Dudgeon and Sheringham Shoal Offshore Wind Farm Extensions

Preliminary Environmental Information Report

Volume 3

Appendix 20.3 - Geomorphology Baseline Report

April 2021

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Title:
Dudgeon and Sheringham Shoal Offshore Wind Farm Extensions **Preliminary Environmental Information Report** **Appendix 20.3 Geomorphological Baseline Survey Technical Report**
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Glossary of Acronyms

BDC	Broadland District Council
DCO	Development Consent Order
DEFRA	Department for the Environment and Rural Affairs
DEP	Dudgeon Extension Project
DOW	Dudgeon Offshore Wind Farm
EC	European Commission
EIA	Environmental Impact Assessment
EPS	European Protected Species
EQS	Environmental Quality Standards
ES	Environmental Statement
EU	European Union
GIS	Geographical Information System
km	Kilometre
LPA	Local Planning Authority
MW	Megawatts
NNDC	North Norfolk District Council
NorCC	Norwich City Council
NP	National Park
NSIP	Nationally Significant Infrastructure Project
OS	Ordnance Survey
OWF	Offshore Wind Farm
PEIR	Preliminary Environmental Information Report
PRoW	Public Right of Way
SSSI	Site of Special Scientific Interest
SAC	Special Area of Conservation
SEP	Sheringham Shoal Extension Project
SNC	South Norfolk Council
UK	United Kingdom
WFD	Water Framework Directive

Glossary of Terms

Armouring	Armouring occurs when the bed surface of gravel-bed rivers is coarsened relative to the sub-surface.
Aggradation	A progressive build up or raising of the channel bed and floodplain due to sediment deposition. The geological process by which streambeds are raised in elevation and flood plains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing.
Bankfull discharge	Bankfull discharge is the flow that reaches the transition between the channel and its flood plain and is thus morphologically significant.
Bar	An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the centre of an overwide channel.
Bed	The bottom of a channel.
Bed Slope	The inclination of the channel bottom, measured as the elevation drop per unit length of channel.
Catchment	The total area of land that drains into any given river.
Coarse sediment	Sediment of grain diameter greater than 2 mm.
Cobbles	Substrate particles that are smaller than boulders and larger than gravels and are generally 64 - 256 mm in diameter. Can be further classified as small and large cobble.
Dudgeon Offshore Wind Farm Extension Project (DEP)	The Dudgeon Offshore Wind Farm Extension site as well as all onshore and offshore infrastructure.
Erosion	Process that wears away the river bed and banks. Erosion also breaks up the rocks that are carried by the river.
Equilibrium	Rivers seek a state of dynamic equilibrium between the imposed conditions of valley slope, discharge, and sediment supply, and channel adjustments that can include width, depth, velocity, reach slope, roughness, and sediment size. Over historical time, the channel adjusts to changes in discharge and sediment supply due to human activities, climate change, and extreme events.
Gravel	Gravel or other shallow sediment deposition on the inside of bends.
Glide	A section of smooth or rippled flow, deeper flow than run.
Main Rivers	A statutory type of watercourse in England and Wales, maintained by the Environment Agency (EA). These watercourses are usually larger streams and rivers, but also include some smaller watercourses.

Ordinary Watercourse	Includes every river, stream, ditch, drain, cut, dyke, sluice, sewer (other than a public sewer) and passage through which water flows and which does not form part of a main river.
PEIR boundary	The area subject to survey and preliminary impact assessment to inform the PEIR, including all permanent and temporary works for DEP and SEP. The PEIR boundary will be refined down to the final DCO boundary ahead of the application for development consent.
Planform	The planform evolution of meandering rivers occurs as a result of mutual adjustments between meandering form and processes.
Pool	Discrete areas of deep water typically formed on the outside of meanders.
Point Bar	Gravel or other shallow sediment deposition on the inside of bends.
Reach	A section of watercourse between two defined points and/or a length of an individual river which shows broadly similar physical characteristics.
Riparian	The area of land alongside a river, often planted with trees.
Riffle	A reach of stream that is characterised by shallow, fast-moving water broken by the presence of rocks and boulders.
Run	Shallow, fast flowing section, similar in character to a riffle but not a discrete feature.
Sinuosity	Sinuosity, as applied to stream-channel pattern, is a non-dimensional ratio of the length of the channel thalweg to the length of the stream valley, measured between the same points.
Silt	As fluvial sediment, silt is sediment with a particle diameter between 0.002 & 0.062 mm. Some classification systems define the lower size limit to be 0.004 mm.
Scour	The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.
Wetland scrape	Shallow ponds of less than 1 m depth which hold rain or flood water seasonally and which remain damp for much of the year. They are shallow depressions with gently sloping edges which create obvious water features in fields. They can make a significant difference to wildlife and can be created in areas of damp or floodplain.
Study area	Area where potential impacts from the project could occur, as defined for each individual EIA topic.

Sedimentation (Siltation)	The process by which sediment is mechanically deposited from suspension within a fluid, generally water, or ice, thereby accumulating as layers of sediment that are segregated owing to differences in size, shape, and composition of the sediment particles.
Scour	Removal of sediment such as sand and gravel.
Substrate	Sediment material that rests at the bottom of a river.
The Sheringham Shoal Offshore Wind Farm Extension Project (SEP)	The Sheringham Shoal Offshore Wind Farm Extension site as well as all onshore and offshore infrastructure.
Thalweg	A line connecting the lowest points of successive cross-sections along the course of a valley or river.
Water Framework Directive	Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of water policy (generally known as the Water Framework Directive (WFD).
Wetland	Wetland is a low-lying area, including ephemeral-lake floors, in which water either is shallowly ponded on the surface or has a persistent (weeks or longer) near-surface condition of ground-water saturation adequate to support hydrophytic vegetation.

