Norwich Western Link

Environmental Statement

Chapter 12: Road Drainage and the Water Environment

Appendix 12.4: River Wensum Geomorphology Assessment

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Glossary of Abbreviations and Defined Terms

The definition of key terms used in this report are provided below. These definitions have been developed by reference to the definitions used in EU and UK legislation and guidance relevant to the water environment as well as professional judgement based on knowledge and experience of similar schemes in the context of the Proposed Scheme.

Term	Definition
AOD	Above Ordnance Datum
Bank	Side of a river channel or island which extends above the normal (e.g., mean) water level and is only completely submerged during periods of high river flow
Bar	In-channel, elevated sediment deposit exposed during periods of low flow, which may be a side bar (including a point or counterpoint bar, located respectively along the convex or concave bank of a meander bend) or a mid-channel bar
Berm	Natural or artificial, flat-topped, shelf along the margin of a river channel that is exposed above water level during low flows, but is submerged during high flows: natural berms are vegetated features composed of sediments deposited by the river to the baseflow level, which evolve into benches as further deposited sediment raises their surface gradually to higher elevations within the river channel
Channel Straightening	Engineered shortening of the length of a stream/ river artificially by removing meander bends. Often undertaken in conjunction with relocating a channel to the edge of the valley floor to improve utility of the land for farming or development.
Culvert	Arched, enclosed or piped structure constructed to carry water under roads, railways and buildings

Term	Definition
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.
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	Valley floor adjacent to a river that is (or was historically) inundated periodically by flood waters and is formed of sediments deposited by the river
Floodplain connectivity	Latitudinal connectivity (e.g. movement of water onto floodplain). It is often reduced through channelisation or dredging rivers for flood protection, embankments etc., or through processes of channel deepening / incision.
Flow regime	Typical magnitude, frequency, timing, and duration of river flows that drive physical and some ecological processes and so, within the constraints of valley slope and confinement, influence the sizes and types of river channel that may be present
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.
Groundwater	Water located beneath the ground surface.
Hydrology	The study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks.
Hydromorphology	Morphological and hydrological characteristics of rivers including the underlying processes from which they result

Term	Definition
Large wood	Piece of wood that is more than 1 m long and 10 cm in diameter
Lateral connectivity	Freedom for water, sediments and biota to move between the channel and the floodplain / hillslopes
Longitudinal connectivity	Freedom for water, sediments and biota to move along the river channel
Mitigation Measures	Measures defined in the River Basin Management Plan to ensure a Heavily Modified Water Body meets good ecological potential.
Morphological Diversity	Variation in the form (morphology) of a watercourse channel. Generally, the greater the morphological diversity the greater degree to which the channel can support Biological Quality Elements.
Planform	The geometric form of a river channel viewed from above
Reach	Section of river along which boundary conditions are sufficiently uniform that the river maintains a near consistent internal set of process–form interactions
Reinforcement	Strengthening of river beds and banks for various purposes (e.g. ford construction, erosion control) using materials such as boulders, sheet piling, geotextiles, etc.
Riparian zone	Transitional, semi-terrestrial area of land adjoining a river channel (including the river bank) that is regularly inundated and influenced by fresh water and can influence the condition of the aquatic ecosystem (e.g. by shading and leaf litter input and through biogeochemical exchanges)
River channel cross profile	Two-dimensional representation of river channel morphology perpendicular to the flow

Term	Definition
River long profile	Two-dimensional representation of river bed topography, where bed elevation is plotted against longitudinal distance downstream along the channel
River restoration	The establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas)
River / Riparian Corridor	Strip of land surrounding the stream channel that is directly affected by flow and sediment processes in the stream / river.
Riverbed incision	Process where a river has cut vertically to lower its bed
River hydromorphological type	Group of river channels displaying similar morphological and hydrological characteristics and their associated processes
Sediment transport	The movement of sediment particles of a range of sizes by flowing water, which may include mobilization and deposition
Valley segment	Section of river subject to similar valley-scale influences and energy conditions
Weir	Artificial structure across a river for controlling flow and upstream surface level, or for measuring discharge
Shear stress	Shear stress is the force applied by flowing liquid to its boundary. In this case, the liquid is storm water, and the boundary is the channel surface. Shear stress is also occasionally referred to as the “tractive force”. Shear stress describes the force of water that is trying to drag the channel surface downstream with it.

Term	Definition
Specific stream power	Stream power is the amount of energy the water in a river or stream is exerting on the sides and bottom of the river. Stream power is the result of multiplying the density of the water, the acceleration of the water due to gravity, the volume of water flowing through the river, and the slope of that water. Specific stream power is the stream power divided by channel width.
Froude number	A dimensionless number equal to the ratio of water velocity to the speed of a gravity wave, used to assess whether flow in an open channel is critical, tranquil, or shooting. If the Froude number is less than 1, flow is said to be subcritical or slow; if Fr = 1, flow is critical; and if Fr is greater than 1, flow is fast or supercritical. The range of Froude numbers can be converted to biotopes which define river units such as pool, glide, run, riffle, and cascade / rapid.

1 Introduction

1.1 Purpose of the report

1.1.1 A fluvial geomorphology assessment of potential impacts of the proposed viaduct over the River Wensum is required in relation to the proposed Norwich Western Link (NWL) road (hereafter referred to as the 'Proposed Scheme').

1.1.2 A bespoke fluvial geomorphology assessment is required to determine potential construction and operation impacts of the Proposed Scheme upon the River Wensum SAC. Any changes to fluvial forms and geomorphological process due to the Proposed Scheme could result in alteration to the condition status of the River Wensum SAC.

1.1.3 In accordance with the Design Manual for Roads and Bridges LA113 Guidance (**Ref 1.1**), the approach to the detailed fluvial geomorphological assessment of the River Wensum SAC was agreed with both Natural England and the Environment Agency.

1.1.4 Whilst this report is a standalone fluvial geomorphological assessment of the River Wensum, the results also inform the impact assessments for both **Appendix 12.3: Water Framework Directive (WFD) assessment** (Document Reference: 3.12.03) and **Chapter 12: Road Drainage and Water Environment** (RDWE) of the Environmental Statement (Document Reference: 3.12.00) in support of the Planning Application.

1.2 Aim

1.2.1 The specific aim of this bespoke fluvial geomorphology assessment is to identify the potential construction and operation impacts of the Proposed Scheme on the fluvial processes and geomorphology receptors operating within the River Wensum Study Area.

1.3 Objectives

1.3.1 The specific objectives being tested are set below for the River Wensum:

- To quantify potential impacts upon the fluvial / hydraulic and geomorphological processes of erosion, deposition and sediment transport between baseline, construction, and operation of the Proposed Scheme. This is for a range of flood return periods;
- To specifically assess potential impacts of channel and floodplain shading during construction and operation upon fluvial processes due to the risk of both a reduction in macrophyte cover on the bed of the River Wensum and reduced vegetation growth on the floodplain beneath the viaduct, which could result in changes to hydraulic roughness and fine sediment deposition / erosion; and,
- To quantify potential changes in habitat biotopes between baseline, construction, and operation on the River Wensum for a range of flood return periods.

1.3.2 The results of this assessment will subsequently inform the WFD compliance assessment (**Appendix 12.3: Water Framework Directive assessment** (Document Reference: 3.12.03)) and the RDWE chapter in accordance with LA113 (**Chapter 12: Road Drainage and Water Environment** of the Environmental Statement (Document Reference: 3.12.00) in support of the Planning Application).

1.4 Overview of the Proposed Scheme

1.4.1 The Proposed Scheme comprises approximately 6 Kilometre (km) long dual carriageway connecting the A1067 and A47 roads near Norwich. It interacts with nearby watercourses, hence, requiring an understanding of existing (baseline) and future (construction and operation) fluvial processes and geomorphology receptors potentially affected by the Proposed Scheme.

1.4.2 The Proposed Scheme components that may have an impact upon the baseline characteristics of the River Wensum are defined by a geomorphology Study Area and relevant activities and are summarised below:

- 500 metre long viaduct over the River Wensum divided into a carriageway on a twin-deck arrangement. The design comprises 9 piers at approximately 54 metre intervals, which would neither be located within the active channel nor in nearby watercourses on the floodplain.
- 68.9 metre long length of a watercourse on the River Wensum left floodplain that would be temporarily culverted by a box-shaped structure. The dimensions of the culvert (approximately 3.5 metres wide x 1.5 metres high) are site-specific and have been designed to allow a free-flowing channel.
- During the construction phase, temporary haul routes would be in place to facilitate the construction of the Proposed Scheme. A temporary works platform with 12 embedded flood relief culverts would also to be in place. In addition, a temporary Bailey bridge would be constructed over the River Wensum.
- During operation, permanent access tracks for maintenance of the River Wensum viaduct would be in place. Two permanent ditch crossings on the right bank floodplain would be required for these operation access tracks. These ditches would therefore be permanently culverted.

1.4.3 In addition, the Proposed Scheme also includes modifications to the Foxburrow Stream, a tributary of the River Tud. These modifications include stream diversion, culverting and new outfalls and associated discharges. The proposed modifications to the Foxburrow Stream do not form part of this geomorphology assessment given that it is specifically focused upon the River Wensum and its SAC designation. An assessment of potential impacts to the fluvial geomorphology of the Foxburrow Stream as a result of the Proposed

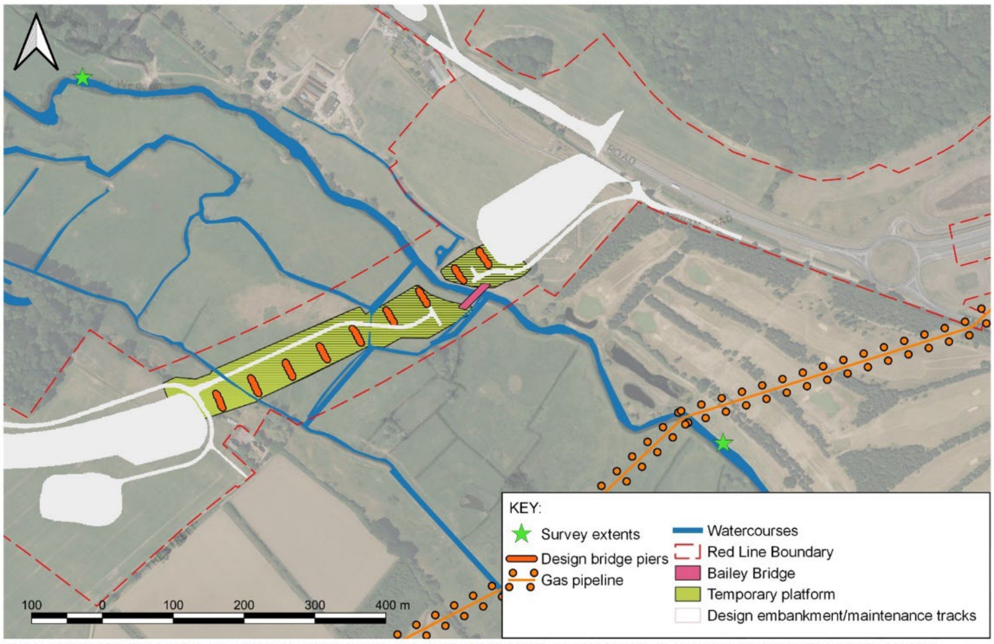
Scheme is provided within **Sub Appendix C: Foxburrow Stream Geomorphology Assessment** of **Appendix 12.3: Water Framework Directive assessment** (Document Reference: 3.12.03c).

1.4.4 The design drawings of the Proposed Scheme are available in **General Arrangement (GA) Drawings** (Document Reference 2.03.00). A description of the Study Area is given in **Section 1.5**. A full description of the Proposed Scheme is provided in **Chapter 3: Description of the Proposed Scheme** (Document Reference: 3.03.00) of the Environmental Statement.

