: 50% AEP Flood Event Velocities Overview**

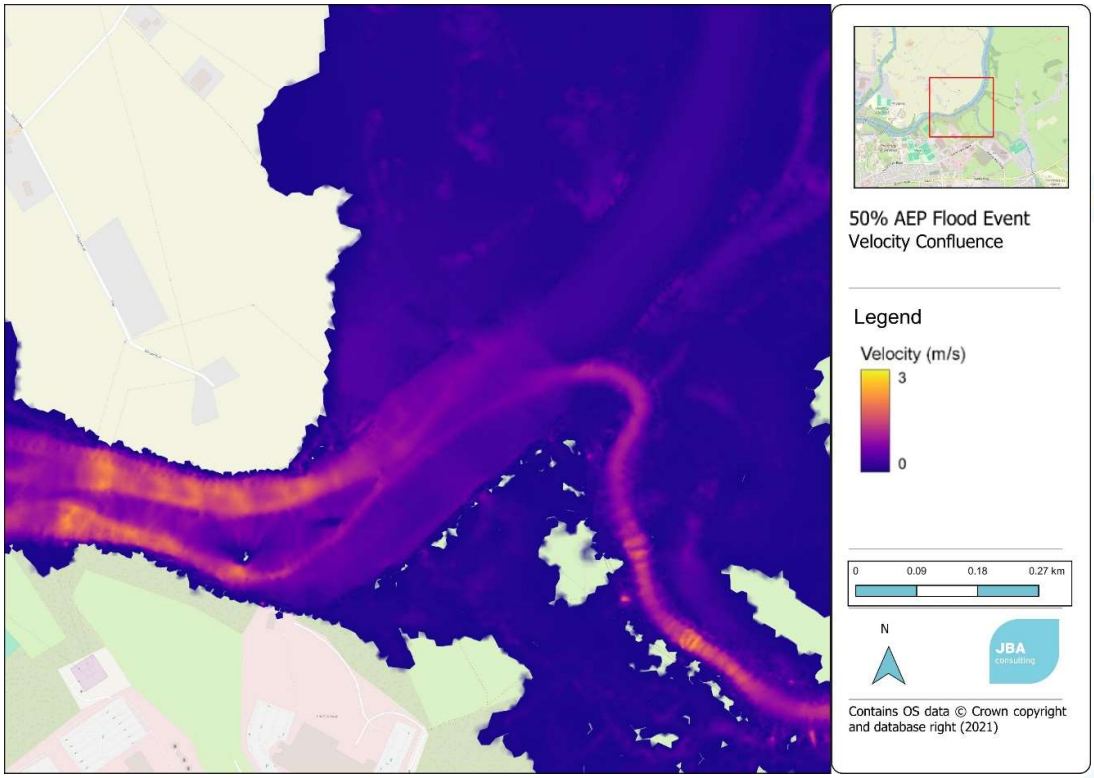



**Figure 6-9: 50% AEP Event Velocities – River Shannon and Mulkear Confluence**

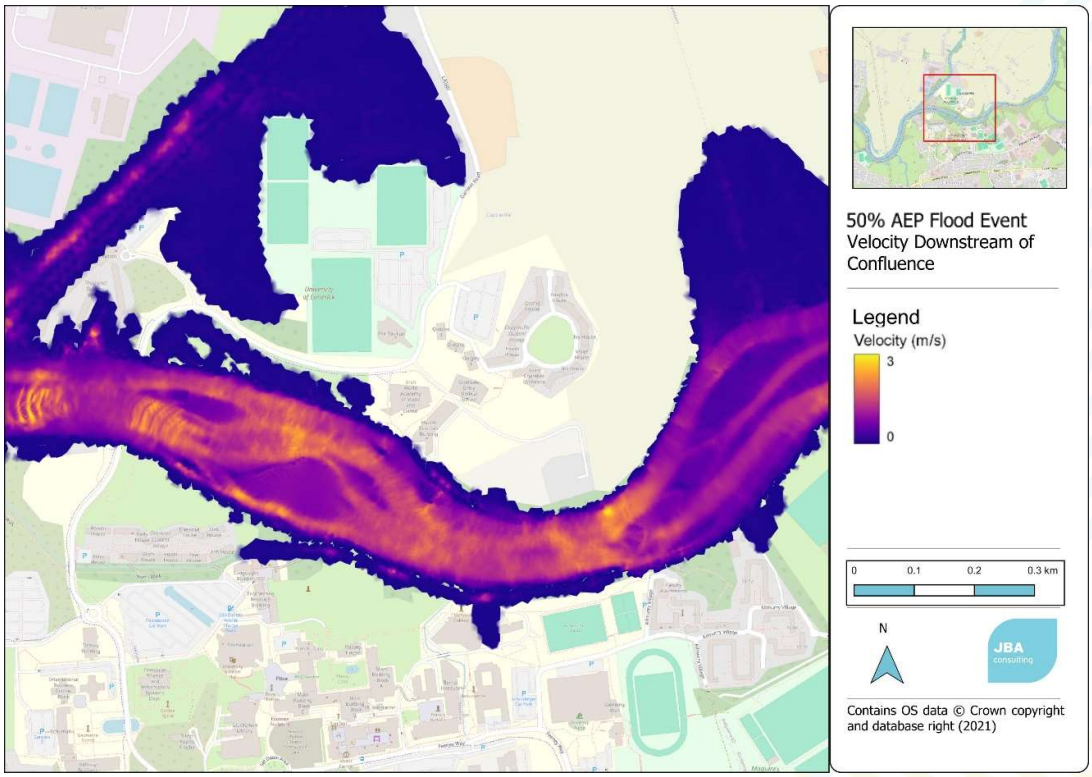



**Figure 6-10: 50% AEP Event Velocities – Downstream of Confluence**

## 6.2 Hydromorphology Report

JBA Consulting was commissioned by the Office of Public Works to undertake a Hydromorphological Report to inform feasible options for the management of sediment and vegetation in the Mulkear River and the Old River Shannon channel in Limerick and Clare[3]. This report is an extension of a previous hydromorphological fluvial audit of the Mulkear catchment produced by JBA Consulting in October 2022.

### 6.2.1 Hydromorphological interpretation (baseline modelling)

The Baseline Model results were analysed to map the predicted maximum mobilised particle size i.e., the critical particle size entrained by each modelled flow. This information was used to develop a conceptual understanding of how different sediment fractions behave through the confluence zone under different flow conditions. For a detailed explanation of this methodology, see Section 4.2.3 and Appendix A of the Hydromorphology Report. This conceptual understanding is described below with figures that illustrate key points.

Baseline model results indicate that under Normal Flow conditions up to median annual flows (i.e., $Q_{90}$, $Q_{70}$, and $Q_{50}$), the confluence zone is competent to entrain up to a coarse sand fraction. This means that most clays, silts, and fine to medium sands can be carried through the confluence zone. Deposition of these materials is likely limited to the channel margins where bank roughness induces localised lower shear stress, and also at the wet woodland that experiences greater connectivity as flows increase. Fine sediment such as silts and clays would be expected to deposit here, and over the course of a typical year, some consolidation and vegetation may occur depending on the frequency and nature of inundation.

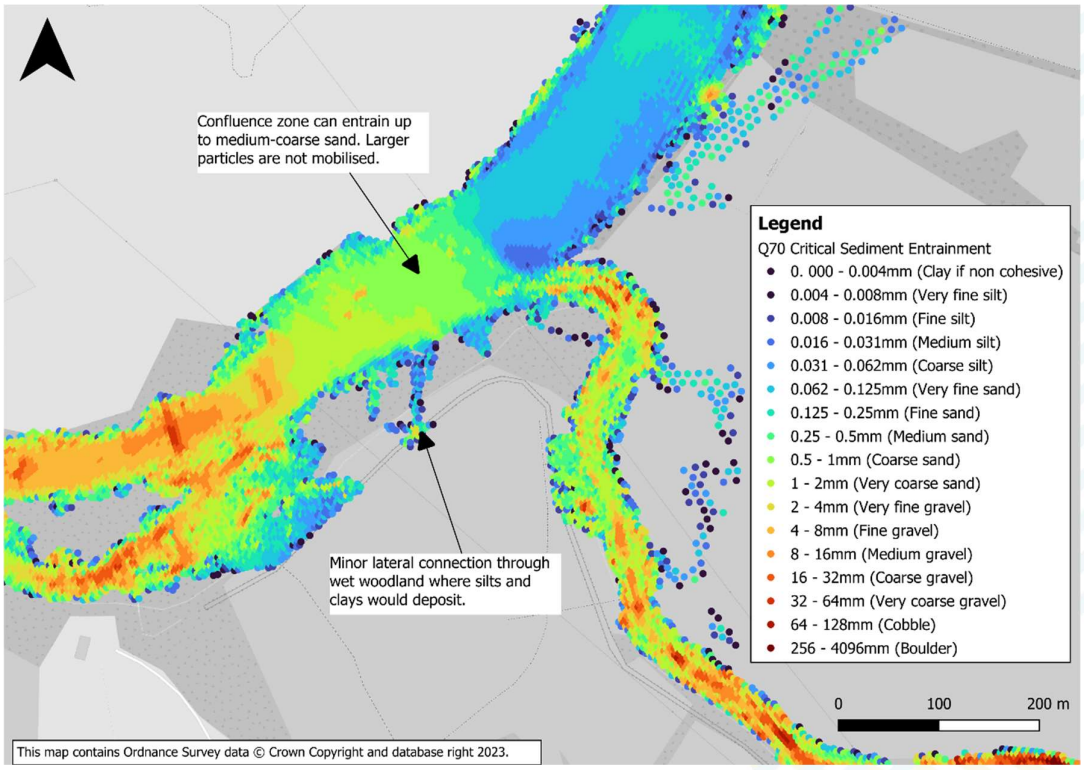



**Figure 6-11 Sediment dynamics under a modelled $Q_{70}$ normal flow.**

[3] Hydromorphology Report Title: IAY-JBAI-XX-XX-RP-HM-0020-S3-P01-Hydromorphology_Report

As flows increase ($Q_{30}$), the thalweg begins to experience different hydraulic conditions to the wider confluence zone (i.e., the sections outside of the thalweg towards the left and right banks). Results show the thalweg is competent to entrain very coarse sand, whereas the remainder of the confluence zone entrains up to a coarse sand. This marks the beginning of different flushing conditions across the width of the confluence zone i.e., less flushing of the largest sands closer to the banks relative to the thalweg. Most clays and silts can be carried through the confluence zone, though deposition of these materials remains likely at the channel margins. No gravel mobilisation occurs within the confluence zone. Under this flow condition, more lateral connectivity occurs through the wet woodland though again, localised roughness by vegetation will induce deposition of finer material (clays, silts, fine sands).

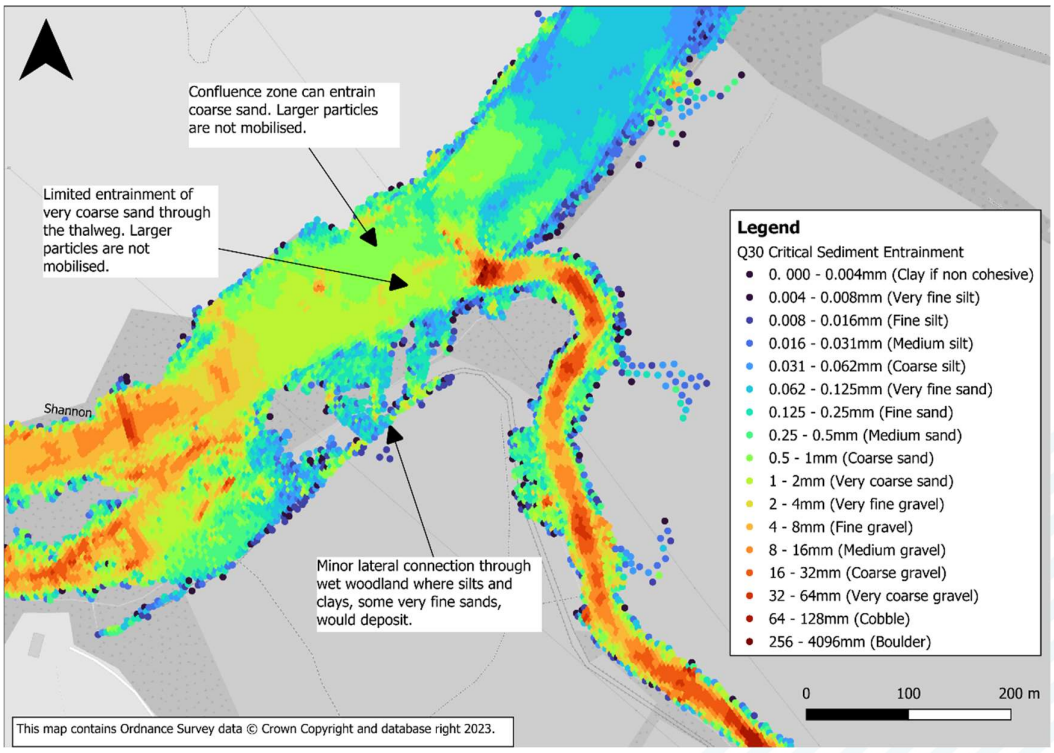



**Figure 6-12 Sediment dynamics under a modelled $Q_{30}$ normal flow.**

Under typical winter flow conditions ($Q_{10}$), the difference between the thalweg and wider confluence zone become more pronounced. The thalweg is competent to entrain very fine to fine gravel, whereas the remainder of the confluence zone entrains up to a very coarse sand. This means more flushing of sands occurs across the confluence zone, but that the mobilisation of any fine gravels is largely contained within the thalweg. Given a winter flow is a key flushing flow for year-on-year management of sediment supply, and the Mulkear is recognised to supply large sediment fractions (such as medium and coarse gravels) into the confluence zone, this means that the wider confluence zone remains a depositional zone for all gravels and the thalweg mobilises some but not all the incoming gravel fraction. Any sediment at or larger than a medium gravel is not being flushed through the thalweg, which features the greatest flushing potential. Additionally, the wet woodland is fully connected at this flow and a balance of mobilisation and deposition is expected as vegetation resists shear stresses. Unconsolidated material (clays, silts, fine sands) remains vulnerable to some re-working whereas sediment that has had time to

properly consolidate and vegetate would remain. This explains the expectation that the wet woodland will experience long term vertical aggradation.

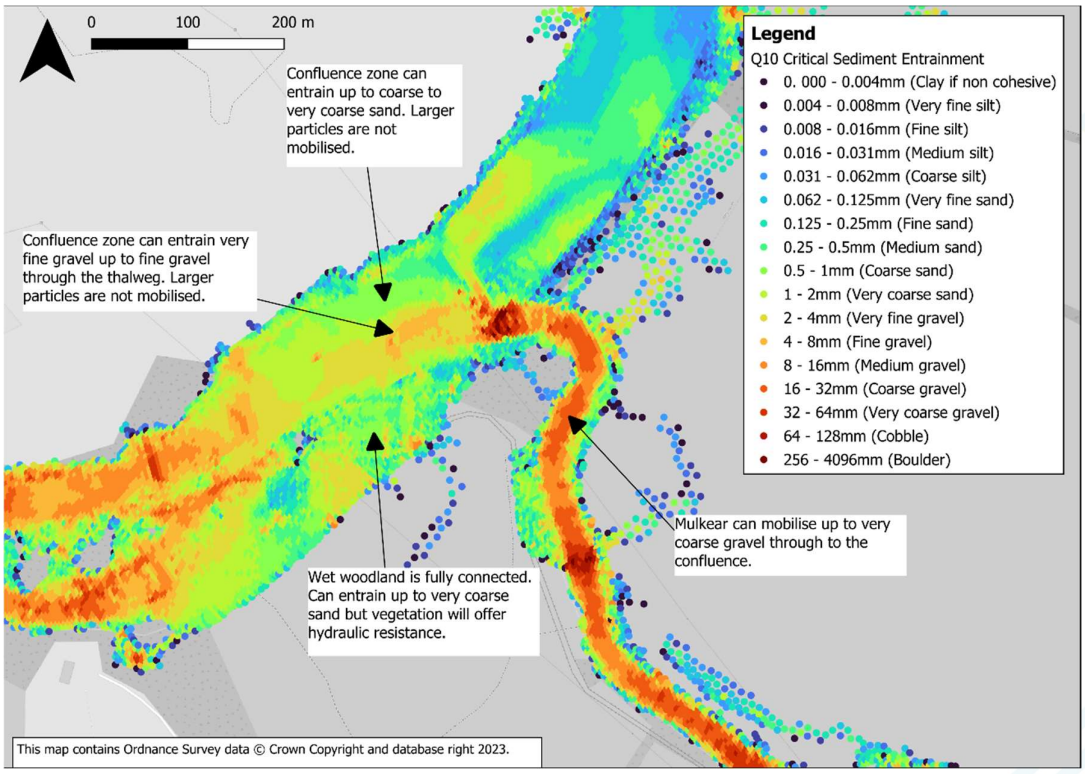



**Figure 6-13 Sediment dynamics under a modelled $Q_{10}$ normal flow.**

Bankfull flow conditions, expected to occur approximately every two years and representing the maximum energy condition of the river during flood conditions, play an important role in entraining sediment that is not moved on an annual basis under the typical winter flow conditions. However, model results indicate that hydraulic conditions at the thalweg and towards the right bank of the confluence zone are not markedly different between these flow scenarios. The same very fine to fine gravels can be mobilised but the entrainment zone of gravels is larger in extent under bankfull flows than the $Q_{10}$ flow scenario. Instead, the main difference is seen at the wet woodland where shear stresses are higher, suggesting greater potential for geomorphic reworking under bankfull conditions. While the roughness of the vegetation will resist these shear stresses, any unconsolidated deposition from lower flows will likely re-mobilise, and some scour of fine gravels may occur. However, sediment that has had time to properly consolidate and vegetate would likely remain. Overall, there is more potential for geomorphic work to be done to reshape the confluence zone under bankfull conditions, but the entrainment of coarse gravels remains limited.

As such, there is an overall aggradation dynamic at the confluence zone driven by the transport disparity between the Mulkear and the Old Shannon for gravel fractions. Where fine sediment deposition may occur in the confluence zone (i.e., not at the channel margins), the flushing conditions across the confluence zone during $Q_{10}$ and bankfull events are enough to prevent long-term consolidation from taking place. This is evident by a lack of vegetating mid-channel bar features as observed in the field (see Fluvial Audit report). Coarse sediment dynamics are the primary control on the aggradation dynamic at the confluence.

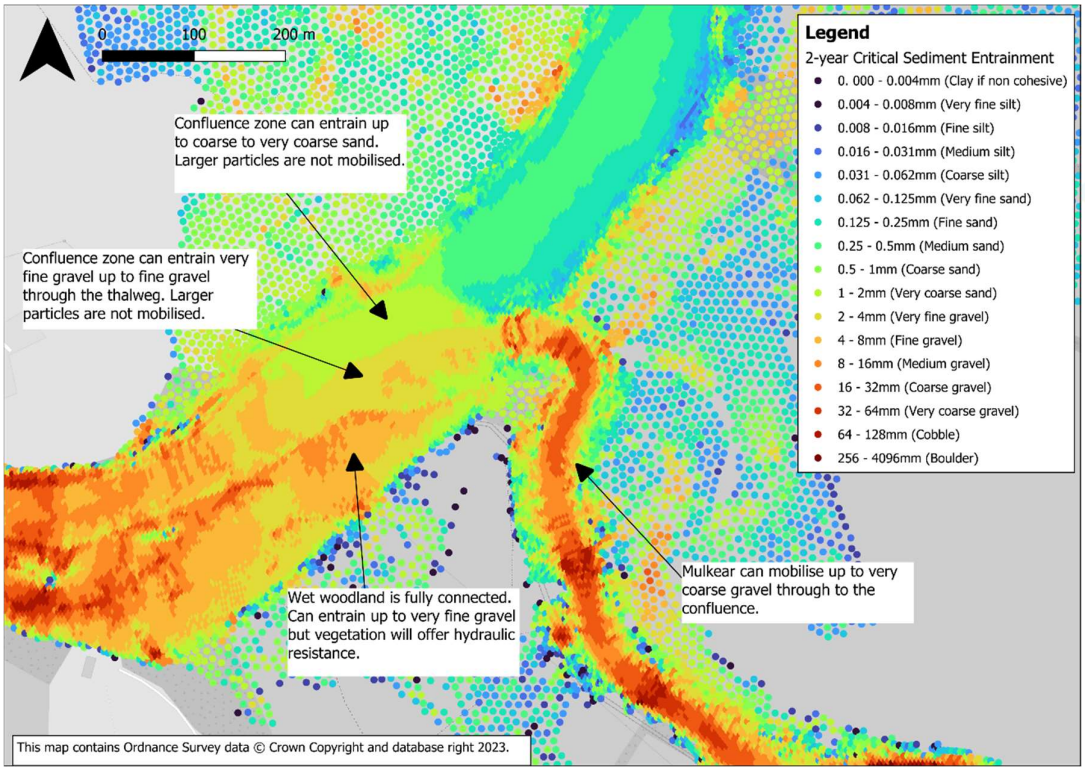



**Figure 6-14 Sediment dynamics under a modelled bankfull (50% AEP) flow.**

### 6.2.2 Continued Areas of Sedimentation

Based on the conclusions drawn from the Hydromorphological assessment, areas likely to have continued sedimentation along the Reach were identified to help inform the basis of the scenarios described in Section 6.3 and 6.4 below. The process for identifying these areas is described below.

Modelled $Q_{10}$ Normal Flow velocities were reviewed against the Hjulström curve (Figure 6-15 below) to categorise velocity predictions into ranges for deposition, transport and erosion. It is noted that the Hjulström Curve simplifies the flow characteristics into two axes. Actual flow characteristics are much more complex, and may not accurately represent what will happen in detail. However, the Hjulström Curve still provides a useful indication of what may occur[4].

Individual particle size classes were reviewed adopting the following sizes for banding: large silts (0.0625mm), large sands (2mm), very fine gravel (4mm), fine gravel (8mm) and medium gravel (16mm). Of the established bandings, the areas in the River Shannon which show 2mm sand and 4mm very fine gravels as being the maximum mobilised particle size have been selected to target locations for ongoing sedimentation. This assumes that this sediment size range will be frequently delivered to the Shannon from the Mulkear, requiring less extreme and frequent storm events to mobilise. These areas were checked visually against Google Maps ™ Aerial Imagery and the aerial (drone) imagery commissioned as part of the AquaUoS study (refer to Section 3.4.2) to ensure that locations predicted were areas of wet channel or in-channel islands, rather than adjacent dry land, albeit the left bank downstream from the Mulkear Confluence is likely to continue to accumulate overbank silts even though it is heavily vegetated already. Figure 6-16 below shows these areas likely to have continued sedimentation.

[4] https://geo.libretexts.org/Courses/University_of_California_Davis/GEL_109%3A_Sediments_and_Strata_(Sumner)/09%3A_Draft_Textbook/9.05%3A_Sediment_Transport

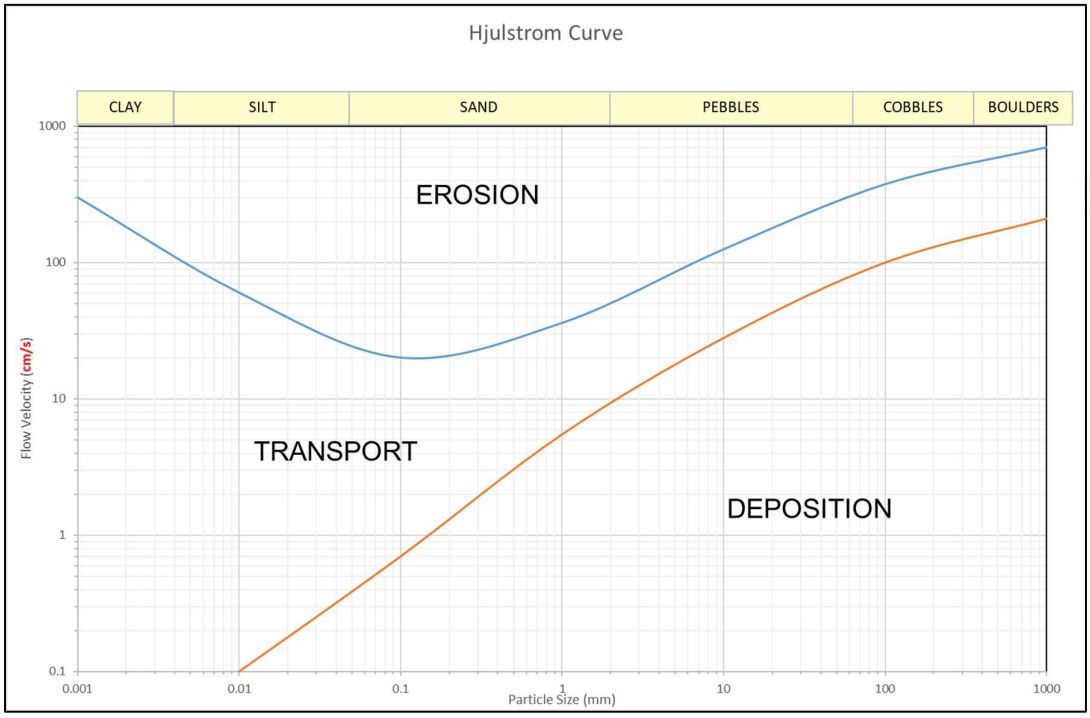



Figure 6-15: Hjulström curve diagram

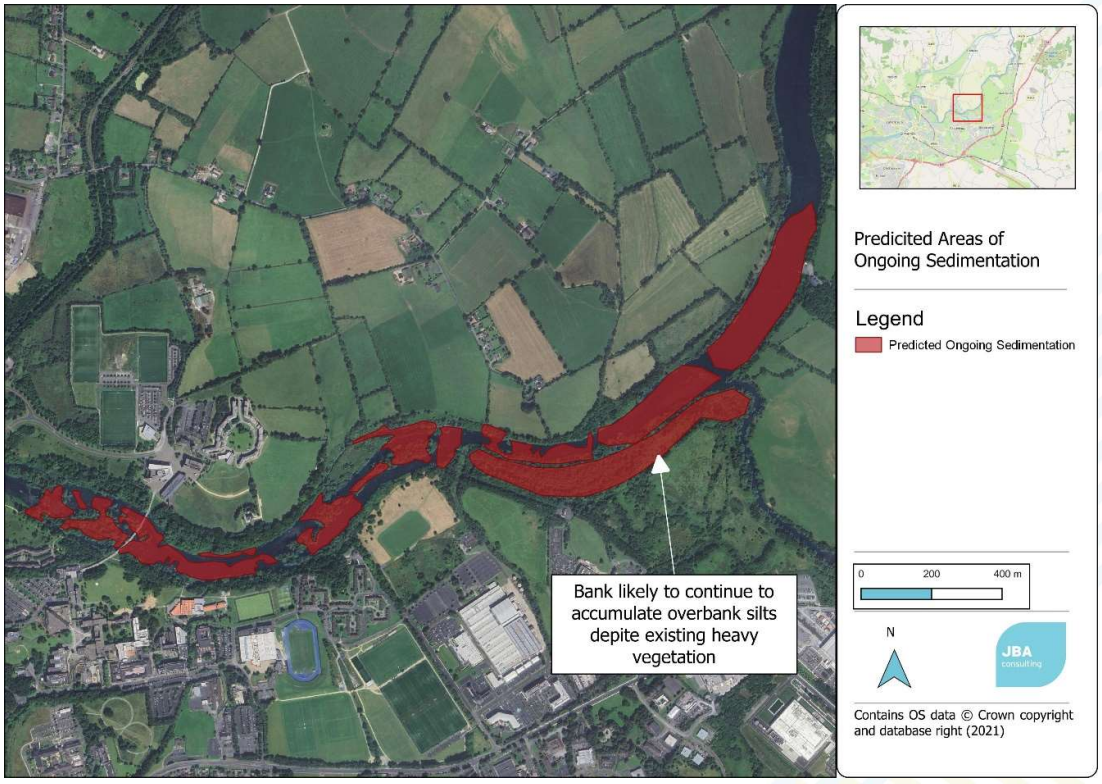



**Figure 6-16: Areas of Sedimentation**

## 6.3 Do-Nothing Scenario

This scenario tests the impacts of a scenario whereby no mitigation measures are carried out and the current system continues to function as it currently is.