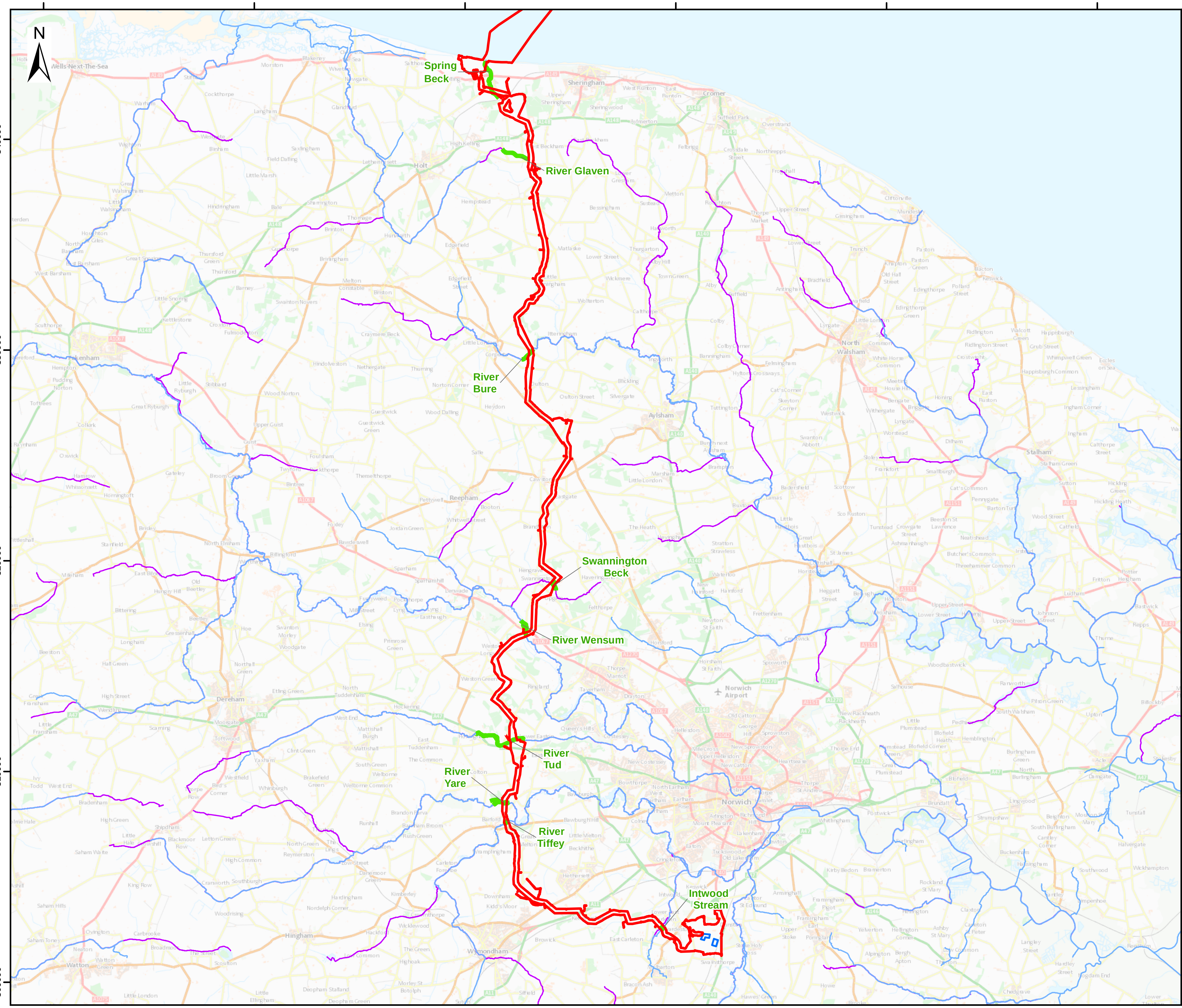
20.3 GEOMORPHOLOGICAL BASELINE SURVEY

20.3.1 Introduction

1. Equinor New Energy Limited (hereafter Applicant) is proposing to extend the existing operational Dudgeon and Sheringham Shoal Offshore Wind Farms named the Dudgeon Offshore Wind Farm Extension Project (hereafter DEP) and the Sheringham Shoal Offshore Wind Farm Extension Project (hereafter SEP). DEP and SEP will include a number of offshore and onshore elements including wind turbines and up to two offshore substations and associated cables to allow connection to the electricity transmission network.
2. Royal HaskoningDHV was commissioned to undertake a geomorphological baseline survey of the major watercourses proposed to be crossed by the DEP and SEP onshore cable corridor. The baseline survey involved a walkover of nine key watercourses to establish and characterise the baseline conditions at those sites (see **Figure 20.3.1**).

20.3.1.1 Aims

3. The aim of the geomorphological walkover survey was to characterise the geomorphological baseline conditions of the major watercourses that are proposed to be crossed by DEP and SEP.
4. Characterising the geomorphology of watercourses provides baseline information on their physical form and the processes (such as sediment transport and deposition) that may influence this form. This baseline information has been used to determine how the watercourses are likely to respond to the construction, operation and decommissioning of DEP and SEP. This baseline environment will then be used to inform the detailed design, construction and monitoring phases of DEP and SEP to ensure the geomorphological and ecological integrity of these watercourses is maintained, and also to inform potential opportunities for Biodiversity Net Gain.
5. The purpose of this report is to present the baseline characteristics of the surveyed watercourses, and to provide an overall understanding of their existing condition against which potential impacts can be assessed. The baseline information gathered during this geomorphological walkover survey has been used to inform the assessments presented in **Chapter 20 Water Resources and Flood Risk** of the Preliminary Environmental Information Report (PEIR); and **Appendix 20.1 Water Framework Directive Compliance Assessment**.



Sheringham Shoal and Dudgeon Extension Projects

Figure 01
Location Plan

Legend:

- PEIR Boundary
- Onshore Substation Site
- Survey Location
- Main River
- WFD River Water Body

Data Sources: Environment Agency, 2020; RHDHV, 2020
Base Map: © Crown copyright and database rights 2020, Ordnance Survey 0100031673; © OpenStreetMap (and) contributors, CC-BY-SA

Document No: PB8164-RHD-ZZ-ON-DR-Z-0057

Co-ordinate System: British National Grid

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Report:
Geomorphology Survey Report
Preliminary Environmental Information Report (PEIR)

Royal HaskoningDHV
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20.3.2 Methodology

6. This section presents the study area and methodology used to undertake the geomorphological walkover survey.

20.3.2.1 Study Area

7. Nine major watercourses which are proposed to be crossed by the DEP and SEP PEIR Boundary were identified for the targeted geomorphological walkover survey. These consisted of all the Main Rivers and/or river water bodies identified under the Water Framework Directive (WFD) in the Anglian River Basin District Management Plan. The nine identified watercourses are presented in **Table 20.3.1** and **Figure 20.3.1**.

Table 20.3.1: Surveyed Watercourses.

Name	Type	Channel length within cable corridor (m)	Grid Reference
Spring Beck	Main River	1338	TG1102343425
River Glaven	WFD water body	947	TG1192939376
River Bure	Main River	768	TG1318929901
Swannington Beck	WFD water body	271	TG1417818892 TG1422919003
River Wensum	Main River	835	TG1282216767
River Tud	Main River	3115	TG1180811215
River Yare	Main River	412	TG1230008406
River Tiffey	Main River	269	TG1172107438
Intwood Stream	WFD water body	215	TG1940302636
	Main River	209	

20.3.2.2 Field Survey

8. A targeted walkover survey was undertaken to characterise the surface water conditions of these nine watercourses. The survey was undertaken between September 28th and October 2nd 2020 by an experienced fluvial geomorphologist using best-practice guidance for geomorphological characterisation and monitoring, including:

- Environment Agency (2003): River Habitat Survey in Britain and Ireland: Field Survey Guidance Manual;
- Environment Agency (2007): Geomorphological Monitoring Guidelines for River Restoration Schemes; and
- River Restoration Centre (2011): Practical River Restoration Appraisal Guidance for Monitoring Options.

9. Following the best-practice guidance stated above, a visual inspection was undertaken along the study area for each watercourse. The main characteristics of each watercourse were carefully recorded from the bank top, which included detailed photographs and locations of key features using GPS. The following parameters were recorded in order to characterise the baseline geomorphology of each watercourse:

- Flow conditions, including dominant flow types and the degree of variability within each reach.
- Channel form, including planform, width and depth variation, bank form and condition, substrate types and the type and presence of bed forms such as pools, riffles and bars. Particular attention will also be paid to the extent of fine sedimentation on the bed of chalk river habitats.
- Floodplain characteristics, including connectivity to the river channel, and the structure of the riparian zone.
- Evidence of channel modification, including enlargement and re-sectioning, artificial bank protection, embankments and in-channel structures.
- The survey aimed to identify any visual contamination of the watercourse (e.g. excessive sedimentation/smothering, hydrocarbons, sewage fungus, discoloration, etc.) as well as any operating discharges/pipes e.g. septic tank outflows etc. in order to identify any evidence of contamination or local sources of pollution.

