A47 North Tuddenham to Easton Dualling

Scheme Number: TR010038

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6.3 Environmental Statement Appendices
Appendix 13.5 – Geomorphology Assessment Report

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ENVIRONMENTAL STATEMENT APPENDICES
Appendix 13.5 - Geomorphology Assessment Report

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Table of contents

Captions

Tables

1. Introduction

1.1.1. This report will describe the geomorphological setting of the River Tud and two minor tributaries that may be impacted by the construction of the A47 North Tuddenham to Easton Proposed Scheme. These surveys were carried out to assess the current geomorphic setting of the watercourses. The surveys also assessed any impacts due to realignment and other pressures, sediment transport potential and other factors.

1.1.2. The morphological stability is assessed in terms of planned infrastructure in the vicinity of the watercourse, with construction and operational impacts discussed and mitigation measures proposed.

2. Methods

2.1. Approach

2.1.1. Fluvial audits of the watercourses specified above were carried out. This involved both a desktop assessment and a walkover survey. The methods of both are summarised below. Guidance on undertaking the assessment was taken from Appendix E of the Design Manual for Roads and Bridges (DMRB) LA 113 guidance on hydromorphological assessment (Highways England, 2020a).

2.2. Desktop review

2.2.1. A desktop review of background and historical information related to the catchment watercourses was undertaken to characterise the geological setting of the catchment.

2.2.2. The following information sources were reviewed as part of the desktop assessment:

- superficial and bedrock geology maps of the catchment area from the British Geological Survey
- historical Ordnance Survey (OS) maps from the National Library of Scotland
- historical air photos and satellite imagery
- Water Framework Directive (WFD) monitoring data for the catchment
- documents related to land use and channel adjustments (for example Estate Papers, River Board and Water Authority records)
- reports documenting any previous research undertaken on the rivers

2.3. Geomorphic walkover survey

2.3.1. The walkover surveys were undertaken to ground truth evidence of geomorphic change and / or instability that may be impacted by the construction of the Proposed Scheme. Dominant geomorphic processes occurring on each river reach were also identified to ensure baseline conditions are adhered to, or improved upon, as far as possible.

2.3.2. The walkover survey was conducted in May 2020. A field tablet computer loaded with ArcGIS Collector was used to record key geomorphic features, processes and anthropogenic pressures whilst walking the length of the river. This approach enabled the production of more accurate mapping of the extent and location of features using the tablet's global positioning system (GPS) receiver. Subsequently, recorded features were automatically uploaded to a geographic information system (GIS) system.

2.3.3. The following information was recorded during the walkover surveys:

- typology of the river and whether this differed from what the predicted natural typology would be (see Table 2-1)
- the stability status of the channel, which characterises the dominant processes occurring within the reach (see Table 2-2 and Table 2-3)
- substrate of the channel
- significant areas of bank erosion or basal scour
- significant areas of deposition
- sources and type of sediment input to the channel (for example landslides, rock fall, bank erosion, tributary streams, poaching)
- anthropogenic pressures on the channel (for example bridges, bank protection, weirs, realignments, invasive species)

Table 2-1 Description of typologies used

Typology	Characteristics
Bedrock	Typically, steep gradient, bed and channel banks show significant areas of obvious bedrock. Cobbles and gravels may exist on the bed also. No floodplain development
Step-pool	Gradient still generally steep, with little floodplain development. Channel has regular or semi-regular well-developed steps, separated typically by pools. Substrate typically composed of large cobbles and boulders, with some gravels.
Plane-bed	A transitionary typology between step-pool and pool-riffle. Typically, moderate gradient, with some floodplain development, but channel often incised below floodplain. Featureless bed often armoured with cobbles. Irregular steps, and irregular bars might be present, as well as a relatively straight planform.
Pool-riffle	Generally shallow gradient, and a relatively wide floodplain. Planform becomes sinuous, with more obvious depositional features such as bars, and more signs of erosion on banks.
Active-meander	Shallow gradient, with a wide floodplain. Extensive depositional and erosional features, and well-developed meanders leading to a sinuous planform.

N.B. In practice, sometimes rivers go through a transitionary reach between typologies, or can be ‘more’ one typology than another. In these cases, it falls to the expert judgment of the geomorphologists surveying the watercourse to understand which typology is more dominant.

2.3.4. A visual assessment of the dominant processes occurring on each reach were classified based on the criteria outlined in Table 2-2. This involved recording observations of erosional or depositional processes occurring within the channel.Table 2-3 lists the observations and assessments conducted as part of the ST:REAM survey (Sediment Transport: Reach Equilibrium Assessment Method) to determine the stability status.

Table 2-2 Criteria for classification of dominant processes

Stability status	Characteristics
Erosional source	No evidence of deposition, only erosion.
Erosional exchange	Erosion dominant, but some small-scale depositional features present.
Balance exchange	Evidence of both deposition and erosion are both present on the reach.
Balance transport	Limited evidence of either deposition or erosion observed (generally bedrock channels or heavily modified channels have this classification)
Depositional exchange	Depositional features dominant, but some evidence of erosion observed.
Depositional sink	Only depositional features present (typically approaching lakes or confluences)

Table 2-3 Field observations indicating erosion or depositional dominant channels (Parker et al., 2015)

Dominant process	Indicators
Erosion	Terraces Old channels in floodplain Undermined structures Exposed tree roots Tree collapse (both banks) Trees leaning towards channel (both banks) Drowned trees in channel Narrow/deep channel Bank failures (both banks) Thick gravel exposure in the banks overlain by fines Armoured compacted bed
Deposition	Buried structures Buried soil horizons Many uncompacted ‘over loose’ bars Eroding banks at shallows Contracting bridge openings Deep, fine sediment overlying coarse particles in bed/banks Many unvegetated bars

3. Geomorphology surveys

3.1. Introduction

3.1.1. The following sections will describe the geomorphology surveys undertaken, per watercourse, noting their geomorphological conditions and any modifications to the channel which may impact their geomorphic stability.