This scenario is tested using the River Shannon model and ties in with the observations and conclusions of the Hydromorphological assessment, as discussed in Section 6.2.

The impacts of the Do-Nothing scenario will be tested over the following time periods for each of the 8 flow events:

- 10 year
- 20 year
- 50 year

### 6.3.1 Hydrodynamic Model Modification

The Aqua UoS report has estimated that the average growth rate of the river bed and depositional features in the River Shannon at the confluence with the Mulkear is approx. 3cm per year. This growth rate is based on analysis on the historic channel change (both erosion and deposition) using archival cross section surveys. Further analysis was conducted by JBA as part of this study in an attempt to confirm the estimations in the Aqua UoS study. This was done by comparing the CFRAM cross section bed profiles with the 2023 cross section collected as part of this JBA study. The comparison of cross sectional areas broadly confirmed that the sedimentation accumulation trends in the Aqua UoS study are still valid. Refer to Section 3.6 for more information on the cross section analysis.

Using the rates of deposition as estimated in the AquaUoS report (approx. 3cm per year), the bed levels were manually adjusted based on the relative time frame in areas where deposition is likely to occur. It should also be caveated that this estimated growth rate assumes that no sediment removal has occurred since 1920 and will not occur over the time frames in Table 6-1. This growth rate also assumes no significant flood events or other factors which may result in considerable changes in the bed profile outside of the estimated growth rates. For this reason, a sedimentation scenario was assigned to each estimated growth rate rather than time frame. The table below shows the estimated growth per sedimentation scenario. Cross sections showing these sedimentation scenarios are provided in Appendix B.

The geometry of the model was adjusted by the growth rates for each of the sedimentation scenario in the identified areas in Figure 6-16 above, which are the areas identified as likely to have continued sedimentation (refer to 6.2).

**Table 6-1: Growth Rates**

| Time Frame | Sedimentation Scenario | Estimated Growth |
|---|---|---|
| 10 years | Short term | 30cm |
| 30 years | Medium term | 60cm |
| 50 years | Long term | 150cm |

### 6.3.2 Model Results

The model results show that the impacts from sedimentation at the estimated growth rate has more of an impact on the Normal Flow events, rather than the Flood Flow Events. Figure 6-17 and Figure 6-18 below show the increased extents in flooding for each of the time frames for the $Q_{10}$ Normal Flow and the 50% AEP event, respectively. As seen in Figure 6-17, increases in flood extents are most noted on the left bank of the Mulkear, at the confluence with the River Shannon in the low sedimentation scenario. In the long term sedimentation scenario there is a significant increase in the flood extent in the Shannon floodplain upstream of the confluence.

In the 50% AEP event, the most notable increases in flood extents as a result of the Do-Nothing scenario are in the Springfield area to the northwest of the Shannon floodplain.

The model results suggest that if the estimated growth rate of 3cm per year is to occur in the future and if measures are not taken to reduce the sediment build up in the channel, then there is an associated increase in flood risk likely to occur in the Lower Shannon catchment. While the impacts in the $Q_{10}$ Normal Flow event are extensive, they are limited to green fields and open space. However, in the 50% AEP events, increases are shown to impact the Springfield area.

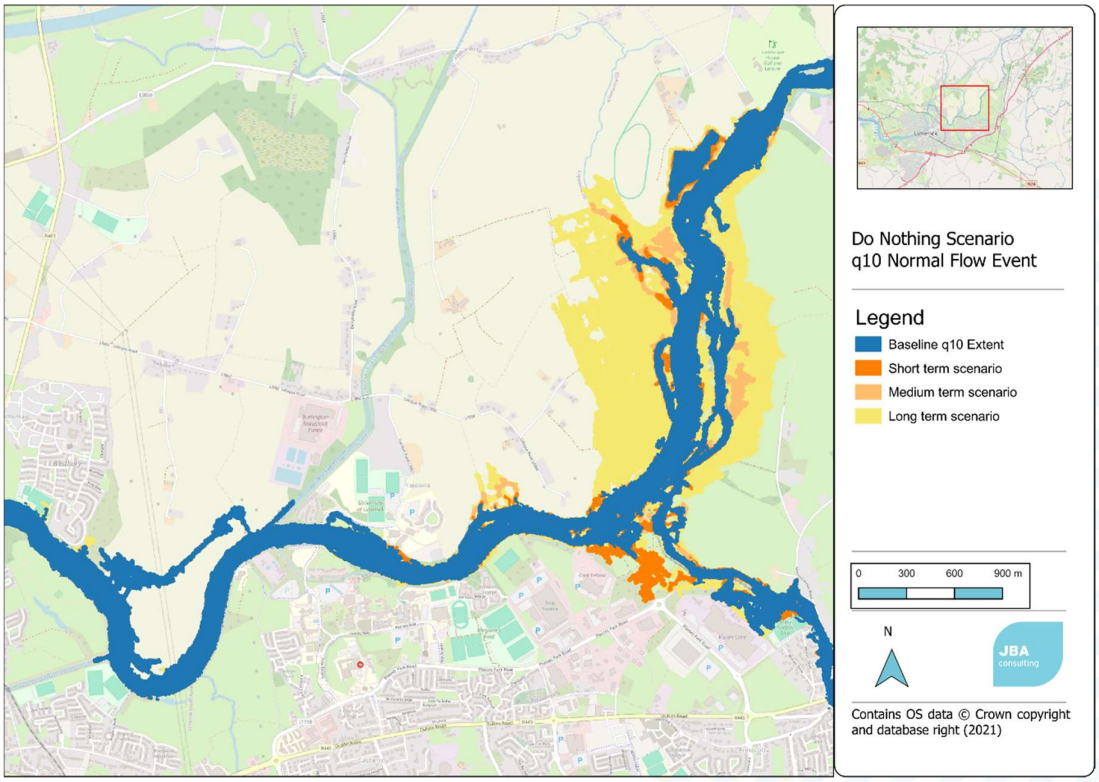



**Figure 6-17: Do Nothing Scenario - $Q_{10}$ Normal Flow Event**

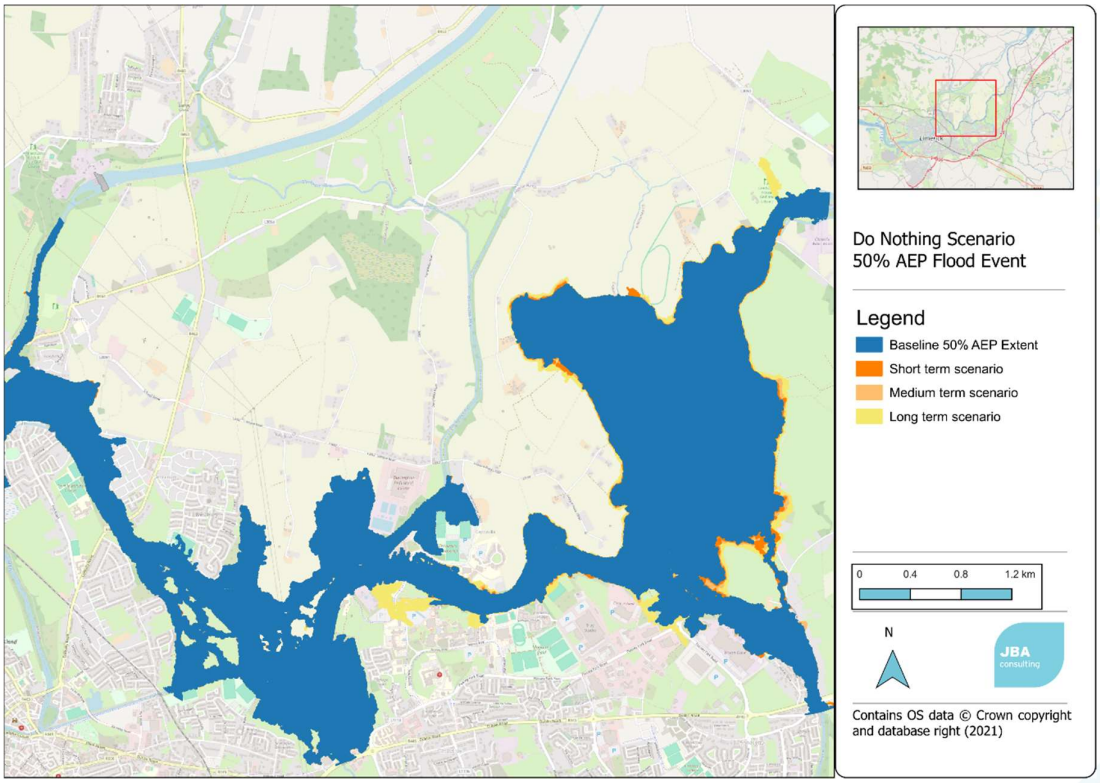



**Figure 6-18: Do Nothing Scenario – 50% AEP Flood Event**

## 6.4 Sediment Equilibrium

Another objective is to determine whether sedimentation within the Reach is at its maximum, or whether it is likely to continue to increase. For the sediment within the Reach to be at its maximum, the system needs to reach a point of dynamic equilibrium, or temporary stability. This is where the rate of deposition equals the rate of erosion and/or the velocities within the channel allow for continued transportation of sediment in the channel. Equilibrium time is influenced by many factors including the dominant sediment type which, for rivers with a coarse sediment supply, is the sediment fraction most likely responsible for long term bed aggradation under the prevailing flow regime[5]. For this equilibrium exercise, the 8-16 mm medium gravel size was most appropriate given this is the coarse sediment fraction readily supplied by the Mulkear but with limited mobilisation by the Shannon (Sections 3.2.1 and 4.3.2 of the Hydromorphology Report).

The proposed approach is to use the formula for velocity to calculate the cross-sectional area require to achieve dynamic equilibrium:

***Q = VA***

Where,

*Q = Flow Rate*

*A = Flow Area*

*V = Velocity*

To determine the cross-sectional area, the formula has been converted to **A = Q/V**.

The flow (Q) is a known value and is based off the flows used in the models. The velocities (V) are based on those required to transport sediments, as per the Hjulström curve (Figure 6-15).

The Hjulström curve indicates that in order to continually transport sediments of this size, the Velocity would need to be between 0.35m/s and 1.6m/s. Both values were assessed in the formula to give the range of velocities required to transport sediments up to the 16mm gravel sizes.

The sediment equilibrium assessment was completed on 4No. cross sections along the River Shannon. Refer to Figure 6-19 below for the cross section locations. One cross section is upstream of the confluence with the Mulkear (25SHAN008869) and the remaining 3No. cross sections are downstream of the confluence. These cross-section locations were selected based on areas likely to have continued sedimentation (refer to Section 6.2.2).

Table 6-2 to Table 6-5 below show the values used in the formula for the $Q_{10}$ Normal Flow and the 50% AEP events, respectively, for both the upper and lower velocity limits. As seen in the tables below, the cross sectional area for equilibrium varies significantly between the upper and lower limits.

With the area calculated from the formula, the bed profile of the river channel below the water level was adjusted so the flow area of the cross section matches that of the formula. The bed was then raised in areas where deposition would be expected to occur over the long term based on the morphology of the existing channel cross-section to reach the target area. An example of such logical locations is in sections where there are multiple channels within a cross section; if a lot of sediment is

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[5] Doyle, M.W. & Harbor, J.M. 2003, "Modelling the effect of form and profile adjustments on channel equilibrium timescales", *Earth surface processes and landforms,* vol. 28, no. 12, pp. 1271-1287.

predicted to occur then overtime, sedimentation would occur in some of the smaller channels with the flows being confined to one flow path/channel.

Figure 6-20 compares the existing cross section collected as part of the Bathymetric Survey (refer to Section 3.5) with the estimated bed profile when sediment equilibrium has been achieved for each of the assessed flow event for both the upper and lower limit. In areas where the current bed level is close to or less than the required area, the expected bed level is not shown on the figures, i.e. in some of the sections only the upper limit of sedimentation is indicated with the current bed acting as the lower limit.

For the $Q_{10}$ Normal Flow event, upstream of the confluence significant deposition is required to achieve equilibrium for the full velocity range. Downstream of the confluence, there is a notable variation between the sedimentation required for the upper and lower limits. For equilibrium to be achieved for the upper limit, the cross sectional area of the channel would need to be reduced by approx. 75-85%. Once equilibrium is reached, the velocities would then be sufficient to erode sediments up to the 16mm gravel size. For the lower limit, the current cross-sectional area is shown to almost be at equilibrium. This suggests that sedimentation is almost at its maximum for the 16mm gravel sizes at which point 16mm gravels would be continually transported along the reach.

For the 50% AEP event, similar to the $Q_{10}$ Normal Flow event, upstream of the confluence significant deposition is required to achieve equilibrium, particularly for the upper limit. Downstream of the confluence, to achieve equilibrium for the upper limit, the cross sectional area would need to be reduced by approx. 50%. However for the lower limit, the current channel area is less than the required area for the 16mm gravel sizes, meaning further sedimentation of this size is unlikely to occur. This would suggest that the sedimentation is at is maximum for the lower limit.

It is noted that this assessment is limited to the 8-16mm gravel size. Larger sediment sizes would likely still be supplied to the River Shannon from the Mulkear River and may be deposited while smaller sediment sizes could be eroded.

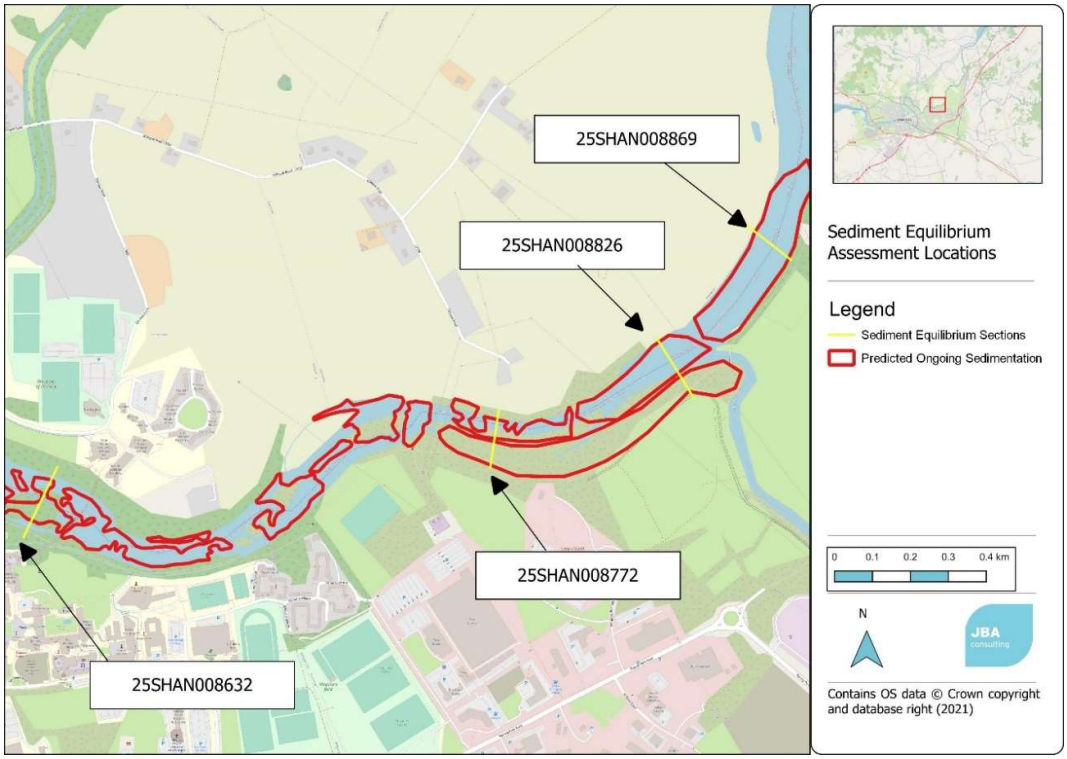



**Figure 6-19: Sediment Equilibrium Assessment Locations**

**Table 6-2: $Q_{10}$ Normal Flow Sediment Equilibrium Calculations – Upper Velocity Limit for transportation**

| Cross Section | Q (m3/s) | V (m/s) | $Q_{10}$ WL (mOD) | Area (Q/V) | Current Area* |
|---|---|---|---|---|---|
| 25SHAN08869 | 20.28 | 1.6 | 7.47 | 13 | 702 |
| 25SHAN08826 | 60.29 | 1.6 | 7.46 | 38 | 241 |
| 25SHAN08772 | 60.29 | 1.6 | 7.34 | 38 | 161 |
| 25SHAN08632 | 60.29 | 1.6 | 5.4 | 38 | 172 |

**Table 6-3: $Q_{10}$ Normal Flow Sediment Equilibrium Calculations – Lower Velocity Limit for transportation**

| Cross Section | Q (m3/s) | V (m/s) | $Q_{10}$ WL (mOD) | Area (Q/V) | Current Area* |
|---|---|---|---|---|---|
| 25SHAN08869 | 20.28 | 0.35 | 7.47 | 58 | 702 |
| 25SHAN08826 | 60.29 | 0.35 | 7.46 | 172 | 241 |
| 25SHAN08772 | 60.29 | 0.35 | 7.34 | 172 | 161 |
| 25SHAN08632 | 60.29 | 0.35 | 5.4 | 172 | 172 |

**Table 6-4: 50% AEP Flood Sediment Equilibrium Calculations - Upper Velocity Limit for transportation**

| Cross Section | Q (m3/s) | V (m/s) | 50% WL (mOD) | Area (Q/V) | Current Area* |
|---|---|---|---|---|---|
| 25SHAN08869 | 210 | 1.6 | 8.69 | 131 | 892 |
| 25SHAN08826 | 337 | 1.6 | 8.67 | 211 | 429 |
| 25SHAN08772 | 337 | 1.6 | 8.4 | 211 | 304 |
| 25SHAN08632 | 337 | 1.6 | 6.69 | 211 | 416 |

**Table 6-5: 50% AEP Flood Sediment Equilibrium Calculations - Lower Velocity Limit for transportation**

| Cross Section | Q (m3/s) | V (m/s) | 50% WL (mOD) | Area (Q/V) | Current Area* |
|---|---|---|---|---|---|
| 25SHAN08869 | 210 | 0.35 | 8.69 | 600 | 892 |
| 25SHAN08826 | 337 | 0.35 | 8.67 | 963 | 429 |
| 25SHAN08772 | 337 | 0.35 | 8.4 | 963 | 304 |
| 25SHAN08632 | 337 | 0.35 | 6.69 | 963 | 416 |

*Area of existing bed profile under relevant Water Level

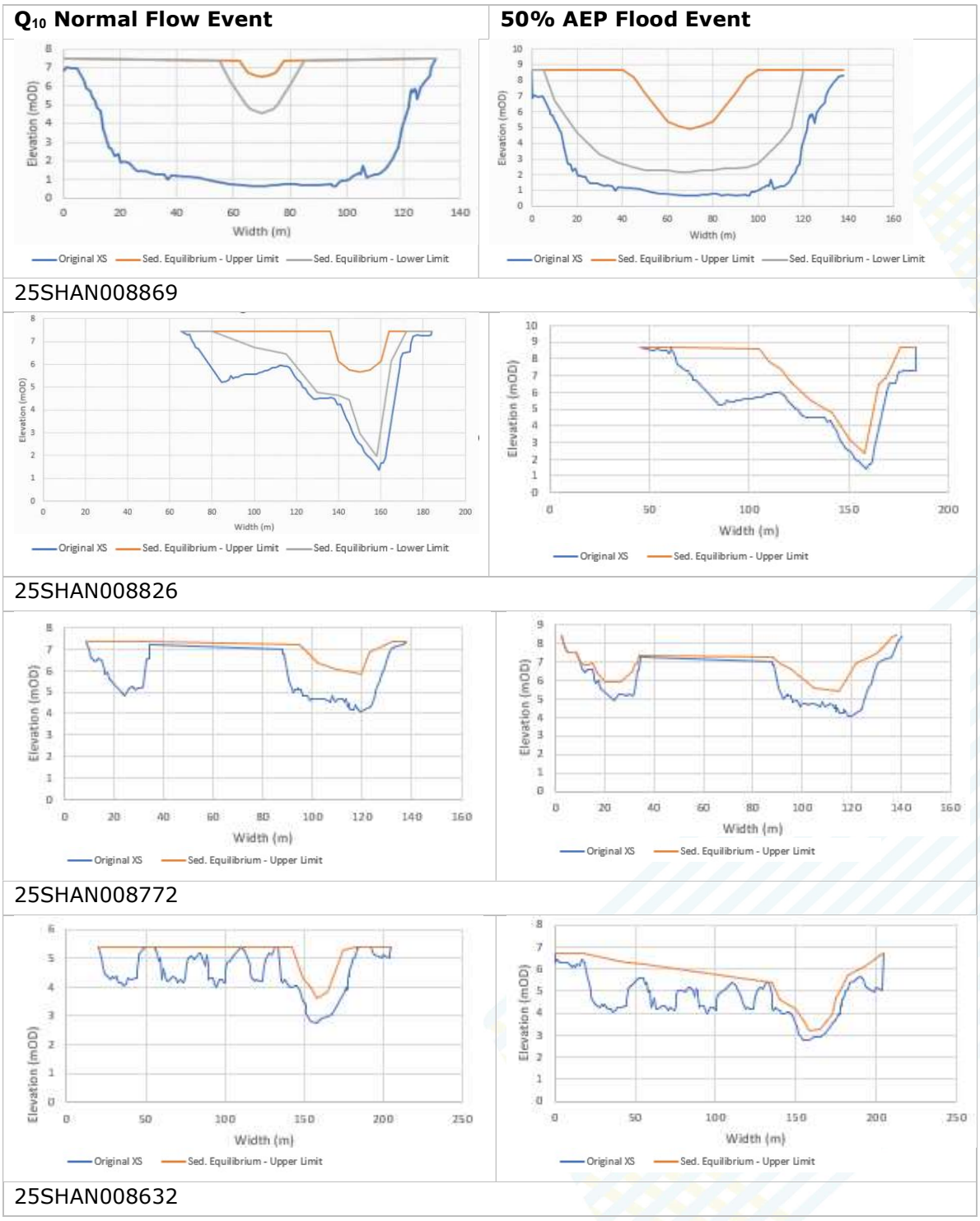



**Figure 6-20: Sediment Equilibrium Sections**

## 6.5 Theoretical Flow Testing

The sediment modelling assessment consists of two parts which are described below. For both of these assessments, the River Shannon Model has been utilised to assess the impacts on the sediment in the channel with varying flows.

- **Flow Regime Testing**

  Determine a theoretical compensatory flow regime over Parteen Weir and down the Old River Shannon that would provide a sustainable sediment transport capacity along the Reach.

- **Sediment Removal**

  Establish the theoretical flows, if any, that would flush out the existing sediment in the Reach.

Section 6.2.1 outlines the transport discrepancy between the Old Shannon and the Mulkear River that is contributing to the sedimentation dynamic at the confluence. Essentially, that the Mulkear River supplies sediment up to coarse gravel size to the River Shannon under a $Q_{10}$ Normal Flow and 50% AEP conditions, but that the Shannon is unable to mobilise all of the fine gravel and any of the medium to coarse gravel component of this supply (Sections 3.2.1, 4.3.2 and 5.1 of the Hydromorphology Report). Therefore, these are the key coarse sediment sizes to consider for transportation (for the Flow Regime Testing) and erosion (for the Sediment Removal scenario).

The flows on the River Shannon were gradually increased and the associated velocities along the Reach were estimated. The flows on the Mulkear were maintained at 40m³/s which representative of the $Q_{10}$ Normal Flow (refer to Section 5.1.2). Using this information in combination with Hjulström Curve (Figure 6-15), the model was used to assess the minimum required velocities necessary to provide a sustainable sediment transport capacity and flush out the existing sediment in the Reach. These velocities are provided in Table 6-6.

This assessment is based solely on velocity banding results from the model and therefore provides an indicative assessment of where there may be transportation or removal of these gravels.

**Table 6-6: Minimum Required Velocities**

| | Sustainable Transport Capacity | Sediment Removal |
|---|---|---|
| Fine Gravel Velocities (m/s) | 0.25 | 1.20 |
| Medium Gravel Velocities (m/s) | 0.37 | 1.70 |
| Coarse Gravel Velocities (m/s) | 0.57 | 2.30 |

### 6.5.1 Flow Regime Testing

Model results indicate that under a 200m³/s flow over Parteen Weir and down the Old River Shannon, the peak model velocities are component to transport the fine and medium but not coarse-sized gravels entering the confluence zone from the Mulkear River (Figure 6-21). This flow regime down the Old River Shannon is equivalent to the 50% AEP flood event. As such, the confluence remains depositional under these flow conditions, which is consistent with the interpretation of the sediment dynamics outlined in the Hydromorphology Report.

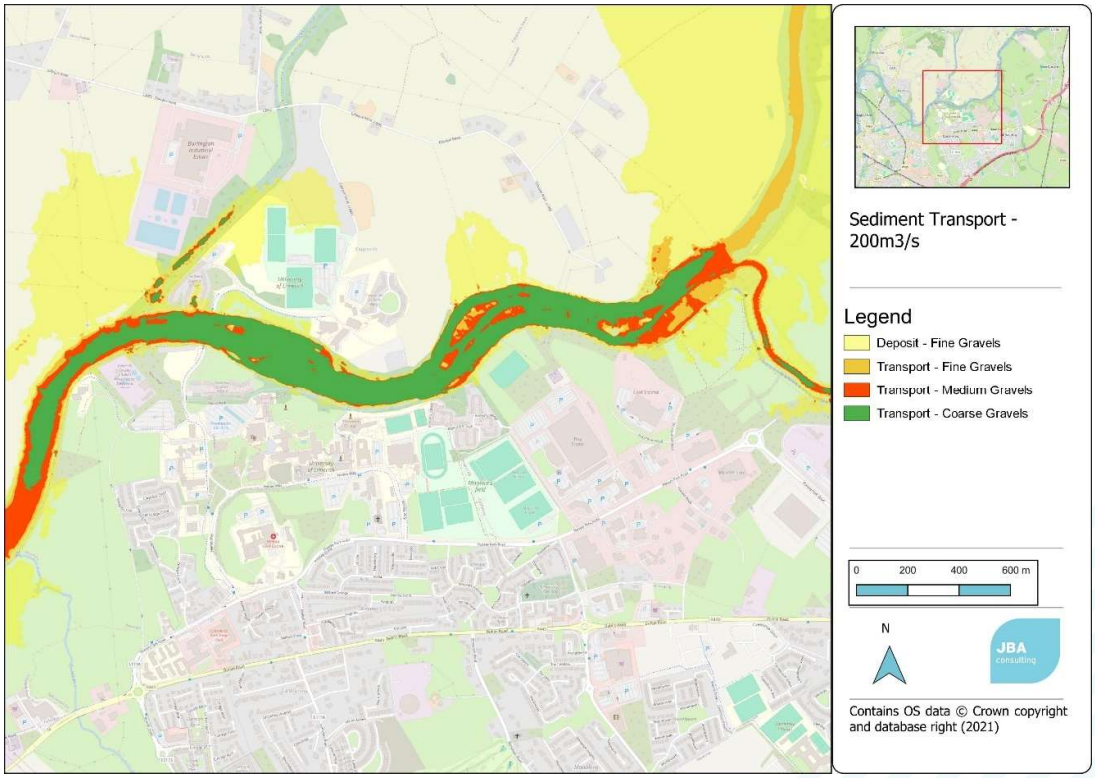



**Figure 6-21: Sediment Transport – 200m³/s**

Testing of higher flood flow conditions reveals the Shannon is not competent to mobilise the coarse-sized gravels within the confluence zone in any of flow regimes tested. Figure 6-22 below shows the sediment transport capacity with 550m³/s down the Old River Shannon. This flow roughly equates to a 1% AEP flow (refer to Section 5.2.1). While coarse-sized gravels are capable of being transported along most of the Shannon reach downstream of the confluence with this flow, the velocities are not sufficient to transport the coarse gravels within the confluence zone.