10. At the proposed crossing points, the targeted walkover survey encompassed the cable corridor width. In areas where the spatial extent of the works is greater (e.g. the grid connection, substation and construction compounds), the targeted walkover survey encompassed the entire length of any watercourses within the footprint of DEP and SEP. All terminology used for the survey was consistent with the latest standard for hydromorphology (CEN, 2018).

20.3.2.3 Survey Limitations

11. During the survey, water levels in the watercourses were predominately below bankfull and of low turbidity providing excellent visibility of the bed and banks of each watercourse to enable their overall geomorphological characteristics to be described.

12. Access to parts of the River Tud was restricted at the time of the survey. However, it was possible to access a large proportion of the river. Field observations were further validated against aerial photography of inaccessible parts of the river. These restrictions are therefore not considered to have limited the geomorphological characterisation of this water body.

20.3.3 Results

13. The results of the geomorphological walkover survey for those watercourses identified in **Table 2.1** and **Figure 2.1** are presented in this section.

20.3.3.1 Spring Beck

14. The characteristics of the Spring Beck are described in **Table 20.3.2** Spring Beck is a minor watercourse which flows through the village of Weybourne, North Norfolk (**Plate 20.3.1**). Its headwaters are in Hundred Acre Wood above Weybourne, 50m above sea level close to Weybourne railway station. From its source, the beck flows under the track of the North Norfolk Railway and out across an open farmland towards Weybourne village, where it has been heavily modified, flows through housing estates, culverts, marshes and finally discharges through a pipe onto a shingle beach.

Table 20.3.2: Details of Spring Beck

Parameter	Details
WFD Water Body	N/A
Water Body ID	N/A
Watercourse Type	Main River
Grid Reference	TG1102343425

Plate 20.3.1: Spring Beck.

20.3.3.1.1 Flow conditions

15. Spring Beck has been modified (see below) and is predominantly characterised by low energy glide and impounded flows, with limited flow diversity or in channel features. Faster flow habitats (such as runs) were observed, although these occurred through the artificial sections of the beck.

20.3.3.1.2 Channel form

16. The course of Spring Beck was modified in the eighteenth century in response to the construction of a watermill and dammed to create a substantial mill pond. As such, the beck in places does not follow the natural watercourse alignment and is diverted along an artificial course for some length through the village of Weybourne. The channel form of the beck through the village is therefore predominately straight, with artificial (concrete) bed and banks in places. The channel is approximately 1m – 2m wide at the bank top; 1m wide at the bank base, with a bankfull depth between 0.5m – 1m. Thus, the overall form of the beck through the village displays a typical box shape uniform channel, with limited instream morphological complexity (**Plate 20.3.2**). On the outskirts of the village, the beck although less confined, displays a U shape uniform channel, typical of drainage ditches in open fields (**Plate 20.3.2**).

Plate 20.3.2: Spring Beck channel form.

20.3.3.1.3 Soils and substrates

17. Spring Beck within the study area is associated with colluvium soils; loose unconsolidated sediments typically composed of a heterogeneous range of rock types; and sediments ranging from silt to rock fragments of various sizes. The beck is also associated with peat soils, an accumulation of partially decayed vegetation or organic matter.

18. The overall substrate of the beck throughout the study area is thus dominated by sands, silts and gravels. The dominant fluvial process appears to be sediment deposition, with slow glide flows, local impoundments caused by small weirs, the mill pond, dense in-stream vegetation, low gradients and low velocities all contributing to the settling out of fine sediments/silts (**Plate 20.3.3**).

19. Although a proportion is likely to be derived from exposed banks during higher-energy flows, the majority of the fine sediment load is likely to be sourced from the agricultural fields on the outskirts of the village (i.e. surface runoff) (**Plate 20.3.3**).

Plate 20.3.3: Sediment sources and local impoundment.

20.3.3.1.4 Floodplain Characteristics

20. Floodplain connectivity is constrained for the majority of Spring Beck's length within the village as a result of channel modifications, with limited floodplain connectivity also on the outskirts of the village due to the U shape (tree lined) uniform channel of the beck.

20.3.3.1.5 In-channel / riparian vegetation

21. There is limited in-channel aquatic vegetation along Spring Beck throughout the study area, with the beck above the mill pond heavily silted and overgrown with reeds. However, there are places were the banks and margins of the beck are suitably vegetated, although these are mainly associated with urban landscaping.

20.3.3.1.6 Modifications/Structures

22. Spring Beck within the study area was modified in the eighteenth century as part of the construction of a watermill (**Plate 20.3.1**); with the beck flowing through an artificial course (concreted in places) and culverts.

20.3.3.2 River Glaven

23. The characteristics of the River Glaven are described in **Table 20.3.3**. The River Glaven, which is classified as a chalk stream, has its headwaters in Lower Bodham, North Norfolk, within the study area for DEP and SEP. The headwaters are predominately characterised by a uniform, incised channel which is straight, heavily vegetated and flowing through a low gradient glacial till floodplain and woodland (**Plate 20.3.4**). There is limited floodplain connection and the channel is overall dominated by glide flows, silt deposition and leaf litter, with occasional faster flowing run sections and a deep online pond. Key sediment sources include local bank scour, access tracks, outfall pipes and upstream land management.

Table 20.3.3: Details of the River Glaven.

Parameter	Details
WFD Water Body	Glaven
Water Body ID	GB105034055780
Watercourse Type	WFD Water Body
Grid Reference	TG1192939376

Plate 20.3.4: River Glaven.

20.3.3.2.1 Flow conditions

24. The River Glaven within the study area is predominantly characterised by glide flows, with occasional faster flowing run sections and a deep slow flowing online pond considerably larger than the inflow and outflow channel of the River Glaven (**Plate 20.3.5**).

Plate 20.3.5: Online pond in the River Glaven.

20.3.3.2.2 Channel form

25. The channel has straight planform sections within the study area, which are incised in places into the floodplain and surrounded by agricultural fields and fishing lakes. The banks are relatively steep, stable and well vegetated throughout the study area. The channel (not including the online pond) varies between 1m – 5m wide at the bank top; 0.5m – 1.5m wide at the bank base, with a bankfull depth between 1m – 2m. The overall channel morphology of the River Glaven displays a predominately uniform channel, with the exception of the start and end locations of the study area in which the River Glaven displays more complex geomorphology, including a high flow bench or two-stage channel on the left bank (**Plate 20.3.6**).

Plate 20.3.6: River Glaven channel form.

20.3.3.2.3 Soils and substrate

26. The River Glaven within the study area is associated with glacial till, with the banks of the river through the study area comprised of clay, sand, gravel, cobbles and boulders (**Plate 20.3.7**).

Plate 20.3.7: Glacial till bank composition in the River Glaven

27. The substrate of the River Glaven throughout the study area is thus dominated clay, sand, boulders, minerals, and gravel. The dominant fluvial process appears to be sediment deposition, with slow flows, low gradients, dense in-channel vegetation (undergrowth) and low velocities contributing to the settling out of fine sediments/silts (**Plate 20.3.8**).

Plate 20.3.8: Silt deposition and outfall pipe.

