Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11A: Legislation, Policy and Guidance

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Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11A

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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Tables

1 Legislation, Policy and Guidance

1.1.1 Tables 1.1 to 1.3 summarise the applicable legislation, policy and guidance to Chapter 11: Water Environment.

Table 1.1: Summary of Legislation

Legislation	Summary	Chapter Reference
The Water Framework Directive (2000/60/EC) (Ref 11A.1)	The Water Framework Directive (WFD) makes provision for the maintenance and improvement of the 'ecological and chemical status' of the water environment, which includes rivers, lakes, wetlands, artificial waterbodies, groundwater, estuaries and coastal waters. For groundwater the overall status has a quantitative and a chemical component. The aim is for designated waterbodies to achieve 'good overall status' and prevent deterioration of status of surface waters and groundwater. Under the WFD, the Environment Agency has prepared River Basin Management Plans (RBMP) which define the current status of designated waterbodies, their objectives and the planned measures to achieve these objectives. Guidance published by the Environment Agency provides further information on assessing the risk of activities in relation to the RBMP and WFD objectives.	This chapter uses the WFD assessment (Appendix 11E (document reference 6.2)) to assess the Scheme against the key objectives of the WFD. The assessment has shown that the Scheme will be compliant with the requirements of the WFD. Also see Section 11.4 and Table 11.16 in this chapter.
Groundwater Directive (2006/118/EC) (Ref 11A.2)	The WFD and the Groundwater Daughter Directive (GDD) (2006/118/EC), which were enacted in 2000 and 2006 respectively, replace the original Groundwater Directive (80/68/EEC) which was repealed in 2013. The GDD introduces procedures for assessing the 'Chemical Status' of groundwater	As above.

Legislation	Summary	Chapter Reference
	as per the WFD and protects groundwater by preventing direct discharge of 'hazardous pollutants' and limiting the direct discharge of non-hazardous pollutants.	
The Salmon and Freshwater Fisheries Act 1975 **(Ref 11A.3)**	The Act is aimed at the protection of freshwater fish, with a particularly strong focus on salmon and trout. This law was created in an attempt to protect freshwater fish from commercial poaching, to protect migration routes, to prevent wilful vandalism and neglect of fisheries and to ensure correct licensing and water authority approval.	This chapter uses the WFD assessment (Appendix 11E (document reference 6.2)) to assess the Scheme against the WFD status of fish. The assessment has shown that there would no significant impacts on salmon or freshwater fisheries and this was acknowledged by the Environment Agency during the consultation meeting on 4th October 2018.
The Land Drainage Act 1991 (as amended) **(Ref 11A.4)**	Local Authorities and Internal Drainage Boards have additional duties and powers associated with the management of flood risk under the Land Drainage Act 1991. As Land Drainage Authorities, consent must be given for any permanent or temporary works that could affect the flow within an ordinary watercourse under their jurisdiction in order to ensure that local flood risk is not increased. The Land Drainage Act specifies that the following works will require formal consent from the appropriate authority: • Construction, raising or alteration of any mill dam, weir or other like	The Drainage Strategy for the Scheme (Appendix 12C (document reference 6.2)) has been developed with consultation with relevant stakeholders, including the IDB and the LLFA. Consents will be applied for at an appropriate project stage unless formally disapplied through the DCO process, details of which are provided in the Consents and

Legislation	Summary	Chapter Reference
	obstructions to the flow of a watercourse; • Construction of a new culvert; • Any alterations to an existing culvert that would affect the flow of water within a watercourse.	Agreements Position Statement (document reference 7.3).
The Water Resources Act 1991 **(Ref 11A.5)**	The Water Resources Act 1991 (WRA) sets out Environment Agency responsibilities in terms of water resource management and issues including flood defence and water pollution. Under the Act there is strict regulation of discharges to rivers, lakes, estuaries and groundwaters. It also aims to ensure polluters cover the costs associated with pollution incidents.	The chapter conforms with the WRA by considering appropriate mitigation measures to minimise the risks and effects of water pollution as a result of the development of the Scheme. See Section 11.7 for embedded mitigations incorporated into the Scheme.
Environment Act 1995 **(Ref 11A.6)**	An Act to provide for the establishment of the Environment Agency and to provide for the transfer of functions, property, rights and liabilities to this corporate body. The Act also makes provision with respect to contaminated land and abandoned mines, and for the control of pollution, the conservation of natural resources and the conservation or enhancement of the environment	The assessment is being carried out with consultation with the Environment Agency in order to address their concerns with respect to the water environment as a result of the development of the Scheme. See Section 11.4 for a summary of consultation activities undertaken with the Environment Agency.
The Control of Pollution (Oil Storage)	The Control of Pollution (Oil Storage) (England) Regulations aim to reduce the number of oil pollution incidents. The Regulations set minimum design	The chapter conforms with the Regulations by ensuring appropriate

Legislation	Summary	Chapter Reference
(England) Regulations 2001 **(Ref 11A.7)**	standards for all new and existing oil storage facilities. The key requirement is the provision of secondary containment to ensure that any leaking or spilt oil cannot enter controlled waters.	mitigation measures are incorporated in the Outline CoCP ((document reference 6.16) to minimise the risk of leakage from oil storage facilities and accidental spillages.
The Water Act 2003 **(Ref 11A.8)**	The Water Act aims to increase the resilience of water supplies to natural hazards such as drought and floods. The key elements of the Act relevant to this chapter are the aim to improve the way water resources are managed and the mechanism to encourage the use of Sustainable Drainage Systems (SuDS).	The Drainage Strategy for the Scheme considers appropriate treatment measures and SuDS (Appendix 12C (document reference 6.2))
The Flood and Water Management Act 2010 **(Ref 11A.9)**	The Flood and Water Management Act 2010 created the role of the LLFA (in this case Norfolk County Council) to take responsibility for leading the co-ordination of local flood risk management in their areas. In accordance with the Flood and Water Management Act, the Environment Agency is responsible for the management of risks associated with main rivers, the sea and reservoirs. LLFAs are responsible for the management of risks associated with local sources of flooding such as ordinary watercourses, surface water and groundwater. The Act is also guiding the role of the LLFA in the review and approval of surface water management systems. In April 2015 this led to a change that requires the LLFA to review and comment on significant development in regard to the recently published Non-Statutory Technical Standards for Sustainable Drainage Systems.	The drainage strategy for the Scheme has been developed with consultation with the LLFA. Details are provided in the Drainage Strategy document (Appendix 12C (document reference 6.2))

Legislation	Summary	Chapter Reference
The Environmental Permitting (England and Wales) Regulations 2016 **(Ref 11A.10)**	The Environmental Permitting (England and Wales) Regulations 2016 is the key legislation for water pollution in the UK. Under the Environmental Permitting Regulations, it is an offence to cause or knowingly permit a water discharge activity, including the discharge of polluting materials to freshwater, coastal waters, relevant territorial waters or groundwater, unless complying with an exemption or an environmental permit. An environmental permit is obtained from the Environment Agency. The Environment Agency sets conditions which may control volumes and concentrations of particular substances or impose broader controls on the nature of the effluent, taking into account any relevant water quality standards from EC Directives. The Environmental Permitting Regulations also manages works that have the potential to affect a watercourse under the jurisdiction of the Environment Agency. Any works in, under or near a main river requires permission from the Environment Agency to ensure no detrimental impacts on the watercourse.	Consents and permitting requirements are considered as part of the DCO application, details of which are provided in the Consents and Agreements Position Statement (document reference 7.3).
The Water Abstraction and Impounding (Exemptions) Regulations 2017 **(Ref 11A.11)**	The Water Abstraction and Impounding (Exemptions) Regulations 2017 provide for exemptions from the restriction on abstraction and the restriction on impounding works in the Water Resources Act 1991.	Consents and permitting requirements are considered as part of the DCO application, details of which are provided in the Consents and Agreements Position Statement (document reference 7.3).

Legislation	Summary	Chapter Reference
The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (Ref 11A.12)	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 transpose the EU Water Framework Directive 2000/60/EC, establishing a framework for community action in the field of water policy. The Regulations also transpose aspects of the Groundwater Directive 2006/118/EC on the protection of groundwater against pollution and deterioration.	This chapter uses the WFD assessment (Appendix 11E(document reference 6.2)) to assess the Scheme against the key objectives of the WFD in line with the Regulations. The assessment has shown that the Scheme will be compliant with the requirements of the WFD.

1.1.2 Consents will be required from the Environment Agency for temporary construction and permanent operational discharges as well as any temporary or permanent abstractions (unless falling under exempted activities). Under the Environmental Permitting Regulations, it is an offence to cause or knowingly permit a water discharge activity including the discharge of polluting materials to freshwater, coastal waters, relevant territorial waters or groundwater, unless complying with an exemption or an environmental permit. If not disapplied by the DCO, the Environment Agency's consent will be required for works in the vicinity of flood defences or in or over a main river, dewatering (if not exempt) or the impoundment of water. The Consents and Agreements Position Statement (document reference 7.3) explains in more detail the Applicant's approach to other consents.

