

Lower Shannon Hydromorphology Report

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OPW

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nOibrecha Poiblí
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This report describes work commissioned by the Office Of Public Works, on behalf of the Shannon Flood Risk State Agency Co-ordination Working Group. Rory Clements and Siobhan Hansford of JBA Consulting UK (JBAU) carried out this work.

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Abbreviations

IGR	Irish Grid Reference
CFRAM	Catchment Flood Risk and Management

Executive Summary

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, between the Clareville Water Treatment Plant and St Thomas Island (the Reach). The overall Project Area was defined to include the Reach and the Mulkear River catchment (referred to collectively as the Lower Shannon).

The overall aim of the hydromorphological study was: i) to understand the current sediment dynamics within the Project Area, and ii) to inform the development of options. To do this, JBA undertook a multi-component methodology that included a desk study, fluvial audit, and modelling. Findings were then synthesised to provide an integrated conceptual model of the sediment dynamics of the Lower Shannon.

This study has revealed that the supply, transport, and deposition of sediments is a normal dynamic for the Mulkear catchment purely based on the erodible character of the dominant superficial sediments, the variable topography, and the flashy response to rainfall. However, there is evidence of excessive sediment supply (i.e. greater than would be expected) occurring in forested upland areas and across all areas of the catchment that feature hydromorphological pressures including a lack of stock fencing, or on farm works with minimal sediment capture mitigation.

The supply of both fine (e.g. silts, fine sands) and coarse (sands, gravels, cobbles) sediments is greatest from the northeast upland areas i.e. upper reaches of Newport, Annagh and Bilboa tributaries. While coarse sediment can be deposited and temporarily stored through the middle reaches of the tributaries, once material reaches the Mulkear River it is able to be transported downstream, with transport capacity of Mulkear River likely enhanced by channel modification and disconnection to the floodplain. Under 50% AEP (bankfull) conditions, the Mulkear River can move fine sediment up to coarse gravels up to, and over, Annacotty Weir and down to the Old Shannon.

The Old Shannon can only mobilise part of the incoming coarse sediment supply due to its reduced flushing capacity because of flow regulation at Parteen Weir. Coarse sediment delivery from the Mulkear River is considered to exceed the flushing capacity of the Old Shannon leading to sedimentation with an overall depositional environment at, and below, the confluence.

Without any changes to the sediment supply from the Mulkear catchment, and assuming the current hydrological regime in the Old Shannon is maintained, then the current sedimentation dynamics will continue. Reducing excessive sediment supply and addressing the erosivity of river flows will both be important solutions. Addressing these concerns requires a catchment-scale perspective to reduce the hydromorphological pressures acting on the Mulkear catchment, and to provide opportunities to allow naturalisation of the river system.

1 Introduction

1.1 Report purpose

The OPW, on behalf of the Shannon Flood Risk State Agency Co-ordination Working Group, are pursuing a targeted approach to fully explore the feasibility of preventing further reduction in, and if possible increasing, channel conveyance/capacity along the Old Shannon between Clareville Water Treatment Plant and St Thomas Island (the Reach). Previous studies (e.g. AquaUoS 2020 report) had identified the Mulkear River tributary as a key source of sediment supply to the Reach, and therefore the overall Project Area was defined to include the Reach and the Mulkear River catchment (together defined as the Lower Shannon Project Area). JBA Consulting Ireland (JBA) was commissioned by the OPW to undertake a hydromorphological study to inform feasible options for the management of sediment and vegetation in the Lower Shannon Project Area.

1.2 Study aims and approach

The overall aim of the hydromorphological study was to understand the current sediment dynamics within the Project Area, and to inform the development of options. To do this, JBA undertook a multi-component methodology that included a desk study, fluvial audit, and modelling (Figure 1-1-1).

Component	Overview	Deliverable
Desk Study	Review of existing available information about the historical and current physical setting (e.g. geology, land cover), hydrology, river condition, and physical modification of the Lower Shannon Project Area.	Hydromorphology Report Fluvial Audit Sediment Modelling Note
Fluvial Audit	Focusing on the Mulkear River catchment, this study used a combination of geomorphological field survey and desk-based GIS analysis to identify key sediment sources and stores. The final output was a conceptual model of the sediment transport regime in the Mulkear catchment.	Fluvial Audit
Modelling (hydraulic and sediment)	Focusing on the Old Shannon and lower <u>Mulkear</u> , this study employed a state-of-the-art hydraulic model (Telemac) to understand how sediment moves through and accumulates in the Lower Shannon and the Mulkear downstream of Annacotty Weir. A second model was also developed for the Mulkear catchment to build on the initial observations from the Fluvial Audit and confirm the likely source areas of sediment.	Sediment Modelling Note
Hydromorphology Overview	This report synthesises the findings of the Desk Study, Fluvial Audit and Modelling components to provide an integrated conceptual model of the current sediment dynamics of the Lower Shannon Project Area and highlight key considerations for options development.	Hydromorphology Report

Figure 1-1-1 Methodology overview

This report summarises the key findings of each component study in a separate chapter, before integrating these findings into an overall conceptual model for the Lower Shannon Project Area. Full reports for the fluvial audit and modelling components are issued separately but relevant sections are referred to throughout.

2 Desk Study

A thorough review of available data sets and published reports was undertaken to build an understanding of the historical and current physical setting (e.g. topography, geology, land cover), hydrology, physical form and modification of the Lower Shannon Project Area.

2.1 Project Area

The Project Area includes a section of the Old Shannon channel between the Clareville Water Treatment Plant (Irish Grid Reference (IGR): R 64303 61362) and St Thomas Island (IGR: R 58197 60104). The Old Shannon channel is the previous course of the River Shannon at the site location. Also included is the Mulkear catchment, that comprises the main stem of the Mulkear River and its main tributary systems - Newport River, River Annagh, Bilboa River, and River Deed. The main stem of the Mulkear River begins at the confluence of the Bilboa River and the Deed River at IGR: R 76213 47899. The Mulkear River flows in a predominantly north-westerly direction for approximately 22 km through the east of County Limerick and discharges into the Old Shannon downstream of Annacotty Weir at the Mulkear-Old Shannon confluence (IGR: R 63551 60032). Figure 2-1 shows the Lower Shannon Project Area.

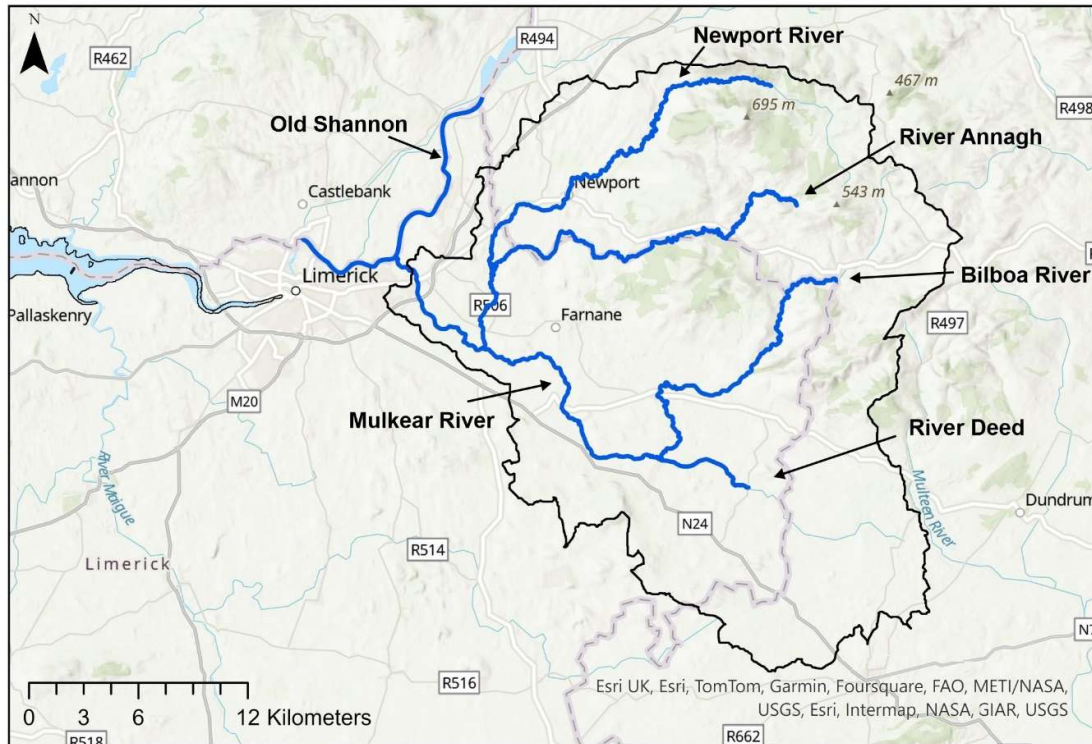


Figure 2-1 Lower Shannon Project Area, with Mulkear River catchment boundary outlined

2.2 Topography and geology

Elevations within the Project Area range from 0 m Above Ordnance Datum (AOD, Poolbeg Datum) in the lowland area covering the Old Shannon and main stem of the Mulkear River, to 690 m AOD in the upper Mulkear catchment. The Mulkear catchment is characterised by a steep gradient along the tributaries with most of gradient change being accommodated in the transition from the upper catchment (termed 'upland') to the middle catchment (Figure 2-2).

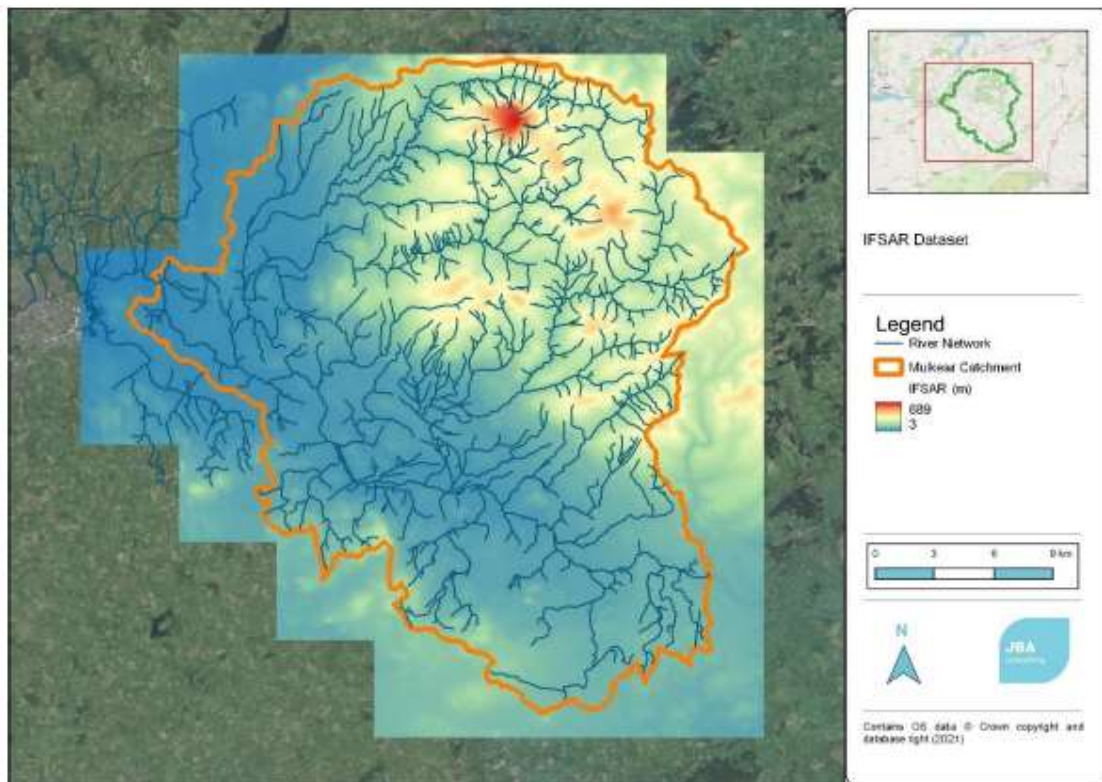


Figure 2-2 Topography of the Mulkear River catchment showing the north east upland area

The Old Shannon and lower Mulkear River are underlain by sedimentary bedrock geology comprising various limestone formations including Lough Gur Formation (limestone), Rathkeale Formation (limestone and shaly mudstone), Ballysteen Formation (dark muddy limestone, shale), Waulsortian Limestones (unbedded lime-mudstone) and Visean Limestones (undifferentiated limestones). The uplands of the Mulkear catchment feature less permeable sedimentary geology including the Keeper Hill Formation (sandstone, grit and claystone) and Hollyford Formation (greywacke, siltstone and grit).

The superficial geology of both the Mulkear River and Old Shannon floodplains comprises Quaternary glacial till deposits, with estuarine silts and clays also found on the Shannon floodplain. This can be attributed to tidal influence given the channel enters the Shannon estuary downstream of Limerick. Within the Mulkear catchment, superficial geology comprises a mix of upland peats, lowland alluvial sands and gravels, and glacial till. This mix of low permeability, erodible sediments and steep topography in the uplands helps to generate significant runoff and potential sediment generation during storm events. Some areas in the Mulkear catchment also have exposed bedrock outcrops.

2.3 Land cover

Land cover across the Project Area is a mixture of rural and agricultural land. Between the Mulkear-Old Shannon confluence and the Clareville Water Treatment Plant, land cover is predominantly rural. Downstream of the confluence, the urban settlement of Annacotty has developed on the left bank floodplain of the Old Shannon and the lower Mulkear River. Agricultural land covers much of the Mulkear catchment with forestry prevalent in upland areas. Also notable within the uplands is the presence of mineral extraction sites, raising the possibility that these areas have high potential to generate local sources of fine sediment which could easily be carried into the fluvial system as wash load during runoff events.

2.4 Hydrology and flow regime

Inflows to the Old Shannon are controlled by Parteen Weir (IGR: R 67871 67959), a structure on the River Shannon that manages the flow split between the Old Shannon and the artificial Ardnacrusha Headrace. The Ardnacrusha channel is approximately 14km long and was created in the 1920s as part of the Shannon Hydro-Electric Scheme.

The diversion of flow towards the Ardnacrusha channel by Parteen Weir (and therefore the available inflow to the Old Shannon) varies with the upstream flow rate in the River Shannon, as determined at Parteen Weir gauge (ref 25075)¹. The Ardnacrusha Headrace can divert a maximum of 400m³/s from the Shannon at Parteen Weir. In normal flow conditions, a statutory discharge of approximately 10m³/s flow enters the Old Shannon. Once the 400m³/s capacity of the Headrace has been reached, any subsequent flow is diverted to the Old Shannon².

This division of the River Shannon inflows between the Ardnacrusha and Old Shannon channels has significantly altered the downstream flow regime of the Old Shannon. AquaUoS (2020) found that:

- The magnitude of mean annual flows in the Old Shannon have reduced.
- The frequency of mean annual and bankfull (defined as 1.5 year return period flow) events have reduced.
- Flood flows in the Old Shannon are now more commonly associated with high flows from the Mulkear River at the site location.
- The diversion of lower magnitude flood flows from the Old Shannon at Parteen Weir reduces the channel's hydraulic capacity to mobilise finer sediments downstream.

The Parteen Weir gauge is the best source of data and information on the flow conditions and flood frequency for the Old Shannon. It has the longest record length

¹ Parteen Weir discharge data received from ESB on the 04/02/2020 & 03/05/2023

² Parteen Weir Flow Split Information https://cdn.esb.ie/media/docs/default-source/generation/river-shannon-infographic.jpg?sfvrsn=cb33ff0_4&_gl=1*p1ppid*_ga*MTUwMDUzMzcwOC4xNjQyNzU4Mjk2*_ga_FK4GRM6Q1X*MTcwODk2MTI0Ni4xLjEuMTcwODk2MTUzMS4wLjAuMA..

of any gauge on the Irish hydrometric register. There are no gauges with any data for pre-1932, specifically no gauge data for the Shannon before the construction of Ardnacrusha. Table 2-1 outlines key flows for the Old Shannon including: i) normal flow conditions as defined by the flow duration curve in Figure 2-3 (e.g. Q10, Q50, Q90 etc.), ii) approximately bankfull, defined as the 50% Annual Exceedance Probability (AEP), and also referred to as the 2 year event, and iii) flood flows, including the 10% AEP (10 year flood) and 1% AEP (100 year flood). Chapter 5 of the Lower Shannon Sediment Transport Modelling Note (JBA, 2024) outlines these hydrological calculations in more detail.

Table 2-1: Normal and flood flow regime information for the Old Shannon at Parteen Weir (ref 25075).

Flow	Old Shannon Inflow m ³ /s
Q ₉₀	9.30
Q ₇₀	9.30
Q ₅₀	9.30
Q ₃₀	9.69
Q ₁₀	15.08
50% AEP (2 year event)	210
10% AEP (10 year event)	364
1% AEP (100 year event)	521

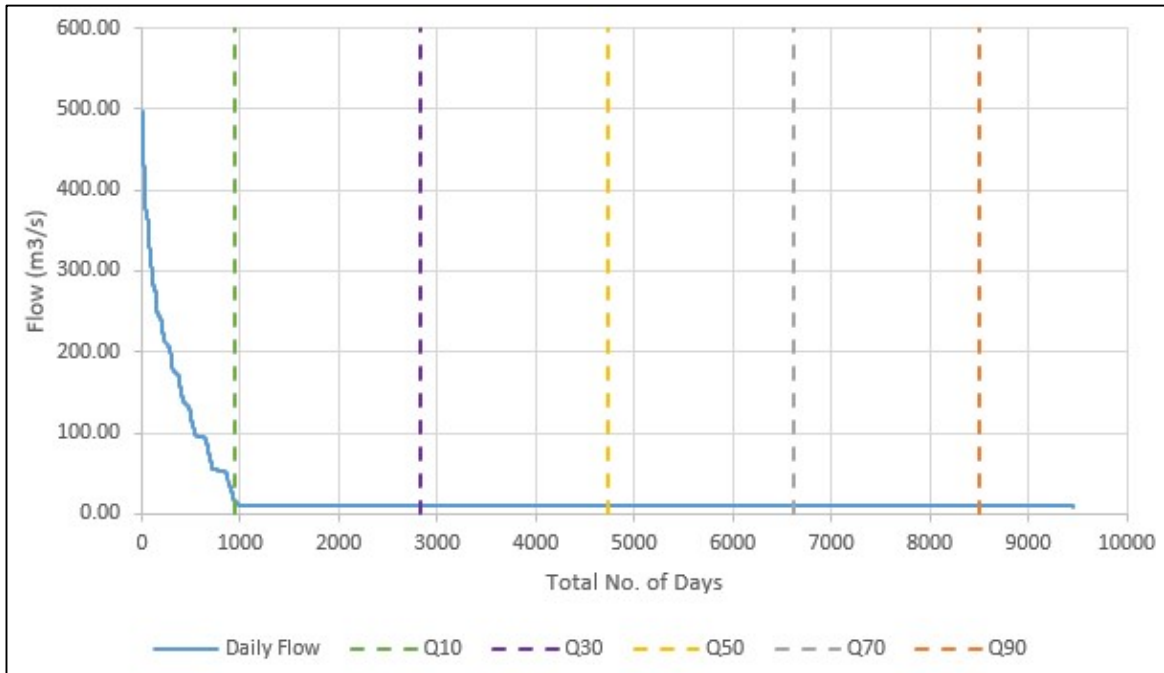


Figure 2-3: Normal Flow Duration Curve on the Old Shannon

The Mulkear River is flashy, with intense response to runoff events. Following storm events, the river has high turbidity, with a significant load of fine sediment. The normal flow duration curve (Figure 2-4) for the Mulkear exhibits a more natural gradient than the Old Shannon as shown by a greater variability of normal flow conditions within Table 2-2.

Table 2-2: Normal and flood flow regime information for the Mulkear River at Annacotty Gauging Station (ref 25001).

Flow	Annacotty Inflow m ³ /s
Q ₉₀	3.26
Q ₇₀	6.02
Q ₅₀	9.71
Q ₃₀	17.71
Q ₁₀	40.01
50% AEP (2 year event)	127
10% AEP (10 year event)	163
1% AEP (100 year event)	201

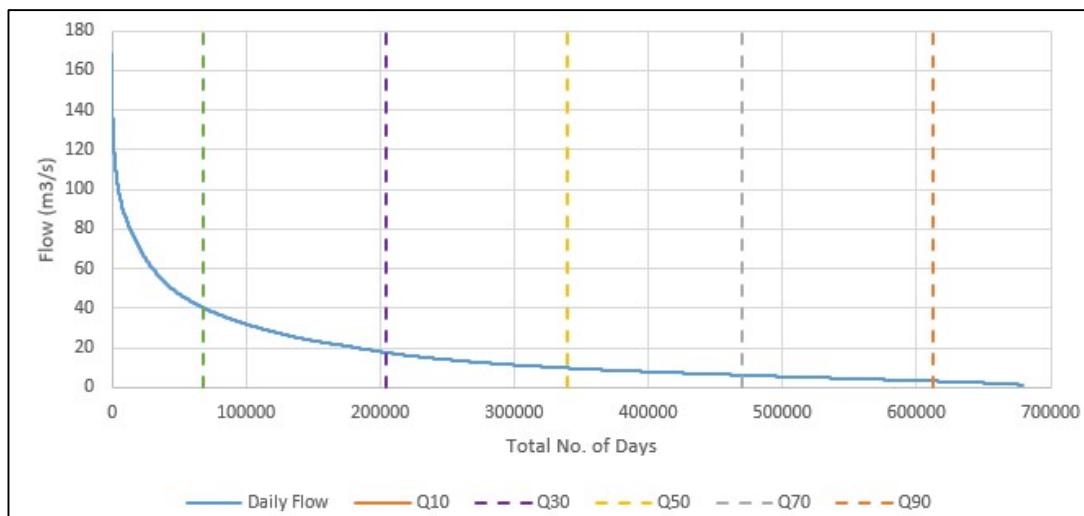


Figure 2-4: Normal Flow Duration Curve on the Mulkear River

2.5 Physical form and modification

2.5.1 Morphological character of the Project Area

AquaUoS (2020) outlines the findings of a fluvial audit and data review conducted for the Old Shannon (referred to as the River Shannon therein) from Parteen Weir to Limerick, and the lower Mulkear downstream of Annacotty Weir. The study describes the Old Shannon from just upstream of the Mulkear-Old Shannon confluence as a single-thread channel with ponded flow and at the time of survey, an increase in fine sediment was observed in the River Shannon in the vicinity of the Mulkear

confluence. Minor fine sediment accumulation was also recorded at Clareville Water Works (IGR: R 64303 61362), suggesting that finer sediment can travel upstream in the ponded reach. Directly downstream of the Mulkear confluence, a large depositional bar was recorded on the left bank of the Shannon. The study identified the Mulkear as transport competent, delivering mixed sediment to the River Shannon. The typical bed substrate identified downstream of the Annacotty weir was gravels, with finer sediment suspended in the water column.