28. A portion of the fine sediment load is likely to be derived from exposed banks during higher-energy flows, outfall pipes, drainage ditches, access tracks and road runoff (noted towards the far downstream end of the study area). The adjacent agricultural fields are also likely to be a major source of fine sediment load through diffuse surface runoff

20.3.3.2.4 Floodplain Characteristics

29. Limited floodplain connectivity along the River Glaven was observed throughout the study area due to the slightly raised flood embankments and incised nature of the channel in places.

20.3.3.2.5 In-channel / riparian vegetation

30. The banks and margins are well vegetated, with the channel itself encroached by dense vegetation, such as grasses and bracken in places reducing flow velocities, although there was limited in-channel aquatic plants (macrophytes).

20.3.3.2.6 Modifications / Structures

31. The banks of the River Glaven within the study area are slightly raised to provide flood protection of adjacent agricultural fields, with access tracks and culverts also present. However, no hard engineering bank protection works were observed during the walkover survey.

20.3.3.3 River Bure

32. The characteristics of the River Bure are described in **Table 20.3.4**. Rising in Melton Constable, North Norfolk, the River Bure, which is classified as a chalk stream, passes through the internationally important Norfolk Broads and discharges into the sea at Great Yarmouth.

33. The River Bure within the study area is characterised by varied channel morphology with several ditches in the floodplain contributing to habitat complexity. Very little silt deposition along the channel bed was observed and water-crowfoot (*Ranunculus* spp.) present. Good floodplain connection is clearly evident and in places the River Bure has a two-stage channel consisting of high and low flow channels within a wider channel belt (**Plate 20.3.9**). Key sediment sources include local bank scour, ditches and upstream land management. Himalayan balsam (*Impatiens glandulifera*) is present in the study area.

Table 20.3.4: Details of the River Bure.

Parameter	Details
WFD Water Body	Bure (u/s confluence with Scarrow Beck)
Water Body ID	GB105034055690
Watercourse Type	Main River
Grid Reference	TG1318929901

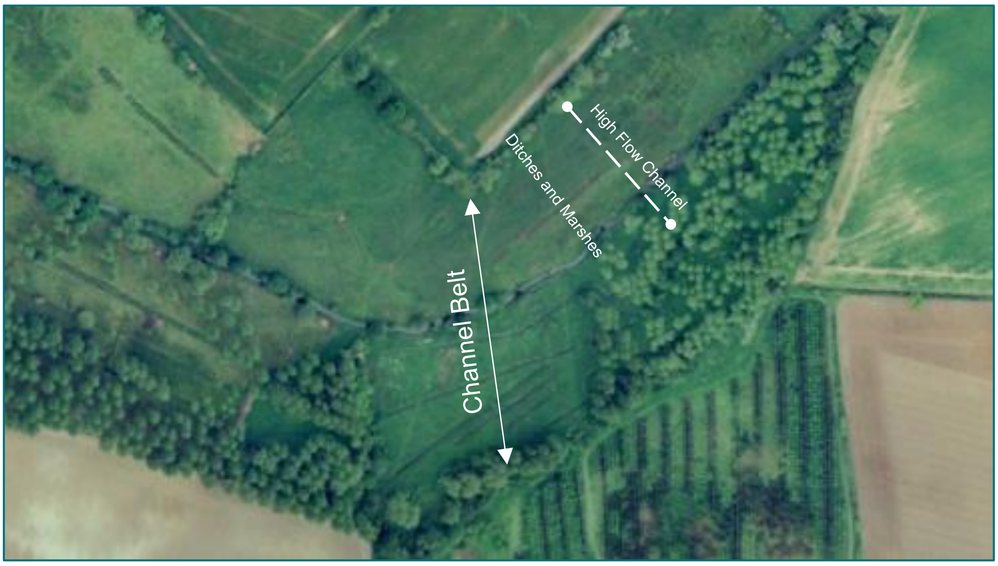
Plate 20.3.9: River Bure and example ditch.

20.3.3.3.1 Flow conditions

34. The River Bure within the study area is characterised by various flow types, including glides, runs and pools, while the drainage ditches in the floodplain are generally associated with slow flows (trickles) connecting small narrow glide or pool flow habitats (**Plate 20.3.9**).

20.3.3.3.2 Channel form

35. The channel has a straight planform within the study area, although displays geomorphological complexity varying in size and shape surrounded by agricultural fields, woodland and open fields with wetland (marsh) features. In general, the banks are relatively stable and well vegetated with the channel size between 4m – 6m at the bank top; 2m – 3m wide at the bank base, with a bankfull depth between 1m – 2m. The main channel is contained within a wider channel belt (approximately 100m – 250m wide) also consisting of a network of ditches and vegetated islands forming a wetland (marsh) system (**Plate 20.3.10**). The River Bure within the wider channel belt takes the form of a large two-stage channel.



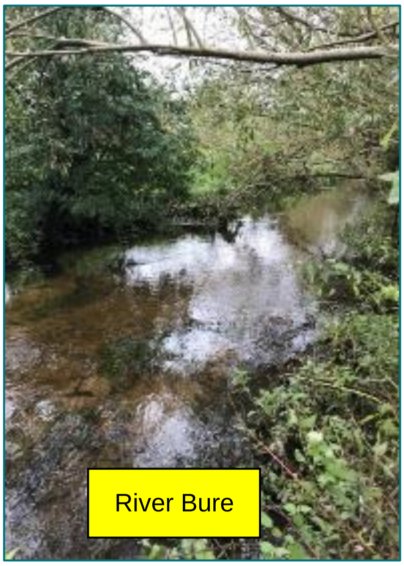


Plate 20.3.10: River Bure floodplain and channel features.

20.3.3.3.3 Soils and substrate

36. The River Bure within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel vegetation, such as sedges and grasses) providing good filtration of water.

37. The substrate of the River Bure throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment transport with very little silt deposition observed on the bed and margins of the river during the walkover survey.

38. Although very little silt deposition was observed, any likely sediment load into the River Bure would be associated with upstream land management. The lack of silt deposition along the River Bure within the study area was most likely in response to the stable nature of the channel, wetland and associated vegetation perhaps acting like a filtration system.

20.3.3.3.4 Floodplain characteristics

39. Good floodplain connectivity or interaction with the wider channel belt of the River Bure within the study area was clearly evident during the walkover survey.

20.3.3.3.5 In-channel / riparian vegetation

The banks and margins of the River Bure are well vegetated, with good coverage of aquatic plants along the bed of the river, including pockets of water-crowfoot (**Plate 20.3.11**). The channel belt has an array of terrestrial and wetland plants, although Himalayan balsam is present.


Plate 20.3.11: Water-crowfoot (left) and Himalayan balsam (right).

20.3.3.3.6 Modifications/ structures

40. No modifications or structures, such as hard engineering bank protection works were observed during the walkover, although directly downstream of B1354 bridge water is abstracted from the River Bure.

20.3.3.4 Swannington Beck

41. The characteristics of the Swannington Beck are described in **Table 20.3.5** Swannington Beck is a tributary of the River Wensum within the Broadland and Broads region of Norfolk. The primary channel of the beck displays varied flow habitats and morphology and meanders through open agricultural and grazing fields (**Plate 20.3.12**).

Table 20.3.5: Details of Swannington Beck.