Table 1.2: Summary of Policy

Policy	Summary	Chapter Reference
National Policy Statement for National Networks (NPS NN) ((Ref 11A.14))	NPS NN sets out detailed policy on environmental mitigations for development including pollution control, and assessment and management of water quality and resources: **Chapter 4: Assessment principles** **Environmental Impact Assessment**: This section sets out the fact that all proposals are subject to the EIA Directive (2011/92/EU) which requires "*an environmental impact assessment to identify, describe and assess effects on…fauna and flora, soil, water…and the interactions between them*". **Pollution control and other environmental protection regimes:** This section sets out the fact that "*issues relating to discharges or emissions from a proposed project which affect…water quality…and the marine environment…may be subject to separate regulation under the pollution control framework or other consenting and licensing regimes. Relevant permissions will need to be obtained for any activities within the development that are regulated under those regimes before the activities can be operated.*"	The chapter fulfils the assessment requirements of the NPS NN. Consents and permitting requirements are considered as part of the DCO application, details of which are provided in the Consents and Agreements Position Statement (document reference 7.3).
	Chapter 5: Generic impacts	See Section 11.5 for the existing status of the water environment and Section 11.8 for the assessment of likely significant effects.

Policy	Summary	Chapter Reference
	Water quality and resources: This section sets out the requirements of the EIA in which "*the applicant should ascertain the existing status of, and carry out an assessment of the impacts of the proposed project on water quality, water resources and physical characteristics as part of the environmental statement.*" This section also states that "*any environmental statement should describe:* • *the existing quality of waters affected by the proposed project;* • *existing water resources affected by the proposed project and the impacts of the proposed project on water resources;* • *existing physical characteristics of the water environment (including quantity and dynamics of flow) affected by the proposed project, and any impact of physical modifications to these characteristics;* • *any impacts of the proposed project on water bodies or protected areas under the Water Framework Directive and source protection zones (SPZs) around potable groundwater abstractions; and* • *any cumulative effects.*"	The Drainage Strategy for the Scheme considers appropriate treatment measures and SuDs (Appendix 12C (document reference 6.2))

Policy	Summary	Chapter Reference
	Furthermore, this section identifies the requirements of appropriate mitigation measures during operation and construction and that "*the project should adhere to any National Standards for sustainable drainage systems (SuDs).*"	
National Planning Policy Framework (NPPF) (Ref 11A.13)	The revised National Planning Policy Framework (NPPF) for England was published in February 2019. In particular, Section 15 of the NPPF (Conserving and enhancing the natural environment) is relevant to the assessment of impacts on the water environment from the Scheme. Paragraph 170 states that the planning system should contribute to and enhance the natural environment by *"preventing new and existing development from contributing to, being put at unacceptable risk from, or being adversely affected by, unacceptable levels of soil, air, water or noise pollution or land instability".* It goes on to state that "*Development should, where possible, help to improve the local environmental conditions such as air and water quality, taking into account relevant information such as river basin management plans*"	This chapter conforms with this policy by considering appropriate mitigation measures to minimise the risks on the water environment from the Scheme. See Section 11.7 for embedded mitigations adopted for the Scheme and Section 11.8 for any proposed additional mitigations.

Policy	Summary	Chapter Reference
National Policy Statement for Ports (Ref 11A.15)	This statement provides the framework for decisions on proposals for new port development. It applies, wherever relevant, to associated development, such as road and rail links, for which consent is sought alongside that for the principal development. Section 4.7 Environmental Impact Assessment sets out the requirement for all proposals "*that are subject to the European EIA Directive to be accompanied by an Environmental Statement (ES) describing the aspects of the environment likely to be significantly affected by the project.*" This includes "*a description of the likely significant effects of the proposed project on the environment, covering the direct effects and any indirect, secondary, cumulative, short-, medium and long-term, permanent and temporary, positive and negative effects of the project, and also of the measures envisaged for avoiding or mitigating significant adverse effects.*" Section 5.6 Water quality and resources sets out the requirements of the ES to assess "*the existing status of, and impacts of, the proposed project on water quality, water resources and physical characteristics of the water environment*."	The chapter fulfils the assessment requirements of this policy. See Section 11.4 for the description of likely significant effects; Section 11.5 for the existing status of the water environment and Section 11.8 for the assessment of likely significant effects.

Policy	Summary	Chapter Reference
Anglian River Basin Management Plan (Ref 11A.16)	River Basin Management Plans (RBMPs) are published under the WFD and focus on the protection, improvement and sustainable use of the water environment. The river basin management approach ensures organisations and individuals that have an impact on the water environment work together to achieve the focus. The Scheme is situated within the Anglian River Basin District. The Anglian RBMP was first published in 2009. Under the WFD, RBMPs are reviewed and revised on a six-yearly cycle to update the status of the objectives for every waterbody, as these objectives can become legally binding and inform decision making by public and private bodies. The updated reports also include economic analysis of the objectives and proposed measures, which the Environment Agency has assessed to be cost effective, technically feasible and proportionate in terms of the benefits outweighing the cost. The first update to the Anglian RBMP was undertaken and published in December 2015.	This chapter uses the WFD assessment (Appendix 11E (document reference 6.2) to assess the Scheme against the key objectives of the WFD. The assessment has shown that the Scheme will be compliant with the requirements of the WFD and would not prevent the achievement of the wider WFD objectives in the operational catchments.

Policy	Summary	Chapter Reference
	The current Anglian RBMP describes the river basin district, and the pressures that the water environment faces. It shows what this means for the current state of the water environment, and what actions will be taken to address the pressures. It sets out what improvements are possible by 2021 and how the actions will make a difference to the local environment – the catchments, the estuaries and coasts, and the groundwater. The RBMP identifies the current key issues in the Anglian River Basin as: • Physical modifications; • Pollution from waste water; • Pollution from towns, cities and transport; • Changes to the natural flow and level of water; • Negative effects of invasive non-native species, and • Pollution from rural areas.	

Policy	Summary	Chapter Reference
	The Study Area covers land within the Waveney Operation Catchment, which incorporates the Waveney, Lower Yare & Lothingland IDB drainage district, the Bure Operational Catchment, and the Norfolk East Transitional and Coastal (TRaC) Operation Catchment, which incorporates the coastal waterbody of Norfolk East and the transitional waterbody of Bure & Waveney & Yare & Lothing. Breydon Water, a designated Ramsar, Site of Special Scientific Interest (SSSI) and Special Protection Area (SPA), is located within the catchment, approximately 2.5km upstream of the Scheme. The main issues associated within these catchments are diffuse and point source pollution resulting from poor nutrient management, physical modification of rivers and lakes and sewage discharge. At present, there are no specific measures identified within the Norfolk East Transitional and Coastal (TRaC) Operation Catchment. Specific measures identified within the Waveney and Bure operational catchments include (Ref 11A.29 and Ref 11A.30): • Additional treatment to reduce concentrations of nutrients from Pulham St Mary sewage treatment works;	

Policy	Summary	Chapter Reference
	• Waveney habitat project to improve the condition of riparian zone and/or wetland habitats; • Additional treatment to reduce concentrations of phosphate from Hoxne sewage treatment works, and • The Broadland 'Slow the Flow' rural sustainable drainage project to address rural diffuse pollution. This project is likely to contribute to improvements in the ecological status of multiple waterbodies through phosphate and sediment reduction.	
Great Yarmouth Borough Council Local Plan: Core Strategy 2013 – 2030 (Ref 11A.17)	The Great Yarmouth Local Plan, adopted in 2015, provides the planning framework for implementing the Council's aims and objectives in the use of land and buildings. It forms the basis for all future developments in the Borough and sets out a series of strategic policies and site allocations which are used in the determination of planning applications.	Appropriate mitigation measures during operation and construction of the Scheme have been considered in the assessment. See Section 11.7 in the chapter and the Outline CoCP document (document reference 6.16). The Drainage Strategy for the Scheme considers appropriate treatment measures and SuDs (Appendix 12C (document reference 6.2))

Policy	Summary	Chapter Reference
	Policy CS11 (Enhancing the natural environment) states that all new development is required to take measures to avoid or reduce adverse impacts on existing biodiversity and geodiversity assets. Where adverse impacts are unavoidable, suitable measures will be required to mitigate any adverse impacts. Where mitigation is not possible, the Council will require that full compensatory provision be made. Furthermore, the Council requires all new development to appropriately contribute to the creation of biodiversity and/or geodiversity features through the use of landscaping, building and construction features, sustainable drainage systems and geological exposures. New development is also encouraged to protect and where possible enhance the quality of the Borough's resources, including inland and coastal water resources.	

Policy	Summary	Chapter Reference
	Policy CS13 (Protecting areas at risk of flooding or coastal change) requires all new development to seek the use of Sustainable Drainage Systems (SuDS) not only to manage surface water in reducing flood risk but also to deliver improved water quality, provide ecological enhancements and benefit local amenity. Where possible, sustainable drainage systems will be expected to contribute towards wider sustainability considerations, including conservation of biodiversity and water quality control.	
Norfolk County Council, Lead Local Flood Authority, Statutory Consultee for Planning, Guidance Document (Ref 11A.18)	The Norfolk County Council (as the Lead Local Flood Authority (LLFA) has outlined their expectations with respect to SuDS and WFD/water quality in this guidance document which supports the application of national planning policy. Key elements with respect to SuDS and surface water drainage are summarised as follows: • Surface water drainage should be managed in a way that replicates natural drainage processes on the site as closely as possible, and any proposed strategy for the management of surface water should utilise methods as high up the drainage hierarchy as possible: 1) into the ground (infiltration); 2) to a surface water body; 3) to a surface water sewer, highway drain or another drainage system and 4) to a combined sewer;	The Drainage Strategy for the Scheme considers appropriate treatment measures and SuDs (Appendix 12C (document reference 6.2)).