1.5 Study Area

1.5.1 The proposed viaduct crossing over the River Wensum is located northwest of Norwich, near the area of Ringland, Norfolk. The Study Area for the geomorphology assessment covers approximately 1 kilometre of the River Wensum for the assessment of potential impacts with proposed viaduct crossing location situated centrally within the reach (**Figure 1.1**). Further details about the Proposed Scheme are provided in **General Arrangement (GA) Drawings** (Document Reference 2.03.00).

Figure 1.1 Study area of the geomorphology assessment and its relation to the proposed scheme



2 Methodology

2.1 Desk Study

2.1.1 A desk study was undertaken to better understand aspects of the geomorphology Study Area that could not be identified through standard field survey. For the desk study, a catchment-wide approach was taken to understand the characteristics of the River Wensum within its catchment setting and the pressures and impacts affecting the river system. A range of data and information were reviewed to build a more comprehensive overview of the area local to the Proposed Scheme. This helped formulate the baseline and assessment phases. The following data sources were used for the desk study:

- Aerial imagery (**Ref 2.1**);
- Anglian River Basin Management Plan (**Ref 2.2**);

- Contemporary Ordnance Survey (OS) maps (**Ref 2.3**);
- Environment Agency Catchment Data Explorer (**Ref 2.4**);
- Geology and soil maps (**Ref 2.5; Ref 2.6**);
- Geomorphological Appraisal of the River Wensum Special Area of Conservation (**Ref 2.7**);
- Historical maps (**Ref 2.8; Ref 2.9**);
- Hydrological and catchment data (**Ref 2.10**);
- River Wensum Strategy (**Ref 2.11**); and,
- Old reports and accounts showing capital works and maintenance modifying parts of the River Wensum (**Ref 2.12**)
- Various academic texts referenced throughout this report.

2.2 Field Survey

2.2.1 Geomorphology walkover surveys were undertaken on 5 December 2019, 15 July 2020, 11 November 2020, and 31 August 2022 to gain an understanding of baseline hydromorphological processes operating within the Study Area of the River Wensum and its floodplain local to the proposed activities. The site survey encompassed an approximately 1km length of river and floodplain, with the location of the proposed viaduct crossing located centrally. Field notes and a photographic record were taken to record and characterise the fluvial geomorphology of the channel and floodplain connectivity.

2.2.2 Weather conditions up to and during the 5 December 2019 survey were dry and cold with water levels having receded following heavy rain and flooding in the previous weeks.

2.2.3 Weather conditions leading up to the 15 July 2020 were rainy but with water levels within the normal range.

2.2.4 Weather conditions up to and during the 11 November 2020 survey were unsettled and water levels were elevated (concurrent with winter aquifer recharge) with near bankfull conditions. Despite elevated flows, channel substrate and bedforms were mostly visible during the walkover survey with partially consolidated gravels and silt observed. Due to the extent of silt, it was not possible to determine whether the bed substrates were fully consolidated to form and armoured layer.

2.2.5 Weather conditions leading up to the 31 August 2022 survey were wet following a period of drought during a dry and hot summer. River levels were normal and within the typical range for summer flows. The survey methodology was adapted from Thorne (**Ref 2.13)** and includes data on:

- Valley form;
- Land use;
- Floodplain and riparian zone;
- Channel geometry;
- Bank material and structure;
- Bed material and forms;
- Erosion features (sediment sources);
- Depositional forms (sediment sinks); and,
- Artificial features and modifications.

2.2.6 In addition to the geomorphological walkover survey, sediment sampling was conducted at discrete locations within the affected reaches. This was conducted during a general summer walkover survey on 15 July 2020 and 31 August 2022 when the water levels were lower. The sediment was sampled with a grab sampler with particle size distribution recorded using the Wentworth (**Ref 2.14)** particle size scale.

2.2.7 Data was plotted by size class (log_2 scale) and frequency to determine the particle size distribution. The following characteristics are calculated for all samples:

- D_{16} – the particle size that 16% of the samples are equal to or smaller than;
- D_{50} – the particle size that 50% of the samples are equal to or smaller than; and
- D_{84} – the particle size that 84% of the samples are equal to or smaller than.

2.3 Geomorphological Dynamics Assessment

River Wensum

2.3.1 A range of geodynamics assessments was undertaken to assess the potential construction and operation geomorphological impacts of the proposed viaduct across the River Wensum. These analyses include from a geomorphology perspective an assessment of velocity, stream power, shear stress, sediment transport and Froude. The methods employed to assess potential impacts to fluvial dynamics are provided in **Sub Appendix A: Geomorphological Dynamics Assessment** of **Appendix 12.4: River Wensum Geomorphology Assessment** (Document reference: 3.12.04a).

2.3.2 Specific geomorphology receptors being assessed include:

- Sediment regime (including changes to erosion and deposition processes);
- Channel morphology (including bank profile, bank and bedforms, bed level and floodplain morphology);
- Natural fluvial processes (including in-channel habitat biotopes).

Hydraulic Modelling

2.3.3 A fully-2D hydrodynamic model of the River Wensum and adjacent floodplain has been constructed and the results also used as to inform the geomorphological dynamics assessment. A fully-2D model has been selected as the appropriate tool to quantify changes to shear stress, stream power, velocity and flow, as high-resolution output parameters are available within the channel. This modelling was undertaken for baseline, construction and operation for a range of flood return periods.

2.3.4 Although previous ecological analysis support that the operation of the proposed viaduct would not result in an overall loss of macrophytes due to shading (see **Section 3.7**), a sensitivity analysis was conducted to quantify the potential impact of macrophyte loss on hydraulics / hydrology and sediments. This is to ensure that any potentially adverse impact is forecast and mitigated appropriately.

2.3.5 In addition, the shading sensitivity analysis also included modelling the potential terrestrial shading effects under the viaduct structure given that any shading could alter the structure and density of vegetation both within the riparian zone and floodplain, as well as in-channel effects.

2.3.6 The potential for a reduction in vegetation cover was simulated within the model by selecting the minimum roughness Manning's coefficient for the river type. This low roughness value was applied to the zone the shading assessment report identified as being impacted by shading effects (**Ref 2.15**).

2.3.7 Further details on the approach to the 2D hydrodynamic modelling are provided in **Sub Appendix A: Geomorphological Dynamics Assessment** of **Appendix 12.4: River Wensum Geomorphology Assessment** (Document reference: 3.12.04a).

3 Baseline Conditions

3.1 Catchment Overview

3.1.1 The River Wensum rises on Colkirk Heath at an altitude of 75m AOD and flows west to east for approximately 78km through the County of Norfolk before joining the River Yare in Norwich. The River Wensum is a groundwater dominated chalk river and represents 'one of the best examples of a naturally enriched calcareous lowland river' (**Ref 2.7**). Consequently in 1993, 70.1 kilometres of the River Wensum was classified as a 'whole river' Site of Special Scientific Interest (SSSI) in recognition of the rich variety of plants, invertebrates, and fish that the river supports.

Land Use

3.1.2 Land use within the catchment is dominated by agriculture and intensive arable farming accounting for around 74% of land use area. The dominance of agriculture creates significant water management pressures within the catchment. The Wensum floodplain is largely occupied by grazing marsh with around 14% of the catchment land use being grassland. In addition, there are discrete parcels of fenland, reedbed and wet grassland. Woodland accounts for around 9% of land use, whilst the remaining 3% is occupied by urban areas (**Ref 2.10)**.

3.2 Hydrology

3.2.1 Flow within the Wensum is derived from groundwater (chalk aquifer) with base flow indices of between 0.7 and 0.85, resulting in a largely predictable flow regime with annual cycles of summer drawdown and winter recharge of the underlying chalk aquifer. Extensive drainage management has a significant effect on floodplain hydrology, while **Ref 2.7** reports that 14 in-channel structures act as hydraulic controls on river flow, including three long-term gauging stations at Fakenham, Swanton Morley and Costessey Mill. Daily gauged data from each station is provided in **Figure 3.1** and key flow metrics are provided in **Table 3-1**.

Figure 3.1 Gauged daily discharge from Costessey Mill, Swanton Morley and Fakenham gauging stations (source: Ref 2.10)

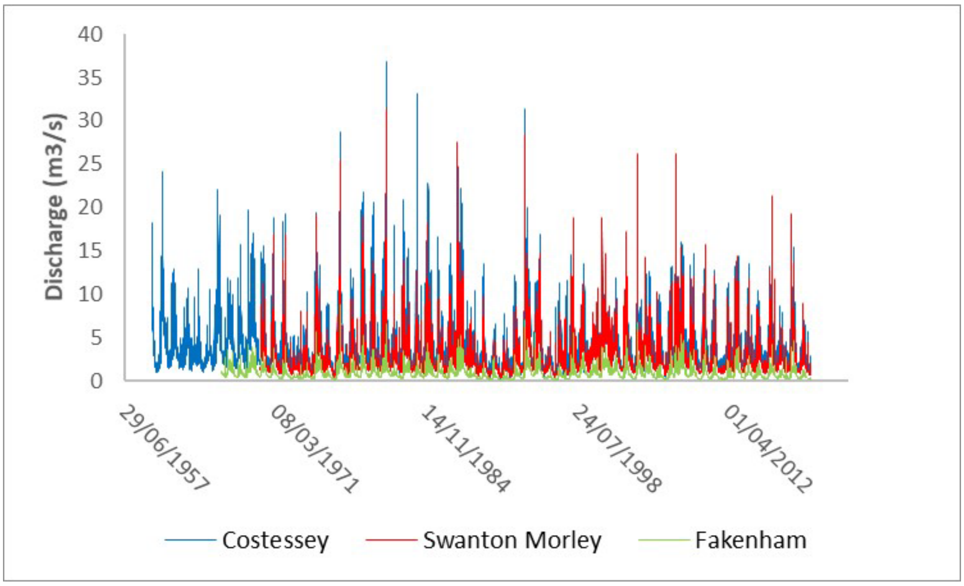


Table 3-1 Flow metrics for Costessey Mill, Swanton Morley and Fakenham (source: Ref 2.10). Annual Exceedance Probability (95%, 70%, 50%, 10%, and 5%) is the probability of a certain size of flood flow occurring in a single year

Flow Metric	Costessey Mill	Swanton Morley	Fakenham
Baseflow Index	0.75	0.75	0.82
Mean Flow (m^3/s)	4.1	2.72	0.85
95% Exceedance (Q_{95}) (m^3/s)	1.35	0.94	0.24
70% Exceedance (Q_{70}) (m^3/s)	2.34	1.51	0.48
50% Exceedance (Q_{50}) (m^3/s)	3.22	2.12	0.68
10% Exceedance (Q_{10}) (m^3/s)	7.44	5.02	1.63
5% Exceedance (Q_5) (m^3/s)	9.65	6.52	1.98

3.3 Geology and Soils

Bedrock Geology

3.3.1 As previously briefly described, the River Wensum catchment is predominantly underlain by chalk belonging to the White Chalk Subgroup formed during the Cretaceous period (**Ref 2.5**).

Superficial Geology

3.3.2 Superficial geology within the Wensum Catchment is broadly dominated by clay and till material deposited during successive glaciations throughout the Quaternary period. However, the River Wensum corridor is underlain with alluvium and successions of terrace deposits concurrent with the more recent fluvial history of the system.

Soils

3.3.3 Soils within the Wensum catchment are variously comprised of rich loams, soils of a high organic content (loamy peat / peaty loam) and silts. The Wensum valley floor is characterised by low permeability soils over clay; while the valley sides accommodate permeable, highly fertile sandy loams which have considerable cultivation potential, but require extensive irrigation (**Ref 2.6**).