Parameter	Details
WFD Water Body	Swannington Beck
Water Body ID	GB105034051070
Watercourse Type	WFD Water Body
Grid Reference	TG1417818892 (South branch, primary channel) TG1422919003 (North branch, secondary channel)

Plate 20.3.12: Swannington Beck – primary channel.

42. The primary channel is also heavily vegetated, tree lined and incised in places (deep and narrow), with limited floodplain connectivity. Substrate sediments are comprised of clay, sands and gravels, with clean pockets of sand and gravel evident, and silt deposition in places (**Plate 20.3.12**). Likely sediment load into the Swannington Beck would be associated with local bank erosion and upstream land management, although banks of the beck within the study area are well fenced which has reduced the impacts of livestock poaching (trampling). The secondary channel (or northern arm) of the Swannington Beck is a smaller watercourse which is wide, deep, straight, tree lined with good marginal vegetation (sedges, bladed grasses – iris). The bed of watercourse is predominantly comprised of silts (**Plate 20.3.13**).

Plate 20.3.13: Swannington Beck – secondary channel.

20.3.3.4.1 Flow conditions

43. The primary channel of the Swannington Beck within the study area is characterised by various flow habitats including runs, riffles, glides and pools; while the secondary channel was generally associated with slow flows (trickles) in response to dense in-channel vegetation, which connected small narrow glide or pool flow habitats.

20.3.3.4.2 Channel form

44. The primary channel of the Swannington Beck has a sinuous planform within the study area. However, the channel is predominantly constrained by riparian and in places characterised by a deep and narrow channel. The bank top width of the channel is between 5m – 7m and width at the base between 3m – 5m. Bankfull depth is approximately 2m (**Plate 20.3.12**).

45. Given the tree lined nature of the channel, the majority of morphological adjustment is through increasing the bed gradient (slope) of the Swannington Beck. Other channel form adjustments, such as the development of anabranches (and in-channel bars) were evident along the beck, with anabranches generally formed through avulsion triggered by debris accumulation (**Plate 20.3.14**).

Plate 20.3.14: Anabranch and wet woodland.

46. The secondary channel of the Swannington Beck is wide and relatively deep (incised), with dense in-channel vegetation. The channel size is approximately 5m at the bank top, 1m at the bank base, with a bankfull depth of approximately 1m.

20.3.3.4.3 Soils and substrate

47. The Swannington Beck within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel vegetation, such as sedges and grasses) providing good filtration of water.

48. The substrate of the primary channel of the Swannington Beck throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment deposition triggered by slow flows, debris and impoundment caused by a small weir (**Plate 20.3.15** and **Plate 20.3.16**). The bed in some places was also armoured, in which coarse grains were on the surface protecting finer particles underneath from erosion (**Plate 20.3.15**).

Plate 20.3.15: Weir and bed armouring along the Swannington Beck.

Plate 20.3.16: Sediment deposition upstream of weir.

49. The secondary channel of the Swannington Beck is dominated by silts in response to slow flows and debris causing settling out of fine sediments.

50. Likely sediment load into the Swannington Beck would be associated with local bank erosion, access tracks and upstream land management. However, the banks of the beck along the primary channel within the study area are well fenced which has reduced the impacts of livestock poaching (and fine sediment input).

20.3.3.4.4 Floodplain characteristics

51. Limited floodplain connectivity along the Swannington Beck was observed throughout the study area in response to the predominantly incised nature of both channels.

20.3.3.4.5 In-channel / riparian vegetation

52. The banks and margins of both channels of the Swannington Beck are well vegetated, with the channels themselves encroached by dense vegetation in places reducing flow velocities. However, there was limited in-channel aquatic plants (macrophytes) in the primary channel, although the smaller watercourse did contain star moss (*Tortula ruralis*).

20.3.3.4.6 Modifications / Structures

53. No modifications or structures, such as hard engineering bank protection works were observed during the walkover. However, along the primary channel of the Swannington Beck, water is abstracted upstream of the small weir at grid reference TG 14193 18842.

20.3.3.5 River Wensum

54. The characteristics of the River Wensum are described in **Table 20.3.6.** The River Wensum, a chalk stream, rises to the west of Fakenham, then flows southeast for 50km towards Norwich and the River Yare, of which it is a major tributary. The river is a biological Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC). The primary channel of the River Wensum within the study area is characterised by a straight to sinuous planform which is wide, deep and slow flowing in places and dominated by glide flow habitat, with good marginal vegetation comprised of sedges, bladed grasses – iris and reeds (**Plate 20.3.17**). There is good floodplain connection as evident by small wetlands, back waters and an overall wetted floodplain.

55. The secondary channel (or northern arm) of the River Wensum is a small, straight and incised watercourse, with good marginal vegetation, although dominated by in-channel vegetation in places (**Plate 20.3.17**).

Table 20.3.6: Details of the River Wensum.

Parameter	Details
WFD Water Body	Wensum US Norwich
Water Body ID	GB105034055881
Watercourse Type	Main River
Grid Reference	TG1282216767

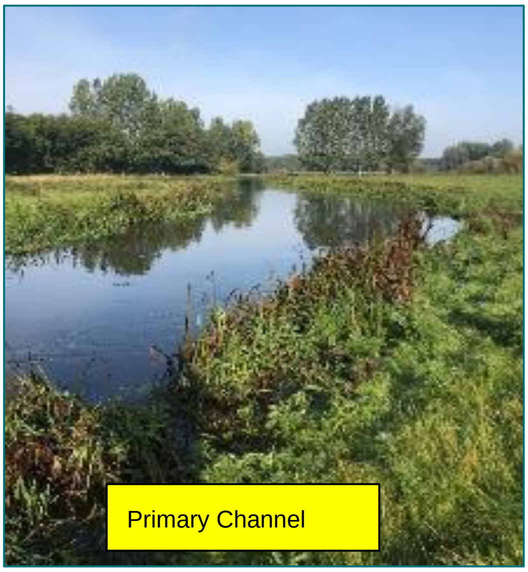


Plate 20.3.17: River Wensum primary and secondary channel.

20.3.3.5.1 Flow conditions

56. The primary channel of the River Wensum within the study area is characterised by various flow habitats including runs and glides; while the secondary channel was generally associated with slow flows, in response to dense in-channel vegetation, which connected small narrow glide or pool flow habitats.

20.3.3.5.2 Channel form

57. The primary channel of the River Wensum has a straight to sinuous planform within the study area and flows through an open floodplain characterised by a wide and deep channel, with the bank top width between 8m – 10m and width at the base between 5m – 6m. Bankfull depth is approximately 2m (**Plate 20.3.17**). Key channel and floodplain features include small benches (steps in the channel which accumulate organic debris and silts), backwaters and wetlands, providing geomorphic complexity and habitat diversity (**Plate 20.3.18**).

Plate 20.3.18: Channel and floodplain features.

58. The secondary channel of the River Wensum is wide and relatively deep (incised), with dense in-channel vegetation. The channel size is approximately 5m at the bank top; 1m at the bank base, with a bankfull depth of approximately 0.5m – 1m. Three small ditches connect to the secondary channel along its length (**Plate 20.3.19**).