Policy	Summary	Chapter Reference
	• Infiltration should be considered first and this should be supported by infiltration testing in line with BRE365 (Soakaway Design) guidance; • In order to protect groundwater from pollution, any infiltration structure must be shown to be able to be constructed 1.2m above the anticipated seasonally high groundwater level; • If it is required to discharge into a watercourse, the Council requires evidence to illustrate that the watercourse is connected to the wider watercourse network and able to convey water away from the development site. Localised drains that are cut off from the wider network are considered unsuitable as discharge destinations; • For brownfield sites, the peak runoff rate from the development for the 1 in 1 year and 1 in 100-year rainfall events should be as close as reasonably practicable to the greenfield runoff rate from the development for the same rainfall event, but should never exceed the rate of discharge from the development prior to redevelopment for that event;	

Policy	Summary	Chapter Reference
	• Drainage strategies must consider the potential increase in the volume runoff from a development as a result of increases in the area of impermeable surfaces; • The assessment of the volume of attenuation storage should be based on the 1 in 100-year critical storm duration with climate change for the site and the allowable discharge rate. With respect to water quality, the Council does not consider that the requirements for water quality treatment would be met if traditional piped drainage schemes are promoted. If piped schemes are promoted as part of a SuDS scheme, e.g. pipes connecting to geo-cellular crates or attenuation tank(s), other SuDS components, such as permeable paving, swales, filter drains or strips should also be used to treat water prior to final discharge. Furthermore, the Council advises that Sections 4 and 26 of CIRIA SuDS Manual (C753) be reviewed to risk assess the development and likely water quality treatment required as mitigation.	

Policy	Summary	Chapter Reference
Norfolk County Council, Norfolk Local Flood Risk Management Strategy (Ref 11A.19)	In addition to policies with respect to flood risk, the Norfolk Local Flood Risk Management Strategy (LFRMS) also outlines the Council, i.e. the LLFA's policies on SuDS, water quality and ordinary watercourse regulation. Policy UC11 (Securing Sustainable Drainage) states that the LLFA will seek to secure the implementation of SuDS, and where practicable, they will also aim to secure adaptation of existing drainage networks to enable SuDS. Policy OW3 (Consenting of works on Ordinary Watercourses) states that the LLFA will only approve alterations to ordinary watercourses if proposed works would not: • Lead to an increase in flood risk; • Increase the risk of erosion on the site or in areas beyond the site; • Result in water quality that does not meet standards required by WFD; • Have a detrimental impact on designated areas; and • Have a materially detrimentally impact on the morphology of natural watercourses.	The Drainage Strategy for the Scheme, including any proposed alterations to ordinary watercourses, has been developed with consultation with relevant stakeholders, such as the LLFA and IDB, to ensure their concerns are addressed, and with consideration of appropriate treatment measures and SuDs (Appendix 12C (document reference 6.2)). Consents and permitting requirements are considered as part of the DCO application, details of which are provided in the Consents and Agreements Position Statement (document reference 7.3).

Policy	Summary	Chapter Reference
	Policy E2 (Protecting habitats) requires all proposed works to be consistent with the need to maintain satisfactory drainage and flood protection to avoid unnecessary and long-term damage to natural habitats. Where possible, the LLFA also encourages new development to take appropriate opportunities to enhance habitats. Policy E4 (Ecological potential) states that the LLFA, and where relevant, the Internal Drainage Boards, will require applications for Ordinary Watercourse Consents to includes measures within the design to preserve or (where practicable) enhance ecological potential, including, where appropriate, providing landscaping using native species that are compatible with the local water environment. Policy E5 (River morphology) requires developments that alter the bank of an ordinary watercourse or create a new watercourse as part of a sustainable drainage scheme to mimic features of natural river morphology and hydrology, wherever it is practicable to do so. Where it is not practicable to do so, compensatory measures may be required.	

Table 1.3: Summary of Guidance

Guidance	Summary	Chapter Reference
Design Manual for Roads and Bridges (DMRB) HD45/09 (Ref 11A.20)	The standard HD45/09 Road Drainage and the Water Environment, Volume 11, Section 3, Part 10 provides guidance on the assessment and management of the impacts that road projects may have on the water environment. These include possible impacts on the quality of water bodies and on the existing hydrology of the catchments through which roads pass.	The assessment, with consideration of the likely significant effects arising from the Scheme upon the water environment (surface water and groundwater), has been completed in line with this guidance. See Section 11.4 for the description of likely significant effects; Section 11.5 for the existing status of the water environment and Section 11.8 for the assessment of likely significant effects. The HAWRAT assessment (Appendix 11D (document reference 6.2)), which evaluates the pollution impacts from routine (operational) runoff and accidental spillage, has been completed in line with the identified guidance.
DEFRA - Non-Statutory Technical Standards for Sustainable Drainage Systems (Ref 11A:21)	This document sets out non-statutory technical standards for sustainable drainage systems, which includes guidance on peak flow and volume control, flood risk management within the development, construction, structural integrity of the drainage system and maintenance considerations.	The Drainage Strategy (Appendix 12C (document reference 6.2)) has been developed in line with this guidance.
The Construction Industry	These documents provide guidance on sustainable drainage systems, pollution control and groundwater	This chapter, with consideration of appropriate mitigation

Guidance	Summary	Chapter Reference
Research and Information Association (CIRIA) notably C532 (Ref 11A.22), C648 (Ref 11A.23), (C750 (Ref 11A.24), and C753 (Ref 11A.25)	control as part of temporary works for construction projects.	measures to minimise the risks and effects of water pollution, has been completed in line with CIRIA C532 and C648. The Outline CoCP (document reference 6.16) provide details of proposed mitigation measures. The temporary groundwater control system required for the construction of the bascule pit cofferdams is being developed in line with CIRIA C750. The Drainage Strategy (Appendix 12C (document reference 6.2)) has been developed in line with CIRIA C753 (Ref 11A.25).
Environment Agency's approach to groundwater protection (Ref 11A.26)	This document contains non-statutory position statements which provide information about the Environment Agency's approach to managing and protecting groundwater and, adopts a risk based approach where legislation allows.	This chapter, with consideration of appropriate mitigation measures to minimise the risks and effects of pollution to groundwater and, protection of it as a resource, has been completed in line with the Environment Agency's approach to groundwater protection 2018. See Section 11.8 in the chapter.
PINS Advice Note 18 (Ref 11A.27); Water Framework	These documents provide guidance on the requirement and approach to the WFD assessment.	A WFD assessment (Appendix 11E (document reference 6.2)) has been completed in line with

Guidance	Summary	Chapter Reference
Directive risk assessment (2016); Water Framework Directive Assessment: Estuarine and Coastal Waters (Ref 11A.28)		the identified guidance to assess the Scheme against the key objectives of the WFD. Also see Section 11.4 and Table 11.16 in this chapter.

2 References

Ref 11A.1: Official Journal of the European Communities (2000). The EU Water Framework Directive - integrated river basin management for Europe. Directive 2000/60/EC.

Ref 11A.2: Official Journal of the European Communities (2006). The Groundwater Directive – on the protection of groundwater against pollution and deterioration. Directive 2006/118/EC.

Ref 11A.3: The Salmon and Freshwater Fisheries Act 1975. Her Majesty's Stationary Office 1975.

Ref 11A.4: The Land Drainage Act 1991 (as amended). Her Majesty's Stationary Office.

Ref 11A.5: The Water Resources Act 1991. The Stationary Office, 1991.

Ref 11A.6: Environment Act 1995. The Stationary Office, 1995.

Ref 11A.7: The Control of Pollution (Oil Storage) (England) Regulations 2001. Her Majesty's Stationary Office, 2001.

Ref 11A.8: The Water Act 2003. The Stationary Office, 2003.

Ref 11A.9: The Flood and Water Management Act 2010. The Stationary Office, 2010.

Ref 11A.10: The Environmental Permitting (England and Wales) Regulations 2016. The Stationary Office.

Ref 11A.11: The Water Abstraction and Impounding (Exemptions) Regulations 2017. The Stationary Office, 2017.

Ref 11A.12: The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. The Stationary Office, 2017.

Ref 11A.13: Ministry of Housing, Communities & Local Government (2019). National Planning Policy Framework.

Ref 11A.14: Department for Transport (2014) National Policy Statement for National Networks. (online) (Accessed June 2018).

Ref 11A.15: Department for Transport (2014) National Policy Statement for Ports. (online) (Accessed June 2018).

Ref 11A.16: DEFRA & Environment Agency (2015). Part 1: Anglian river basin district. River basin management plan.

Ref 11A.17: Great Yarmouth Borough Council (2015). Great Yarmouth Local Plan: Core Strategy 2013-2030.