3.2. Overview of chalk stream geomorphology

3.2.1. It is estimated that of a recognised 210 'true' chalk streams on Earth, 160 of them are in England (Berrie, 1992). This makes them exceedingly rare and sensitive habitats. The River Wensum and its tributaries (including the River Tud) are included in this short list, and thus have special geomorphological properties to be considered as part of the construction and operation of the Proposed Scheme.

3.2.2. The geomorphology of chalk streams, due to their relative rarity, have not had a significant volume of research conducted on them compared to other forms of watercourse. However, it is generally understood that flow in chalk streams is primarily fed by groundwater sources, which creates a relatively persistent flow with large, high-energy floods a rarity. As such, chalk streams have a limited ability to migrate across their floodplain. They generally have gravel beds and are considered sensitive to changes in siltation.

3.3. River Tud

3.3.1. Geomorphological maps of the River Tud are presented in Annex A.

3.3.2. The River Wensum, of which the River Tud is a tributary, is designated a Site of Special Scientific Interest (SSSI) throughout its entire reach. The River Tud itself is not part of the SSSI status but is evidence of its rare setting.

3.3.3. The River Tud itself rises to the south of East Dereham and flows in a mostly easterly direction until it joins the River Wensum at Hellesdon Mill. It passes close to and through several villages and has a history of being modified and utilised for mill works. For example, diversion channels and mill lades are present around the village of Honingham which still function as conveyance channels for flow. Several reaches show obvious signs of channel realignment also, likely related to agriculture.

3.4. Water Framework Directive (WFD) classification

3.4.1. The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 requires that all groundwater and surface waterbodies achieve 'good' ecological status (or potential). This classification requirement is expected to continue beyond the United Kingdom leaving the EU. To achieve 'good' status overall, a water body must achieve 'good' status in all the River Basin Management Plan (RBMP) assessment criteria (biological, hydro-morphological, physio-chemical and chemical quality), therefore, a deterioration in one of these criteria may result in the water body failing to meet the Water Framework Directive (WFD) objectives.

3.4.2. Tud WFD water body (WBID: GB105034051000) current hydromorphological classification is set as 'heavily modified' (as it has been physically modified by human activity). It is part of the Wensum Operational Catchment and the Broadlands Rivers Management Catchment.

3.4.3. Based on the 2019 status, the current Anglian RBMP, as shown by the Environment Agency's Catchment Data Explorer website (Environment Agency, 2020) indicates that the Tud WFD water body overall classification is 'moderate'. The Tud's WFD water body ecological potential (for heavily modified water bodies) is limited to 'moderate' by the physico-chemical quality elements ('moderate' potential for phosphate). The chemical status is classified as a 'fail' due to the presence of priority hazardous substances (polybrominated diphenyl ethers). The overall status is expected to remain at 'moderate' due to unfavourable balance of costs and benefits.

3.4.4. Table 3-1 below lists the reasons for the River Tud not achieving 'good' overall status:

Table 3-1 - Tud WFD water body (WBID: GB105034051000) Reasons for Not Achieving Good Status (Environment Agency, 2020)

Id	Significant Water Management Issues (SWMI)	SWMI Certainty	Activity	Activity Certainty	Category	Category Certainty	Business Sector	Classification Element
486758	Point source	Probable	Sewage discharge (continuous)	Probable	Water industry	Probable	Waste water treatment	Phosphate
486759	Diffuse source	Probable	Poor nutrient management	Probable	Agriculture and rural land management	Probable	Agriculture - arable	Phosphate
530366	Diffuse source	Probable	Poor livestock management	Probable	Agriculture and rural land management	Probable	Agriculture - livestock	Phosphate
530367	Diffuse source	Probable	Transport drainage	Probable	Urban and transport	Probable	Urban	Phosphate
530368	Point source	Probable	Private sewage treatment	Probable	Urban and transport	Suspected	Urban	Phosphate

3.4.5. With respect to the Proposed Scheme, it can be seen that the existing WFD status is probably lowered by the presence of phosphates being washed into the watercourse via roadways as a pathway. No further information is available on the contribution of the transport sector to the elevated phosphate concentrations or which roads it is being transported by. Phosphorous can be transported in both dissolved and sediment bound forms.

3.5. Geomorphological walkover

3.5.1. This section describes the conditions found on the geomorphological walkover survey undertaken in May 2020.

River Tud

3.5.2. The geomorphic walkover survey began on Mattishall Lane, just south of Oakwood Farm, approximately 2km upstream from the village of Hockering.

3.5.3. The typology of the River Tud is pool - riffle, due to its relatively well developed floodplain and shallow gradient, and evidence of sinuosity and the potential to create bedforms and opposing bar / erosion features on meander bends. The River Tud continues to exhibit a pool - riffle typology throughout the entire survey stretch, despite some modifications made to the channel which are discussed below.

3.5.4. The reach between the start of the survey and Whitford Bridge appears relatively natural with few anthropogenic pressures present. There is evidence of some agricultural realignment with the channel appearing over deepened in places, however this is limited in scale. The substrate varies between clear gravel, which would be expected in a natural chalk stream, and uniform silt. The origin of the silt was not clear; however, it is likely to be a product of both bank erosion and runoff from surrounding land (Caption 3.1).

Caption 3.1 Looking upstream between Mattishall and Whitford Bridge.

3.5.5. Beyond Whitford Bridge, the watercourse flows through a deciduous woodland with a continuing planform of meanders, expected from a pool - riffle typology. The substrate in the woods is primarily silt, with several areas of large woody debris caused by tree fall. Some areas of bank erosion are present. The watercourse exits the woodland after approximately 600m and enters pastoral farmland. An artificial pond is close to the left bank of the watercourse in this field, thought to be used as a duck shooting pond. An abstraction point next to the channel appears to be used to refill the pond (Caption 3.2).

