A1 in Northumberland: Morpeth to Ellingham

Scheme Number: TR010041

6.7 Environmental Statement – Appendix 10.4 Geomorphology Assessment – River Coquet

Part A

APFP Regulation 5(2)(a)

Planning Act 2008

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

June 2020

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

The A1 in Northumberland: Morpeth to Ellingham
Development Consent Order 20[xx]

Environmental Statement - Appendix

Regulation Reference:	APFP Regulation 5(2)(a)
Planning Inspectorate Scheme Reference	TR010041
Application Document Reference	TR010041/APP/6.7
Author:	A1 in Northumberland: Morpeth to Ellingham Project Team, Highways England

Version	**Date**	**Status of Version**
Rev 0	June 2020	Application Issue

CONTENTS

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

The River Coquet within the study reach is characterised by a bedrock channel with boulder and cobble deposits. At the location of the existing crossing and the new River Coquet bridge, the channel is characterised by a domed bedrock outcrop in the centre of the channel and a depositional area, where boulders, ranging from small to very large, and cobbles have accumulated. The cobbles and boulders are frequently moss covered; this, coupled with the presence of vegetation on this mid-channel bar feature, indicates that these deposits are stable.

The results of the particle size analysis confirmed the dominance of bedrock through the Study Area. Within the Riffle-bar Reach, which is the proposed zone for construction activities, bedrock was recorded spanning the entire channel. Coarse substrates were present throughout this zone, with a D50 particle size falling into the very large boulder particle size class. This suggests that the construction and operational activities of Part A would not have an adverse impact on the erosion, deposition and sediment transport processes operating within the study reach.

The stream power results indicate a low energy system under Scenario A conditions. Under Scenario B flow events, the river falls into the medium energy category but still lacks the stream power for the onset of fluvial erosion processes. Only during the Scenario C flow test, which would be a high magnitude, low frequency event, did the stream power suggest that fluvial erosion could occur. During construction, the river may also have the power to transport boulders during extreme events.

These results were further supported by sediment transport analysis. These results concluded that the entrainment and transport of the sediment present within the Riffle-bar Reach is only likely to occur during extreme high magnitude, low frequency events. This concurs with scientific literature on sediment transport rates in the UK.

During construction, the key adverse impact relates to the release of fine sediment into the watercourse. Fine sediment entering the river would be transported, but would eventually be deposited, which could have adverse impacts on morphological forms within the river channel and resulting negative impacts on aquatic ecology. The River Coquet is an important habitat for Atlantic salmon, sea lamprey, brook lamprey and has some of the best examples of exposed riverine sediment for ground beetles in England. Thus, extensive silt management plans would be required and implemented as part of the **Outline Construction Environment Management Plan** (**Outline CEMP**) (**Application Document Reference: TR010041/APP/7.3**). Water quality testing is also recommended prior to, during and post-construction.

Vegetation clearance would not only contribute to the potential input of fine sediment, but also impact on the structure and composition of the riparian zone, increase flow velocities due to reduced roughness, and potentially make the banks and valley sides more prone to

erosion and instability issues. Thus, minimising the extent of vegetation clearance is recommended, along with prompt reinstatement with a suitable mix of species.

Backfill of earth creating made-ground should be a cohesive mix of a clay sandy loam, capped with coarse, angular and compacted very coarse gravel-sized material.

Assuming mitigation is implemented, Part A would not have an adverse impact upon the fluvial geomorphology of the River Coquet.

1 INTRODUCTION

1.1 BACKGROUND

1.1.1. A fluvial geomorphology assessment has been undertaken to assess the potential impacts of the proposed River Coquet bridge, which forms part of the A1 in Northumberland: Morpeth to Ellingham Scheme (the Scheme), Part A: Morpeth to Felton (Part A). Part A requires the construction of an open span bridge over the Coquet valley, with piers located on the valley sides aligned with the existing piers. Potential risks to the geomorphological functioning of the River Coquet were considered during the design stage to inform the preferred option for the River Coquet bridge. Consequently, the need for a temporary pier during the construction phase was eliminated; this reduces potential impacts on the fluvial dynamics and geomorphological processes operating within the Study Area.

1.2 AIMS AND OBJECTIVES

1.2.1. This geomorphological assessment presents the current baseline conditions of the River Coquet within the Study Area. The specific aim is to determine the potential impacts of Part A during both construction and operation upon the fluvial geomorphological processes operating within the Study Area.

1.2.2. The objectives of this geomorphological assessment are to:

a. Characterise the River Coquet in terms of its geomorphological character, channel morphology, fluvial processes and sediment regime.
b. Identify existing erosion, deposition and sediment transport processes operating within the Study Area.
c. Assess the risk of increasing the erosion risk and sediment transport during construction and operation.
d. Determine both the potential construction and operational impacts of Part A on the geomorphology of the river.
e. Develop appropriate mitigation measures to reduce or eliminate potential residual impacts.

1.2.3. The specific performance criteria for this assessment is that the construction and operation impacts of the proposed new River Coquet bridge do not cause significant alteration to the fluvial processes operating within the study reach, and have no adverse impact on either the sediment entrainment and transport capability of the watercourse or the erosion and depositional processes.

1.3 STUDY AREA

1.3.1. The Study Area comprises a 1.2 km reach of the River Coquet, near Felton, Northumberland, with the existing A1 river crossing located at approximately midpoint (refer to **Figure 1-1**). The reach falls between two weir features marking step-changes in bed level and combines two meander wavelengths. The reach was divided into two distinct reaches, roughly situated either side of the existing crossing (refer to **Figure 1-1**). The reach was further sub-divided for sediment sampling purposes into a Reference Reach for general characterisation and a Riffle-bar Reach to specifically target the zone of influence of the proposed new River Coquet bridge. The proposed design for the new River Coquet crossing is provided in **Figure 1-2**, which also shows the indicative water levels for the three flow scenarios tested.

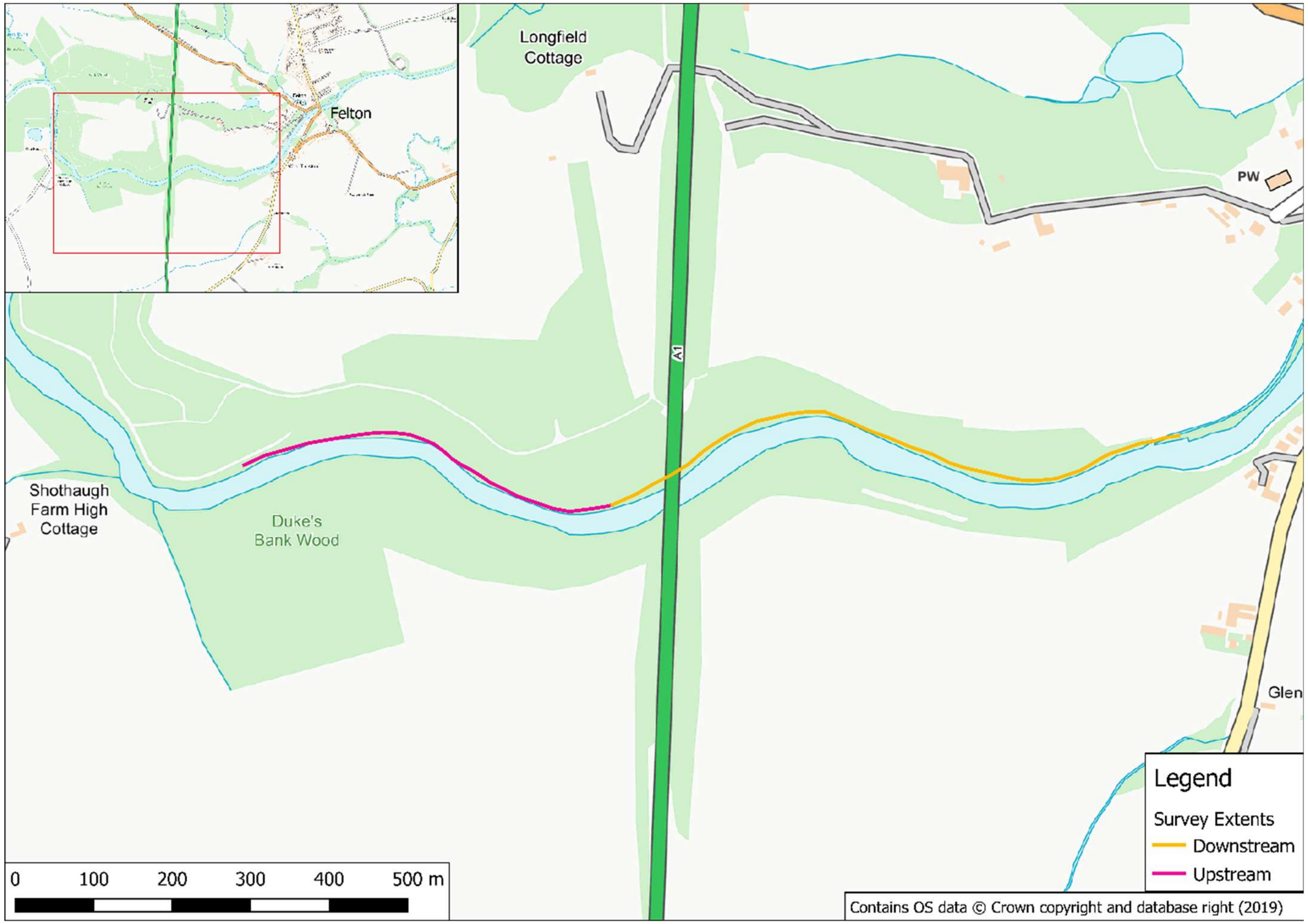

Figure 1-1 – Study Area for the geomorphological survey of the River Coquet, Northumberland showing both the upstream and downstream reaches

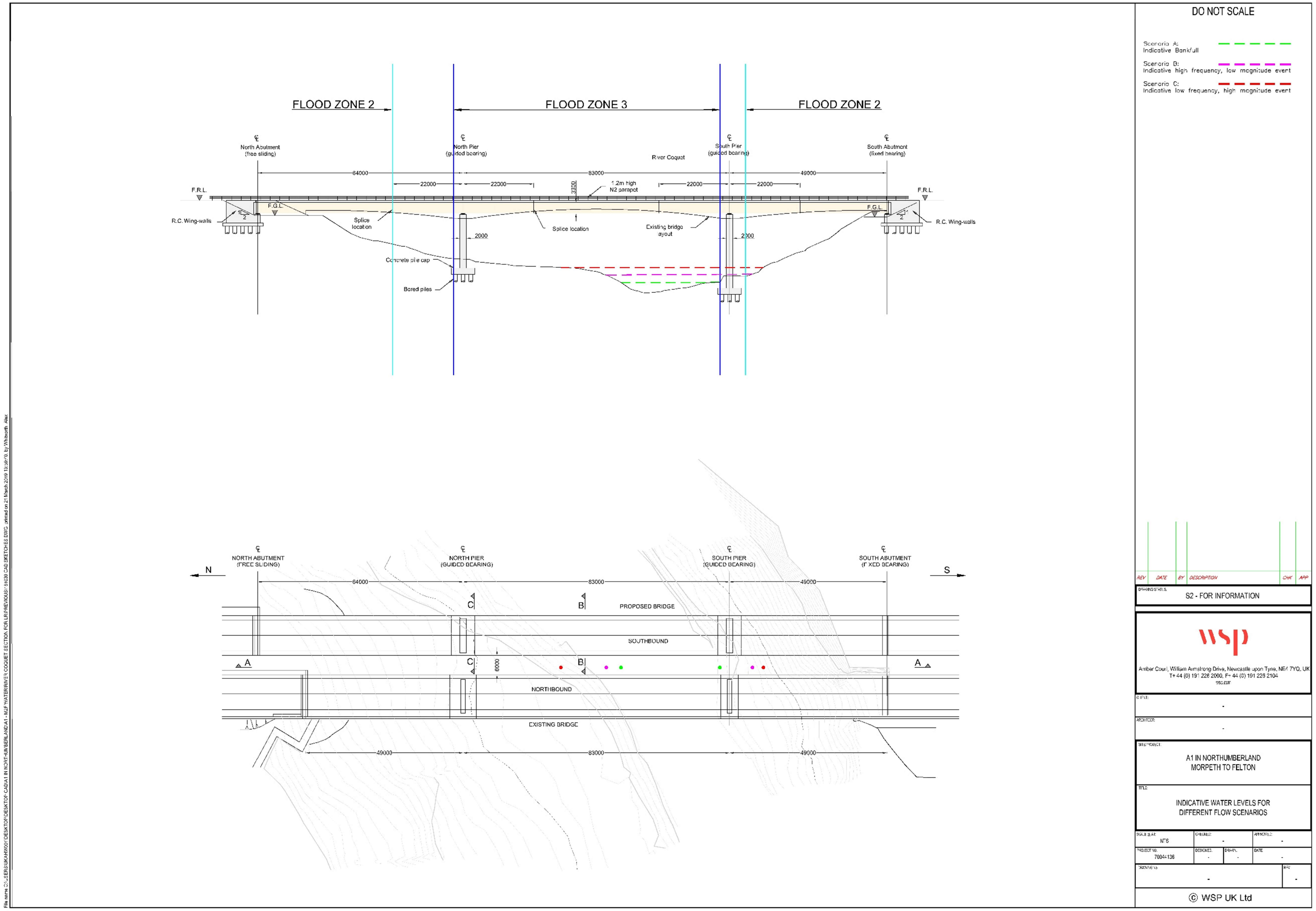

Figure 1-2 – Proposed new River Coquet bridge showing the indicative water levels for the three flow scenarios

2 METHODOLOGY

2.1 OVERVIEW

2.1.1. The assessment methodology comprises a combination of desk study, field survey and data analysis and interpretation. The desk study information is supported by field survey data from two separate geomorphological surveys, one to undertake a river reconnaissance survey and the second to undertake sediment sampling. Hydraulic modelling was scoped out of the assessment due to the proposed construction methodology for the new River Coquet bridge. Consequently, existing data was used to determine stream power and sediment transport capability of the river.

2.1.2. An Environmental Statement (ES) has been undertaken based upon the results. The methodology for the ES is presented in **Section 5**.

2.2 DESK STUDY

2.2.1. A range of data was collected and interpreted to characterise the River Coquet prior to field survey. Desk-based data and information enables initial characterisation and understanding of fluvial form and processes through a combination of factors including valley form, geology, hydrogeology, hydrology, topography, historical channel change and land use. Data sources used for the desk study comprise:

a. Ordnance Survey (OS) mapping.
b. Historical maps (Accessed February 2019) (**Ref. 10.4.1**).
c. Aerial imagery (Google Earth).
d. British Geological Survey (BGS) Geology of Britain Viewer (Accessed February 2019) (**Ref. 10.4.2**).
e. Hydrological and land use data (Centre for Ecology and Hydrology (CEH)) (Accessed February 2019) (**Ref. 10.4.3**).
f. Geotechnical report undertaken by Halcrow (dated 2008) (**Ref. 10.4.4**).
g. Geomorphological assessment undertaken by CH2MHill (dated 2014) (**Ref. 10.4.5**).
h. Northumbria River Basin Management Plan (2015) (**Ref. 10.4.6**).
i. Environment Agency's Catchment Data Explorer (Accessed February 2019) (**Ref. 10.4.7**).