Ref 11A.18: Norfolk County Council (2017). Lead Local Flood Authority: Statutory Consultee for Planning. Guidance Document, Version 3.

Ref 11A.19: Norfolk County Council (2015). Norfolk Flood Risk Management Strategy. Post Consultation Final Draft. V13.1

Ref 11A.20: Design Manual for Roads and Bridges (2009). Volume 11, Section 3, Part 10 (HD 45/09) Road Drainage and the Water Environment, former Highways Agency, November 2009.

Ref 11A.21: DEFRA (2015). Sustainable Drainage Systems. Non-statutory standards for sustainable drainage systems.

Ref 11A.22: CIRIA (2001). Control of water pollution from construction sites: Guidance for Consultants and Contractors. C532.

Ref 11A.23: CIRIA (2006). Control of water pollution from linear construction projects. C648.

Ref 11A.24: CIRIA (2016). Groundwater control, design and practice. C750. Second edition.

Ref 11A.25: CIRIA, DEFRA and the Environment Agency (2015). The SuDS Manual. C753.

Ref 11A.26: Environment Agency (2018). Approach to groundwater protection.

Ref 11A.27: The Planning Inspectorate (2017). Advice note eighteen. The Water Framework Directive. Version 1.

Ref 11A.28: Environment Agency (2017). Water Framework Directive assessment: estuarine and coastal waters and Environment Agency (2016). Water Framework Directive risk assessment: how to assess the risk of your activity.

Ref 11A.29: Environment Agency (2019). Catchment Data Explorer - Operational Catchment Measures. Waveney.

Ref 11A.30: Environment Agency (2019). Catchment Data Explorer - Operational Catchment Measures. Bure.

Great Yarmouth Third River Crossing

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Document 6.2: Environmental Statement Volume II: Technical Appendix 11B: Impact Assessment Criteria for Surface Water and Groundwater

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11B

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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Tables

1 Impact Assessment Criteria for Surface Water and Groundwater

Table 1.1: Receptor Importance / Sensitivity

Importance	Criteria	Example
Very High	Attribute has a high quality and rarity on regional or national scale	• Large or medium watercourses with pristine / near pristine water quality, i.e. Water Framework Directive (WFD) Class 'High'.
		• Site protected/designated under EU or UK habitat legislation: Special Areas of Conservation (SAC), Special Protection Area (SPA), Site of Special Scientific Interests (SSSI), Water Protection Zone (WPZ), Ramsar site, species protected by EU legislation.
		• Watercourses supporting a wide range of significant species and habitats sensitive to changes in suspended sediment concentrations and turbidity such as salmon or freshwater pearl mussels. Water dependent ecosystems of international/national biodiversity value.
		• Water feature sediment regime provides a diverse mosaic of habitat types.
		• Water feature includes varied morphological features (e.g. pools, riffles, bars, natural bank profiles) with no sign of channel modification.
		• A watercourse or groundwater body and associated abstraction boreholes used for public water supply or private water supply serving >10 properties.
		• Principal Aquifer providing a regionally important resource or supporting site protected under EC and UK habitat legislation.
		• Source Protection Zone (SPZ) 1.

Importance	Criteria	Example
		• Water body of high amenity value, including areas of bathing and where water emersion sports are regularly practised.
High	Attribute has a high quality and rarity on local scale	• Medium or small watercourses with minor degradation of water quality as a result of anthropogenic factors. Water body of good chemical and biological quality i.e. WFD Class ‘Good’.
		• Species protected under UK legislation
		• Water dependent ecosystems of regional/county biodiversity value. Watercourses supporting some species and habitats sensitive to changes in suspended sediment concentrations and turbidity.
		• Water feature sediment regime provides habitats suitable for species sensitive to changes in sediment concentration and turbidity.
		• Water feature exhibiting a natural range of morphological features (e.g. pools, riffles, bars, varied natural river bank profiles), with limited signs of artificial modifications or morphological pressures.
		• A watercourse or groundwater body and associated abstraction boreholes supporting minor/non-critical public drinking water supplies, or private water supply serving 2-10 properties.
		• Principal Aquifer providing locally important resource or supporting river ecosystem.
		• SPZ 2.

Importance	Criteria	Example
		• Water body of a moderate amenity value including public parks, boating, non-contact water sports, popular footpaths adjacent to watercourses, or watercourses running through housing developments/town centres.
Medium	Attribute has a medium quality and rarity on local scale	• Small watercourses with degradation of water quality as a result of anthropogenic factors. WFD Class of 'Moderate'.
		• Water dependent ecosystems of county/district biodiversity value.
		• Watercourses supporting limited species and habitats sensitive to changes in suspended sediment concentrations and turbidity.
		• Water feature sediment regime provides some habitat suitable for species sensitive to change in suspended sediment concentrations or turbidity.
		• Water feature exhibiting some morphological features (e.g. pools, riffles and depositional bars). The channel cross-section is partially modified in places, with obvious signs of modification to the channel morphology.
		• A watercourse or groundwater body and associated abstraction boreholes supporting a private water supply serving a single property, or for agricultural/industrial use.
		• Aquifer with limited connection to surface water.
		• SPZ 3.
		• Water body of particular local social/cultural/educational interest. Water body of low amenity value with only casual access, e.g. along a road or bridge in a rural area.

Importance	Criteria	Example
Low	Attribute has a low quality and rarity on local scale	• Small, heavily modified watercourses or drains with poor water quality as a result of anthropogenic factors.
		• Water of poor or bad chemical or biological quality, i.e. WFD Class of ‘Poor’ or ‘Bad’.
		• Water dependent ecosystems of local/less than local biodiversity value.
		• Watercourses which do not support any significant species and habitats sensitive to changes in suspended sediment concentrations and turbidity.
		• Water feature sediment regime which provides very limited physical habitat for species sensitive to changes in suspended solids concentration or turbidity.
		• Water feature that has been extensively modified (e.g. by culverting, addition of bank protection or impoundments) and exhibits limited-to-no morphological diversity. The water feature is likely to have uniform flow, uniform banks and absence of bars. Insufficient energy for morphological change.
		• Watercourses not supporting water abstractions.
		• Borehole without abstractions.
		• Non-Aquifer.
		• Water body of no amenity value, seldom used for amenity purposes, in a remote or inaccessible area.

Table 1.2: Impact Magnitude

Magnitude	Criteria	Example
Major Adverse	Results in loss of attribute and / or quality and integrity of the attribute	• High risk of pollution to surface water during construction, significant temporary or long-term change in water quality, resulting in a permanent change in WFD status. Preventing attainment of target overall status of 'Good' in the absence of other factors unrelated to the scheme.
		• Failure of both soluble and sediment bound pollutants in Highways Agency Water Risk Assessment Tool (HAWRAT) and Environmental Quality Standard (EQS) routine runoff compliance failure.
		• Risk of pollution from accidental spillage during operation > 2% annually.
		• Results in loss of feature(s) and failure of hydromorphological elements (morphology, quantity and dynamics of flow). Loss or damage to existing habitats. Significant/extensive alteration to channel planform and/or cross section. Significant shift away from baseline conditions with potential to alter natural fluvial processes at the catchment scale.
		• Significant impacts on the water feature bed, banks and vegetated riparian corridor resulting in changes to sediment characteristics, transport processes, sediment load and turbidity.
		• Permanent loss of surface water supply.
		• Loss of, or extensive change to, an aquifer/groundwater supported designated wetlands.
		• Extensive change to pumping rate and water quality in abstraction wells.

Magnitude	Criteria	Example
		• Potential high risk of pollution to groundwater from routine runoff (Method C score >250).
		• High risk of pollution to groundwater during construction, significant temporary or long-term change in water quality, resulting in a permanent change in WFD status. Preventing attainment of target overall status of 'Good' in the absence of other factors unrelated to the scheme.
Moderate Adverse	Results in effect on integrity of attribute, or loss of part of attribute	• Moderate risk of pollution to surface water during construction, moderate temporary change in water quality, resulting in a temporary change of WFD status or contributing to preventing attainment of target overall status of 'Good'.
		• Failure of both soluble and sediment bound pollutants in HAWRAT routine runoff but compliance with EQS limits.
		• Risk of pollution from accidental spillage during operation > 1% annually.
		• Some changes and impacts on the water feature bed, banks and vegetated riparian corridor resulting in some changes to sediment characteristics, transport processes, sediment load and turbidity.
		• Some alteration to channel planform and/or cross section, including modification to bank profiles or the replacement of a natural bed. A shift away from baseline conditions with potential to alter natural fluvial processes.
		• Temporary loss of water supply.
		• Partial loss or change to an aquifer/groundwater supported designated wetlands.
		• Partial change to pumping rate and water quality in abstraction wells.