Figure 2-5 shows paleochannels on the left and right bank floodplains of the Old Shannon upstream of the confluence with the Mulkear that are activated during high flow conditions. These paleochannels developed when the river behaved as a more active, multi-thread system in response to a deglaciating landscape (i.e. a combination of higher flows and post-glacial uplift) (AquaUoS, 2020). Under modern landscape dynamics, this channel bifurcation is no longer supported and instead the Old Shannon maintains a single thread planform.

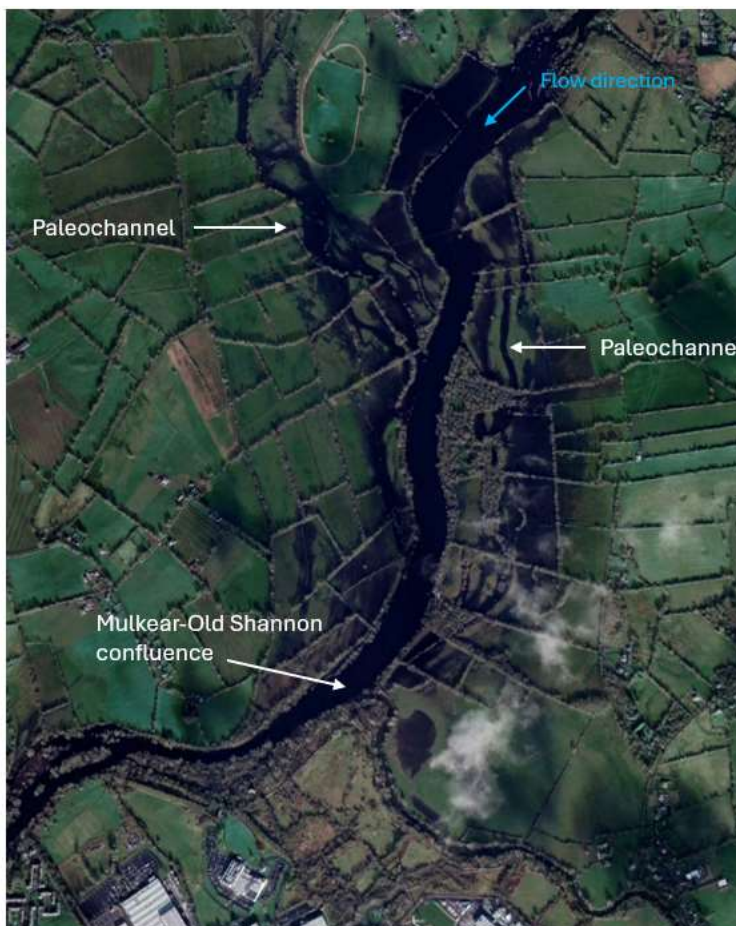


Figure 2-5 Paleochannels on the Old Shannon floodplain activated during high flow conditions in February 2018 (Google Earth)

2.5.2 Physical modifications

Several in-channel flow regulating structures (weirs, culverts) occur within the Project Area (Figure 2-6). Key structures include Annacotty Weir (IGR: R 64334 57554) on the Mulkear River, and the weir at the Old Shannon (IGR: R 61929 58510) approximately 1.3 km downstream of the Mulkear-Old Shannon confluence. There are also several gravel traps and smaller impounding weirs throughout the Mulkear catchment, including one at Black Boy Bridge (IGR: R 79867 51556). Conversation with OPW revealed this structure is believed to fill with sediment bi-annually and occasionally must be emptied, however coarse sediment can pass by the structure so full depletion does not occur to the downstream reach.

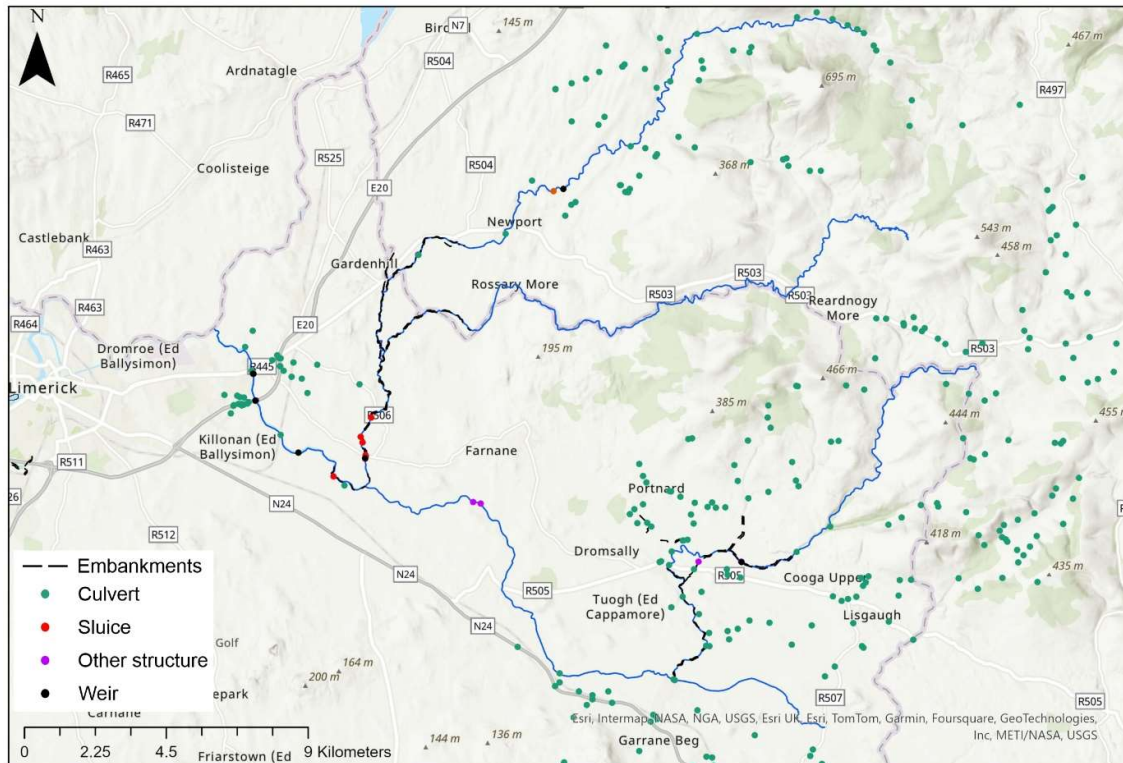


Figure 2-6 Physical modifications to the Mulkear River catchment (OPW, 2004; IFI, 2023)

There is a long history of land drainage effort in the Mulkear catchment. Sections of the Mulkear River and lower reaches of all tributary systems have all been incorporated into formal drainage schemes at specific times since the Mulkear Drainage District Act 1880. Modern drainage schemes include (see Figure 2-7):

- Mulkear River (Ballymackeogh) Flood Relief Scheme completed in 1998 under the Arterial Drainage (Amendment) Act, 1995. This scheme covers the lower reaches of the Newport River and River Annagh, includes approximately 15.3 km of embankments, and is maintained by the OPW. There are also 1.6 km of embankments on the Mulkear River that are associated with this scheme.

- Mulkear River (Cappamore) Flood Relief Scheme completed in 2000 under the Arterial Drainage (Amendment) Act, 1995. This scheme covers the lower reaches of the Bilboa River, includes approximately 10.4 km of embankments, and is maintained by the OPW. The primary purpose of this scheme is to provide localised flood protection for urban areas and critical infrastructure.
- Mulkear Drainage District, covering the lower reaches of the River Deed and the Mulkear river from the Deed-Mulkear confluence to the approximately Brittas town. This scheme is maintained by Limerick County Council.
- Bunkey Drainage District, covering a tributary of the Newport River. This scheme is also maintained by Tipperary County Council.

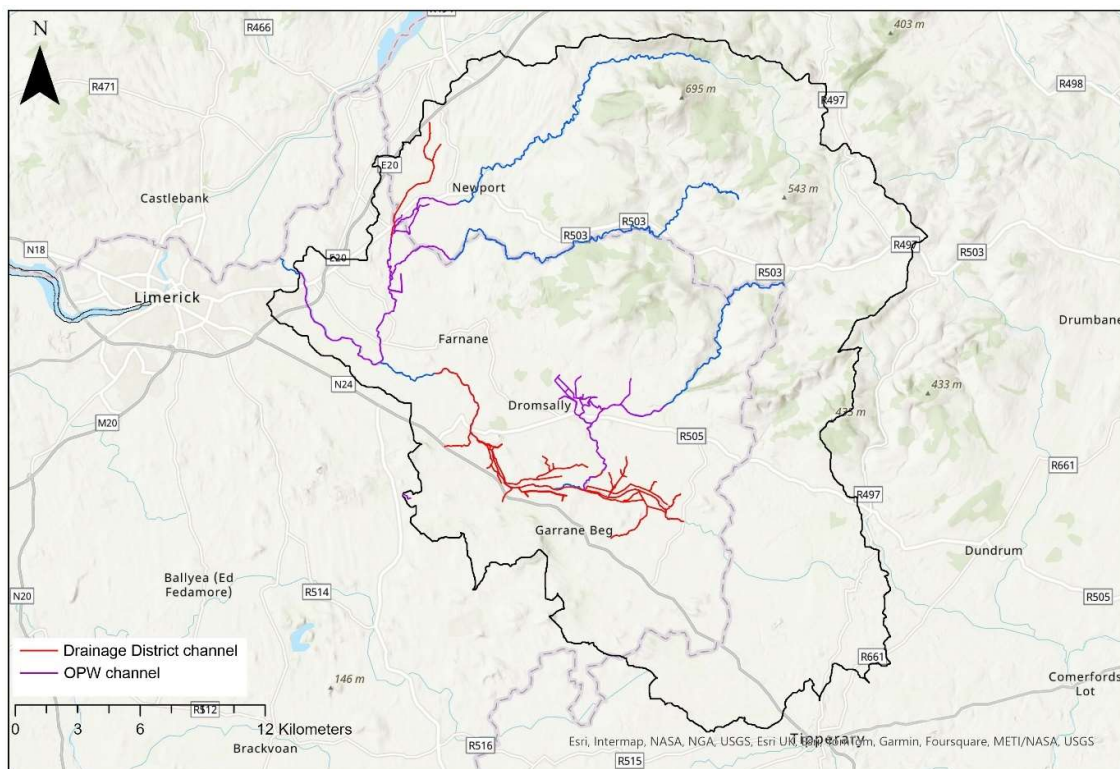


Figure 2-7 Drainage channels for formal schemes in the Mulkear catchment (OPW, 2021)

The primary purpose of the flood relief schemes maintained by the OPW is to provide localised flood protection for urban areas and critical infrastructure, whereas the Drainage Districts were originally associated with supporting agricultural field drainage. Both types of schemes are associated with straightening of the river planform and embankment installation. Review of historical Ordnance Survey mapping for the Mulkear catchment revealed that much river straightening occurred prior to the first mapping exercise in 1837-1888, with the main Mulkear River and main tributaries generally located in the same historic planform throughout most of

their length. However, some evidence of more recent meander cutoff was visible on the River Bilboa near Cappamore, along with channel realignment on the River Annagh at Lackamore and Newport River near Ballymackeogh (for details see Chapter 2 of the Lower Shannon Hydromorphology: Fluvial Audit report).

These physical modifications are likely to have influenced high flow dynamics in the Mulkear catchment by restricting or even preventing connection between the river and its floodplain. Lateral connectivity between a river and its floodplain plays an important role in reducing the erosional energy of high flow events by enabling a portion of the flow volume to temporarily spread out, encounter resistance, and slow downstream passage (Wohl, 2017). Modifications that reduce lateral connectivity therefore contain more of a high flow event within the channel and potentially increase its erosivity. Similarly, channel straightening reduces the length of the river line and provides a more direct, and therefore potentially more rapid, downstream pathway than a natural meandering channel.

2.6 Review of underwater video imagery

Underwater imagery taken of the River Shannon riverbed and the Mulkear River riverbed in the vicinity of the Mulkear Shannon confluence has been analysed (Murphy Geospatial, 2023). Flows in the Mulkear were around $8\text{m}^3/\text{s}$ on the day of the survey, actual flow in the Old Shannon is unknown but the total flow at Parteen weir was around $100\text{m}^3/\text{s}$, as per the Total Parteen Weir flow on the ESB website³, suggesting flows down the Old Shannon were the statutory discharge of $10\text{m}^3/\text{s}$. Video imagery was recorded on 17 May 2023 at several locations corresponding with the CFRAM (Catchment Flood Risk and Management) cross section locations. The underwater imagery does not follow the exact line of each CFRAM section but these locations are displayed below in Figure 2-8 for reference.

³ [chrome-extension://efaidnbmninnibpcjpcglclefindmkaj/http://www.esbhydro.ie/shannon/08-Total-Parteen-Weir-Flow.pdf](http://www.esbhydro.ie/shannon/08-Total-Parteen-Weir-Flow.pdf)

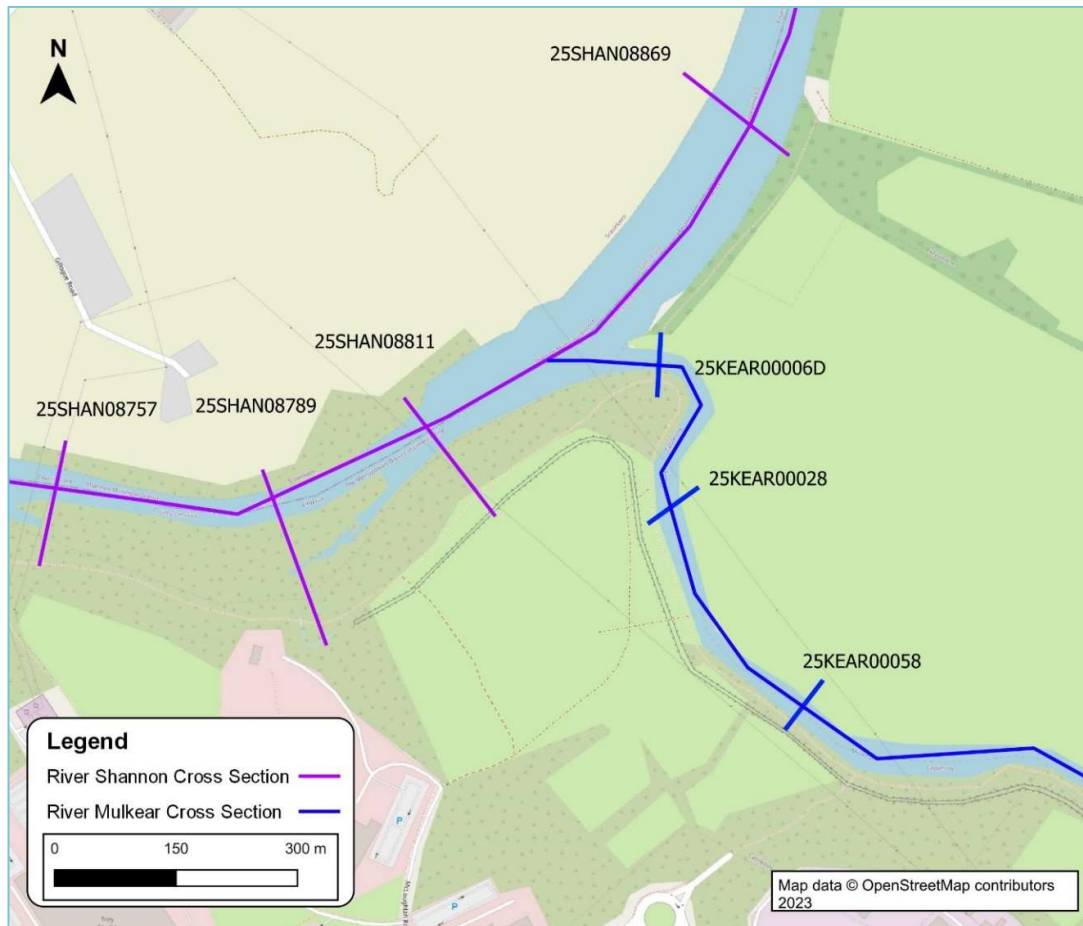



Figure 2-8 Map of the video imagery cross sections

2.6.1 Lower Mulkear River

Lower Mulkear	
2SKEAR00058	
	<p>The riverbed of the Mulkear at cross section 2SKEAR00058 is composed of fine sands and silts, with coarser cobbles coated by fine material. The accumulation of fine material on the cobbles suggests infrequent mobilisation. It is likely that the coarse material is only entrained in high flow events. The flow is turbid in the imagery, with fine sediment suspended in the water column. This supports the findings of the fluvial audit that the lower Mulkear is likely depositional for fine sediment under low to median normal flow conditions.</p>
2SKEAR00028	

Lower Mulkear



Further downstream at cross section 2SKEAR00028 the riverbed is composed mainly of sand, with small gravels and some coarser cobbles. Unlike upstream, the cobbles are not coated by fine material, suggesting there are sufficient velocities at this location to transport fine material downstream. Fine material has accumulated at the channel margins, where flow velocities are reduced.



2SKEAR00006D

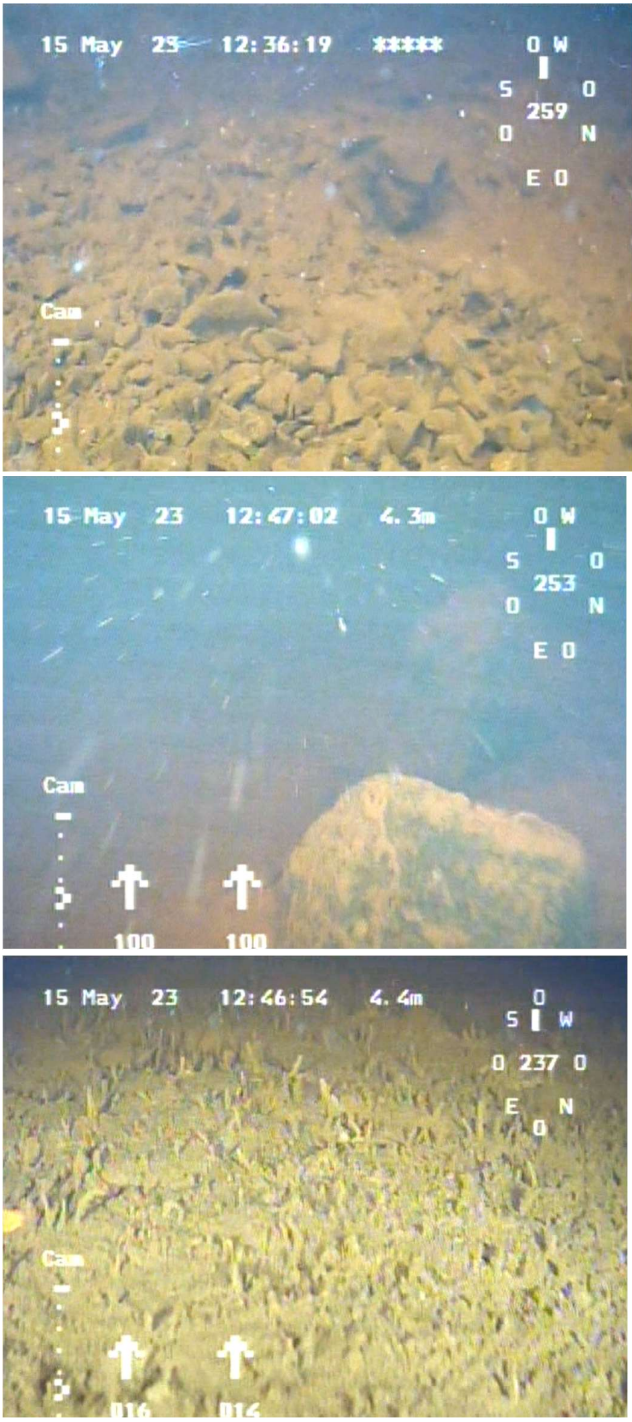
Lower Mulkear



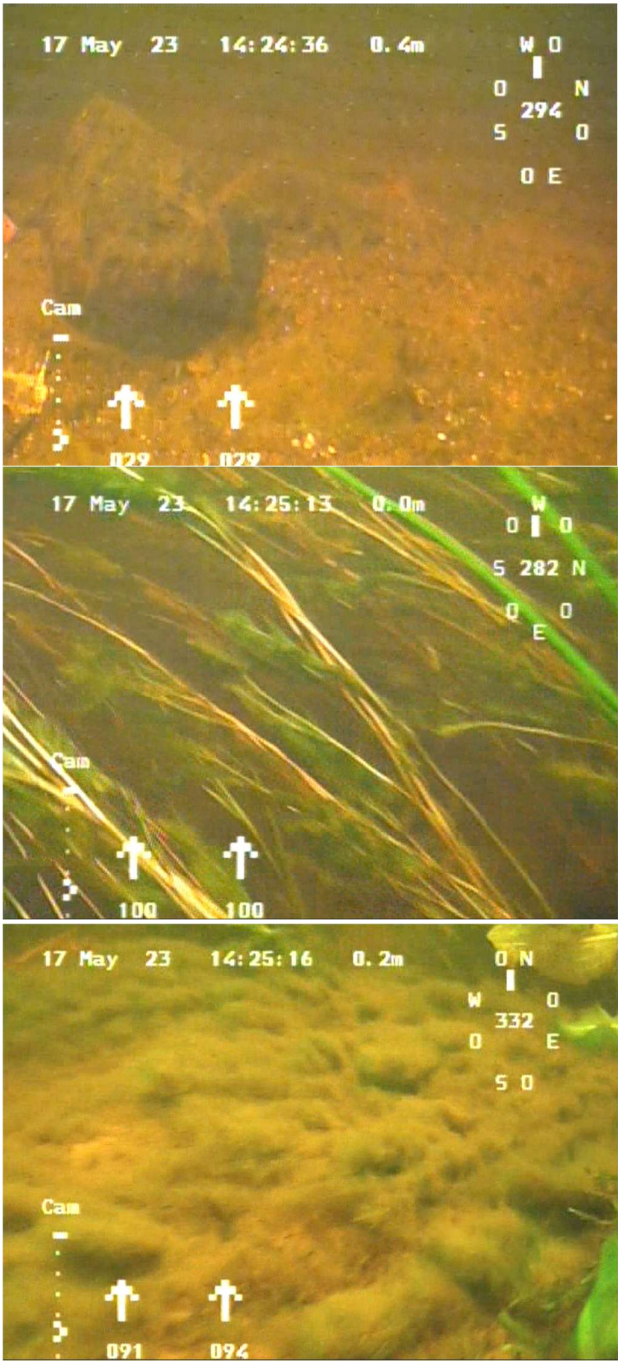
The riverbed of the Mulkear at cross section 2SKEAR00006D (directly upstream of the confluence with the River Shannon) is composed of fine sands and gravel, with very coarse gravel coated by fine material. The flow appears turbid in the video imagery and no large cobbles were recorded at this location. This suggests a reduction in flow energy at this location. This supports the findings of the fluvial audit that describes a backwater impact from the Old Shannon.