2.3 FIELD SURVEY

RIVER RECONNAISSANCE SURVEY

2.3.1. A river reconnaissance survey was undertaken by an experienced fluvial geomorphologist on 5 December 2018. The survey covered a 1.2 km Study Area between two weir features, with the existing and new River Coquet bridge being located approximately centrally within the Study Area (refer to **Figure 1-1**). The Study Area covered two meander wavelengths, which enables general geomorphological characterisation of the river. The Study Area was divided into two distinct reaches of approximate equal length (refer to **Figure 1-1**). The standard river reconnaissance survey methodology was adopted as set out by Thorne (**Ref. 10.4.8**). Key features recorded during the survey comprise:

a. Valley form.
b. Land use.
c. Floodplain and riparian zone.
d. Channel geometry.
e. Bank material and structure.
f. Bed material and forms.
g. Erosion features (sediment sources).
h. Depositional forms (sediment sinks).
i. Artificial features and modifications.

2.3.2. The information recorded during the river reconnaissance survey was based on visual observations and measurements by visual estimation. A photographic record of the channel, banks and valley were taken to inform the assessment; these are presented in **Annex A: Photographic Record – River Coquet**.

SEDIMENT SAMPLING

2.3.3. A site visit was undertaken on 20 February 2019 to undertake sediment sampling within the Study Area from approximately 200 m upstream of the existing A1 river crossing to 300 m downstream of the existing crossing. The standard Wolman pebble count method was adopted as set out by Wolman (**Ref. 10.4.9**) using the Wentworth particle size scale. Two separate sediment samples were collected: 1) a Reference Reach pebble count; and 2) a Riffle-bar Reach pebble count, including a largest particle on bar count.

2.3.4. For the Reference Reach sampling, a series of ten transects were sampled; four upstream of the existing bridge crossing, one at the location of the existing bridge, and five downstream. Transect 1 was located at the downstream extent, and Transect 10 at the upstream extent of the Reference Reach. These transects roughly correspond with one meander wavelength for characterising sediment within the reach. The locations of these transects is illustrated in **Annex B: Wolman Pebble Count Data**.

2.3.5. For the Riffle-bar Reach count, a series of zig-zag transects across the riffle-bar feature were recorded; these extend approximately 100 m upstream and 125 m downstream of the existing bridge. Transect 1 was recorded at the upstream extent of the reach and Transect 10 at the downstream extent of the riffle-bar feature. The locations of these transects is illustrated in **Annex B: Wolman Pebble Count Data**.

2.3.6. A minimum of ten sediment samples are recorded at each transect, with at least 100 samples required for analysis. Data was plotted by size class (log2 scale) and frequency to determine the particle size distribution. The following characteristics are calculated for both the Reference Reach and the Riffle-bar Reach:

a. D16 – the particle size that 16 % of the samples are equal to or smaller than.
b. D50 – the particle size that 50 % of the samples are equal to or smaller than.

c. D84 – the particle size that 84 % of the samples are equal to or smaller than.
d. Largest particle (Dmax).

2.4 GEOMORPHOLOGICAL DYNAMICS ASSESSMENT

2.4.1. A geomorphological dynamics assessment was undertaken to determine potential impacts of Part A on the baseline geomorphological processes operating within the River Coquet. The assessment involved analysis of stream power and the sediment transport capability of the river, as described below. Sensitivity testing was undertaken around the cross-section data to confirm the bankfull and out-of-bank cross-sectional areas based on a combination of topographical survey data, site observations and photographical information. Three flow scenarios were tested:

a. Scenario A – which relates to approximate bankfull flow conditions.
b. Scenario B – which considers a flood event that would inundate the proposed construction zone.
c. Scenario C – which represents an estimated extreme high magnitude, low frequency flood event.

2.4.2. Whilst bankfull is difficult to determine in v-shaped valleys, geomorphologists frequently use indicators, such as trashlines or where terrestrial vegetation begins to dominate. Thus, bankfull was estimated based upon field observations of where terrestrial vegetation dominates, combined with evidence of localised undercutting of the banks due to fluvial processes.

2.4.3. The Manning's n values (**Ref. 10.4.10**) selected to represent roughness were derived based on Option 2b to represent the presence of cobbles and boulders within the channel. For the bankfull roughness, a Manning's n value of 0.050 was selected. For the baseline Scenarios B and C, 0.070 was applied and 0.050 to represent vegetation removal during the construction phase.

2.4.4. Hydraulic modelling was scoped out due to the proposed design and construction methodology for the new River Coquet bridge. Therefore, existing data and information, along with cross-section data taken at the location of the existing bridge crossing, was used to inform the geomorphological dynamics assessment.

STREAM POWER

2.4.5. Stream power is a measure of the rate of energy that is dissipated, per river bankfull width, against the bed and banks of the channel and describes the energy required to transport sediments. Stream power (Ω) is determined by:

$$\Omega\ (Wm^{-1}) = pgQs$$

Where Ω = stream power (Wm^{-1}), Q = stream discharge in m^3s^{-1}, p = the specific weight of water (1000 kg/m^3), g = acceleration due to gravity (9.81 m/s^2), and s = slope.

2.4.6. Unit stream power (ω), expressed as $Wm^{-2,}$ is a widely used dimensionless index and is described as:

$$\omega = \frac{pgQs}{b}$$

Where b = channel width.

SEDIMENT TRANSPORT ASSESSMENT

2.4.7. The initial sediment transport assessment was undertaken by comparing velocity data with empirical sediment transport data derived from Hjulström (**Ref. 10.4.11**), illustrated in **Figure 2-1**. Using this chart, the likelihood of erosion, sediment transport and deposition within the channel may be implied.

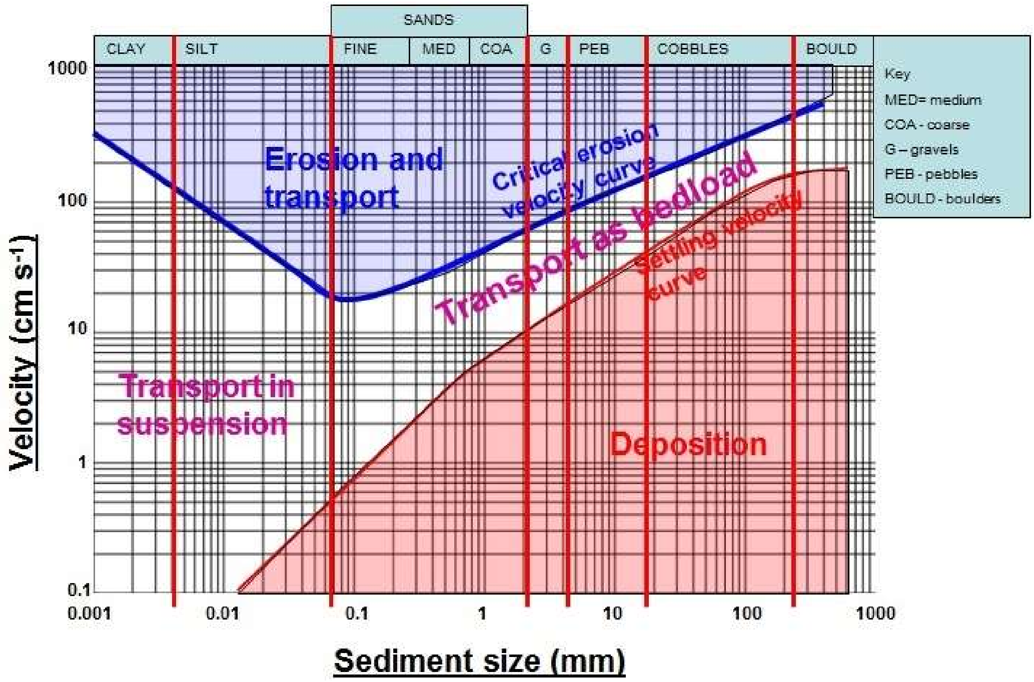

Figure 2-1 - Plot Showing the Empirical Relationship between Flow Velocity with Erosion, Sediment Transport and Deposition

2.4.8. Sediment transport was estimated using the Schoklitsch formula (**Ref. 10.4.12**), revised by Bathurst (**Ref. 10.4.13**) and described in Knighton (**Ref. 10.4.14**). This Schoklitsch-Bathurst equation, hereafter referred to as the 'sediment transport equation', provides a critical water discharge per unit width for a given particle size using slope and the acceleration due to gravity. It is described as:

$$qc = 0.15g\ 0.5\ D50\ 1.5\ S^{-1.12}$$

Where qc is the critical water discharge per unit width for the D50 particle size (the size of particle (intermediate axis) for which 50 % of all particles are finer), S is slope and g is acceleration due to gravity. It does not account for roughness but gives an indication of varying discharge rates on sediment mobilisation. Using this equation, the critical discharge for a given particle size can be derived and compared to the discharge data for the watercourse.

2.4.9. The ability of the river to entrain sediment and the onset of transport is described by shear stress, which is defined as:

$$\tau o = \gamma w R S$$

Where, τo = average bed shear stress (kPa), γw = unit weight of water (9.807 kN/m^3), R = hydraulic radius (m) and S = channel slope (m/m).

2.4.10. A dimensionless form of shear stress defined by Shields (in Sear et al., 2010 (**Ref. 10.4.15**), predicts the onset of bed motion and follows the equation:

$$\theta = \tau o / \Upsilon w (Ss - 1) D50$$

Where θ = dimensionless shear stress or Shields parameter, Ss = specific gravity of sediment (2.65) and D50 = median size of bed sediment (m).

3 BASELINE CONDITIONS

3.1 CATCHMENT OVERVIEW

3.1.1. The River Coquet rises at Coquet Head within the Cheviot Hills, Northumberland, at an approximate elevation of 440 m AOD and flows into the North Sea at Amble. The catchment is characterised by a steep, deep valley with slopes in the magnitude of 1v: 1.5h to 1v: 2h . The steep slopes are heavily vegetated; on the northern face, the vegetation is dominated by managed coniferous and deciduous woodland; and the southern face is dominated by ancient woodland (Dukes Bank Wood). The River Coquet and Dukes Bank Wood are designated as Sites of Special Scientific Interest (SSSI).

3.1.2. Land use within the catchment is predominantly upland vegetation and agriculture. There are no major urban centres within the catchment, with small rural communities, namely Harbottle, Alwinton and Netherton in the upper catchment and Rothbury, Felton and Warkworth in the lower catchment. Urban land use occupies less than 1 % of the catchment (**Ref. 10.4.3).** The catchment area is 65.6 km^2 with a river length of 31.2 km. Landcover within the catchment is summarised in **Table 3-1** as taken from CEH (**Ref. 10.4.3**).

Table 3-1 - Land Cover of the Coquet Catchment Recorded at Gauging Stations

Parameter	Rothbury Gauging Station (Upstream) (% cover)	Morwick Gauging Station (Downstream) (% cover)
Woodland	16.59	16.0
Arable/horticultural	10.38	17.88
Grassland	56.17	52.96
Mountain/heath/bog	16.48	12.56
Urban extent	0.65	0.84

3.2 WATER FRAMEWORK DIRECTIVE

3.2.1. The River Coquet lies within the Northumbria River Basin District (RBD); the Management Catchment is Northumberland Rivers, and the Operational Catchment is the Coquet Lower. The study reach forms part of the 'Coquet from Forest Burn to Tidal Limit' Water Framework Directive (WFD) water body (GB103022076693). The water body is not designated as either artificial or heavily modified and is currently achieving Good status. The hydromorphological status and hydrological regime currently Supports Good. A summary of the WFD classification is provided in **Table 3-2** as taken from the Environment Agency's Catchment Data Explorer (**Ref. 10.4.7**).

3.2.2. The River Coquet is divided into two operational catchments; the Coquet Upper and the Coquet Lower. The upper catchment covers an area from the Cheviot Hills to the village of Sharperton. Key tributaries include the River Alwin, the Wreighburn and Barrow Burn. Land-use is dominated by moorland, woodland, acid grassland, arable land, heathland, blanket bog and improved grassland. Designated Areas in this catchment include Harbottle Moors Special Area of Conservation and Northumberland National Park.

3.2.3. The lower operational catchment extends from Sharperton to the North Sea at Amble. Key small tributaries of the River Coquet include Tod Burn, Thirston Burn and the Forest Burn. Flooding is an issue within the lower catchment area as documented by the Environment Agency (**Ref. 10.4.16**). Designated areas within this catchment include the Northumberland National Park, Northumberland Coast Area of Outstanding Natural Beauty, Simonside Hills Special Area of Conservation and Northumberland Coast Special Protection Area.

Table 3-2 - WFD Classification Data for the Coquet from Forest Burn to Tidal Limit Water Body

WFD Parameter	Classification Data
Water body name	Coquet from Forest Burn to Tidal Limit
Water body ID	GB103022076693
Water body type	River
Designation	Not A/HMWB*
Catchment area	65.6 km^2
Catchment length	31.2 km
Overall WFD classification (2016)	Good
Ecological status	Good
Physico-chemical status	Good
Chemical status	Good
Hydromorphological status	Supports Good
Hydromorphological regime	Supports Good

*A/HMWB means artificial or heavily modified water body

3.3 CATCHMENT GEOLOGY AND SOILS

3.3.1. In the upper catchment, low permeability bedrock dominates; in the lower reaches of the catchment, moderately permeable bedrock is more prevalent. Mixed permeable superficial deposits dominate in both the upper and lower catchment reaches. Where there is low bedrock permeability, the loss of water from the surface water body to groundwater and aquifers is limited. The permeability of superficial bedrock affects the flood hydrograph curve, which reflects the response of the river to rainfall. A low permeability of the superficial bedrock results in faster rising water level following rainfall in the catchment. A summary of the permeability properties of the catchment geology is summarised in **Table 3-3** as taken from CEH (**Ref. 10.4.3**).

Table 3-3 - Permeability Properties of the Catchment Geology within the Coquet Valley at Gauging Stations

Parameter	Rothbury Gauging Station (Upstream) (%)	Morwick Gauging Station (Downstream) (%)
Moderately permeable bedrock	25.13	52.09
Low permeability bedrock	44.13	26.4
High permeability superficial deposits	0.85	3.72
Low permeability superficial deposits	11.58	7.01
Mixed permeability superficial deposits	30.46	48.02

3.3.2. The soils of the study reach are dominated by Cambisols, which are described as freely draining, slightly acid, loamy soils indicated by BGS online mapping (**Ref. 10.4.2**). The soil texture along the valley slopes of the River Coquet is predominantly clay to sandy loam and is cohesive. The left bank is dominated by medium to light soils and the right bank by medium to heavy soils. The soil profiles immediately adjacent to the river banks are typically shallow soils over bedrock. Further up the valley sides, deep to intermediate soil profiles have formed.

SOLID GEOLOGY

3.3.3. The geology of the Coquet Valley is dominated by Stainmore formation: mudstone; siltstone; and sandstone with localised outcrops of limestone within the valley bottom within the Study Area. These limestone outcrops are both prominent along the valley sides and as exposed bedrock within the river channel. The 2008 Halcrow study (**Ref. 10.4.4**) detailed that limestone is reported to be slightly weathered, well cemented and moderately strong to strong.

3.3.4. The solid geology of the Coquet Valley forms part of the Millstone Grit Group, which is overlain on the higher ground to the north and south by superficial deposits comprising glacial sand and gravel. Sandstone is the typical sedimentary rock type associated with the Millstone Grit Group in the Study Area. The 2008 Halcrow study (**Ref. 10.4.4**) detailed that the sandstone within the study has east-west trending faults, located both to the north and south, with the strata within this block typically dipping to the east.