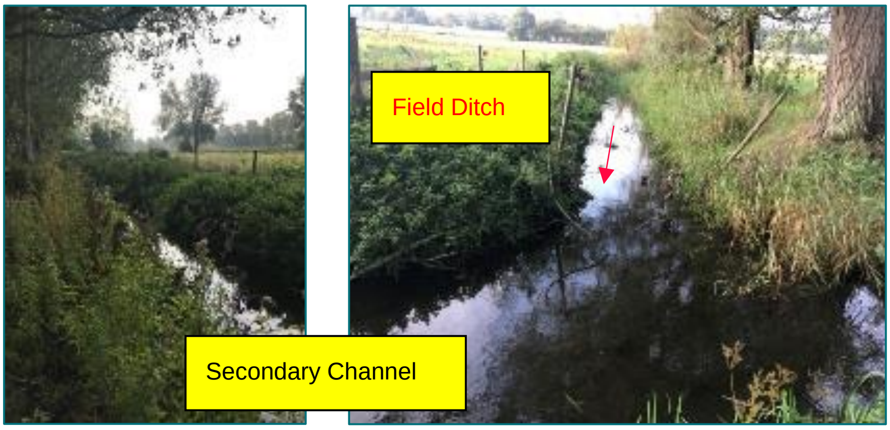


Plate 20.3.19: Secondary channel and field ditches.

20.3.3.5.3 Soils and Substrate

59. The River Wensum within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel vegetation, such as sedges and grasses) providing good filtration of water.

60. The substrate of the primary channel of the River Wensum throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment deposition triggered by slow glide flows allowing fine sediments to settle out on the riverbed and backwaters (**Plate 20.3.20**). The banks of the river were well fenced in places with no evidence of livestock poaching. Likely sediment load into the primary channel of the River Wensum would be associated with local bank erosion, access tracks, and upstream land management.

61. The secondary channel of the River Wensum and field ditches are dominated by silts in response to slow flows and debris causing settling out of fine sediments (**Plate 20.3.20**).

Plate 20.3.20: Silt deposition.

20.3.3.5.4 Floodplain characteristics

62. Good floodplain connectivity along the primary channel of the River Wensum within the study area was clearly evident during the walkover survey (**Plate 20.3.18**).

63. Good floodplain connectivity was also evident towards Old Fakenham Road (downstream end of study area) along the secondary channel in response to the change in channel morphology, with the channel not incised and channel banks gently sloping allowing inundation of the floodplain in places (**Plate 20.3.21**).

Plate 20.3.21:: Secondary channel floodplain connectivity.

20.3.3.5.5 In-channel / riparian vegetation

64. The banks and margins of both channels of the River Wensum are well vegetated, with the secondary channel encroached by dense vegetation in places such as grasses, reducing flow velocities. However, there was limited in-channel aquatic plants (macrophytes) along both channels.

20.3.3.5.6 Modifications / structures

65. No modifications or structures, such as hard engineering bank protection works were observed during the walkover along the primary channel of the River Wensum, although the secondary channel in places is modified with stone bank protection along the back of a housing estate. Two small pipes also discharge into the secondary channel towards the downstream end of the study area (**Plate 20.3.22**).

Plate 20.3.22: Modification of the secondary channel.

20.3.3.6 River Tud

66. The characteristics of the River Tud are described in **Table 20.3.7**. The River Tud, a tributary of the River Wensum in Central Norfolk, has its source south of East Dereham, where it then flows in an easterly direction for 27 kilometres to its confluence with the River Wensum below the village of Hellesdon. The River Tud within the study area is characterised by a straight to gently sinuous planform which is wide and shallow in places and dominated by varied flow habitats including glides, runs, pools and riffles (**Plate 20.3.23**). The river has good marginal vegetation dominated by sedges, bladed grasses, iris and reeds, with good coverage of aquatic plants along the bed of the river, including pockets of water-crowfoot. There is good floodplain connection, although livestock poaching does occur along the River Tud within the study area.

Table 20.3.7: Details of the River Tud.

Parameter	Details
WFD Water Body	Tud
Water Body ID	GB105034051000
Watercourse Type	Main River
Grid Reference	TG1180811215

20.3.3.6.1 Flow conditions

67. The River Tud within the study area is characterised by various flow types, including

Plate 20.3.23: River Tud.

glides, runs, pools and riffles, with strong eddies observed on the outside of meander bends.

20.3.3.6.2 Channel form

68. The River Tud has a straight to sinuous planform within the study area and flows through an open floodplain characterised by a wide and shallow channel, with the bank top width between 5m – 8m and width at the base between 4m – 5m. Bankfull depth is approximately 2m (**Plate 20.3.23**). Key channel and floodplain features include small benches (steps in the channel which accumulate organic debris and silts), relic channels, drainage ditches, scrapes (or ponds) and wetlands, providing geomorphic complexity and habitat diversity (**Plate 20.3.24**).

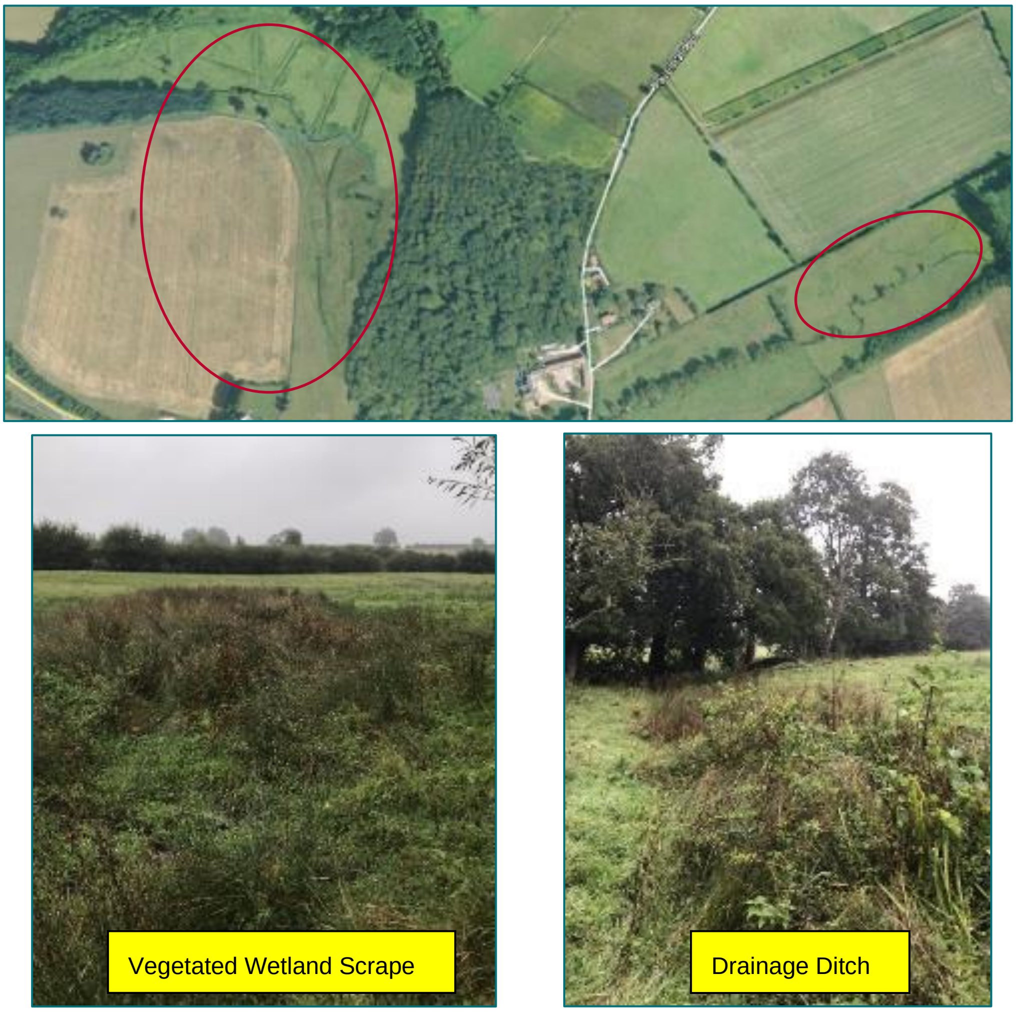


Plate 20.3.24: River Tud floodplain features

20.3.3.6.3 Soils and substrate

69. The River Tud within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel and marginal vegetation, such as sedges and grasses) providing good filtration of water and clean gravels (**Plate 20.3.25**).