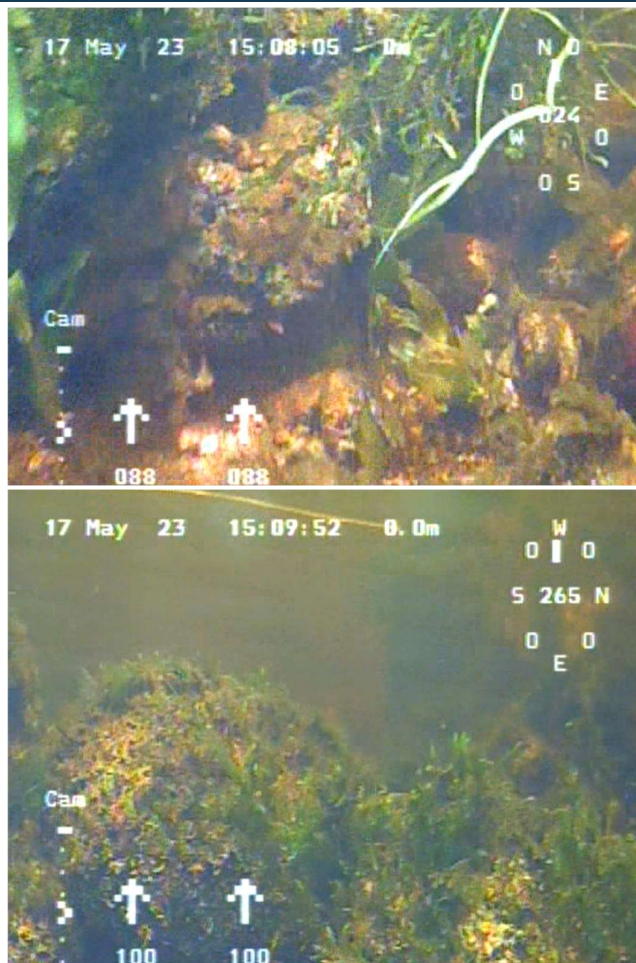
2.6.2 Shannon upstream of the Mulkear confluence

Shannon upstream of the Mulkear confluence	
25SHAN08869	
	<p>The riverbed of the Shannon at cross section 25SHAN08869 is composed of gravels and cobbles, coated with fine material. The accumulation of fine material on the bed suggests infrequent mobilisation of coarse material. Isolated boulders, colonised with algae/moss have deposited on the riverbed, indicating that the material is infrequently mobilised. Coarse material is likely only mobilised in flood events and will rarely be transported downstream due to limited flow variability in the Shannon.</p> <p>The riverbed is mostly silt in places. There are insufficient velocities at low flows to transport fine material, which is stored in this reach of the Shannon. The silt riverbed has stabilised over time and this has allowed vegetation to colonise. This supports the findings of the AquaUos fluvial audit which identified the accumulation of silt upstream of the Mulkear confluence.</p>

2.6.3 Shannon downstream of the Mulkear confluence

Shannon downstream of the Mulkear confluence	
25SHAN08811	
	<p>Cross section 25SHAN08811 is directly downstream of the Mulkear Shannon confluence. Coarse material is deposited in the River Shannon at this location, including cobbles and boulders. The coarse material likely transported from the Mulkear in flood events. The material will drop from the water column as flow enters the River Shannon due to a drop in flow velocities. This supports the conclusions of the AquaUos Hydro-Geomorphology study which found that there are insufficient flow velocities in the lower Shannon to transport material supplied by the Mulkear River.</p> <p>The riverbed of the Shannon at cross section 25SHAN08811 is colonised with moss and in-channel vegetation has established. This indicates that the bed material is rarely mobilised. It is probable that the material is only entrained in peak flow events by flows supplied from the Mulkear River.</p>
25SHAN08789	

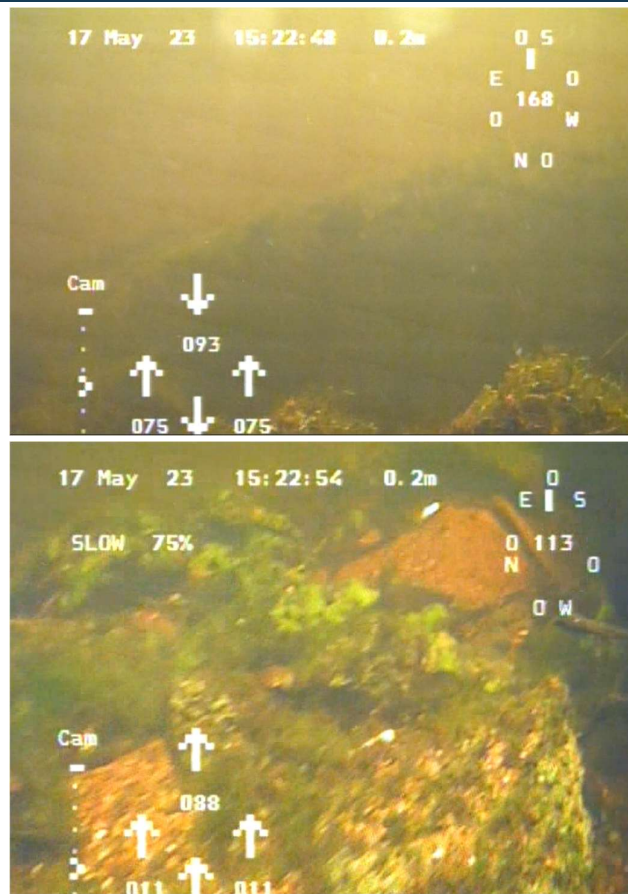
Shannon downstream of the Mulkear confluence



Further downstream at cross section 25SHAN08789, the riverbed of the Shannon is composed of coarse boulder and cobble material. The coarse material is colonised with moss indicating that the material is infrequently mobilised and is not transported from this reach. Coarse boulder material is not visible in video imagery of the River Shannon upstream of the Mulkear confluence. As such, it can be inferred that the coarse material has been delivered to the River Shannon by the Mulkear River. The presence of moss and in-channel vegetation on the boulder material indicates that this material is rarely mobilised and has been resident in the Old Shannon for some time.

25SHAN08757

Shannon downstream of the Mulkear confluence



Further downstream at cross section 25SHAN08757 the flow appears turbid. Fine sediment is likely to have been delivered by the Mulkear and due to low flow variability and slow velocities in the Lower Shannon this material remains suspended in the water column. As seen upstream the typical bed substrate is large boulders, colonised with moss.

3 Fluvial Audit

3.1 Overview

Focusing on the Mulkear catchment, the fluvial audit used a combination of geomorphological field survey (Section 3.2) and desk-based GIS analysis (Section 3.3) to identify key sediment sources and stores. The final output was a conceptual model of the sediment transport regime in the Mulkear catchment (Section 3.4).

3.2 Field survey

Geomorphological field survey was conducted during August 2022 at targeted locations in each tributary system and along the Mulkear River. The aim of the survey was to establish the morphological character of the Mulkear River and tributaries by examining local geomorphological processes to identify potential sources, stores and transportation reaches for fine and coarse sediment. It also noted pressures acting on the river system and how they may be affecting sediment dynamics.

Figure 3-1 shows the locations visited and whether the sediment dynamics at that location and the upstream reach were judged to be primarily erosional (Source), erosional and transportational (Source-Transfer), or transportational (Transfer). Section 3.2.1 outlines the morphological character of each of the rivers in the catchment, while pressures are summarised at Section 3.2.2. These sections summarise the detailed descriptions provided with the Lower Shannon Hydromorphology: Mulkear Catchment Fluvial Audit report.

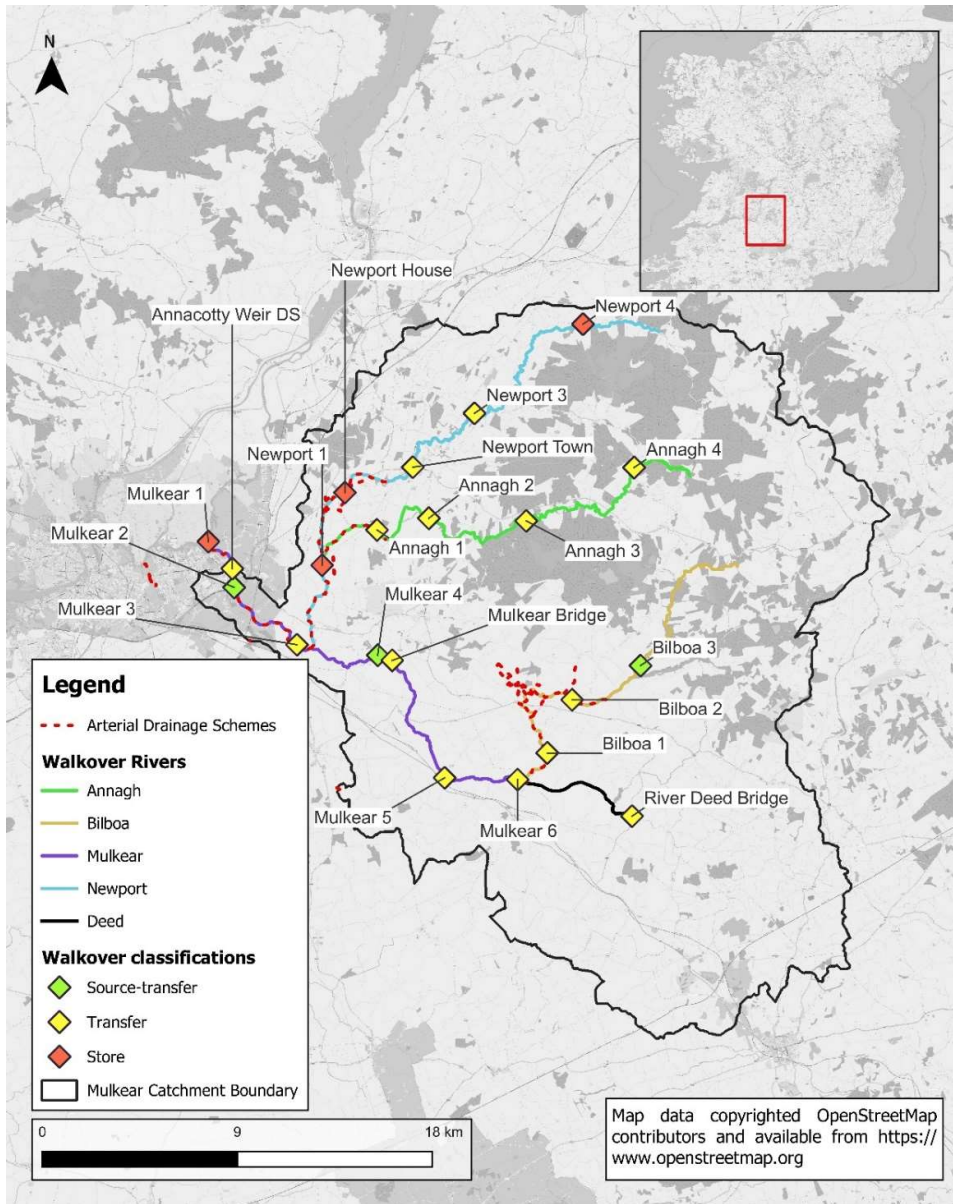


Figure 3-1 Field survey locations and dominant sediment dynamics observed

3.2.1 Morphological character of the Mulkear River catchment

Figure 3-2 summarises the morphological character of each of the main tributary systems in the catchment and the Mulkear River itself. Overall, the catchment is characterised by strong sediment supply from the tributary systems (fine and coarse sized material) into the Mulkear River. The Mulkear looks able to mobilise this sediment load further downstream and its transport capacity has likely been enhanced by channel modification. The lower Mulkear is largely depositional under normal flow conditions but is likely to mobilise and transport the fine sediment to coarse gravel material received from upstream during high flow conditions.

Newport tributary: shows both single thread planform with plane bed form characterised by a mobile, coarse bed and unbranching planform (i.e. in-channel islands and bars) in several locations through the lower and middle reaches, except where over-widened. Where it looks to be straightened, river is depositing material to restore a more sinuous planform. Generally competent to transport fine to coarse material.

Mulkear: Single thread, notably straight planform in sections, with overall low geomorphic diversity. River is incised relative to the floodplain likely reflecting drainage practices and ongoing erosion with containment of high flows. Over the coarse cobble bed is a mobile bed of fine to coarse gravels and fine sediment deposition that can be transported under high flows. At the downstream end near the confluence with the Old Shannon, the channel has a shallow gradient and exhibits turbid flow under normal flow conditions. This low energy environment is linked to the backwater effect from the confluence.

Deed Tributary: Supplies a fine sediment plume to the Mulkear during low flow conditions, suggesting it is capable of mobilising and transporting a large fine sediment load downstream under high flow conditions.

Annagh Tributary: Generally low gradient and wide reaches with a mobile, gravel-pebble sized coarse sediment bed. Some morphologically diverse flow (e.g. riffle-pool development, bars) within an overall single thread planform, with a bedrock cascade sequence near Annagh 2. Evidence of reduced floodplain connection with some embankments. Multiple hillslope streams drain the forested areas where finer sediment is being eroded from the coarse bed.

Bilboa Tributary: Upper reaches feature bedrock and boulder step-pool sequences and riffles. Downstream the single thread channel is less diverse, including an impounded reach at the weir that promotes deposition of fine to coarse material. Downstream of the weir, planform is more sinuous with some coarse sediment features (e.g. bars) and scour pools. There is evidence of both fine and coarse sediment supply to the Mulkear from this tributary.

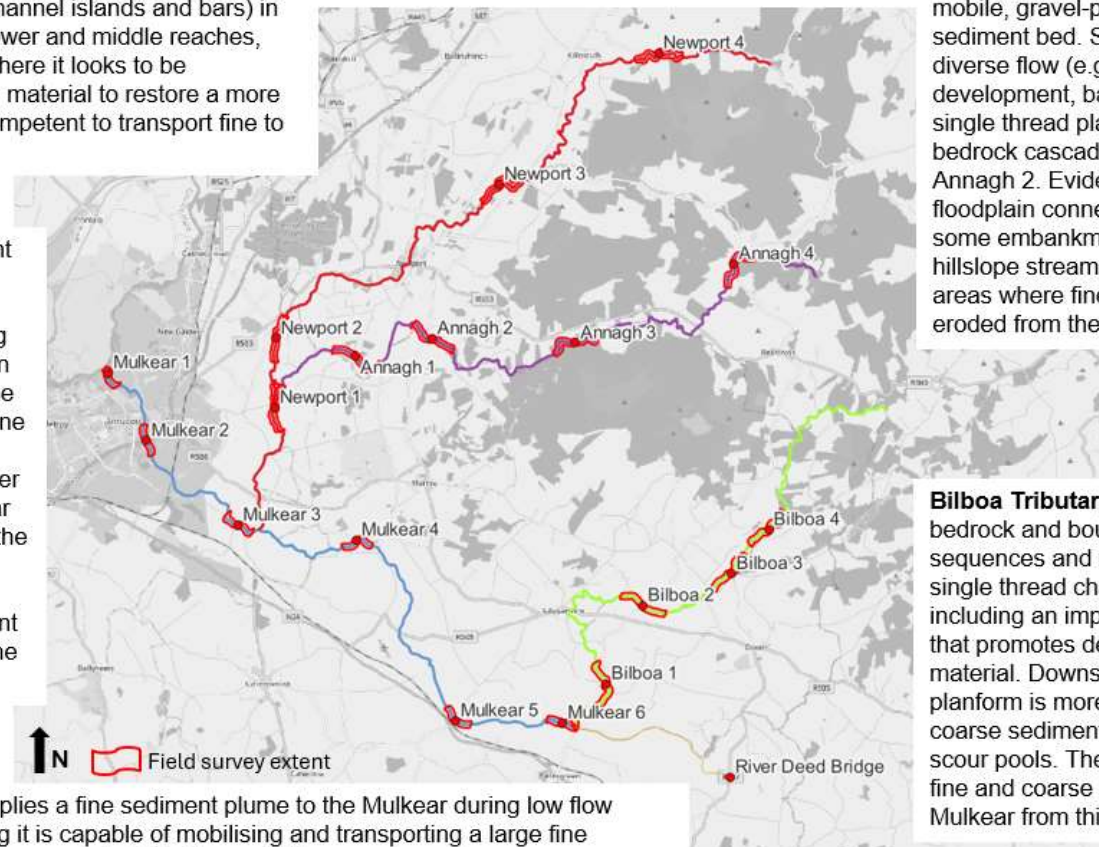


Figure 3-2 Overview of fluvial audit findings for the Mulkear catchment

As part of the fluvial audit, five Wolman pebble count samples were also taken on bar features to help characterise the coarse sediment distribution within the system. The Wolman pebble count statistics illustrate the distribution of sediment sizes of the sampled sizes by classifying these into percentiles. D15 is the calculated particle size which 15% of the sample density is finer than, the D50 is the 50% or median particle size which half of the sample density is finer than and as such there is only 15% of the total sample density larger than the D85.

The coarse sediment distributions at each of the five locations is summarised in Table 3-1. These samples revealed that the largest sediment sizes were found in the Bilboa and Annagh rivers, indicating these systems are capable of mobilising very coarse material through to the Mulkear River. They also reveal that the typical bed substrate in the Mulkear River at Annacotty Weir is gravel, though it is likely that coarser material is stored upstream of the weir. This refers to the very coarse gravel and cobble material identified at the tributary systems, which over time may be mobilised through the tributaries and along the Mulkear during flood events. Storage of this material along tributaries would occur in depositional features like mid-channel bars and riffles. Any of this material that moves through to the Mulkear is unlikely to be mobilised past Annacotty Weir, and so some may also be stored locally within the Mulkear. The field survey also recorded most of the sediment downstream of Annacotty Weir to be finer than elsewhere in the catchment.

Table 3-1 Wolman pebble count results for the Mulkear catchment

Location	X (ITM)	Y (ITM)	Particle size percentile (mm)		
			D15	D50 (median)	D85
Annacotty Weir (left bank bar)	564270	657625	4.1 fine gravel	15.2 medium gravel	24.4 coarse gravel
Bilboa 2 (mid channel bar)	579715	651660	23.9 coarse gravel	55.9 coarse gravel	85.5 cobble
Newport 4 (left bank/central bar between secondary channel and main flow)	580206	668734	13.8 medium gravel	31.5 coarse gravel	58 very coarse gravel
Annagh 1 (left bank bar)	570841	659380	7.3 fine gravel	13.5 medium gravel	21.1 coarse gravel
Annagh 4 (right bank bar)	573202	659913	19.9 coarse gravel	39.7 very coarse gravel	71.2 cobble

3.2.2 Hydromorphological pressures

Hydromorphological pressures are defined as activities (historical or modern) that influence the natural form and function of a river. The field survey identified several pressures at the survey locations within the Mulkear river and tributaries, which are likely to be affecting the natural sediment erosion, transport, and deposition processes within the catchment. These include channel modification, impoundments, bank protection, on-farm sediment management, stock poaching, invasive species, and forestry.

Examples of **channel modification** include changes to river planform (e.g. channel straightening, see Section 2.5.2) and dredging activities that maintain a desired channel geometry. These kinds of channel modifications can create over-deepened rivers that are less connected to their floodplain, meaning flows are contained primarily in-channel creating more potential for bank and bed erosion. Dredging can also destabilise banks, raising the risk of slumping during high flow conditions. Suspected dredging activities were observed on the Newport River (Figure 3-3). Sediment removal is also known to occur at the deflector associated with the flood relief channel on the River Bilboa near Cappamore. Floodplain disconnection was evident at each of the tributary systems and along the Mulkear main stem. Figure 3-4 shows the over-deep and over-wide channel of the Mulkear River downstream of the Bilboa confluence.



Figure 3-3 Potentially dredged material stored on the right bank of the Newport River (Location: Newport 4)



Figure 3-4 Floodplain disconnection on the Mulkear main stem (Location: Mulkear 6)

Impoundments are created by in-channel flow regulating structures (such as weirs) and were observed at all rivers in the Mulkear catchment except the Annagh. Large impoundments were observed at Annacotty Weir on the Mulkear, and at the weir and gravel trap structures on the Bilboa at Bilboa 2. These structures create low energy environments upstream and affect the continuity of downstream sediment transport. The weir at Bilboa appears to be restricting the transport of cobble sized material downstream (Figure 3-5).



Figure 3-5 Mid-channel bar feature upstream from weir crest (Location: Bilboa 2).

Bank protection measures are designed to prevent natural bank erosion processes and lateral movement of a river by enforcing a desired planform. By restricting natural sediment processes, these measures can prevent the development of in-channel depositional geomorphological features and therefore disrupt the river's natural supply and storage dynamic. Boulder-reinforced banks and timber bank protection measures were observed on the Newport River (Figure 3-6). That several of the timber protection measures are failing indicates that lateral migration is a natural part of how this system manages its sediment supply, and efforts to constrain these processes are not sustainable.



Figure 3-6 Bank protection at the Newport River (Location: Newport 2)

Evidence of **poor sediment management** related to construction at a property in the Annagh catchment was observed and could be indicative of practices elsewhere in

the wider Mulkear catchment. Without adequate runoff management to manage flow pathways into watercourses, such works can act as sources of fine sediment.

A **lack of stock fencing** leaves banks vulnerable to frequent disturbance, leading to unstable and more easily eroded and collapsible banks. This bank poaching creates additional fine sediment inputs to the channel and, consequently, higher rates of in-channel siltation. Multiple examples of unfenced banks were observed in the Mulkear catchment across all tributaries and the Mulkear River main stem (Figure 3-7).



Figure 3-7 Bank poaching at the River Annagh (Location: Annagh 4)

Invasive non-native species not only present a management challenge for biodiversity but can also leave riparian zones and banks exposed during winter dieback, leaving them more vulnerable to erosion. Himalayan Balsam, Giant Hogweed and Japanese Knotweed were observed particularly along the Mulkear River, Newport River, and River Annagh (Figure 3-8).



Figure 3-8 Stands of Giant Hogweed and Himalayan Balsam on the left bank and Japanese Knotweed present on right bank of the Mulkear River (Location: Mulkear 5)

Forestry is a key land use in the upland environments of the Newport, Annagh, and Bilboa tributaries and is potentially linked to excessive sediment supply. In general terms, concerns between forestry and sediment issues relate to land drainage practices and the type of felling management regime employed. Firstly, the installation of new drainage channels and/or straightening of natural channels is likely to funnel more water into the river network and create additional opportunities for erosion. Secondly, felling and post-felling practices that are not supported by robust fine sediment management have been linked to elevated concentrations of fine sediment in other Irish rivers (EPA, 2016). Many hillslope streams were observed in the upland Mulkear catchment that exhibited evidence of fine sediment being eroded from the bed that would be transported downstream during rapid runoff events (Figure 3-9). Forestry is therefore identified as a possible source of excess fine sediment in the Mulkear catchment.