Magnitude	Criteria	Example
		• Potential medium risk of pollution to groundwater from routine runoff (Method C score 150 - 250).
		• Moderate risk of pollution to groundwater during construction, temporary or moderate long-term change in water quality, resulting in a temporary change in WFD status or contributing to preventing attainment of target overall status of 'Good'.
Minor Adverse	Results in some measurable change in attribute's quality or vulnerability	• Minor risk of pollution during construction to surface water, relatively minor temporary changes in water quality such that ecology is temporarily affected. Equivalent to a temporary minor, but measurable, change within WFD status class.
		• Failure of either soluble or sediment bound pollutants in HAWRAT routine runoff but compliance with EQS limits.
		• Risk of pollution from accidental spillage during operation > 0.5% annually.
		• Limited impacts on the water feature bed, banks and vegetated riparian corridor resulting in limited (but notable) changes to sediment characteristics, transport processes, sediment load and turbidity.
		• A small change or modification in the channel planform and/or cross section. Minimal shift away from natural fluvial baseline conditions with typically localised impacts.
		• Temporarily reduced quality of water supply.
		• Temporary change to pumping rate and water quality in abstraction wells.
		• Potential low risk of pollution to groundwater from routine runoff (Method C score <150).

Magnitude	Criteria	Example
		• Minor risk of pollution to groundwater during construction, temporary change in water quality with temporary effects on groundwater dependent systems. Equivalent to a temporary minor, but measurable, change within WFD status class.
Negligible Adverse	Results in effect on attribute, but of insufficient magnitude to affect the use of integrity	• Negligible risk of pollution to surface water during construction, very slight temporary change in water quality with no discernible effect on watercourse ecology or water supply.
		• All elements of HAWRAT and EQS routine runoff assessments passed.
		• Risk of pollution from accidental spillage during operation < 0.5% annually.
		• Minimal or no measurable change from baseline conditions in terms of sediment transport, channel morphology and natural fluvial processes. Any impacts are likely to be highly localised.
		• No measurable impact upon an aquifer.
		• Negligible risk of pollution to ground water during construction, very slight temporary change in water quality with no discernible effect on dependent systems or water supply.
		• No measurable change to pumping rate and water quality in abstraction wells.
No Change	Results in no change to the receptor	• No predicted adverse or beneficial impact to the receptor.
Negligible Beneficial	Results in beneficial effect on attribute, but of insufficient	• The scheme options may beneficially affect the integrity of the water environment, but this is not considered measurable.
		• No measurable impact upon an aquifer.

Magnitude	Criteria	Example
	magnitude to affect the use of integrity	
Minor Beneficial	Results in some beneficial effect on attribute or a reduced risk of negative effect occurring	• Potential for slight reduction in pollution to a surface water or groundwater body, but insufficient to cause noticeable benefit in quality, fishery productivity or biodiversity.
Moderate Beneficial	Results in moderate improvement of attribute quality	• Moderate improvement to a fishery/designated nature conservation site. Potential increase in the productivity of a fishery.
		• Reduced pollution of a receiving water body, but insufficient to change the environmental status/classification, including water quality classification.
Major Beneficial	Results in major improvement of attribute quality	• Significant improvement to a fishery/designated nature conservation site.
		• Removal of existing polluting discharge, or removing the likelihood of polluting discharges occurring.
		• Change to the environmental status/classification of a water feature, including water quality classification.

Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11C: Sediment Transport Assessment

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11C

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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Glossary of Abbreviations and Defined Terms

AAP	Area Action Plan
AEP	Annual Exceedance Probability
AOD	Above Ordnance Datum
FRA	Flood Risk Assessment
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWS	Mean High Water Spring Tide
MLWS	Mean Low Water Spring Tide
MHWN	Mean High Water Neap Tide
MLWN	Mean Low Water Neap Tide
GYBC	Great Yarmouth Borough Council

1 Introduction

1.1 Overview

1.1.1 A Sediment Transport Assessment for the proposed Great Yarmouth Third River Crossing (hereinafter referred to as "the Scheme") within the town of Great Yarmouth on the East Anglian coast of England has been prepared as part of the DCO Application. A Rochdale Envelope approach has been adopted and the reasonable worst-case scenario for sediment transport has been assessed. A hydraulic model has been built to assess the impact of the Scheme on the sediment regime in Great Yarmouth and this report details the model build and outputs.

1.1.2 This assessment investigates the impact of the Scheme on the sediment regime within the River Yare, looking specifically at the magnitude and range of the impact. The assessment has been carried out for a Spring and Neap Tide and likely extreme events. For this assessment, out of channel flooding events have not been considered, therefore no floodplains have been included in the model. This is because once the water level is sufficient to overtop the flood defences, the velocity magnitude in the channel is unlikely to increase as water flowing out onto the floodplain increases the flow area and limits the velocity magnitude in channel. In addition, the focus of this assessment is on regular, everyday events and as floodplain flows occur infrequently, it has not been necessary to include them in this assessment.

1.2 Sediment Assessment Study Area

1.2.1 Great Yarmouth is a seaside town in Norfolk on the east coast of England. The River Yare flows through the centre of the town and is a commercial port with a number of large ship berths along both quays. Tidal defences line the river edge, providing protection from coastal flooding to the town and containing the water flow during the normal tidal cycle. The river flows in a southerly direction, under two existing bridges before turning at almost a right angle to discharge in an easterly direction into the sea.

1.2.2 The River Yare is one of the sea boundaries of the Broadlands Rivers Catchment and is tidally driven. The tidal boundary drives the levels in the River Yare and across the Norfolk Broads. Great Yarmouth currently has two road bridge crossings over the River Yare; Breydon Bridge and Haven Bridge as shown in Plate 1-1. These are currently the only two ways for traffic to cross the River Yare in Great Yarmouth. Both bridges are constructed using traditional methods each supporting the bridge deck on vertical support columns built into the river bed.

Plate 1.1 – Study Location

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Plate 1-1: Study Location

1.2.3 The River Bure is a tributary which flows into the River Yare approximately 240m downstream of the A47 Bridge. Upstream of Breydon Bridge, the River Yare forms a lake known as Breydon Water. Breydon Water is an area of intertidal mud flats and salt marshes and contributes a significant volume of storage to the estuary.

1.3 The Scheme

1.3.1 The Principal Application Site is located approximately 2.3km upstream of the harbour mouth and 2.3km downstream of Breydon Water. The Satellite Application Sites have not been included in this assessment as they are remote from the river channel and do not have an impact on the sediment regime within the river. The Scheme consists of twin bascule bridge decks supported on vertical columns, which extend from the east and west quay walls. The columns are surrounded by small knuckles with ship fenders attached, which provides a 50m navigable channel for vessels. The total width of the opening under the bridge deck is approximately 55m. Each side of the bridge has an approach road sloping from the deck height to the existing ground level on either side of the bridge. Both approach roads are on an embankment to provide vehicular access to the bridge deck. On either side of the bridge, each embankment has an opening allowing access underneath the approach roads for local traffic. For the full Scheme description refer to Chapter 2 of the Environmental Statement. Document reference 2.1 and 2.2 shows the design of the Scheme.

2 Data Collection and Review

2.1 Overview

2.1.1 The data listed in Table 2-1 has been collected as part of this study. All the data has been reviewed and its suitability for use in this assessment determined.

Table 2-1: Collected Data Summary

Data	Source
1D/2D ISIS TUFLOW Classic River Yare, 2011 Model	Environment Agency/Halcrow
1D/2D Flood Modeller/TUFLOW Classic flooding model, 2018	WSP
General Arrangement Plans (document reference 2.2) Engineering Plans, Drawings and Sections (document reference 2.11)	BAM Farrans
OS mastermap As-built construction drawing of Haven Bridge	Norfolk County Council (NCC)/Environment Agency
Bathymetry Survey (2017) P16-General-Port-Pilotage-information.pdf	Peel Ports Great Yarmouth
Sediment Particle Size Survey (July 2018)	Norfolk County Council
Velocity Survey (April 2018)	Norfolk County Council
2015, 0.5m LiDAR 2009, 1m LiDAR Extreme Sea Levels 15-minute gauge data for Haven Bridge, Great Yarmouth (Gorleston on Sea), Three Mile House and Burgh Castle	Environment Agency

2.1.2 As part of the Sediment Transport Assessment, the Environment Agency has provided a 1D/2D ISIS-TUFLOW flooding model which has been used in previous projects in Great Yarmouth and as part of this application, WSP have developed a new 1D/2D Flood Modeller-TUFLOW model to assess flooding. A review of both models has been carried out to understand if any elements can be used in the sediment assessment. However, the flood models were specifically developed to assess flooding within Great Yarmouth and it was decided that only level information (including the channel bed and flood defence levels) from the flood models would be useful within the sediment transport model developed for this assessment.

2.1.3 In addition to the 1D/2D hydraulic models received as part of the Scheme, various reports and datasets have also been collected. The design information has been used to schematise the bridge within the model. As-built drawings for Haven Bridge have been received which have been used to schematise the existing bridge in the model. The drawings provide sufficient information to specify the bridge dimensions in the model.

2.1.4 Several surveys have been carried out to provide information for use in the sediment model. Bathymetric survey of the river channel is carried out regularly by Peel Ports Great Yarmouth and the latest survey dataset (2017) was made available for this assessment. The data has been used to set the bathymetry in the water channel within the model. A sediment survey has been carried out in the channel near the Principal Application Site. The sediment survey provides particle size distribution information at ten sample locations, for further information on the sediment survey see Section 4.2.

2.1.5 Peel Ports Great Yarmouth produced a document (Ref 11C.1) providing general information to mariners who use the port. This document provides anecdotal evidence suggesting the current speed peaks around 3 knots (1.5m/s) on the incoming tide and up to 3 to 4 knots (1.5m/s to 2m/s) on the outgoing tide. There is no mention of where these velocity magnitudes have been observed and as such they have only been used for information purposes.