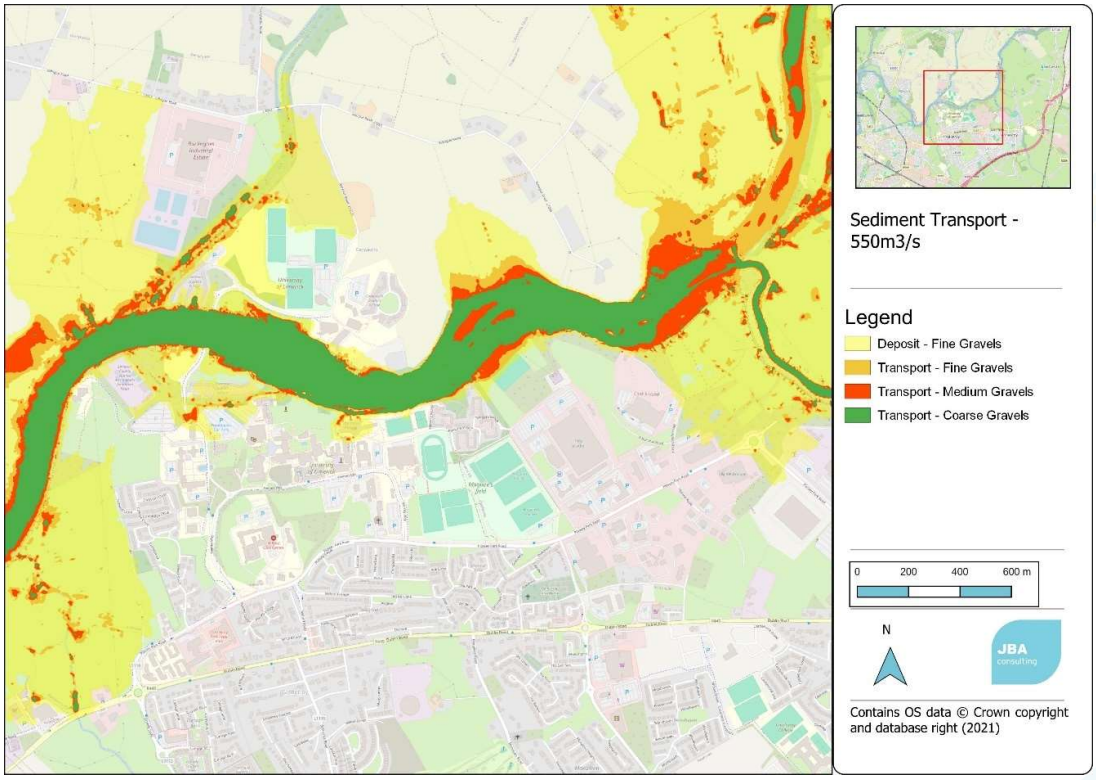



**Figure 6-22: Sediment Transport – 550m³/s**

Once flows down the River Shannon are further increased above 550m³/s, the backwater impact of the flow down the River Shannon causes the velocities along the Mulkear and at the confluence zone to decrease, creating a depositional zone for the fine, medium and coarse gravels. This is evident from the model results with 600m³/s down the River Shannon in Figure 6-23 below. The backwater impacts from the River Shannon causing the drop in velocities at the confluence zone and along the Mulkear continues as the flows over Parteen Weir and down the River Shannon are increased. This is the case for the maximum tested flow down the River Shannon of 750m³/s, which is equivalent to the 1% AEP HEFS event.

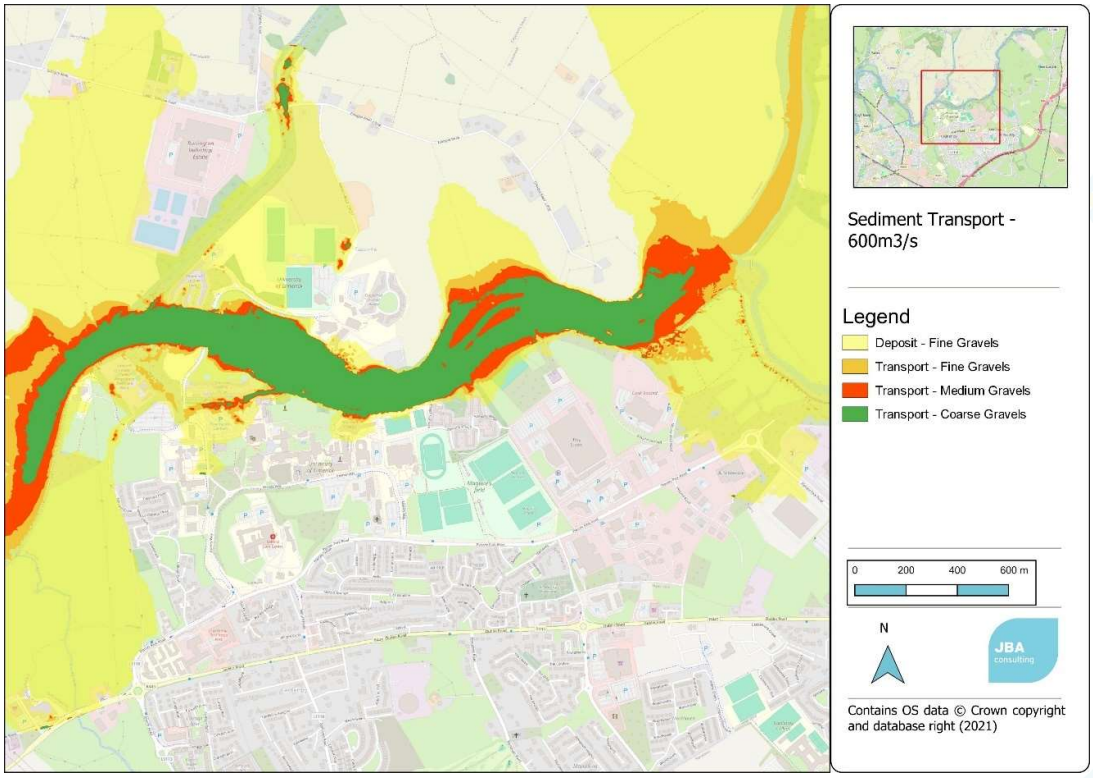



**Figure 6-23: Sediment Transport – 600m³/s**

The model results from the Flow Regime Testing estimate that while velocities are competent to transport the fine and medium gravels entering the confluence zone from the Mulkear River with 200m³/s down the River Shannon, a flow regime capable of providing a sustainable sediment transport capacity for the coarse gravels has not been identified with the flows tested. There may be a competent flow between the 550m³/s and 600m³/s flow regime (when the backwater effects of the River Shannon start to reduce the transport capacity at the confluence) which was not tested. However, given the minor 50m³/s difference between these two flow regimes, the conclusions of the analysis completed thus far suggest that there is no theoretical compensatory flow regime over Parteen Weir and down the River Shannon that would provide a sustainable sediment transport capacity along the Reach.

The full suite of flow regime testing results over Parteen Weir and down the River Shannon are included in Appendix C.

### 6.5.2 Sediment Removal

The Flow Regime Testing concluded that the peak model velocities are not capable of providing a sustainable sediment transport capacity for gravels entering the confluence zone from the Mulkear River and along the Reach. It can therefore be assumed that velocities in the channel are not capable of flushing out the existing sediment in the Reach. This assumption is confirmed by the model results.

Figure 6-24 shows the flushing capabilities for gravels along the reach with 550m³/s over Parteen Weir and down the River Shannon. Figure 6-25 shows the same when flows are increased to 750m³/s down the River Shannon. The results show that the peak model velocities for each of the flow regimes are not capable of flushing fine, medium or coarse gravels from the confluence zone at the Mulkear River and along the Reach. Analysis of the range of flows estimates that the in-channel velocities do not increase significantly as the flow increases (as noted when comparing Figure 6-24 and Figure 6-25). As the surrounding area is low-lying, larger flows spill out of the channel and inundate the floodplain, rather than increasing in-channel energy (as would likely occur if flows were contained in-channel). This means that the ability to erode the in-channel sediments does not necessarily increase as the flows increase in these higher flood events.

The modelling work has therefore failed to estimate a flow regime capable of flushing out the existing sediment in the Reach. The conclusion is that modification of the flow regime alone to provide flushing flows is unlikely to clear the fine, medium and coarse gravels for the flows tested.

The full suite of the Theoretical Flows Regimes over Parteen Weir and down the River Shannon tested for sediment removal are included in Appendix D.

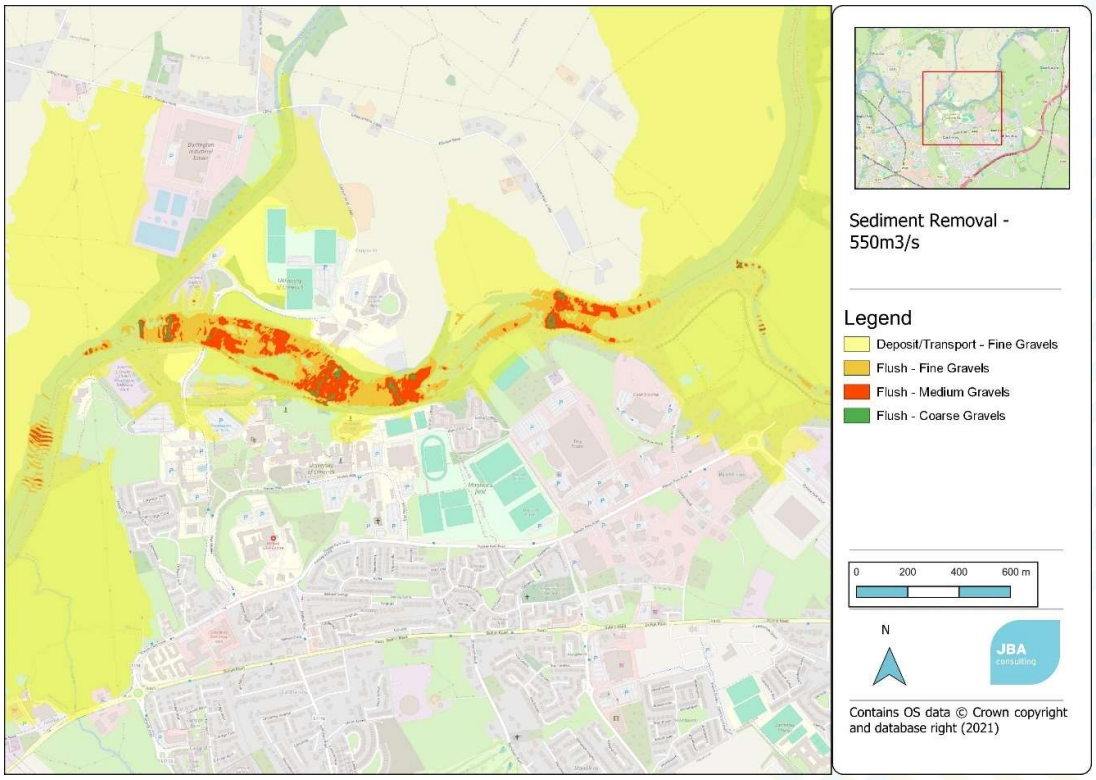



**Figure 6-24: Sediment Removal – 550m³/s**

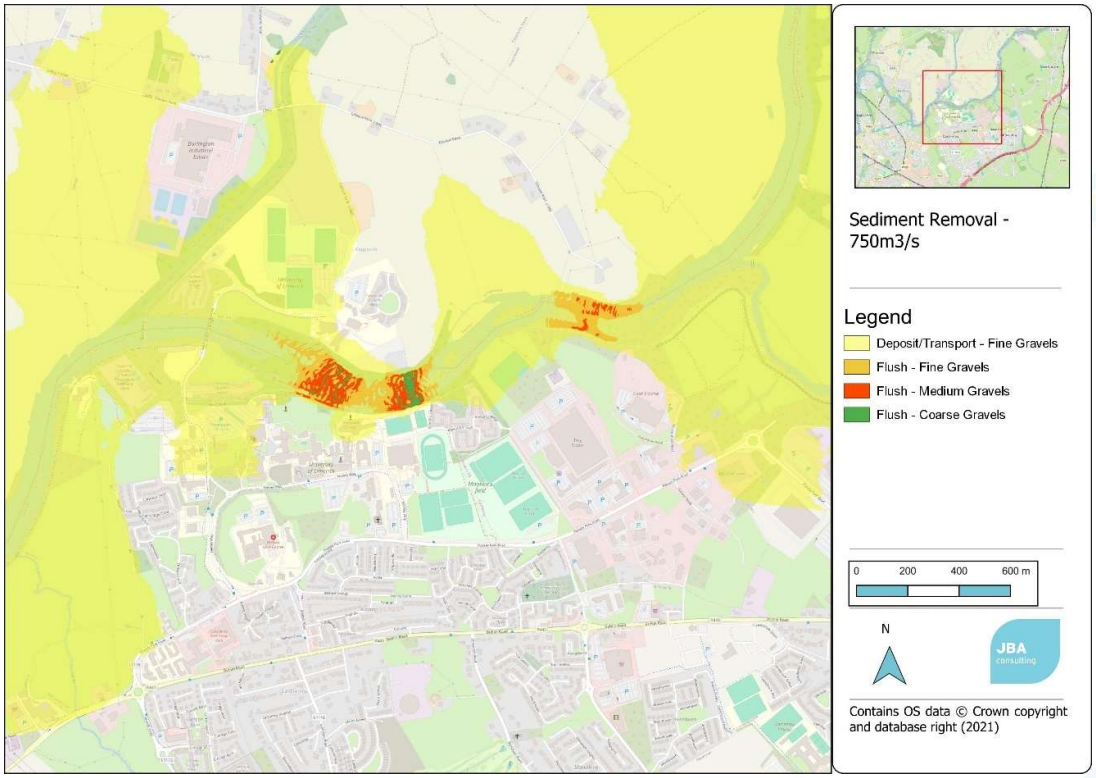



**Figure 6-25: Sediment Removal – 750m³/s**

# 7 Sensitivity Checking

Sensitivity tests were completed on the River Shannon hydrodynamic model in order to ensure it is fit for the purpose of the sediment modelling discussed in Section 6 above, these are outlined below.

## 7.1 Flow

The sensitivity of the hydrodynamic model to the flows was assessed by increasing and decreasing the flow by 20%. This sensitivity test was completed on the $Q_{10}$ Normal Flow event. Table 7-1 below shows the updated sensitivity flows used in the model. As seen in Figure 7-1 below, the flow sensitivity test has minimal impacts on the flood extent along the length of the model. There are a number of locations where the flood extent is sensitive to the flow, including at the confluence of the Mulkear and the River Shannon.

Figure 7-2 shows a comparison of the velocities as a result of the change in flow values. The images in Figure 7-2 focus on the confluence between the River Shannon and the Mulkear River. The colour banding in the images below is representative of the velocities required to entrainment each of the sediment sizes, i.e., follows the orange line on Hjulström curve diagram (Figure 6-15). The figures indicate that, as with the flood extents, the velocities are not particularly sensitive to minor variations to the flow values used in the model.

**Table 7-1: Flow Sensitivity Testing**

| Scenario | Shannon Inflow (m3/s) | Mulkear Inflow (m3/s) |
|---|---|---|
| $Q_{10}$ | 20.98 | 40.01 |
| $Q_{10}$ + 20% flow | 25.17 | 48.01 |
| $Q_{10}$ - 20% flow | 16.78 | 32.01 |

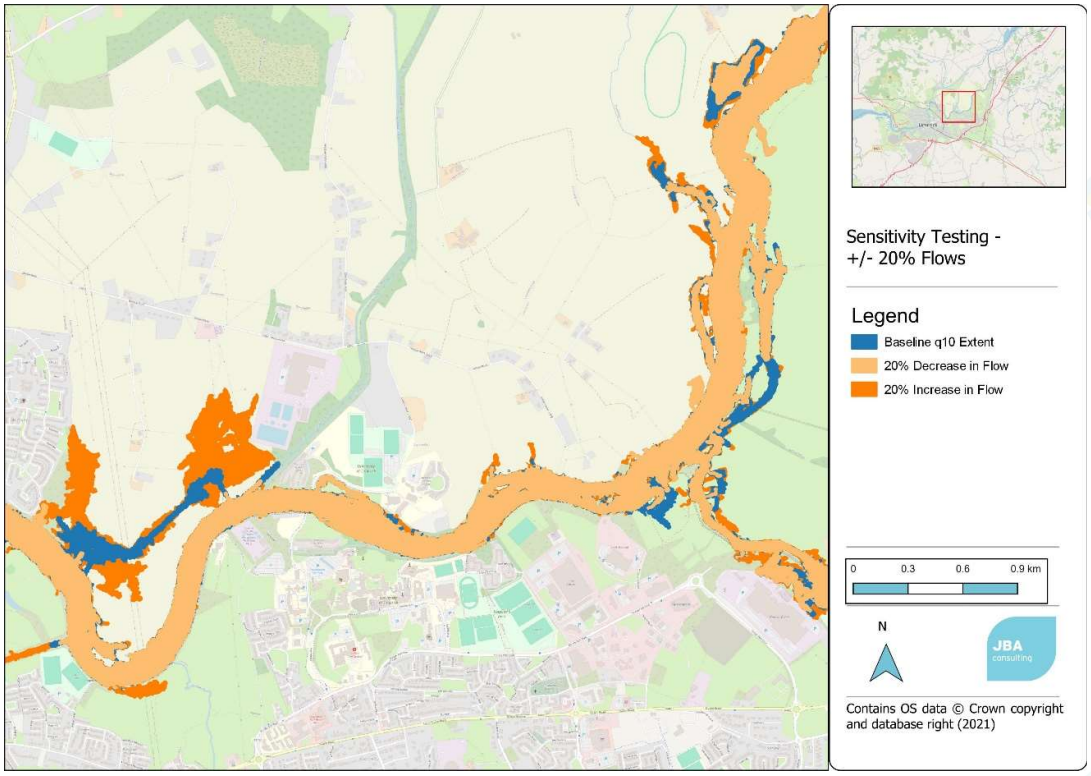



**Figure 7-1: Flow Sensitivity Testing - Flood Extents**

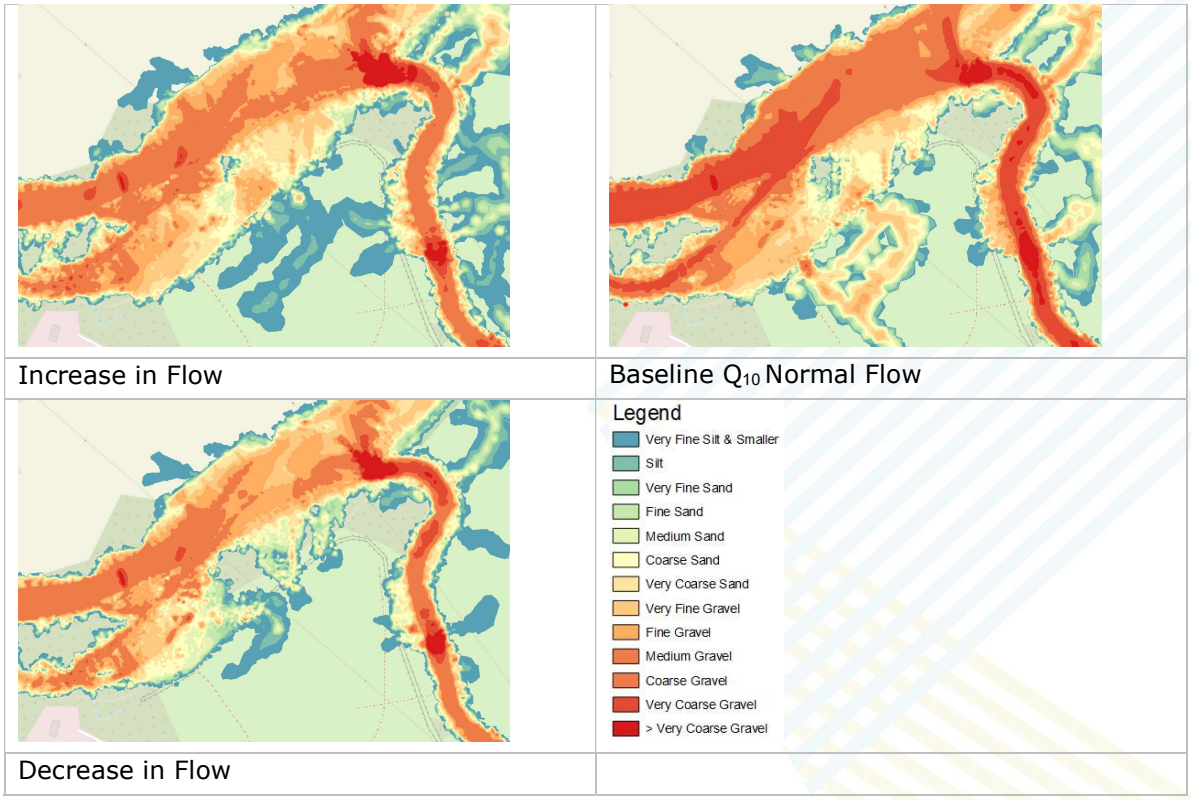



**Figure 7-2: Flow Sensitivity Testing -– $Q_{10}$ Velocities**

## 7.2 Roughness

The hydraulic roughness (represented by Manning's *n*) was increased and decreased by 20%, refer to Table 7-2. These adjustments were applied to all material classifications to represent both summer and winter vegetation. This sensitivity test was completed on the $Q_{10}$ Normal Flow event and the 50% AEP event.

**Table 7-2: Land Use Values**

| Land Use Type | Mannings *n* Value | Decreased Values | Increased Values |
|---|---|---|---|
| Roads | 0.015 | 0.012 | 0.018 |
| Pastures | 0.033 | 0.026 | 0.040 |
| Short Grass | 0.035 | 0.028 | 0.042 |
| General Rural | 0.040 | 0.032 | 0.048 |
| Watercourse | 0.045 – 0.050 | 0.035- 0.045 | 0.050 – 0.060 |
| Heavy Vegetation | 0.06 | 0.050 | 0.070 |
| Dense Veg / Islands | 0.08 | 0.064 | 0.096 |
| Buildings | 0.10 | 0.080 | 0.120 |

### 7.2.1 $Q_{10}$ Normal Flow

Figure 7-3 below shows the impacts of the roughness sensitivity test on the flood extents for the $Q_{10}$ Normal Flow event. The extent of flooding is not unduly sensitive to the roughness values used in the model. There are some locations, such as the IDA lands in Castletroy and along Mount Shannon Road where there are some slight impacts as a result of changed roughness values.

Figure 7-4 shows a comparison of the velocities as a result of the change in roughness values. The images in Figure 7-4 focus on the confluence between the River Shannon and the Mulkear River. The colour banding in the images below is representative of the velocities required to entrainment each of the sediment sizes, i.e., follows the orange line on Hjulström curve diagram (Figure 6-15). The figures indicate that, as with the flood extents, the velocities are not particularly sensitive to minor variations with the roughness values used in the model.

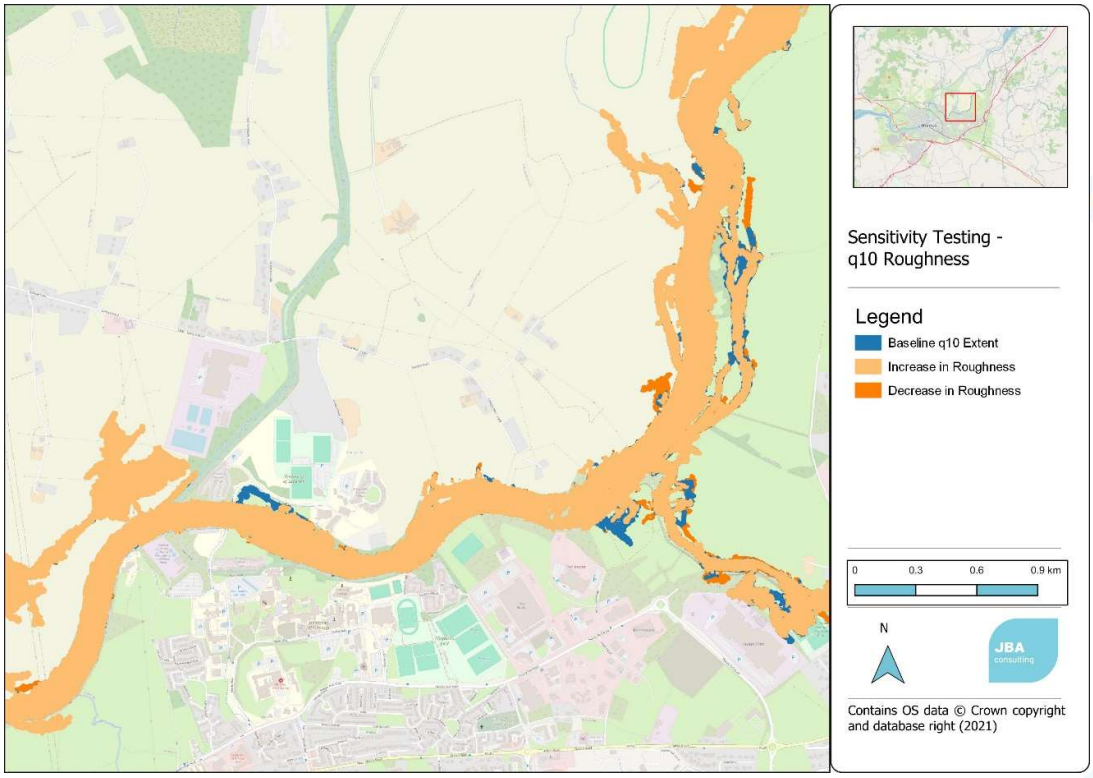



**Figure 7-3: Roughness Sensitivity Testing – $Q_{10}$ Flood Extents**

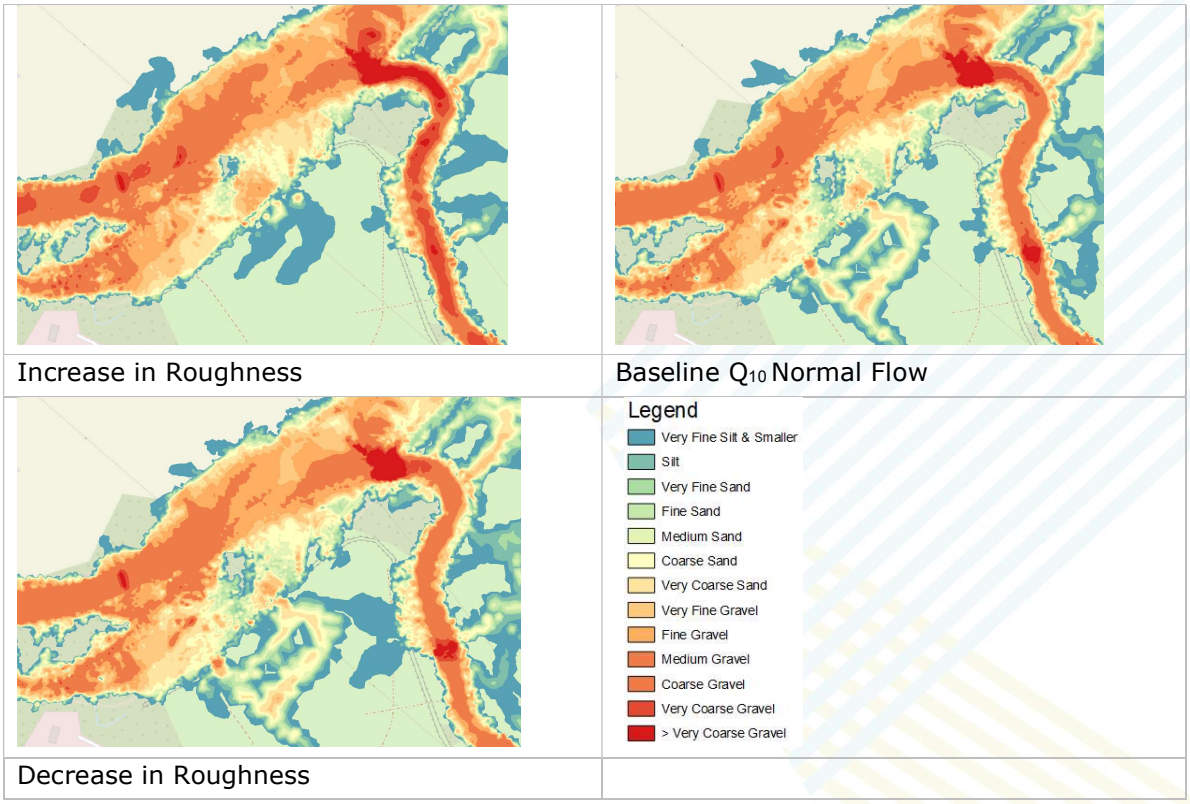



**Figure 7-4: Roughness Sensitivity Testing – $Q_{10}$ Velocities**

### 7.2.2 50% AEP Event

Figure 7-5 below shows the impacts of the roughness sensitivity test on the flood extents for the 50% AEP event. As with the $Q_{10}$ Normal Flow event, the extent of flooding is not unduly sensitive to minor changes to the roughness values used in the model.