3.4 Historical Channel Change

3.4.1 The evolution of the River Wensum system may be considered over the last 10,000 years following the Last Glacial Maximum (LGM) heralding a period of warming and glacial retreat throughout the Upper Pleistocene (17,000 to 6,000 B.P) and Holocene (6,000 B.P. to the present) – a period referred to as The Flandrian. The climatic conditions at the beginning of this period, coupled with periglacial processes, such as rapid deglaciation and meltwater discharge, generated high-energy floods capable of mobilising and transporting large quantities of sediment. Accordingly, this brought about sequences of valley floor alluviation and incision, thus developing the depositional forms that are observable today, for example river terrace sequences. During this period, the River Wensum exhibited a more braided channel morphology, concurrent with high sediment yield and high energy flow regime. As the climate changed, so the River Wensum transitioned from a high energy braided system to low energy, multi-channel anastomosed, in response to development of cohesive floodplain deposits and afforestation.

3.4.2 The complex natural evolution of the Wensum system was further compounded by the introduction of anthropogenic pressures midway through the 10,000-year period considered here. Extensive deforestation and land clearing from around 5,000 B.P. resulted in mobilisation of fine sediment which ultimately deposited across valley floors, blocked multiple channels, and led to the creation of the stable, single-thread, passively meandering system evident today. However, evidence of former channels can be found across the valley floor, many of which have been exploited for land drainage purposes (widened, deepened and straightened). Contemporary alteration of the hydrological functioning of the system throughout the last few centuries, by means of water milling and extensive land drainage, has further reinforced the inactive, modified character of the River Wensum and its tributaries.

3.5 River and Floodplain Morphology (Typology)

3.5.1 As suggested above, the morphology of the River Wensum is intrinsically linked to its underlying geology, climatic conditions, flow and sediment regime and gradient; along with the wide-ranging anthropogenic pressures that exist within its catchment. More specifically, the morphology of the Study Area is defined by its setting within the catchment. **Ref 2.7** sub-divides the River Wensum into two broad groups of morphological similarity, and describe the downstream region, in which the Study Area sits, as: "*Sinuous meandering channel formerly multi-threaded with woody debris and limited development of pool-riffle sequence. Groundwater dominated hydrology with extensive wet fen / Carr floodplain communities underlain by peat. Upwelling groundwater creates mosaic of wetland habitats including pools on floodplain surface*."

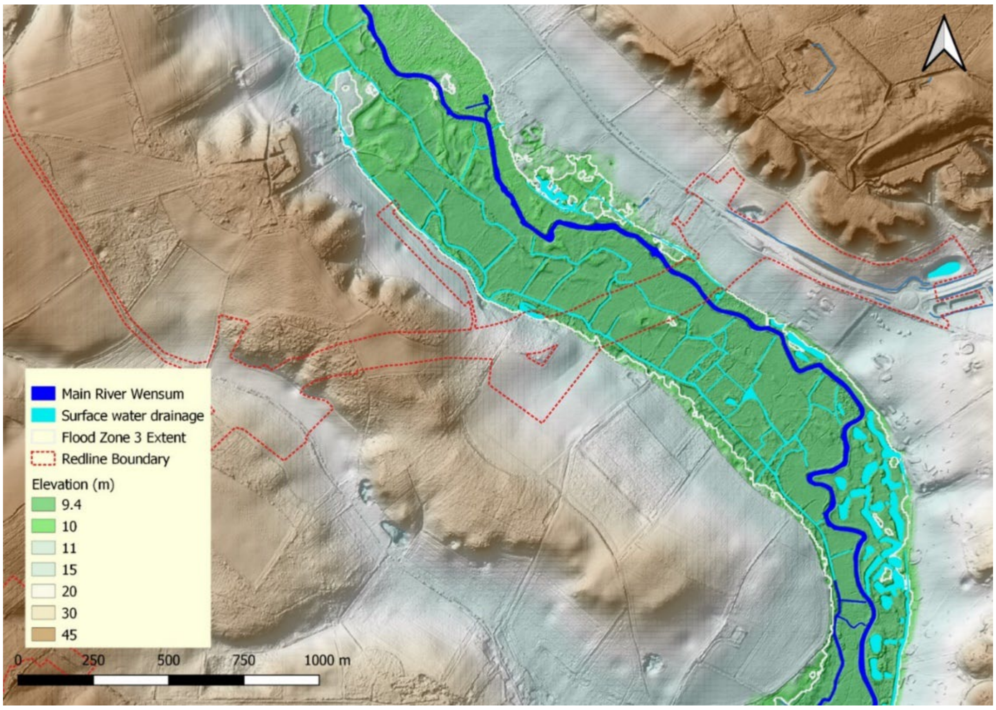
3.5.2 The walkover survey in November 2020 largely confirmed this broad characterisation of the lower Wensum, although extensive wet fen / carr and woody debris was not recorded in any significant quantity within the Study Area specifically. According to Lewin (**Ref 3.1**) the River Wensum is a clay lowland river, with negligible planform historic changes due to naturally low lateral channel-migration rates. It has a relatively low regional slope (and low stream powers) and cohesive bank materials. This combination explains the lack of perceptible channel migration in such channels. The Wensum has been further classified as having an inactive floodplain (with wetlands) (**Ref 3.2**).

3.5.3 Flow patterns within the survey reach were noted to be mostly smooth, laminar flow; however, considerable assemblages of submerged *Ranunculus penicillatus subsp*. pseudofluitans. This is the dominant plant in many British base-rich rivers and streams, favouring moderately or rapidly flowing, mesotrophic or meso-eutrophic water, and being most frequent where the water flow is broken by riffles. In sluggish eutrophic rivers it is replaced by other species. In addition, riparian vegetation was noted similarly to generate a range of niche hydraulic habitat, while over-hanging trees, usually willow and alder, created additional flow variance.

3.5.4 The man-modified form of the Wensum, coupled with its lowland river morphology, has resulted in limited presence of depositional bedforms such as bars and riffles. Water depth throughout the Study Area was noted to be fairly uniform (notwithstanding the presence of *Ranunculus* sp), similarly indicating a lack of bedform variation.

3.5.5 A map of the River Wensum floodplain, topography and drainage network is provided in **Figure 3.2**.

Figure 3.2 Topography and drainage network of the River Wensum study area



3.5.6 Substrate throughout the Study Area was noted to comprise predominantly of fine to medium gravels (see **Section 4.2**) whilst bank material was noted to be comprised of cohesive soils capable of supporting a rich riparian zone. However, the riparian zone was noted to be somewhat fragmented throughout the Study Area, with lengths of very high-quality riparian habitat interspersed with lengths where practically none is present. No significant structures were noted in the Study Area capable of influencing sediment transport processes or impounding flow. The only structure being the footbridge near Attlebridge Hall. Here, a ford crossing was noted on the immediate upstream side of the footbridge, whose operation likely exerts a localised adverse influence by constricting the flow.

3.5.7 No significant erosion was noted in the Study Area, which reaffirms the Wensum's inactive morphology; however, discrete lengths of bank were apparently affected by livestock poaching where no riparian buffer was observed to be present.

3.5.8 The Wensum channel within the Study Area sits towards the left (north-eastern) side of the wide valley floor. Its right-hand floodplain (looking downstream) extends around 350m to the south-west before becoming confined by the rising valley sides; the left floodplain becomes almost immediately confined by rising topography (see **Figure 3.2**). The floodplain is strewn with man-made ditches that drain the valley sides and floodplain, generally flowing perpendicular to the main channel. The ditches are often intercepted by relict channels that once would have formed part of the natural anastomosed system previously described. Many of the ditches and former active channels, despite being either unnatural or functionally diminished, nevertheless have considerable ecological value, supporting strips of fen / carr habitat, and populations of nationally rare aquatic species such as lamprey (*Lampetra* Spp). Whilst this assessment does not consider the plants and animals that are supported by the Wensum specifically (see **Appendix 12.3: Water Framework Directive Assessment** (Document Reference: 3.12.03), **Chapter 10: Biodiversity** (Document Reference: 3.10.00)**, Chapter**

11: Bats (Document Reference: 3.11.00)**, and Appendix 10.35: Arboriculture** (Document Reference: 3.10.35) of the Environmental Statement), it is important to stress that sensitive habitats and species such as these are considered in the development of mitigation for the Proposed Scheme elsewhere within the Environmental Statement.

3.6 Designations

3.6.1 The River Wensum is a 'whole river' Site of Special Scientific Interest (SSSI). The river was designated a SSSI in 1993 and a Special Area of Conservation SAC in 2000.

3.7 Solar Exposure and Ecological Response

3.7.1 A combination of field and modelling analysis were conducted by a bespoke shading assessment (**Ref 2.15**) to understand potential impacts on macrophytes because of viaduct-induced shading. Any alteration to macrophytes could trigger a fluvial response due to potential changes in bed roughness, which in turn could alter sediment transport processes and bedforms within the channel.

3.7.2 According to this shading assessment, 24 macrophyte taxa were recorded in the macrophyte survey conducted on 16 August 2022, 12 of which are LEAFPACS2 scoring taxa. The majority of the Survey Area was dominated by macrophytes with an Ellenberg light indicator value of 7 (plants that grow generally in well-lit places but also occur in partial shade).

3.7.3 Clasping-leaved pondweed *Potamogeton perfoliatus* was the most dominant species, accounting for an estimated 60% of the Survey Area’s total macrophyte cover. Stream water-crowfoot *Ranunculus penicillatus* subsp. *pseudofluitans*, a species characteristic of the River Wensum SAC, was the only species of water-crowfoot observed, accounting for an estimated 15% of the Survey Area’s total macrophyte cover.

3.7.4 In addition to stream water-crowfoot and clasping-leaved pondweed, a further four macrophyte species listed as characterising habitat type 3260 vegetation 'watercourses of plain to montane levels with *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation' were recorded in the survey.

3.7.5 The macrophyte community within the Survey Area was found to be diverse and indicative of "High" ecological status as defined by the WFD.

3.7.6 During the construction phase, the shading assessment concludes that the Bailey bridge would likely result in localised shading and temporary loss of the macrophyte community within its immediate vicinity. However, the shading effect caused by the temporary crossing would be transient in nature (for the duration of the construction period), and, therefore, no long-term vegetation loss or reduction to roughness is foreseen.

3.7.7 The shading assessment report (**Ref 2.15**) states that during the operational phase, there would be a potential change in the composition of the plant community in areas affected by shading, but it would not affect the overall status of the river. This is because some of the more shade-tolerant plants within the designated community could still grow, whilst others less tolerant of shading may eventually be replaced.

3.8 Utilities

3.8.1 During a site visit in November 2022, an underground gas pipeline crossing the River Wensum was observed (see **Figure 3.3**). The gas pipeline is approximately 450m downstream of the proposed viaduct crossing.

3.8.2 During a site visit in November 2022, an underground gas pipeline crossing the River Wensum was observed (see **Figure 3.3**). The gas pipeline is approximately 450 metres downstream of the proposed viaduct crossing.

Figure 3.3 Underground gas pipeline crossing the River Wensum (OS NGR TG 14426 15194)

4 Geomorphological Assessment

4.1 Geomorphology Assessment Results

4.1.1 A combination of desk study, field investigation, hydraulic modelling, standard assessment methodologies and professional judgement has been employed to assess changes to geomorphological processes and forms operating with the River Wensum catchment that could have an impact on, or that may be affected by, the Proposed Scheme. Each component of the Geomorphology Assessment is presented in **Section 4.2** below. All mapped outputs from the River Wensum hydraulic modelling are provided in **Sub Appendix B: Velocity** (Document Reference: 3.12.04b) to **Sub Appendix F: Froude Number** (Document Reference: 3.12.04f) of **Appendix 12.4: River Wensum Geomorphology Assessment**.