DRIFT GEOLOGY

3.3.5. The superficial geology upstream of the A1 river crossing is dominated by till (Devensian – diamicton) on the right bank and glaciofluvial deposits (sand and gravel) on the left bank. River terrace deposits, composed of silt, sand and gravel are also present on both banks as well as alluvium deposits of clay, silt, sand and gravel at the more upstream extent of the study reach.

3.3.6. Downstream of the A1 river crossing, the superficial deposits are dominated by glaciofluvial deposits (sand and gravel) on both banks. Localised pockets of alluvium (clay, silt, sand and gravel) occur on both banks at the more downstream extent of the study reach. These deposits are typically thin, ranging from approximately 3 m to the north of Felton to 0.6 m south of the River Coquet. Previous borehole data recorded in the 2008 Halcrow study (**Ref. 10.4.4**) reports firm to stiff and very stiff grey sandy silty clay with some fine to medium gravel, which indicates cohesive material.

3.4 HYDROLOGY

3.4.1. The low permeability geology and the presence of exposed bedrock contributes to the catchment having a flashy hydrological regime. The mean monthly flow velocity varies seasonally, with the lowest mean monthly flow velocity typically being in June and the highest during November as detailed by CEH (**Ref. 10.4.3**). This reflects more precipitation and the effects of snow melt and runoff volume through the catchment during the winter months, and reduced runoff during the drier summer months.

3.4.2. There are two gauging stations on the River Coquet in proximity to the Study Area; the Rothbury gauging station (station ID 22009), and the Morwick gauging station (ID 22001), located upstream and downstream of Part A respectively. Data recorded at these gauging stations is summarised in **Table 3-4** as taken from CEH (**Ref. 10.4.3**). The Rothbury gauging station is located at NGR NU067016 where daily gauged flow has been recorded since 1972 to the present day. Mean flow recorded is 5.86 m^3/s, with Q95 (Q95 is defined as the flow equalled or exceeded for 95 % of the flow record and is a low flow parameter) recorded as 0.87 m^3/s. At Morwick, which is located at NGR NU234044, daily gauged flow has been recorded since 1963. Here, mean flow is recorded as 8.68 m^3/s and the Q95 as 1.24 m^3/s.

Table 3-4 - Hydrology Data for the River Coquet Catchment Recorded at Gauging Stations

Parameter	Rothbury Gauging Station (Upstream)	Morwick Gauging Station (Downstream)
Catchment Area (km^2)	346	569.8
Station level (m AOD)	70.7	5.2
Mean flow (m^3/s)	5.86	8.68
95 % exceedance probability (Q95) (m^3/s)	0.87	1.24
Q70 (m^3/s)	1.90	2.66
Q50 (m^3/s)	3.43	4.74
Q10 (m^3/s)	12.10	18.90
Q5 (m^3/s)	17.60	29.20
Qmed (m^3/s)	133.50	152.44
Rainfall (mm)	905	850

3.4.3. Whilst the data above reflects the annual average picture, variation in flow during the winter months (December to March) and the summer period (June to September) is provided in **Table 3-5** as taken from CEH (**Ref. 10.4.3**). Here, Q95 flow typically exceeds 2 m^3/s at the Rothbury gauging station and 3 m^3/s at the Morwick gauging station during the winter period. In contrast, Q95 flows are equal to or less than 1 m^3/s during the summer period.

Table 3-5 - Hydrological Data for Average Winter and Summer Flows for the River Coquet Catchment Recorded at Gauging Stations

Parameter	Rothbury Gauging Station (Upstream)		Morwick Gauging Station (Downstream)	
Season	December - March	June - September	December - March	June - September
95 % exceedance probability (Q95) (m^3/s)	2	0.7	3	1
Q70 (m^3/s)	4.8	1.02	6	1.8

Parameter	Rothbury Gauging Station (Upstream)		Morwick Gauging Station (Downstream)	
Q50 (m^3/s)	6	1.6	8	2
Q10 (m^3/s)	15	5	30	7
Q5 (m^3/s)	20	7	40	11

3.5 ECOLOGY

3.5.1. The River Coquet forms part of the River Coquet and Coquet Valley Woodlands SSSI, designated for Atlantic salmon, brook lamprey and sea lamprey. Within the study reach, aquatic habits vary considerably upstream and downstream of the existing bridge. The upstream section is dominated by bedrock, and the downstream reach consists of bedrock, boulders and other coarse substrate, with shallower water and more diverse flow types.

3.5.2. The citation for the River Coquet and Coquet Valley Woodland SSSI states that the riverside shingle habitats support an important assemblage of ground beetles with several nationally scarce species. The Northumberland Biodiversity Action Plan for rivers and streams (**Ref. 10.4.15**) states that the River Coquet as the second-best river in England for exposed riverine sediment quality. For more information regarding the ecology of the River Coquet refer to **Chapter 9: Biodiversity, Volume 2** of this ES (**Application Document Reference: TR010041/APP/6.2**).

3.6 HISTORICAL CHANNEL CHANGE

3.6.1. The planform of the River Coquet within the Study Area has remained stable since early mapping records from 1866. The river within the Study Area is confined within a deep cut valley, bound by bedrock controls. The river is typical of deeply cut valleys in the north east of England following post-glacial adjustment following the Pleistocene glaciation with distinct terrace formations, as detailed by Macklin (**Ref. 10.4.18**). The historical map record reveals a decline in woodland cover on the valley sides and at the top of the valley in the post-World War II period. Legacy industrial activities within the catchment include mills, which were powered by the river.

3.7 CHANNEL MORPHOLOGY AND CHARACTERISTICS

3.7.1. The overall form of the catchment is controlled by the underlying geology and topography where bedrock outcrops, on both the banks and within the channel, exert a significant control on the river planform and cross-sectional profile. The dominance of bedrock in this setting suggests timescales for the rate of base-level adjustment over hundreds to thousands of years. The deep symmetrical valley, with a valley height of approximately 25 m on both banks, is likely to be legacy of the Pleistocene glaciation. Terrace formations are present, with three terrace sequences clearly visible on the left bank. It is likely that these terrace formations have formed through internal readjustment of river long-profiles since the last glaciation as detailed by Ferguson (**Ref. 10.4.19**). The river is characterised by a sinuous planform (sinuosity index 1.09); however, lateral adjustment of the channel is constrained due to the valley form and geology.

3.7.2. There is localised evidence of bank undercutting and the development of point bar features where the valley is less confined. Some parallel flow erosion was observed on both banks. However, the presence of bedrock and the formation of shallow cohesive soils, due to the mudstone and siltstone underlying geology, result in banks that are resistant to erosion. Overall, bank erosion risk was assessed as low or insignificant.

3.7.3. The average channel width in the Study Area is estimated at 20.8 m. The channel bankfull width typically varied between 18 m at pool locations and 27 m at riffle locations within the upstream study reach; and between 27 m wide at pool locations and 35 m wide at riffle locations within the downstream study reach. Channel gradient within the study reach is estimated at 0.002 (0.2 %).

3.7.4. Flow patterns were predominantly uniform within both reaches, with more rapid flow in the upstream reach and tranquil flow downstream of the A1 crossing. Flow types through the study reach are dominated by runs, glides and riffles. At the upstream limit of the study reach, a weir provides a grade control on the channel; a weir also marked the most downstream extent of the Study Area.

3.7.5. At the location of the existing bridge structure, the thalweg was observed to be located toward the left of the centre of the channel, where the main flow was focused along the left-hand bank. Here, bedrock spans the entire channel width. The right bank was reinforced for the existing bridge pier.

3.7.6. The channel bed composition was observed to be composed of primarily bedrock with poorly graded large boulders and cobbles present. Some degree of sediment sorting was observed during sediment sampling, with boulders, cobbles and very coarse gravels being dominant within the riffle sections, and medium to very coarse gravels within the pools and runs. The sediment sampling transect taken at the location of the existing bridge was all bedrock and bedrock dominated for the remainder of the Reference Reach upstream transects.

3.7.7. Sediment appeared to be supply-limited within the study reach. At the upstream extent of the study reach, a deposition zone was observed immediately downstream of the weir feature where the channel is wide and shallow. The reach was then observed to become a sediment transfer zone, with laminar flow and bedrock spanning the channel. Mid-reach, at the location of the existing bridge, the river width was noted to widen considerably. Here, the bedrock appeared to be domed in the centre of the channel. These factors combined reduce channel depth, increase friction and reduce the ability of the river to transport sediment. This middle section of the study reach was characterised as a deposition zone, where accumulations of cobbles and boulders, forming mid-channel bars, were observed. These accumulations of coarse substrates were moss-covered and the bar features were vegetated, indicating low mobility of these particle sizes and stability of the bar features. Entrainment and transport of these coarse particle size classes would possibly only occur rarely and during extreme events. Where the river narrows downstream of the existing bridge, the system reverts to a sediment transfer zone, where gravels were observed. At the downstream extent of the study reach, a weir feature marks the start of a deposition zone. Over-bank deposits of fine sand were observed along the entire study reach, suggesting recent out-of-bank flows.

3.7.8. The river through the study reach is predominantly free of modifications. Notable modifications are the piers for the existing A1 bridge and associated bank revetments on the right bank, and the presence of weirs along the watercourse.

3.8 GEOTECHNICAL

3.8.1. Slope instability, dating back to the end of the Pleistocene glaciation, has been reported to be active within the study reach, with slope failures reported in the Halcrow geotechnical report (**Ref. 10.4.4**). Geotechnical failures were observed throughout the Study Area with shallow slides and rotational slips present.

3.8.2. The slope adjacent to the north-east bridge abutment is reported to be affected by slope instability. Recent instability has been reported within the Made-ground, which was placed on top of the original ground surface and ancient landslide during the construction of the River Coquet bridge as detailed by Halcrow (**Ref. 10.4.4**). The composition of the Made-ground has been described as dark brown to brown slightly sandy slightly gravelly clay to clayey sandy gravel or clayey gravelly sand. The Made-ground has been assessed as being approximately 10 m thick as detailed by Halcrow (**Ref. 10.4.4**). The slope around the existing northern bridge abutment was reprofiled during the construction of the existing A1 bridge with an approximate gradient of 1v: 2h. Compacted limestone hardcore fill was used during the construction.

4 GEOMORPHOLOGICAL ASSESSMENT

4.1 INTRODUCTION

4.1.1. The spatial variation of flow velocities and depths within a short reach are determined by channel morphology as detailed by Petts and Bravard (**Ref. 10.4.20**). Thus, any construction and operation impacts that may affect the morphology of the channel, its physical form and shape, may result in local alteration to the flow velocities and water depths. This, in turn, may cause alteration to the baseline erosion, sediment transport and deposition processes operating within the reach.

4.1.2. Sediment entrainment and transport is linked with flow hydraulics where the critical velocity, or shear stress, exceeds the forces acting on the particle resisting erosion. Bedload transport is primarily a function of the transporting capacity of the flow; this is where particles roll, slide or saltate (hop) along the bed.

4.1.3. Large flood events have greater potential to erode and transport sediment and these have a low return frequency; small flood events, which have a high frequency, tend to be less effective in sediment transport as detailed by Gilvear and Bravard (**Ref. 10.4.21**). The flood discharge that is typically the most geomorphologically effective is referred to as the dominant discharge; these flows are also referred to as channel-forming events as detailed by Gilvear and Bravard (**Ref. 10.4.21**).

4.2 PARTICLE SIZE ANALYSIS

4.2.1. The potential for sediment transport within the Study Area is assessed by determining the particle size distribution within the Study Area, the use of empirical data and by undertaking a series of calculations, outlined in **Section 2**.

REFERENCE REACH PEBBLE COUNT

4.2.2. The particle size distribution within the Reference Reach suggest that there is a degree of sediment sorting according to bed morphology. Finer substrate, that is medium to coarse gravels, were located within the pool sections, and poorly graded cobbles and boulders within the riffle locations. The upstream extent of the Reference Reach was characterised bedrock. Mid-reach, at the location of the existing bridge, cobbles and boulders were recorded with bedrock spanning the channel. Downstream, beyond the riffle-bar feature, the sediment was characterised by coarse and very coarse gravels, with cobbles, boulders and bedrock also present. Bedrock was recorded at most transect locations. The particle size distribution and cumulative frequency for the Reference Reach is provided in **Figure 4-1**. The particle size data is provided in **Annex B**.

4.2.3. Between Transects 4 to 8, the bedrock was raised mid-channel with cobbles and boulders deposited forming a stable riffle-bar feature. Transect 7 was recorded at the location of the existing bridge, where bedrock was recorded at all sample points across the transect. At

Transect 9 and 10 (at the upstream extent of the Reference Reach), bedrock was dominant and the channel was deep.

4.2.4. Transect 2 (near to the downstream extent of the Reference Reach) was recorded at a pool location. Riffles were present at Transects 1, 5, 6 and 7; with runs present at the other transects recorded.

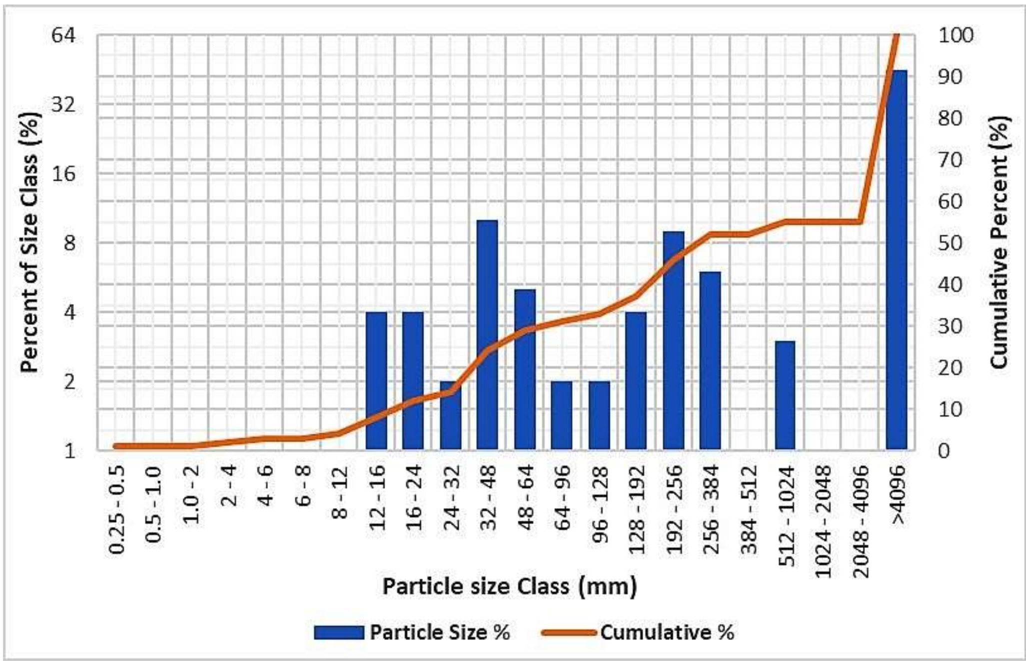

Figure 4-1 - Particle Size Distribution and Cumulative Percent for the River Coquet Reference Reach

4.2.5. Analysis of the particle size distribution reveals D50 to be within the boulder size range (refer to **Table 4-1**), indicating that 50 % of the particle sizes present were smaller than boulders. D84 falls into the bedrock category, and D16 is within the very coarse gravels size class. **Table 4-1** also provides the actual particle size for these percentiles. A bi-modal particle size distribution was observed, which is typical of riverine sediments as detailed by Ferguson (**Ref. 10.4.19**).