Figure 7-6 shows a comparison of the velocities as a result of the change in roughness values. The images focus on the confluence between the River Shannon and the Mulkear River. The colour banding in the images below is representative of the velocities required to entrainment each of the sediment sizes, i.e., follows the orange line on Hjulström curve diagram (Figure 6-15). The figures indicate that, overall, velocities are not particularly sensitive to the roughness values used in the model. There are some changes to the gravel particle sizes being entrained downstream of the confluence but these changes are not consistent across the length of the watercourse to efficiently entrain these particles sizes from the confluence to further downstream on the River Shannon.

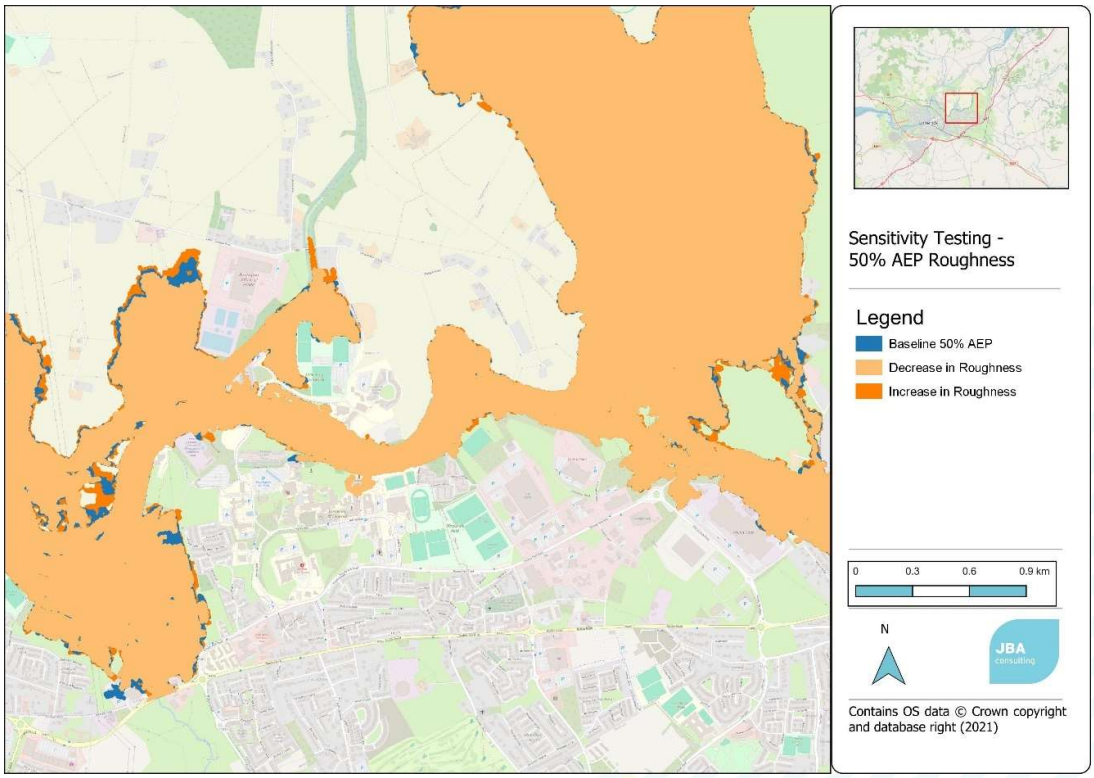



**Figure 7-5: Roughness Sensitivity Testing**

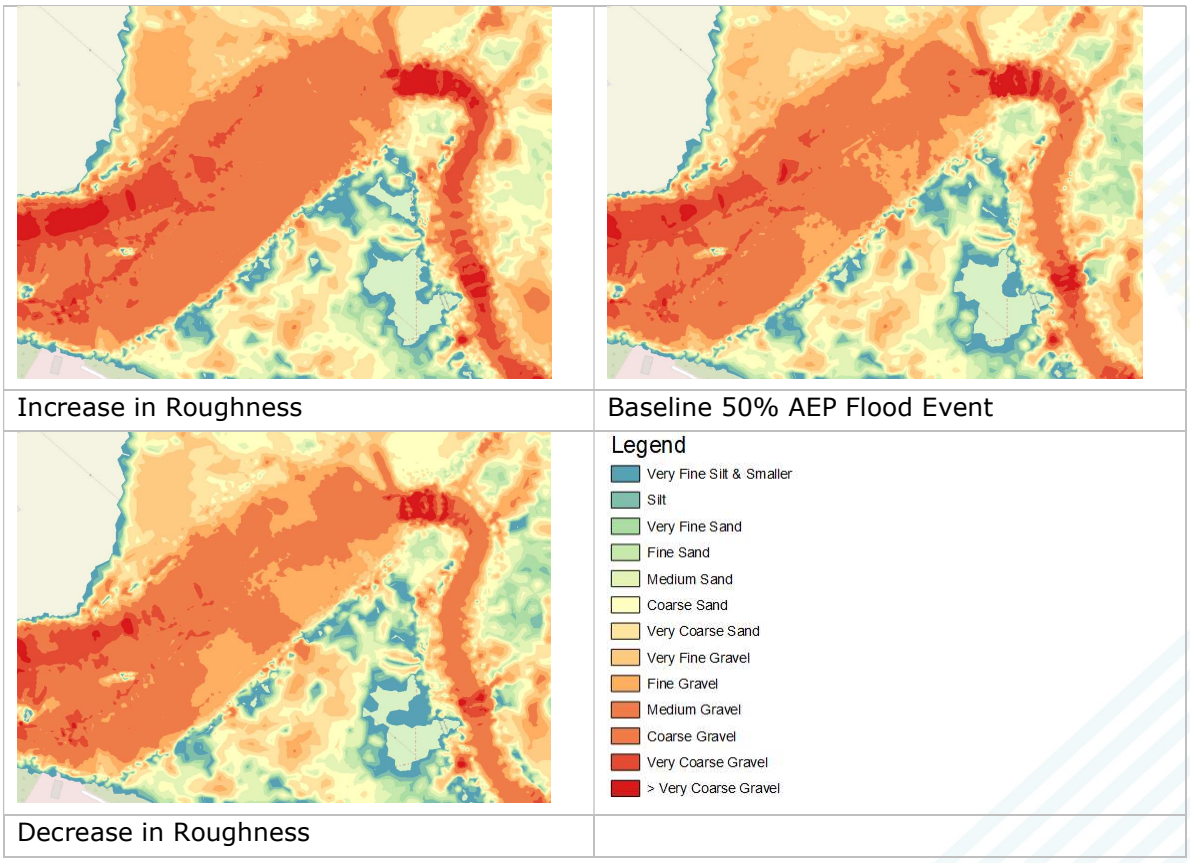



**Figure 7-6: Roughness Sensitivity Testing –50% AEP Flood Event Velocities**

## 7.3 Downstream boundary

The downstream boundary has been tested against the tidal conditions in the River Shannon. The fluvial 50% AEP event was run with the 2% AEP tidal event. The 2% AEP tidal plot is shown in Figure 7-7 below. Figure 7-8 below illustrates that the downstream boundary has negligible impacts on flood extents in the Reach and Figure 7-9 shows how it has negligible impacts in velocities in the channel further upstream. The colour banding in Figure 7-9 is representative of the velocities required to entrainment each of the sediment sizes, i.e., follows the orange line on Hjulström curve diagram.

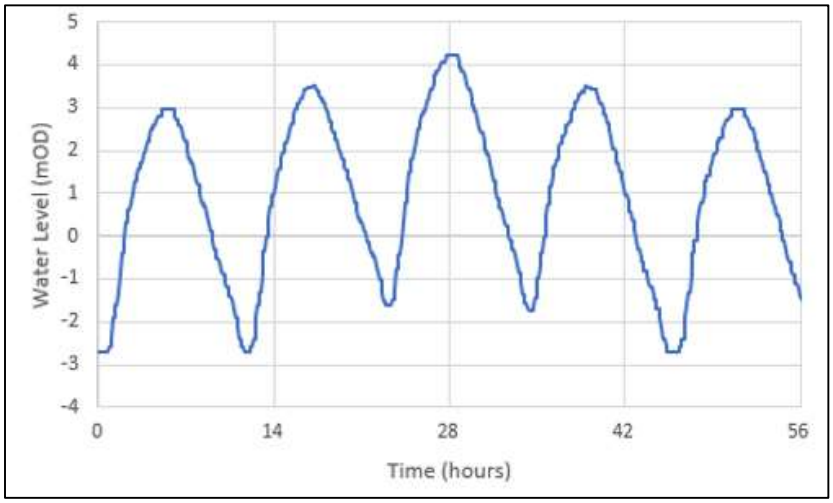



**Figure 7-7: 2% AEP Tide Plot**

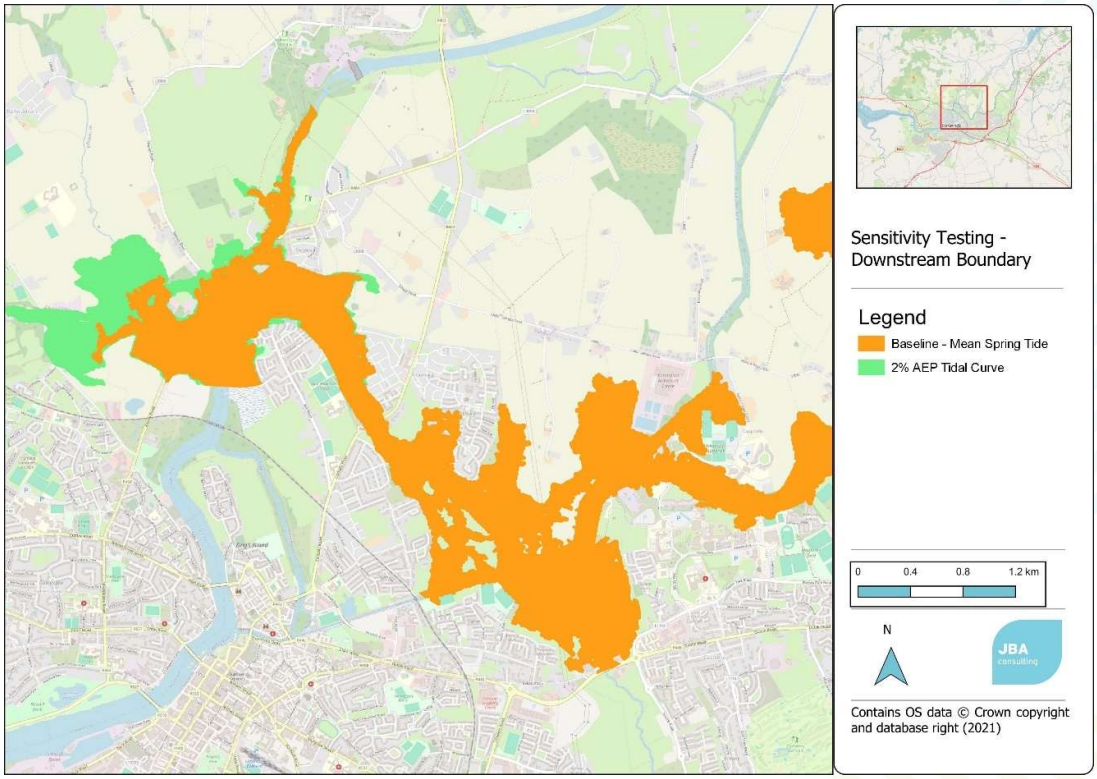



**Figure 7-8: Downstream Boundary Sensitivity Test Flood Extents**

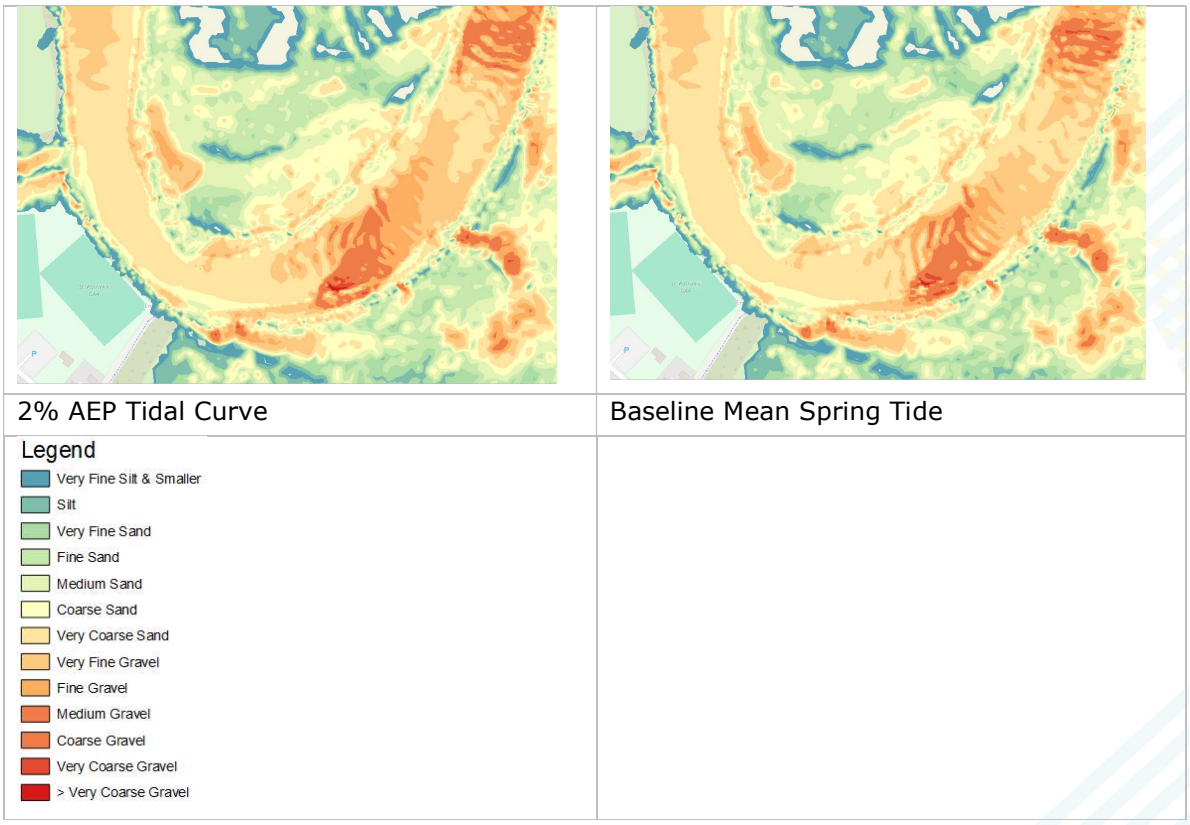



**Figure 7-9: Downstream Boundary Sensitivity Testing Velocities**

## 7.4 Model Validation

As there is insufficient data available to calibrate the hydrodynamic model, the model will be validated against the February 2020 flood event. This event is the only flood event with recorded information suitable for model validation. Shapefiles are available for the maximum flood extents during this event as collect by Drone Survey, as described in Section 3.4.2. Validation can only be carried out from a hydraulic aspect as there is no sediment rate information available.

Gauge flows and hydrograph shapes for the peak of this event were estimated using the gauge data available from the Annacotty Weir Gauge, refer to Figure 7-10 and the Castleconnell FRS model which also completed model validation using the February 2020 flood event. The Castleconnell FRS estimated this event as being between a 5% and 2% AEP event. Refer to Appendix A.3 for information of the Castleconnell FRA model validation.

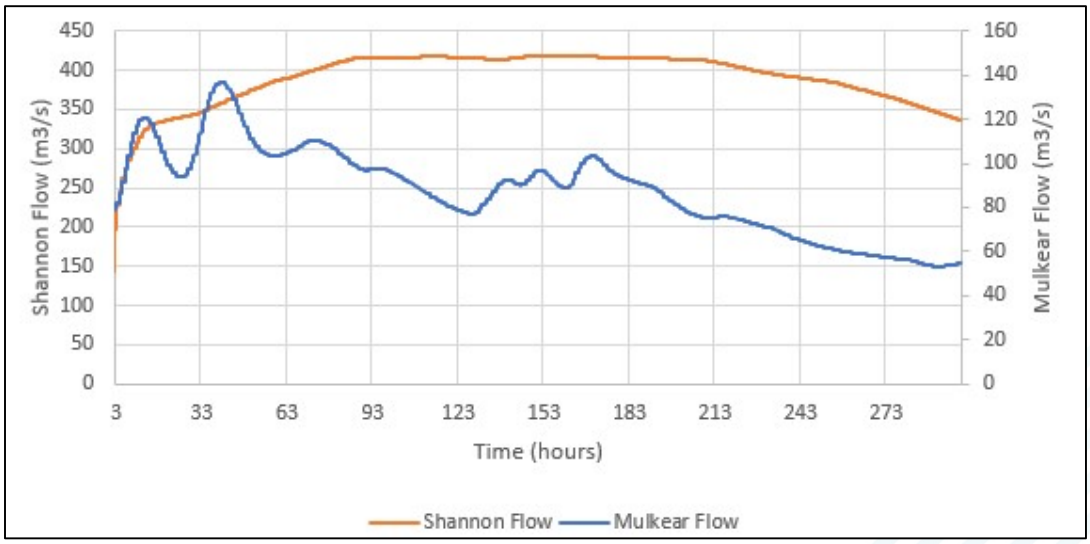



**Figure 7-10: February 2020 Flood Event Hydrographs**

Figure 7-11 shows a comparison between the February 2020 flood event shapefile outline and the model flood depth results. As shown by the figure, the model exhibits good agreement with the observed data in the Shannon floodplain. There are some exceptions where the flood outline and model results differ, these differences, and the reasons behind them, are discussed in detail in the next few pages.

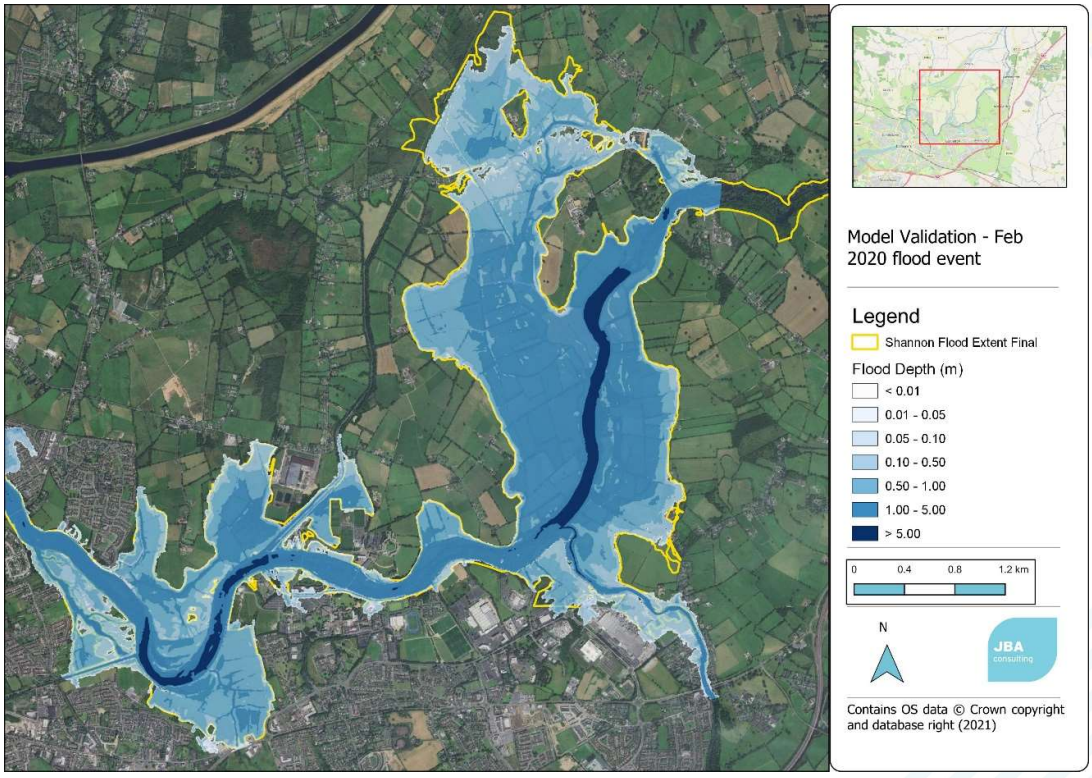



**Figure 7-11: Model Validation**

Figure 7-12 below shows the model results overlaying the drone footage of the Feb 2020 flood event. The model does not show any flooding to the west of the road as is identified in the drone footage of the flood event. The reason for this is the culvert identified in the footage under this road is not represented in the current model, and as there is no spill over the road, the flood waters remain to the east of this road. Another difference in this area is in the northern section where the modelled flood extents do not extend as far as the shapefile. The drone footage does not show any flooding in this section of the field, so while the model does not match the shapefile it does match the drone footage.

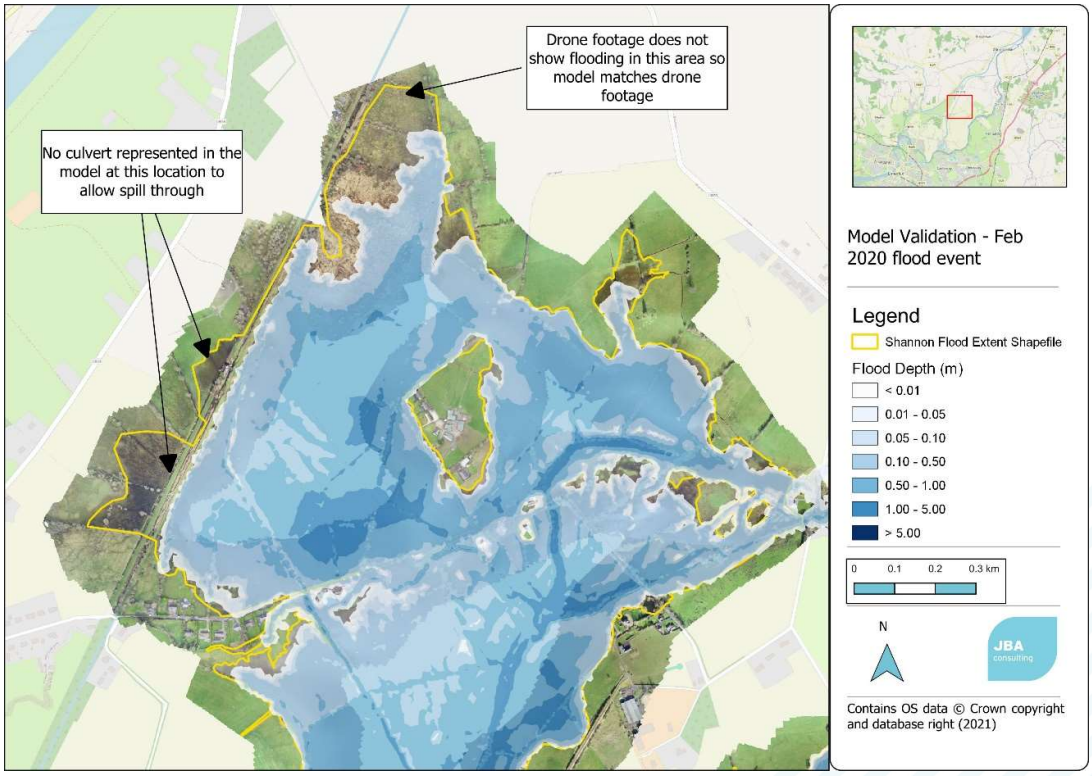



**Figure 7-12: Model Validation Comparison – North**

Figure 7-13 below shows a detailed comparison of the modelled flood extents and flood footage on the Mulkear River. It is worth noting that the model does not have a detailed representation of walls, buildings etc which could alter flood extents on a local scale. While most of the extents in this area match well there are a few areas where the modelled flood extents are greater than the Flood Event Shapefile. However, the drone images of the flood event give evidence that the peak flood extent in these areas was greater than shown by the Shapefile and therefore the model results can be considered more representative. The figure below shows 3No. examples where this occurs northwest of the IDA lands, additional spill into the UL Bohs pitch and on the right bank of the Mulkear.

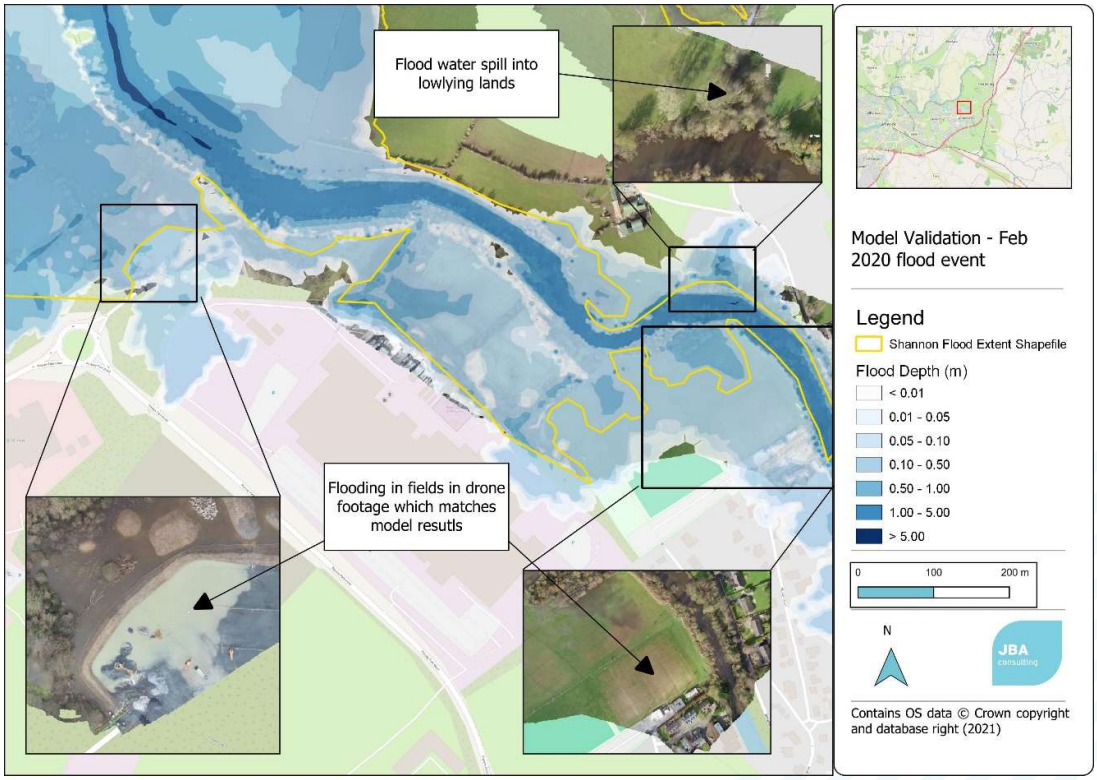



**Figure 7-13: Model Validation Comparison – Mulkear**

# 8 Mulkear Catchment Model

## 8.1 Hydrodynamic Model

Using the Telemac software (modified in-house at JBA), a Rain on Grid model was developed to determine the origin of sediment within the Mulkear River which then enters the River Shannon. This is a broadscale assessment of the entire Mulkear catchment. Figure 8-1 below shows the model boundary/catchment area. The model purpose is to identify the likely source areas of sediment in the Mulkear catchment by dividing the catchment into small sub-catchments/polygons with a large number of particles randomly seeded into each polygon. Each particle is identified uniquely, and the time history of each particle's motion can be traced. These particles follow the flow route through the model, and the particles which reach the confluence with the River Shannon represent the likely source areas of sediment. The model also takes into account land use types to identify areas of a greater run-off probability. The work completed as part of the fluvial audit ground truths the model. Once these likely areas of sediment source are identified, the options for managing the sediment in these areas can be considered further.

It is noted that the particles are passive tracer particles. The particles do not have active characteristics and can therefore represent any sediment associated with the land use at their place of origin.

The model assists in identifying sediment source areas, in conjunction with the Hydromorphological assessment, and determines the high priority areas which need to be considered in the testing of measures at the next stage of the modelling assessment.

