Norwich Western Link

Environmental Statement

Chapter 12: Road Drainage and the Water Environment

Appendix 12.4: River Wensum

Sub Appendix A: Geomorphology Assessment

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1.1 Introduction

1.1.1 An assessment of velocity, shear stress, stream power, and Froude for the River Wensum was undertaken to assess the potential changes to flow and sediment processes caused by the Proposed Scheme and impacts on geomorphology receptors. These analyses informed the assessment of the sediment transport regime of the River Wensum.

1.1.2 The spatial variation of flow velocities and depths within a short reach are determined by channel morphology (**Ref A.1**). Thus, any construction and operation impacts that could affect the morphology of the channel, its physical form and shape, could result in local alteration to the flow velocities and water depths. This, in turn, may cause alteration to the baseline erosion, sediment transport and deposition processes operating within the reach.

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

1.1.4 Large flood events have greater potential to erode and transport sediment and these have a low return frequency; small flood events, which have a high frequency, tend to be less effective in sediment transport (**Ref A.2**). The flood discharge that is typically the most geomorphologically effective is referred to as the dominant discharge; these flows are also referred to as channel-forming events (**Ref A.2**) and are comparable to bankfull flow.

Stream Power

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

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

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

1.1.7 Specific stream power (ω), expressed as Wm^{-2}, is a widely used dimensionless index and is described as:

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

Where b = channel width.

1.1.8 For stream power, a threshold at 35Wm^{-2} has been identified where channels are likely to experience erosion dominated adjustment (**Ref 2.12**). Use of this tool needs to be caveated as it is based on a limited data set. Stream power results may tentatively be divided into the following descriptive categories:

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

Sediment Transport

1.1.9 An initial sediment transport assessment was undertaken by comparing velocity data with empirical sediment transport data derived from Hjulström

(**Ref 4.1**). Using the Hjulström curve, the likelihood of erosion, sediment transport and deposition within the channel may be implied.

Shear Stress

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

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

1.1.11 Where, τo = average bed shear stress (kPa), γw = unit weight of water (9.807kN/m^3), R = hydraulic radius (m) and *S* = channel slope (m/m). Shear stress was selected as an output in the hydraulic model and generated as a raster grid of the entire reach and local floodplain for both baseline and proposed scenarios at 2-year, 20-year, 100-year, and 100-year plus 20% climate change allowance. Baseline scenario results were subtracted from proposed scenario results in a GIS platform to provide an overview of increases in shear stress as a result of the Proposed Scheme.

1.1.12 Boundary shear stress is a measure of the tractive forces required to move loose gravels relative to the gravitational forces that resist movement. Accordingly, analysis of boundary shear stress in this study is employed as a measure of thresholds of motion. There is an approximately linear relationship between boundary shear stress (Nm^{-2}) and the D_{84} mobility threshold of loose gravels. This approximation does not take into account hiding, imbrication, particle shape and cohesion of sediments, nor can the model identify instantaneous spikes of shear stress that occur in nature, which can be responsible for initiating entrainment. However, simulated boundary shear stress, modelled in a 2D domain, provides an indication of the distribution of forces responsible for transporting sediment over an extensive area. Accordingly, these results allow an assessment of impact to be made with a greater degree of confidence than would be provided by cross sectional analysis.

1.1.13 In order to provide context to modelled boundary shear stress results, the output raster grids were rendered with an identifying colour for sediment size fractions taken from the Wentworth (**Ref 2.14**) sediment scale. These results may be compared against sediment data gathered on site.

1.1.14 The boundary shear stress cut-off values used to estimate particle size mobility are provided in the Table A-1. They are from experimental results published by Julien (**Ref A.3**)

Table 1.1 Boundary shear stress cut-off values

Particle size, D_s (mm)	**Critical shear stress, τ_{cr} (Nm^{-2})**
> 2048	1,789.0
1024 - 2048	895.0
512 - 1024	447.0
256 - 512	224.0
128 - 256	112.0
64 - 128	54.0
32 - 64	26.1
16 - 32	12.1
8 - 16	5.64
4 - 8	2.72
2 - 4	1.26

Froude

1.1.15 In addition to identifying forces responsible for driving change the assessment of the River Wensum considers the eco-hydraulics of the reach and demonstrates, quantifiably, the variety and variability of flow types (also referred to as ‘hydraulic habitat’ and ‘biotopes’) that exist across the flow regime. To meet this objective, the Froude number (Fr) was selected as an output variable from the hydraulic models and has been employed here as a surrogate for representing flow types.