Caption 3.2 - Artificial pond on left bank, fed with water abstracted from the Tud.

3.5.6. The channel bed along this reach, until the ford south of the Hockering sewage works (that discharges into the Hockering tributary), is covered with a uniform layer of silt and has been re-aligned in the past, presumably for agricultural purposes.

3.5.7. After the ford, a weir is present in the channel, however it appears to have negligible impact on sediment transport. The channel continues through agricultural fields before entering private gardens as it approaches Blois Bridge. Anecdotal evidence from a local resident who had lived in the area since the early 1970s suggests that Church Lane acts as a flow pathway for silt runoff from the existing A47 and surrounding land during periods of rainfall, which then deposits into the watercourse near the bridge (Caption 3.3). The channel bed in this reach was covered with a layer of silt for some distance downstream of the bridge, although the provenance of this silt could not be determined.

Caption 3.3 - Blois Bridge, looking upstream.

3.5.8. The channel continues flowing roughly east towards Honingham through unimproved pastureland, with evidence of channel realignment present. Some recovery has taken place, with evidence of gravel riffles and sinuosity in the channel. However, the over deepening of the channel below the floodplain prevents any major recovery from taking place.

3.5.9. At Berry's Bridge, there are large weir structures upstream and downstream of a triple culvert (Caption 3.4). The upstream weir has a sluice gate with an offtake channel, which appears to have been originally used as a mill lade.

Caption 3.4 – Berry's Bridge, looking upstream.

3.5.10. The watercourse runs through gardens as it passes through the village of Honingham. The mill lade channel re-enters the main watercourse just downstream of The Street in the centre of Honingham. The main watercourse then passes underneath the existing A47 and enters estate land (Caption 3.5).

Caption 3.5 - Downstream of A47, looking upstream under A47 bridge.

3.5.11. The watercourse has undergone approximately 300m of significant realignment for the construction of the existing A47, according to historic OS mapping. The channel flows north-east under the A47 bridge and turns at a 90 degree angle towards the south east. The channel appears over deepened and shows no signs of any natural geomorphological features that would be associated with a chalk stream as observed upstream in the survey. The bed is uniformly covered in silt. Caption 3.5 shows significant over deepening and siltation within the channel.

Caption 3.6 - River Tud through estate land, looking upstream.

3.5.12. Approximately 100m downstream of the A47 bridge, the channel returns to a more natural morphology (Caption 3.6). The elevation of the bed is much closer to the elevation of the floodplain, and a gravel bed relatively clear of silt. The channel passes through unimproved pastureland on the left bank and woodland on the right bank in a realigned reach, until it turns to flow south on a relatively natural course through pastureland.

Caption 3.7 - River Tud through estate land, looking downstream.

3.5.13. The channel in this reach appears relatively natural (Caption 3.7), with bank erosion and some pool and riffles present in the gravel bed channel.

3.5.14. Close to Church House Farm, a side channel enters the main channel on the left hand side. After this, the channel bed becomes uniformly covered in silt again for approximately 200m the river turns to flow east again and passes under Taverham Road bridge.

3.5.15. The channel continues to show evidence of agricultural realignment as it passes into pasturelands beyond Taverham Road. There was evidence of sinuosity and some bank erosion and gravel bedforms that would be expected from a chalk stream with a pool - riffle typology. The survey ended approximately 700 m downstream of Church House Farm.

Oak Farm tributary

3.5.16. The Oak Farm tributary in the vicinity of the planned A47 extension is a heavily modified field drain passing under the road in a pipe culvert. Upstream of the culvert is a straightened agricultural channel flowing south before turning south-west just before the culvert. Few natural geomorphic features are present in the channel (Caption 3.8).

Caption 3.8 - Typical cross section of Oak Farm tributary, looking downstream - heavily modified channel with few natural features.

3.5.17. Downstream of the A47, the channel passes adjacent to Oak Farm and Hawthorn Lodge before passing under a minor road before flowing towards the River Tud.

Hockering tributary

3.5.18. The Hockering tributary in the vicinity of the Proposed Scheme is also a heavily modified field drain, flowing south towards the River Tud. The tributary flows out of a series of online ponds approximately 200m to the north of the existing A47. It then flows through farmland, passing under the A47 and through a series of private properties before joining the River Tud. Very few natural geomorphic features are present in the channel (Caption 3.89).

Caption 3.9 - Typical cross section of Hockering tributary, looking upstream - heavily modified channel with few natural features.

3.6. Discussion

3.6.1. The River Tud shows the typical features and dynamics of a chalk stream, albeit heavily modified due to agriculture and historic mill works. The survey results and the background information assessed all points to the River Tud being particularly sensitive to siltation from surrounding land and roadways. Its status as a chalk stream also makes it particularly susceptible to siltation.

3.6.2. Discrete reaches of silt-covered bed and clear gravel beds were observed intermittently throughout the survey, with little evidence of conveyance between these reaches. This is likely due to the majority of the discharge in a chalk stream being derived from groundwater. Due to this, transport of silts and sediments by fluvial processes is relatively weak, a product of relatively low stream power due to the groundwater-fed discharge. Stream power is a measure of the energy expenditure per unit area of river bed, and thus channels with low stream power do not transport sediment effectively.

4. Impacts of proposed scheme

4.1.1. The major infrastructure planned that may impact the geomorphological status of the River Tud are the proposed River Tud Crossing, the West Culvert Extension and the New West Culvert on Oak Farm tributary and the Newgate House

Culvert on the Hockering tributary. A complete description of the Proposed Scheme can be found in Chapter 2 (The Proposed Scheme) (**TR010038/APP/6.1**).

River Tud Crossing

4.1.2. The underbridge has been designed in consultation with the Environment Agency. The clear span of the structure would be 37.5m to meet proximity requirements from the Environment Agency that the structure is a minimum of 5m from the River Tud bank top. The soffit of the deck provides a 2.7m clearance above the bank level which meets the requirements to provide at least 600mm of freeboard above the 1 in 100-year flood event (with 65% allowance for climate change) peak flood level.