Plate 20.3.25: Clean gravel bed substrate.

70. The substrate of the River Tud throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment transport with very little sediment deposition on the bed during the time of the walkover (**Plate 20.3.25**). However, fine sediments were evident along the margins of the river.

71. Despite livestock poaching prevalent within the study area, there was minimal fine sediments on the riverbed, although poaching is likely to be a key sediment source along with point source pollution from ditches (iron leaching observed in one ditch) and upstream land management. A potential reason why livestock poaching did not have an impact on bank erosion and thus contribute more as a sediment source, appears to be in response to the well vegetated floodplain, banks and margins of the River Tud (**Plate 20.3.23**).

20.3.3.6.4 Floodplain characteristics

72. Good floodplain connectivity along the River Tud within the study area was clearly evident during the walkover survey (**Plate 20.3.24**).

20.3.3.6.5 In-channel / riparian vegetation

73. The River Tud throughout the study area has good marginal vegetation dominated by sedges, bladed grasses, iris and reeds, with good coverage of aquatic plants along the bed of the river, including pockets of water-crowfoot and watercress).

Plate 20.3.26: Water-crowfoot and watercress

20.3.3.6.6 Modifications / structures

74. No modifications or structures, such as hard engineering bank protection works were observed along the River Tud during the walkover survey or through inspection of aerial photos.

20.3.3.7 River Yare

75. The characteristics of the River Yare are described in **Table 20.3.8**. The River Yare rises to the south of Dereham and flows eastwards through the central region of Norfolk passing the isolated marshland settlement of Berney Arms before entering the tidal lake of Breydon Water and discharging into the North Sea at Gorleston. The River Yare within the study area is characterised by a straight to sinuous planform which is wide and deep in places and dominated by glide and pool flow types (**Plate 20.3.27**). The river has good marginal vegetation including sedges, bladed grasses, iris and reeds, with good floodplain connection. The floodplain contains small wetland scrapes (or ponds) and backwaters (**Plate 20.3.27**).

Table 20.3.8: Details of the River Yare

Parameter	Details
WFD Water Body	Yare (u/s confluence with Tiffey - Lower)
Water Body ID	GB105034051290
Watercourse Type	Main River
Grid Reference	TG1230008406

Plate 20.3.27: River Yare and floodplain

20.3.3.7.1 Flow Conditions

76. The River Yare within the study area is characterised by glide and pool flow types.

20.3.3.7.2 Channel form

77. The River Yare has a straight to sinuous planform within the study area and flows adjacent to Colton Wood and open floodplain, characterised by a wide and deep channel, with the bank top width between 5m – 8m and width at the base between 4m – 5m. Bankfull depth is approximately 2m. Key channel and floodplain features include wetland scrapes and backwaters (**Plate 20.3.28**).

Plate 20.3.28: River Yare channel form and floodplain features

20.3.3.7.3 Soils and substrate

78. The River Yare within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel and marginal vegetation, such as sedges and grasses) providing good filtration of water.

79. The substrate of the River Yare throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment deposition. Likely sediment load into the River Yare would be associated with local bank erosion, access tracks and upstream land management.

20.3.3.7.4 Floodplain characteristics

80. Good floodplain connectivity along the River Yare within the study area was clearly evident during the walkover survey (**Plate 20.3.27**).

20.3.3.7.5 In-channel / riparian vegetation

81. The banks and margins of River Yare well vegetated with terrestrial species. However, there was limited in-channel aquatic plants (macrophytes) along the River Yare, although dense patches of in-channel vegetation, such as rushes, were observed towards the upstream end of the study area.

20.3.3.7.6 Modifications / structures

82. Other than a small footbridge towards the downstream limits of the study area adjacent Colton Wood, no major modifications or structures such as hard engineering bank protection works, were observed along the River Yare during the walkover survey.

20.3.3.8 River Tiffey

83. The characteristics of the River Tiffey are described in **Plate 20.3.29**. The River Tiffey, a tributary of the River Yare, rises near Hethel and flows north-eastwards through the central region of Norfolk and several villages before joining the River Yare near Barford. The River Tiffey within the study area is characterised by a relatively straight planform which is deep and narrow in places and dominated by glide and pool flow habitats (**Plate 20.3.29**). The river has good marginal vegetation including sedges, bladed grasses, iris, bull rushes and reed, with good floodplain connection. The floodplain contains ditches, a small lake (offline pond) and wet woodland (**Plate 20.3.29**).

Table 20.3.9: Details of the River Tiffey.

Parameter	Details
WFD Water Body	Tiffey
Water Body ID	GB105034051282
Watercourse Type	Main River
Grid Reference	TG1172107438

20.3.3.8.1 Flow Conditions

84. The River Tiffey within the study area is characterised by glide and pool flow habitats.

Plate 20.3.29: River Tiffey and floodplain features

20.3.3.8.2 Channel form

85. The River Tiffey has a straight to sinuous planform within the study area and flows adjacent woodland and open floodplain characterised by a relatively deep and narrow channel, with the bank top width between 4m – 5m and width at the base between 2m – 3m. Bankfull depth is approximately 2m (**Plate 20.3.30**). Key channel and floodplain features include several straight ditches 2m wide and approximately 0.5m deep which are well vegetated in places; and a small lake which was once used for angling (**Plate 20.3.29**). The lake is approximately 20m wide by 50m in length, although much of the lake has now been infilled within a planted woodland (**Plate 20.3.29**).

Plate 20.3.30: River Tiffey channel form.

20.3.3.8.3 Soils and substrate

86. The River Tiffey within the study area is associated with riverine clay, sands and gravels, with the banks predominantly composed of clay and sand (i.e. clay to sandy loam banks), with the properties of the soils (along with the in-channel and marginal vegetation, such as sedges and grasses) providing good filtration of water.

87. The substrate of the River Tiffey throughout the study area is thus dominated clay and sand. The dominant fluvial process appears to be sediment deposition in response to the slow flows (low velocities) contributing to the settling out of sediments. However, there was minimal silt deposition, with the majority of deposition associated coarser sediments, such as sand (**Plate 20.3.31**).

88. Likely sediment load into the River Tiffey would be associated with local bank erosion and upstream land management.

Plate 20.3.31: Sand ripples.

20.3.3.8.4 Floodplain characteristics

89. Good floodplain connectivity along the River Tiffey within the study area was clearly evident during the walkover survey (**Plate 20.3.29**).