Figure 3-9 Fine sediment and fine gravel deposition in a small stream draining forested land in the Annagh catchment (Location: Annagh 3)

3.3 GIS analysis

Following the field survey, GIS analysis was completed to map potential erosion and sediment source hotspots and develop a catchment-wide understanding of where sediment was likely generated and/or transported downstream. Existing data sets

such as the FSU river lines, FSU QMED4, and topographic data were examined to calculate the specific stream power under bankfull conditions. This provided a measure of river energy that was examined against data sets like CORINE land cover and GSI Quaternary Sediments, while in consideration of the physical setting of each reach, to infer the likelihood of fine and coarse sediment erodibility across the catchment. The potential for fine and coarse sediment generation was then combined into an Overall Erosivity Index that ultimately defined river reaches as depositional (low sediment yield), transportation (moderate yield) and erosional (high yield).

Figure 3-10 shows the output map of potential sediment supply and transport across the Mulkear catchment. The key findings of the GIS analysis are:

- The highest generation of fine sediment is anticipated to come from the upland areas, which are both steeper and comprise predominantly forestry land-use. Moderate amounts of fine sediment are anticipated from the lower reaches of the catchment.
- While local areas of fine sediment deposition and storage do exist throughout the catchment, under bankfull conditions this material is able to be mobilised and transported downstream to the lower reaches of the Mulkear River and towards the Old Shannon.
- For coarse sediment, the higher energy uplands are more erosional than the less erosive lower reaches. There are few low erosivity reaches predicted in general, which suggests that coarse sediment delivered from the uplands may readily pass through the system to the lower reaches of the Mulkear River and towards the Old Shannon.

Overall, GIS analysis showed high erosion/transport in the uplands and moderate erosion/transport within the lower reaches. Most of the Mulkear River main stem is shown as high transport/erosional, suggesting the sediment transport regime is likely imbalanced towards erosional.

⁴ QMED is used as an approximation for bankfull flow - see discussion at Section 4.2.2. Using QMED also removes the need to use growth curves and the uncertainty associated with these.

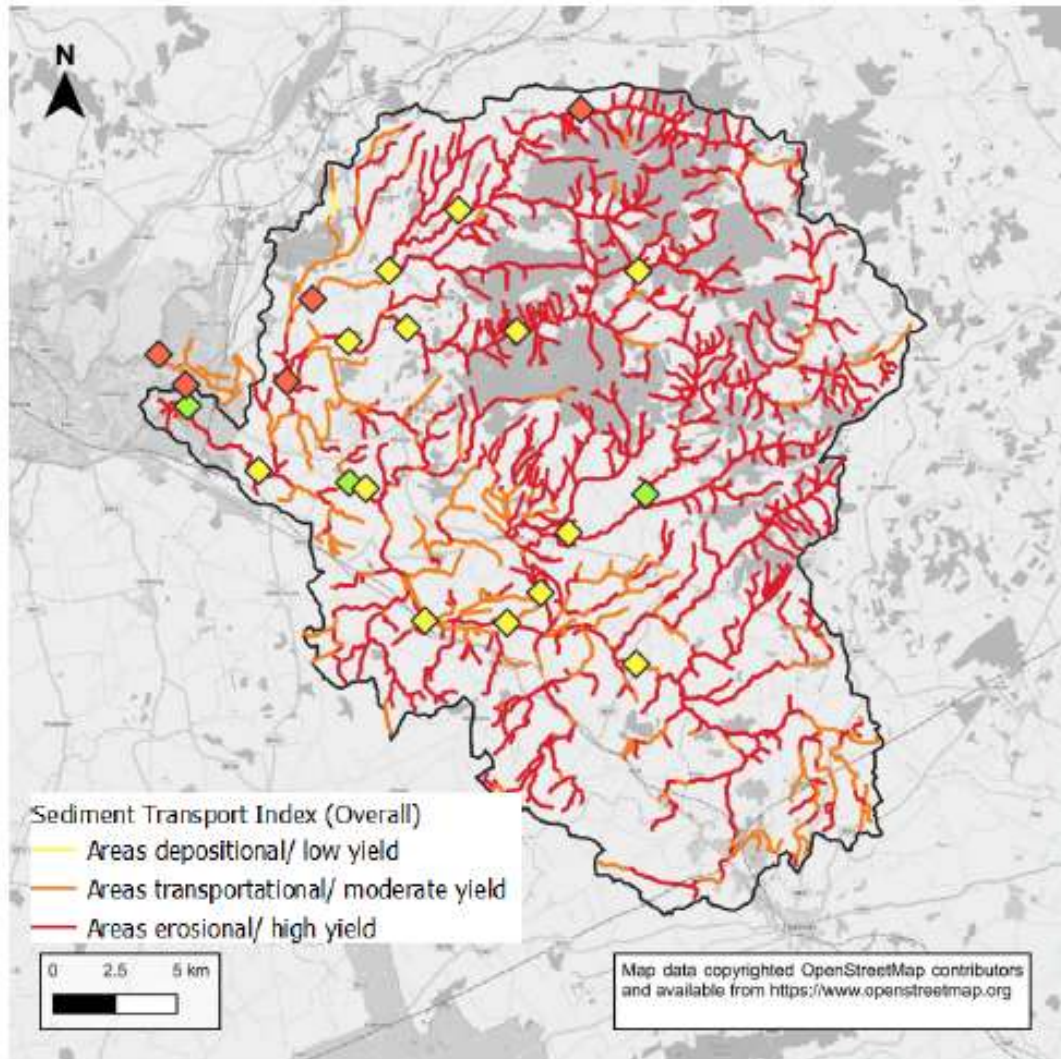


Figure 3-10 Catchment-wide map of potential sediment transport and supply

3.4 Conceptual model (Mulkear catchment)

Findings from the field survey and GIS analysis components of the fluvial audit were integrated to produce a conceptual model of the sediment transport regime in the Mulkear River catchment (Figure 3-11). These components were consistent in their findings that:

- For the Mulkear tributaries, the upper reaches showed high potential sediment yield and are primarily erosional zones. The lower reaches showed moderate sediment yield and are primarily transportational zones.
- The Mulkear river is both transportational and erosional across its length.
- There is potential for fine sediment up to coarse gravel to be readily mobilised from, and transported through, the Mulkear catchment towards the Old Shannon.

Hydromorphological pressures, particularly channel modification, have contributed to floodplain disconnection at each of the tributary systems and along the Mulkear main stem. It is highly likely that these changes have increased the in-channel stream power under bankfull flow conditions and therefore are likely to have enhanced the erosional nature and transport competency of the tributaries and Mulkear River. Other pressures such as a lack of stock fencing and forestry are likely to be contributing excess fine sediment to the catchment.

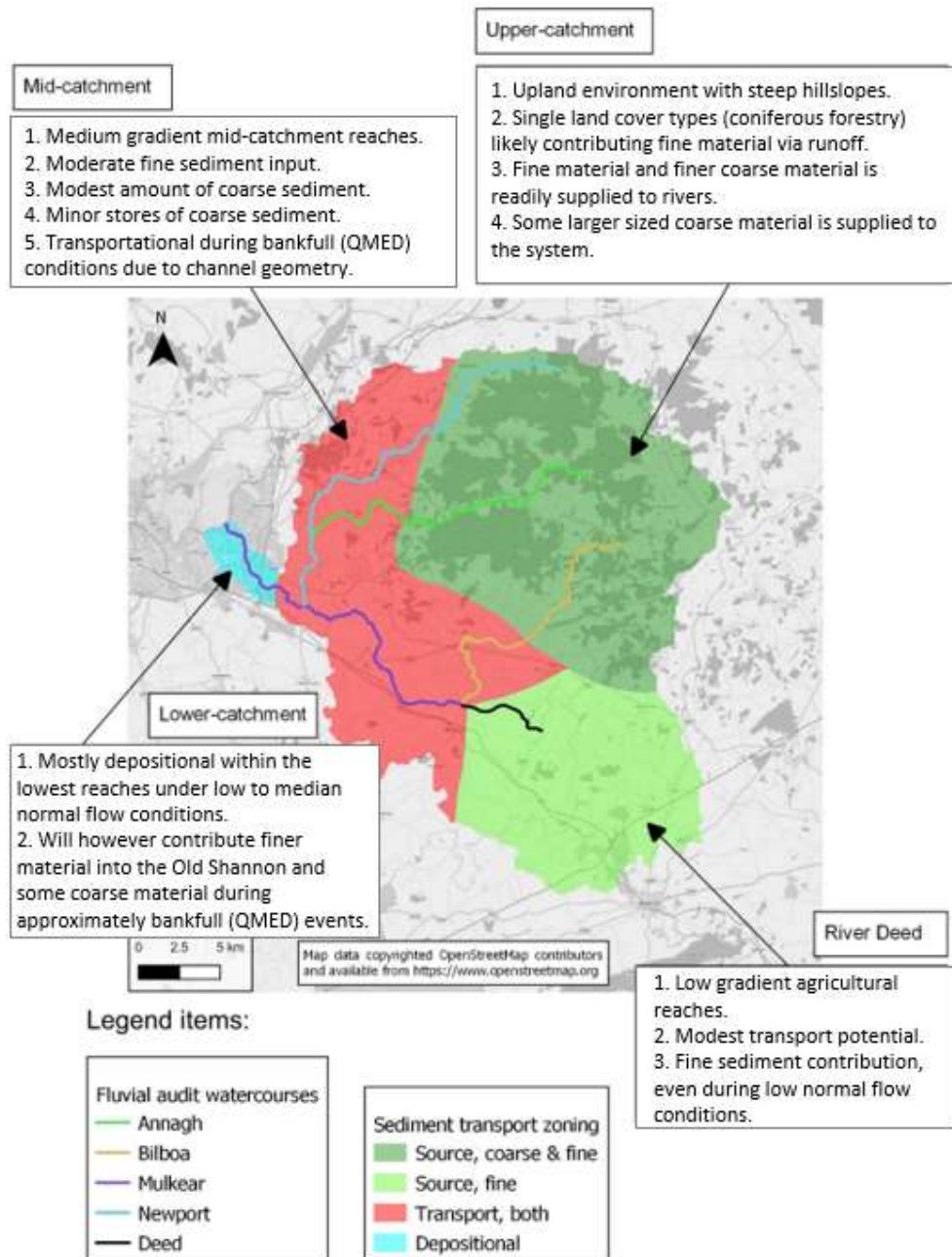


Figure 3-11 Conceptual model for the Mulkear River catchment

4 Modelling

4.1 Overview

Hydrodynamic modelling was conducted in support of two specific hydromorphological questions arising from the Fluvial Audit:

1. What are the baseline hydraulic conditions within the Project Area (particularly at the lower Mulkear, Mulkear-Old Shannon confluence, and Old Shannon upstream and downstream of the confluence) under the existing flow regime, and how are these conditions likely to interact with the incoming sediment supply from the Mulkear catchment?
2. Can the origin of sediment within the Mulkear River catchment be clarified beyond the findings of the Fluvial Audit?

A state-of-the-art hydrodynamic model was employed to undertake two separate but related modelling exercises to answer these questions. The first modelling exercise sought to understand how sediment moves through the Old Shannon and lower Mulkear and then interacts at, and downstream of, the confluence (Section 4.2 and 4.3). The second modelling exercise employed particle tracing in the Mulkear catchment to identify the most likely source areas of sediment (Section 4.4).

Main findings as they relate to the above questions are provided below. For the first modelling exercise, only the most relevant results that focus on the lower Mulkear and Mulkear-Old Shannon confluence are presented. Further technical information (including detailed results across the entire model domain) can be found in the Sediment Transport Modelling Note.

4.2 Methodology

4.2.1 Modelling approach

The model is a fully 2D Telemac flexible mesh hydrodynamic model. The flexible mesh allows for the representation of greater detail within areas of interest e.g. channels and coarser resolution within wide flat areas such as floodplains ensuring that run-time efficiency is retained.

For the first modelling exercise (examining sediment dynamics), the model extent is shown in Figure 4-1.

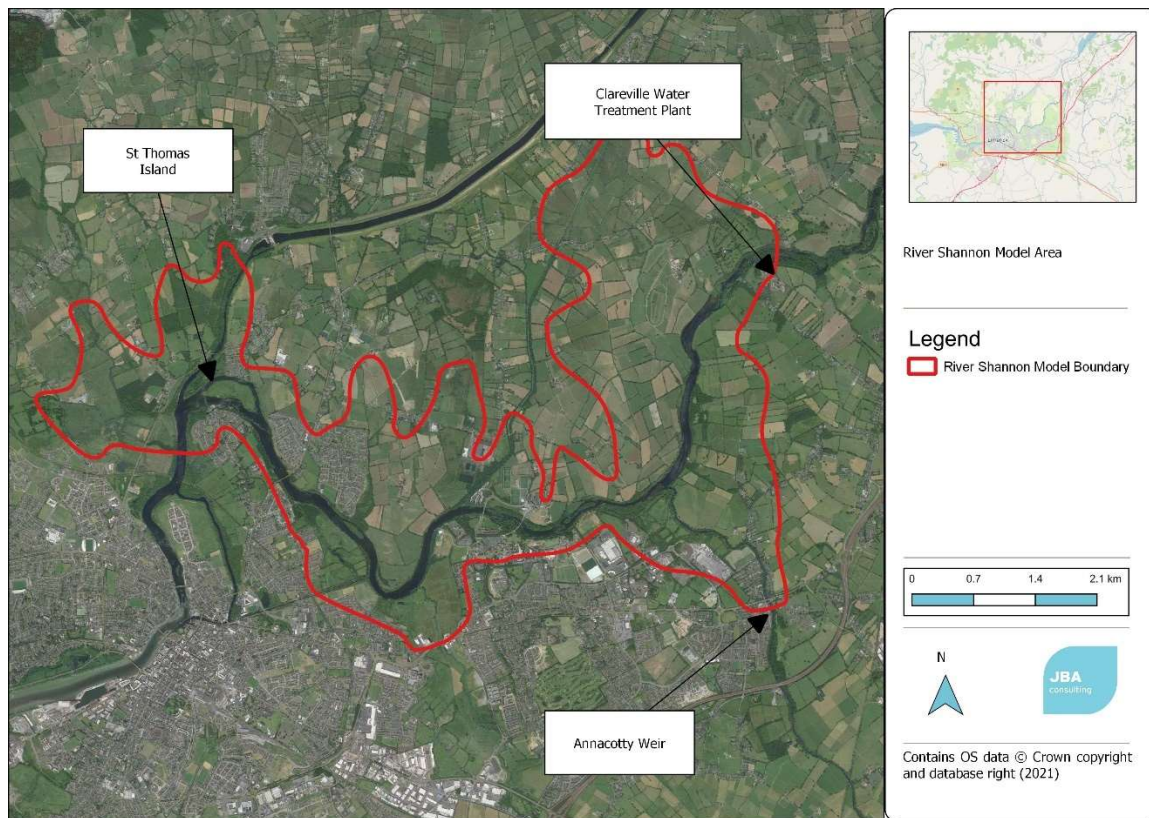


Figure 4-1 Model domain for the Old-Shannon and lower Mulkear River model

This modelling simulated several important flows to understand the flow hydraulics and inundation extents in support of both this hydromorphological study and the optioneering work. Flows included were:

- Normal flows as defined by the flow duration curve for Q10, Q30, Q50, Q70 and Q90.
- Flood flows for the 50% AEP (2 year event), 10% AEP (10 year event) and 1% AEP (100 year event).

The Normal and Flood flows used in the model are provided in Table 2-1 and Table 2-2 for the River Shannon and the Mulkear River, respectively. Further information on the hydrological conditions in the model are provided in Sediment Modelling Note (Section 5 of that report).

4.2.2 Selection of flows relevant to sediment dynamics

To understand the sediment dynamics in the lower Mulkear and Old Shannon channels, hydraulic outputs were examined for the Q10 and 50% AEP simulations based on the following rationale:

- The Q10 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 (2 year event) 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. The 50% AEP event is referred to as the bankfull event from here onwards.

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 model showed that flow begins to spill out of bank in a 50% AEP event into the surrounding floodplain of the Old Shannon upstream of the confluence (Figure 4-2). Along the Mulkear River, flow spills predominantly into the left bank inundating the low-lying ground in this area. This implies that there is the potential for significant morphological change and associated transport competence to occur during both Q10 and 50% AEP conditions, given they represent high flow scenarios where flow is largely contained in-channel (Q10) 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.

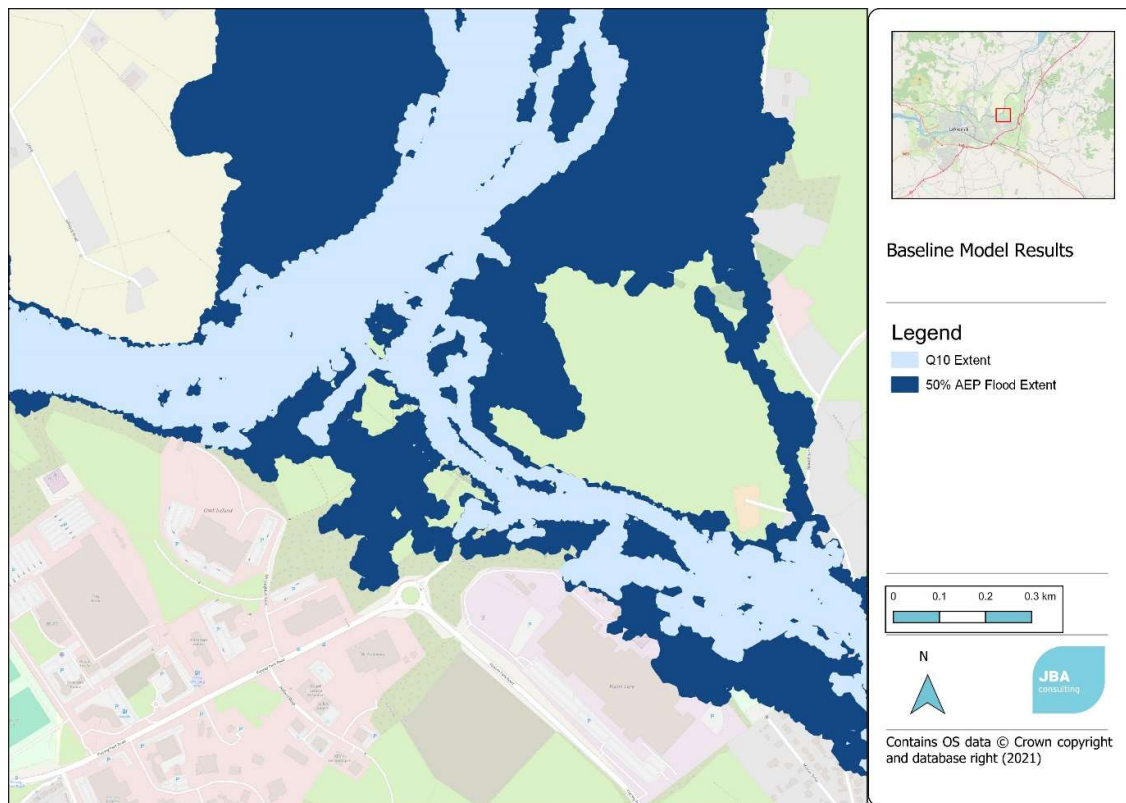


Figure 4-2: Baseline model results

4.2.3 Interpretation of model results for sediment dynamics

Two approaches have been used to interpret the modelled peak velocities for the Q10 and bankfull events.

To examine fine sediment dynamics in the lower Mulkear and Old Shannon during normal flow conditions, the Q10 modelled peak velocity has been reviewed against the Hjulstrom curve for silt sediment size transport (see Appendix A). Velocity values were categorised based on the erosion, transport, and depositional ranges for the smallest (0.0039mm) and largest (0.0625mm) silt particle sizes taken from the Hjulstrom curve. These ranges are:

- 0 to 0.12m/s for transport and greater than 0.12m/s for erosion of 0.0039mm diameter silt.
- 0 to 0.0047m/s for deposition, 0.0047 to 0.225m/s for transport and greater than 0.225m/s for erosion of 0.0625mm diameter silt.

To examine coarse sediment dynamics in the lower Mulkear and Old Shannon during normal and bankfull flow conditions, the Q10 and bankfull modelled peak velocities were first converted to an estimate of shear stress (see Appendix A). To determine the predicted maximum mobilised particle size for an estimate of shear stress, a re-arrangement of the critical shear stress equation was adopted and applied to the calculated maximum bed shear stress grids in GIS. The output

produced maps of predicted maximum mobilised particle size i.e. the critical particle size entrained by that flow. The grids are styled using a categorical banding based on the Wentworth particle size grading (see Appendix A). This allowed visual appraisal of local river energy with areas showing smaller particle sizes being lower energy and areas showing larger particle sizes being high energy areas of river. A series of maps were produced for the Q10 and bankfull events to appraise how the sediment carrying capacity of the river is likely to change as flow magnitude increases.

4.2.4 Model uncertainty

Uncertainty is inherent within in any modelling exercise and as such appropriate critiquing of model results against known information must be undertaken. For example, downstream from the Mulkear-Old Shannon confluence field work had identified small gravels that were assumed to be supplied from the Mulkear. This broadly corresponds with the estimates shown in the mapped model results in Section 4.2. The model results highlight that the Mulkear River downstream from Annacotty weir is very confined, providing a high energy transport route through to the Shannon. In another example, modelled Q10 peak velocity values correspond with visual observations of mobile sediments downstream from Annacotty Weir made during the fluvial audit field survey.

Although uncertainty exists for specific values, modelled results provide clear indications of river energy trends and flow pathways at the local hydraulic level and when used alongside other geomorphological datasets help provide a more complete analysis of geomorphological functioning within the area of the Mulkear-Old Shannon confluence.

4.3 Model results and interpretation

4.3.1 Hjulstrom transport potential (Fine fraction)

The results from the Q10 analysis indicate that finer silts are likely to be transported throughout the Mulkear and potentially generated from the bed and banks, with these areas showing potential for erosion (

Figure 4-3). Fine sediment will be transported into the Old Shannon, with the majority of the Old Shannon indicating transport competence potentially preventing deposition of the finest material.

For the larger diameter silt (0.0625mm) the Mulkear is less erosional, but both the Mulkear and Shannon are shown to be transport competent (Figure 4-4). There are areas of potential deposition around the modelled water surface extents, indicating depositional zones towards channel margins for larger silts.