4.1.3. The bridge deck is designed to be 30m in width, therefore it is unlikely that vegetation will be impacted by shading to the degree that this may impact morphological stability in this reach.

West Culvert Extension and the New West Culvert

4.1.4. There would also be an extension of the existing A47 culvert (West Culvert Extension) to provide passage of the tributary underneath the full width of the new A47 carriageway. This structure would be a circa 17m long concrete pipe culvert, exclusive of the existing section (inclusive length is circa 38m) and would have an internal diameter of 750mm; replicating the existing culvert dimensions. The extended culvert shall continue on the existing line and will be perpendicular to the proposed mainline. A new headwall would be formed at the northern end of this extended culvert. The watercourse would be locally diverted to tie back into the existing watercourse.

4.1.5. A new culvert (New West Culvert) would be constructed to carry an unnamed tributary of the River Tud (known as Oak Farm tributary herein) below a new unnamed local access road. This structure would be a circa 43m long concrete pipe culvert with an internal diameter of 750mm, headwalls would be formed by precast concrete units. This new culvert will cross the sideroad at a skew in order to tie into the existing watercourse.

4.1.6. These culverts have been designed to maintain the existing culvert diameter (750mm internal dia.) over the extended and new sections. This is required in order to avoid increasing flood risk to downstream properties.

4.1.7. In accordance with DMRB CD529 (Highways England, 2020c), the New West Culvert would normally have a diameter of at least 1.2m to allow for maintenance access as the culvert is in excess of 12m in length. In order to accommodate a 1.2m diameter culvert the level of the proposed sideroad above the culvert would need to be raised by circa 800mm to 1000mm in order to provide the necessary clearance to accommodate the new road pavement. This will result in a substantial length of new sideroad needing to be lifted onto embankment and will have further repercussions to the proposed new junction to the west as well as visual impact, and additional mitigation for headlight glare along the A47 mainline.

4.1.8. In addition, a bund would be constructed upstream of the New West Culvert and would incorporate a 350mm orifice to protect the new unnamed local access road from flood risk. The orifice plate and bund results in a net betterment in terms of flood risk (a reduction in flood depths and extents) downstream but will displace floodwater further upstream (Environmental Statement Appendix 13.1 Flood risk assessment ((**TR010038/APP/6.3**)). The requirement to maintain a throttle on flood flows, together with the visual impact of raising the local access road and the resulting impact on A47 road users, makes the use of larger diameter culvert, arch or portal solutions as well as the continuity of a sediment bed unfeasible.

Newgate House Culvert

4.1.9. A new culvert would be constructed to maintain an unnamed tributary to the River Tud (known as Hockering tributary herein) located east of Hockering at Newgate House. This structure would be a 2.05m by 2.05m precast concrete box frame. The culvert would be approximately 44m in length. This structure would be designed to maintain a minimum 600mm freeboard above the design flood levels for the Proposed Scheme and would also provide a mammal ledge with suitable access upstream and downstream of the culvert. The ledge will have minimum 150mm clearance above the design flood levels. A 300mm depth of stream bed material is assumed at the base of the culvert to tie-in with existing bed levels upstream and downstream. There is a minor watercourse diversion at the culvert outlet to tie into the existing watercourse.

4.1.10. The box preliminary design was developed through consultation with Norfolk County Council and it is considered that this provides a cost proportionate solution whilst meeting environmental objectives such as continuity of bedding throughout. The box design also addresses significant health and safety risks associated with placing bedding material within a confined space. The preferred solution is to include temporary works which will allow pre-filling of discrete precast concrete box units prior to moving into its final position therefore removing confined space working. Precast arch and portal frame solutions, which do not have an integrated invert slab element, were considered. However, the confined space risk would be realised during construction, and hence these were not considered to be preferrable at this stage.

Outfalls

4.1.11. Twelve outfall structures would discharge surface water runoff from the highway (including natural catchment drainage) into the River Tud and the Oak Farm tributary. Two outfalls draining natural catchment drainage only and a up to 10 pre earthworks ditches would discharge to watercourses. The exact number and location of the proposed outfalls is to be confirmed once a drainage survey of the existing systems identifies existing outfalls and their location. The indicative location of these is shown in Annex B of Environmental Statement Appendix 13.2 Drainage strategy (**TR010038/APP/6.3**).

4.2. Construction impacts

4.2.1. There is the potential for mobilisation of sediment and contaminants from surface water runoff to watercourses from road construction activities such as vegetation removal, earthworks, materials management and the use of plant and vehicles.

4.2.2. The construction of the proposed outfalls, New West Culvert, West Culvert Extension and New Gatehouse Culvert would require temporary construction works within the channel and the culvert construction would require temporary diversion of the Oak Farm and Hockering tributaries. This also has the potential to mobilise sediment and contaminants.

4.2.3. The construction of the River Tud Crossing near to and over the river also has the potential to mobilise sediment and contaminants. As stated above, evidence suggests that the River Tud appears to have limited capacity for sediment conveyance. Therefore, any increase in sedimentation caused by construction activities would have a proportionately significant impact on the channel due to the greater residence time in a particular channel reach.

4.3. Operational impacts

4.3.1. The proposed culverts will result in the loss of existing riparian channel bed and banks. An additional 60m of culverts are proposed on the Oak Farm tributary and an additional 44m are proposed on the Hockering tributary.

4.3.2. The proposed culverts on the Oak Farm and Hockering tributaries are unlikely to have any significant impact on sediment transport in the watercourse, provided that there is no change in conveyance capacity for any sediment that is transported by the tributaries. Artificial culvert beds may decrease channel roughness and may increase velocities and thus sediment transport rates in the local reach, which has the potential to impact the geomorphic stability of the watercourse over the longer term.