Table 4-1 - Particle Size Distribution Percentiles within the River Coquet Reference Reach

Particle Size Percentile	Particle Size Range (mm)	Particle Size (mm)	Particle Size Class
D16	32 - 48	35.4	Very coarse gravel
D50	256 - 384	328.0	Small boulder

Particle Size Percentile	Particle Size Range (mm)	Particle Size (mm)	Particle Size Class
D84	> 4096	> 4096	Bedrock

RIFFLE-BAR REACH

4.2.6. The Riffle-bar Reach, (shown in **Annex B**), represents the specific zone of interest for potential impacts of Part A on the sediment transport, erosion and deposition processes. Here, bedrock dominates along with the occurrence of large particle size classes, namely cobbles and boulders (refer to **Figure 4-2**).

4.2.7. Transects 1-5 were bedrock dominated, with Transect 1 being located at the head of the riffle-bar feature and Transect 5 located at the existing right-bank bridge pier. Gravels were recorded along the channel margins at Transects 6 and 7 on the left bank and right bank respectively. Bedrock was present in the banks in the downstream section of the study reach, thus indicating resistance to erosion.

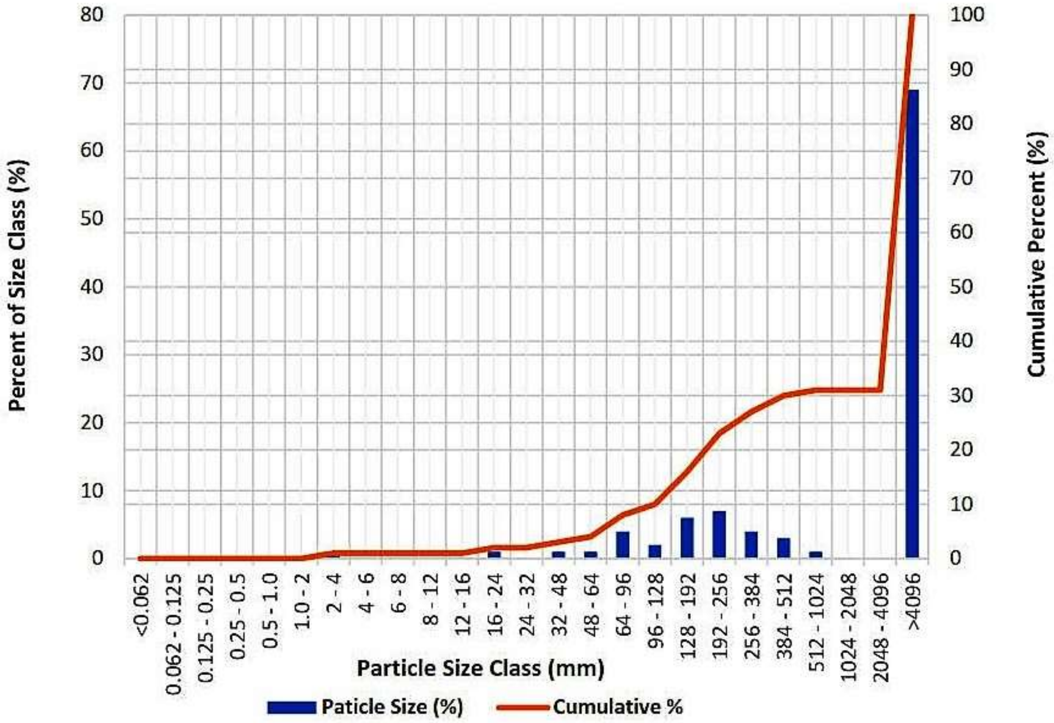

Figure 4-2 - Particle Size Distribution and Cumulative Percent for the River Coquet Riffle-bar Reach

4.2.8. Bedrock was dominant within the proposed construction zone and the D50 falls within the very large boulder size class. The lower percentile revealed the D16 to be 181 mm, which is in the large cobble size class. The largest particle on the depositional bar recorded was 840 mm (medium boulder).

4.2.9. Within the Riffle-bar Reach, cobbles and boulders were frequently moss-covered, indicating long periods of stability, suggesting mobilisation only during more extreme, low frequency events.

Table 4-2 - Particle Size Distribution Percentiles within the River Coquet Riffle-bar Reach

Particle Size Percentile	Particle Size Range (mm)	Particle Size Class
D16	128 - 192	Large cobbles
D50	2048 - 4096	Very large boulders
D84	> 4096	Bedrock

4.2.10. **Figure 4-3** shows the particle size histogram for both the Reference Reach and the Riffle-bar Reach, indicating the presence of mobile gravels within the Reference Reach. The proportion of cobbles and boulders within both the Reference Reach and Riffle-bar Reach have a similar distribution.

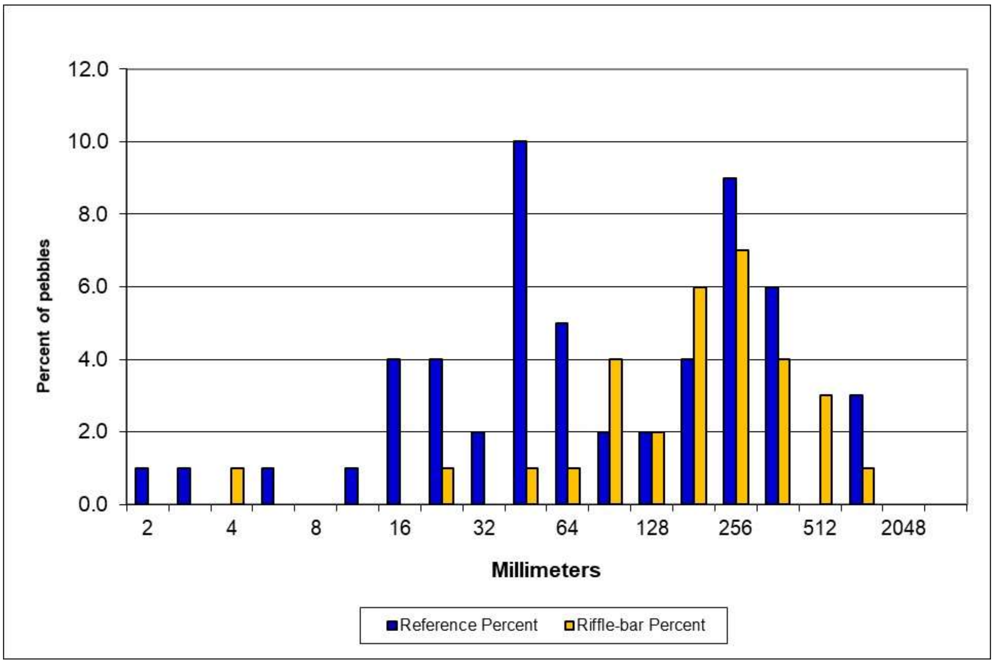

Figure 4-3 - Particle Size Distribution Comparison between the Reference Reach and the Riffle-bar Reach for the River Coquet

4.3 GEOMORPHOLOGICAL DYNAMICS ASSESSMENT

INTRODUCTION

Analysis was undertaken for three flow scenarios, based upon professional judgement, to assess potential impacts on Part A. Analysis included assessment of:

a. Scenario A – which relates to approximate bankfull flow conditions, with bankfull being determined based upon field observations of both bank undercutting and the start of terrestrial vegetation being dominant.
b. Scenario B – which considers a flood event that would inundate the proposed construction zone.
c. Scenario C – which represents an estimated extreme high magnitude, low frequency flood event.

Stream Power

4.3.1. Stream power provides an important expression explaining the hydraulics of channel flow as detailed by Gilvear and Bravard (**Ref. 10.4.21**). It describes the work expended or energy loss within the system and is a key parameter in determining the erosion and sediment transport capability of a river. Stream power is normally calculated for bankfull flows as this flow is generally accepted as being important for channel forming events.

4.3.2. The movement of sediment, especially coarse bedload, requires that the transport threshold for bed material erosion is exceeded, therefore, significant bedload movement in the UK is typically low and tends to be episodic as detailed by Sear et al., (**Ref. 10.4.22**).

4.3.3. For stream power, a threshold at 35 Wm^{-2} has been identified where channels are likely to experience erosion dominated adjustment as detailed by Brookes (**Ref. 10.4.23**). Stream power results may be divided into the following descriptive categories:

a. High energy system = ω >300 Wm^{-2} – here significant erosion may occur; where lateral erosion is restricted, vertical erosion is likely.
b. Medium energy system = ω 10 to <300 Wm^{-2} – localised erosion may occur which may de-stabilise features such as riffles and pools.
c. Low energy system = ω <10 Wm^{-2} – sedimentation is most likely.

4.3.4. For boulders to be transported, a stream power of >90 Wm^{-2} is typically required.

4.3.5. **Table 4-3** provides results for estimates of stream power and shear stress at different flows within the Study Area. The results enable an estimation of the potential changes in stream power and shear stress under different flow conditions and enable a broad assessment of the potential impacts of these flow dynamics during the construction of the proposed pier.

4.3.6. The Manning's n value for estimating roughness was taken from Chow (**Ref. 10.4.10**) to represent the channel in both bankfull and out-of-bank flows for the baseline. The roughness was reduced during the construction phase for Scenarios B and C due to the impacts of vegetation removal. No impacts are anticipated on the Scenario A flows during construction. The Manning's n values selected are consistent with the range of flow resistance coefficients for boulder-bed channel types identified by Bathurst (**Ref. 10.4.16**).

Table 4-3 - Hydraulic Data including Stream Power and Shear Stress results for three flow Scenarios*. Slope = 0.002

Cross-Section	Channel Width (m)	Area (A) (m^2)	Wetted Perimeter (P) (m)	Hydraulic Radius (R)	Manning' s n	Velocity (ms^{-1})	Discharge (Q) (m^3s^{-1})	Stream Power (ω)	Shields Shear Stress (θ)
Scenario A – baseline	33.8	23.1	34.7	0.67	0.050	0.68	15.75	9.12	0.002
Scenario B – baseline	36.6	50.6	38.4	1.32	0.070	0.77	38.84	20.78	0.005
Scenario B – construction	36.6	50.6	38.4	1.32	0.050	1.07	54.38	29.10	0.005
Scenario C – baseline	45.2	152.7	53.5	2.81	0.070	1.26	193.0	83.74	0.010
Scenario C – construction	45.2	152.7	53.5	2.81	0.050	1.77	270.2	117.23	0.010

*Due to the absence of hydraulic modelling, the estimated return periods of the flow scenarios assessed could not be determined

Baseline Stream Power

4.3.7. The stream power results for Scenario A indicate a low-energy system where deposition of sediments is likely. This is supported by field observations where accumulations of predominantly cobbles and boulders are present in the Riffle-bar Reach, where this reach has been classified as a sediment deposition zone.

4.3.8. For the baseline Scenario B flows, the stream power result falls within the lower end of a medium-energy system. However, the energy of the river falls below the cited threshold for erosion, which is 35 Wm^{-2} as detailed by Brookes (**Ref. 10.4.23**). In addition, the results indicate that the river does not have the power to transport the large particle size classes present within both the Reference Reach and the Riffle-bar reach, with a stream power greater than 90 Wm^{-2} being required to transport boulders. The river has the power to transport the smaller particle size fractions, namely the gravel fractions. Out of bank deposits of sand indicate that smaller grain sizes are also being transported.

4.3.9. For the baseline Scenario C flows, the stream power is 83.7 Wm^{-2}, which suggests erosion may occur, however, it still falls below the cited threshold for the transport of boulders.

Construction Phase Stream Power

4.3.10. During construction, the stream power for flows greater than bankfull (Scenario A) increases due to the reduced roughness caused by vegetation removal. However, the increase in stream power during Scenario B flows still falls below the cited threshold for the onset of erosion of 35 Wm^{-2}. In addition, these impacts on stream power are likely to be localised to the construction zone only and the river is unlikely to have the power to transport the larger particle sizes. The D50 within the Riffle-bar Reach is very large boulders, which are unlikely to be mobilised except for during extreme events.

4.3.11. During construction under Scenario C flows, the stream power increases to 117.2 Wm^{-2}. Here, the river may have the potential to transport boulders, however, shear stress value still falls below the threshold for entrainment. Under this event, the D50 particle size for the Reference Reach may be mobilised (328 mm, small boulders), but the mobilisation of the median particle size within the Riffle-bar Reach (very large boulders) is unlikely. The key potential risk would be erosion of the bare earth exposed on the valley sides due to vegetation removal. The risk of such an extreme event occurring during the construction phase, however, would be low. Appropriate mitigation would still be required to manage the risk of fine sediment input to the river and erosion of the banks during the construction phase, along with prompt vegetation reinstatement.

SEDIMENT TRANSPORT CAPABILITY

4.3.12. Flow velocity provided for both baseline conditions and the construction phase (**Table 4-3**) was compared with the particle size analysis results and the Hjulström curve to assess the likelihood of sediment transport and the risk of erosion. The maximum sediment transport velocity shown per particle size range is the critical velocity for the potential onset of erosion, based on the Hjulström curve. The assessment of D84 was eliminated due to it being bedrock. The results are provided in **Table 4-4** (based on Hjulström (**Ref. 10.4.11**)) and **Figure 4-4**.

4.3.13. The results suggest that a flow velocity of at least 1.8 m^3/s is required to entrain and transport the D50 particle size within the Reference Reach. Erosion would only potentially occur once the threshold of 6 m^3s^{-1} is exceeded for this size class. The large cobbles within the Riffle-bar Reach may be entrained and transported when velocity reaches 1.5 m^3/s with the potential onset of erosion at 4.5 m^3s^{-1}. The Hjulström curve does not enable assessment of sediment sizes over 1000 mm, therefore, the potential for transporting the median (D50) particle size within the Riffle-bar Reach could not be assessed.