2.1.6 As part of the calibration process, a velocity survey was carried out. The survey was undertaken over a two-day period at the weekend during a relatively quiet period for port operations to minimise disturbance due to vessel movement. The survey has been used to validate the velocity outputs of the model, see Section 5.3.

2.1.7 The Environment Agency own several datasets that can assist with model development. LiDAR has been obtained from the Environment Agency’s data website, the 50cm resolution, 2015 flight dataset has been used predominately and the 1 m resolution, 2009 flight dataset has been used to fill in any gaps in data. The Environment Agency has provided 15-minute level gauge data for Haven Bridge, Gorleston-on-Sea, Three Mile House and Burgh Castle, all of which are within the Broadlands catchment area. This data has been used to generate the tidal boundaries in conjunction with the extreme sea levels and calibrate the model.

3 Tidal Boundaries

3.1 Overview

3.1.1 Tidal levels have been derived to define the eastern boundary of the hydraulic model that represents the sea level along the Great Yarmouth coastline. The tidal boundaries have been generated in two ways; firstly, an extract from the gauge at Gorleston-on-Sea for a Spring and Neap cycle has been extracted to simulate the typical tidal cycle and used to represent an everyday event.

3.1.2 Secondly, Environment Agency guidance on estimating design sea levels (Ref 11C.2) has been used to derive the extreme tidal boundary inflows used in the model. An extreme tide curve has also been derived for several scenarios scaled to the 5% Annual Exceedance Probability (AEP) tidal event; 2.84mAOD, taken from the guidance. These scenarios represent an extreme event which the Scheme is likely to experience during its lifetime (assumed design life is 120 years).

3.1.3 The events that have been simulated in the model are as follows:

- Everyday Events:
  - Spring; and
  - Neap.
- Extreme Events:
  - Mean High Water Spring (MHWS) to Mean Low Water Spring (MLWS) + 5% AEP Sea Surge Event; and
  - Mean High Water Neap (MHWN) to Mean Low Water Neap (MWWN) + 5% AEP Sea Surge Event.

3.1.4 This section provides an overview of the tidal curve derivation process, for full details see Annex A.

3.2 Everyday Scenario

3.2.1 In order to generate the “everyday” tidal boundary, the recorded tidal data at the Gorleston-on-Sea gauge was downloaded from the British Oceanography Data Centre (BODC) website for 2018. Plate 3-1 shows the water elevation recorded for the full year for 2018 at the gauge.

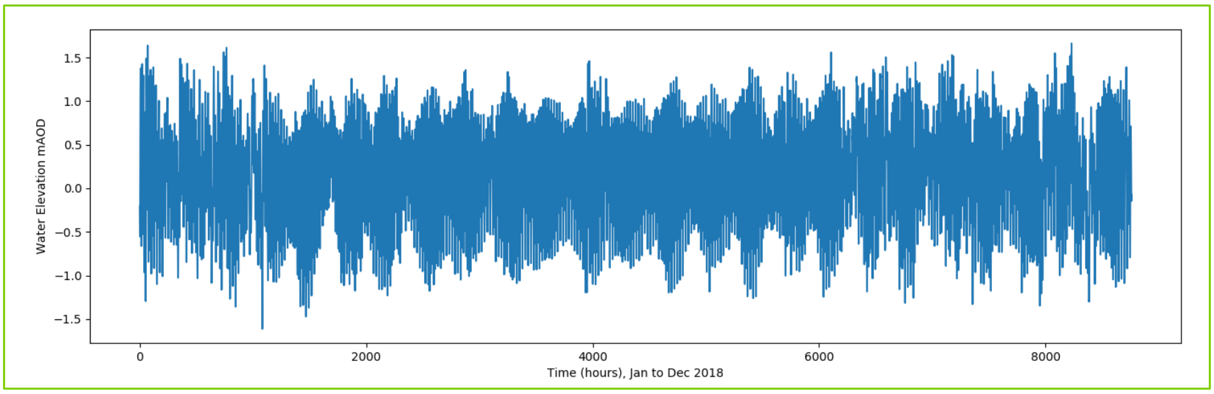

Plate 3-1: 2018 – January to December Tidal Levels Recorded at Gorleston on Sea Gauge

3.2.2 Plate 3-1 shows the full year of recorded data at Gorleston-on-Sea for 2018. The time series plot shows the typical spring/neap cycle repeating approximately every week throughout the year and several surge tides particularly around the early part of the year from January to February. For the purpose of this assessment a typical spring/neap tide cycle is required; therefore, the curve shown in Plate 3-2 has been extracted making sure no surge events are captured.

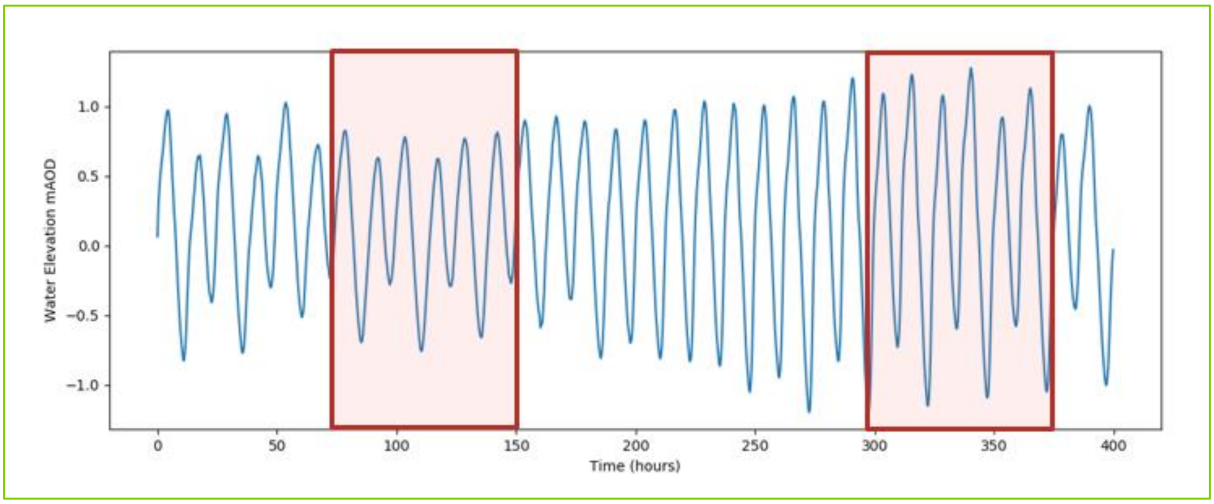

Plate 3-2: Extracted Tidal Curve

3.2.3 Plate 3-2 shows a typical water level time series ranging from a Neap to Spring tide. The data has been selected from the yearly recorded data shown in Plate 3-1 to represent a typical tide with minimal surge events. At this point, the date of the profile is no longer relevant, therefore the plots show the tidal cycle time in hours starting at zero hours. In an effort to reduce model simulation time, the curve shown in Plate 3-2 has been split into two separate simulations (shown in the red boxes) of approximately 75 hours; one simulating a spring tide and one simulating a neap tide. These simulations will be used to approximate the amount of sediment movement on a typical spring and neap tide.

3.3 Extreme Tide Event

3.3.1 In order to understand the impact of likely extreme tidal events, Environment Agency guidance on estimating design sea levels (Ref 11C.2) has been used to derive the extreme tidal boundary inflows used in the model. The Environment Agency guidance has a ten-step procedure to create a tidal boundary for the model:

1. Check study location is outside of the estuary boundaries;
2. Select an appropriate chainage point for extreme sea levels;
3. Select an AEP peak sea level;
4. Consider allowance for uncertainty;
5. Identify base astronomical tide;
6. Convert levels to Ordnance Datum (OD);
7. Identify surge shape to apply;
8. Produce the resultant design tide curve;
9. Sensitivity testing;
10. Apply allowance for climate change (if required).

3.3.2 The guidance is the best method currently available for tidal curve derivation in UK waters. An overview of the derivation is provided here, for a full description, see Annex A.

3.3.3 Steps one and two require the estuary boundaries and extreme sea level datasets provided with the guidance. Using the datasets, checks have been carried out to ensure the location of the tidal boundary is outside of the River Yare estuary and the nearest chainage node is 4,150.

3.3.4 Steps three and four select the appropriate AEP event and the measure of uncertainty. For this assessment, it has been decided that 5% AEP event represents the likely extreme event. This is because the event remains in channel and it is probability says this is likely to happen in the Scheme's design life. To that end, Table 3-1 shows the extreme sea level for the 5% AEP taken from the guidance.

Table 3-1: Extreme Sea Level

Annual Exceedance Probability (AEP)	Extreme Sea Level (mAOD)
5%	2.84

3.3.5 The uncertainty value is +/- 0.2m, this is a measure of the uncertainty in the modelling used to generate the extreme sea levels. This is considered an acceptable uncertainty for this assessment because the water level is not the focus of this assessment.