4.3.3. A key operational impact on the geomorphological features of the watercourses from the Proposed Scheme is sedimentation. Increases in hard standing areas due to the presence of the road surface and associated infrastructure has the potential to increase surface water runoff, and with it, increased sediment being washed into the River Tud. This coupled with the associated increase in traffic volumes will result in an increase in pollutant loads, including sediment, in highway runoff being discharged into the River Tud.

4.3.4. A key impact of the Proposed Scheme on the geomorphology features of the River Tud would be on channel stability. The main area in which channel stability may be impacted is the proposed River Tud Crossing downstream of Honingham. Should bridge infrastructure be placed within 5 metres of the channel, this may limit the channel's natural ability to migrate across the floodplain over time.

4.3.5. The proposed outfalls have the potential to impact on the channel bank and bed morphology. The discharge from the outfalls has the potential to result in erosion, leading to further sedimentation of the channel.

5. Mitigation during construction and operation

5.1.1. Consultation with the Environment Agency and Norfolk County Council was undertaken to discuss the Proposed Scheme's impacts and mitigation requirements.

5.1.2. For no deterioration in river water quality, aquatic ecology, and hence the WFD status of the river, robust silt management during construction and operation of the Proposed Scheme is required. Due to the low conveyance of silt in channel, any additional load of silt will likely have a local but particularly detrimental effect on a reach. Sediment should be controlled as close to the source as possible, and sediment traps should be installed alongside new drainage measures. These should be maintained with regular inspection and cleaning.

5.2. River Tud Crossing

5.2.1. While chalk streams are not thought or observed to be particularly active in terms of channel migration across their floodplain in comparison to other stream types, lateral movement does still occur. The first edition Ordnance Survey maps (approximately dated to 1890) show that some lateral movement of the channel has occurred over the past 100 years on reaches of the River Tud south of Hockering, just downstream of Honingham. This has implications for any road infrastructure, in that to avoid undermining or destabilising channel banks, as well as the risk of destabilising road infrastructure, it is recommended that River Tud Crossing infrastructure is built set back from the banks.

5.2.2. The Environment Agency was concerned that any infrastructure built within 5m of the channel would impact on the riparian habitat and cause significant impact to the River Tud, as well as affecting the channel's natural ability to migrate over time, and required that any Proposed Scheme works be placed outside of this riparian margin. Design changes to the Proposed Scheme were undertaken to ensure that any engineering works for the River Tud Crossing downstream of Honingham would satisfy the Environment Agency's requirements.

5.2.3. To avoid working within 5m of the River Tud, a construction methodology was developed and presented to the Environment Agency. This will avoid degradation and destabilisation of the riparian habitat and banks of the River Tud and minimise the risk of sediment entering the watercourse.

5.3. Culverts

5.3.1. To minimise geomorphological impacts on the watercourses, the culvert design, and associated watercourse diversion where it ties into the existing watercourse, must maintain existing flow and sediment conveyance. The installation of natural sediment beds within the culvert will minimise the impact on channel connectivity including the aquatic ecology.

5.3.2. Norfolk County Council suggested the inclusion of habitat enhancement measures where possible on the tributaries to mitigate against the inclusion of the culverts in the Proposed Scheme.

5.3.3. For planned culverting on the Oak Farm and Hockering tributaries, habitat restoration measures such as riparian buffer strips / planting, re-meandering and leaky dams must be considered to ensure no reduction in WFD status. At least length for length mitigation must be provided to offset the impact of additional culverting.

5.3.4. Location details of the proposed mitigation measures can be found on the Environmental Masterplan (**TR010038/APP/6.8**).

5.3.5. The design of the measures would be undertaken at detailed design stage in discussion with the Environment Agency, Norfolk County Council and other stakeholders.

5.4. Outfalls

5.4.1. An assessment of pollution impacts from routine runoff to surface waters was undertaken using Highways England Water Risk Assessment Tool (HEWRAT).

This assessment establishes potential impacts of pollutants (including sediment) in routine highway runoff for the Proposed Scheme upon the watercourses within the study area and the requirement for mitigation measures to adequately reduce the risk. The routine runoff assessment shows that there is a negligible impact following dilution in the channel for both soluble and sediment-bound pollutants when required water treatment measures are incorporated into the assessment. Additional water quality treatment measures include attenuation features designed as vegetated detention basins or wetlands; both of these measures facilitate sediment removal with treatment efficiencies of 50% and 60% respectively (DMRB CG501; Highways England, 2020b). Vegetated detention basins and wetlands will provide further water quality and biodiversity improvements including the removal of nitrate and phosphate. Therefore, it is highly likely there will be a reduction in sediment and other pollutant concentrations into the River Tud and its tributaries when compared to the existing scenario; however, it is not possible to quantify this using HEWRAT as there is a lack of information on the existing drainage system including outfall locations.

5.4.2. The output from the routine runoff assessments can be found in Volume 3, Appendix 13.3 (Water quality assessment) and the proposed drainage design can be found in Environmental Statement Appendix 13.2 (Drainage strategy). The significance level of the impacts post mitigation has been fully detailed in Chapter 13 (Road drainage and water environment) 1 of the Environmental Statement (**TR010038/APP/6.1**).

5.4.3. Site specific design of the outfalls has not been undertaken at preliminary design. Outfall design should ensure the outfall structure is set back from the channel bank and bed to minimise the impact on flow and sediment conveyance. The outfall should be placed at location that is geomorphologically active (erosion, deposition or channel migration). Scour protection should be incorporated into the design to ensure no bank or bed erosion results from the discharge to the watercourse.

5.4.4. Outfall design should comply with the guidance set out in CIRIA's Culvert, screen and outfall manual (Benn. J. *et al*., 2019).

5.5. Recommendations

5.5.1. Should infrastructure be required in channel, it is recommended to carry out hydraulic modelling to specifically determine the shear stress present on the channel banks and the proposed infrastructure. This will allow structures to be designed to withstand expected hydraulic loading from the flow of water. This would also give an understanding on the likely changes to flow regimes any infrastructure may cause, which could have an impact on erosion rates of the channel.