4.2 Sediment Transport

4.2.1 The potential for sediment transport along the River Wensum is geomorphologically assessed by determining the particle size distribution within the Study Area, the use of sediment sampling data, and 2D hydraulic modelling with varying roughness to simulate changes in macrophyte coverage due to shading. Three scenarios are considered for analysis: baseline, construction, and operation phases.

Baseline

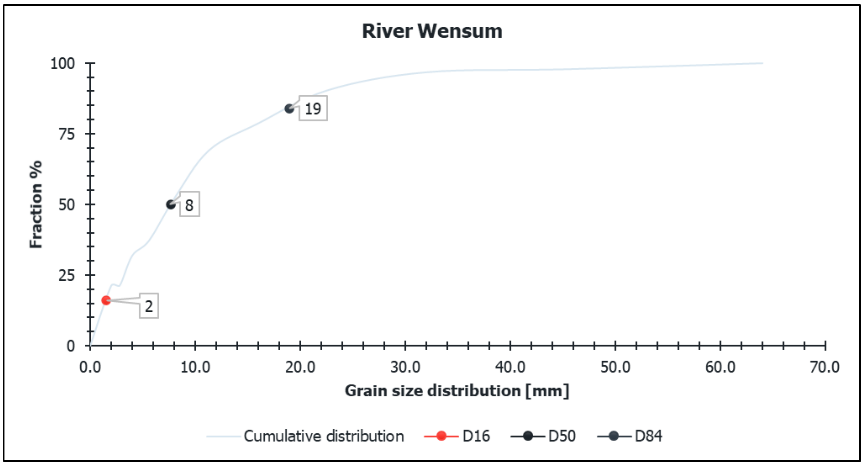
4.2.2 The grain size distribution analysis conducted shows that the River Wensum within the Study Area has a median grain size, D_{50}, equivalent to fine gravel (8mm), whilst the D_{16} and D_{84} are equivalent to very coarse sand (2mm) and coarse gravel (19mm), respectively. The largest particle (D_{100}) from the sample is 49mm (very coarse gravel). The sediments were noted to be partially consolidated, however, silt deposition on the river bed obscured observations preventing the identification of an armoured bed. **Figure 4.1** details the cumulative distribution of grain sizes in the Study Area.

4.2.3 According to the Hjulström curve (**Ref 4.1**), these particles require flow velocities between 0.10m/s and 1m/s to be transported. Velocities higher than 0.50m/s, 1m/s, 2m/s and 3m/s are sufficient to erode the riverbed if the substrate is equivalent to D_{16} to D_{100}.

4.2.4 Hydraulic data from a previous fluvial geomorphology report (**Ref 4.2**) indicates that bankfull discharge (the approximate 2-year flow event) is between 0.5 and 0.6m/s. These velocities are sufficient to erode the riverbed if the substrate is equivalent to D_{16}, and to transport those ranging from D_{50} to D_{84}. The largest particle size on the riverbed (D_{100}) is just below the threshold of motion, and, hence, would not be transported.

4.2.5 More accurate data from the 2D hydraulic model shows that 2-year baseline flow velocities are typically within 0.4 to 0.6m/s (see **Sub Appendix B: Velocity** (Document Reference: 3.12.04b)), like those previously estimated by **Ref 4.1**. Bed shear stress (see **Sub Appendix C: Bed Shear Stress** (Document Reference: 3.12.04c)) estimated for the same 2-year baseline flow supports that particles coarser than medium gravel (8 - 16mm) and medium gravel (13 – 32mm) would be stable on the river bed. These results correspond with the Hjulström curve prediction.

Figure 4.1 Cumulative grain-size distribution of sediment samples from the River Wensum



Construction

4.2.6 Whilst 2D hydraulic model shows that 2-year baseline flow velocities are typically within 0.4 to 0.6m/s (see **Sub Appendix B: Velocity** (Document Reference: 3.12.04b)) it predicts an increase of in-channel flow velocity to between 1m/s to 1.4m/s (2-year flow) for the construction phase. However, the impact of the construction phase on sediment transport is expected to be negligible. According to the Hjulström curve, smaller particles (e.g., D_{16}) would still be eroded, whilst coarser particles (D_{50} to D_{84}) would be transported in a 2-year flow event mirroring the baseline transport pattern. Similarly, to the baseline condition, the largest particle size on the riverbed (D_{100}) is just below the threshold of motion, and, hence, would not be transported.

4.2.7 Bed shear stress (see **Sub Appendix C: Bed Shear Stress** (Document Reference: 3.12.04c)) estimated for the same 2-year construction phase flow supports that particles coarser than medium gravel (8mm - 16mm) and medium gravel (13 – 32mm) would be stable on the river bed, supporting the Hjulström curve prediction and reflecting the same behaviour as the baseline condition.

4.2.8 Further implications to transport processes in higher flows (5-year to 100-year) during the construction phase are assessed below through modelled velocities, shear stress, stream power and Froude. Using these results, inferences will be made on the potential changes to geomorphological processes and receptors (sediment regime, channel morphology and natural fluvial processes).

Operation

4.2.9 The simulations of vegetation loss due to shading demonstrate that the impact in fluid and sediment dynamics is negligible. When compared, simulations with minimum roughness coefficient remain spatially similar to those with average roughness. The similarity remains for all investigated parameters (maximum velocity (m/s), maximum depth (m), bed shear stress (N/m^2) Froude number (dimensionless), and stream power (W/m^2)), and for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change). Therefore, no changes to the geomorphological receptors are anticipated should the shading effect reduce channel and floodplain roughness through vegetation die-back.

4.2.10 The potential operation impacts on sediment transport are further assessed below through the assessment of modelled velocities, shear stress, stream power and Froude. Using these results, inferences will be made on the potential changes to geomorphological processes and receptors (bank profile and forms, bedforms and bed level, floodplain morphology, and in-channel habitat biotopes).

4.3 Flow Velocity

Baseline

4.3.1 Baseline velocities shown in **Sub Appendix B: Velocity** (Document Reference: 3.12.04b) reveal that the River Wensum has a typical flow velocity of between 0.4 – 0.8m/s at the 1 in 2-year return period (i.e., for flows that are roughly equivalent to bankfull). The mapped outputs reveal localised zones of both lower and higher flow velocities within the 0.2 – 0.4m/s and between 1-1.4m/s respectively.

4.3.2 The patterns of baseline flow velocity remain consistent for the other modelled flood return periods of 1 in 20, 1 in 100, and 1 in 100-year +20% CC events.

Construction

4.3.3 2D hydraulic model results predicts an increase of in-channel flow velocity from baseline conditions for all return intervals in the vicinity of the proposed temporary works zone due to the constriction of flows. The maximum velocities of the construction phase are 1.4m/s (2-year flow), 1.6m/s (20-year flow), 2.0m/s (100-year flow), and 2.25m/s (100-year + CC flow).

4.3.4 The zone of influence of flow velocities starts at the upstream extent of the proposed temporary works zone and extends for approximately 175 metres downstream for all modelled return periods. Therefore, the modelled results indicate that the zone of impact does not extend far enough downstream so as to have an adverse impact upon the gas pipeline.

4.3.5 As attested by maximum water depth values, the temporary footprint increases water depth upstream during flood flows (>2-year events) whilst conveying more water to the main channel. Hence, the higher water conveyance to channel increases velocity along the Study Area.

4.3.6 The modelled velocity results indicate the ability of the river to entrain and transport sediment, which could result in localised alteration to bed levels and bedform during the construction phase. Vegetation removal for the enabling works may also expose the banks to erosive forces due to the increase in velocity. Bank material was observed to be cohesive, however, the disturbance to the ground during the construction phase could result in localised effects to bank profile and form due to exposure to higher velocities during the construction phase.

4.3.7 When accounting for a reduction in roughness due to the potential shading effect caused by the Bailey bridge, the flow velocity values remain largely similar to what would occur during the construction phase with the baseline roughness (i.e., with no shading impacts). The similarity between those scenarios occurs for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change), and supports that the reduction in roughness due to shading would not be sufficient to produce a significant change in river processes. Therefore, the modelled results indicate no sensitivity to the effects of shading during construction.

Operation

4.3.8 The results of the 2D hydraulic modelling suggest no notable difference between baseline and operation flow velocities for the range of flood return periods modelled including accounting for potential reduction in roughness due to shading effects. Flow velocities remain typical for this watercourse and within the normal ranges. Therefore, no impacts on flow velocity within the River Wensum are anticipated during operation as a result of the Proposed

Scheme. Consequently, no changes to geomorphology receptors are expected during operation.

4.4 Shear Stress

Baseline

4.4.1 Under baseline conditions, the shear stress results, presented in **Sub Appendix C: Bed Shear Stress** (Document Reference: 3.12.04c), reveal that the River Wensum has the energy to overcome the frictional forces to transport medium gravels (8mm-16mm) under all flood return periods modelled. There are also some localised zones both upstream and downstream of the proposed crossing where coarse (16 mm-32 mm) and very coarse gravels (32 mm-64 mm) may be mobilised. Whilst the River Wensum may have the energy to overcome the frictional forces for sediment entrainment, coarse and very coarse gravel sized particles are likely to drop out of suspension rapidly. These results concur with the Hjulström curve prediction.

Construction

4.4.2 During the construction phase, there is no impact to bed shear stress under the 1 in 2-year flood return period.

4.4.3 Under the 1 in 20-year flood return period, there is a localised increase in bed shear stress within the zone of the temporary works. Here, the bed shear stress increases with the ability to overcome the frictional forces for entrainment of coarse gravels (16mm-32mm). The zone of influence extends for approximately 120 metres. From approximately 50 metres downstream of the temporary works, the bed shear stress values return to those of baseline conditions.

4.4.4 Therefore, potential impacts on bed shear stress under a 1 in 20-year flood return period are highly localised.

4.4.5 Under a 1 in 100-year flood return period, the increase in bed shear stress extends for approximately 135 metres both within and downstream of the proposed temporary works zone. The results (see **Sub Appendix C: Bed Shear Stress** (Document Reference: 3.12.04c)) suggest that the bed shear stress has the energy to overcome the frictional forces to entrain coarse (16 mm-32 mm) and very coarse gravels (32 mm-64 mm) particle sizes. Downstream of the zone of influence, bed shear stress levels return to those of baseline conditions.

4.4.6 The results for the 1 in 100-year plus 20% CC event are consistent with the 1 in 100-year flood return period.

4.4.7 Therefore, under a 1 in 2-year return period, no change to geomorphological processes or receptors are anticipated during the construction phase.

4.4.8 Should higher magnitude events occur during the construction phase, changes to boundary shear stress within the channel may result in increased ability of the river to entrain, and transport coarse gravels and very coarse gravels for the 100-year flood return period or greater. These impacts would be localised with a modelled maximum extent of impact of 135 metres. Should high magnitude events occur during the construction phase, impacts to geomorphology receptors may include a localised alteration to bedforms and bed level due to bed scour and deposition of the entrained and transported sediment and alteration to bank form and profiles within the zone of impact.

4.4.9 It is pertinent to note that there would be no changes to bed shear stress under the 1 in 2-year flood return period. During the temporary works phase, the likelihood of a high magnitude event occurring is low and therefore the risk of increased ability of the River Wensum to overcome the frictional forces to entrain coarser sediment fractions compared to baseline is also low.