20.3.3.8.5 In-channel / Riparian Vegetation

90. The banks and margins of the River Tiffey are well vegetated, although there was limited in-channel aquatic plants (macrophytes) along the bed of the river. Himalayan balsam is present within the study area.

20.3.3.8.6 Modifications / Structures

91. No major modifications or structures such as hard engineering bank protection works, were observed along the River Tiffey during the walkover survey.

20.3.3.9 Intwood Stream

92. The characteristics of the Intwood Stream are described in **Table 20.3.10**. Intwood Stream, a tributary of the River Yare, rises near Mulbarton, and flows north-eastward through Swardeston and Keswick, where it then meets the River Yare. The Intwood Stream within the study area is characterised by two connected watercourses, a predominately main larger western channel (the WFD water body) and a smaller eastern channel (the Main River) (**Plate 20.3.32**).

Table 20.3.10: Details of Intwood Stream.

Parameter	Details
WFD Water Body	Intwood Stream
Water Body ID	GB105034051240

Parameter	Details
Watercourse Type	WFD water body and Main River
Grid Reference	TG1940302636

Plate 20.3.32: Intwood Stream channels.

93. The western channel of the Intwood Stream within the study area is characterised by a straight planform which varies in size and shape from a deep incised channel to a wide and shallow channel with good floodplain connectivity. The channel has varied flow habitats including glides, riffles and runs and contains wooded debris, with good marginal vegetation comprised of sedges, bladed grasses and iris (**Plate 20.3.33**). Floodplain features include ditches and ponds, although livestock poaching is prevalent along the western channel contributing to silt deposition on the bed. However, in places the bed shows some good clean sand and gravel deposition, associated with the glacial till nature of the surrounding soils, which are free of silt.

Plate 20.3.33: Western channel of the Intwood Stream

94. The eastern channel of the Intwood Stream within the study area is a smaller watercourse than the western channel and resembles a wide shallow drainage ditch, although does display varied flow habitats, including runs, riffles and pools, with pockets of pond weed. There is good marginal vegetation, such as bull rushes and sedges; and there is good floodplain connectivity (**Plate 20.3.34**). However, livestock poaching is also prevalent contributing to silt deposition on the channel bed. However, in places the bed shows some good clean coarse sand and gravel substrates (associated with the glacial till nature of the surrounding soils) which are free of silt.

95. A pipe discharges into a land drainage ditch which joins the channel towards the downstream end of the study area. The central reach of the eastern channel also has a culvert providing access to the inner floodplain.

Plate 20.3.34: Eastern channel of the Intwood Stream.

20.3.3.9.1 Flow Conditions

96. The western channel of the Intwood Stream within the study area is characterised by various flow types including glides, riffles and runs; while the eastern channel, to a lesser degree also displays similar flow habitats.

20.3.3.9.2 Channel form

97. The western channel of the Intwood Stream appears to have a modified planform which has been historically straightened, although despite this does show some geomorphic complexity within the study area varying in size and shape. The channel flows through an open floodplain and woodland, with the morphology of channel being deep and incised to wide and shallow, with good floodplain connectivity (see below). In places the channel had a bank top width between 3m – 4m and width at the base between 1m – 2m. Bankfull depth various between 1m – 2m (**Plate 20.3.35**).

Plate 20.3.35: Western channel form.

98. Key channel and floodplain features included backwaters, ditches and wetlands, providing geomorphic complexity and habitat diversity (**Plate 20.3.36**).

Plate 20.3.36: Western channel wetland and example ditch.

99. The eastern channel of the Intwood Stream within the study area is a smaller watercourse than the western channel and resembles a wide shallow drainage ditch, although does display some geomorphic complexity. The channel size is between 1 m - 2 m at the bank top; and approximately 1 m at the bank base, with a bankfull depth between 1 m – 1.5 m (**Plate 20.3.34**).

20.3.3.9.3 Soils and substrate

100. The Intwood Stream within the study area is associated with glacial till with the banks of the channels through the study area comprised of clay, sand, boulders, minerals, and gravel (**Plate 20.3.37**).

Plate 20.3.37: Glacial till bank composition.

101. The Intwood Stream channels throughout the study area are thus dominated by clay, sand, boulders, minerals, and gravel. There is not one dominant fluvial process, with both sediment deposition and transport occurring at a similar degree along both channels in response to the varied nature of the flow habitats.

102. A portion of fine sediment load along the channels is likely to be derived from exposed banks caused by livestock poaching, with higher-energy flows further eroding the banks contributing to fine silts on the channel beds (**Plate 20.3.38**). In addition, a pipe discharges into a land drainage ditch which joins the channel towards the downstream end of the study area potentially allowing fine sediment and/or contaminants to enter the watercourse **Plate 20.3.38**.

Plate 20.3.38: Livestock poaching and silts on channel bed.

20.3.3.9.4 Floodplain Characteristics

103. Good floodplain connectivity along the Intwood Stream channels throughout the study area was clearly evident during the walkover survey (**Plate 20.3.36**).

20.3.3.9.5 In-channel / Riparian Vegetation

104. The banks and margins of the Intwood Stream channels are well vegetated, with some in-channel aquatic plants (macrophytes).

20.3.3.9.6 Modifications / structures

105. A pipe outfalls into a land drainage ditch which joins the eastern channel towards the downstream end of the study area. The central reach of the eastern channel also has a culvert providing access to the inner floodplain (**Plate 20.3.39**).

Plate 20.3.39: Outfall pipe and small culvert.

20.3.4 SUMMARY

106. The geomorphological walkover survey undertaken between September 28th and October 2nd 2020 has demonstrated that watercourses in the study area predominantly consist of lowland, low gradient channels, which despite flowing across varied land uses do vary in the degree of morphological complexity and flow habitats, with some channels having good floodplain connectivity resulting in array of geomorphic features, such as wetland scraps, ditches and ponds, providing a diversity of habitats for wildlife.

107. The channel banks and margins of the watercourses are generally well vegetated with sedges and bladed grasses (iris) with good coverage of in-channel aquatic plants (macrophytes) along some watercourses, in particular those which had clean sandy substrates and classified as chalk streams (Rivers Glaven, Bure and Wensum). Although a proportion is likely to be derived from exposed banks during higher-energy flows, the majority of the fine sedimentation observed along most watercourses is likely to be sourced from adjacent agricultural fields and upstream land management.

108. The results of the walkover survey have been used to inform the baseline assessment presented in **Chapter 20 Water Resources and Flood Risk** of the PEIR. The results have also been used as the basis of the assessment of potential impacts from DEP and SEP on the geomorphology and physical habitat condition of surface waters presented in **Chapter 20 Water Resources and Flood Risk**; and the assessment of potential impacts on the hydromorphological quality elements supported by river water bodies presented in **Appendix 20.1 Water Framework Directive Compliance Assessment**. Further discussion regarding the outcomes of this survey and the implications for DEP and SEP are provided in these reports.

20.3.5 References

Environment Agency (2003) River Habitat Survey in Britain and Ireland: Field Survey Guidance Manual. Environment Agency, Bristol.
Environment Agency (2007) Geomorphological monitoring guidelines for river restoration schemes. Environment Agency, Bristol.
European Committee for Standardization (CEN) (2018) Water Quality – Guidance standard for assessing the hydromorphological features of rivers. CEN, Brussels.