6. Conclusion

6.1.1. The River Tud is a rare example of a chalk stream, linked to the wider SSSI-designated catchment of the River Wensum, and is relatively unmodified for much of the surveyed reach.

6.1.2. The watercourse's WFD status is 'moderate'. Diffuse pollution from transport sources is listed as one of the reasons for not attaining 'good' status.

6.1.3. Chalk stream dynamics typically have very low sediment loads, and provide poor conveyance for sediments within the channel when present. Evidence is present of siltation in discrete reaches of the river without obvious evidence of transport.

6.1.4. The Proposed Scheme will install a bridge across the River Tud to the west of the existing A47 bridge, downstream of Honingham. This is an area of the channel that shows slight evidence of channel migration, when compared to historic maps.

6.1.5. Construction impacts upon the channel are primarily due to increased siltation of the channel. This would be exacerbated by the relative inefficiency of the watercourse's ability to discharge sediment.

6.1.6. Operational impacts would be sedimentation, along with potential restrictions of channel migration should infrastructure be built within 5 m of the channel. Proposed water quality treatment measures in the drainage design will result in negligible impacts and it is highly likely that these measures will result in the reduction of pollutants, including sediment, from road runoff entering the River Tud and its tributaries compared to the existing scenario.

6.1.7. Mitigation should include robust silt measures during both construction and operation, to ensure no additional siltation occurs within the channel. Any infrastructure should be placed a minimum of 5 metres away from the channel to allow the channel sufficient room to shift course.

6.1.8. The geomorphological impacts of planned culverts on the Oak Farm and Hockering tributaries may be offset by the addition of habitat restoration and enhancement measures, such as riparian planting, leaky dams or re-meandering. Length-for-length mitigation of unavoidable bed discontinuity impacts will be implemented.

7. References

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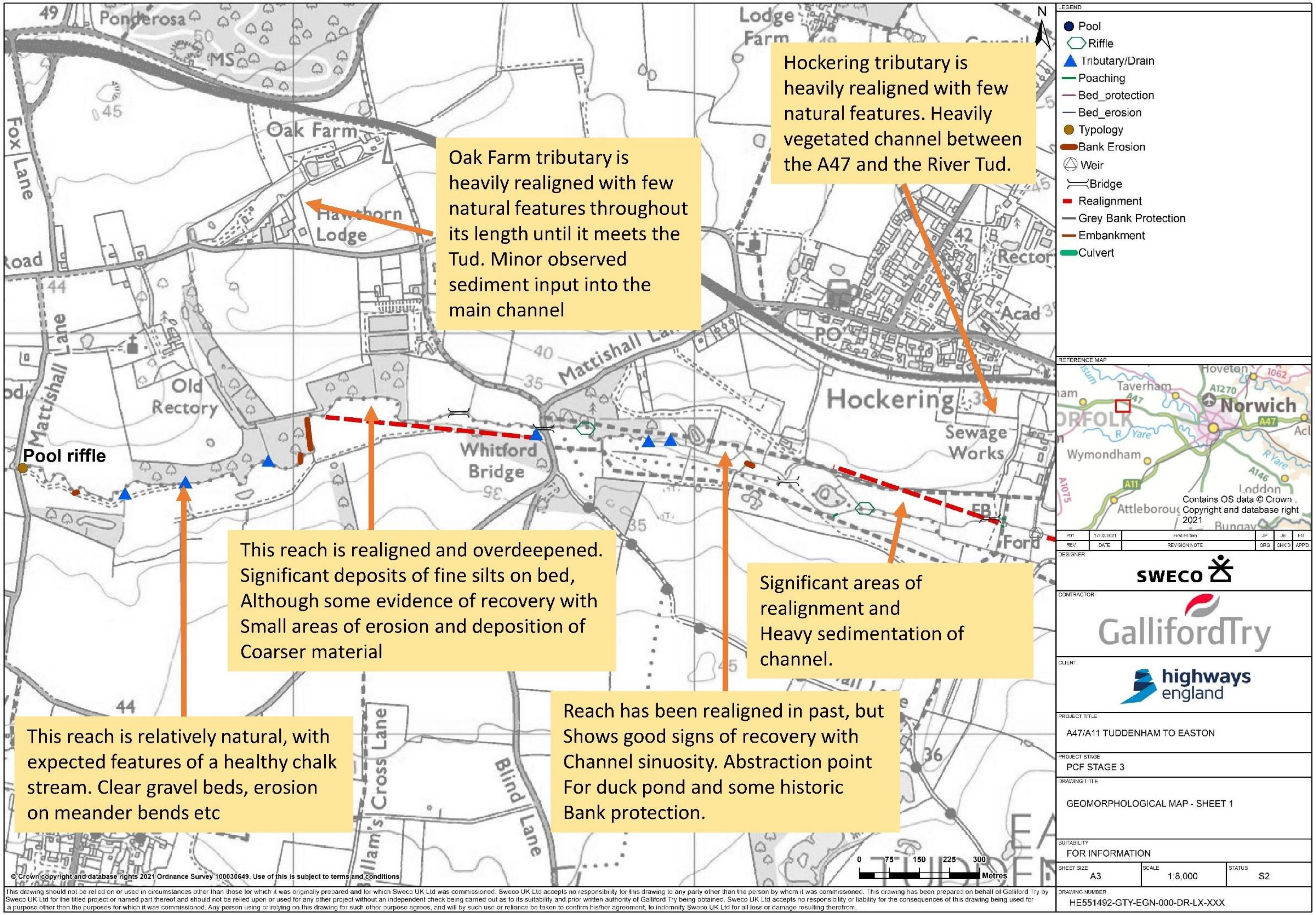
Annex A. Geomorphological survey maps