4.4.10 The likelihood of a 1 in 100-year event occurring during the temporary works phase is extremely unlikely. Even with a 1 in 20-year flood return period occurring during the temporary works phase, the potential mobilisation of coarse gravels would be limited to approximately a 120m length of channel. Any entrainment of coarse gravel fractions would also likely be deposited rapidly as the river is unlikely to have the energy to keep the particles in suspension. Therefore, even in an extreme event during the construction phase, the results indicate that any bed or bank scour would be highly localised and unlikely to extend downstream to the location of the existing gas pipeline. Any scour would also likely be infilled by sedimentation during successive floods and therefore any impacts would likely be temporary in nature.

4.4.11 When accounting for a reduction in roughness due to the potential shading effect caused by the Bailey bridge the bed shear stress values remain largely similar to what would occur during the construction phase with the baseline roughness (i.e., with no shading impacts). The similarity between those scenarios occurs for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change), and supports that the reduction in roughness due to shading would not be sufficient to produce a significant change in river processes. Therefore, the modelled results indicate no sensitivity to the effects of shading during construction.

Operation

4.4.12 During operation, the results (see **Sub Appendix C: Bed Shear Stress** (Document Reference: 3.12.04c)) reveal no perceptible change in bed shear stress between baseline and operation for the range of flood return periods modelled including accounting for potential reduction in roughness due to shading effects. Therefore, no significant changes on bed shear stress are anticipated during operation as a result of the Proposed Scheme. Consequently, no changes to geomorphology receptors are expected during operation.

4.5 Water Depth

Baseline

4.5.1 Under baseline conditions, the water depth results, presented in **Sub Appendix D: Water Depth** of **Appendix 12.4: River Wensum Geomorphology Assessment** (Document Reference: 3.12.04d)), reveal that the River Wensum can be flooded for all flood return periods modelled and primarily on the right floodplain, where a set of interconnected ditches coexist. The maximum flood extents remain largely similar for the modelled scenarios, reaching 325 metres on the river right floodplain and 150 metres on river left floodplain. However, water depth varies spatially between modelled flood flows, with maximum 600-900mm in a 2-year flow up to 1,500-3,000mm in a 100-year +20% CC flow.

Construction

4.5.2 During the construction phase, and under the 1 in 2-year flood return period, there is an increase in water depth upstream of the zone of the temporary works (see **Sub Appendix D: Water Depth** (Document Reference: 3.12.04d)). The water depth increases because of the flow barrier imposed by the temporary works area. The zone of influence extends for approximately 400 metres upstream of the temporary works structure. From immediately downstream of the temporary works, the water depth values return to those of baseline conditions. Therefore, potential changes to water depth values under a 1 in 2-year flood return period are localised to a 400 metres zone upstream of the temporary structure.

4.5.3 Under a 1 in 20-year flood return period, the increase in water depth extends for approximately 850 metres upstream of the proposed temporary works zone. Downstream of the zone of influence, water depth levels return to those of baseline conditions. Under a 1 in 100-year flood return period, the increase in water depth also extends for approximately 850 metres upstream of the proposed temporary works zone, and downstream of the zone of influence, water depth levels return to those of baseline conditions. The results for the 1 in 100-years plus 20% CC event show slightly deeper water levels than the 1 in 100-year flood return period, especially in the uppermost area of influence (approximately 850 metres upstream).

4.5.4 Hence, there would be a localised impact to the water level upstream of the temporary works under the 1 in 2-year flood return period, and more widespread changes in water levels to high magnitude / low likelihood events only (>5-year flows). However, modelled results indicate that the maximum extents of the flood zone would remain similar for all flood events, therefore, with limited impact upon the adjacent valley areas. Water depth returns to baseline downstream of the temporary works area.

4.5.5 The results therefore indicate greater storage of water upstream of the temporary works area. This could result in greater sedimentation within the floodplain, which could cause highly localised changes to floodplain morphology as a receptor and greater storage of fine sediment within the floodplain upstream of the temporary works. The increased water depth explains the change in habitat biotopes (as a geomorphology receptor) to glide-pool habitat in the reach upstream of the temporary works during the construction phase (see **Section 4.7**).

4.5.6 When accounting for a reduction in roughness due to the potential shading effect caused by the Bailey bridge, the water depth values remain largely similar to what would occur during the construction phase with the baseline roughness. The similarity between those scenarios occurs for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change), and supports that any potential reduction in roughness due to shading would not be sufficient to produce a significant change in river processes (i.e., with no shading impacts). Therefore, the modelled results indicate no sensitivity to the effects of shading during construction.

Operation

4.5.7 During operation, there is a small increase in water depth values along the right floodplain with no impact on flood extents (see **Sub Appendix D: Water Depth** (Document Reference: 3.12.04d)). The water depth increase is restricted to small areas (<10m^2) near the floodplain boundary.

4.5.8 The results of the 2D hydraulic modelling suggest negligible difference between baseline and operation for water depth for the range of flood return periods modelled including accounting for potential reduction in roughness due to shading effects. No significant impacts on water depth during flood flows are anticipated during operation as a result of the Proposed Scheme.

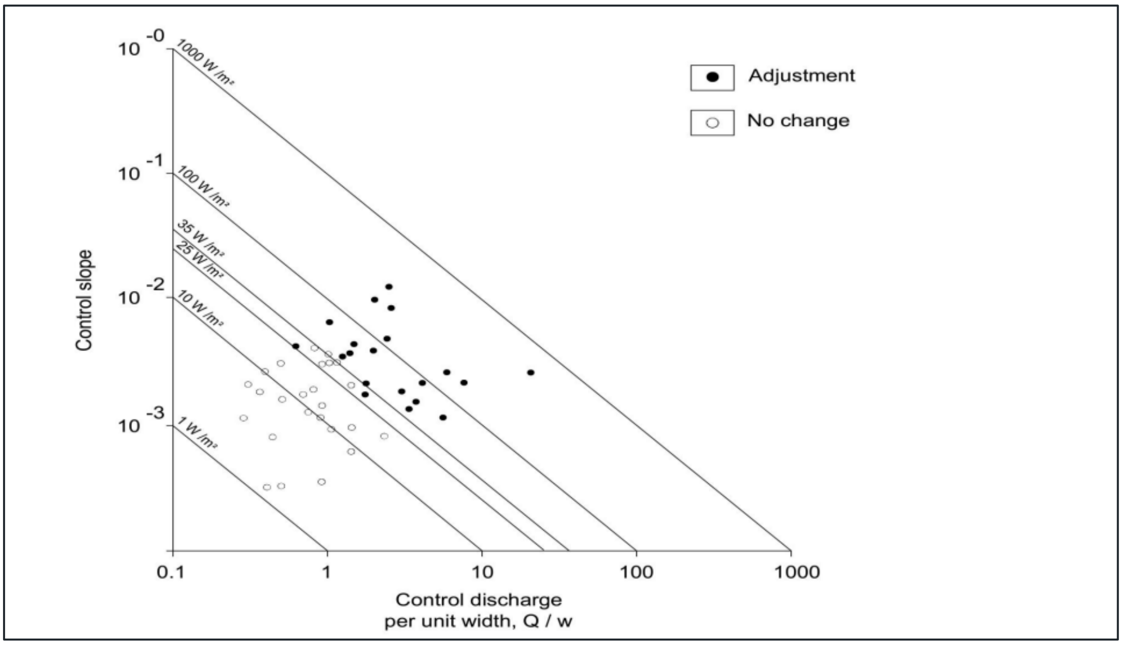
Consequently, no changes to geomorphology receptors are expected during operation.

4.6 Specific Stream Power

4.6.1 Specific stream power can define if, and how, a Proposed Scheme may be affected by geomorphic processes of erosion or deposition (and vice-versa). Given that geomorphic processes are modulated by hydraulic parameters (e.g., flow velocity and depth), any change in hydraulics is expected to impact geomorphology receptors. However, channel processes are also determined by river morphology in the short to medium spatial scales (**Ref 4.3** and **Ref 4.4**). Hence, construction and operation of infrastructure schemes that change river morphology would eventually alter existing hydraulic processes and can lead to further morphological impacts. These impacts in geomorphic processes can alter river geometry, and, ultimately, baseline condition within the reach.

4.6.2 Channel adjustment usually occurs when specific stream power, a measure of the combined effect of slope, fluid dynamics, discharge and channel width, exceeds the critical threshold required for sediment entrainment. The threshold for the onset of erosion is generally regarded as a specific stream power of $35W/m^2$ (**Ref 2.12**). However, the onset of channel adjustment may occur between a specific stream power range of $25W/m^2$ - $35W/m^2$. Where specific stream power exceeds $35W/m^2$ channel adjustment is more likely to occur (see **Figure 4.2**). This dataset is limited so use of the tool at a specific site/ geographic area needs to be treated with caution.

Figure 4.2 Relationship between specific stream poser and channel adjustment adapted from Brookes (Ref 2.12)



Baseline

4.6.3 The 2D hydraulic modelling results for specific stream power are provided in **Sub Appendix E: Specific Stream Power** of **Appendix 12.4: River Wensum Geomorphology Assessment** (Document Reference: 3.12.04e) and in **Table 4-1**, **Table 4-2**, and **Table 4-3**.

4.6.4 Under baseline conditions, specific stream power values upstream, downstream and at the vicinity of the proposed viaduct are less than 25W/m^2 for all modelled return periods. The results, therefore, indicate a deposition and transport-dominated system with no morphological adjustments due to erosion.

Table 4-1 Reach-average specific stream power (W/m^2) results for baseline of the proposed River Wensum Viaduct

Return period	2-year return period (W/m^2)	20-year return period (W/m^2)	100-year return period (W/m^2)	100-year + 20% CC return period (W/m^2)
Upstream of viaduct	1.6	0.7	0.9	1.1
Viaduct location	1.2	1.0	1.0	1.1
Downstream of viaduct	0.4	0.4	0.4	0.5

Table 4-2 Reach-average specific stream power (W/m^2) results for construction (temporary works platform) of the proposed River Wensum Viaduct

Return period	2-year return period (W/m^2)	20-year return period (W/m^2)	100-year return period (W/m^2)	100-year + 20% CC return period (W/m^2)
Upstream of viaduct	0.5	0.4	0.5	0.6
Viaduct location	5.2	12.3	19.1	26.1

Return period	**2-year return period (W/m²)**	**20-year return period (W/m²)**	**100-year return period (W/m²)**	**100-year + 20% CC return period (W/m²)**
Downstream of viaduct	0.6	0.7	0.8	1.0

Table 4-3 Reach-average specific stream power (W/m²) results for operation of the proposed River Wensum Viaduct

Return period	**2-year return period (W/m²)**	**20-year return period (W/m²)**	**100-year return period (W/m²)**	**100-year + 20% CC return period (W/m²)**
Upstream of viaduct	1.7	0.5	0.6	0.7
Viaduct location	1.1	0.9	0.9	0.9
Downstream of viaduct	0.4	0.4	0.4	0.5

Construction

4.6.5 The modelled 2D hydraulic results reveal that specific stream power increases primarily at the vicinity of the proposed viaduct, and minimal changes are modelled both up- and downstream from it for the range of flood return intervals. The maximum difference between baseline and operation specific stream power is 1.1W/m² in the up- and downstream reaches from the temporary works platform and all those reaches remain with a similar hydraulic behaviour (i.e., below 25W/m²). This variation in specific stream power is caused by changes in water level slope induced by the temporary works platform, which creates steeper water slopes (and higher specific stream power) around the platform, whilst establishing more gentle water slopes to the upstream reach (see **Sub Appendix E: Specific Stream Power** (Document Reference: 3.12.04e)).

4.6.6 The maximum specific stream power is 5.2W/m^2 (2-year return period), 12.3W/m^2 (20-year flow), 19.1W/m^2 (100-year), and 26.1W/m^2 (100-year + CC flow), and all occur at the vicinity of the proposed viaduct.