1.1.16 The rationale for using the Froude number is that, by using modelled data, ambiguity and surveyor bias associated with traditional habitat mapping techniques is removed. In addition, hydraulic modelling permits assessment of physical habitat receptors across a broad range of flood return periods (which would normally require multiple site visits); furthermore, potential changes to habitat brought about by the Proposed Scheme may be simulated and assessed.

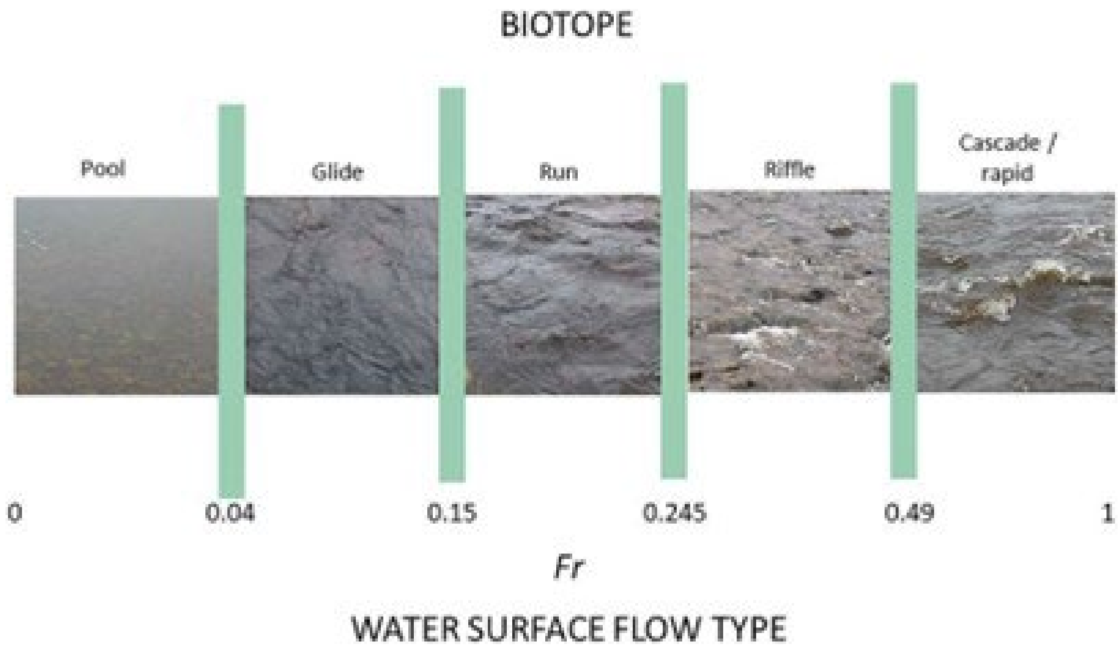
1.1.17 Froude number is essentially a dimensionless indicator of flow turbulence and defines the ratio of internal to gravitational forces in flow:

$$Fr = \frac{V}{\sqrt{gd}}$$

1.1.18 Where Fr is Froude number, V is velocity, g is gradational acceleration, and d is flow depth.

1.1.19 The interplay of flow depth, velocity and bed roughness is widely reported as being the determinant process of physical habitat; therefore, Froude is the most commonly utilised variable for characterising flow. At Froude values below 1, flow is dominated by gravitational forces and is subcritical; whereas Froude values greater than one flow is dominated by internal forces and is supercritical (**Ref 4.5**). In essence, the greater the Fr value, the more turbulent the flow. Froude number may be analysed in greater detail if Fr values between 0 and 1 are divided into sub-units that each represents a characteristic flow type (see **Ref 4.5**) and is demonstrated in **Figure 1.1**.