Generally, the Mulkear is shown to have greater energy to transport fine material than the Old Shannon, with areas of potential erosion predicted in the lower Mulkear

during the Q10 normal flow. The Old Shannon is shown to be transport competent at Q10, however there is an elevated risk of fine sediment deposition within the river under lower flow conditions. This finding is supported by the underwater image 25SHAN08757 (see Section 2.6.3).

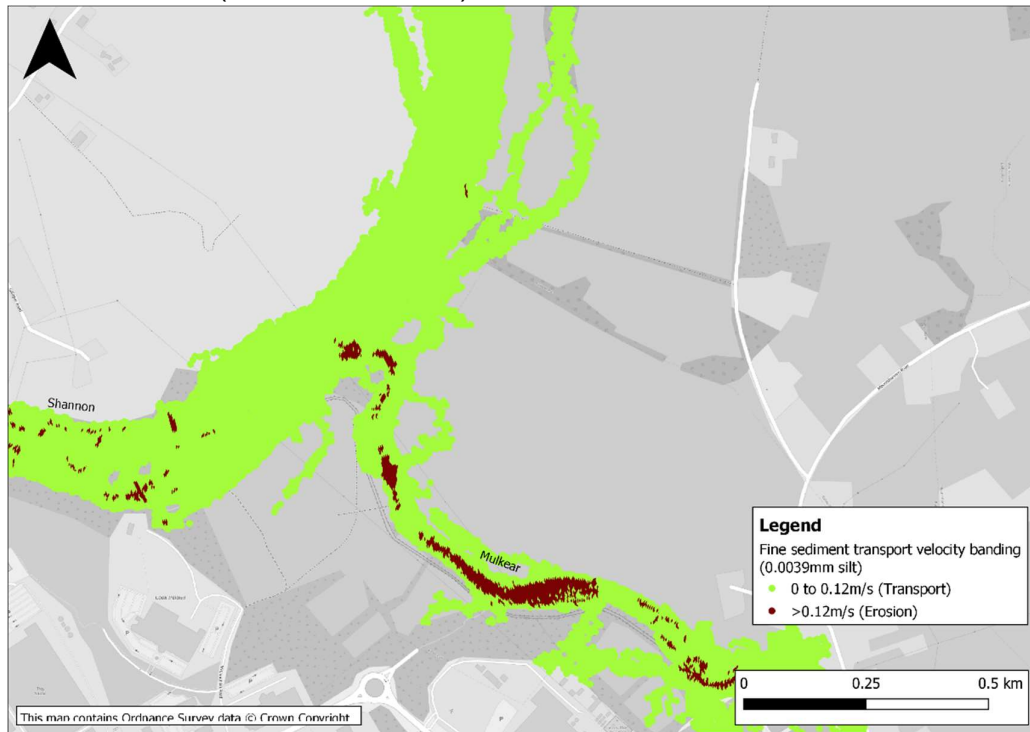


Figure 4-3 Transport potential for lower band silts (0.0039mm) during Q10 normal flow

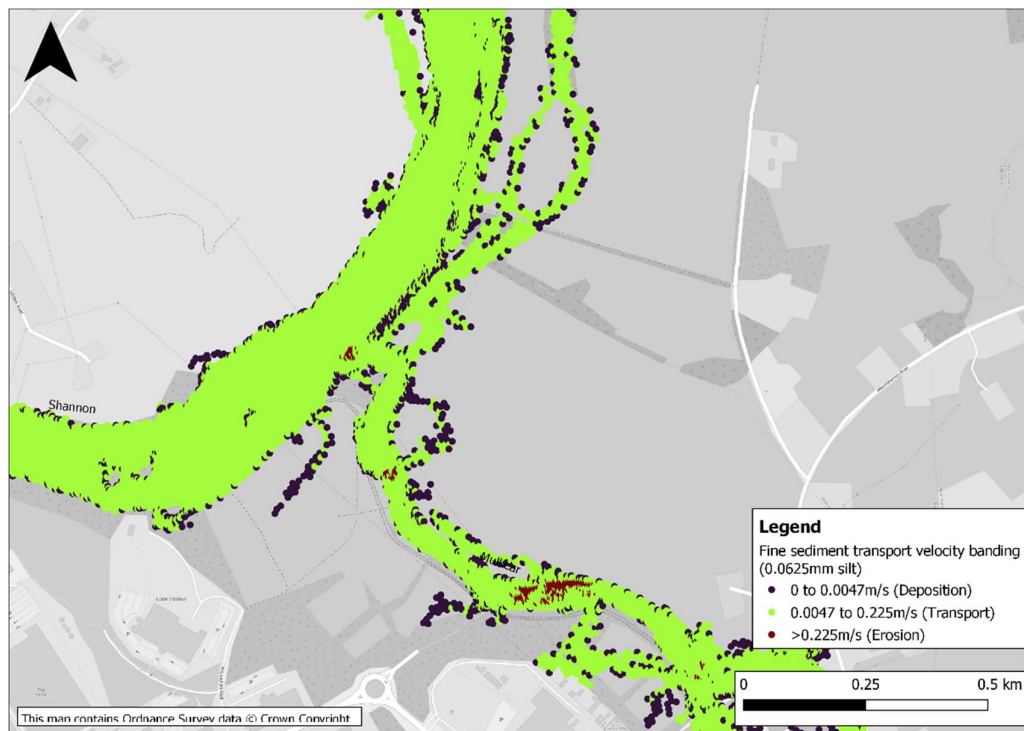


Figure 4-4 Transport potential for lower band silts (0.0625mm) during Q10 normal flow

4.3.2 Critical Sediment Entrainment

Appendix A provides several maps for the Q10 and bankfull critical sediment entrainment results for the lower Mulkear, Mulkear-Old Shannon confluence, and Old Shannon downstream of the confluence. Outputs for the confluence only are shown below along with an interpretation of the kind of material likely to be mobilised and/or transported.

Critical Sediment Entrainment in Q10 (Typical winter flow)

The maximum shear stresses and sediment sizes mobilised in the Mulkear River and the River Shannon during Q10 flow conditions are presented below in

Figure 4-5.

The model results show that the Mulkear River is able to entrain and transport coarse sediment during a Q10 normal flow (typical winter high flow), including gravels, cobbles, and some boulder material. This supports underwater imagery taken of the lower Mulkear river bed that showed coarse gravel and cobbles in the lower Mulkear.

The maximum sediment size entrained by the Old Shannon downstream of the Mulkear confluence under Q10 flow conditions is fine gravel. This is consistent with the conclusions from AquaUoS (2020) and the underwater imagery of the Old Shannon that show coarse material colonised with moss at this location.

Lower Critical Sediment Entrainment values are visible along the left bank of the Old Shannon downstream of the confluence. Flows are concentrated in the thalweg of the channel. At this location the maximum sediment size entrained is very coarse sand. As such, any coarser material will deposit at this location.

Upstream of the confluence the Critical Sediment Entrainment values are lower in the Old Shannon than they are downstream, with the maximum sediment size entrained being very coarse sand. Downstream of the confluence the Old Shannon can transport coarser gravel material in addition to sands, suggesting that the increased velocity downstream of the confluence (due reduced cross-sectional area) allows greater sediment transport. This is consistent with the findings of AquaUoS (2020) that found high flows in the Old Shannon are associated with higher flows from the Mulkear River.

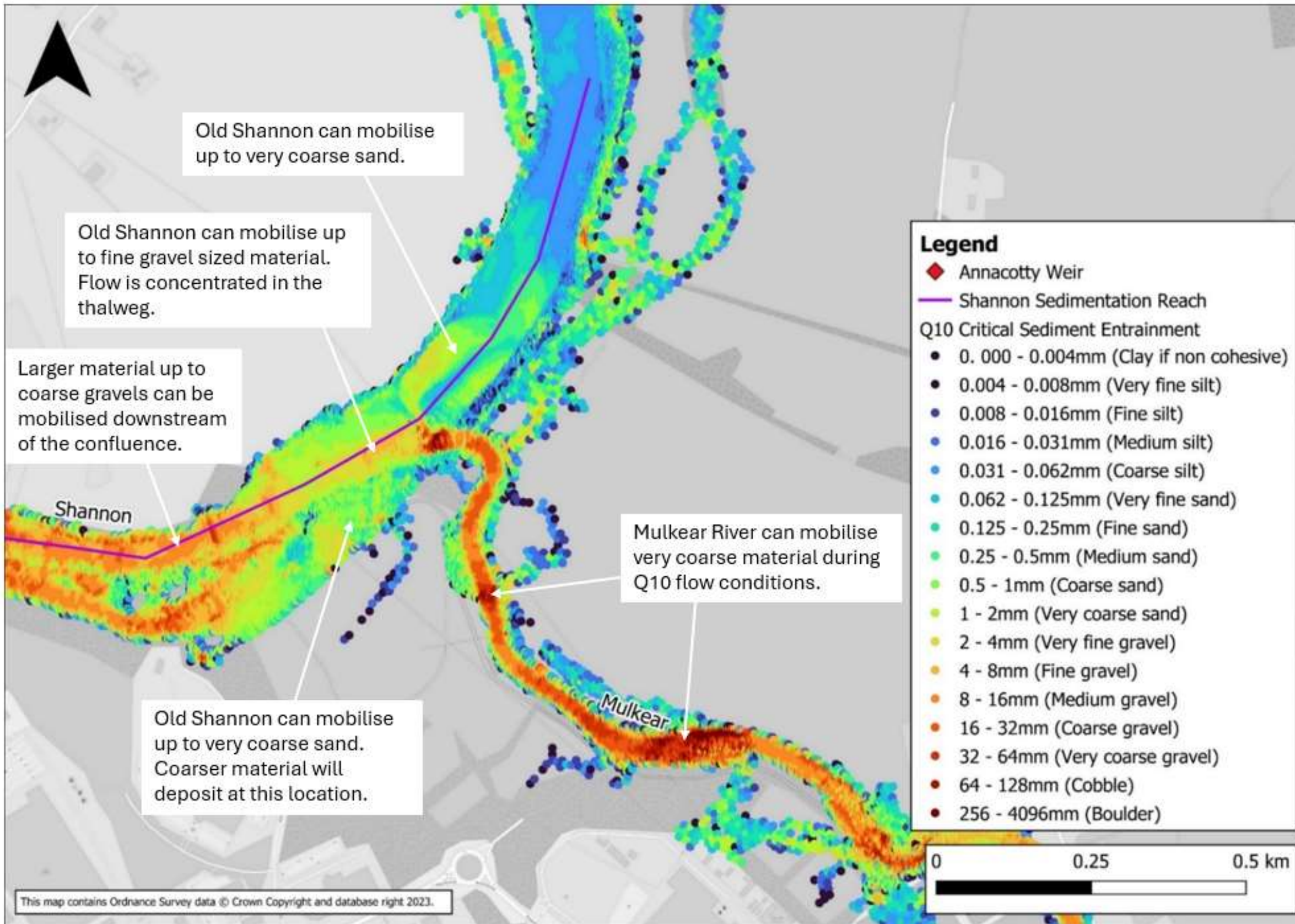


Figure 4-5 Maximum sediment sizes mobilised in the Mulkear River during a Q10 event

Critical Sediment Entrainment at 50% AEP (bankfull flow)

The maximum shear stresses and sediment sizes mobilised at the site location in a 50% AEP bankfull event are presented below in Figure 4-6.

Flow can spill into the floodplain during a Q2 flood event. A range of finer sediments are shown to be entrained across the wider floodplain and range from fine gravel to fine silt. The results show a flow pathway on the left bank floodplain, with high Critical Sediment Entrainment values capable of mobilising fine to coarse gravels. The flow pathway identified follows the route of relic paleochannels identified on the left bank floodplain by AquaUoS (2020).

The model results highlight the erosive energy of the Mulkear River in bankfull flow events, with the lower Mulkear capable of transporting coarse gravels to the Old Shannon under these flow conditions. The Old Shannon can carry very fine gravel downstream of the confluence. As such, coarser gravels are likely to be deposited in the Old Shannon in a bankfull event.

Downstream of the confluence, the Critical Sediment Entrainment values increase in the Old Shannon (due reduced cross-sectional area) and the maximum sediment size entrained in a bankfull event is boulders, with gravels and cobbles likely to be mobilised downstream.

The results show areas of the River Mulkear that are susceptible to erosion in a Q2 flood event (where the Critical Sediment Entrainment values are high enough to erode and mobilise coarse cobble and boulder material). The erosive energy of the River Mulkear can be attributed to the over deep incised channel shape. Flow is unable to dissipate across the floodplain as a result of embankments and this results in erosive flow velocities.

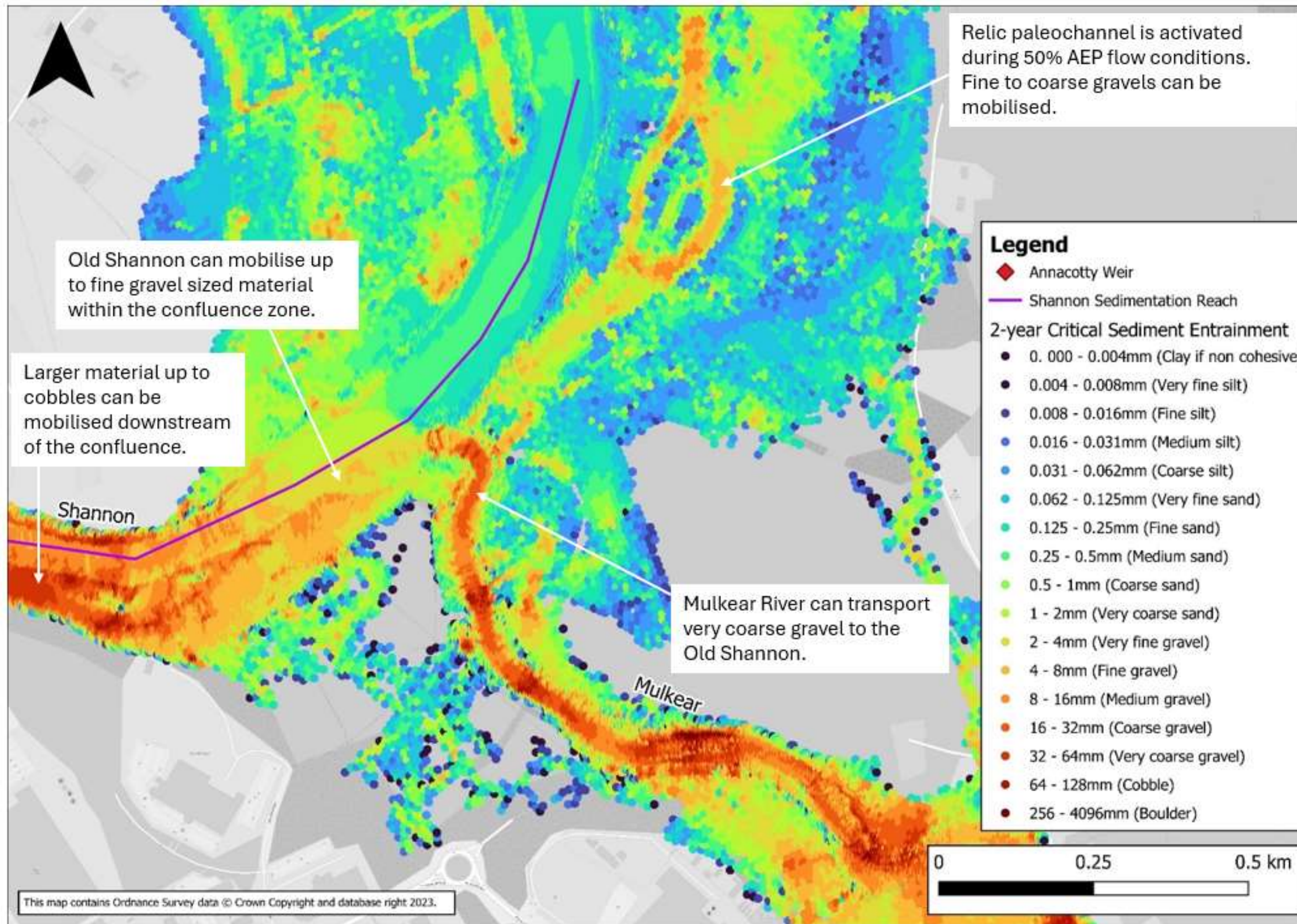


Figure 4-6 Maximum sediment sizes mobilised in the Mulkear River during a 50% AEP (bankfull) event

4.3.3 Sedimentation risk

A sedimentation risk map has been produced for the lower Mulkear and Mulkear-Old Shannon confluence to highlight locations likely to experience continued sedimentation during bankfull conditions, assuming the status quo of hydrological and sedimentological processes is sustained. The risk map uses the model-derived estimates of critical particle size, compared with the Wolman sediment count from the Annacotty Weir. The risk categories are based on the sizes of the finer D15 (High risk), medium D15 to D85 (Moderate risk) and large \geq D85 (Low risk) coarse sediment fractions from the sample. Due to uncertainty inherent in modelling discussed above, it is useful to assign risk categories rather than exact values of sediment size to prevent bias of option selection at this stage.

The risk categories have been selected based on theoretical potential to transport material, the acknowledgement that the Mulkear catchment generates both fine and coarse sediment, and the knowledge that it can deliver this material downstream of Annacotty Weir. Areas of river shown to be competent to transport large sediment within the modelling are unlikely to experience sustained deposition and are therefore at low risk of ongoing sedimentation, conversely areas with lower energy are likely to experience ongoing sedimentation.

The results are unsurprising, showing that the reach of the lower Mulkear downstream from the Annacotty Weir is transport competent with areas at low risk of sedimentation under bankfull conditions, indicating the river has enough energy to transport up to coarse gravel sized sediment through to the Old Shannon. Much of the floodplain is shown to be at risk of sedimentation, consistent with overbank deposition.

The Old Shannon is generally shown to be at 'Moderate risk' of sedimentation, with some areas of low risk, however the area immediately downstream from the Mulkear is at high risk agreeing with underwater photography which shows deposition of fine to medium gravel at this location. Larger material (i.e. medium sized coarse sediment) which is delivered from the Mulkear may deposit within the Shannon and, any material which backwaters into the reach upstream from the Mulkear will not be transported downstream, leading to ongoing sedimentation.

Figure 4-7 shows the sedimentation risk for the lower Mulkear and Mulkear-Old Shannon confluence under a 50% AEP (bankfull) event. Key points include:

- The risk of sedimentation remains high in the Old Shannon upstream of the Mulkear confluence. This can be attributed to a lack of flow conveyance from upstream, causing low velocities.
- In a 50% AEP (bankfull) event, the risk of sedimentation in the Mulkear River is low to moderate. The results consider peak flow, as flow velocity reduces on the falling limb of the hydrograph some material may drop out of suspension and be stored locally within the Mulkear, but much of this will be transported into the Shannon.

- There is potential for scour downstream of the Annacotty Weir in a bankfull event, and it is likely that material is mobilised at this location in flood flows and transported downstream.
- There is high risk of sediment deposition downstream of the Mulkear confluence in a bankfull event, indicating insufficient flow energies to transport material downstream.
- Risk of sedimentation is reduced in the Old Shannon further downstream but remains moderate and it is likely that material from the Mulkear is deposited near to the islands.

Sedimentation risk in a 50% AEP (bankfull) event

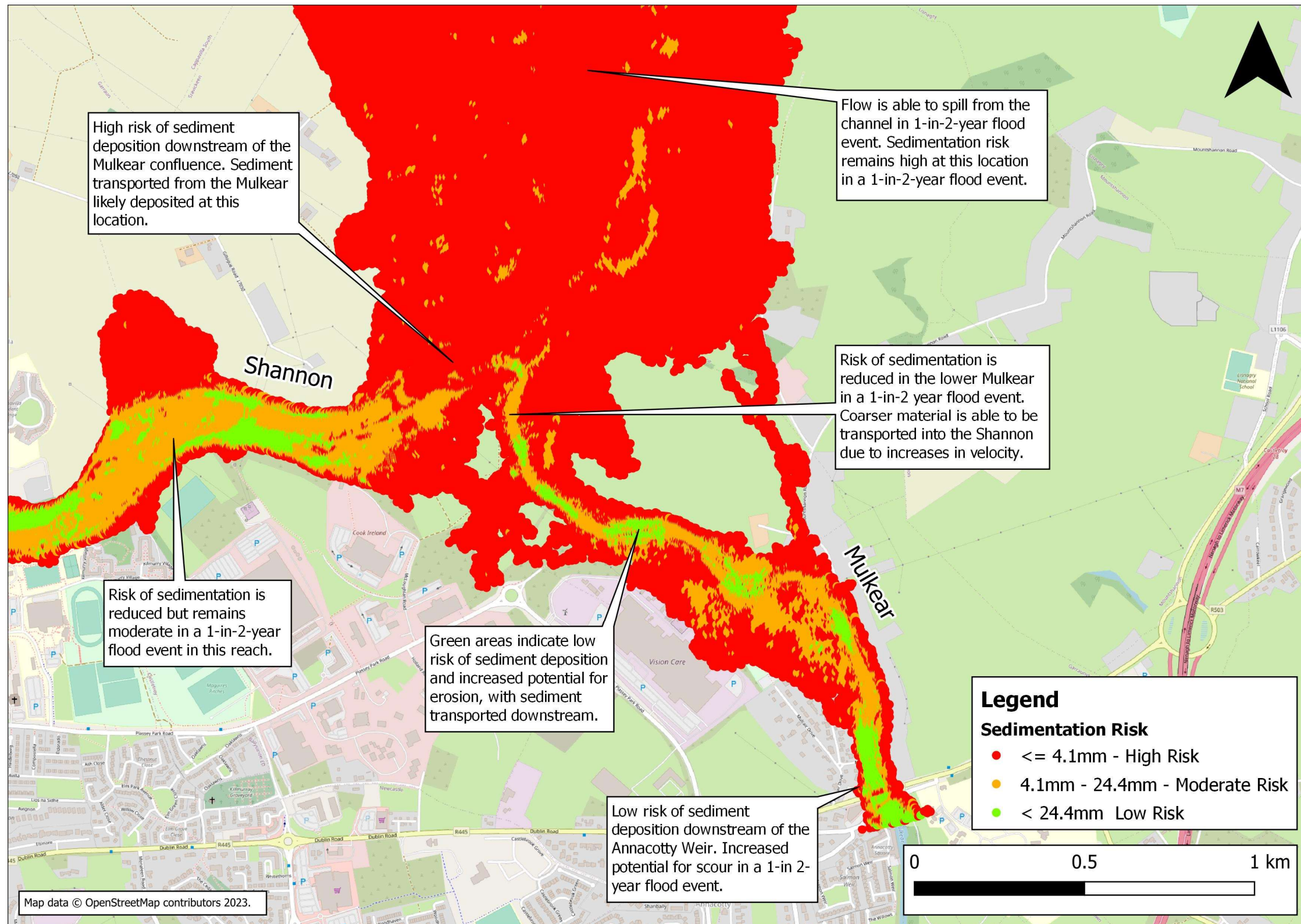


Figure 4-7 Sedimentation risk during 50% AEP (bankfull) event

4.4 Particle tracing study

For the second modelling exercise (particle tracing), the model extent is shown in Figure 4-8.