4.6.7 The results indicate that the threshold for the onset of erosion-dominated processes (25W/m^2) can be marginally exceeded (by 1.1W/m^2) during the temporary works construction phase in the event of an extreme event (100-year + CC flow). However, it is pertinent to note that the likelihood of a high magnitude event (100-year or 100-year + CC flood return period) occurring during the construction phase is very low (1% for any given year). Therefore, the proposed activities of the construction phase are not anticipated to affect the geomorphic processes and forms, nor the geomorphology receptors in any of the investigated reaches.

4.6.8 The specific stream power assessment results therefore suggest that the gas pipeline downstream of the of the proposed construction zone over the River Wensum is located beyond the zone of influence and increases in specific stream power are highly localised to the construction zone. The appointed Contractor may wish to consider monitoring of bed levels prior to and during the construction phase however as a precautionary measure.

Operation

4.6.9 During operation, the hydraulic modelling results (**Table 4-1**) (see **Sub Appendix E: Specific Stream Power** (Document Reference: 3.12.04e)) reveal that the proposed viaduct would exert minimal influence on the in-channel dynamics associated with specific stream power for the range of flood return periods modelled (including accounting for potential reduction in roughness due to shading effects). The maximum difference between baseline and operation specific stream power is 0.4W/m^2 and all reaches remain with a similar hydraulic behaviour (i.e., below 25W/m^2). The results, therefore, indicate a deposition and transport-dominated system with no morphological adjustments due to erosion, similar to the baseline. As no significant impacts to stream power are anticipated during operation as a result of the Proposed Scheme, no changes to geomorphology receptors are expected during operation.

4.7 Froude

Baseline

4.7.1 The Froude number index, calculated by simulated depth and velocity data, is widely recognised to be closely associated with habitat biotope type (**Ref 4.5** and further information is provided in **Sub Appendix A: Geomorphological Dynamics Assessment** (Document reference: 3.12.04a)). Under baseline conditions, the results for habitat biotope as a geomorphological receptor, as represented by Froude number (see **Sub Appendix F: Froude Number** of **Appendix 12.4: River Wensum Geomorphology Assessment** (Document Reference: 3.12.04f)), reveal that the River Wensum within the Study Area is dominated by glides within the vicinity of the Proposed Scheme. A glide is an area where the flow is characterised by slow-moving, nonturbulent flow known as laminar. A glide is too shallow to be a pool, but the water velocity is too slow to be a run. It usually occurs downstream of a pool and upstream of a riffle in a meandering channel.

4.7.2 Upstream, the River Wensum is characterised by riffle and run habitats. Riffles are the shallow portions of a river characterised by relatively fast-moving, turbulent water with bottom materials composed of cobble, gravel, or bedrock. A run is a relatively shallow portion of a stream characterized by relatively fast-moving, nonturbulent flow, and it generally occurs upstream of pools and downstream of riffles in a meandering channel.

4.7.3 The modelled results show the riffle-run-glide habitat pattern for each of the modelled return periods within the modelled reach.

Construction

4.7.4 During the temporary works phase, the modelled Froude results (see **Sub Appendix F: Froude Number** (Document Reference: 3.12.04f)) reveal changes to habitat biotope receptors within the river for all modelled flood return periods.

4.7.5 For the 1 in 2-year flood return period, the glide habitat within the zone of the temporary works is replaced by riffle-run habitat for approximately 150 metres at peak flow. This change in flow type and habitat biotope is likely due to the constriction of flows caused by the temporary works platform and Bailey bridge.

4.7.6 The modelled results (see **Sub Appendix F: Froude Number** (Document Reference: 3.12.04f)) for the 1 in 20-year flood return period indicate the glide habitat biotope within the zone of the temporary works would be replaced by riffle-run habitat.

4.7.7 Upstream, the flow constriction caused by the Bailey bridge indicates a change to pool habitat at the meander bend upstream of the proposed crossing location and more extensive glide habitat upstream. These changes in habitat biotope are also consistent with the changes predicted during the temporary works phase for the higher magnitude events modelled.

4.7.8 The increase in energetic flow types within the temporary works zone, and the predicted increases in velocity, shear stress and stream power, could combine to cause bed and bank scour locally. Whilst this could lead to localised changes to the geomorphology receptors of sediment regime, channel morphology and natural fluvial processes during the construction phase, it is pertinent to note that the threshold for the onset of erosion-dominated processes, indicated by the specific stream power results, suggests that scour is unlikely.

4.7.9 When accounting for a reduction in roughness due to the potential shading effect caused by the Bailey bridge, the habitat biotopes estimated through the Froude number remain largely similar to the results with no shading effect.

The similarity between those scenarios occurs for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change), and supports that any reduction in roughness due to shading would not be sufficient to produce a significant change in river processes. Therefore, the modelled results indicate no sensitivity to the effects of shading during construction.

Operation

4.7.10 The Froude results for all modelled return periods reveal no notable change in habitat biotopes between baseline and operation including accounting for potential reduction in roughness due to shading effects (see **Sub Appendix F: Froude Number** (Document Reference: 3.12.04f)). Therefore, no significant changes to habitat biotopes are anticipated during operation as a result of the Proposed Scheme. Consequently, no changes to geomorphology receptors are expected during operation.

4.8 Summary of Results

4.8.1 The effect of the temporary work structures upon flow velocity and bed shear stress along the Study Area could affect particle size stability locally within the river bed. There could be the potential for increased entrainment and transport of coarse gravel particles (16mm to 32mm) for 20-year flood return periods, and very coarse gravels (32 mm-64 mm) for 100-year and 100-year + CC flood return period events.

4.8.2 In addition, the physical barrier imposed by the temporary work structures upon flow can increase flood water retention upstream, as attested by higher water depth levels on the right floodplain. This barrier also increases in-channel flow velocity from baseline conditions for all return intervals because of flow conveyance that would otherwise flow along the floodplain.

4.8.3 On the contrary, specific stream power results indicate that the threshold for the onset of erosion-dominated processes would not be exceeded during the temporary works construction or operational phases for any return interval.

Therefore, the channel is predicted to remain as a transport-dominated system with no morphological adjustments due to erosion.

4.8.4 During the temporary works phase, there could be a localised change in habitat biotopes, as measured by Froude, with a change from glide habitat to riffle-run habitat within the zone of the temporary works. In addition, the results indicate a pool habitat would develop at the upstream meander bend and a more extensive glide habitat upstream during the temporary works phase. Habitat biotopes would return to baseline during operation.

4.8.5 The results indicate that the most notable construction-phase impacts would occur during high magnitude events (e.g., 1 in 20-years or 5% annual exceedance probability or greater), which have a low likelihood of occurrence within the timeframe of the construction phase. In addition, any potential alterations to the bed and bank forms that may occur would be highly localised and are likely to be off set in the short term (<5-10 years) by sedimentation during successive flood events.

4.8.6 The operation phase shows no in-channel morphology changes in any of the investigated geomorphology receptors and fluvial processes with regards to the baseline condition. The only perceptible change would occur in water depth along the floodplain as represented by a small increase in the flood area and depth. Importantly, in the hydraulic simulations of macrophyte reduction due to shading, the effects to geomorphology receptors upon the operation phase are negligible. Therefore, the operation phase is not expected to cause significant changes to the existing hydraulics, sediment dynamics, or geomorphology receptors.

5 Impact assessment

5.1 Introduction

5.1.1 The impact assessment methodology presented within this section has been undertaken in accordance with the guidance in the Design Manual for Roads and Bridges LA113 (**Ref 1.1**). Using this methodology, the level of significance of a potential impact upon the baseline condition arising due to the Proposed Scheme upon the River Wensum is determined by the sensitivity of the geomorphology receptor combined with the magnitude of impact.

5.1.2 This approach assesses both the construction and operation potential impacts both before and after the application of any required mitigation measures along with identifying any potential residual effects.

5.1.3 The results of the geomorphology assessment presented in Section 4 have been used to determine the potential for significant effects both during construction and operation.

5.1.4 The assessment of impacts to geomorphology receptors includes the following geomorphology receptors:

- Sediment regime (including changes to erosion and deposition processes);
- Channel morphology (including bank profile, bank and bedforms, bed level and floodplain morphology);
- Natural fluvial processes (including in-channel habitat biotopes).

Sensitivity

5.1.5 The sensitivity of the River Wensum was determined using the sensitivity criteria presented in **Table 5-1**.

Table 5-1 Sensitivity criteria for fluvial geomorphology receptors

Sensitivity	Criteria
Very High	**Sediment Regime** Water feature is designated as a Special Area of Conservation (SAC). Water feature sediment regime provides a diverse mosaic of habitat types suitable for species sensitive to changes in sediment concentration and turbidity, such as White-Clawed Cray Fish, Brook Lamprey, Bullhead and Desmoulins Whorl Snail (DWS). Water feature appears in complete equilibrium with natural erosion and deposition occurring. The water feature has sediment processes reflecting the nature of the catchment and fluvial system. As the water feature is groundwater fed with little surface run-off, hence there is little organic matter and low turbidity. The sediment grain size distribution is predominantly gravels and an absent of fine-grade sediments (sands and silts). **Channel Morphology** The channel has a meandering planform morphology. Water feature includes varied morphological features associated with chalk rivers (e.g., natural bank profiles and bedforms) with no / limited sign of channel modification. Stable planform morphology. The channel has a high degree of naturalness, governed by dynamic processes which result in a mosaic of characteristic physical habitats or channel width and depth, in-channel and side-channel sedimentation features (including transiently exposed sediments), bank profiles (including shallow and steep slopes), erosion features (such as cliffs) and both in-channel and bankside (woody and herbaceous) vegetation cover. **Natural Fluvial Processes** Water feature displays natural fluvial processes and natural flow regime, which would be highly vulnerable to change as a result of modification. Water feature includes varied habitat biotopes (e.g., runs, glides, smooth flows).
High	**Sediment Regime** Water feature sediment regime provides habitats suitable for species sensitive to changes in sediment concentration and turbidity, such as such as White-Clawed Cray Fish, Brook Lamprey, Bullhead and DWS. Water feature appears largely in natural equilibrium with some localised accelerated erosion and / or deposition caused by land use and / or modifications. Primarily the sediment regime reflects the nature of the natural catchment and fluvial system. Turbidity is relatively low with a lack of fine-grade bed sediments. **Channel Morphology** Water feature exhibiting a natural range of morphological features associated with chalk rivers (e.g., natural bank profiles and bedforms), with limited signs of artificial modifications or morphological pressures. **Natural Fluvial Processes** Predominantly natural water feature with a diverse range of fluvial processes that is highly vulnerable to change as a result of modification. Water feature includes varied habitat biotopes (e.g., runs, glides, smooth flows).

Sensitivity	Criteria
Medium	**Sediment Regime** Water feature sediment regime provides some habitat suitable for species sensitive to change in suspended sediment concentrations or turbidity. A water feature with natural processes occurring but modified, which causes notable alteration to the natural sediment transport pathways, sediment sources and areas of deposition. **Channel Morphology** Water feature exhibiting some natural morphological associated with chalk rivers (e.g., natural bank profiles and bedforms). The channel cross-section is partially modified in places, with obvious signs of modification to the channel morphology. Natural recovery of channel form may be present (e.g. eroding cliffs, depositional bars). **Natural Fluvial Processes** Water feature with some natural fluvial processes, including varied flow types. Modifications and anthropogenic influences having an obvious impact on natural flow regime, flow pathways and fluvial processes. Water feature includes some variation in habitat biotopes (e.g., runs, glides, smooth flows).
Low	**Sediment Regime** Water feature sediment regime which provides very limited physical habitat for species sensitive to changes in suspended solids concentration or turbidity. Highly modified sediment regime with limited / no capacity for natural recovery. **Channel Morphology** Water feature that has been extensively modified (e.g. by culverting, addition of bank protection or impoundments) and exhibits limited-to-no morphological diversity. The water feature is likely to have uniform flow, uniform banks, and absence of bars. Insufficient energy for morphological change. **Natural Fluvial Processes** Water feature which shows no or limited evidence of active fluvial processes with unnatural flow regime or / and uniform flow types and minimal secondary currents. Water feature has uniform habitat biotopes.