Figure 1.1 Biotope characterisation determined by Froude number boundaries (source: Entwhistle et al., Ref 4.5)



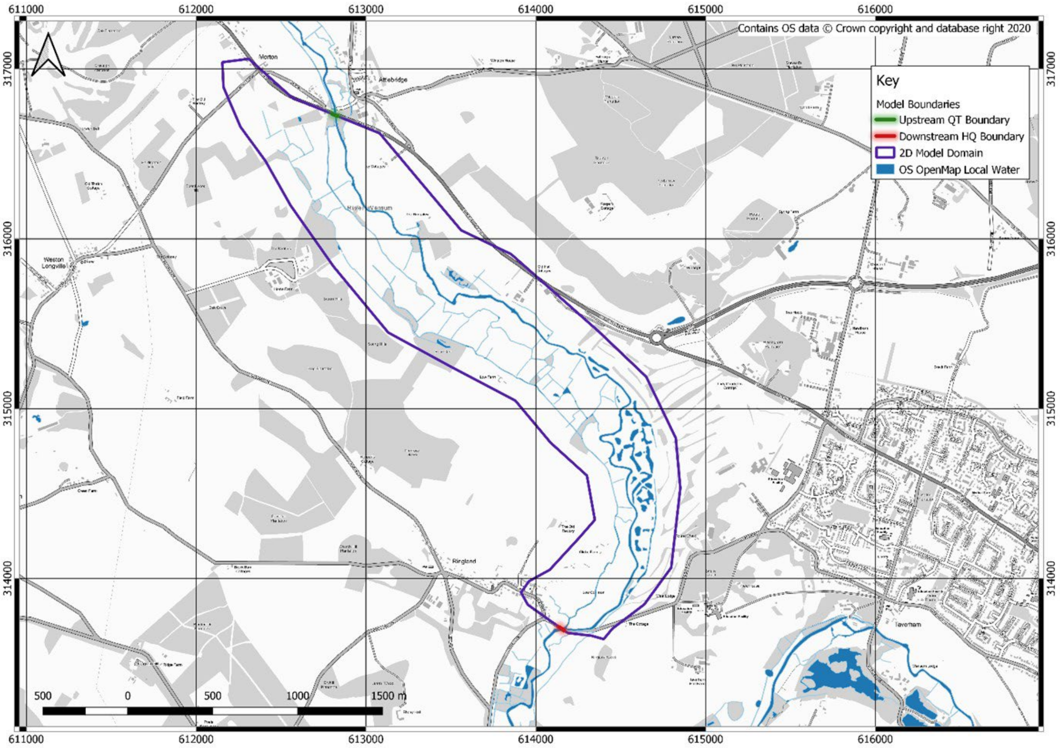
1.1.20 Modelled maximum Froude results for each of the return periods were saved as an .asc format raster surface and imported into a GIS (QGIS 3.8). The raster grids were then rendered by the flow type Froude thresholds and assigned an identifying colour for visual outputs. These results were then directly compared to reveal any changes to physical habitat that would occur as a result of the Proposed Scheme.

Hydraulic Modelling

River Wensum

1.1.21 A fully two-dimensional (2D) hydraulic model was developed for the River Wensum in TUFLOW using a combination of Environment Agency aerial LiDAR (2m resolution) and topographic survey data. The hydraulic model has been produced to assess impacts the Proposed Scheme on maximum velocity (m/s), maximum depth (m), bed shear stress (Nm^{-2}) Froud number (dimensionless), and stream power (W/m) for a range of return period peak flows (2-years, 5-years, 20-years, 100-years, and 100-years +20% climate change). The hydraulic model is of a relatively simple set up and is described below and shown in **Figure 1.2**.

Figure 1.2 2D hydraulic model set up



1.1.22 A model cell size of 2m has been selected, which provides the level of detail necessary in-channel to capture changes in flow regime at peak flow with the Proposed Scheme in place. To facilitate runs times at this resolution the models has been run using the HPC solver with a GPU processer.

1.1.23 The bathymetry of the Wensum is based on LIDAR as a complete 2D dataset for the area. This data has been adjusted to reflect topographic survey that confirmed the typical difference between bank top and the Wensum bed level at the toe of the bank. This difference was found to be 0.51m and the LIDAR data in the footprint of the Wensum has been lowered by this amount.