Table 4-4 – Critical Velocities Required to Transport Sediment

Particle Size Percentile	Particle Size (mm)	Particle Size Class	Velocity Range for Sediment Transport (ms^{-1})
D16 (Reference Reach)	35.4	Very coarse gravel	0.6 - 2.5
D16 (Riffle-bar Reach)	181	Large cobble	1.5 - 4.5
D50 (Reference Reach)	328	Small boulder	1.8 - 6.0
D50 (Riffle-bar Reach)	N/A	N/A	N/A
Dmax	840	Medium boulder	2.0 - 8.0

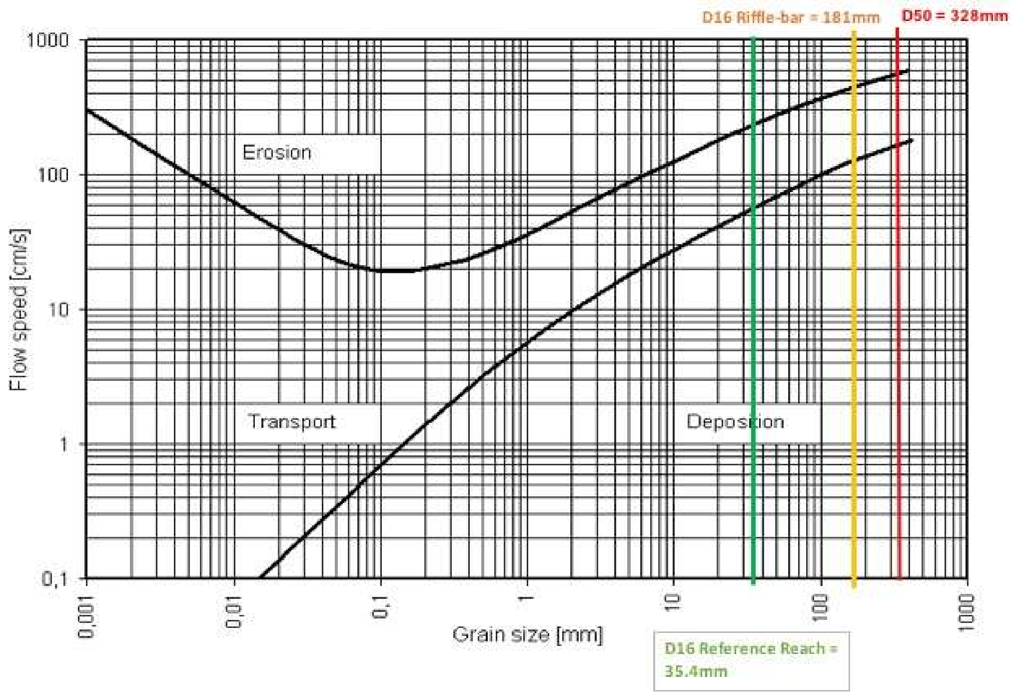

Figure 4-4 – D50 and D16 Particle Size Classes Indicating the Likelihood of Sediment Transport

Scenario A - Baseline

4.3.14. Under Scenario A, the reading from the Hjulström curve suggests that only gravels less than 35.4 mm (the D16 particle size range) and smaller, that were recorded within the Reference Reach, would be transported. Given the lack of gravel particle size classes recorded within the Riffle-bar Reach, this supports the evidence that gravels are being transported through the system. The D16 class within the Riffle-bar Reach (181 mm), which is located at the existing and new River Coquet bridge, is too large to be transported during Scenario A flows. Under Scenario A flows, sand sized particles would be subject to the forces of erosion.

4.3.15. Using the sediment transport equation set out by Knighton (**Ref. 10.4.14**), results suggest that, under Scenario A flows, the D50 particle size class would not be mobile. Particles less than 125 mm (small cobbles) may be mobilised. This equates to the D32 particle size class within the Reference Reach and D10 within the Riffle-bar Reach. When comparing this with the Hjulström curve, velocities greater than 1 m^3/s would be required. It should be noted that the sediment transport equation used does not account for roughness, thus the results are assumed to be over-estimates for this assessment given the bed roughness through the study reach.

4.3.16. Under Scenario A, the construction and operation of the new River Coquet bridge should not alter the sediment dynamics operating within the study reach. Sediment being transported would only be those smaller size fractions that are presently mobilised through the study reach.

Scenario B - Baseline

4.3.17. For Scenario B flows, the Hjulström curve reading indicates that very coarse gravels may be transported. Sand particle size classes would be subject to the forces of erosion.

4.3.18. During Scenario B baseline flows, the sediment transport equation results suggest that sediment size less than 225 mm (which equates to D40 within the Reference Reach and D20 within the Riffle-bar Reach) may be mobilised. Thus, within the Riffle-Bar Reach, only a small proportion of the bed substrate may become mobilised. When comparing this with the Hjulström curve, velocities greater than approximately 1.7 m^3/s would be required.

Scenario C - Baseline

4.3.19. Under Scenario C, the velocity of 1.28 m^3/s suggest that the river does not have the power to transport large cobbles or larger particles. Small cobbles may be transported.

4.3.20. Under Scenario C baseline flows, the sediment transport equation result suggests that medium boulders may be mobilised. This is consistent with the findings of Sear et al. (**Ref. 10.4.22**) where significant bedload movement in UK rivers tends to be rare and episodic. Erosion of the valley sides and where river banks are not composed of boulders or bedrock may occur. Again, these results do not account for bed roughness so are potentially over-estimates.

SHEAR STRESS

4.3.21. The shear stress results indicate that the frictional forces are unlikely to be overcome by the fluid forces of drag and lift to enable entrainment, suggesting extremely low mobility of the large substrate (cobbles and boulders). Shields equation for shear stress (θ) identified that sediment motion begins under a range of dimensionless shear stresses between 0.03 and 0.06 as set out by Sear et al., (**Ref. 10.4.22**).

4.3.22. With regards to the sediment transport capability of the coarse substrates (cobbles and boulders) within the River Coquet study reach, it should be noted that the sediment is typically poorly graded, especially within the Riffle-bar Reach. Here, the poor grading is highly significant to the sediment transport potential. This is due to the mobility of a particle being not only dependant on its own size but also its size relative to the other particles surrounding it as detailed by Sear at al., (**Ref. 10.4.22**). This is due to the 'hiding factor' where a particle is protected to some extent from fluid shear forces and turbulence due to the sheltering effect of the larger particle sizes surrounding it. In the case of the River Coquet, the mobility of cobbles is impeded due to the hiding effect of larger cobbles and boulders. Therefore, particles smaller than the reference size (D50) require stronger flow to set them in motion than would be necessary within a uniform bed as set out by Reid et al., (**Ref. 10.4.24**).

Scenario A - Construction

4.3.23. Construction activities are not anticipated to impact on flows and sediment transport dynamics as there would be no alteration to the cross-sectional area of the channel during Scenario A flows.

Scenario B - Construction

4.3.24. During construction, velocity is shown to increase to over 1 m^3/s for the flows assessed, which indicates that larger particle sizes may be transported, based on the Hjulström curve. Thus, small cobbles, as well as gravels may be mobilised and transported during the construction phase under flow Scenario B. Small cobbles mobilised would likely be transported short distances as bedload and, due to the low stream power, rapidly deposited. However, the shear stress results indicate that the river lacks the energy to overcome the frictional forces operating for particle entrainment and mobilisation of the larger particle size fractions.

4.3.25. During construction under Scenario B flows, the sediment transport equation results suggest that particles less than 282 mm may be transported (small boulders); this represents D24 of the Riffle-bar Reach particle size distribution, thus, only a small fraction of the bed material may be mobile. When comparing this with the Hjulström curve, velocities greater than approximately 1.9 m^3/s would be required.

Scenario C - Construction

4.3.26. Under a Scenario C flow event during construction, velocity increases to 1.77 ms^{-1}, which suggests the potential to transport small boulders.

4.3.27. During construction under Scenario C flows, the sediment transport equation result indicates that medium-sized boulders may be transported. Again, these results are likely to be over-estimates given that the equation does not allow for bed roughness.

SEDIMENT TRANSPORT SUMMARY

4.3.28. The median particle size within the Riffle-bar Reach was very large boulders (2048 - 4096 mm). Thus, for all three scenarios, entrainment and transport of the median sediment size is unlikely.

4.3.29. It has been estimated that less than 1 % of the flow area would be impacted during construction, thus, in the absence of modelling, it is assumed that this would have a negligible impact on stream power and shear stress.

4.3.30. When comparing the results of the sediment transport equation with the Hjulström curve and shear stress, it is concluded that the results of the sediment transport equation represent the worst-case scenario, especially as bed roughness is not considered.

4.3.31. In summary, under Scenario A, the transport of sediment within the River Coquet study reach is limited primarily to the smaller particle size fraction (gravel and sands) recorded within the Reference Reach. Sand sized particles also fall within the thresholds of erosion; these particle sizes are of low frequency occurrence within the Reference Reach, where sand was only recorded once at one transect.

4.3.32. The stream power results indicate that the river falls below the threshold for the onset of erosion except for under Scenario C flow events. Under Scenario A flows, deposition is indicated within the Riffle-bar Reach, as observed on site.

4.3.33. During construction, small cobbles may be mobilised due to the reduced roughness, with potentially small-to-medium sized boulders being mobilised during more extreme flood events. These may be transported short distances as bedload. However, the thresholds for the entrainment and onset of transport are unlikely to be overcome, especially when taking into the account the ‘hiding factor’. Any movement that may occur would most likely be rolling along the bed with the particle being rapidly deposited due to the lack of energy required to sustain transport. These results are consistent with the observations of Bathurst (**Ref. 10.4.25**) for bedrock-boulder dominated channels where significant transport of the coarse bedload only occurs during more extreme flows.

4.3.34. During construction, the key impact could be the erosion of finer material that is exposed following vegetation removal. Here, sands, silt and clays may be eroded from the banks that are exposed by construction activities and vegetation removal. This would require adequate mitigation measures to prevent an increase in fine sediment delivery to the channel. This is considered further in **Section 5**.

4.3.35. Post-construction, reinstatement of both trees and an understorey would be required to control sediment input to the river and to replace the riparian vegetation structure to baseline equivalent conditions. Where bare earth is likely due to the shading effect from the new River Coquet bridge, compacted and appropriately sized material would be required to prevent it from being eroded during high flows. An angular and compacted mix of very coarse gravels and or small cobbles greater than 40 mm would be recommended for the surface horizon of the Made-ground.

4.3.36. Overall, the impacts of the construction activities on the geomorphological dynamics, that is stream power, velocity and sediment transport capability of the river, are considered minor.

4.3.37. Following reinstatement of vegetation, the operational impacts on geomorphological dynamics, that is stream power, velocity and sediment transport capability of the river, are assessed as minor.

4.3.38. An impact assessment is presented in **Section 5** which considers both the construction and operation phases, with and without mitigation, upon the fluvial geomorphology and associated impacts upon aquatic ecology.

5 IMPACT ASSESSMENT

5.1 INTRODUCTION

5.1.1. This section forms part of the ES for Part A, presented in **Chapter 10: Road Drainage and Water Environment**, **Volume 2** of this ES (**Application Document Reference: TR010041/APP/6.2)**. Here, the standard DMRB (HD 45/09) methodology (**Ref. 10.4.26**) has been modified for this specific geomorphological assessment, given that geomorphology is not specifically covered within DMRB (HD 45/09) (**Ref. 10.4.26**). This section focuses specifically on the potential construction and operational impacts on the fluvial geomorphology of the River Coquet. Given the sensitivity of the River Coquet, the impact assessment considers the potential impacts and significance of effects firstly without mitigation, and, secondly, demonstrates how the proposed embedded mitigation reduces the magnitude of impact and the resulting significance of effects.

5.1.2. The key legislative driver for inclusion of a fluvial geomorphology assessment of potential impacts on the River Coquet is the WFD (**Ref. 10.4.27**); refer to **Section 3.2**. The WFD (**Ref. 10.4.27**) is implemented in England by The Water Environment (WFD) (England and Wales) Regulations 2003 (**Ref. 10.4.28**). Hydromorphology, as a supporting quality element, is assessed under the WFD (**Ref. 10.4.27**). The WFD (**Ref. 10.4.27**) does not permit either a deterioration in status of WFD water bodies nor a deterioration in the status of any of the WFD quality elements. In addition, any development must not compromise the ability of a water body to meet its status objectives.

5.1.3. The principal focus of a geomorphological assessment is the relationship between sediment regime, that is the erosion, deposition and sediment transport processes, and channel morphology.

5.1.4. Due to the construction activities associated with the new River Coquet bridge, an assessment of potential impacts on the fluvial geomorphological processes is required.

PROPOSED DESIGN

5.1.5. The new River Coquet bridge comprises a three-span composite steel/concrete deck with RC piers and abutments. The proposed piers would be on the same alignment as the existing piers on the existing northbound bridge. The proposed southern abutment on the new bridge would also be on the same alignment as the existing southern abutment on the existing bridge. The proposed northern abutment on the new bridge would be approximately 25 m further north than the northern abutment on the existing bridge.

PROPOSED CONSTRUCTION METHODOLOGY

5.1.6. Construction access would be via haul roads down the valley sides on both banks. Tower cranes would be used to construct the pier-base and stem construction and for servicing the deck construction. Haul routes and laydown areas would not encroach on the adjacent SSSI and environmental measures would be in place to avoid potential impacts from construction activities; these measures would be detailed in the **Outline CEMP** (**Application Document Reference: TR010041/APP/7.3**).

5.1.7. Sheet piles would be installed to construct the southern pier base, which would avoid entering the watercourse under normal flow conditions. This would be installed using a tracked piling rig to a depth of approximately 8 m below ground level; some pre-augering may be required to drive the piles to the required level, depending on the quality of the underlying rock. The bore piled rig wall would be installed to bedrock level. These sheet piles, located outside of assumed bankfull channel, would then serve two functions: firstly, as a cofferdam to create a dry working area for construction; and, secondly, would form part of the permanent framework for the new pile cap. Once constructed, the sheet piles would be cut off to the pile cap level. The full details of the proposed construction methodology are provided in **Appendix 2.4: River Coquet Bridge Construction Methodology Sequence**, **Volume 1** of this ES (**Application Document Reference: TR010041/APP/6.1**).

5.2 ASSESSMENT AIMS

5.2.1. This section aims to assess the potential construction and operation impacts of Part A on the fluvial geomorphological processes operating and to identify mitigation measures that would reduce the identified impacts. An assessment of residual impacts with mitigation in place is then undertaken.

5.2.2. The specific objectives of this assessment are to assess potential impacts on:

a. Sediment regime: major, moderate or minimal impacts to the riverbed over the reach due to accelerated deposition or erosion and/or impacts to sensitive receptors (species and/or habitats) due to changes in suspended sediment load or turbidity.
b. Channel morphology: major, moderate or limited impacts to the diversity of channel morphology, with consequences for ecological quality.
c. Natural fluvial processes: major, moderate or minimal interruption to the fluvial processes, such as channel planform evolution or erosion and deposition.

5.2.3. For fluvial geomorphology, the proposed construction methodology and operation of Part A must satisfy several interrelated environmental requirements:

a. There must be no detrimental increase in sediment load in the watercourse both during construction and operation.
b. The watercourse must not be subject to significant erosion, either through bank or bed erosion.
c. The construction and operation of Part A must not lead to an increase in flood risk.
d. Part A, particularly during construction, should neither have a detrimental impact on the morphology of the watercourse nor the physical habitats it provides for aquatic species.

5.3 METHODOLOGY

5.3.1. The desk-based assessment has considered relevant guidance, legislation and regulations, comprising those listed below:

a. River Geomorphology: A Practical Guide (**Ref. 10.4.29**).
b. Guidebook of Applied Fluvial Geomorphology (**Ref. 10.4.22**).
c. WFD – The Water Environment (WFD) (England and Wales) Regulations 2003 (**Ref. 10.4.28**).
d. Design Manual for Roads and Bridges (DMRB) Volume 11, Section 3, Part 10 (HD 45/09): Road Drainage and the Water Environment (**Ref. 10.4.26**).

5.3.2. DMRB (HD 45/09) (**Ref. 10.4.24**) does not provide a specific methodology for the assessment of geomorphological impacts. The methodological approach adopted was developed using the guidelines from Research and Development Programmes of the National Rivers Authority, Environment Agency and Scottish Natural Heritage. These guidelines are described in Guidebook of Fluvial Geomorphology (**Ref. 10.4.30**).

5.3.3. A desk study and field survey was undertaken to inform the impact assessment. Details of these are provided in **Section 2** and the results in **Section 3** and **Section 4**.

5.3.4. For the impact assessment, the significance of effect (both without and with mitigation) has been determined based on the importance of the River Coquet combined with the magnitude of potential impact, during both construction and operation.