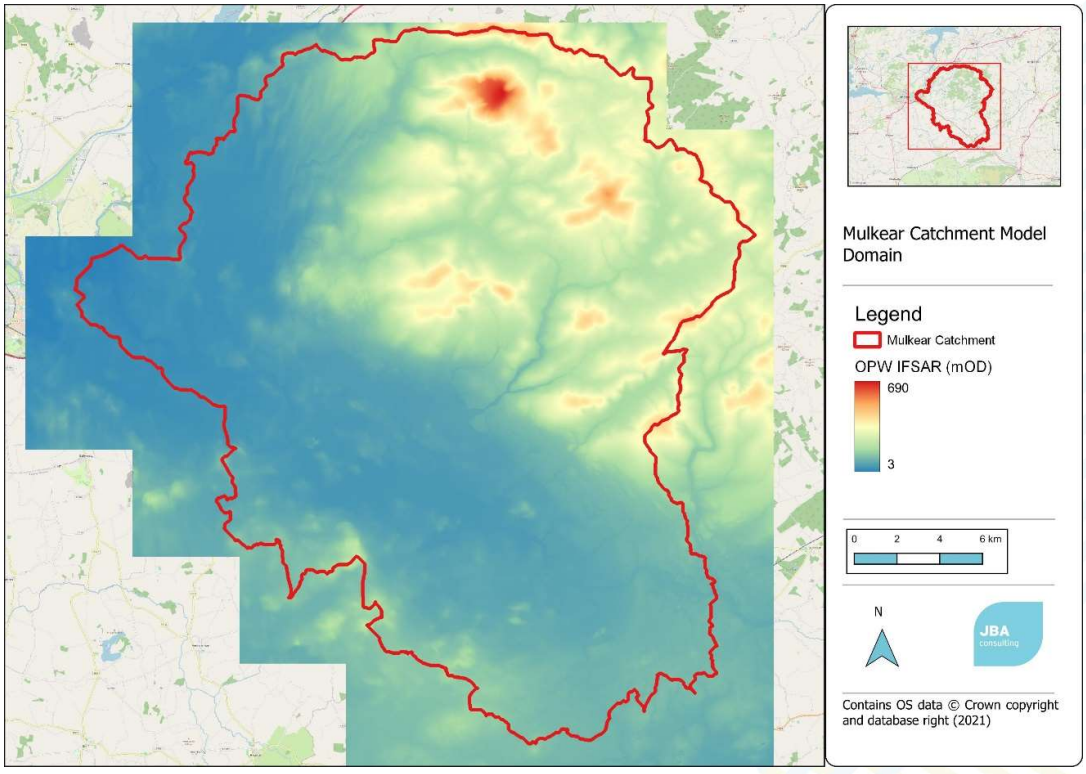



**Figure 8-1: Mulkear Catchment Model Domain**

### 8.1.1 Model Build

The model has a variable mesh with a coarse grid in the larger catchment area and a finer grid size along the watercourses, refer to Figure 8-2.

For flexibility and computational efficiency reasons, the model employs an unstructured mesh comprising a Delaunay triangulation of the model domain. The mesh is high resolution within the rivers and areas of importance (flood plains etc.) and is of lower resolution where accuracy is not paramount. The mesh comprises 399004 computational nodes (~796300 computational elements). The mesh edge length ranges from a minimum edge length of 3m to a maximum edge length of 160m; the mean interior edge length is 41m.

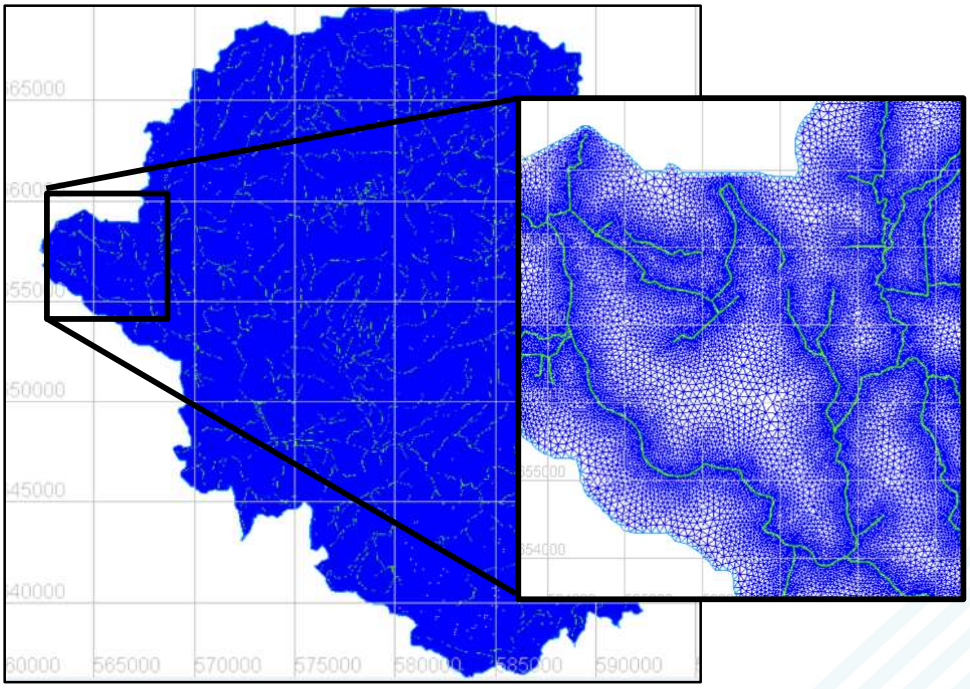



Figure 8-2: Mesh used in the Mulkear Catchment Rain-on-Grid Model

### 8.1.2 Topography

The Mulkear catchment is almost entirely outside of the LiDAR data available. 5m IFSAR which available for the catchment area, as described in Section 3.3.2 has been used to define the topography. Bilinear interpolation was employed to transfer this data to the model grid. Figure 8-1 shows the IFSAR in the model domain. This data is appropriate for the assessment as it represents the river channels using approx. 5m mesh size, and a larger mesh size with mean interior edge length of 41m as discussed in the section above.

### 8.1.3 Land Use

The model takes into account land use types and soil types to identify areas of a greater run-off probability by assigning curve number[6] (CN) values to the catchment. CN values relate to the soil type, soil infiltration capability, land use and the depth of the seasonal high-water table. The CN values are assigned as follows:

1. HSG Groups

   To account for different soils' ability to infiltrate, soils are divided into four hydrological soil groups (HSGs). The HSGs are summarised below.

   - HSG Group A – Low runoff potential Soils with high infiltration rates even when thoroughly wetted.
   - HSG Group B - Soils with moderate infiltration rates when thoroughly wetted.
   - HSG Group C - Soils with slow infiltration rates when thoroughly wetted.
   - HSG Group D - High runoff potential. Soils with very slow infiltration rates when thoroughly wetted.

   The IFS Soils Map (refer to Section 3.8) provides information on the soils types across the catchment and whether the soils are well drained, poorly drained, etc. This IFS soils information was used to categorise into each of the HSGs. Table 8-1 below shows the IFS soils type and the corresponding HSG and Figure 8-3 shows an overview of the HSGs assigned to the catchment.

**Table 8-1: IFS Soils & HSGs**

| HSGs | IFS Soil Type |
|---|---|
| A | AminDW – Deep well drained mineral |
| | BminDW – Deep well drained mineral |
| B | AminSW - Shallow well drained mineral |
| | BminSW - Shallow well drained mineral |
| C | AminSRPT – Shallow rocky drained mineral soils with peaty topsoil |
| D | AminPD - Deep poorly drained mineral |
| | AminPDPT - Poorly drained mineral soils with peaty topsoil |
| | AminSP - Shallow poorly drained mineral |
| | AminSPPT - Shallow poorly drained minerals with peaty topsoil |
| | BktPt - Peat |
| | BminPD - Deep poorly drained mineral |
| | BminPDPT - Poorly drained mineral soils with peaty topsoil |
| | BminSP - Shallow poorly drained mineral |

[6] Urban Hydrology for Small Watersheds TR-55 (U.S. Department of Agriculture, June 1986)

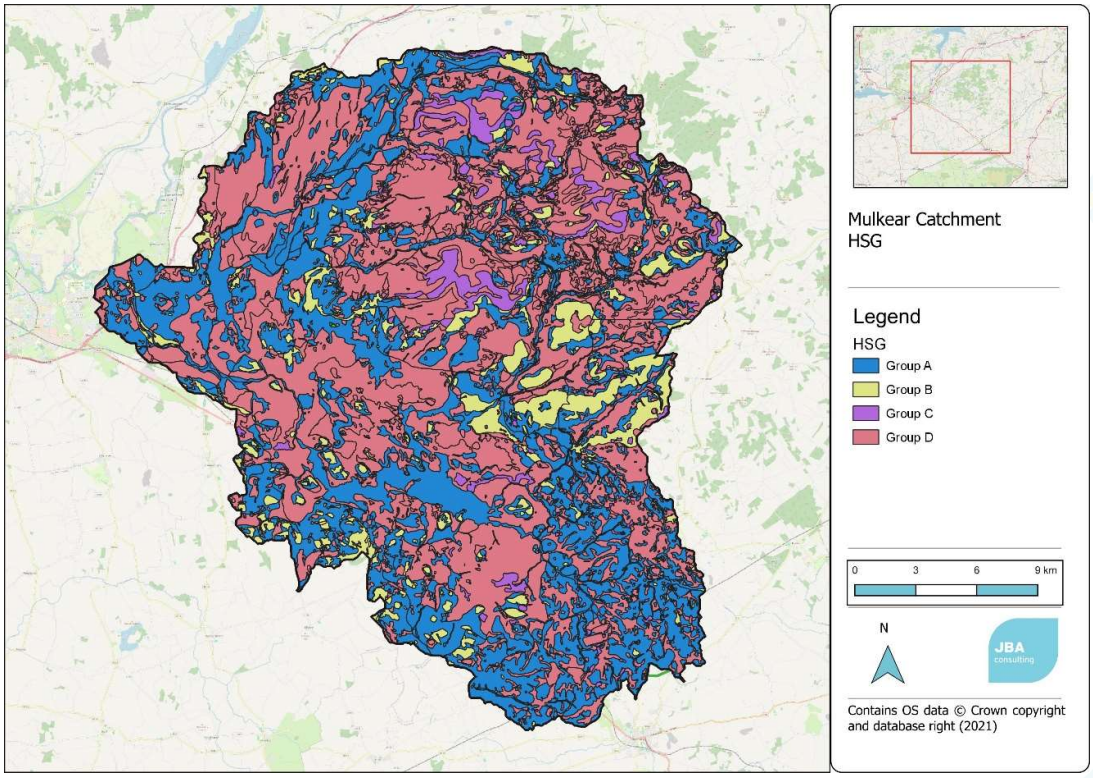



**Figure 8-3: Mulkear Catchment HSGs**

2. Land Cover

   Land cover uses are assigned to the model based off the EPA Corine Land Use map, as described in Section 3.7.

3. Curve Number

   After land covers type and HSGs was assigned to the Mulkear catchment, CN values for the catchment could be derived, using Table 8-2 below. The ranges for each of the CN values depends on the hydrological condition of the soils. Poor hydrological conditions assigned lower values while good hydrological conditions are assigned higher values. Poor hydrological conditions are those which generally have <50% ground cover, while good hydrological conditionals are those with >75% ground cover. The hydrological condition (or ground cover) was broadly estimated using Google Maps ™ Aerial Imagery of the catchment.

   Figure 8-4 shows the CN values assigned to the Mulkear Catchment which are used in the model.

**Table 8-2: CN Values**

| Cover Description | CN for HSG | | | |
|---|---|---|---|---|
| **Cover Type** | **A** | **B** | **C** | **D** |
| Pasture, grassland | 39 - 68 | 60 - 79 | 74 - 86 | 80 - 89 |
| Brush | 30 - 48 | 48 - 67 | 65 - 77 | 73 - 83 |
| Woods, grass combo | 43 - 57 | 65 - 73 | 76 - 82 | 82 - 86 |
| Woods | 30 - 45 | 55 - 66 | 70 - 77 | 77 - 83 |
| Farms | 59 | 74 | 82 | 86 |
| Urban | 89 | 92 | 94 | 95 |

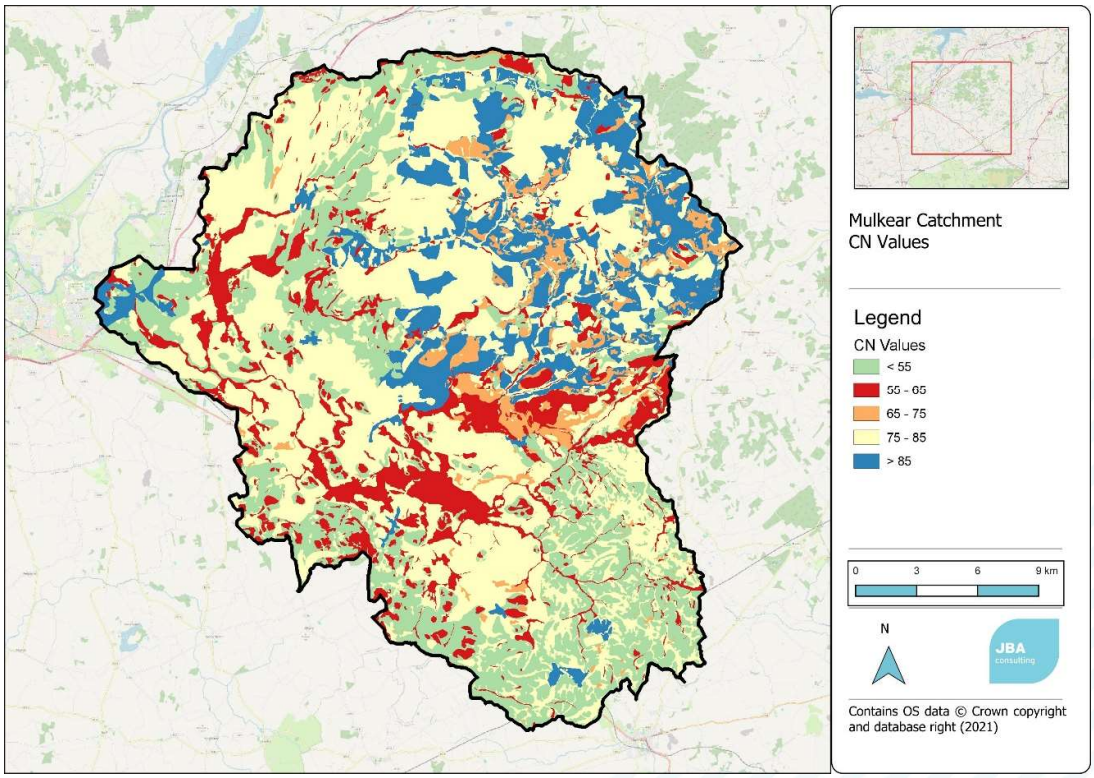



**Figure 8-4: Mulkear Catchment CN Values**

## 8.2 Hydrology

As the Mulkear Catchment Model is a Rain-On-Grid model, the Met Eireann DDF layer (as described in Section 3.10) was used to calculate the rainfall depths within the catchment. The rainfall data is applied spatially across the catchment, varying between DDF points within the model. The rainfall events have been for a range of storm durations, ranging from the 1hr, 6hr and 24hr storm durations.

222No. DDF points fall within the Mulkear Catchment. The Rainfall Depths for each of these DDFs points were collected for each of the rainfall events. An example of the values for 3No. of the DDF points within the catchment are shown in Table 8-3 below while the point locations are identified in Figure 8-5.

**Table 8-3: Met Eireann DDF Rainfall Intensities**

| Point | 2yr 1hr | 10yr 6hr | 100yr 24hr |
|---|---|---|---|
| 1 - 5 | 10.8 | 32.95 | 80.5 |
| 2 - 183 | 13 | 40.85 | 104.1 |
| 3- 154 | 13.1 | 39.25 | 95.9 |

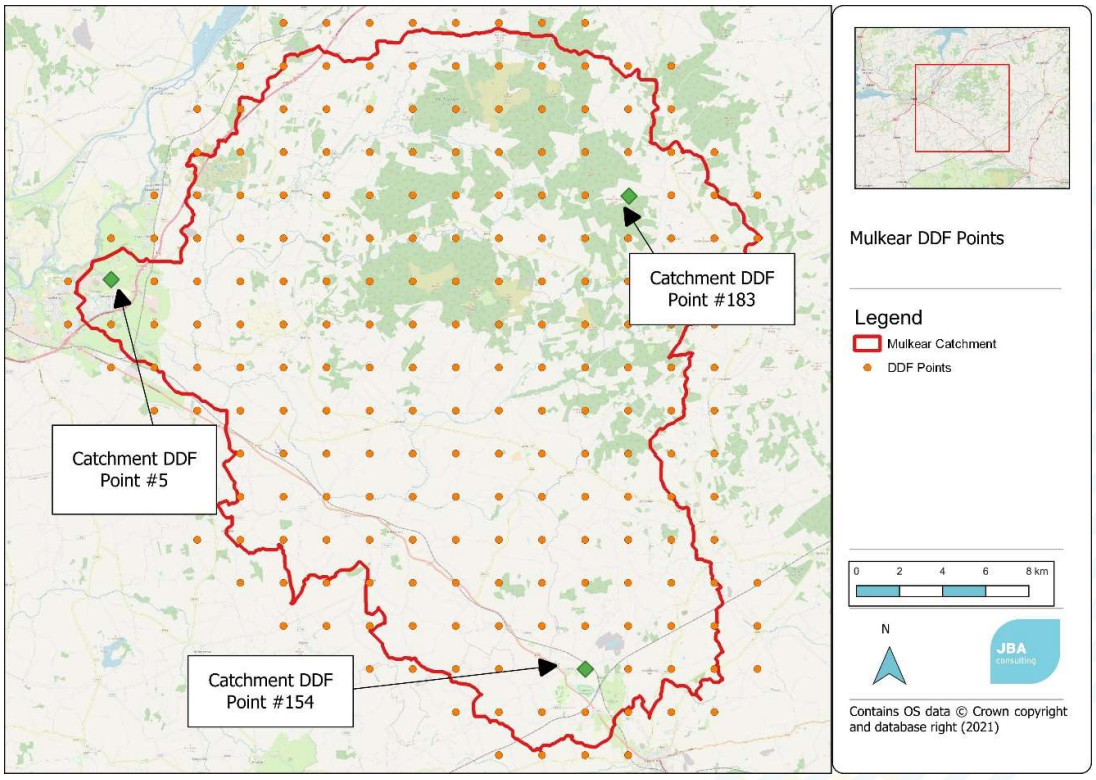



**Figure 8-5: Mulkear Catchment DDF Points**

Hyetographs were then generated for each DDF points for each of the modelled rainfall events. Figure 8-6 and Figure 8-7 show an example of the Hyetographs produced at Point 5 for the 2-year 1-hour event and the 100-year 24-hour event, respectively.

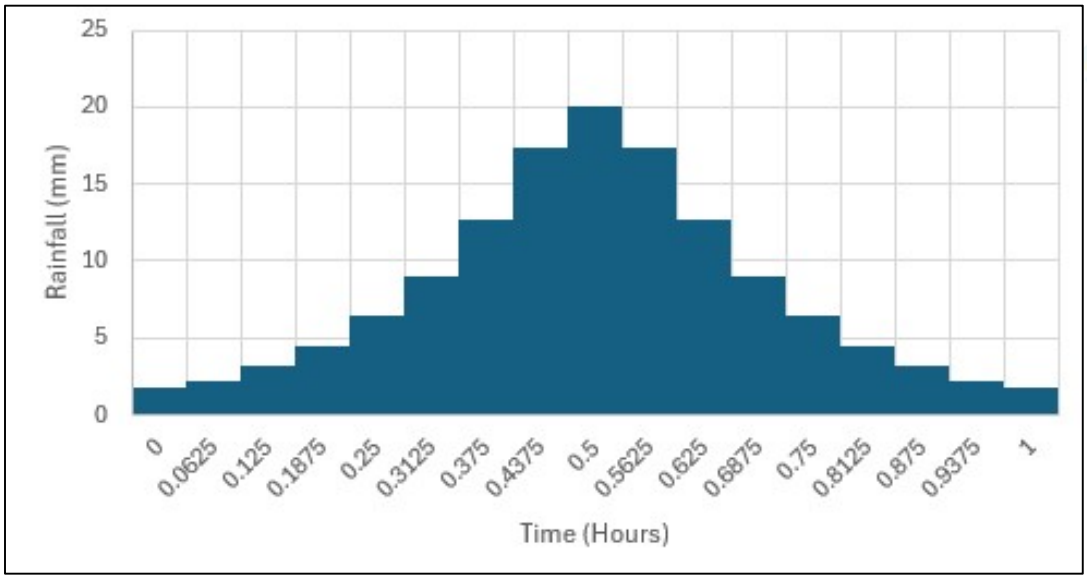



**Figure 8-6: DDF Point #5 2-year 1-hour Hyetograph**

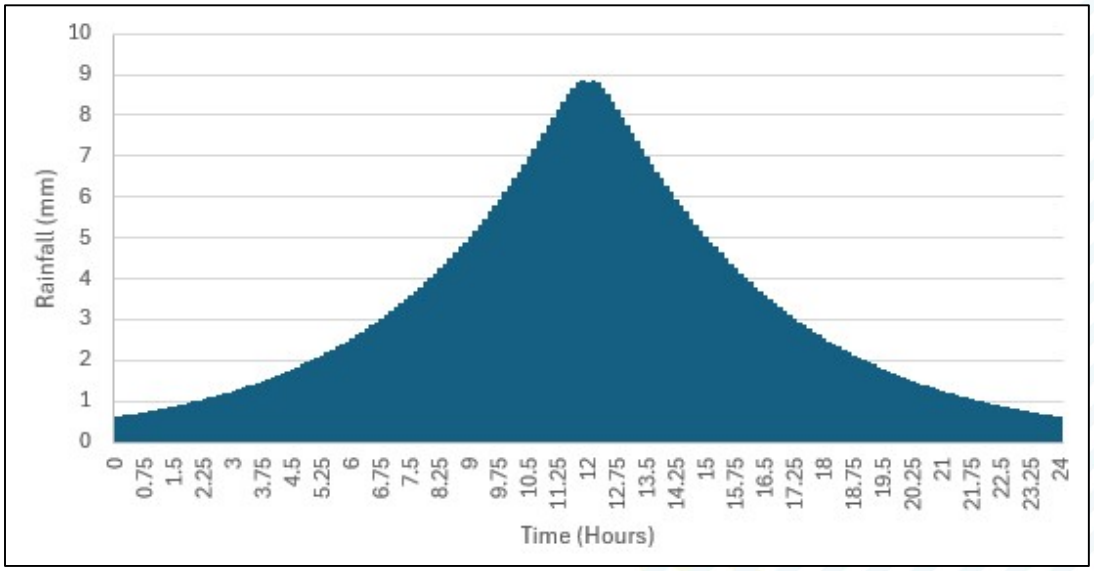



**Figure 8-7: DDF Point #5 100-year 24-hour Hyetograph**

## 8.3 Particle Tracking

To determine the origin of sediment within the catchment, particles were randomly seeded into pre-defined polygons in the Mulkear catchment model. The polygons with the seeded particles are shown in the figure below. These polygons were digitised based on observations during the geomorphological field survey of potential sediment sources. These include areas of active sediment erosion/transport/deposition processes (i.e. observed evidence of in-channel geomorphic diversity such as coarse sediment bed features) or adjacent pressures with potential to add excessive sediment supply e.g. evidence of bank poaching, or streams connecting to forested parts of the catchment (see Hydromorphology Report, Section 3.2.1 for reach-scale observations and Section 3.2.2 for a description of pressures and where they were observed). . The particles then follow the flow route, due to the rainfall run-off, through the model, and the particles which reach the confluence with the River Shannon represent the likely source areas of sediment.

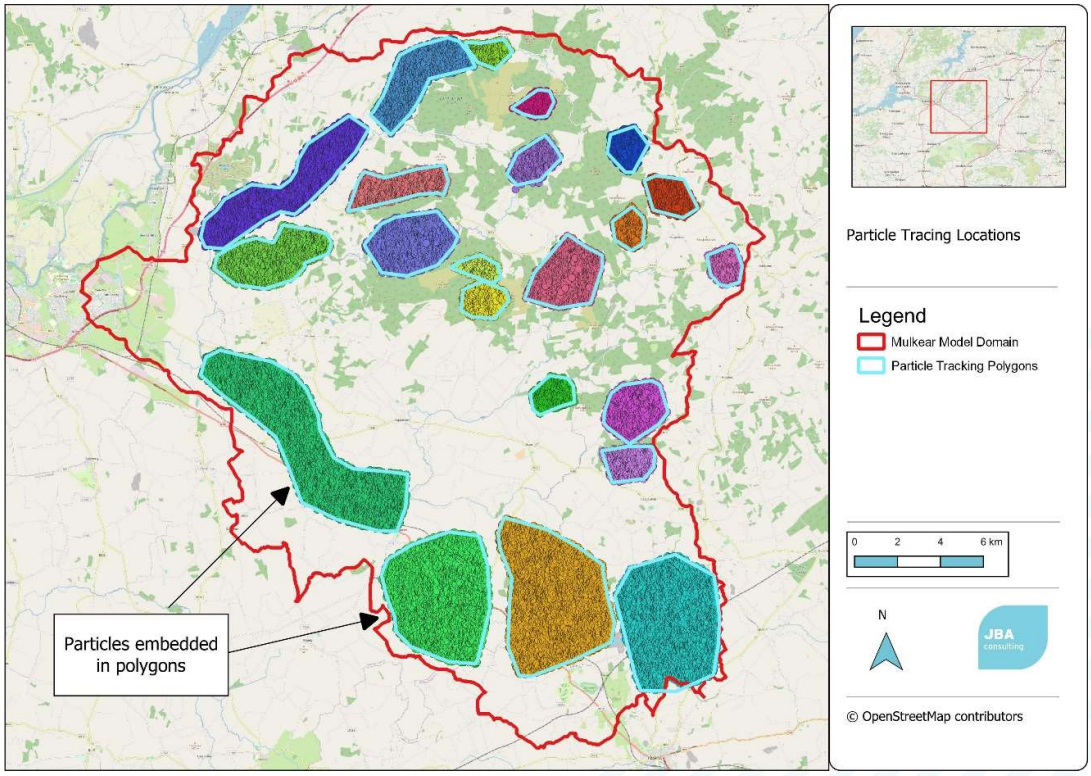



**Figure 8-8: Initial Conditions for the Particle Tracking Simulations**

### 8.3.1 Particle Movement Comparison

The particle movements were analysed across a range of rainfall events and durations. Table 8-4 shows a comparison of the particle movement after a 24 hour rainfall event with a 2yr return period, a 10yr return period and a 100yr return period. The particle tracking model suggests that particles seeded in the north of the catchment are more likely to provide source material than particles to the south of the catchment, along the River Deed, particularly with lower rainfall return periods. In the 2yr event, there is very little movement from particles in the south of the catchment while there is movement from particles in the north. As the return period of the rainfall increases, more particle movement is estimated across the catchment.