Impact Magnitude

5.1.6 The magnitude of potential impacts was assessed on a scale of ‘major’ to ‘negligible’ for both adverse and beneficial impacts based on the likely effect of proposed activities, guided by the criteria and examples provided in **Table 5-2** and using professional judgement where necessary. The assessment of magnitude was influenced by the timing, scale, size and duration of changes to the baseline conditions, in addition to the likelihood or probability of occurrence.

5.1.7 The highest magnitude of impact is applied when any one of the criteria are met from the adverse categories presented in **Table 5-2**.

Table 5-2 Magnitude criteria for fluvial geomorphology receptors

Magnitude of impact (Change)	Criteria
Major adverse	**Sediment Regime** Extensive impacts on the water feature bed, banks and vegetated riparian corridor resulting in changes to sediment characteristics, transport processes, sediment load and turbidity. Impacts would be at the water body scale. Extensive lack of riparian vegetation allowing for silt ingress. Coarse sediment supply interrupted or altered by the addition of new structures resulting in channel incision and heavy bankside erosion that have consequences for both biodiversity and river management (e.g., flood risk). Removal of native sediments or augmentation of coarse sediments. **Channel Morphology** Extensive alteration to channel planform and / or cross section, including modification to bank profiles, the replacement of a natural bed, or over widening of the channel. This could include: significant channel realignment (negative); extensive loss of lateral connectivity; loss of connectivity to groundwater, and / or, significant modifications to channel morphology due to installation of structures. Impacts would be at the water body scale. **Natural Fluvial Processes** Major shift away from baseline conditions with potential to alter processes at the catchment scale. **Condition Status** Adverse impacts causing loss or damage to habitats. Impacts have the potential to cause deterioration in hydromorphology quality elements (quality and quantity of flow; river depth and width variation; structure and substrate of the bed dynamics; river continuity; structure of the riparian zone) preventing the achievement of water body objectives for Good Ecological Status (GES) or Good Ecological Potential (GEP). Removal of, or degradation to, macrophytes (specifically water-crowfoot) resulting in the removal of habitats and features that qualify for SAC designation. Adverse impacts to the extent, structure, function and distribution of qualifying physical habitats and their supporting processes, preventing the achievement of River Wensum SAC Conservation Objectives.

Magnitude of impact (Change)	Criteria
Moderate adverse	**Sediment Regime** Some changes and impacts on the water feature bed, banks and vegetated riparian corridor resulting in some changes to sediment characteristics, transport processes, sediment load and turbidity. Impacts would be at the multiple-reach scale. Coarse sediment supply partially interrupted by the addition of new structures resulting in potential channel incision and bankside erosion that have consequences for both biodiversity and river management (e.g., flood risk). Partial removal of native sediments or potential augmentation of coarse sediments. **Channel Morphology** Some alteration to channel planform and / or cross section, including modification to bank profiles or the replacement of a natural bed. Activities could include: channel realignment; modified bed and / bank profiles, replacement of bed and / or banks with artificial material and / or installation of culverts. Impacts would be at the multiple reach scale. **Natural Fluvial Processes** A shift away from baseline conditions with potential to alter processes at the reach or multiple reach scale. **Condition Status** Moderate adverse impacts at the reach or multiple reach scale, which causes some loss or damage to habitats. Impacts have the potential to cause failure or deterioration in one or more of the hydromorphological quality elements (quality and quantity of flow; river depth and width variation; structure and substrate of the bed dynamics; river continuity; structure of the riparian zone). May prevent the achievement of water body objectives for GES or GEP. Removal of, or degradation to habitats and features that qualify for SAC designation. Adverse impacts to the extent, structure, function and distribution of qualifying physical habitats and their supporting processes, potentially preventing the achievement of River Wensum SAC Conservation Objectives.

Magnitude of impact (Change)	**Criteria**
Minor adverse	**Sediment Regime** Limited impacts on the water feature bed, banks and vegetated riparian corridor resulting in limited (but notable) changes to sediment characteristics, transport processes, sediment load and turbidity at the reach scale. Limited interruption of coarse sediment supply by the addition of new structures resulting in limited channel incision and bankside erosion that have consequences for both biodiversity and river management (e.g., flood risk). Limited removal of native sediments and augmentation of coarse sediments. Impacts would be at the reach scale. **Channel Morphology** A small change or modification in the channel planform and / or cross section with impacts limited to the reach scale. **Natural Fluvial Processes** Minimal shift away from baseline conditions with typically localised impacts up to the reach scale. **Condition Status** Minor adverse impacts at the reach scale, which may cause partial localised alteration to habitats. Impacts would not result in deterioration in hydromorphological quality elements (quality and quantity of flow; river depth and width variation; structure and substrate of the bed dynamics; river continuity; structure of the riparian zone). Minor and localised adverse impacts on the extent, structure, function, and distribution of qualifying physical habitats and their supporting processes for the River Wensum SAC Conservation Objectives.
Negligible	Minimal or no measurable change from baseline conditions in terms of sediment transport, channel morphology and natural fluvial processes. Any impacts are likely to be highly localised and not have an effect at the reach scale.

Magnitude of impact (Change)	Criteria
Minor beneficial	**Sediment Regime** Partial improvement to sediment processes at the reach scale, including reduction in siltation and localised recovery of sediment transport processes. **Channel Morphology** Partial improvements include enhancements to in-channel habitat, riparian zone and morphological diversity of the bed and / or banks. **Natural Fluvial Processes** Slight improvement on baseline conditions with potential to improve flow processes at the reach scale. **Condition Status** Slight beneficial impacts at the reach scale, which may cause partial habitat enhancement. Impacts have the potential to improve one of the hydromorphological quality elements (quality and quantity of flow; river depth and width variation; structure and substrate of the bed dynamics; river continuity; structure of the riparian zone). Slight beneficial improvements to the habitats and features that qualify for SAC designation. Slight improvements on the extent, structure, function, and distribution of qualifying physical habitats and their supporting processes, allowing the achievement of River Wensum SAC Conservation Objectives.

Magnitude of impact (Change)	**Criteria**
Moderate beneficial	**Sediment Regime** Reduction in siltation and recovery of sediment transport processes at the reach or multiple reach scale. **Channel Morphology** Partial creation of both in-channel and vegetated riparian habitat. Improvement in morphological diversity of the bed and / or banks at the reach or multiple reach scale. Includes partial or complete removal of structures and / or artificial materials. Measures to narrow the channel to increase flow velocities, reduce sedimentation, provision of damp / wet marginal habitats. **Natural Fluvial Processes** Notable improvements on baseline conditions and recovery of fluvial processes at the reach or multiple reach scale. Improvements in connectivity with wider areas of the floodplain could be achieved through wetland improvement and the reconnection of remnant meanders. **Condition Status** Notable beneficial impacts at the reach to multiple reach scale. Impacts have the potential to improve one or more of the hydromorphological quality elements (quality and quantity of flow; river depth and width variation; structure and substrate of the bed dynamics; river continuity; structure of the riparian zone) and / or assist in achieving the water body objectives for GES or GEP. Notable beneficial improvements to the habitats and features that qualify for SAC designation. Notable improvements on the extent, structure, function, and distribution of qualifying physical habitats and their supporting processes, encouraging the achievement of River Wensum SAC Conservation Objectives.

Magnitude of impact (Change)	**Criteria**
Major beneficial	**Sediment Regime** Improvement to sediment processes at the catchment scale, including recovery of sediment supply and transport processes. **Channel Morphology** Extensive creation of both in-channel habitat and riparian zone. Morphological diversity of the bed and / or banks is restored, such as natural planform, varied natural cross-sectional profiles, recovery of fluvial features (e.g. riffles, gravel bed, and marginal habitats) expected for river type. Removal of modifications, structures, and artificial materials. Measures to narrow the channel to increase flow velocities, reduce sedimentation, provision of damp / wet marginal habitats. **Natural Fluvial Processes** Substantial improvement on baseline conditions at catchment scale. Recovery of flow and sediment regime. Improvements in connectivity with wider areas of the floodplain could be achieved through wetland improvement and the reconnection of remnant meanders. **Condition Status** Substantial beneficial impacts at the catchment scale, which result in recovery / restoration of natural habitats suitable for supporting sensitive species. Potential improvement of overall status condition, which could lead to achievement of water body objectives for GES or GEP. Substantial beneficial improvements to the habitats and features that qualify for SAC designation. Substantial improvements on the extent, structure, function, and distribution of qualifying physical habitats and their supporting processes, ensuring the achievement of River Wensum SAC Conservation Objectives.
No change	No loss or alteration of characteristics, features or elements; no observable impact in either direction.

Impact Significance

5.1.8 The significance of impacts (either with or without mitigation measures) was determined as a function of the sensitivity of the water feature and the magnitude of a predicted impact. The matrix for the determination of significance, provided in the LA113 guidance is shown in **Table 5-3**.

5.1.9 Where the matrix indicates two alternative options (e.g. Slight / Moderate), the significance rating is selected using professional judgement, considering the sensitivity of receptor and duration or extent of works, in accordance with the LA113 guidance.

5.1.10 The selection of a higher significance is chosen where a greater number of high-risk activities are proposed.

Table 5-3 Matrix for classifying effects based upon sensitivity of the receptor and magnitude of impact

Matrix	No Change	Negligible	Minor	Moderate	Major
Sensitivity / Value Very High	Neutral	Slight	Moderate or Large	Large or Very Large	Very Large
Sensitivity / Value High	Neutral	Slight	Slight or Moderate	Moderate or Large	Large or Very Large
Sensitivity / Value Medium	Neutral	Neutral or Slight	Slight	Moderate	Moderate or Large
Sensitivity / Value Low	Neutral	Neutral or Slight	Neutral or Slight	Slight	Slight or Moderate

Matrix	**No Change**	**Negligible**	**Minor**	**Moderate**	**Major**
Sensitivity / Value Negligible	Neutral	Neutral	Neutral or Slight	Neutral or Slight	Slight

5.2 Baseline Sensitivity

5.2.1 Baseline conditions for the River Wensum are described in Section 3. For the purposes of the impact assessment, the River Wensum has been identified as being of Very High sensitivity for fluvial geomorphology receptors given its SAC status.

5.3 Potential Impacts

5.3.1 An assessment of potential impacts upon the River Wensum fluvial geomorphology receptors during both construction and operation are provided below.

5.3.2 The assessment takes into account embedded mitigation, which has been accounted for in the design of the Proposed Scheme being assessed. Embedded mitigation includes the proposed design of the viaduct, the number, position and spacing of the piers, the design of the temporary and permanent works access track, and the Bailey bridge.

Construction

5.3.3 This section presents the potential impacts of the Proposed Scheme that may occur during the construction period, with embedded mitigation in place but with the absence of additional mitigation measures. Embedded mitigation includes measures within the **Outline Construction Environmental Management Plan (OCEMP)** (Document Reference 3.03.01), which includes standard pollution prevention measures.

5.3.4 Potential impacts arising from construction activities are typically considered short-term. However, some effects may be long-lasting and may extend to downstream receptors.

5.3.5 **Table 5-4** outlines potential construction impacts on fluvial geomorphology receptors that may arise due to the Proposed Scheme.