3.3.6 In order to generate the astronomical tide, the gauge data at Gorleston-on-Sea has been used. In addition to the Gorleston-on-Sea gauge, in line with the Environment Agency guidance, the MHWS, MLWS, MHWN and MLWN levels have been obtained from the nearest primary gauge at Lowestoft. The Environment Agency guidance states that when generating the base tidal curve, the tidal parameters from the nearest primary gauge should be used. Lowestoft harbour is 12km south of Great Yarmouth and therefore it is considered appropriate to use these gauge parameters for this assessment. Table 3-2 lists the Lowestoft tidal gauge parameters.

Table 3-2: Lowestoft Primary Gauge Properties

Property	Value (mAOD)
MHWS	1.08
MLWS	-0.86
MHWN	0.74
MLWN	-0.34

3.3.7 To generate the tidal curve, gauge data from the Gorleston-on-Sea gauge at Great Yarmouth has been analysed and a typical tidal cycle has been extracted. The extracted tidal profile has been repeated to create a minimum of 75 hours and scaled to the appropriate levels in Table 3-2 for a given event. In following this method, the shape of the tidal profile is replicated in the model. This is particularly important because the shape and rate of change in water level drives the velocity in the harbour. Plate 3-3 shows the tidal cycle extracted from the gauge data which represents the tidal levels in Great Yarmouth.

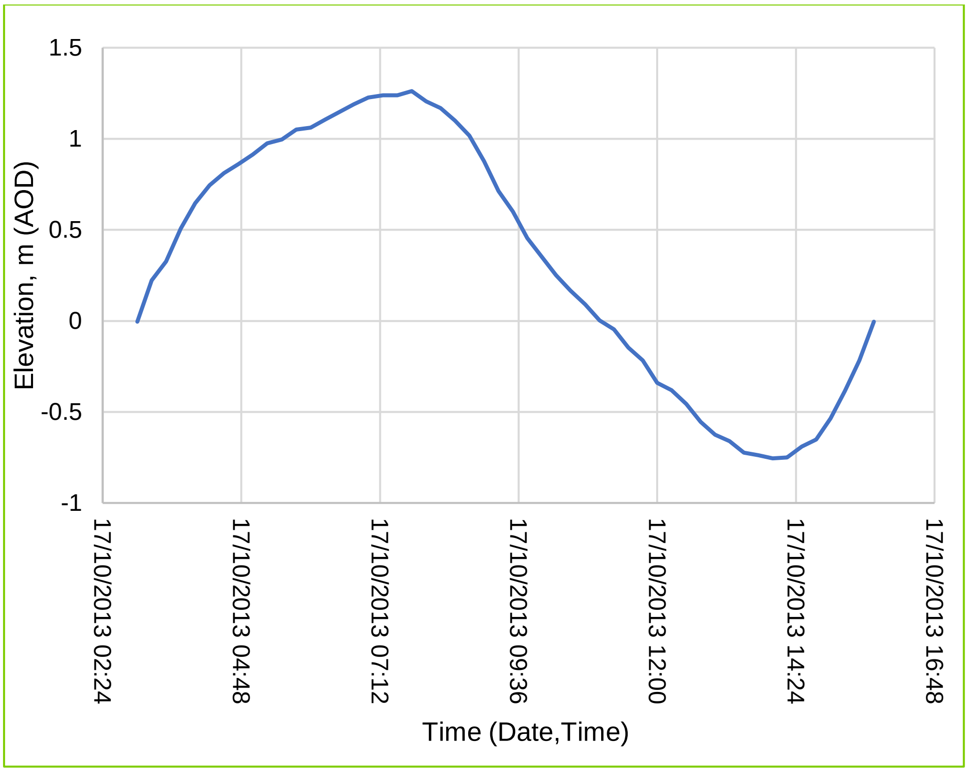

Plate 3-3: Typical Tidal Curve (Extracted from Gauge Data)

3.3.8 Following the extraction of the typical tidal curve shown in Plate 3-3, the peaks and troughs are scaled to the appropriate levels in order to create the base tidal curve events. Plate 3-4 shows the final base curves for the MHWS to MLWS and the MHWN to MLWN events.

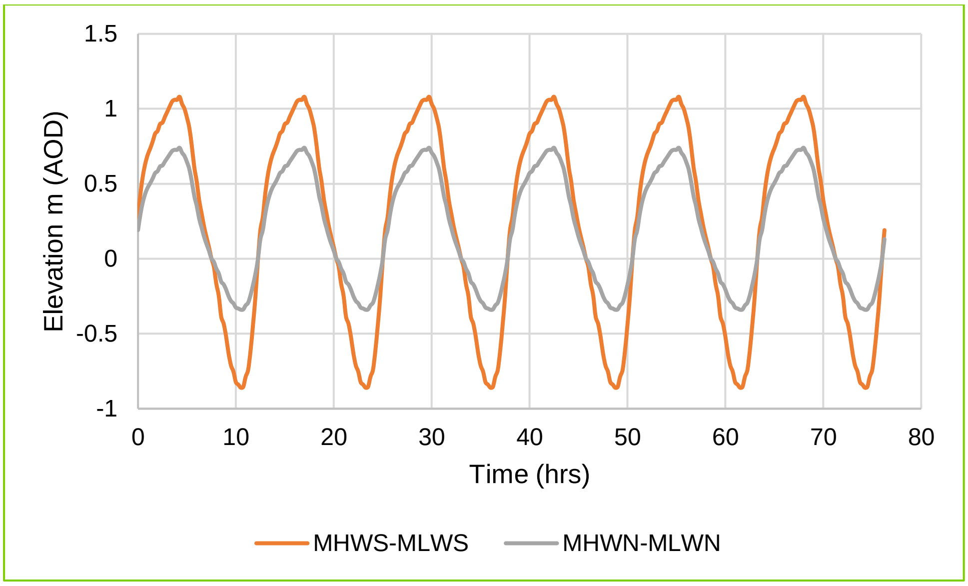

Plate 3-4: Base Tidal Profiles MHWS – MLWS and MHWN - MLWN

3.3.9 Once the extreme sea level and the base tidal profiles have been identified, sea surge is applied. This has been carried out by obtaining the normalised surge shape from the Environment Agency guidance. For Great Yarmouth, the normalised surge shape is number 9 in the dataset provided with the guidance documentation.

3.3.10 The guidance states that the resultant design tide curve is derived by combining the extreme sea level, base tide and surge shape. The first process is to align the base tides and surge shape peaks, in this case this is at 42.5 hours.

3.3.11 Once the base tide and surge shape are aligned, it is necessary to scale the base tide to the required extreme sea level. To explain this procedure, the MHWS-MLWS + 5% AEP event has been used as an example. Firstly, the difference between the required extreme sea level (2.84 m AOD) and the base tide peak (1.48 m AOD) is calculated, which in this example is 1.36 m. As the surge shape is aligned with the peak water level time in the base tide, the maximum surge value of 1.0 occurs at the same time as the peak water level. The surge shape can now be scaled by the coefficient 1.36/1.0 = 1.36m AOD, thus creating a surge height which can be added to the base tide curve resulting in the required tidal profile for the event.

3.3.12 The procedure has been carried out for the events shown in Plate 3-4 to produce the two extreme tidal boundaries required for this assessment as shown in Plate 3-5.

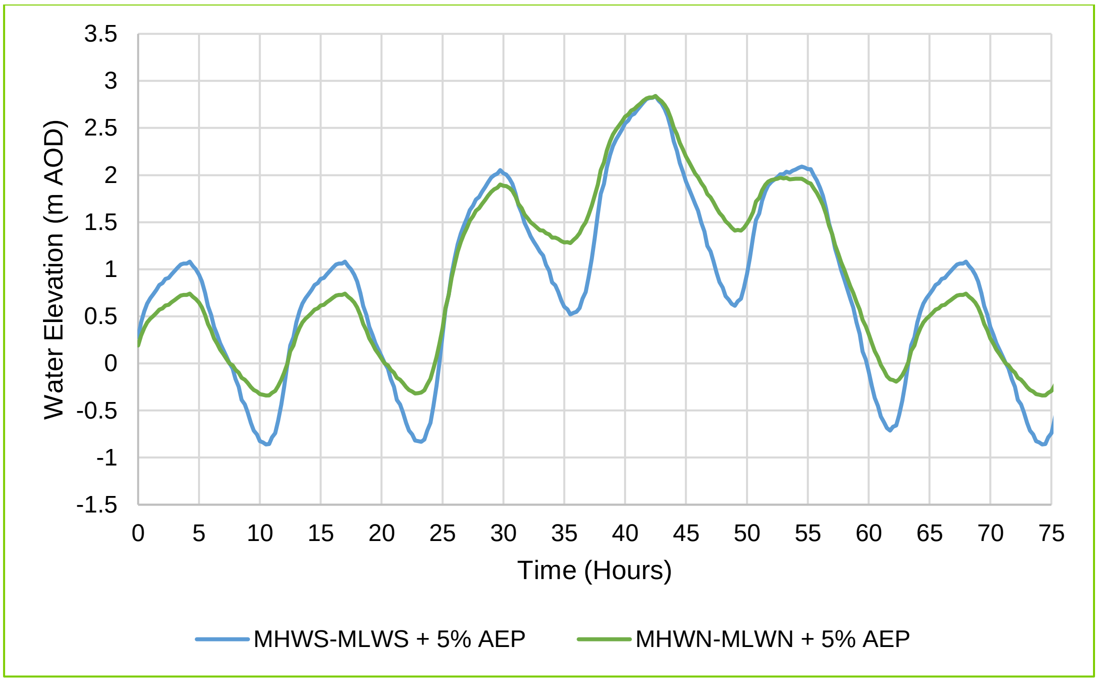

Plate 3-5: Extreme Tidal Curves

3.3.13 The final step in the Environment Agency guidance is to consider climate change. For this assessment climate change (sea level rise) is not considered. This is because the velocity in the channel is predominately driven by the rate of change of water level and simply increasing the base profile elevation will not dramatically increase the velocity in the River Yare. In addition, during high water level events, the flood defences will be overtopped allowing water to flow onto the floodplain outside of the channel. Once the water level is sufficient to overtop the flood defences, the velocity magnitude in the channel is unlikely to increase as water flowing out onto the floodplain increases the flow area and limits the velocity magnitude in channel.