Oak Farm tributary is heavily realigned with few natural features throughout its length until it meets the Tud. Minor observed sediment input into the main channel
Hockering tributary is heavily realigned with few natural features. Heavily vegetated channel between the A47 and the River Tud.
Pool riffle
This reach is realigned and overdeepened. Significant deposits of fine silts on bed, Although some evidence of recovery with Small areas of erosion and deposition of Coarser material
Significant areas of realignment and Heavy sedimentation of channel.
This reach is relatively natural, with expected features of a healthy chalk stream. Clear gravel beds, erosion on meander bends etc
Reach has been realigned in past, but Shows good signs of recovery with Channel sinuosity. Abstraction point For duck pond and some historic Bank protection.
Pool
Riffle
Tributary/Drain
Poaching
Bed_protection
Bed_erosion
Typology
Bank Erosion
Weir
Bridge
Realignment
Grey Bank Protection
Embankment
Culvert
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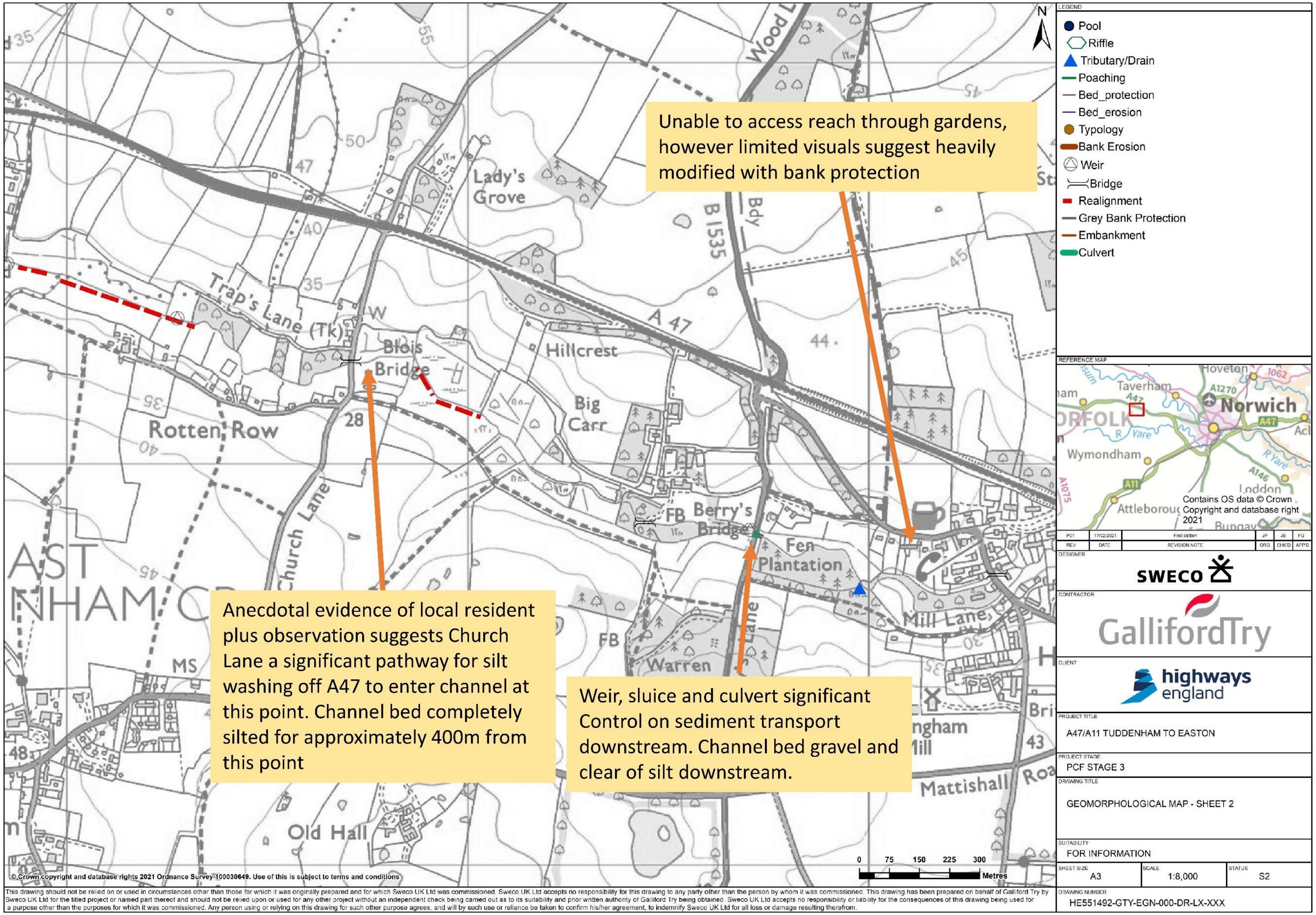
SWECO
GallifordTry
highways england
A47/A11 TUDDENHAM TO EASTON
PCF STAGE 3
GEOMORPHOLOGICAL MAP - SHEET 1
FOR INFORMATION
A3
1:8,000
S2
HE551492-GTY-EGN-000-DR-LX-XXX