Table 5-4 Potential construction impacts

Type of Impact	Receptor	Potential Impacts from Construction Activities	Magnitude	Significance
Generic	Changes to sediment regime	▪ Release of suspended solids from: exposed bare earth surfaces; due to in-channel working for temporary culvert installation within the floodplain; installation of the Bailey bridge, construction of the viaduct; and vegetation clearance. ▪ Increased sediment supply from accidental damage to riverbanks or bed resulting from vegetation clearance, plant movement or other construction activities. ▪ Increased sediment delivery and transport due to temporary works and potential alteration to overland flow paths.	Negligible	Slight
Generic	Changes to channel morphology	▪ Alteration to bedforms due to increased fine sediment supply arising from construction activities and enabling works. ▪ Disturbance to the channel bed and banks due to the Bailey bridge. ▪ In-channel adjustments, through erosion and deposition, due to alterations to cross-section and planform and flow constriction. ▪ Reduced bank stability due to vegetation clearance and Bailey bridge installation. This could result in increased bank erosion and associated sediment release.	Negligible	Slight
Generic	Changes to natural fluvial processes	▪ Increased bare earth surfaces and changes to flow pathways could result in alterations to the quantity of flow entering the channel with potential to locally alter flow patterns. This could lead to changes in erosion and deposition and sediment processes. ▪ Alteration to fluvial processes and associated erosion and deposition regimes due to changes to the quantity of flow. ▪ Changes in lateral (floodplain) connectivity because of the temporary works.	Negligible	Slight

Type of Impact	Receptor	Potential Impacts from Construction Activities	Magnitude	Significance
Specific	Changes to natural fluvial processes	▪ Increases in flow velocity within the zone of the temporary works during construction. Impacts are limited to approximately 175m within the temporary works area. ▪ For all modelled flood return periods during construction there would be localised alteration to habitat biotopes from glide flows to riffle-run habitat within the temporary works zone with impacts extending for approximately 150m at peak flow. ▪ Constriction of flows due to the Bailey bridge result in the formation of pool habitat at the meander bend upstream of the proposed crossing and an extension to glide habitat in the upstream reach during the temporary works during high magnitude flood events. ▪ However, the modelled results indicate a change in the spatial distribution of habitat biotopes but no change in the types of habitat biotopes typical for the modelled reach.	Negligible	Slight
Specific	Changes to channel morphology	▪ Increase in floodplain sedimentation upstream of the temporary works area due to localised increases in floodplain water depth during out-of-bank flows. ▪ Increases in flow velocity within the temporary works zone could increase the ability of the river to entrain and transport sediment and therefore alter bank and bedforms locally. Increases in velocity are likely to occur over a 175m reach within the zone of the temporary works area. ▪ However, these impacts are only likely during high magnitude events, which have a very low likelihood during construction (5% in any given year for 20-year flow, and 1% for a 100-year flow). ▪ In addition, specific stream power results support that the threshold for the onset of erosion-dominated processes (25W/m^2) would not be exceeded during the temporary works construction phase for any investigated return flows. Therefore, the proposed activities of the construction phase are not anticipated to affect the channel morphology of the investigated reaches.	Negligible	Slight

Operation

5.3.6 This section presents the potential impacts of the Proposed Scheme that may occur during the operation phase, with embedded mitigation in place but with the absence of additional mitigation measures.

5.3.7 Operation impacts are generally longer-term or permanent in nature.

5.3.8 **Table 5-5** outlines potential operation impacts on fluvial geomorphology receptors that may arise due to the Proposed Scheme.

Table 5-5 Potential operation impacts

Type of Impact	Potential Effects	Potential Impacts from Operation Activities	Magnitude	Significance
Generic	Changes to sediment regime	▪ Potential for changed sediment processes due to increased runoff from impervious surfaces and new infrastructure.	Negligible	Slight
Generic	Changes to channel morphology	▪ The new viaduct and piers within the floodplain would locally alter floodplain morphology. ▪ The permanent access track would locally alter floodplain morphology. ▪ The minor watercourse crossings would introduce new hard bank reinforcement and alter cross-sectional profile.	Negligible	Slight
Generic	Changes to natural fluvial processes	▪ Potential for increase in runoff which could locally alter flow regime within the channel. ▪ Lateral and longitudinal connectivity would be impacted locally by the permanent access track and minor watercourse crossings.	Negligible	Slight

Type of Impact	Potential Effects	Potential Impacts from Operation Activities	Magnitude	Significance
Specific	Changes to sediment regime	■ Modelling results indicate no changes to the sediment regime of the River Wensum during operation.	No change	Neutral
Specific	Changes to channel morphology	■ Modelling results indicate no changes to channel morphology during operation. ■ Modelling results indicate that there would be a slight and localised increase in water depth within the floodplain; however, this would not affect flood risk. There may be increased sedimentation of the floodplain locally.	Negligible	Slight
Specific	Changes to natural fluvial processes	■ Modelling results indicate no changes to the natural fluvial processes of the River Wensum during operation.	No change	Neutral

5.4 Mitigation

5.4.1 Additional mitigation that may be required to reduce the potential impacts to fluvial geomorphology during both the construction and operation phases are provided below. These measures are in addition to the embedded mitigation that has been incorporated into the design.

Construction

5.4.2 The depth of the gas pipeline located downstream of the proposed viaduct is currently unknown. Whilst the specific stream power results indicate that the threshold for erosion-dominated processes would not be exceeded during the construction and operation of the Proposed Scheme, the appointed Contractor may wish to consider monitoring of bed levels prior to and during the construction phase as a precautionary measure.

5.4.3 Any localised alteration to bed and bank forms that may occur during the construction phase are likely to be resolved by sedimentation processes during successive flood events in the short-term (e.g. 5-10 years). Therefore, no additional mitigation is proposed.

Operation

5.4.4 The operation phase is not expected to cause significant changes to the existing hydraulics, sediment dynamics, or geomorphology receptors. Except for routine inspections of the viaduct and the piers including monitoring for any scour or increased risk of fine sediment input from under the viaduct structure (e.g., BD 97/12 standard assessment of scour and other hydraulic actions at highway structures), no additional mitigation measures are proposed.

5.5 Residual Impacts

5.5.1 A summary of residual impacts to fluvial geomorphology receptors for both the construction and operation phase are set out below.

Construction

5.5.2 No residual impacts of Neutral significance or above are expected from the construction phase provided all proposed mitigation measures are adhered to.

5.5.3 The modelling results indicate highly localised impacts and mostly as a result of high magnitude flood events, which are unlikely to occur during the construction period.

Operation

5.5.4 No residual significant fluvial geomorphology impacts are expected from operation of the proposed scheme.

5.6 Assessment Against Future Baseline

5.6.1 The assessment methodology for potential impacts to fluvial geomorphology receptors took into account climate change scenarios. The modelled results indicate that there would be no significant effects as a result of the Proposed Scheme during operation.

5.6.2 Given that no effects have been identified during the operation phase, the delivery of the River Wensum Restoration Strategy, which may affect the future baseline, is not considered to result in any changes to geomorphology receptors with the Proposed Scheme in place.

Cumulative Effects

5.6.3 Other proposed schemes within the vicinity of the Proposed Scheme are considered for cumulative effects. The proposed pipeline and cabling schemes are not anticipated to impact upon fluvial geomorphology as the associated infrastructure would not directly interact with fluvial processes.

In-combination Climate Change Impacts

5.6.4 Climate change was taken into account in the 2D hydraulic modelling, and no impacts were observed during the operation of the Proposed Scheme. In addition, as stated above, other schemes proposed within the vicinity of the proposed viaduct crossing are not anticipated to interact with fluvial processes and therefore no in-combination climate change impacts are expected.

5.7 Opportunities for Environmental Enhancement

5.7.1 Environmental enhancements have been developed to contribute towards the Biodiversity Net Gain (BNG) Rivers and Streams metric for the River Wensum. These measures would provide at least 10% net gain for Rivers and Streams.

5.8 Difficulties and Uncertainties

5.8.1 Identifying viable environmental enhancements for BNG Rivers and Streams is challenging and current proposals to deliver the 10% net gain for Rivers and Streams is under discussion with the landowner.

5.9 Summary

Table 5-6 provides a summary of the findings of the assessment.

Table 5-6 Summary of geomorphology receptor effects

Receptor	Potential Effects	Additional Mitigation	Residual Effects	Monitoring
Construction Phase River Wensum	Release of suspended solids. Increased sediment, supply, delivery and transport. Alteration to bank profiles, bank and bedforms, and bed levels. In-channel adjustments, as a result of instability and sediment release, through erosion and deposition. Alterations to the quantity of flow entering the channel due to changes to flow paths. Alteration to fluvial processes and associated erosion and deposition regimes within a channel. Alterations to the erosion and transportation of particles under higher flows events, resulting in changes to bed levels and bedforms. Localised increases in water depth under higher flood return periods. Potential localised increased sedimentation within the floodplain. Changes to the distribution of habitat biotopes. Potential localised increase in bed shear stress, and stream power which could mobilise coarser sediment during high magnitude events.	Mitigation embedded within design. Construction phase monitoring and implementation of the OCEMP. All impacts are temporary and negligible.	**Negligible (Not significant)** T / D / ST	The Contractor is advised to undertake proportional assessments prior to and during construction, such as monitoring and bathymetry surveys.

Receptor	Potential Effects	Additional Mitigation	Residual Effects	Monitoring
Operational Phase River Wensum	Potential for changed sediment processes due to increased runoff from impervious and new infrastructure. Local alteration to floodplain morphology due to the permanent access track and piers. Increased runoff could alter the flow regime. Impacts to connectivity due to the permanent access track. Increases to water depth during out-of-bank flows and increased localised sedimentation of the floodplain.	The operation phase is not expected to cause significant changes to the existing hydraulics, sediment dynamics, or geomorphology receptors. Routine inspections of the viaduct would include scour monitoring around the piers and the floodplain impacted by shading from the viaduct. No additional mitigation is required.	**Negligible (Not significant)** P / I / LT	No residual significant fluvial geomorphology impacts are expected from operation of the Proposed Scheme.

Key to table: P / T = Permanent or Temporary, D / I = Direct or Indirect, ST / MT / LT = Short Term, Medium Term or Long Term, N/A = Not Applicable

6 Conclusion

6.1.1 This fluvial geomorphology assessment report has been prepared to assess the potential changes and impacts of the Proposed Scheme upon fluvial processes and form of the River Wensum. Based upon sediment and ecological field data, hydraulic modelling, and solar exposure modelling, the following conclusions can be drawn.

6.1.2 During the **construction phase**, the existing hydraulics and sediment dynamics of the River Wensum could change because of the temporary works structure, particularly for high magnitude / low likelihood flows. These changes would be highly localised to the temporary works area and be of minor localised and temporary impact only. Potential changes to the fluvial geomorphology are most likely to be restricted to high-magnitude flood events, which have a low likelihood of occurrence during the construction phase. Overall, the sediment regime and river morphology would remain constant for all investigated flows during the construction phase.

6.1.3 In addition, any erosion-related features that may arise during the construction phase (e.g., lowered river bed, sediment coarsening, habitat biotope replacement as geomorphology receptors) are likely to be off-set in the short-term (<5-10 years), when the geomorphological and hydraulic processes return to pre-disturbance conditions. However, it is pertinent to note that the modelled results for specific stream power indicate that the threshold for erosion-dominated processes would not be exceeded during any of the modelled flood return periods during the construction phase.

6.1.4 During the **operation phase**, the Proposed Scheme is not expected to alter geomorphological processes operating or result in changes to geomorphology receptors. The 2D hydraulic modelling results simulating shading impacts do not show any further impacts upon geomorphology receptors for the operation phase. Therefore, it is concluded that the Proposed Scheme would not have a significant adverse effect upon the River Wensum and consequently no off-setting mitigation is proposed.

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