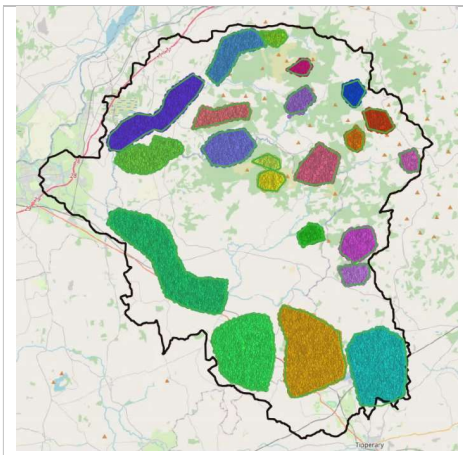
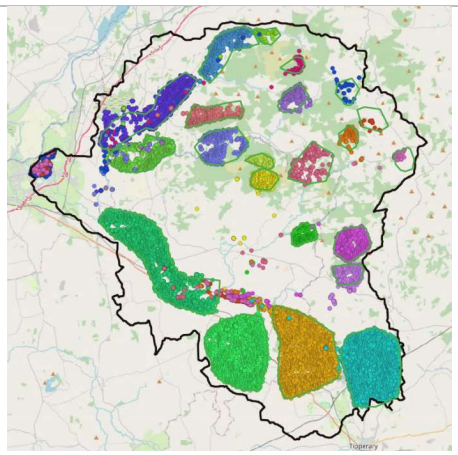
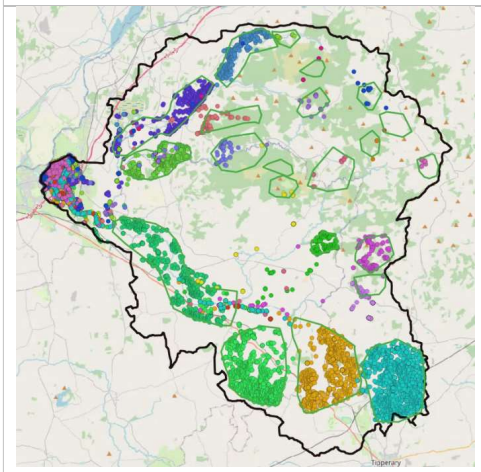
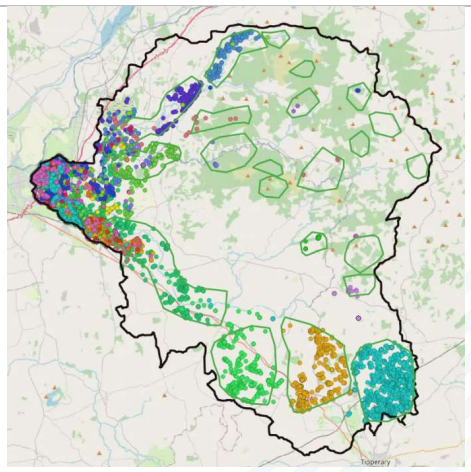
Figure 8-9 below is an extract of the Conceptual Catchment Model from the Hydromorphology Report. The outputs of the Particle Tracking model have been ground-truthed using the Conceptual Catchment Model. Figure 8-9 also identifies the sub-catchments along with the watercourses which are referred to below.

As seen in Table 8-4 and discussed above, there is very little movement from particles in the southeast corner in the lower return periods while most of the particle in the north east corner of the have moved towards the downstream end of the catchment. This catchment is an upland environment with steep hillslopes and predominantly forested landcover (refer to Section 8.1.3 for more information on the land cover and soil types in the catchment). As confirmed in the Hydromorphological assessment, these forestry land cover types are likely contributing fine material from the run-off. The model indicates that most of the particles transported from the Upper catchment along the Annagh River end up at the downstream boundary of the model, i.e. these particles reach the Annacotty Weir.

The southern section of the catchment is low gradient agricultural lands. The lack of sediment movement in this area in the lower return periods ties in well with the Hydromorphology Report where a modest transport potential is identified in this area. Most of the particles which have movement from this section in the lower return periods originate from the upper reaches of the Bilboa River and upper tributaries of the River Deed in the mid east of the catchment. These particles do not reach the downstream boundary of the model but drop out in the upper reaches of the Mulkear. As the return period increases towards to the 10year event and the 100year event, the particles from the upper reaches of the River Bilboa are transported along the Mulkear towards Annacotty Weir, along with more particles from the River Deed.

The Mid-catchment has a medium gradient, and the model results show some movement of the particles that are initially seeded here.

**Table 8-4: 24 Hour Events**

| | |
|---|---|
|  |  |
| Particle Starting Locations | 2yr 24hr event |
|  |  |
| 10yr 24hr event | 100yr 24hr event |

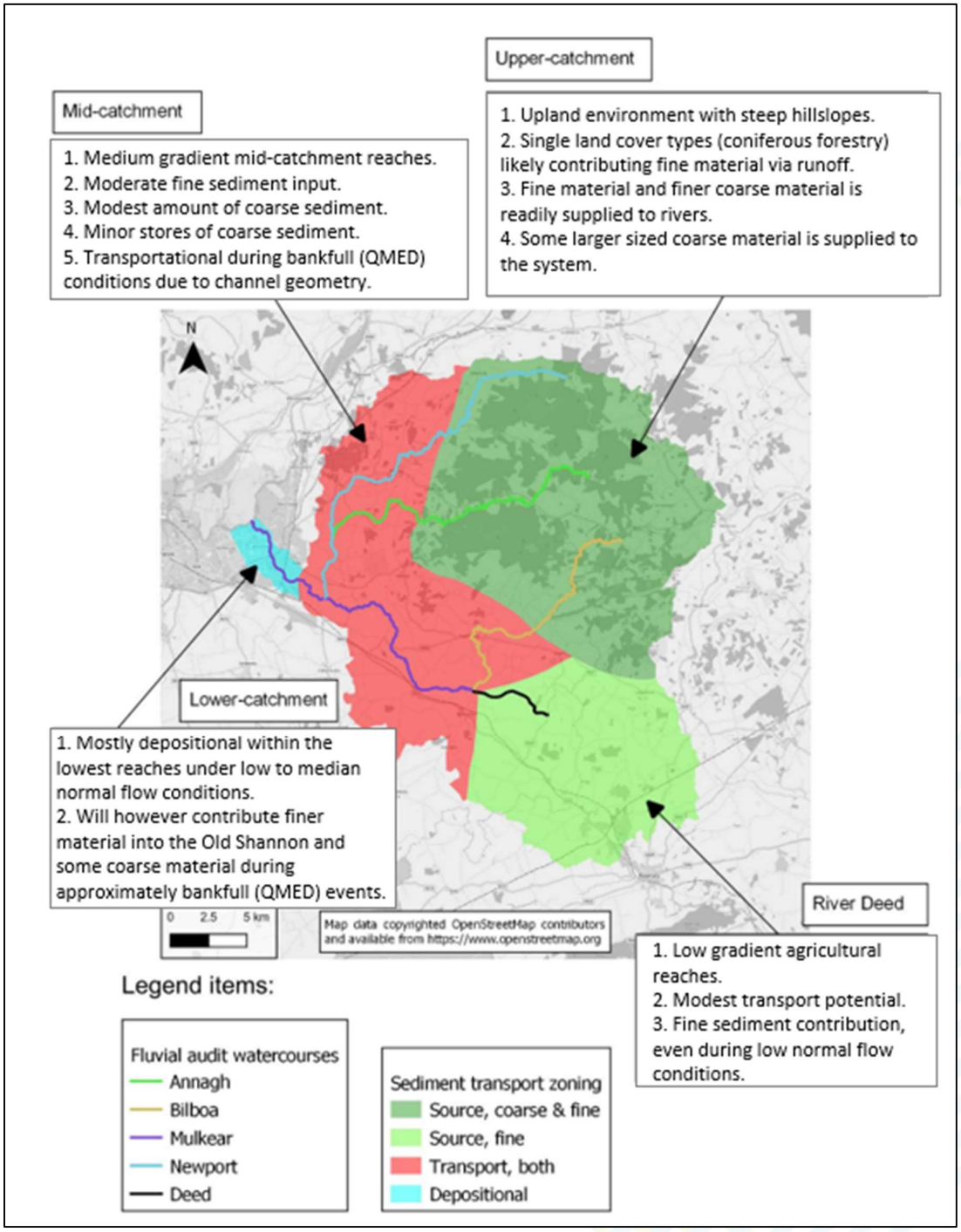



**Figure 8-9: Conceptual Catchment Model (Extract from the Hydromorphology Report)**

### 8.3.2 Particle Density Pathways

The particle tracking model is also able to identify the primary flow routes through the catchment. This is done by tracking the density of particles which move through a particular flow route. The higher the density, the greater the number of particles transported along this route. This gives a sense of the primary transport routes across the catchment.

Figure 8-10 below shows the density of particle movement across the catchment during a 24hr rainfall event. The figure does not indicate absolute sediment densities but relative densities. As seen in the figure, there are a number of pathways which estimate a high particle density, such as along the River Bilboa into the Mulkear and along the lower reaches of the River Annagh.

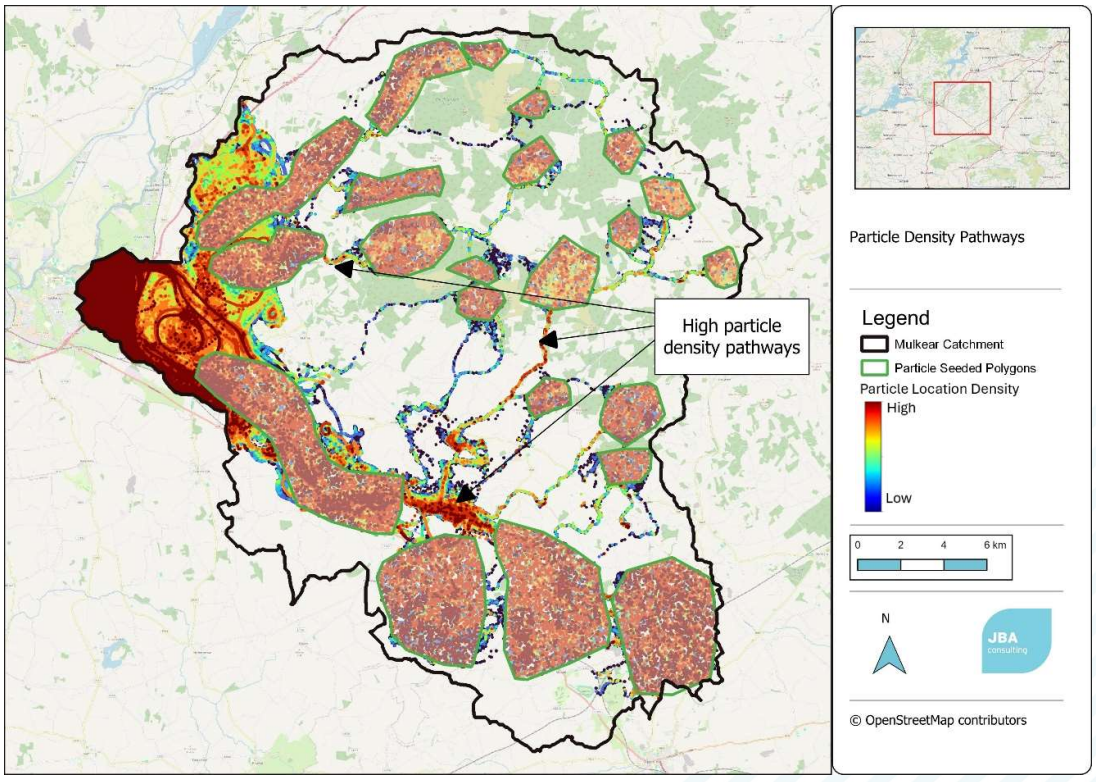



**Figure 8-10: Particle Density Pathways**

### 8.3.3 Conclusions

The particle tracking study has allowed both the primary source areas for sediment and the primary flow routes to establish the origin of sediment within the catchment.

The analysis suggests that the upland catchment is the key source area for sediment, as these areas are shown to have the potential to transport sediment in lower rainfall events as well as in higher rainfall events. The particle density pathway model then estimates that the key routes in the catchment are from these upland area into the Mulkear River via the River Bilboa and the River Annagh.

# Appendices

## A Castleconnell Flood Relief Scheme

The overall purpose of the Castleconnell FRS project is to design and build flood defences that will protect properties and critical infrastructure in future flood events, with a standard of protection up to 1% AEP. Hydraulic modelling of the River Shannon downstream of the Parteen Weir was developed to assess design flood levels and potential defence options.

### A.1 Hydraulic Modelling

The Shannon River channel through the study area is characterised by high hydraulic complexity, with many islands, pools and weirs present along the channel, influencing the hydraulic regime. A 1-dimensional (1D) model built by interpolating cross sections is not capable of capturing the hydraulic effects and spatial variation created by the in-channel features, therefore, this study commissioned additional topographical and river survey to provide sufficient detail to construct a 2-dimensional (2D) model able to directly represent the hydraulic behaviour of these features. Reaches upstream and downstream of the scheme area have retained representation of the channel within 1D to provide routing from Parteen Weir to the study area and to provide sufficient distance downstream of the study area to reduce uncertainty associated with tailwater conditions.

Two models were built for this study. The primary model represents the Shannon River from Parteen Weir to the Mulkear River confluence, whilst the second model represents the Cedarwood tributary in Castleconnell.

The Cedarwood Stream at the northern end of Castleconnell is a significantly smaller watercourse than the Shannon River. CFRAM modelling has shown it is a source of flood risk to Castleconnell and there is also the potential for backwater flow from the Shannon River exceeding bank heights of the Cedarwood Stream.

Due to the significant change in scale between the Cedarwood Stream and the Shannon River, a separate 1D-2D FM-Tuflow model was built for Cedarwood Stream with a downstream water level – time boundary using the water levels recorded on the Shannon from the main model.

In the main Shannon River model, Cedarwood Stream is not included, with the flows being added directly into the 2D domain at its outlet to the Shannon River. The main Shannon model includes the Stradbally stream, modelled in 2D, with the culverts modelled in 1D as Estry elements. Table A below provides a summary of general model details for the Shannon model.

| **1D model** | **Value** |
|---|---|
| Total 1D modelled length | 10.29km (5.88km upstream and 4.41km downstream) |
| 1D timestep | 2 seconds (half the 2D 8m domain timestep) |
| Number of inflows | 2 inflows (points) |
| Number of outflows | 1 1D outflow (Normal depth boundary) |
| **2D model** | |
| Total model area | 1.94 km2 |
| Model orientation | North-east to South-west |

| | |
|---|---|
| 2D grid cell size | 8m/4m multi-domain |
| 2D timestep | 4 seconds for the 8m domain/2 seconds for the 4m domain (half the grid cell size) |
| Number of inflows | 4 2d inflows |
| Number of outflows | No 2d outflows |
| 1D-2D model linkage | Via SX and CN points and lines |
| Coordinate reference system | TM65 (Irish National Grid) |
| Total model area | 1.94 km2 |

**Software**

The model was developed using Flood Modeller and TUFLOW software packages creating a linked model with 1D and 2D components. The 1D model domain was modelled using Flood Modeller (FM) Pro v4.5, while the culverts on the Stradbally tributary have been modelled in Estry and linked to the 2D domain. The 2D domain has been modelled using TUFLOW Classic 2018-03-AE. These versions were the latest releases at the time of initial model build. The double precision versions of both software were used.

**Schematisation**

The full Castleconnell model is composed of 3 parts:

- 1D only upstream;
- 2D only in the study area (with 1D structures);
- 1D only downstream.

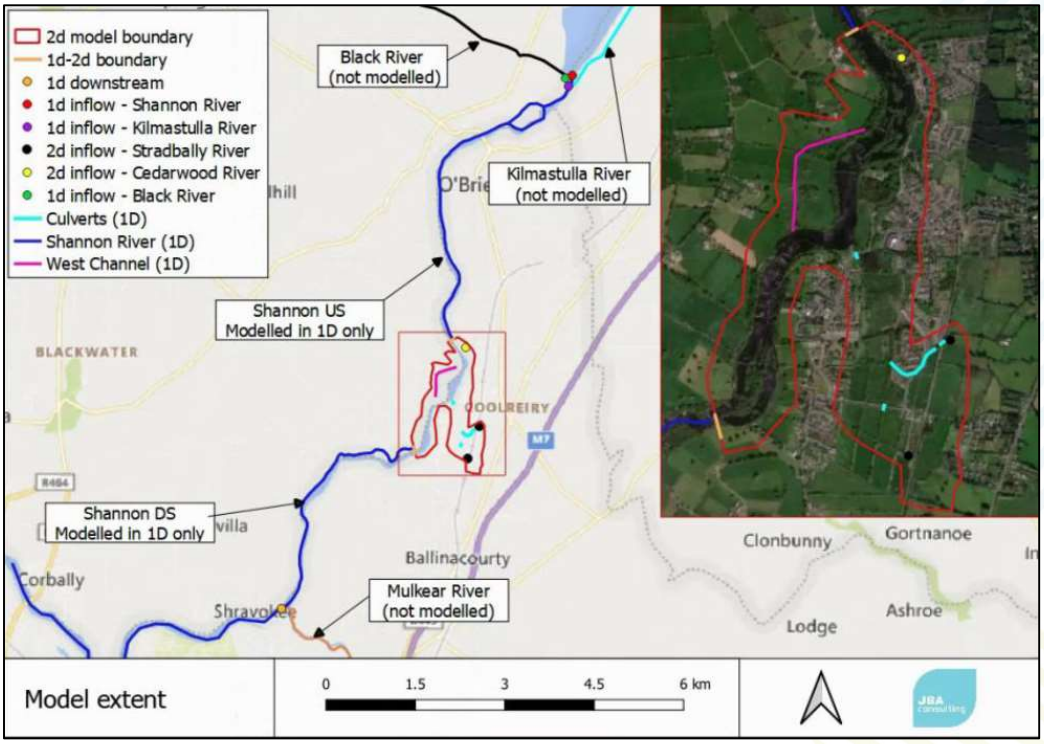



Figure A-1-1: Model Extent

## A.2 Hydrology

The hydrographs and flows calculated for this study were applied both in the 1D and the 2D components of the model. Shannon flows are applied at the upstream end of the model, immediately downstream of the Parteen Weir. The flows are derived from the Parteen Weir AMAX single site LN2 distribution growth curve and the hydrograph shape is derived from the 2015 hydrograph shape of Old Shannon flows.

Black River and Kilmastulla flows are applied at their confluence with Shannon, approximately 100m and 200m downstream of Parteen Weir. The Black River hydrograph was calculated using standard FSU methods, while the Kilmastulla hydrograph is derived from a routing model from the Coole Gauge to the confluence with the Shannon. It is unlikely that a Kilmastulla or Black River flood response could occur at the same time as when the Shannon is in high flow conditions. The probability of such an event would be less than the Shannon flow probability (e.g. a 1% AEP Kilmastulla or a 1% AEP Black River at the same time as a Shannon 1% AEP event would in total be less likely than the 1% AEP event). The joint probability of flow events on the Kilmastulla and Black River with the Shannon are assessed in the Hydrology Report. For the 1% AEP event, a 5% AEP Kilmastulla and Black River flow hydrograph was applied to the Shannon River flows, the peaks of Kilmastulla and Black River being applied at the peak of Shannon River.

The magnitude of the Shannon River hydrograph is significantly higher compared to the Kilmastulla and Black River hydrographs, in terms of both peak flows and flood duration, as shown in Figure A-2-1. The Kilmastulla and Black River hydrographs are displayed in Figure A-2-2 and the location of the inflow boundaries (flow-time) within the model are presented in Figure A-2-3.

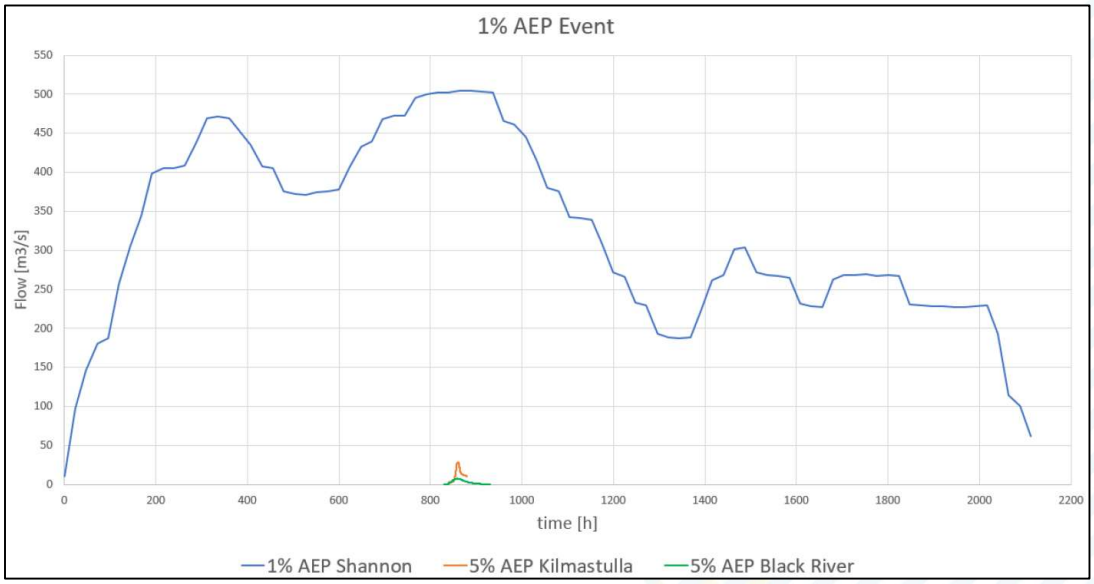



Figure A-2-1: Old Shannon downstream of Parteen Weir 1% AEP (after headrace flow of 345 m3/s to Ardnacrusha – "504 event")

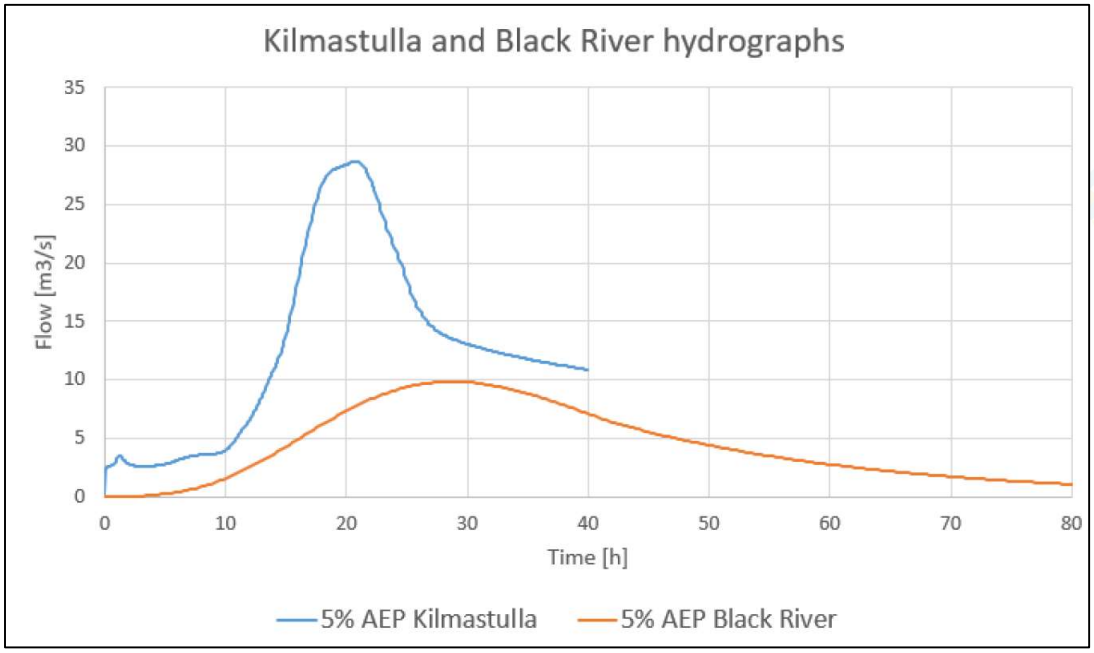



Figure A-2-2: Kilmastulla and Black River 5% AEP

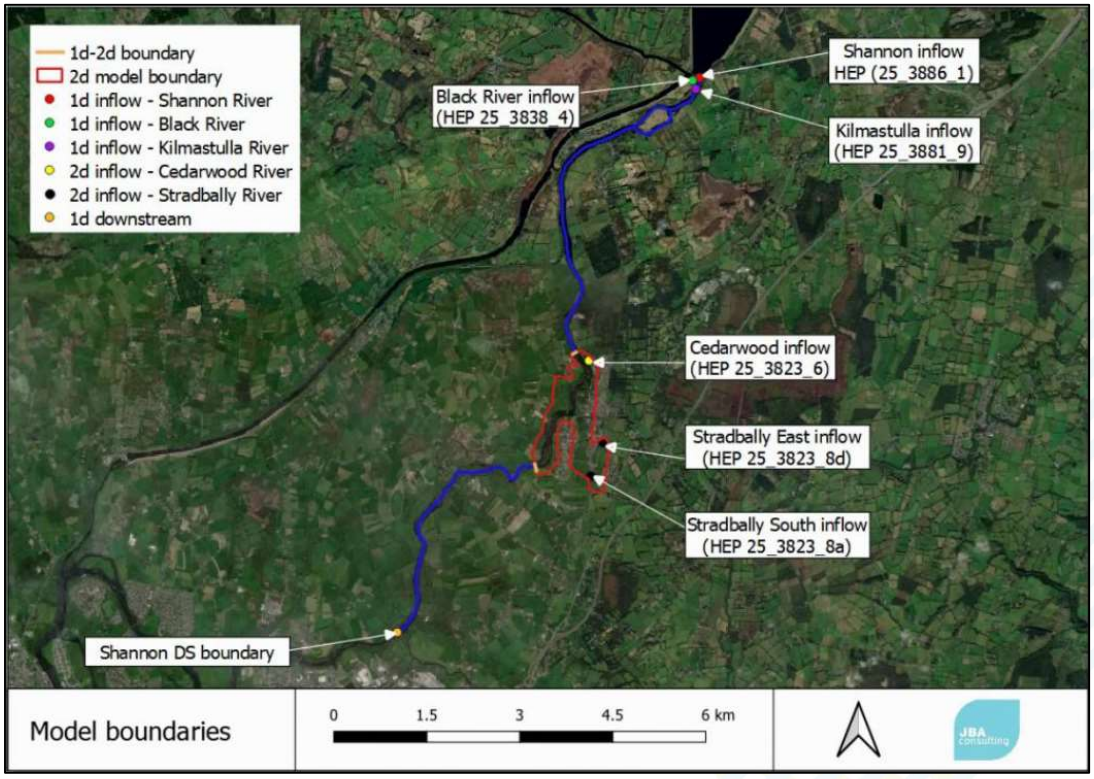



Figure A-2-3: Model Boundaries

The Cedarwood and Stradbally streams have significantly smaller catchments than the River Shannon, therefore the peak flows and the flood durations are also considerably smaller, as presented in Table A-2-1.

Flood events in the Shannon can last for prolonged periods, so it is possible that during a flood event on the Shannon when the water levels are high, a flood event could also occur on the smaller tributaries. Therefore, it is an acceptable approach to have the Cedarwood and Stradbally peaking at the same time as the Shannon River.

As presented in the Hydrology Report, the Cedarwood Streams flows were calculated at four HEP locations (25_3823_6a, 25_3823_6b, 25_3823_6c, 25_3823_6d). The combined flow was added directly into the 2D domain at its outlet to the Shannon River (HEP 25_3823_6).

Table A-2-1: Hydrograph Values

| Watercourse | HEP reference | Peak flow [m3/s] | Duration [hours] |
|---|---|---|---|
| Old Shannon downstream of Parteen Weir (1% AEP) | 25_3886_1 | 504.4 (with 345 m3/s headrace flow to Ardnacrusha – "504 event") | 2112 |
| Kilmastulla (5% AEP) | 25_3881_9 | 28.71 | 40 |
| Black River (5% AEP) | 25_3838_4 | 9.82 | 80 |
| Cedarwood (1% AEP) | 25_3823_6 | 1.07 | 13 |
| Stradbally East | 25_3823_8d | 1.31 | 15 |
| Stradbally South | 25_3823_8a | 0.63 | 15 |

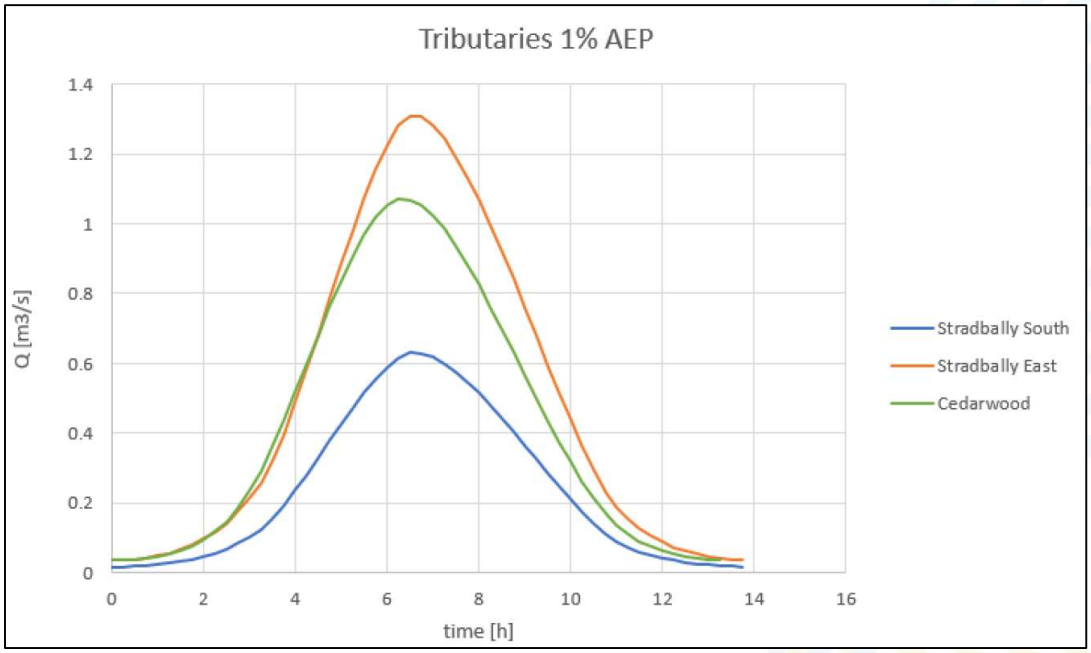



Figure A-2-3: Cedarwood and Stradbally Streams 1% AEP

## A.3 February 2020 Flood Event

The peak flow over Parteen Weir during the 2020 event was 410 m3/s, which would be the approximate equivalent of an event between 5% AEP (394 m3/s) and 2% AEP (458 m3/s) during standard operational conditions. To note the heads race flow to Ardnacrusha was 376 m3/s as a result of the levels in the basin and canal at that time. The flows and times corresponding to the Kilmastulla hydrograph are derived from recorded data at Coole Gauge during the flood event, applying routing effects from the gauge to the confluence with Shannon River. The peak flow on the Kilmastulla River at the confluence with the Shannon River was 30.75 m3/s, slightly higher than the 5% AEP event (28.71 m3/s). The peak flow on Kilmastulla occurred on the 22nd of February, corresponding to the 335m3/s flow over Parteen Weir.