IMPORTANCE

5.3.5. The criteria used to assess the importance of the River Coquet is provided in **Table 5-1**.

Table 5-1 - Indicators of Importance of the Fluvial Geomorphology Receptor

Importance	Criteria
Very High	Fluvial Geomorphology: A very high sensitive watercourse must show no, or limited signs, of previous modification and or be experiencing no morphological pressures at the current time. Sediment regime: Watercourse appears to be in complete natural equilibrium. That is, it is operating as a sediment source, sink or transfer zone and is not undergoing excessive unnatural deposition and or erosion. It may also be the case that such an environment supports a range of species and habitats which would be sensitive to a change in suspended sediment concentrations and turbidity such as migratory salmon. Channel morphology: Watercourse exhibits a natural range of morphological features such as pools and riffles, active gravel bars and varied river bank types, with no signs of modifications or morphological pressures. Natural fluvial processes: A watercourse where there is a diverse range of fluvial processes which are free from any modification or anthropogenic influence, which would be highly vulnerable to changes as a result of modifications.

Importance	Criteria
High	Fluvial Geomorphology: A high sensitivity watercourse must show only limited signs of previous modification with limited morphological pressures at the current time. Sediment regime: A highly sensitive watercourse appears to be in natural equilibrium. That is, it is operating as a sediment source, sink or transfer zone and is not undergoing excessive unnatural deposition and or erosion. It may also be the case that such an environment supports a range of species and habitats which would be sensitive to a change in suspended sediment concentrations and turbidity such as migratory salmon. Channel morphology: Watercourse exhibits a natural range of morphological features such as pools and riffles, active gravel bars and varied river bank types, with very limited signs of modifications or morphological pressures. Natural fluvial processes: A watercourse where there is a diverse range of fluvial processes which have very limited signs of modifications or anthropogenic influences, which would be highly vulnerable to changes in fluvial processes as a result of modifications.
Medium	Fluvial Geomorphology: A medium sensitivity watercourse may show some degree of obvious modification with associated morphological pressures being evident at the current time. Sediment regime: Watercourse shows signs of modification and is recovering a natural equilibrium. That is, it is operating as a source, sink or transfer zone but may be undergoing elevated levels of deposition and or erosion. It may also be the case that such an environment supports limited species and habitats which may be slightly sensitive to a change in suspended sediment concentrations and turbidity. Channel morphology: Watercourse exhibits a limited range of morphological features such as pools and riffles, few active gravel bars and relatively uniform bank types, with signs of modifications and morphological pressures. There may be signs of recovery of morphological features, such as the development of berms within an over wide channel. Natural fluvial processes: A watercourse where there is a limited range of fluvial processes which are influenced by modifications or anthropogenic influences, which would be vulnerable to changes in fluvial processes as a result of modifications.
Low	Fluvial Geomorphology: A low sensitivity watercourse is typically severely modified. Examples may include extensive realignments

Importance	Criteria
	and channel straightening. Low sensitivity watercourses are often artificial drainage ditches. Sediment regime: Watercourse that has a highly modified sediment regime. That is, the natural equilibrium of the watercourse as a source, sink or transfer zone has been changed by channel modifications or anthropogenic pressures. The watercourse may have insufficient capacity to recover its natural equilibrium and is stable acting as a transfer or sink of sediment. It may also be the case that such an environment does not support any significant species sensitive to changes in suspended solids concentration or turbidity. Channel morphology: Watercourse exhibits no morphological diversity; uniform flow, gravel bars are absent and bank types uniform. May have been subject to past modification such as bank protection and culverting. Likely to be stable with insufficient capacity to develop morphological features. Natural fluvial processes: A watercourse which shows no evidence of active fluvial processes and is not likely to be affected by modification to boundary conditions.

5.3.6. The potential impacts are assessed based on evaluating a predicted change in baseline conditions (sediment regime, channel morphology and natural fluvial processes) caused by Part A.

5.3.7. The River Coquet within the Study Area is classified as **High** importance.

MAGNITUDE OF IMPACT

5.3.8. The potential impacts were considered in terms of the degree of change to the baseline conditions during both the construction and operation phases of Part A.

5.3.9. The key potential impacts of Part A on the fluvial geomorphology of the River Coquet are:

a. Increased fine sediment delivery to the watercourse during the construction phase.
b. Increased modification to the watercourse due to the construction of two permanent piers on the valley sides.
c. Potential for the alteration of the sediment regime during the construction phase.
d. An increase in fluvial activity, such as erosion due to the introduction of new engineering; this would also result in increased sediment delivery.

5.3.10. The criteria used to determine the magnitude of potential impacts on a watercourse is provided in **Table 5-2**. Given that the potential impacts of the construction and operation phase are firstly specific to the River Coquet and secondly are only potentially going to have an adverse impact, an assessment of beneficial impacts has been scoped out as they are not considered relevant. Consequently, they are not provided in the criteria listed in **Table 5-2**.

Table 5-2 - Criteria for Estimating the Magnitude of Impact on the River Coquet

Magnitude	Typical examples
Major Adverse	Fluvial Geomorphology: Piers required in the channel. Additional bank reinforcement which significantly increases the extent of watercourse modification and has the potential to result in the following changes: Sediment regime: Major change to the natural equilibrium through modification, significantly changing the natural function of the watercourse (sediment source, sink or transfer zone). This may arise from a major increase in amount of fine sediment and turbidity and transport of large (boulder) particle sizes. Channel morphology: Major impacts on channel morphology through the removal of a wide range of morphological features. Pier alignment that significantly alters the natural channel cross-section and bank profiles. A significant increase in stream power may result. Which may pose erosion risk problems. Natural fluvial processes: Major interruption to fluvial processes such as channel planform evolution or erosion and deposition.
Moderate Adverse	Fluvial Geomorphology: Piers located outside of the bankfull channel, increasing the extent of watercourse modification which has the potential to result in the following changes: Sediment regime: Moderate change to the natural equilibrium through modification, partially changing the natural function of the watercourse (sediment source, sink or transfer zone). This may arise from a moderate increase in amount of fine sediment and turbidity and transport of large substrate sizes (large cobbles and small boulders). Channel morphology: Moderate impact on channel morphology through the removal of a range of morphological. Pier alignment that may alter out-of-bank flows and cause scour. Natural fluvial processes: Moderate interruption to fluvial processes such as channel planform evolution or erosion.
Minor Adverse	Fluvial Geomorphology: Piers aligned with existing piers with limited potential impacts that may include: Sediment regime: Minor change to the natural equilibrium through modification, locally changing the natural function of the watercourse (sediment source, sink or transfer zone). This may arise from a slight increase in amount of fine sediment and turbidity and transport of small cobbles.

Magnitude	Typical examples
	Channel morphology: Limited impact on channel morphology, through removal of some morphological features. Natural fluvial processes: Slight change in fluvial processes operating in the river; any change is likely to be highly localised.
Negligible	Fluvial Geomorphology: No direct engineering impact but potential indirect impact due to proximity of the watercourse to Part A. Sediment regime: Negligible change to the natural equilibrium. Negligible amount of sediment released into the watercourse, with no noticeable change to the turbidity or bed substrate. Channel morphology: No significant impact on channel morphology in the local vicinity of proposed new River Coquet bridge. Natural fluvial processes: No change in fluvial processes operating in the river; any change is likely to be highly localised.

SIGNIFICANCE OF EFFECT

5.3.11. The significance of effect for both the construction and operation phase is determined via the matrix below according to the importance of the receptor and the magnitude of impact.

The overall effect significance is determined using the impact matrix outlined in **Table 5-3** below, which cross-references the importance of the receptor and the magnitude of the potential impact. A significance rating score from Neutral to Very Large is used, in accordance with the DMRB (HD 45/09) (**Ref. 10.4.26**). Where there is a choice between the effect score, for example Large or Very Large, professional judgement is applied is selecting a single effect score.

Table 5-3 - Criteria used to Estimate the Significance of Effects

		Magnitude of Potential Impact			
		Negligible	Minor	Moderate	Major
Importance of receptor	Very High	Neutral	Moderate or Large	Large or Very Large	Very Large
	High	Neutral	Slight or Moderate	Moderate or Large	Large or Very Large
	Medium	Neutral	Slight	Moderate	Large
	Low	Neutral	Neutral	Slight	Slight or Moderate

5.4 POTENTIAL IMPACTS

5.4.1. Generic impacts are assessed for both the construction and operation phase in the absence of mitigation. The residual impact assessment (refer to **Section 5.6**) considers proposed mitigation measures.

5.4.2. Given the proposed construction activities would be located outside of the bankfull channel identified for this assessment, the key impacts on fluvial geomorphology would likely occur during flows that exceed bankfull. Bankfull width within this confined v-shaped valley has been determined based upon the evidence of bank undercutting observed on site and the point where terrestrial vegetation begins to dominate, given that terrestrial vegetation would not be tolerant of frequent inundation.

CONSTRUCTION IMPACTS

5.4.3. Potential impacts during the construction phase would be short-term. A key potential impact relates to suspended solids due to the increase fine sediment source due to vegetation clearance, runoff, plant and vehicle washing, and excavation works.

5.4.4. Fine sediment that may be released into the channel is likely to be held in suspension given the flow velocities within the study reach. However, settling of fine sediment may occur, especially in the shallow water zones and raised bed areas that are common within the study reach.

5.4.5. Weather conditions would also influence the severity of impacts. This includes the occurrence of out-of-bank flows during construction, especially if the dry working area within the cofferdam became inundated. Many of these impacts would worsen with intense or prolonged rainfall events during the construction phase.

5.4.6. A geomorphological dynamics assessment revealed an increase in velocity during construction under out-of-bank flows, where the velocity was shown to increase from 0.77 m^3/s under baseline conditions to 1.07 m^3/s during construction under flow Scenario B. This results in an alteration from gravels and finer particle sizes being mobile to small cobbles having the potential to be mobilised during the construction period. During Scenario C flow events, the velocity would potentially increase to 1.77 m^3/s, which could mobilise small-to-medium boulders. However, the low shear stress values suggest any entrainment and transport would only be very localised and occur over short distances as bedload.

5.4.7. Should out-of-bank flows encroach on the construction zone, there may be slight increases in flow velocity, stream power and sediment transport capability due to less friction with the river bed and increased water depth. During out-of-bank flows, the cross-sectional area and wetted perimeter within the construction zone would be reduced compared with the baseline. Thus, the hydraulic radius, which is a function of the cross-sectional area divided by the wetted perimeter, would also be altered through the construction zone. This could result in potential increased efficiency of the river to transport sediment due to reduced bed friction with a system response of higher flow velocity.

5.4.8. The removal of vegetation may impact on bank stability and could increase erosion of the exposed bare earth, which is composed of sand, silts and clays. Whilst the risk of river bank erosion is assessed as low due to stream power, the presence of boulders and bedrock forming the channel and its banks, and bank revetment adjacent to the existing pier, the vegetation clearance may cause a local destabilising factor. This could trigger further slope instability and landslip activity. Fine sediment deposited on mid-channel bars may also be washed out and be deposited downstream.

5.4.9. The potential erosion of exposed earth is a key issue during construction due to the potential for the release of fine sediment into the river. Vegetation removal and earthworks to regrade slopes, create a haul road and excavation for the pier foundations is a major source of fine sediments. Whilst fine sediment is likely to be rapidly transported by the river, and primarily as suspended load, it may have detrimental impacts further downstream and potentially extending beyond the study reach. An increase in fine sediments into the channel could, consequently, have a negative impact on ecology, including habitats for Atlantic salmon, brook lamprey, sea lamprey and exposed riverine sediment for ground beetle, which are noted to be among the best nationally.

5.4.10. During out-of-bank flows, the excavation for the pier may become flooded. The water contained within the excavation area would be laden with fine sediments, which may be released into the watercourse.

5.4.11. A summary of the potential construction impacts on the fluvial geomorphology of the River Coquet is provided in **Table 5-4**.

Table 5-4 - Potential Impacts on Fluvial Geomorphology during Construction

Source of Impact	Description	Magnitude of Impact	Significance of Effect
Suspended Solids	Sediment Regime: A possible increase in water turbidity and siltation of channel substrate may occur due to a potential increase in fine sediments. The introduction of fine sediments due to the removal of vegetation resulting in exposed earth, earthworks and excavation would contribute to the release of sediment. This sediment may be carried considerable distances downstream, altering the sediment regime with potential detrimental impacts on important aquatic habitats. Channel Morphology: Smothering of bedforms with fine sediment as a result of increased fine sediment supply. This may	Major Adverse	Large Adverse

Source of Impact	Description	Magnitude of Impact	Significance of Effect
	settle between the cobbles and boulders and, where the water is shallow or the sediment is exposed during baseflow conditions, in-channel vegetation may establish. Any spawning gravels may also be smothered. These impacts could be far-reaching, extending beyond the downstream extent of the Study Area. Natural Fluvial Processes: Increased bare surfaces could result in changes to the quantity of flow entering the channel due to more rapid runoff, which has the potential to locally alter flow dynamics.		
Vegetation Clearance	Sediment Regime: An increase in supply of fine sediment through exposed valley sides and loss of the riparian zone and increased exposed bare earth surfaces. The reduced roughness during out-of-bank flows also increases the sediment transport capability of the river and its erosive power for eroding the bare exposed earth that is composed of finer particle sizes (sand, silt and clay). Channel Morphology: Reduced morphological diversity due to loss of tree roots, large wood and the loss of riparian vegetation. The potential smothering of the bed by silt as a result of increased fine sediment supply due to exposed valley sides and construction activities may cause a loss in the morphological diversity of the channel bed. Natural Fluvial Processes: Vegetation clearance could reduce river bank stability, increasing the rates of erosion which could increase the rate at which channel changes shape in response to flow variation.	Major Adverse	Large Adverse
Clear Span Bridge (no in-channel piers)	Sediment Regime: Construction of the pier and associated haul road could increase the volume of fine sediment directly entering the channel and consequently increase turbidity. The restriction of flow and reduced channel width during out-of-bank high flows that	Major Adverse	Large Adverse

Source of Impact	Description	Magnitude of Impact	Significance of Effect
	encroach into the construction zone may alter the sediment transport capability of the river enabling the transport of small cobbles. In addition, flood-water contained within the excavation for the pier would be laden with fine sediment, which may be released to the watercourse. Channel Morphology: The construction of the pier would alter the cross-sectional area and water depth during out-of-bank flows within the construction zone, thus impacting on channel shape with a response change in flow velocity, stream power and sediment transport capability. Natural Fluvial Processes: The construction processes could alter the dynamics of flow during out-of-bank flows, which could result in increased erosion and sediment transport rates.		

OPERATIONAL IMPACTS

5.4.12. Potential operational impacts are likely to be localised to the footprint of the new River Coquet bridge, which are summarised in **Table 5-5**.