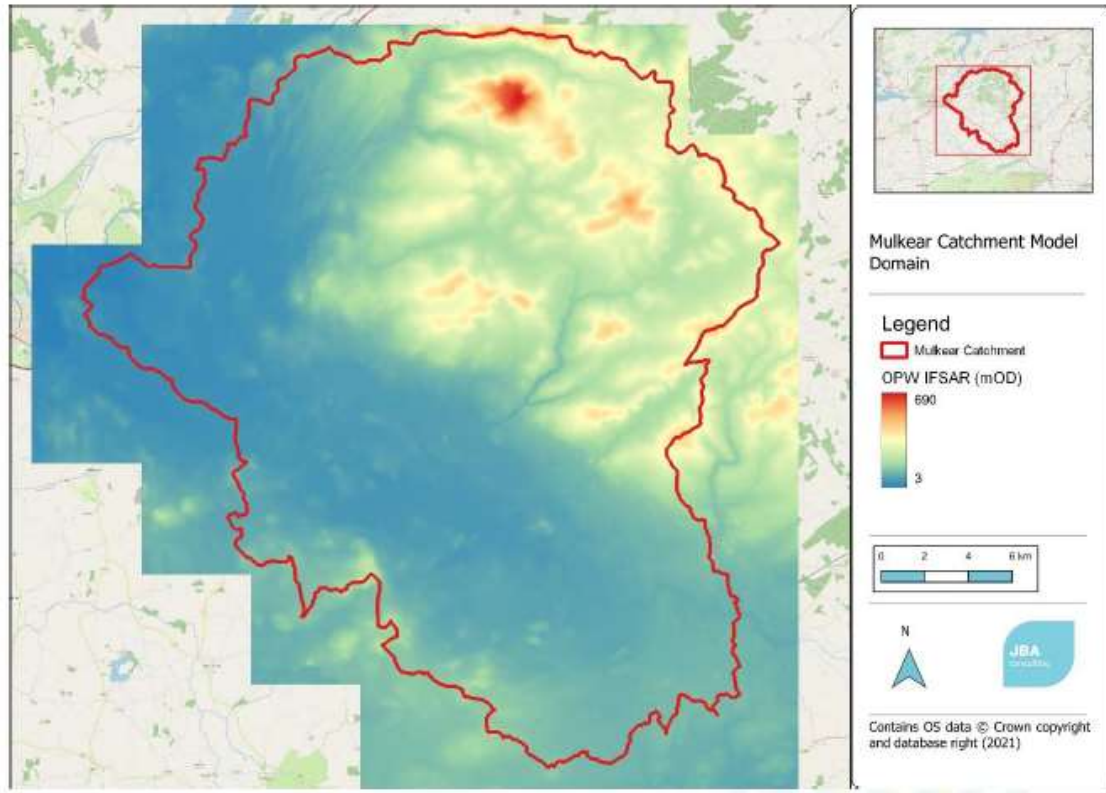


Figure 4-8 Model domain for the Mulkear catchment

The Mulkear catchment was divided into sub-catchments and each was seeded with particles (representing sediment) in areas that were identified as sediment source locations during the fluvial audit. This included the uplands, the Deed catchment, and the Mulkear main stem. Rainfall associated with several return periods was applied to the model domain and runoff was determined based on topographic flow pathways and by taking into account land use and soil types to identify areas of a greater run-off probability. The seeded particles were then tracked in their movement through the Mulkear catchment. Particles reaching the Annacotty Weir represent likely source areas of sediment.

Figure 4-9 shows a comparison of model results for particle movement during a 24 hour rainfall event for different return periods. Particles are initially seeded into the coloured polygons on each river system as shown in the top left, and then for each event the loss of colour in each polygon represents how much of the seeded particle material has been mobilised downstream. The key findings are that: i) particle movement starts in the north and east for smaller rainfall events, and ii) only as the return period increases do we see movement from the south. 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.

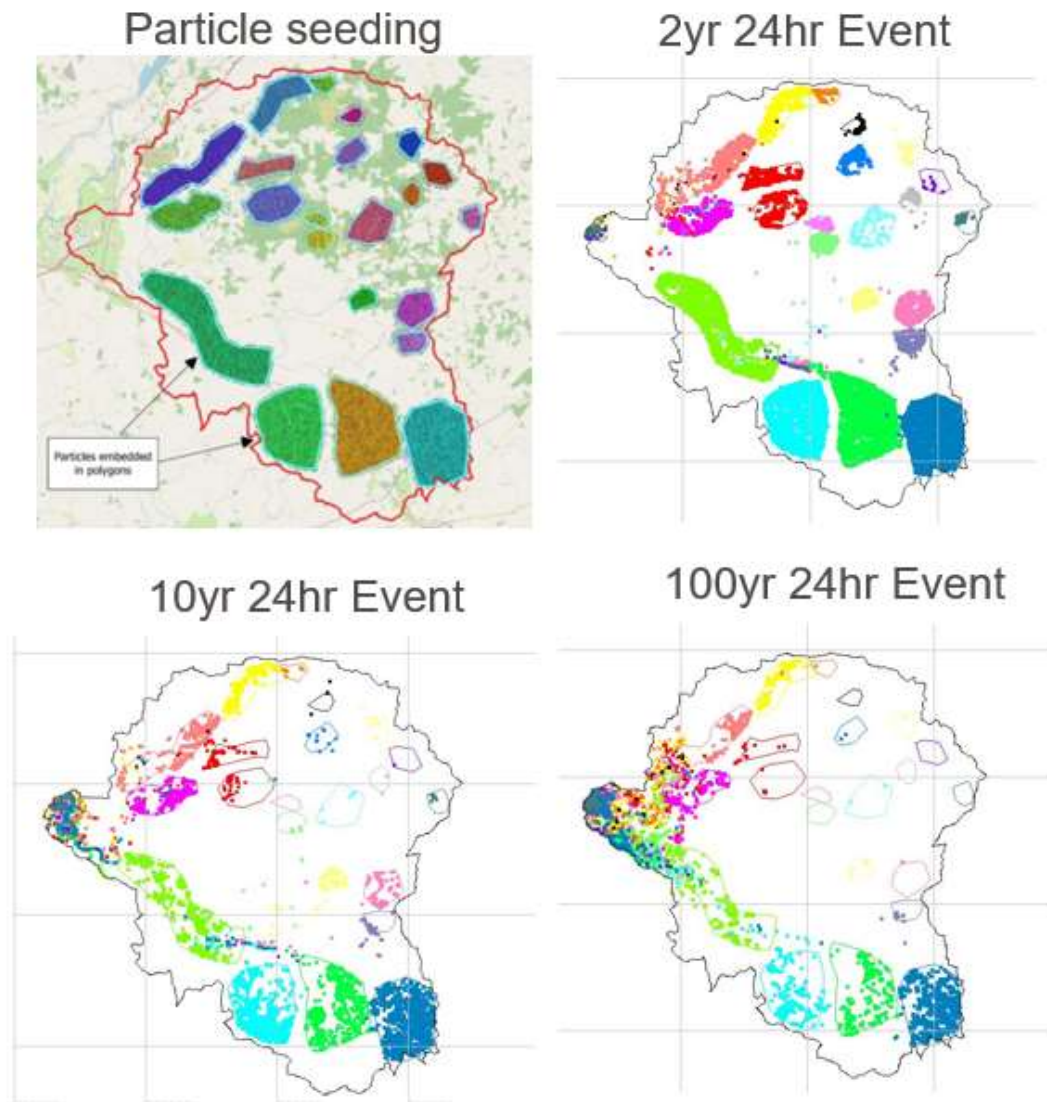


Figure 4-9 Particle locations following 24-hour rainfall event (multiple return periods)

5 Lower Shannon Conceptual Model

5.1 Conceptual model (current dynamics)

Findings from the desk study, fluvial audit, and modelling components have been synthesised to provide an integrated conceptual model of the Lower Shannon. This presents the understanding of the current sediment dynamics of the Lower Shannon under the current hydrological and sedimentological regime. Key points are outlined below and represented in Figure 5-1.

Supply, transport, and deposition of sediments is a normal dynamic for the Mulkear catchment purely based on the erodible character of the dominant superficial sediments, the variable topography, and the flashy response to rainfall. However, there is evidence of excessive sediment supply (i.e. greater than would be expected) occurring in forested upland areas and across all areas of the catchment that feature hydromorphological pressures including a lack of stock fencing, or on farm works with minimal sediment capture mitigation.

Supply of both fine (e.g. silts, fine sands) and coarse (sands, gravels, cobbles) sediments is greatest from the northeast upland areas i.e. upper reaches of Newport, Annagh and Bilboa tributaries. However middle reaches are also contributing both fine and coarse sediment supply. The Deed tributary is a key source of fine sediment.

While coarse sediment can be deposited and temporarily stored through the middle reaches of the tributaries, once material reaches the Mulkear River it is able to be transported downstream during 50% AEP (bankfull) flows. The transport capacity of Mulkear River is likely enhanced by channel modification and disconnection to the floodplain. The Mulkear itself also supplies fine and coarse material to the system.

Under 50% AEP (bankfull) conditions, the Mulkear River can move fine sediment up to coarse gravels up to, and over, Annacotty Weir down to the Old Shannon. The lower Mulkear can also move this same material between Annacotty Weir and the Old Shannon under a Q10 event (typical winter high flow). This means that under these higher flow conditions coarse sediment is being moved towards and into the Old Shannon-Mulkear confluence and deposited there. Fine sediment is also being mobilised under these flows but is largely flushed through, and only likely to be deposited in the lower Mulkear and confluence area under lower normal flow conditions or at the very margins of the confluence area during higher flows.

However, under both Q10 and 50% AEP flow conditions, the Old Shannon can only mobilise part of the incoming coarse sediment supply. The reduced flushing capacity in the Old Shannon because of flow regulation at Parteen Weir, means that the hydraulic conditions in the Old Shannon around the Mulkear-Old Shannon confluence can only mobilise sediment up to very fine gravel in size. This explains the overall depositional environment at, and below, the confluence.

#3: Middle reaches of the tributaries can temporarily store this sediment, however under bankfull flows will transport this material downstream. Under a typical winter high flow, they will also contribute additional sediment to the system.

#6: Under the same high flow conditions, the Old Shannon can only mobilise part of the incoming sediment supply from the Mulkear (i.e. up to very fine gravel).

#5: Under normal flow conditions, the lower Mulkear is mainly depositional. However, under a typical winter high flow (Q10) and bankfull, sediment up to coarse gravel can be transported over Annacotty Weir and to the Old Shannon.

#4: The transport capacity of the Mulkear is enhanced by floodplain disconnection. Once sediment reaches the Mulkear, under bankfull conditions, it can be transported downstream. Erosion on the Mulkear also adds sediment to the system under these conditions.

#1: Greatest supply of both fine (e.g. silts, fine sands) and coarse (sands, gravels cobbles) sediment originates in the northeast upland areas of the Newport, Annagh and Bilboa tributary catchments.

#2: The Deed tributary is a key source of fine sediment.

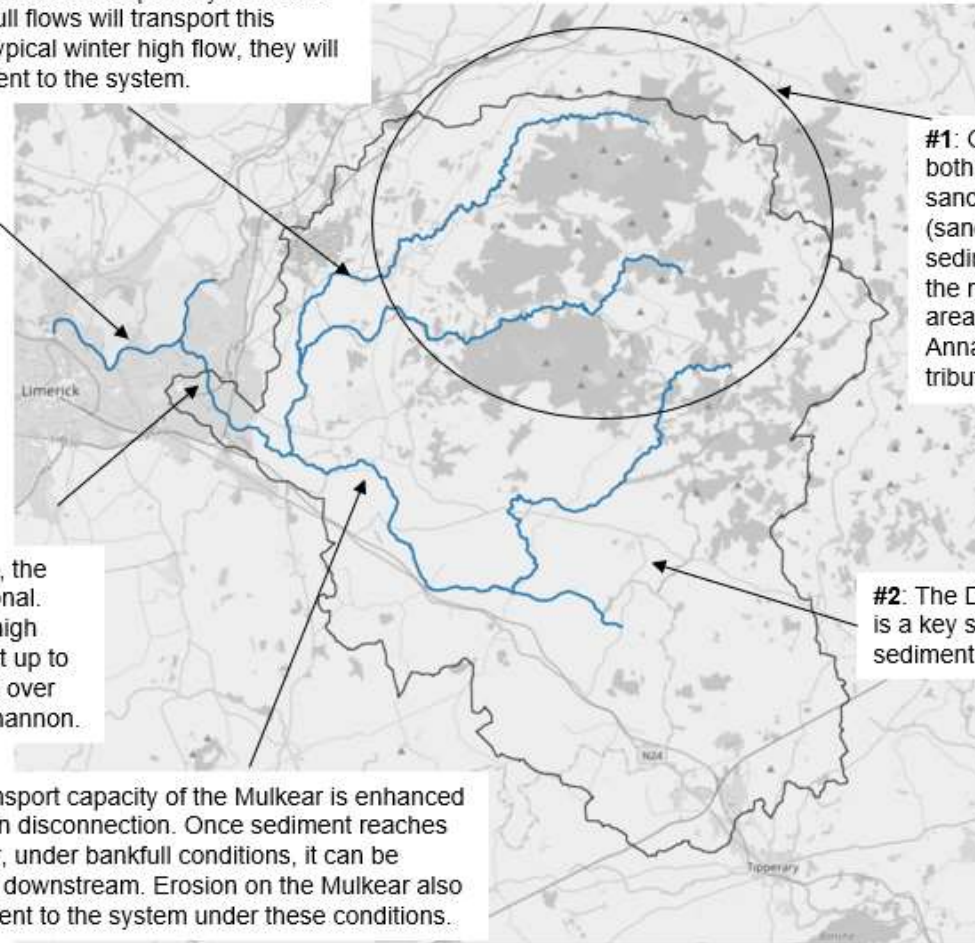


Figure 5-1 Conceptual model of the current sediment dynamics of the Lower Shannon

5.2 Conceptual model (possible future dynamics)

Without any changes to the sediment supply from the Mulkear catchment, and assuming the current hydrological regime in the Old Shannon is maintained, then the current sedimentation dynamics will continue. The Mulkear catchment will continue to experience more frequent transport competent events than the Shannon, adding more sediment to the Lower Shannon than the Old Shannon can re-mobilise. While there are many possible scenarios for how the Old Shannon-Mulkear system could evolve under a long-term depositional condition, the most common feature is that river bed level and profile in this area will remain dynamic. Deposition at and below the confluence would likely continue to promote sedimentation around the island features and in the ponded reach of the Old Shannon upstream of the confluence.

Future effects of climate change on the hydrological regime of either river system raises the possibility of change to the prevailing sediment dynamics. Ireland is forecast to experience wetter winters in future (Steele-Dunne et al., 2008) and is displaying a long-term trend of more intense rain events (Ryan et al., 2022). This may influence the erosion and transportation dynamics in the Mulkear catchment during those most geomorphologically effective flows (Q10 and 50% AEP) and in turn, alter the sediment supply to the Old Shannon. It may also influence vegetation types across the catchment and therefore influence runoff dynamics. Future changes in land use practices are also possible, which could alter sediment supply by making the landscape more or less vulnerable to erosion. Any combination of external (i.e. climate-driven) and internal (i.e. related to the catchment) drivers in the future could affect the sediment dynamics at the Lower Shannon.

6 Recommendations

This hydromorphological study has revealed that under current conditions, coarse sediment delivery from the Mulkear River is considered to exceed the flushing capacity of the Old Shannon leading to sedimentation at, and below, the confluence.

Current sediment dynamics are likely to continue unless measures are taken to address:

- The excessive sediment supply entering the river system across the Mulkear catchment, **and**
- The current inability of the Mulkear catchment to develop a balanced sediment erosion-transport-deposition regime, linked to channel modifications that restrict important lateral connectivity and channel adjustment processes that are key to a healthy river system's sediment management.

Addressing these concerns requires a catchment-scale perspective to reduce the hydromorphological pressures acting on the Mulkear catchment, and to provide opportunities to allow naturalisation of the river system. Potential measures could include:

- Changes to channel geometry to create inset floodplain areas and reduce bankfull energy within the Mulkear River.
- Set back embankments to allow river space and slow flows and, associated transport energy within the Mulkear River.
- Where space allows, combine channel geometry changes with re-connection to floodplain and allow more regular flooding of targeted areas.
- The addition of in-channel features, such as log jams, to encourage deposition of sediment in the Mulkear River and its smaller feeder tributaries.
- Review of land-use practices i.e. forestry and farming to slow down catchment runoff and prevent soil erosion or silt run-off at source.
- Provide a more naturalised compensation flow regime for the Old Shannon which will flush some sediment and, provide a naturalised flow duration curve to encourage localised rearrangement of coarse sediment. There are some limitations to this, and these are discussed in more detail in the Sediment Transport Modelling Note.

Ultimately the objectives of any future measures should seek to **protect** land from erosion and sediment loss, **intercept** and improve infiltration, **store** surface water, and **slow** surface water as it travels downstream.

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8 Appendices

A.1 Background information for interpreting modelled velocities for sediment dynamics

Hjulström curve

The threshold for erosion, deposition and channel change can be roughly defined using measures of flow energy such as velocity, stream power or shear stress. The Hjulström curve⁵ is a useful tool for inferring sediment transport processes, in particular lateral erosion, within a channel given knowledge of the flow velocities. The Hjulström curve differentiates between processes of erosion, transportation, and deposition.

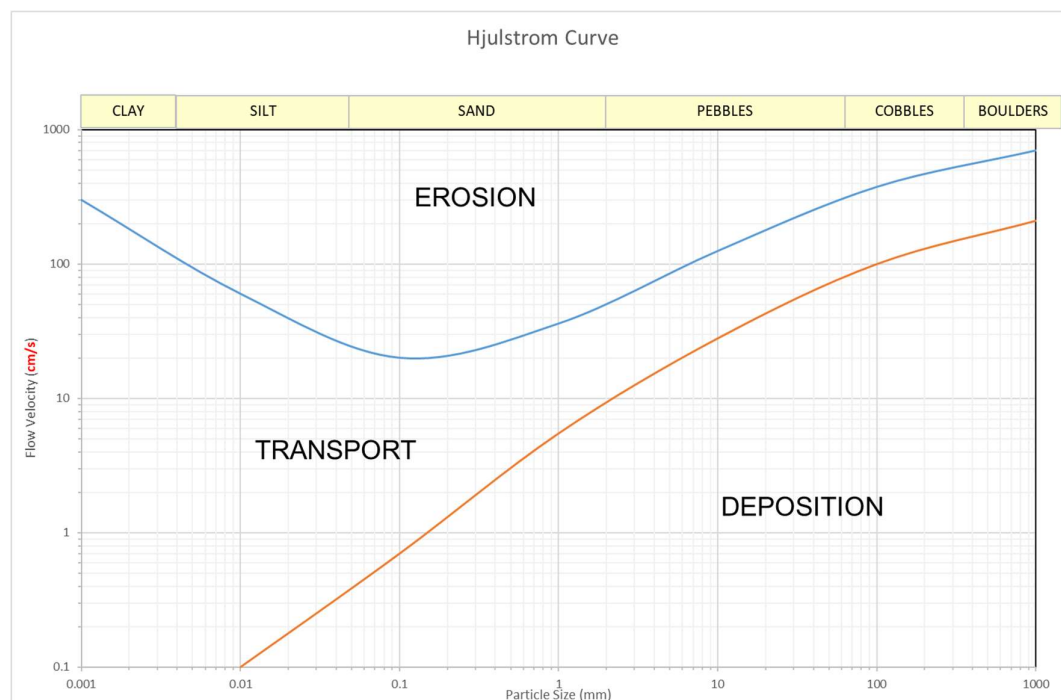


Figure 8-1 Hjulström curve diagram

Each process is determined by flow velocity and sediment cohesion and size. Higher flow velocities are required to erode cohesive silts and clays, in comparison to velocities required to erode loose sand and fine gravel. The Hjulström curve demonstrates that once sediment is in transport, less energy is required to maintain movement, with deposition occurring at lower velocities than entrainment. The difference between velocities required to erode material and velocities required to deposit material reduces dramatically for sediment that is coarser than sand (>2 mm).

⁵ Hjulstrom, F. (1935). Studies of the morphological activity of rivers as illustrated by the River Fyris, Bulletin. Geological Institute Upsalsa, 25, 221-527.

Shear Stress Analysis Calculations

Bed load movement and sediment transport is a function of shear stress. When the drag force of flowing water against a particle is greater than the gravitational force holding it in place it begins to move. The moment when the directive forces (shear forces) overcome restrictive forces (inertia, friction) is known as the moment of incipient motion and is the threshold of particle entrainment. The shear stress at this threshold is known as the critical shear stress.

The Telemac model used by JBAI to undertake the analysis provides an estimate of friction velocity allowing an estimate of the magnitude of bed shear stress to be computed. The estimate bed shear stress derived from the following expression:

(Eq. 1)

$$\tau = \rho U_s^2$$

Where τ is shear stress (N/m²), ρ is the density of water (kg/m³) and U_s is the friction velocity (m/s). The expression is derived from a combination of the basic definition of shear stress and the Manning's equation as shown in Box 1.

The calculated bed shear stress can be used to predict the mobile sediment size when used in conjunction with Shields (1936)⁶ entrainment function, derived from the following expression:

(Eq.2)

$$\tau_{0c} = \theta(\rho_s - \rho_w)gD$$

Where τ_{0c} is the critical shear stress (N/m²), θ is the Shields parameter (non-dimensional), ρ_s is the density of sediment (kg/m³), ρ_w is the density of water (kg/m³) and, g is acceleration due to gravity (m/s²) and D is a characteristic diameter of the sediment (mm).