The Shannon and Kilmastulla hydrographs used in the 2020 event are presented in Figure A-3-1 below.

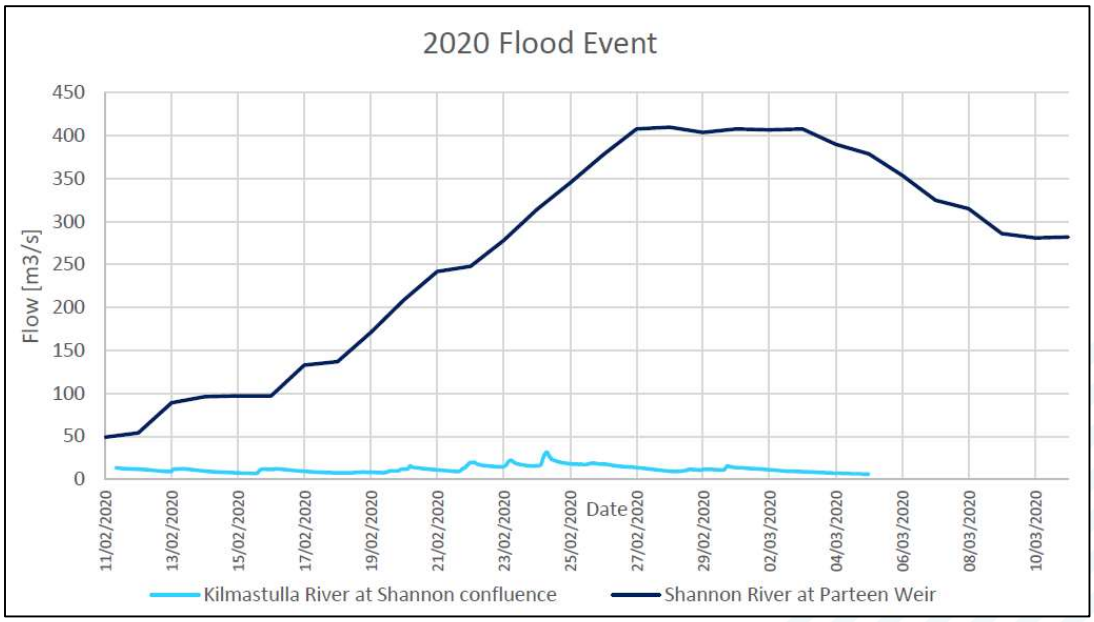



Figure A-3-1: 2020 event – Flow Hydrograph

The orange wrack marks represented in Figure A-3-2 were collected before the flood peak, on the 26th February and the blue wrack marks were collected at high peak, on the 1st of March.

Figure A-3-2 presents the calibration results – the water level difference between the recorded water levels and modelled water levels at the wrack marks.

The model is calibrating well against the 2020 event, with most of the points being in a range of +/- 100mm and a few in an acceptable range of +/- 200mm. All model results are within the specified range of accuracy from the tender specifications.

Figure A-3-2 presents the flood extent and the location of the wrack marks. During the flood event it was noted that the river water levels had a degree of wave action, therefore the wrack marks would be the peak water level observed and not the average still water level.

The water levels at wrack marks are presented in Table A-3-1.

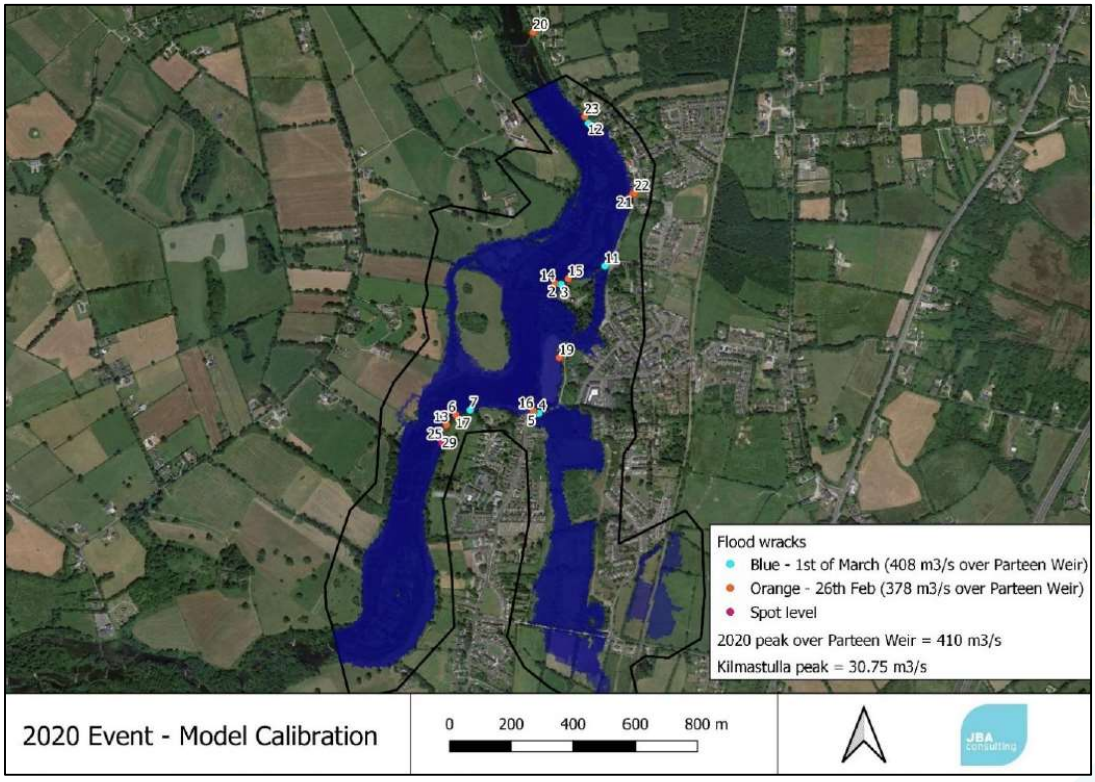
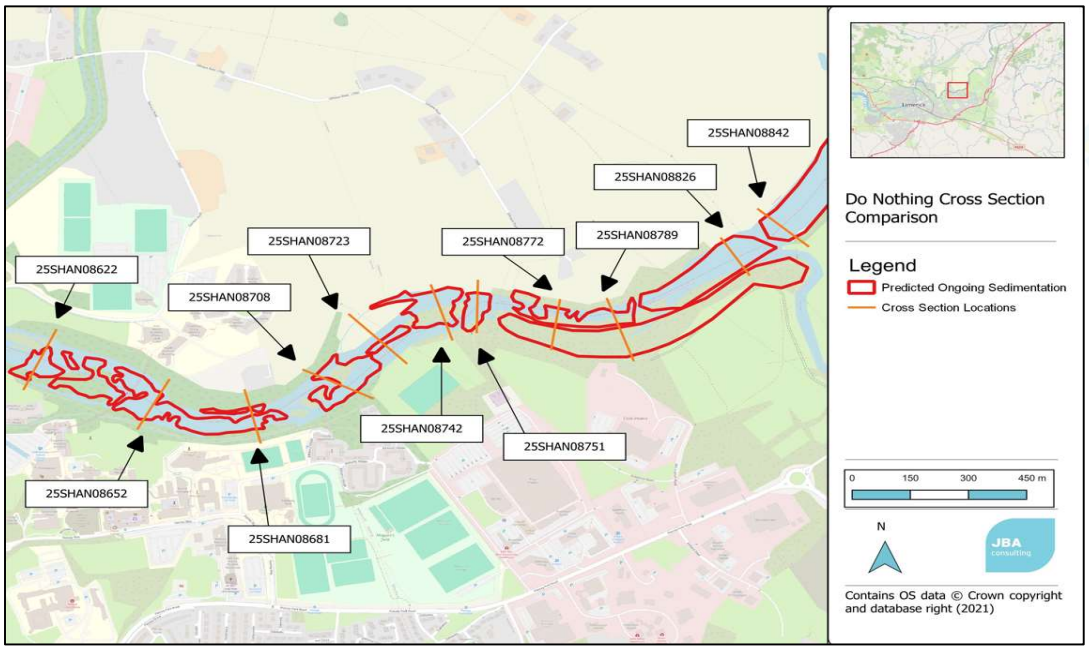


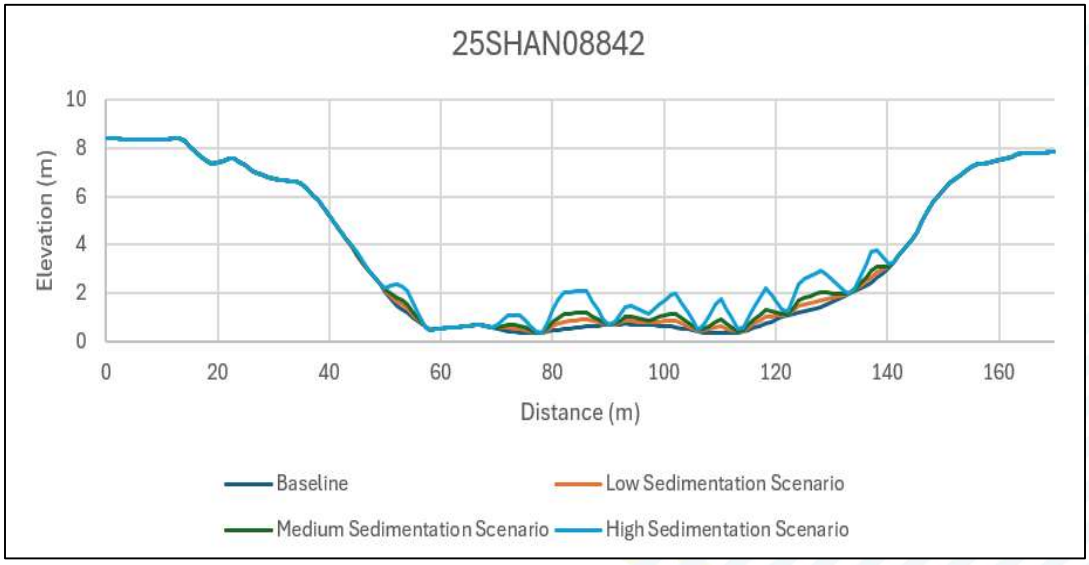

Figure A-3-2: Model Calibration

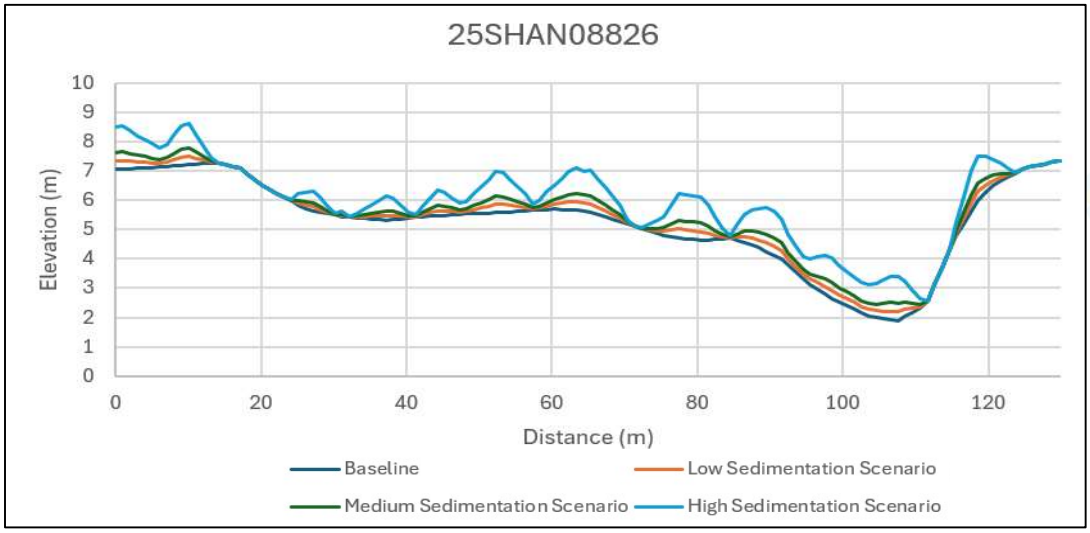
Table A-3-1: 2020 Event Calibration

| Location | ID Flood wrack | Measured WL [mOD] | Modelled WL [mOD] | Difference [m] |
|---|---|---|---|---|
| 1D model | 20 | 24.44 | 24.52 | 0.08 |
| US Cedarwood confluence | 23 | 23.93 | 23.78 | -0.15 |
| | 12 | 23.92 | 23.85 | -0.07 |
| US Western Channel | 21 | 23.57 | 23.51 | -0.06 |
| | 22 | 23.49 | 23.51 | 0.02 |
| Island House Structure | 11 | 23.29 | 23.29 | 0 |
| US Eel bridge | 15 | 22.92 | 22.96 | 0.04 |
| | 3 | 22.96 | 23.04 | 0.08 |
| Eel Bridge | 1 | 23.17 | 23.08 | -0.09 |
| | 2 | 23.11 | 23.06 | -0.05 |
| | 14 | 23.02 | 22.93 | -0.09 |
| DS Island House channel | 19 | 22.47 | 22.48 | 0.01 |
| Car park | 4 | 22.56 | 22.63 | 0.07 |
| | 5 | 22.56 | 22.63 | 0.07 |
| | 16 | 22.46 | 22.48 | 0.02 |
| US Doonas Bridge | 7 | 22.25 | 22.3 | 0.05 |
| | 6 | 22.01 | 22.16 | 0.15 |
| | 17 | 21.95 | 22.02 | 0.07 |
| | 13 | 21.77 | 21.78 | 0.01 |
| DS Doonas bridge | 25 | 21.35 | 21.33 | -0.02 |
| | 29 | 21.4 | 21.33 | -0.07 |

# B Sedimentation Scenario Cross Sections

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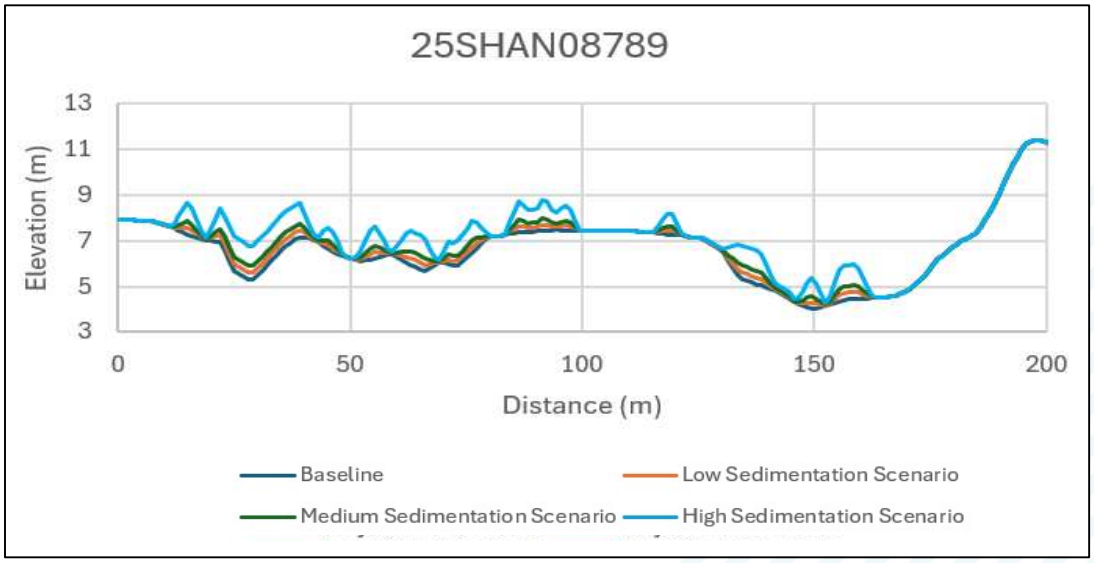
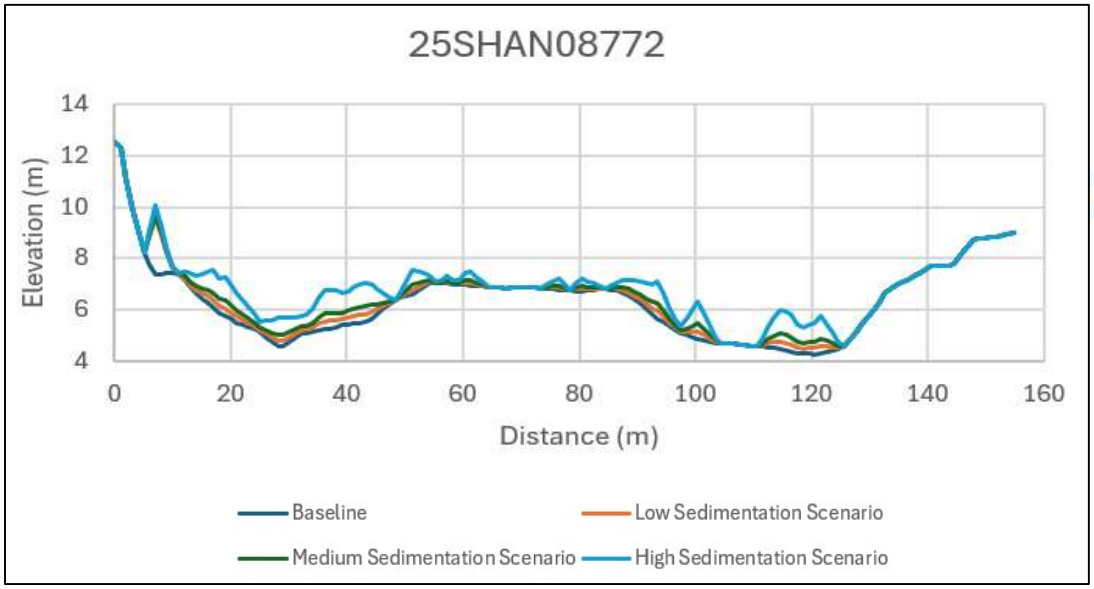
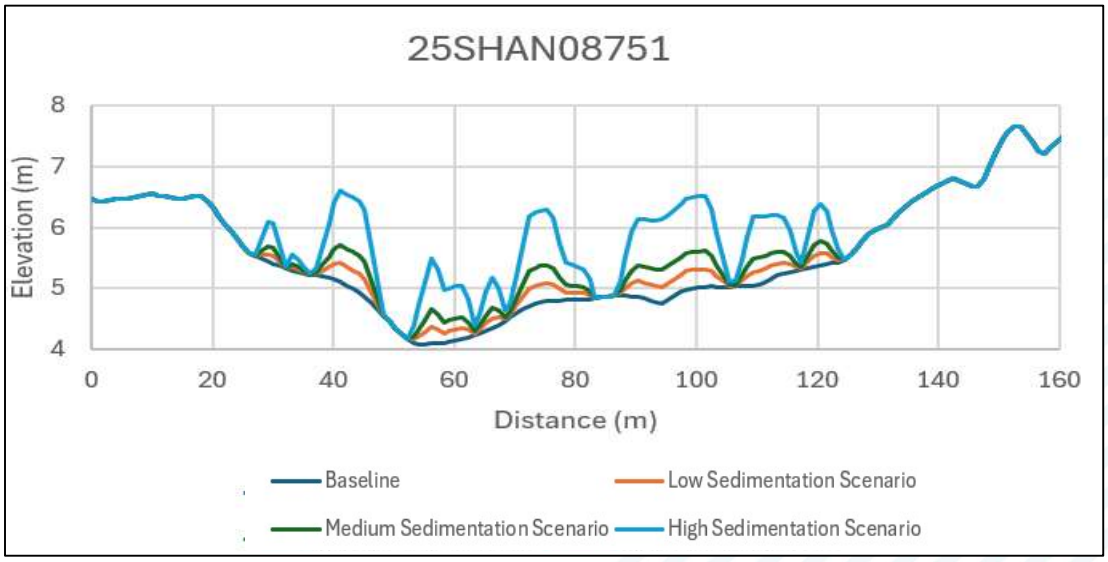
Elevation (m)
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
Distance (m)
Baseline
Low Sedimentation Scenario
Medium Sedimentation Scenario
High Sedimentation Scenario

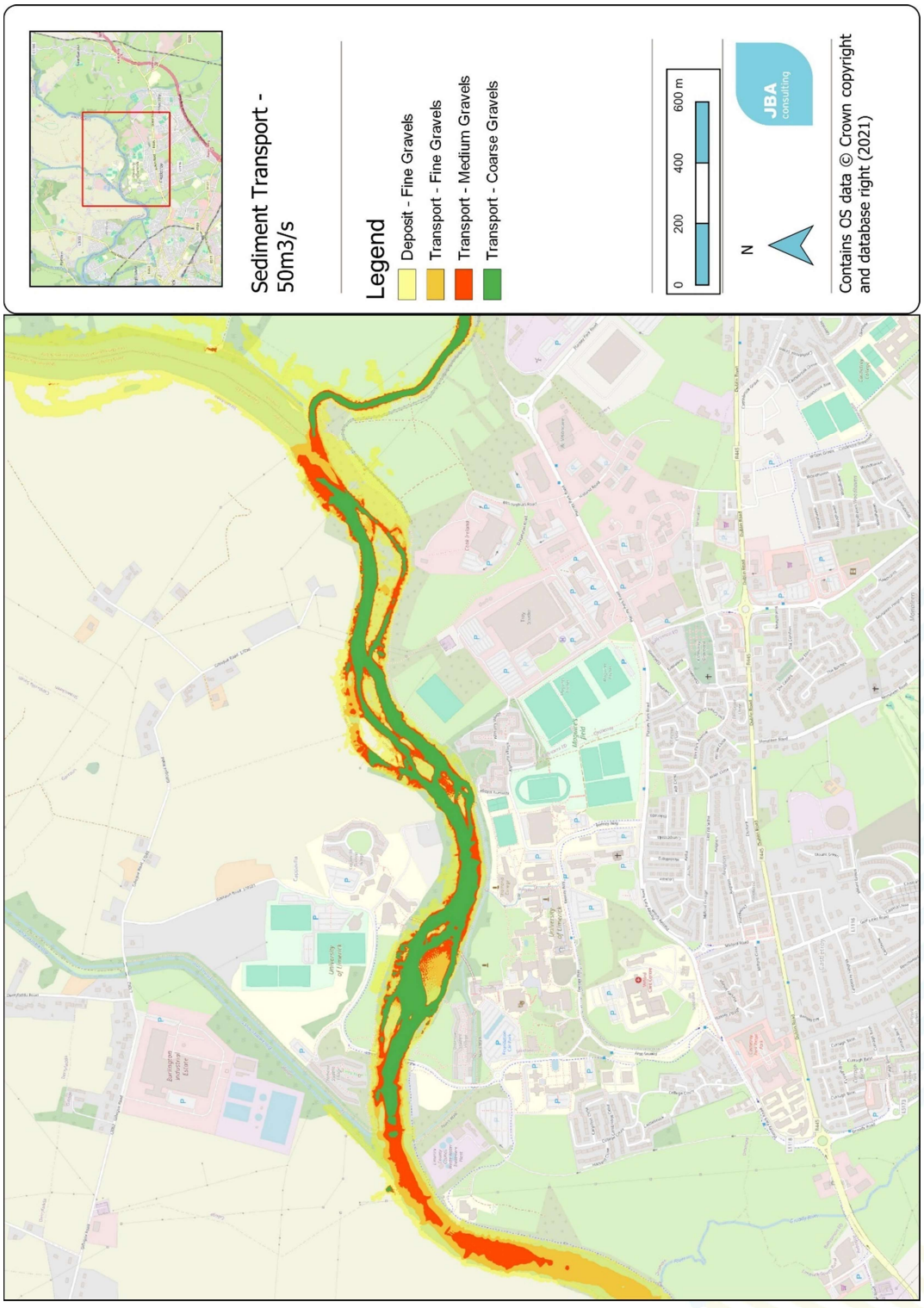

25SHAN08789
Elevation (m)
13
11
9
7
5
3
0
50
100
150
200
Distance (m)
Baseline
Low Sedimentation Scenario
Medium Sedimentation Scenario
High Sedimentation Scenario


25SHAN08772
Elevation (m)
14
12
10
8
6
4
0
20
40
60
80
100
120
140
160
Distance (m)
Baseline
Low Sedimentation Scenario
Medium Sedimentation Scenario
High Sedimentation Scenario

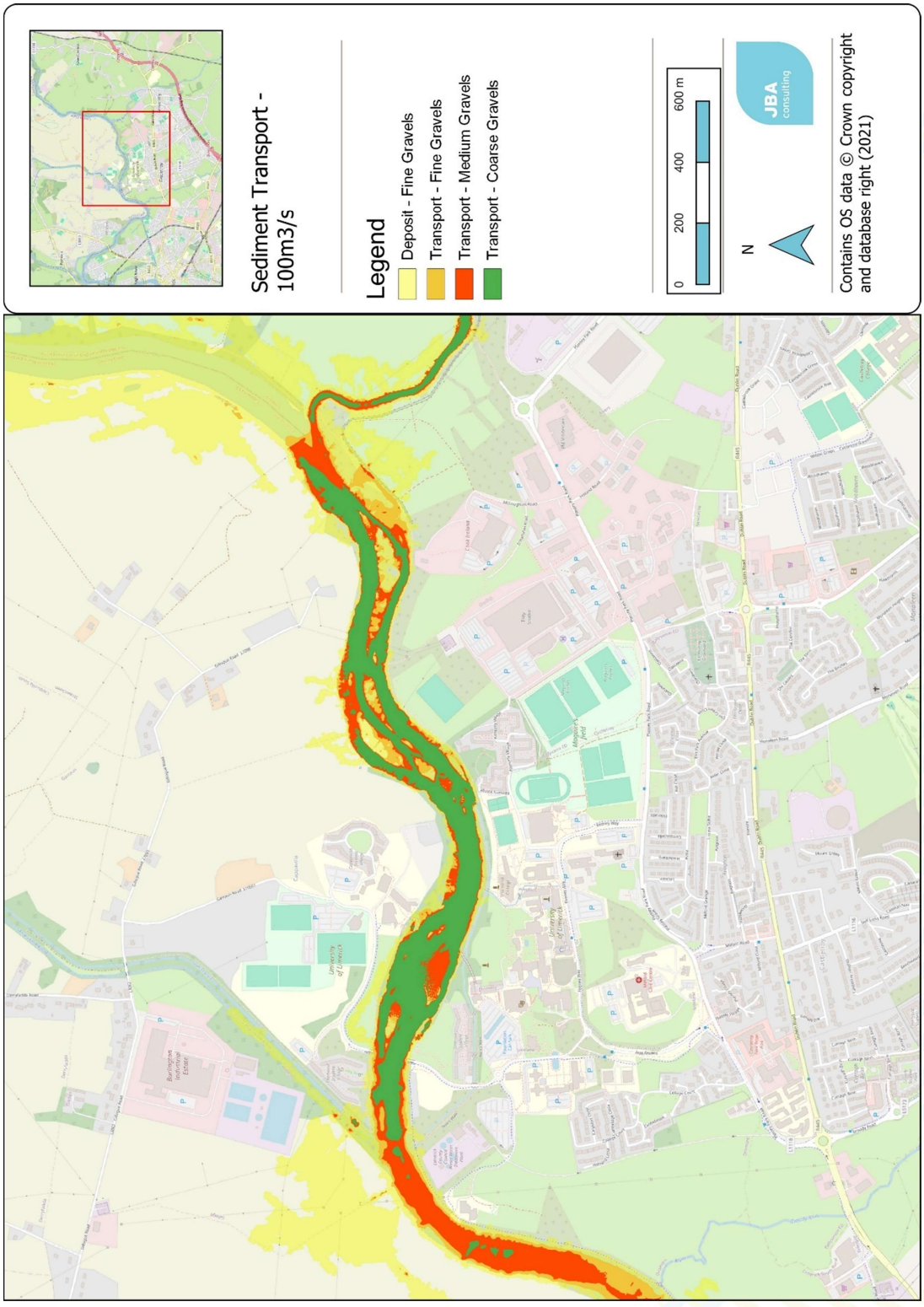

25SHAN08751
Elevation (m)
8
7
6
5
4
0
20
40
60
80
100
120
140
160
Distance (m)
Baseline
Low Sedimentation Scenario
Medium Sedimentation Scenario
High Sedimentation Scenario