1.1.24 The local drains in the floodplain were not picked up appropriately in the LIDAR data and the 2D model resolution insufficient to pick up these flow paths. Alternatives were considered but the preferred approach for these drains was to represent these as 1D channels embedded in the floodplain.

1.1.25 Channel and floodplain roughness values have been specified utilising OS MasterMap data to classify landcover types, the values remain unchanged from the FRA model for the baseline condition. The temporary (construction phase) and permanent (operational phase) conditions were adapted to reflect changes in roughness caused by vegetation loss triggered by light exposure reduction due to the Proposed Scheme.

1.1.26 The shading assessment report (**Ref 2.15**) indicates that changes in light exposure due to the Proposed Scheme are unlikely to produce long-term impact upon roughness. The main reason is the replacement of area with vegetation loss by light-resistant species, which would off-set impacts upon fluid dynamics. However, short-term variations may occur due to different vegetation growth paces. To simulate the short-term effects of vegetation loss due to shading, a minimum value approach was adopted for the operational phase simulations. In these scenarios, the landscape area with shading impacts is represented in the model dimension with the lowest roughness coefficient of the landcover type defined by an OS MasterMap data.

1.1.27 The upstream boundary is located at Fakenham Road. Flows at this location have been extracted from the flows beneath Fakenham Road in the 1D 2D flood model and these are applied directly onto the Wensum channel downstream of Fakenham Road Bridge.

1.1.28 The downstream boundary is located at Ringland Road. This structure cuts across the floodplain and constrains floodplain flow, diverting most of it through Ringland Road Bridge. The Ringland Road Bridge has been represented in the model as a 1D structure and the stage flow relationship through this structure extracted from the larger 1D 2D flood model. This ensures that the downstream channel capacity is appropriately represented in the model. In larger events the Ringland Road is overtopped in the floodplain. Ringland Road is included in the 2D model and so the weiring of flows over the crest of this structure effectively forms the downstream boundary of the floodplain. In the model downstream of Ringland Road, floodplain flow stage relationships allow flows to leave the model, but results are not sensitive to these given the influence of the Ringland Road crest on upstream water levels.

1.1.29 The modelled reach of the River Wensum has been represented for the baseline (BAS), temporary works (TEMP) and proposed (DEV) scenarios. The temporary works scenario incorporates the temporary working platform, and associated flood relief culverts and the bailey bridge across the River Wensum. The proposed scenario incorporates the proposed viaduct piers, embankments, and maintenance tracks. This scenario also includes a sensitivity assessment of the impact of shading as discussed above.

1.1.30 The model output parameters produced are boundary shear stress (N/m^2); discharge (m^3/s); flow velocity (m/s); unit stream power (W/m); water level (m); and depth (m) and are output as raster files that could be analysed in a GIS platform. Water level and depth were not specifically required for the geomorphological assessment but have been output to assist with model development and proving. In each case the maximum result that occurs over the duration of the modelled flood event for each parameter have been extracted for analysis. It is important to note that maximum values for each parameter may not occur at the same point in the event hydrograph.

Table 1.2 Modelled peak flows

Return Period (% AEP)	Return Period (year)	Peak Flow (m^3/s)
50%	2yr	24.9
5%	20yr	47.2
1%	100yr	61.7
1% + 20CC	100yr + 20%	74.9
1% + 20CC	100yr + 20%	74.9

References

Ref A.1 - Bravard, J. P., & Gilvear, D. J. (1996). Hydrological and geomorphological structure of hydrosystems. In The Fluvial Hydrosystems (pp. 98-116). Springer, Dordrecht.

Ref A.2 - Gilvear, D. J., & and Bravard, J. P. (1996). Geomorphology of temperate rivers. In G. E. Petts, Fluvial Hydrosystems (pp. 68-97). London: Chapman and Hall

Ref A.3 - Julien (1998). Sediment mobility for a given particle size occurs when the bed shear stress exceeds the critical shear stress. Original source: Julien, P. Y., and Y. Raslan. "Upper-regime plane bed." Journal of Hydraulic Engineering 124.11 (1998): 1086-1096.