Table 5-5 - Potential Impacts on Fluvial Geomorphology during Operation

Source of Impact	Potential impacts	Magnitude of Impact	Significance of Effect
Clear Span Bridge (no in-channel piers)	Sediment Regime: Potential for increase fine sediment delivery due to the potential for bare earth exposed by vegetation clearance on the valley sides and due to shading impacts from the new bridge. Channel Morphology: Alteration of channel cross-sectional area at the location of the new pier, which would potentially cause localised changes to stream power, channel velocity and sediment transport capability. Natural Fluvial Processes: Loss of mature riparian vegetation. Increase runoff locally	Moderate Adverse	Moderate Adverse

Source of Impact	Potential impacts	Magnitude of Impact	Significance of Effect
	due to immature vegetation and the potential for bare ground around the new bridge pier.		
Reinstated Made-ground	Sediment Regime: Potential for erosion of reinstated Made-ground during out-of-bank flows around the southern pier during operation, which may increase fine sediment delivery to the river. Channel Morphology: The potential for erosion of the reinstated Made-ground may result in increased fine sediment delivery, which may cause localised fine sediment deposits within the shallow sections of the channel, altering the bed morphology. Natural Fluvial Processes: May result in increased erosion during high flow conditions.	Moderate Adverse	Moderate Adverse

5.5 MITIGATION

EMBEDDED MITIGATION

5.5.1. Through design and construction methodology iteration, many of the potential impacts on the fluvial geomorphology of the River Coquet have been eliminated. The proposed bridge construction methodology eliminates the requirement for a temporary pier. The locations of the proposed piers are also aligned with the existing piers to minimise any potential impacts on flow dynamics.

5.5.2. The proposed construction methodology for the southern pier entails the installation of sheet piles. This would be installed to a depth of approximately 8 m below ground level with a tracked piling rig and, dependant on the quality of the underlying rock, some pre-augering may be needed to allow the piles to be driven to the required level. These sheet piles, located outside of assumed bankfull channel, would then serve two functions: firstly, as a cofferdam to create a dry working area for construction; and, secondly, would form part of the permanent framework for the new pile cap. Once constructed, the sheet piles would be cut off to the pile cap level.

5.5.3. Regrading of slopes for enabling works would also reduce the risk of slope instability.

CONSTRUCTION MITIGATION

5.5.4. A summary of mitigation measures to reduce the impact of the construction activities are provided in **Table 5-6**.

Table 5-6 – Mitigation Measures for the Construction of the new River Coquet Bridge

Source of Impact	Mitigation Measure	Type of Mitigation
Suspended solids – fine sediment	Provide sediment barriers between earth works and the construction zone and the watercourse to prevent sediment from washing into the river. Silt management needs to be considered not only adjacent to the watercourse, but also up the valley sides and at the valley top to minimise fine sediment input to the watercourse. An exclusion zone of 8 m from the watercourse and top of the valley sides should be maintained as far as practicable.	Reduction
	Avoid the positioning of stockpiles near to the river, ensure they are located outside of the flood zone. Ideally, stockpiles should be located at the valley top and set back from the top of the valley sides.	Prevention
	Cover stockpiles when not in use.	Reduction
	Contain the stockpiles with bunds or sediment fences.	Reduction
	Use a sediment trap to treat surface runoff.	Reduction
	Do not wash vehicles near to the watercourse.	Prevention
	Avoid undertaking works adjacent to the watercourse, where practicable. When working adjacent to the watercourse is required, maintain the maximum distance possible from the watercourse along with appropriate mitigation outlined above for fine sediment management.	Reduction
	Avoid works during high flow events to reduce the risk of fine sediment release.	Reduction
Vegetation clearance	Limit the clearance of vegetation on the channel banks, valley sides and riparian zone. Where practicable, maintain a vegetated buffer strip between the construction zone and the watercourse. Ideally, a minimum buffer strip of 8 m should be retained where possible.	Reduction
	Use seeded biodegradable fibre matting to encourage re-vegetation after works on, or near, the banks.	Reduction
	Maintaining, where possible, vegetation cover on the banks close to the river and prompt reinstatement of vegetation to minimise the impact of reduced roughness, thus potentially	Reduction

Source of Impact	Mitigation Measure	Type of Mitigation
	reducing stream power, flow velocity and sediment transport capability through the construction zone.	
Open span bridge (no in-channel piers)	The creation of a dry-working area is outside of the assumed bankfull channel to minimise the risk of potential impacts on flow during construction. Impacts on flow would only be incurred should out-of-bank flows that encroach on the construction zone occur.	Reduction
Timing of works	Avoid critical periods for fish migration and spawning.	Prevention
	In river works would be restricted to daylight hours to reduce the impacts to fish including salmon and brown trout.	Reduction
	In river works would not occur during high flows. Monitoring of flows and rainfall within the upstream catchment should be undertaken and action taken to halt works should high flows be anticipated due to prevailing weather conditions.	Reduction

5.5.5. Monitoring of weather and flow conditions would be crucial to minimise potential impacts. The river has a responsive and flashy flow regime where peak flow and a return to normal flow conditions may occur within four hours of a rainfall event. Thus, monitoring weather and flow conditions in the upper catchment areas and those of significant tributaries is important.

5.5.6. Limit the extent of vegetation clearance as far as practicable on the banks and valley sides of the River Coquet and ensure prompt reinstatement of vegetation. During construction, maintaining some of the vegetation for roughness during flows that exceed the assumed bankfull could potentially reduce the flow velocities and stream power through the construction zone compared with total vegetation clearance.

5.5.7. Mitigation for the potential impacts outlined should be included within the **Outline CEMP** (**Application Document Reference: TR010041/APP/7.3**) and adhered to. The **Outline CEMP** should include measures to control runoff during construction. This may include creating temporary drainage systems to both alleviate flood risk and help to prevent sediment laden runoff entering the watercourse.

5.5.8. The main contractor shall be required to comply with the relevant sections of BS6031:2009 Code of Practice for Earthworks (**Ref 10.4.31**) with respect to protection of water quality and control of site drainage including washings, dewatering, abstractions and surface water.

5.5.9. Best practice measures associated with storage of oils and fuels shall be followed and included within the **Outline CEMP** (**Application Document Reference: TR010041/APP/7.3**).

5.5.10. Concrete mixing and washing areas shall be located more than 10 m from the watercourse; have settlement and re-circulation systems for water reuse; have a contained area for washing out of concrete batching plant or ready-mix lorries; and collect wash-waters and, where necessary, contain wash-water for authorised off-site disposal. Wash-water from concrete shall not be discharged into the watercourse.

5.5.11. The main contractor shall be required to monitor water quality prior to and during construction.

OPERATION MITIGATION

5.5.12. A summary of mitigation measures to reduce the operational impacts is provided in **Table 5-7**.

Table 5-7 – Mitigation Measures for the Operation of the new River Coquet Bridge

Source of Impact	Mitigation Measure	Type of Mitigation
Clear Span Bridge (no in-channel piers)	Reinstate vegetation post-construction with a mix of native tree species with an understorey, including reinstatement of the riparian zone.	Reduction
	Align new River Coquet pier with the existing piers to reduce impact of flow during operation.	Reduction
	Piers constructed on bedrock to reduce the risk of slope instability and landslip issues.	Reduction
Reinstated Made-ground	Ensure any backfill and Made-ground following construction of the piers is to be composed of cohesive clay, sandy loam and suitably sized, compacted angular material. Made-ground should be planted with vegetation following construction. Where vegetation is unlikely to establish due to shading from the structure, coarse, angular and compacted coarse stones should be used for the surface horizon. The sizing should be sufficient to resist sediment transport during out-of-bank flows. The analyses presented suggests a minimum substrate size of greater than 40 mm up to small cobble size.	Reduction

5.6 RESIDUAL IMPACTS

5.6.1. With the proposed mitigation in place, the residual impacts primarily relate to the potential introduction of fine sediment during the construction phase. Over time, the residual impacts are likely to lessen with the establishment of mature woodland. The magnitude of the impact is considered to be **Negligible**.

5.6.2. With mitigation measures in place, the overall significance of residual effects during both construction and operation is reduced to **Neutral**.

6 REFERENCES

Ref 10.4.1: Old Maps (2019) *Old Maps*. [Available online] https://www.old-maps.co.uk/#/ [Accessed February 2019].
Ref 10.4.2: British Geological Society (2019) *Geology of Britain Viewer*. [Available online] https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html [Accessed February 2019].
Ref 10.4.3: Centre for Ecology and Hydrology (2019) *Catchment Data*. [Available online] https://nrfa.ceh.ac.uk/data/search [Accessed February 2019].
Ref 10.4.4: Halcrow Group Limited (2008) *A1 River Coquet bridge landslip monitoring options feasibility report*. Halcrow Group Ltd.
Ref 10.4.5: CH2MHILL (2014) *Geomorphological assessment River Coquet crossing*. CH2MHILL.
Ref 10.4.6: Environment Agency (2015) Northumbria River Basin Management Plan. [Available online] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/718333/Northumbria_RBD_Part_1_river_basin_management_plan.pdf [Accessed February 2019].
Ref 10.4.7: Environment Agency (2019) *Catchment Data Explorer*. [Available online] https://environment.data.gov.uk/catchment-planning/ [Accessed February 2019].
Ref 10.4.8: Thorne, C. R. (1998) *Stream reconnaissance handbook*. Wiley, Chichester.
Ref 10.4.9: Wolman, M. G. (1954) A method of sampling coarse river bed material. *Transactions, American Geophysical Union*, Vol. 35, No. 6, 1954, pp. 951-956.
Ref 10.4.10: Chow, V. T. (1959) *Open-channel hydraulics.* New York, McGraw-Hill, pp 680. Reference tables available at: http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm
Ref 10.4.11: Hjulström, F. (1935) *Studies of the morphological activity of rivers as illustrated by the River Fyris*. Bulletin of the Geological Institute University of Uppsala 25, 221-527.
Ref 10.4.12: Schoklitsch (1962) *Handbuch des Wasserbaus (in German)*, 3rd ed., Springer, Vienna.
Ref 10.4.13: Bathurst, J.C., Graf, W.H. and Cao, H.H. (1987) *Bed load discharge equations for steep mountain rivers*. In: Thorne, C.R., Bathurst, J.C. and Hey, R.D. (Eds) Sediment Transport in Gravel-bed Rivers. Wiley, Chichester, 453-477.
Ref 10.4.14: Knighton, D. (1998) *Fluvial forms and processes: a new perspective*. Hodder Arnold, 2nd edition.
Ref 10.4.15: Sear, D. A.; Newson, M. D. and Thorne, C. R. (2010) *Guidebook of applied fluvial geomorphology*. Thomas Telford, London.
Ref 10.4.16: Environment Agency (2014) *The Northumberland Rivers Management Catchment: A summary of information about the water environment in the Northumberland Rivers management catchment*. [Available online] https://circabc.europa.eu/webdav/CircaBC/env/wfd/Library/framework_directive/implementation_documents_1/2012-

2014%20WFD%20public%20information%20and%20consultation%20documents/UK/UK03%20Northumbria/Northumberland%20Rivers.pdf [Accessed February 2019].
Ref 10.4.17: Northumberland Wildlife Trust (2008) *Northumberland Biodiversity Action Plan*. [Available online] http://www.nwt.org.uk/northumberland-BAP [Accessed February 2019].
Ref 10.4.18: Macklin, M. G. (1997) *Fluvial geomorphology of North-East England. In: Fluvial Geomorphology of Great Britain*. K. J. Gregory (Ed) Chapman and Hall, London, pp 201-238.
Ref 10.4.19: Ferguson, R. I. (1981) *Channel Form and Channel Changes*. In: British Rivers. J. Lewin (Ed), George Allen and Unwin, London, pp 90-125.
Ref 10.4.20: Petts, G. E. and Bravard, J. P. (1996) *A drainage basin perspective*. In: Fluvial Hydrosystems. G. E. Petts and C. Amoros (Eds) Chapman and Hall, London, pp 13-36.
Ref 10.4.21: Gilvear, D. J. and Bravard, J. P. (1996) *Geomorphology of temperate rivers*. In: Fluvial Hydrosystems. G. E. Petts and C. Amoros (Eds) Chapman and Hall, London, pp 68-97.
Ref 10.4.22: Sear, D. A.; Newson, M. D. and Thorne, C. R. (2010) *Guidebook of applied fluvial geomorphology*. Thomas Telford, London.
Ref 10.4.23: Brookes, A. 1990. Restoration and enhancement of engineered river channels: some European experiences. *Regulated Rivers Research and Management*, 5, 45-56.
Ref 10.4.24: Reid, I., Bathurst, J.C., Carling, P.A., Walling, D.E. and Webb, B.W. 1997. *Sediment erosion, transport and deposition*. In: Thorne, C.R., Hey, R.D. and Newson, M.D. (Eds) Applied Fluvial Geomorphology for River Engineering and Management. Wiley, Chichester, 95-136.
Ref 10.4.25: Bathurst, J. C. (1997) *Environmental river flow hydraulics*. In: Thorne, C.R., Hey, R.D. and Newson, M.D. (Eds) Applied Fluvial Geomorphology for River Engineering and Management. Wiley, Chichester, 69-94.
Ref 10.4.26: Highways Agency (2009) Design Manual for Roads and Bridges Volume 11, Section 3, Part 10 (HD 45/09): Road Drainage and the Water Environment.
Ref 10.4.27: European Parliament (2000) *Water Framework Directive (2000/60/EC)*. European Parliament, Brussels.
Ref 10.4.28: Her Majesty's Stationary Office (HMSO) (2017) *The Water Environment (Water Framework Directive) (England and Wales) Regulations*. HMSO, London.
Ref 10.4.29: Environment Agency (1998) *River Geomorphology: A Practical Guide, Guidance Note 18*. Environment Agency National Centre for Risk Analysis and Options Appraisal.
Ref 10.4.30: Sear, D. A.; Newson, M. D. and Thorne, C. R. (2003) *Guidebook of applied fluvial geomorphology*. R&D Technical Report FD1914.
Ref 10.4.31: British Standards (2009) BS 6031:2009 Code of practice for earthworks. Available at: https://geotechnicaldesign.info/download/bs6031-2009.pdf

Annex A

PHOTOGRAPHIC RECORD – RIVER COQUET

A-1 – General Character Photographs of the River Coquet Study Area from Upstream to Downstream

	
1: Looking upstream towards the weir that marks the start of the study reach	2: Looking upstream at the weir marking the start of the study reach
	
3: Looking upstream with exposed boulders on the left-handside of the channel	4: Looking downstream – general character
	

5: Looking across the channel upstream of the existing A1 river crossing showing glide flow with bedrock substrate spanning the width of the channel	6: Looking downstream on the approach to the existing A1 river crossing
	
7: Looking upstream on the approach to the existing A1 river crossing	8: View across the channel upstream of the existing A1 river crossing with exposed bedrock in the centre of the channel; the thalweg is along the left bank with broken standing waves present
	
9: Looking downstream showing revetment on the right bank; bedrock is present on the channel bed	10: Looking upstream, downstream of the existing A1 river crossing

	
11: Looking downstream, downstream of the existing A1 river crossing, showing exposed bedrock with cobble and boulder deposits on the raised bedrock zone	12: Looking upstream towards the existing A1 river crossing. Exposed boulders are present, which are moss-covered, suggesting a low rate of mobility
	
13: Looking upstream from the downstream extent of the study reach	14: Looking downstream, end of study reach
	

15: Showing bedrock exposed on the left bank	16: Exposed bedrock on the right bank

A-2 - Views Looking Across the Channel at the Location of Each Transect within the Reference Reach

	
T1	T2
	
T3	T4
	

T5	T6
	
T7	T8
	
T9	T10

A-3 - Views looking across the channel at the location of each transect within the Riffle-bar Reach

	
T1	T2
	
T3	T4
	
T5	T6

	
T7	T8
	
T9	T10

T10: Showing moss covered cobbles and boulders at the downstream extent of the riffle-bar feature, downstream of the existing A1 river crossing suggesting low mobility of these substrate sizes with mobilisation only likely during extreme low frequency flow events