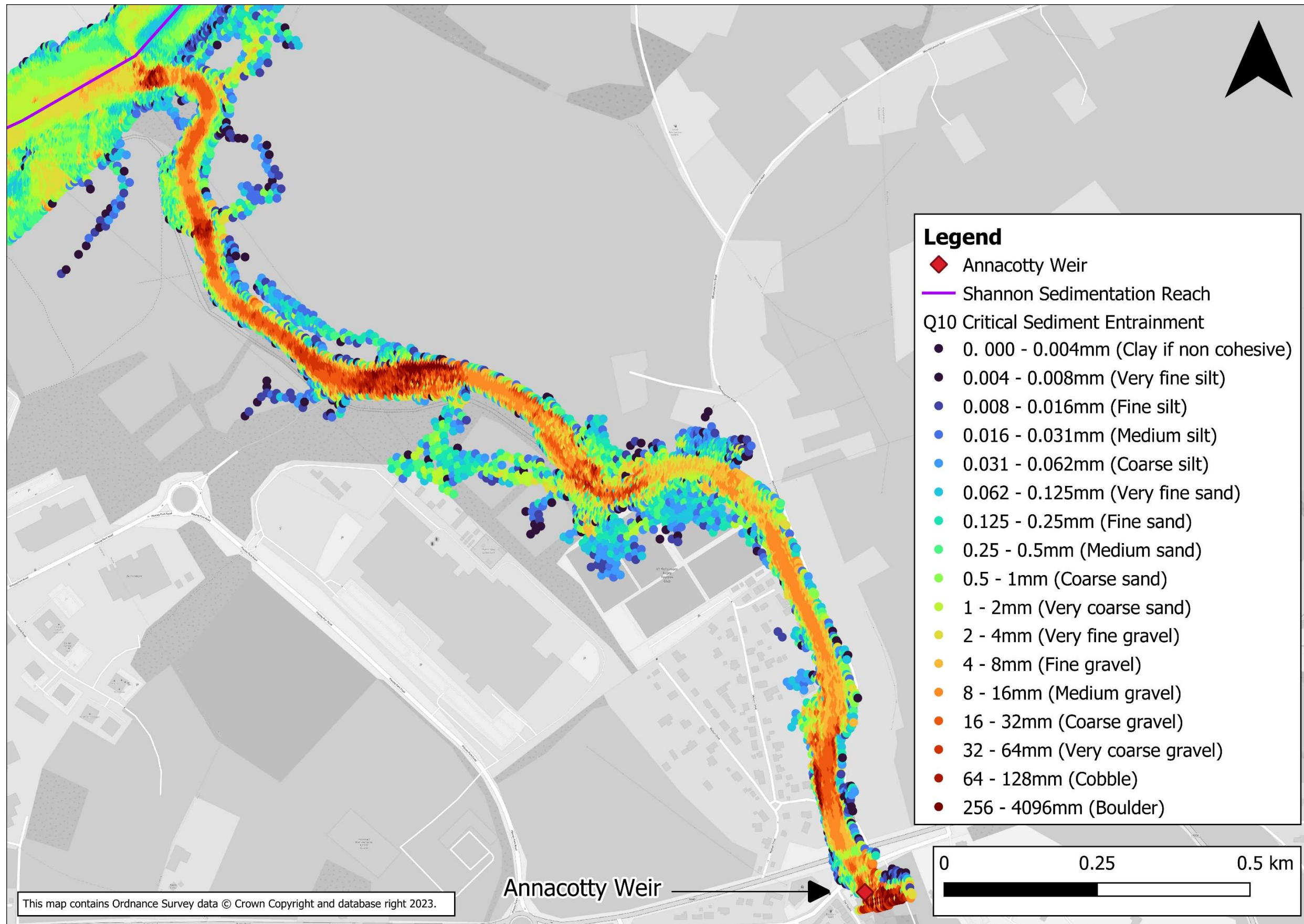
On hydraulically rough beds (the common condition in natural rivers), the Shields parameter rapidly attains a constant value (reported values range from 0.03 to 0.06), with 0.045 now accepted as a good approximation (Komar, 1988)⁷.

6 Shields, A. (1936), Anwendung der Aehnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung, Mitt. Preuss. Versuchsanst. Wasserbau Schiffbau, 26, 36 pp.

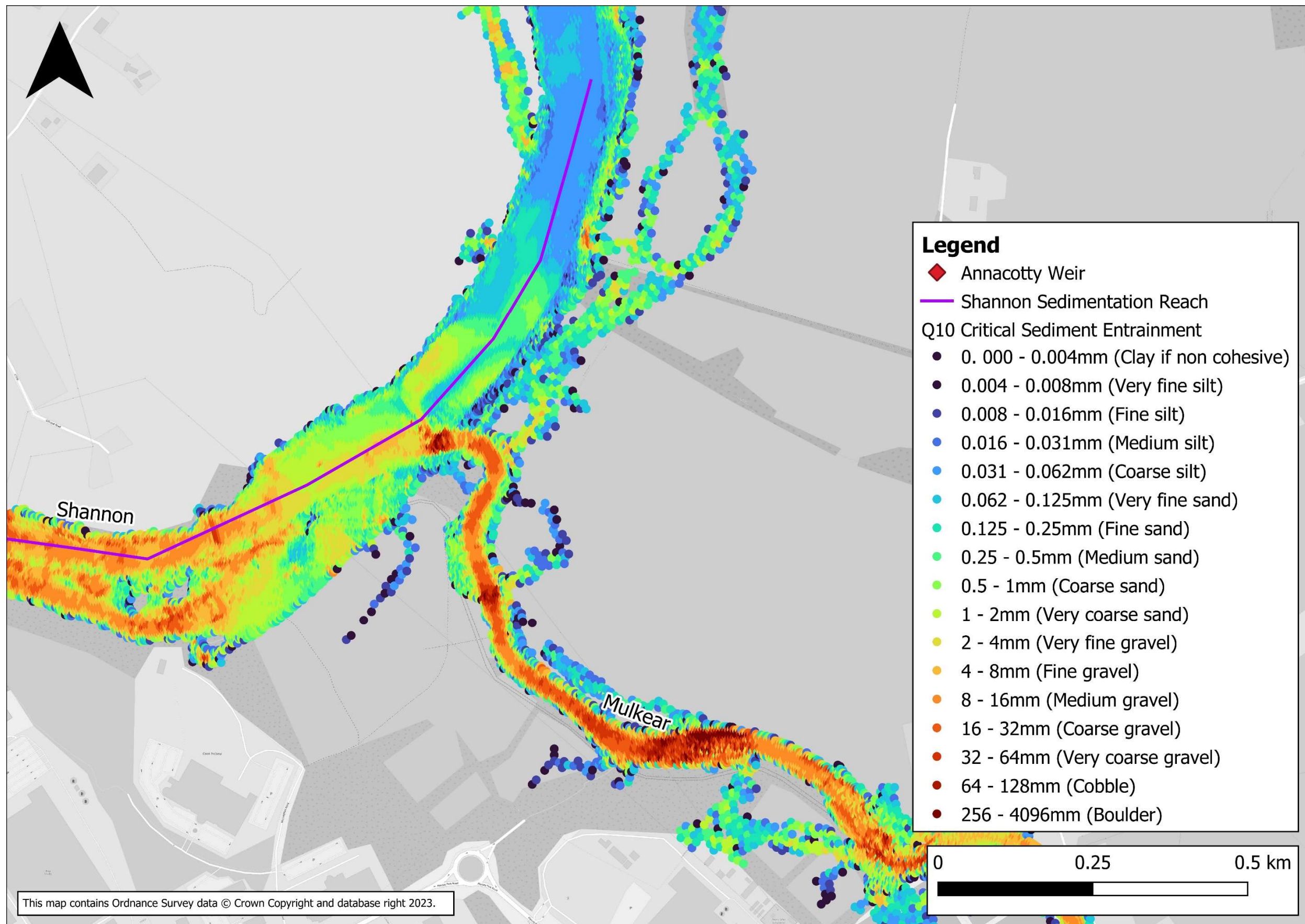
7 Komar, P.D. (1987), Selective entrainment by a current from a bed of mixed sizes: A reanalysis. Journal of Sedimentary Petrology, 57(2), 203-211.