Unable to access reach through gardens, however limited visuals suggest heavily modified with bank protection
Anecdotal evidence of local resident plus observation suggests Church Lane a significant pathway for silt washing off A47 to enter channel at this point. Channel bed completely silted for approximately 400m from this point
Weir, sluice and culvert significant Control on sediment transport downstream. Channel bed gravel and clear of silt downstream.
LEGEND
Pool
Riffle
Tributary/Drain
Poaching
Bed_protection
Bed_erosion
Typology
Bank Erosion
Weir
Bridge
Realignment
Grey Bank Protection
Embankment
Culvert
REFERENCE MAP
Contains OS data © Crown Copyright and database right 2021
Lady's Grove
Trap's Lane (Tk)
Blois Bridge
Hillcrest
Big Carr
Rotten Row
Church Lane
Berry's Bridge
Fen Plantation
Mill Lane
Warren
Old Hall
Mattishall Road
A 47
B 1535
0 75 150 225 300 Metres
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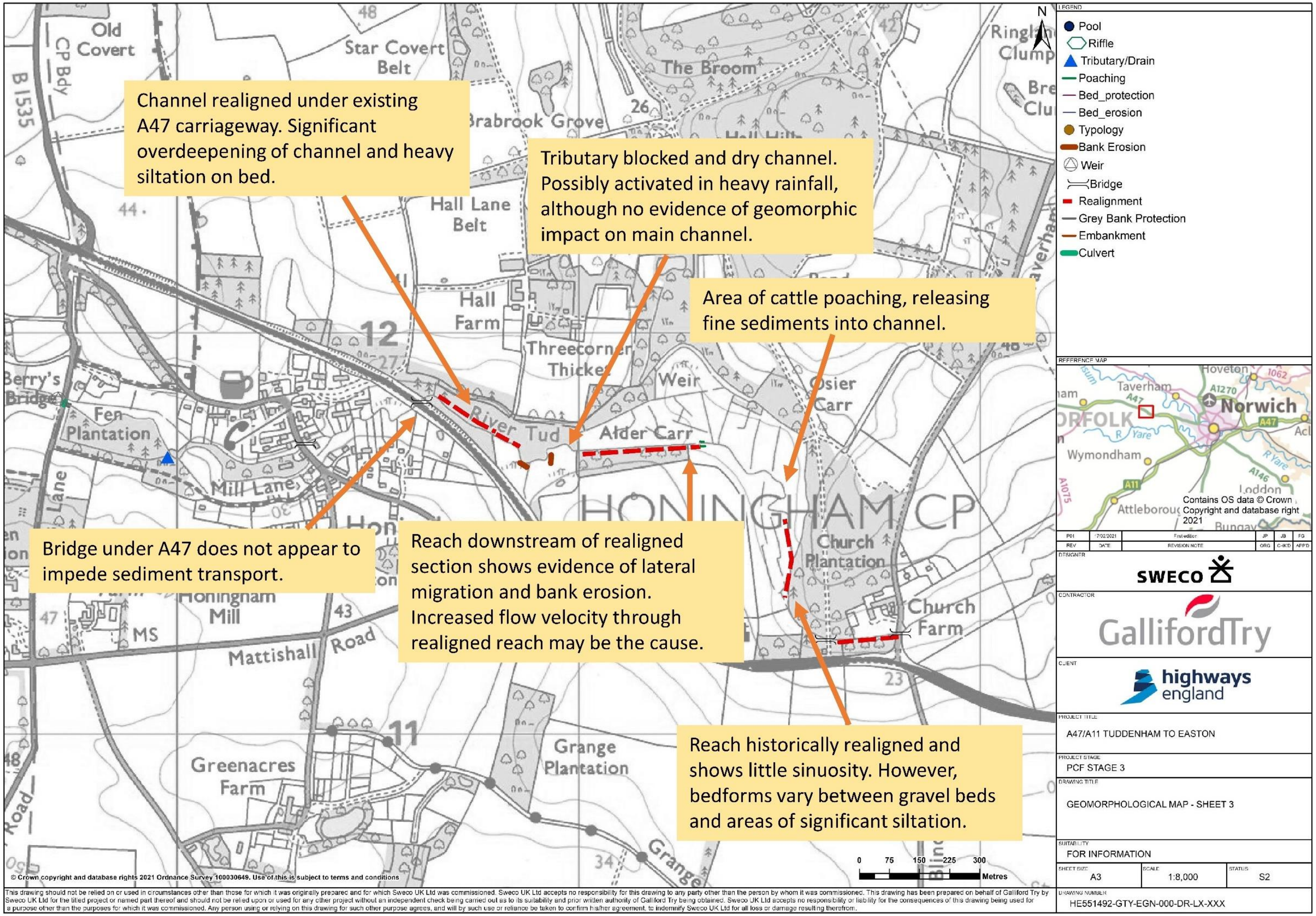
SWECO
Galliford Try
highways england
PROJECT TITLE
A47/A11 TUDDENHAM TO EASTON
PROJECT STAGE
PCF STAGE 3
DRAWING TITLE
GEOMORPHOLOGICAL MAP - SHEET 2
SUITABILITY
FOR INFORMATION
SHEET SIZE A3
SCALE 1:8,000
STATUS S2
DRAWING NUMBER
HE551492-GTY-EGN-000-DR-LX-XXX


Channel realigned under existing A47 carriageway. Significant overdeepening of channel and heavy siltation on bed.
Tributary blocked and dry channel. Possibly activated in heavy rainfall, although no evidence of geomorphic impact on main channel.
Area of cattle poaching, releasing fine sediments into channel.
Bridge under A47 does not appear to impede sediment transport.
Reach downstream of realigned section shows evidence of lateral migration and bank erosion. Increased flow velocity through realigned reach may be the cause.
Reach historically realigned and shows little sinuosity. However, bedforms vary between gravel beds and areas of significant siltation.
LEGEND
Pool
Riffle
Tributary/Drain
Poaching
Bed_protection
Bed_erosion
Typology
Bank Erosion
Weir
Bridge
Realignment
Grey Bank Protection
Embankment
Culvert
REFERENCE MAP
Contains OS data © Crown Copyright and database right 2021
DESIGNER
SWECO
CONTRACTOR
GallifordTry
CLIENT
highways england
PROJECT TITLE
A47/A11 TUDDENHAM TO EASTON
PROJECT STAGE
PCF STAGE 3
DRAWING TITLE
GEOMORPHOLOGICAL MAP - SHEET 3
SUITABILITY
FOR INFORMATION
SHEET SIZE
A3
SCALE
1:8,000
STATUS
S2
DRAWING NUMBER
HE551492-GTY-EGN-000-DR-LX-XXX
0 75 150 225 300 Metres
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