Annex B

WOLMAN PEBBLE COUNT DATA

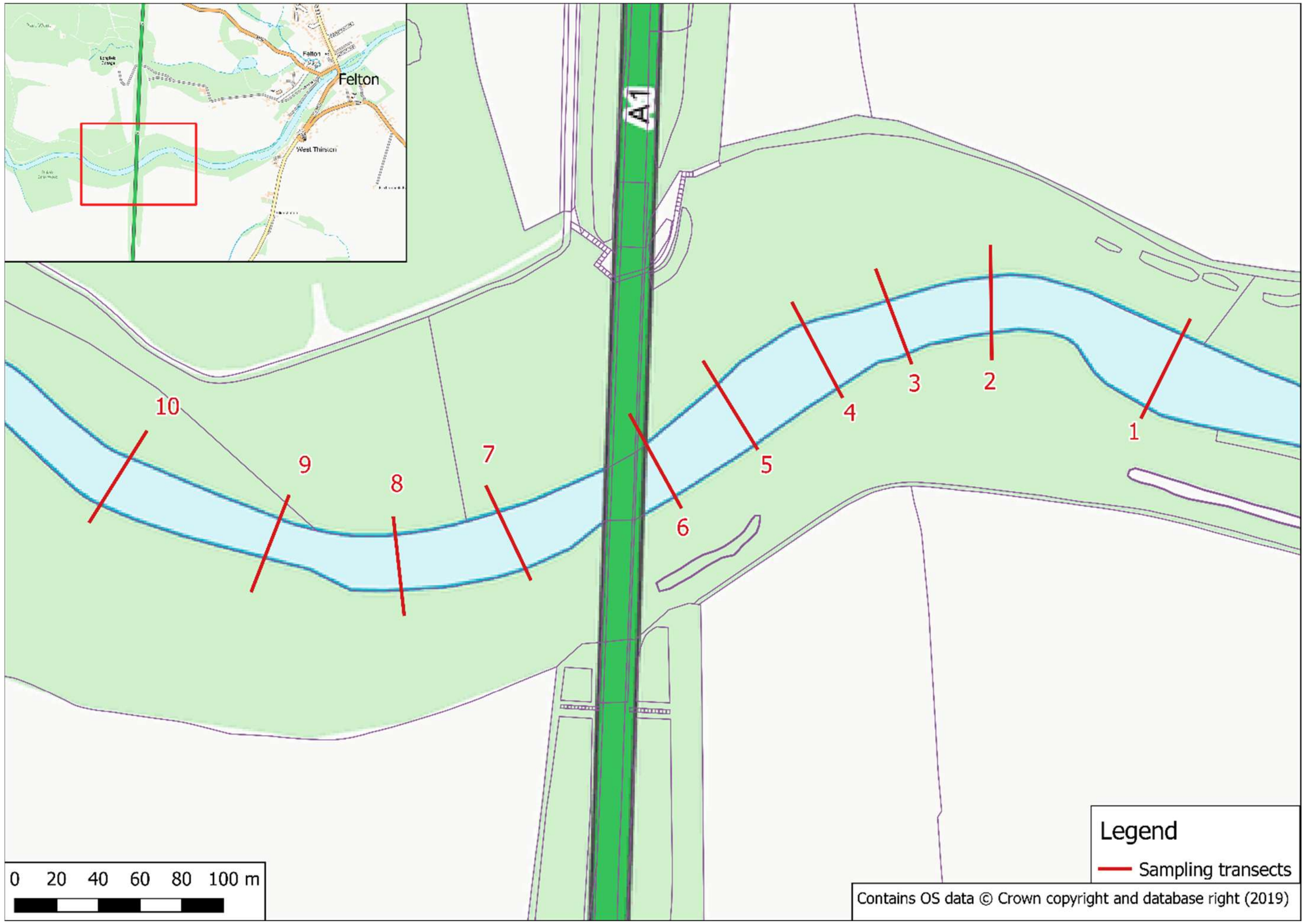

Figure B-1 – Sediment sampling transect locations within the Reference Reach

Reference Reach Particle Size Data – River Coquet

			PARTICLE TALLY COUNTS BY TRANSECT													
Particle	mm	Description	1	2	3	4	5	6	7	8	9	10	Tot Pool	Tot Riff	Comb Tot	Cum Freq (%)
Silt/Clay	<0.062	S/C													0	0
Very Fine	0.062 - 0.125	S													0	0
Fine	0.125 - 0.25	A													0	0
Medium	0.25 - 0.5	N				1								1	1	1
Coarse	0.5 - 1.0	D													0	1
Very Coarse	1.0 - 2	S													0	1
Very Fine	2 - 4		1											1	1	2
Fine	4 - 6	G						1						1	1	3
Fine	6 - 8	R													0	3
Medium	8 - 12	A		1									1		1	4
Medium	12 - 16	V		2		2							2	2	4	8
Coarse	16 - 24	E		1	1	2							1	3	4	12
Coarse	24 - 32	L		1	1								1	1	2	14
Very Coarse	32 - 48	S	1	2	2	3	1	1					2	8	10	24
Very Coarse	48 - 64		2		3									5	5	29
Small	64 - 96	C			1		1							2	2	31
Small	96 - 128	O					1	1						2	2	33
Large	128 - 192	B					3			1				4	4	37
Large	192 - 256	L	1		1		3	3		1				9	9	46
Small	256 - 384	B	4					1		1				6	6	52
Small	384 - 512	L													0	52
Medium	512 - 1024	D	1				1			1				3	3	55
Large	1024 - 2048	E													0	55
Very Large	2048 - 4096	R													0	55
Bedrock	>4096	BDRK		3	1	2		3	10	6	10	10	3	42	45	100
		SUM	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***Total No. Samples***		***100***	
FEATURE SAMPLED			Riffle	Pool	Run	Run	Riffle	Riffle	Riffle	Run	Run	Run				

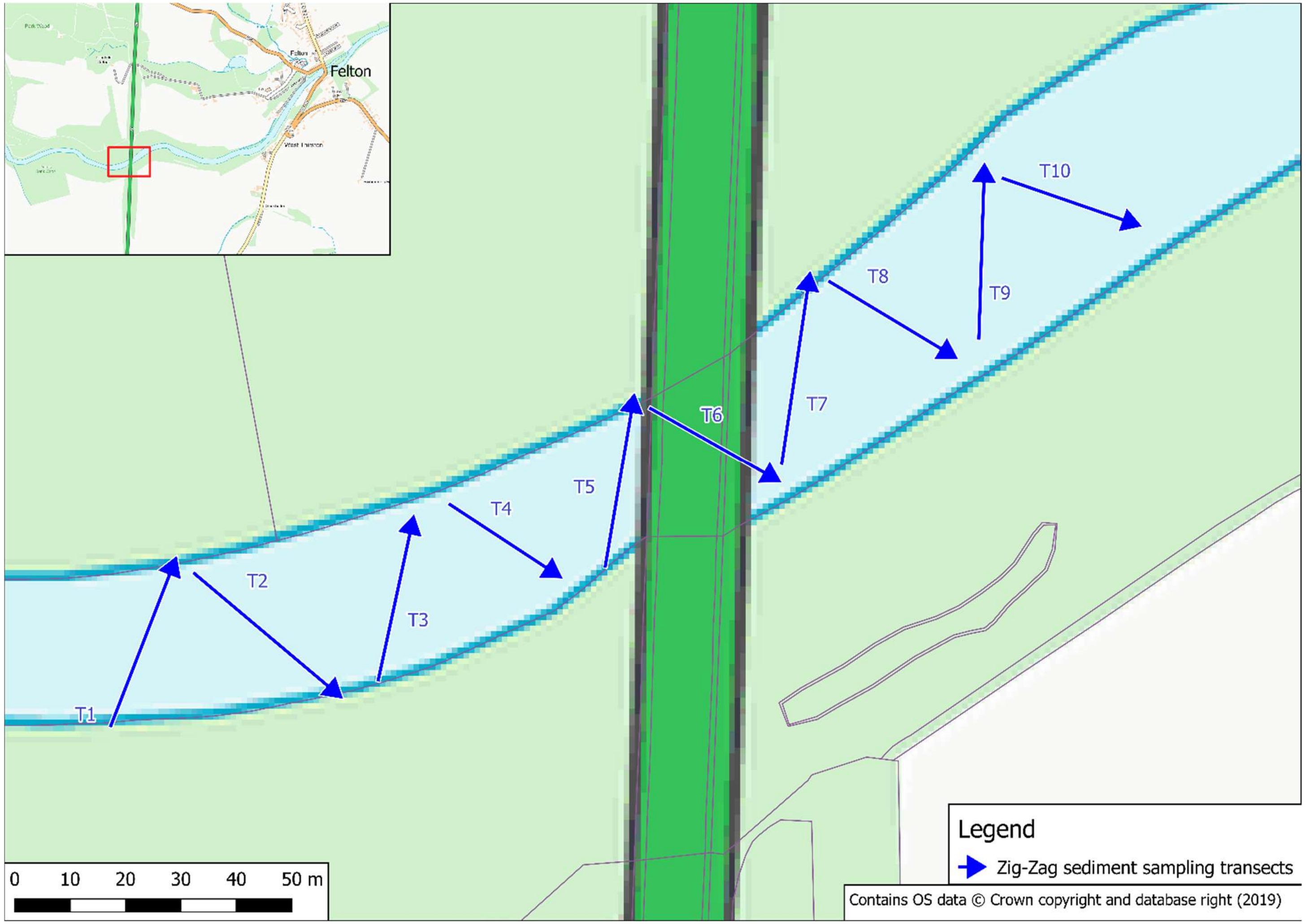

Figure B-2 - Sediment sampling transect locations within the Riffle-bar Reach

Riffle-bar Reach Particle Size Data – River Coquet

				PARTICLE TALLY COUNTS BY TRANSECT													
	Particle	mm	Description	1	2	3	4	5	6	7	8	9	10	Tot #	% Part Siz	Paticle Size (%)	Cum Freq (%)
	Silt/Clay	<0.062	S/C											0		0	0
	Very Fine	0.062 - 0.125	S											0		0	0
	Fine	0.125 - 0.25	A											0		0	0
	Medium	0.25 - 0.5	N											0		0	0
	Coarse	0.5 - 1.0	D											0		0	0
	Very Coarse	1.0 - 2	S											0		0	0
	Very Fine	2 - 4										1		1		1	1
	Fine	4 - 6	G											0		0	1
	Fine	6 - 8	R											0		0	1
	Medium	8 - 12	A											0		0	1
	Medium	12 - 16	V											0		0	1
	Coarse	16 - 24	E						1					1		1	2
	Coarse	24 - 32	L											0		0	2
	Very Coarse	32 - 48	S									1		1		1	3
	Very Coarse	48 - 64										1		1		1	4
	Small	64 - 96	C							1	1	1	1	4		4	8
	Small	96 - 128	O										2	2		2	10
	Large	128 - 192	B		1						1	1	3	6		6	16
	Large	192 - 256	L		1						2	2	2	7		7	23
	Small	256 - 384	B								2	1	1	4		4	27
	Small	384 - 512	L			1					1		1	3		3	30
	Medium	512 - 1024	D								1			1		1	31
	Large	1024 - 2048	E											0		0	31
	Very Large	2048 - 4096	R											0		0	31
	Bedrock	>4096	BDRK	10	8	9	10	10	9	9	2	2		69		69	100
			SUM	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***10***	***Total No. Samples***		***100***	
	Largest Particle on Bar			Dmax: Mid-reach 840mm													

Annex C

GLOSSARY

C-1 – Glossary of Key Terms

Key word	Definition
Catchment	Area drained by a river and its tributaries.
Deposition	Laying down of part, or all, of the sediment load of a stream on the bed, banks or floodplain. Mostly occurs at the end of a high flow event. Forms various sediment features such as bars, berms and floodplain deposits.
Ecological status	A Water Framework Directive (WFD) term. Ecological status may be Bad, Poor, Moderate, Good or High. Ecological status comprises quality elements that fall into three categories: i) biological quality elements, ii) physico-chemical quality elements and iii) hydromorphological quality elements. Ecological status is also influenced by Chemical status.
Erosion	Removal of sediment or bedrock from the bed or banks of a channel by flowing water. Mostly occurs during high flows and flood events. Forms various river features such as scour holes and river cliffs.
Floodplain	A floodplain is flat or nearly flat land adjacent to a stream or river, stretching from the banks of its channel to the base of the enclosing valley walls and (under natural conditions) experiences flooding periods of high discharge.
Fluvial geomorphology	The study of sediment sources, fluxes and storages within a river catchment over all timescales and the associated interaction with the channel's floodplain.
Good ecological status	WFD term denoting a slight deviation from 'reference conditions' in a water body, or the biological, chemical and physico-chemical and hydromorphological conditions associated with little or no human pressure. A primary aim of the WFD is for all water bodies to achieve Good Ecological Status. For a water body to achieve overall Good Ecological Status, all quality elements must be 'good' or 'high' and its chemical quality must pass.
Glide	Deeper water flowing smoothly over a river bed. Occasional larger cobbles or boulders on the bed may create some surface disturbance.
Grading (of particles)	Grading describes the range of sizes of particles making up the sediment load. Well-graded refers to particles of almost uniform size and poorly-graded sediments consist of a mixture of widely differing sizes of material.

Key word	Definition
Hydrology	The study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks.
Mobility (of sediment)	The mobility is the ease at which sediment is picked up (entrained) and carried (transported). Mobility is dependent on the size of the particles making up the bed.
Out-of-bank flows	Flows that overtop the top of the banks of the channel and inundate the valley sides
Planform	River channel pattern when viewed from above. This often referred to as either straight, sinuous, meandering or braided.
Pool	Deeper, steadier water. Pools are usually located at bends in watercourses, and depth increases towards the outside of a bend.
Reach	A length of channel which, for example, may have a homogeneous (similar) geomorphology (river type) or restoration solution.
Riffle	A stream bed accumulation of coarse alluvium typically linked with the scour of an upstream pool. They are characterised by shallow, fast-flowing water with unbroken standing waves flow type over gravel-pebble or cobble substrate. Channel substrate must be unconsolidated to provide suitable spawning habitat.
Riparian zone	Strip of land along the top of a river bank. Plant communities along the river banks are often referred to as riparian vegetation.
Run	Fast flow of water, deeper than riffles and usually with a stony or rocky bed which creates a rippled surface.
Saltation/saltate	The hopping motion of sediment transported by water. Grains of sediment are ejected from the river bed by lift forces, and accelerate into the flow direction when affected by fluid drag.
Sediment	Particles derived from rock or biological material that have been transported by water.
Thalweg	The line of the maximum depth along a river.
Water body	A water body is a WFD term and is the division of rivers, lakes, tidal/ coastal and groundwaters into discrete units for management and reporting. Water bodies are defined using criteria set out in the WFD legislation.

This document is also available on our website at **www.gov.uk /highways**

If you have any enquiries about this document A1inNorthumberland@highwaysengland.co.uk or call **0300 470 4580***.

*Calls to 03 numbers cost no more than a national rate call to an 01 or 02 number and must count towards any inclusive minutes in the same way as 01 and 02 calls.
These rules apply to calls from any type of line including mobile, BT, other fixed line or payphone. Calls may be recorded or monitored.

Registered office Bridge House, 1 Walnut Tree Close, Guildford GU1 4LZ
Highways England Company Limited registered in England and Wales number 09346363