# C Theoretical Flow Testing – Flow Regime Testing

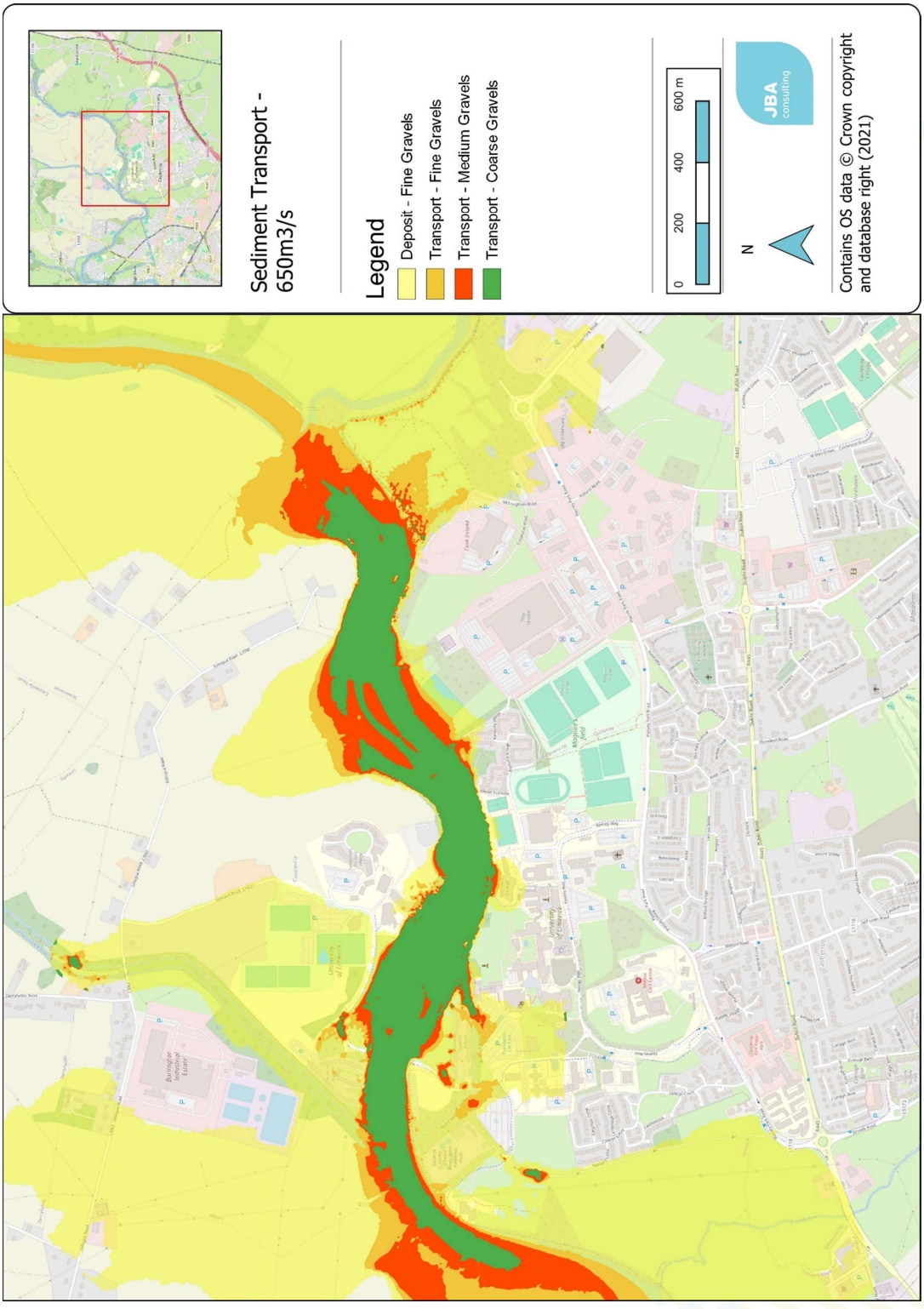
## C.1 Sediment Transport – 50m³/s



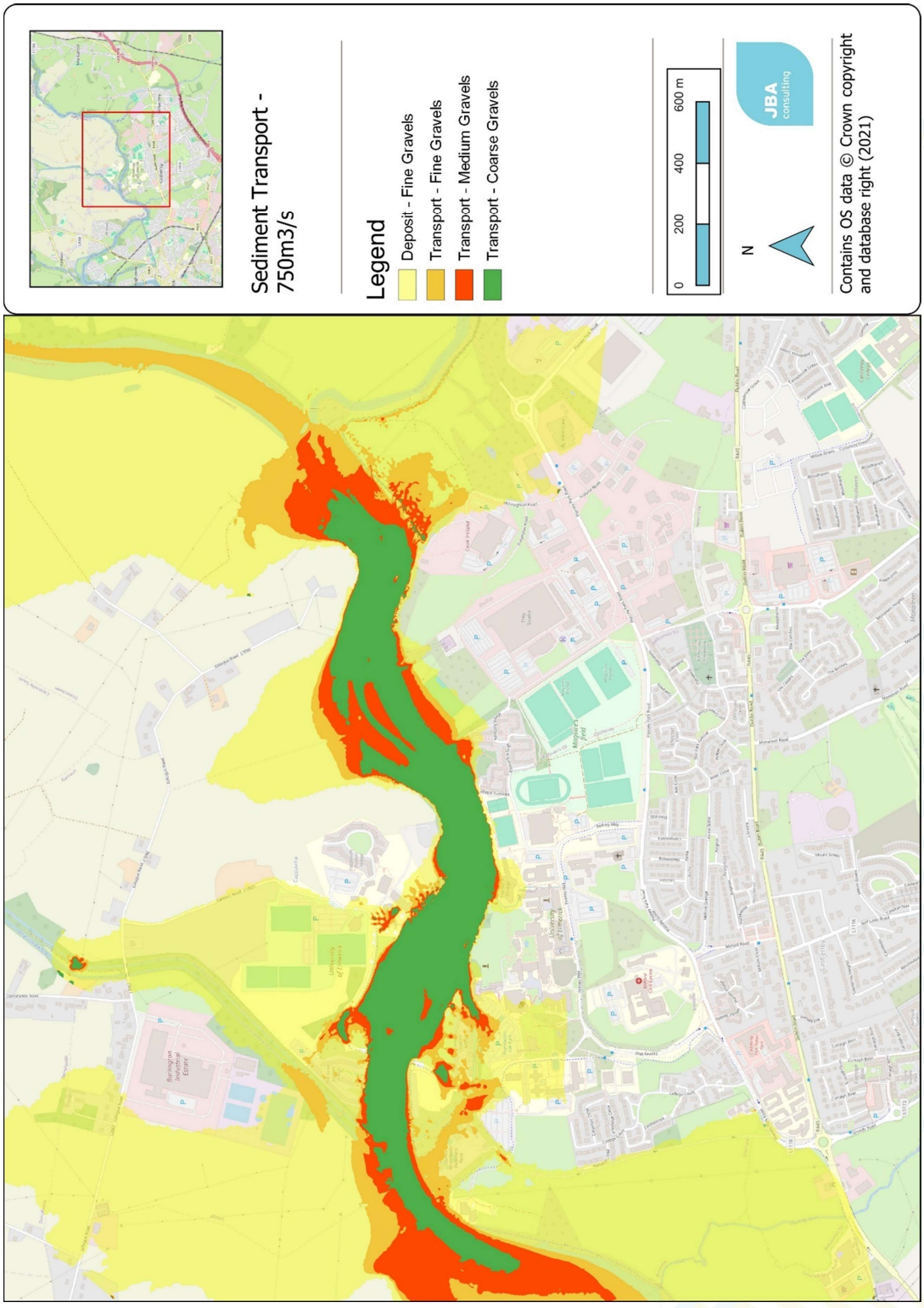
## C.2 Sediment Transport – 100m³/s



## C.3 Sediment Transport – 650m³/s

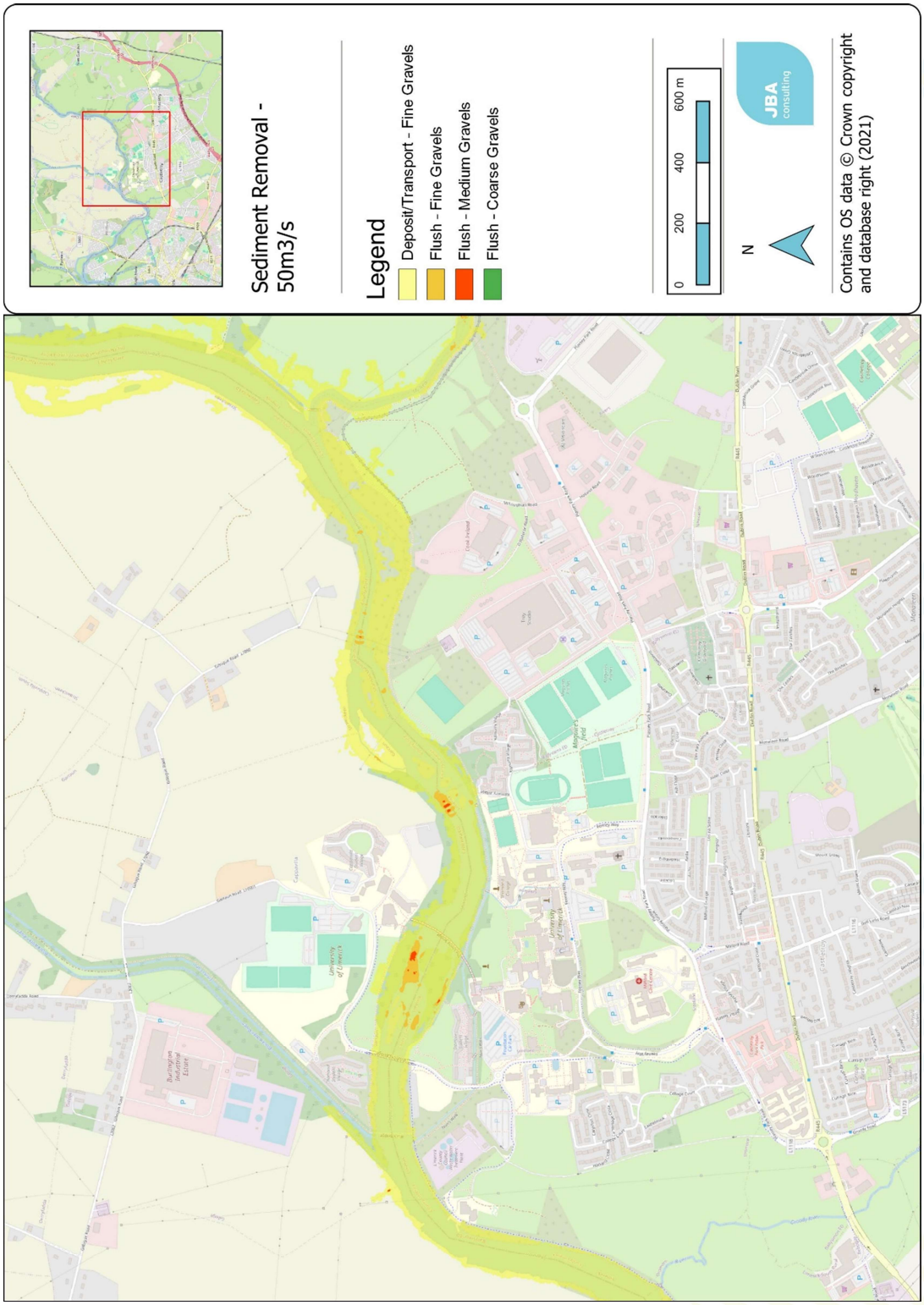


## C.4 Sediment Transport – 750m³/s

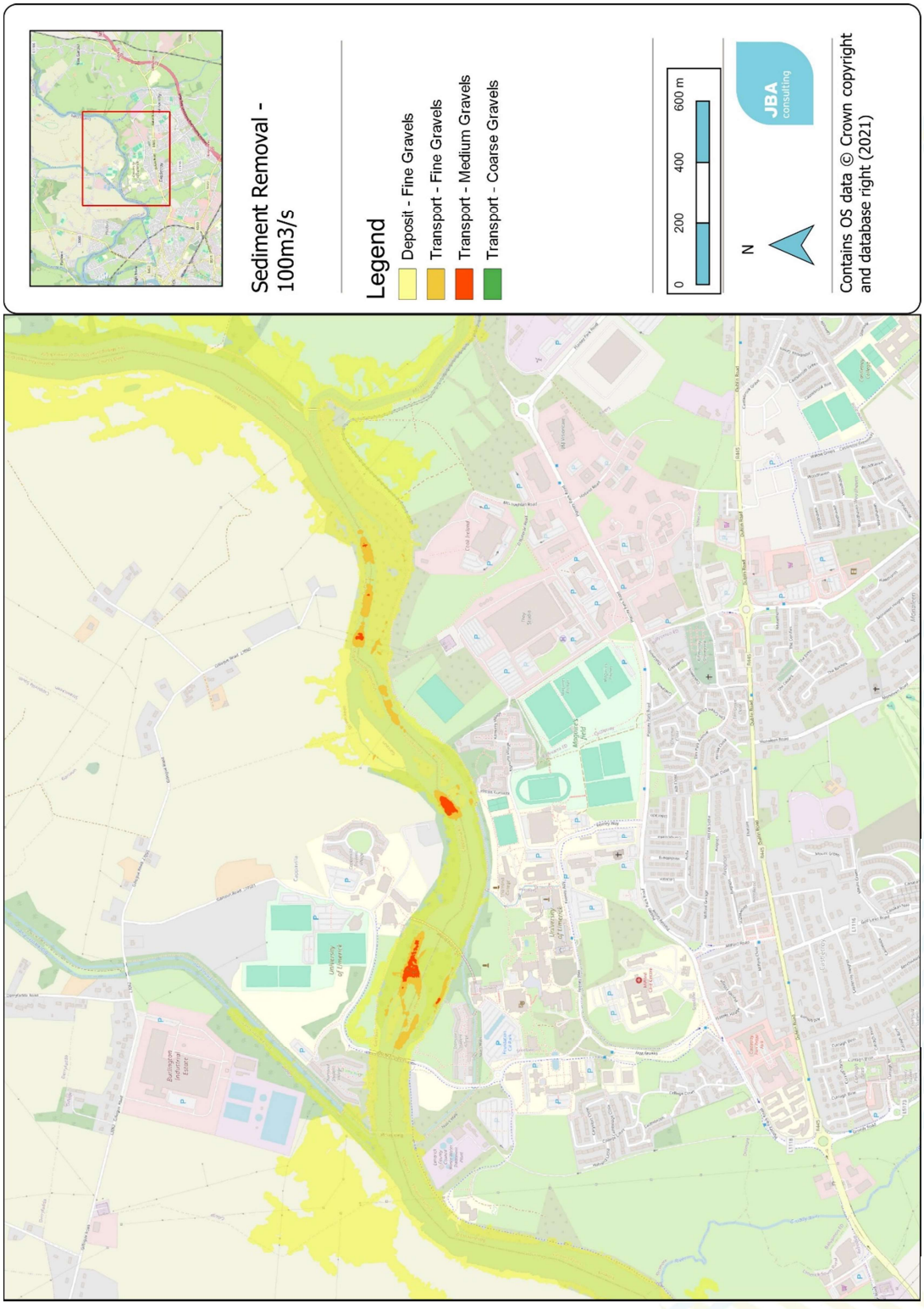


# D Theoretical Flow Testing – Sediment Removal

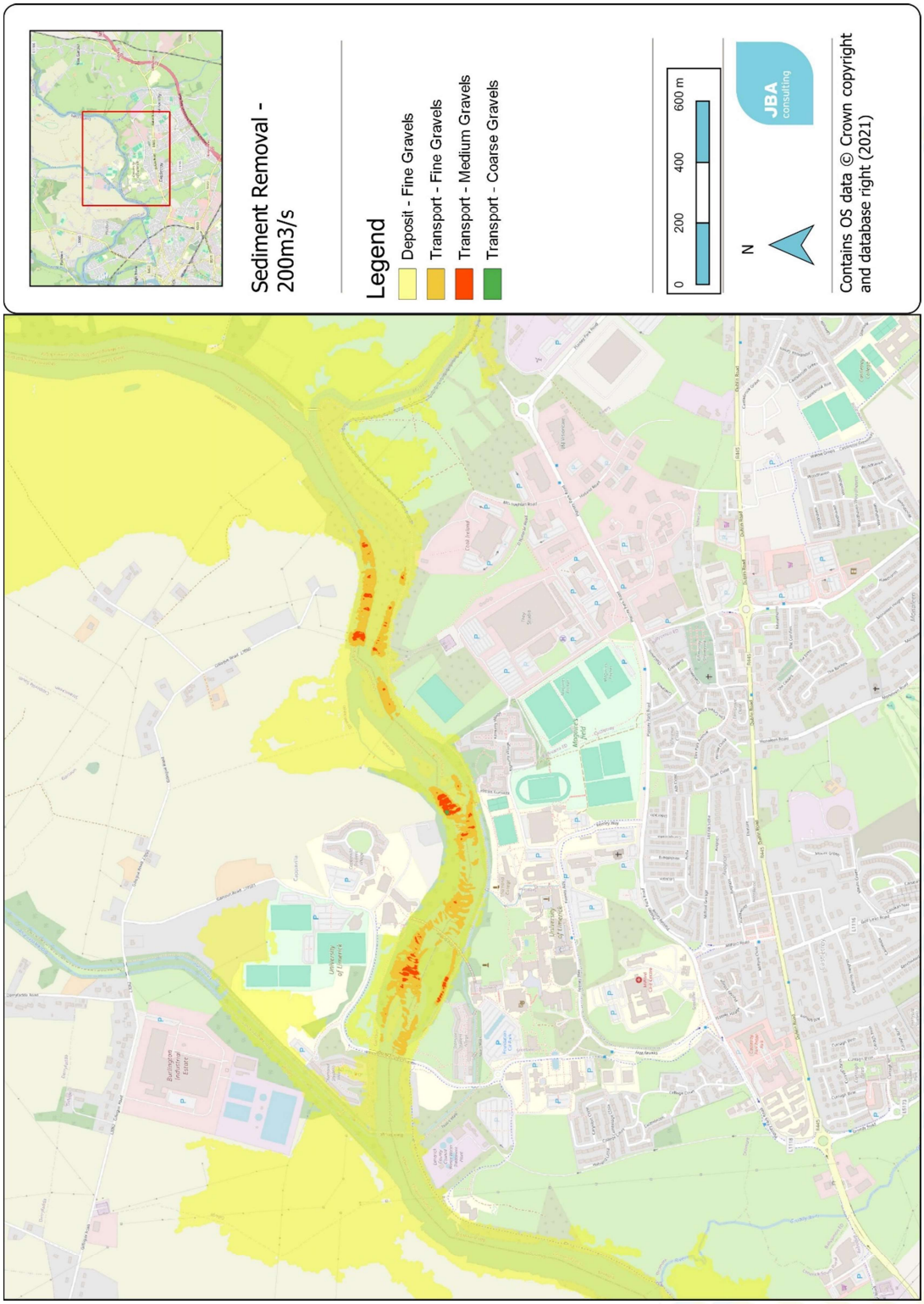
## D.1 Sediment Removal – 50m³/s



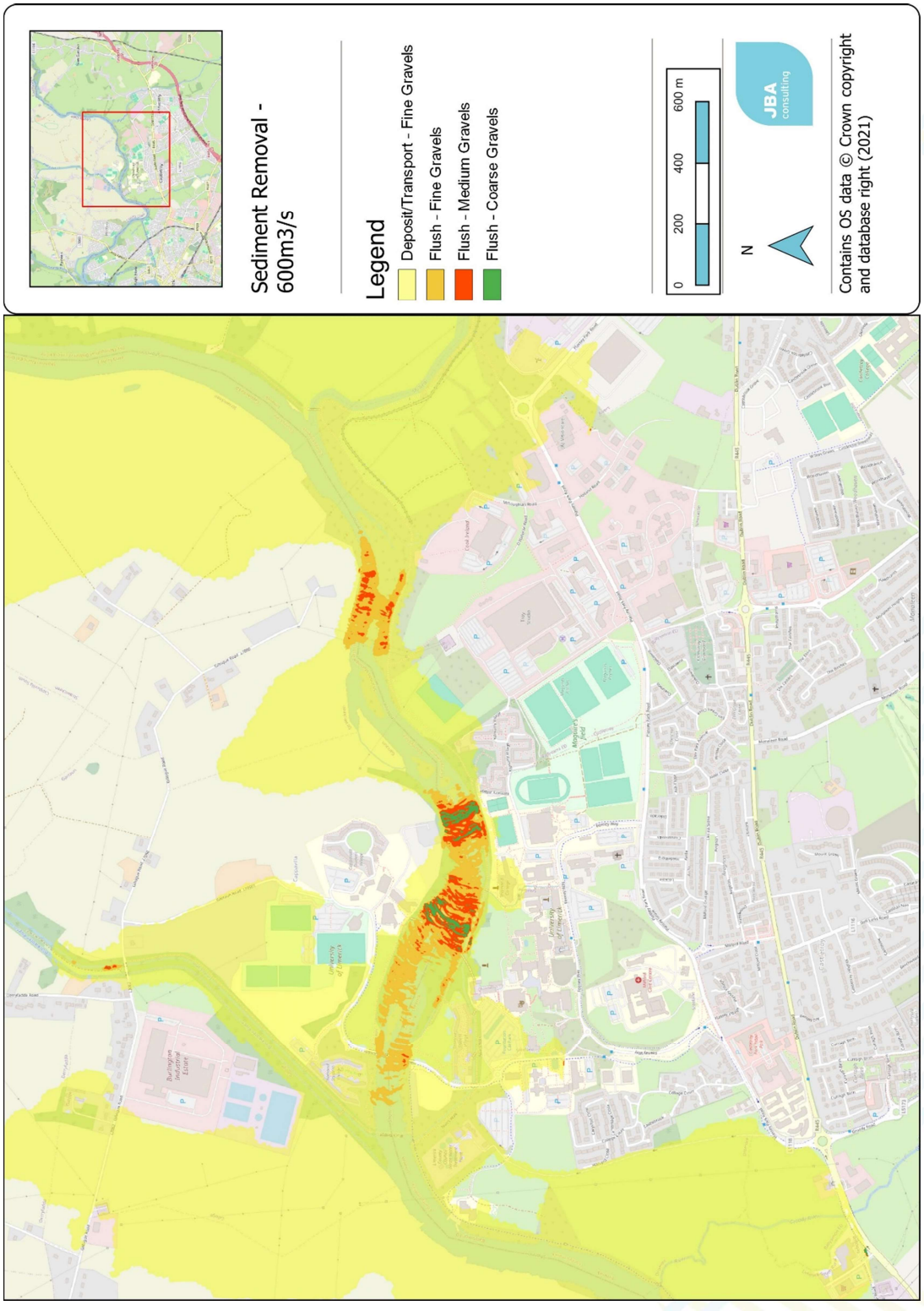
## D.2 Sediment Removal – 100m³/s



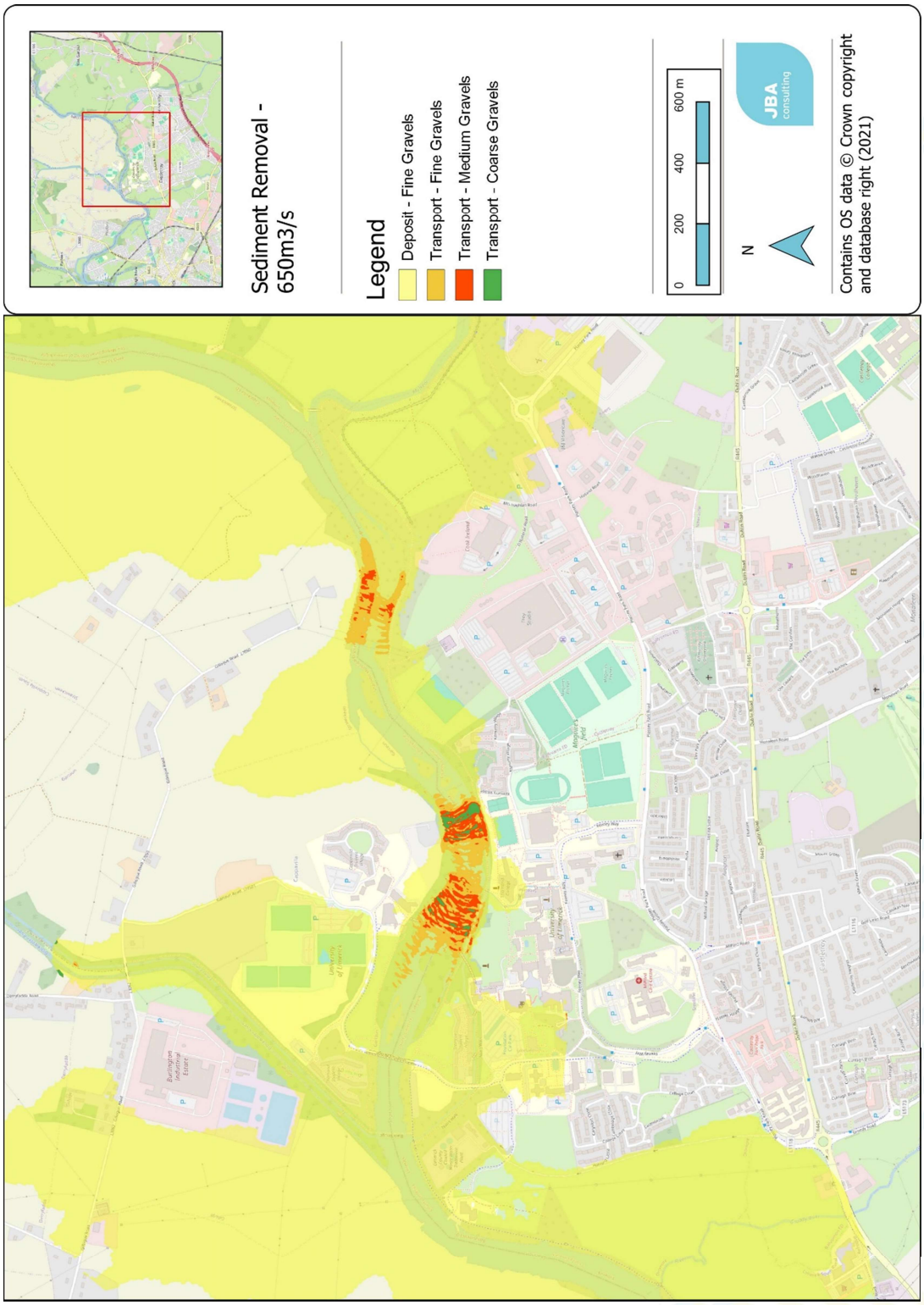
## D.3 Sediment Removal - 200m³/s



## D.4 Sediment Removal – 600m³/s



## D.5 Sediment Removal – 650m³/s



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