A.2 Additional model outputs

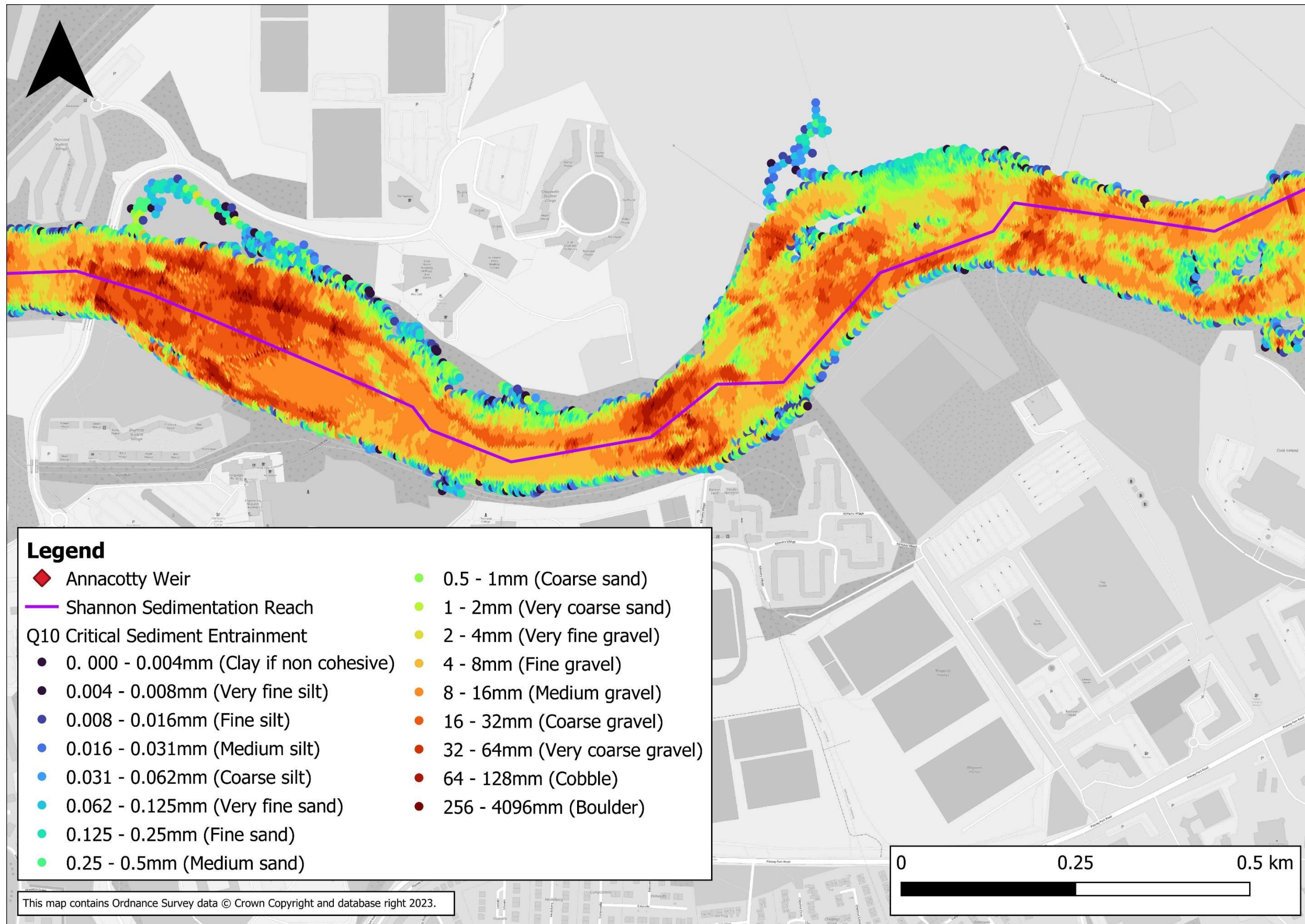
Q10 Lower Mulkear



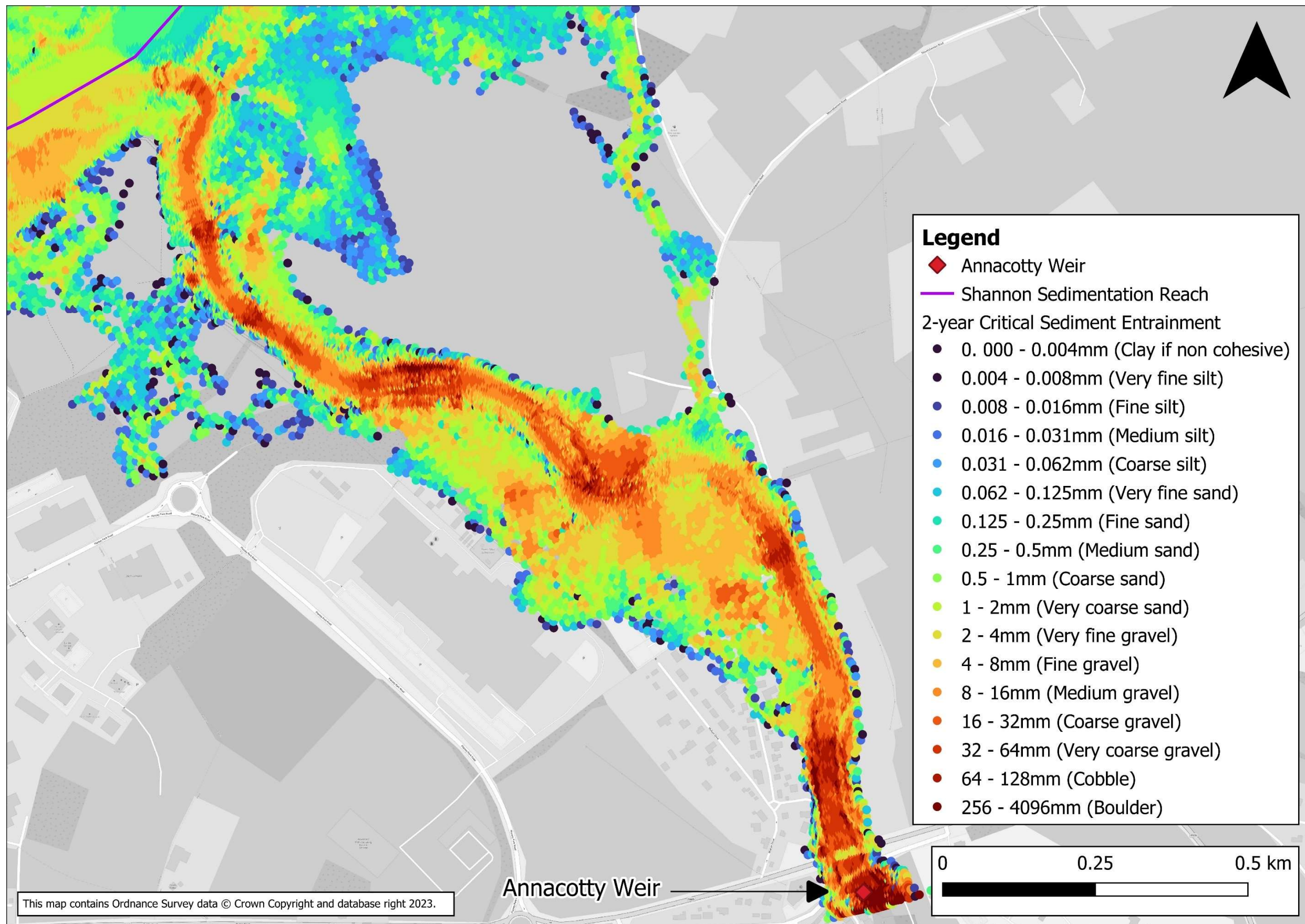
Q10 Mulkear Shannon confluence



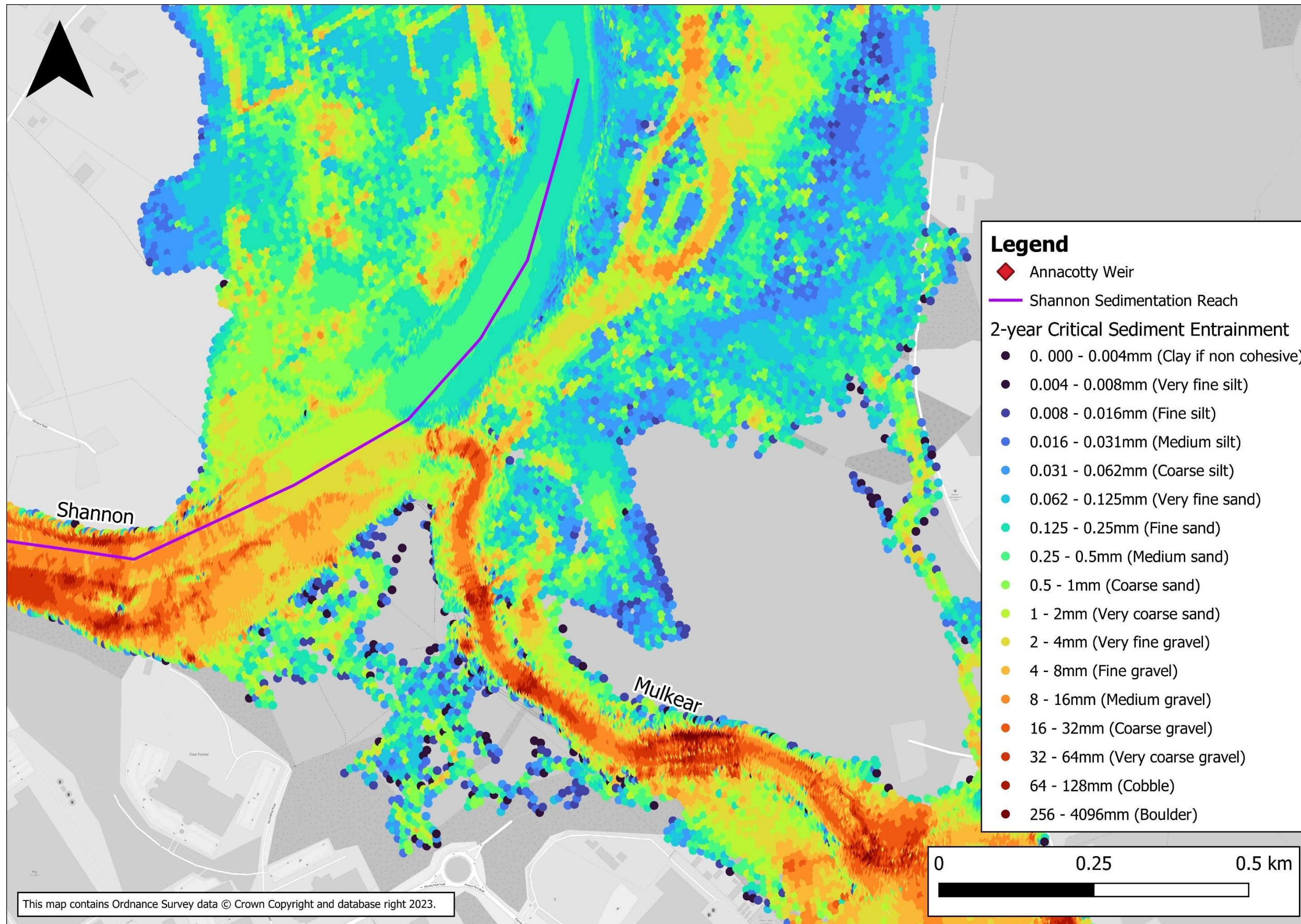
Q10 Shannon downstream of confluence



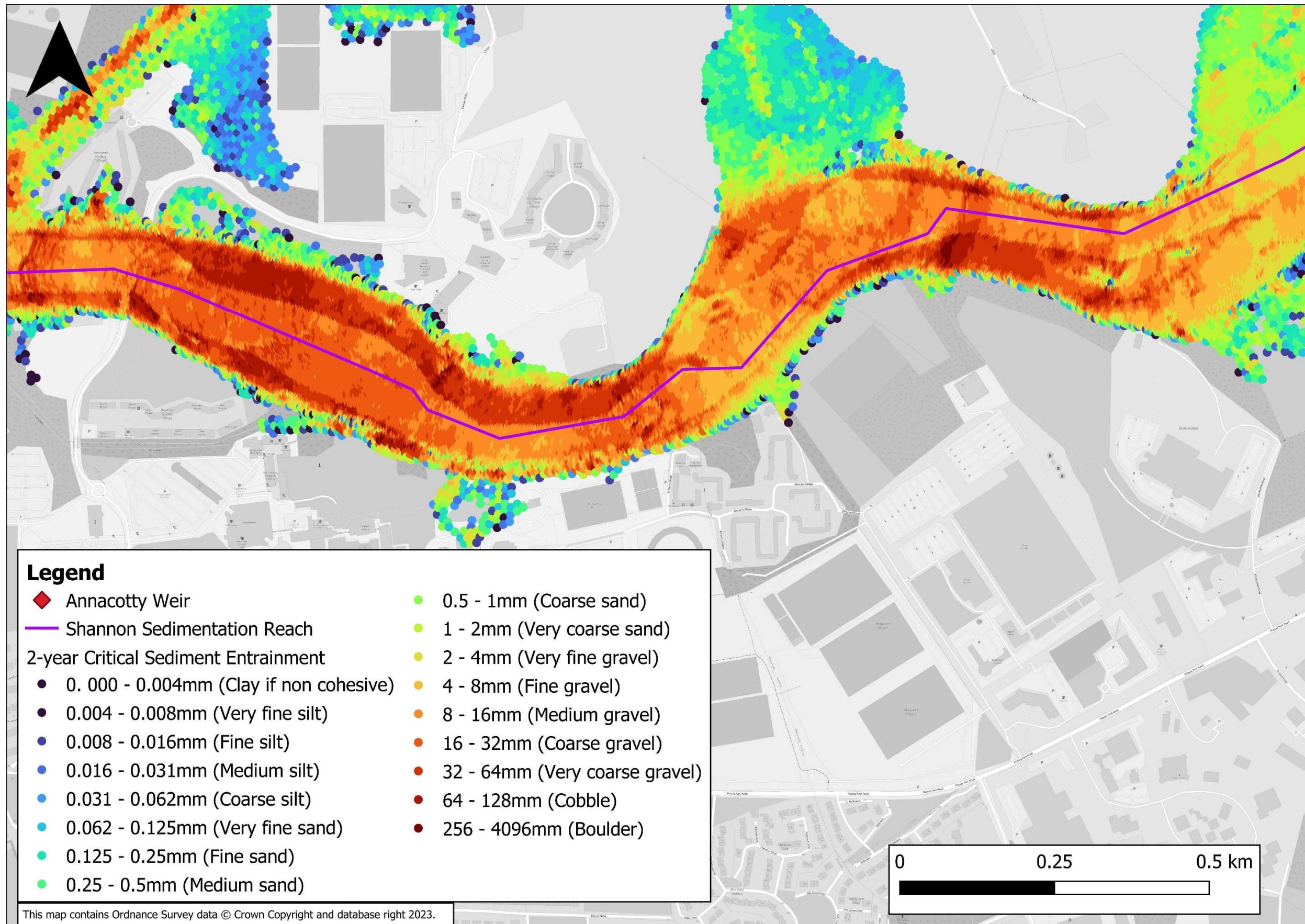
Q2 Lower Mulkear



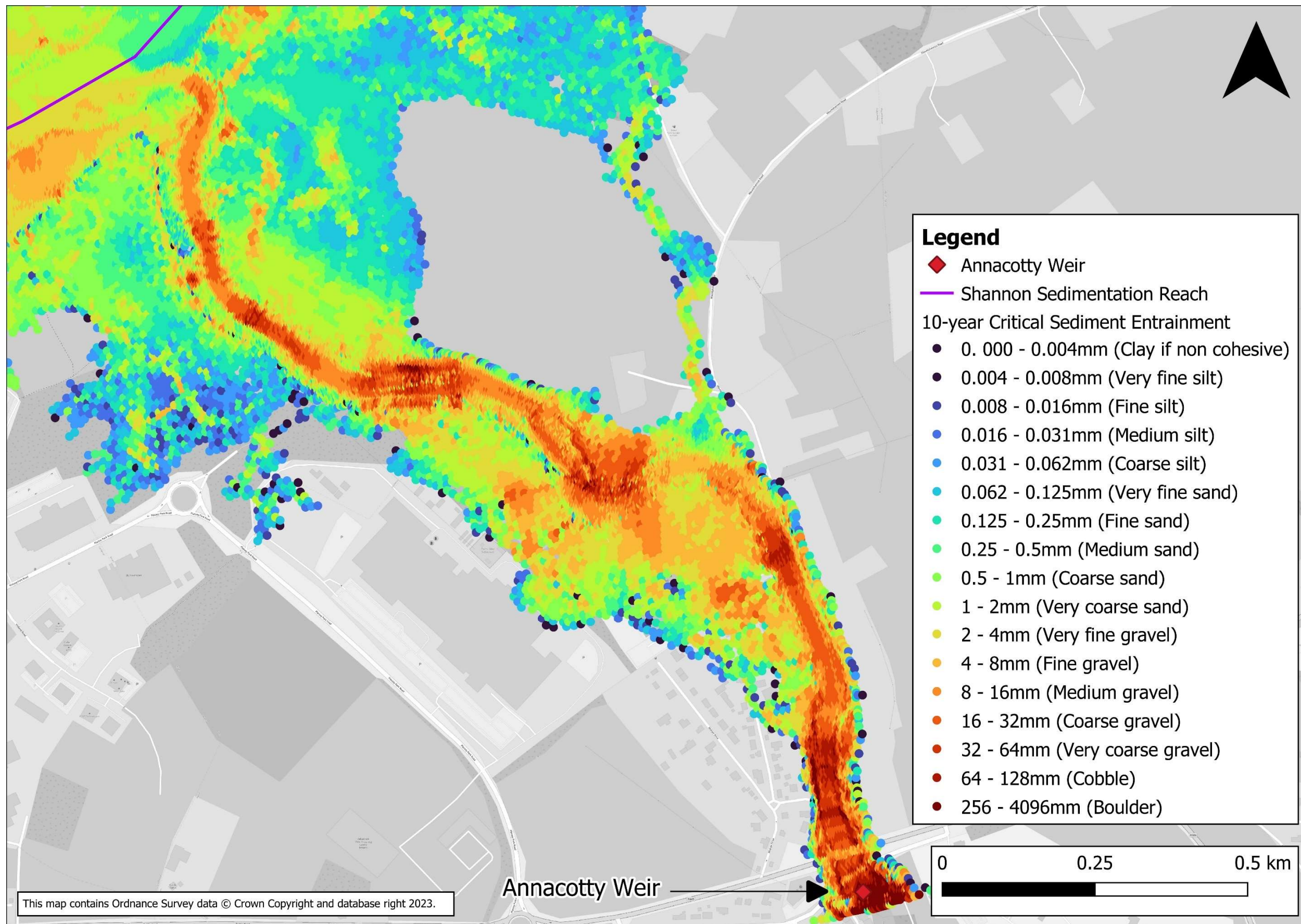
Q2 Mulkear Shannon confluence



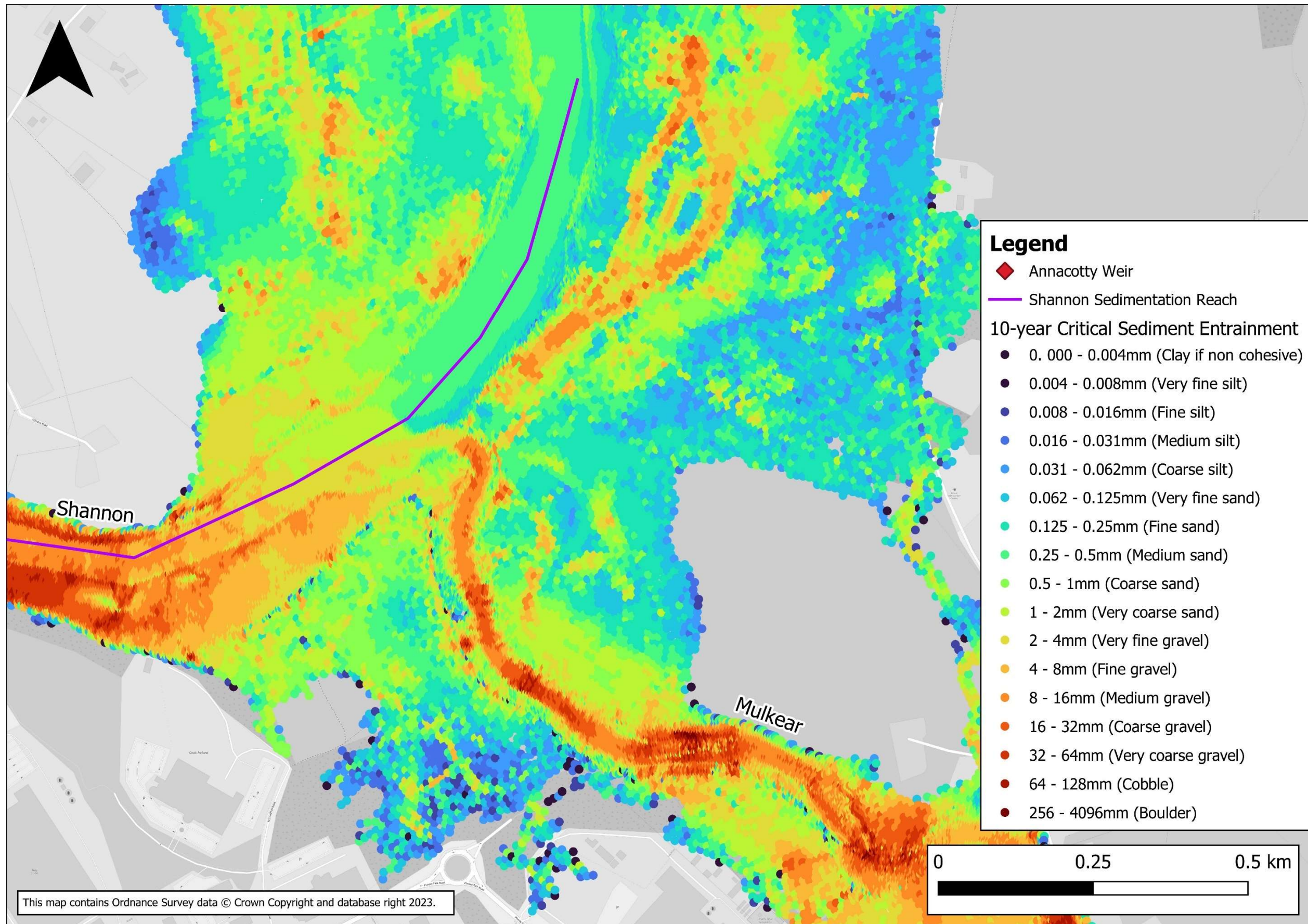
Q2 Shannon downstream of confluence



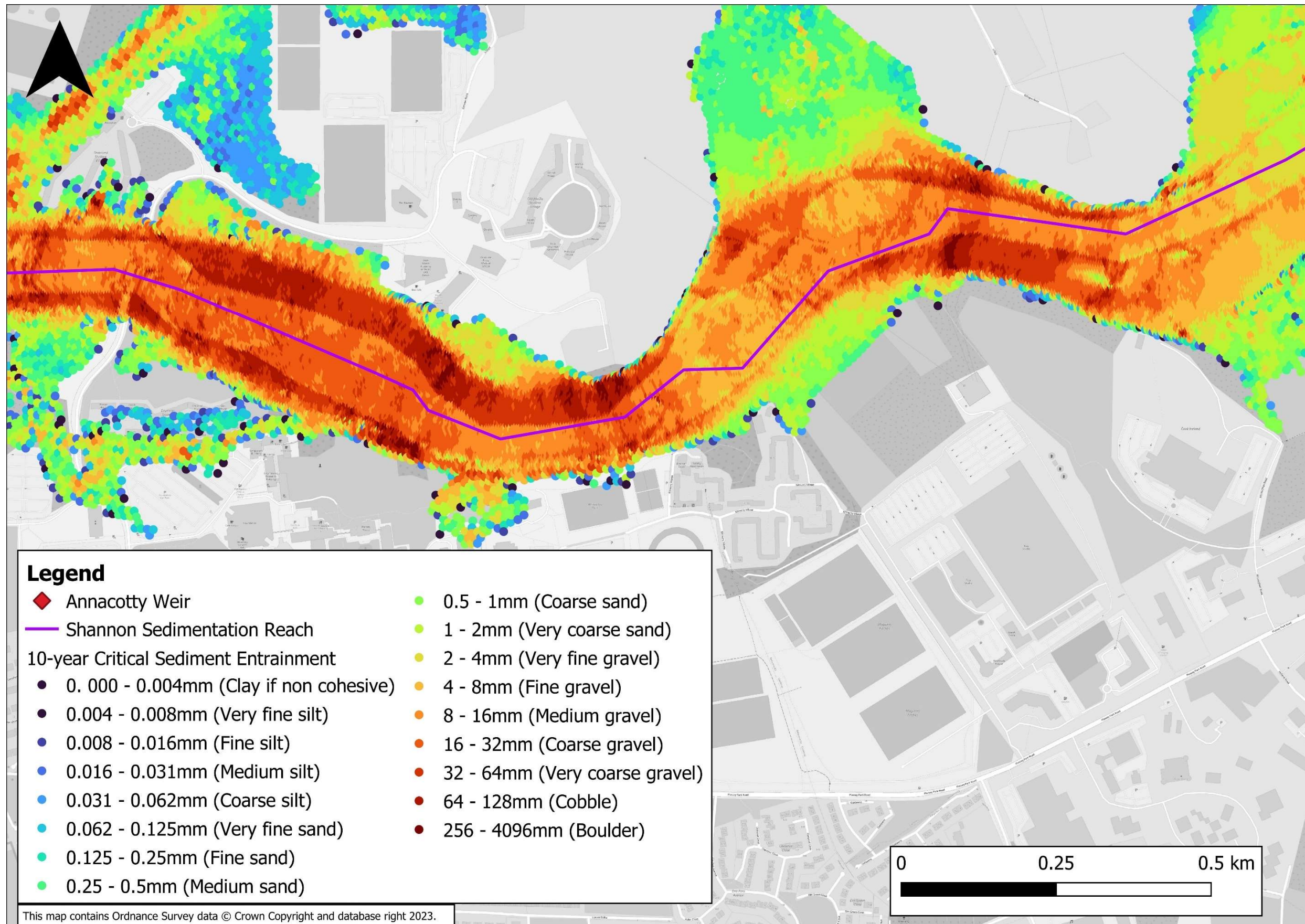
Q10 Lower Mulkear



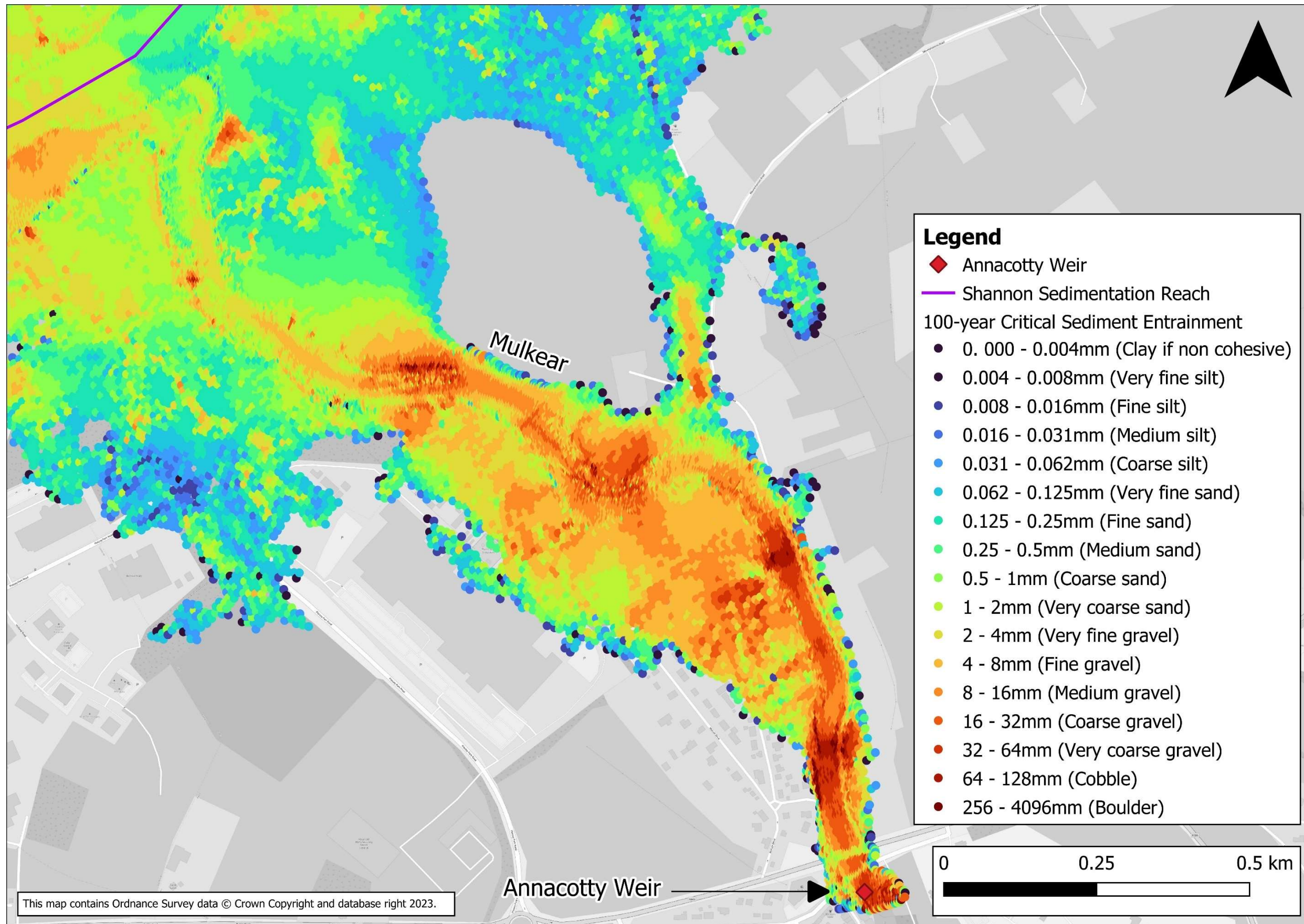
Q10 Mulkear Shannon confluence



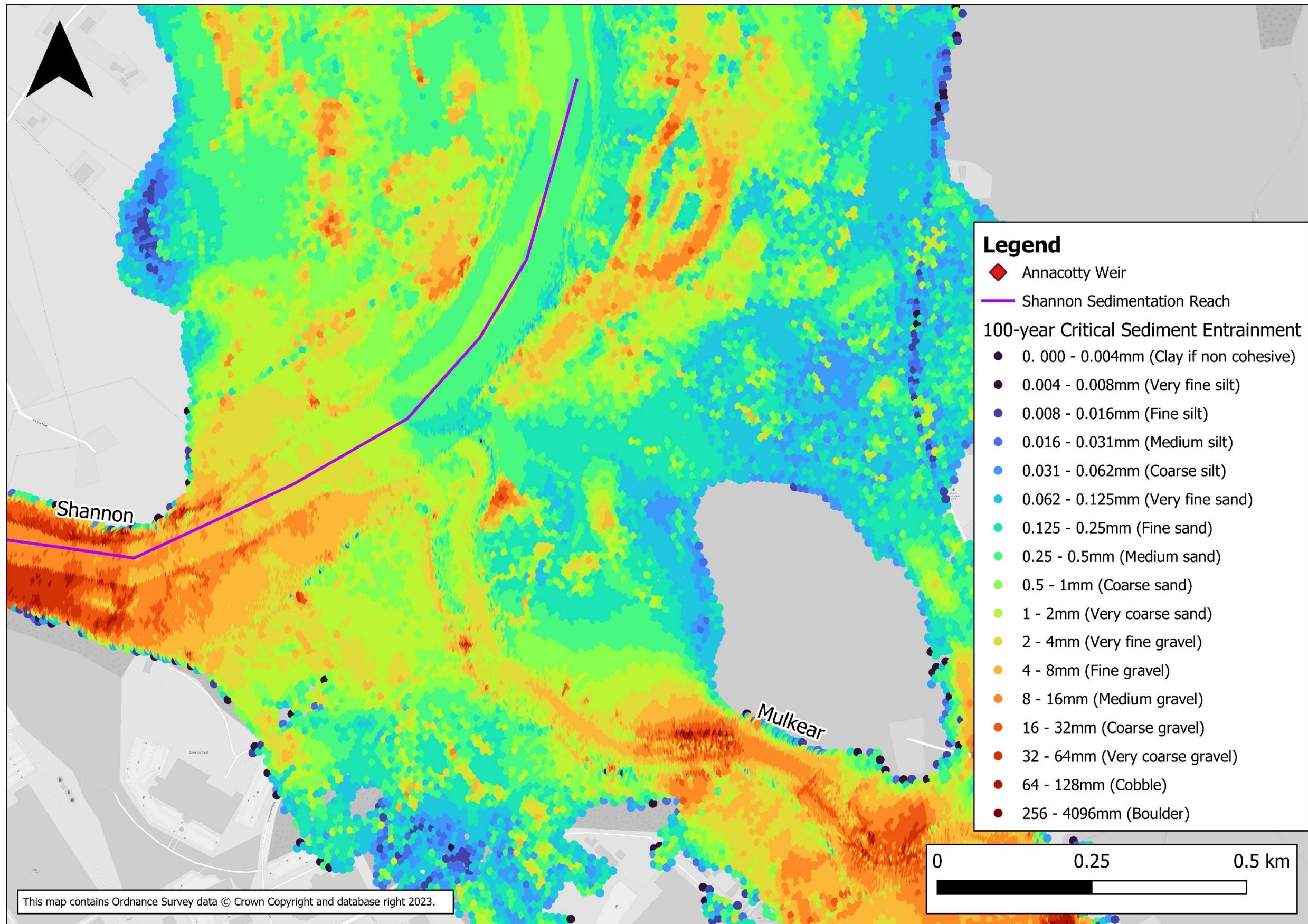
Q10 Shannon downstream of confluence



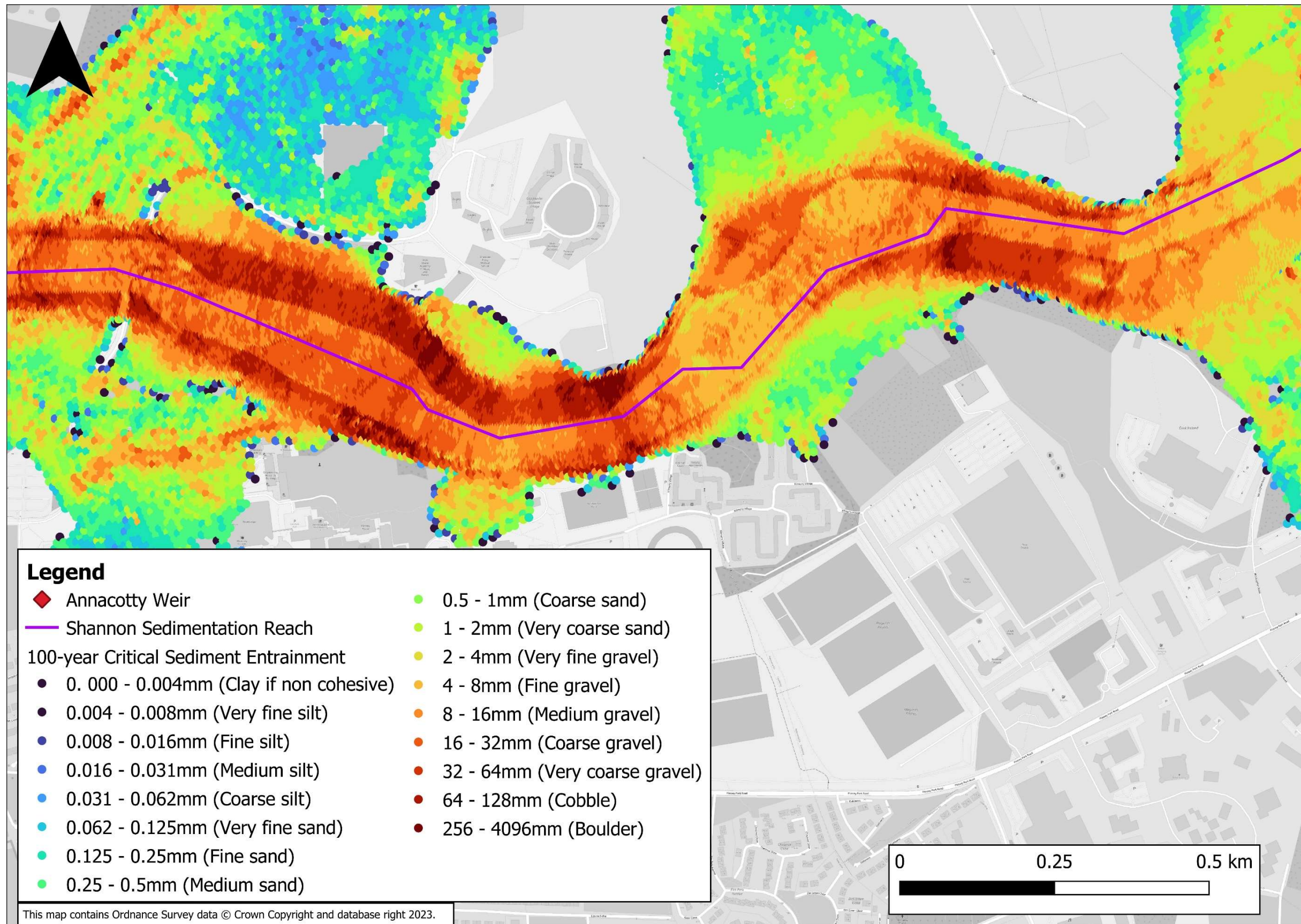
Q100 Lower Mulkear



Q100 Mulkear Shannon confluence



Q100 Shannon downstream of confluence



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