4 Existing Regime

4.1.1 The existing tidal regime has been investigated to understand the baseline environment in which the Scheme will be constructed. This section provides information on the existing sediment regime including particle size analysis, tidal prism, typical cross-sections in the River Yare channel and Breydon Water, tidal symmetry and tidal dominance.

4.2 Particle Size Analysis

4.2.1 A sediment survey was carried out in 2018 to ascertain the particle sizes of sediment in the River Yare channel at the Principal Application Site, the survey was carried out at ten locations as shown on Plate 4-1. Samples were taken from the channel and tested in a laboratory to determine the Particle Size Distribution (PSD).

4.2.2 The sediment survey suggests that the D50 particle size ranges from 0.03mm to 0.55mm diameter in the river at the Principal Application Site. Table 4-1 lists all the particle size data received from the sediment sampling. In cross referencing the D50 particle size with the locations in Plate 4-1, it is possible to see that smaller particle sizes are typically found closer to the western quay wall with larger particle sizes nearer to the eastern quay.

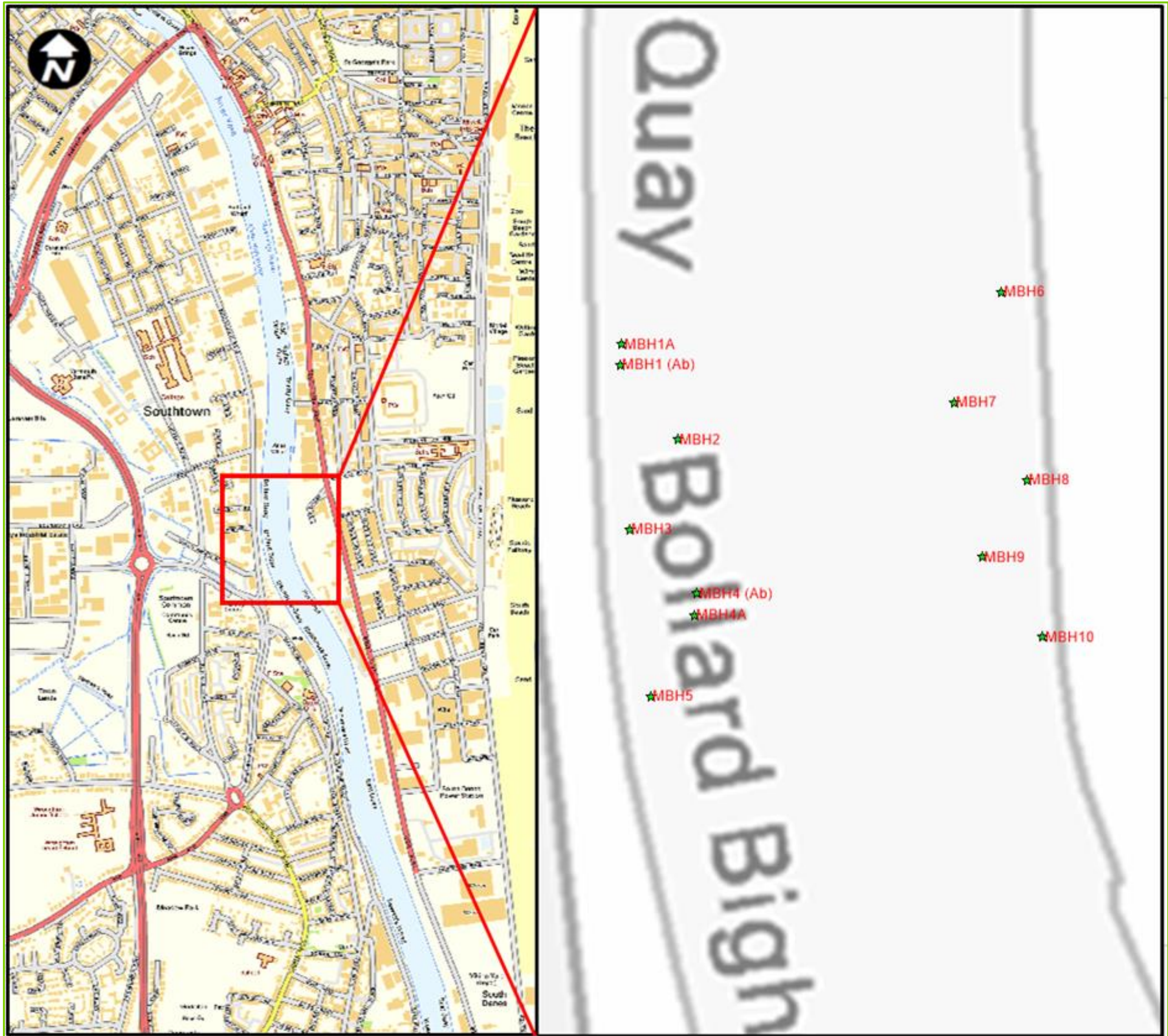

Plate 4.1 – Sediment Survey Locations

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Plate 4-1: Sediment Survey Locations

Table 4-1: Sediment Survey Results

			mm Passing					
Sample	**Deck Level (mOD)**	**Date**	**D10**	**D50**	**D60**	**D100**	**Moisture Content (%)**	**Comments**
MBH1 (Abandoned)	2.71	11/06/2018	NA	NA	NA	NA	NA	NA
MBH1A	3.32	19/06/2018	0.00	0.07	0.15	14.00	85.00	Soft grey clayey gravelly very silty fine to coarse SAND. Gravel is fine to medium subrounded flint and quartz.
MBH2	3.13	13/06/2018	0.00	0.03	0.05	10.00	37.00	Soft brownish-grey very sandy, very silty CLAY.
MBH3	3.53	18/06/2018	0.11	0.40	0.54	20.00	35.00	Dark grey very gravelly silty fine to coarse SAND. Gravel is fine to coarse subrounded flint.

			mm Passing					
Sample	**Deck Level (mOD)**	**Date**	**D10**	**D50**	**D60**	**D100**	**Moisture Content (%)**	**Comments**
MBH4 (noted as abandoned however there is a PSD card.)	2.95	15/06/2018	0.00	0.20	0.35	38.00	28.00	Soft grey very silty very gravelly clayey fine and medium SAND. Gravel is medium to coarse subrounded to subangular flint, concrete and sandstone. Some shell fragments.
MBH4A	3.01	17/06/2018	0.22	0.49	0.62	38.00	17.00	Olive rapidly Weathering to brown very gravelly medium SAND. Gravel is fine to coarse subrounded to angular flint
MBH5	3.23	20/06/2018	0.00	0.08	0.14	5.00	86.00	Very soft dark greyish orange very sandy clayey SILT.
MBH6	2.94	24/06/2018						NO REPORT CARD

			mm Passing					
Sample	**Deck Level (mOD)**	**Date**	**D10**	**D50**	**D60**	**D100**	**Moisture Content (%)**	**Comments**
MBH7	3.15	25/06/2018	0.25	0.55	0.92	14.00	16.00	Greyish brown very gravelly medium to coarse SAND. Gravel is fine and medium angular to subrounded flint, concrete and occasional shell fragments.
MBH8	3.30	21/06/2018	0.09	0.24	0.26	14.00	47.00	Grey and brown slightly gravelly silty fine and medium SAND. Gravel is medium angular to subangular flint.
MBH9	3.07	03/07/2018	0.24	0.38	0.41	10.00	17.00	Brown medium SAND.
MBH10	3.33	22/06/2018	0.14	0.29	0.32	2.00	27.00	Dark grey and black medium SAND.

4.3 Tidal Prism

4.3.1 The tidal prism of an estuary is defined as the volume of water between the mean high-water level and mean low-water level or in other words the volume of water that exits the estuary on the ebb tide. The prism is used to gain an understanding of the potential sediment movement through the estuary because it is this water that contains the sediment and directly links to sedimentation/erosion.

4.3.2 The River Yare has an unusual estuary mouth because the first section of the estuary is a narrow, defended channel through the town centre which then opens into the large mudflats and saltmarsh of Breydon Water. In order to calculate the tidal prism, the estuary boundary has been defined as the section of the Yare through Great Yarmouth town centre and Breydon Water.

4.3.3 Plate 4-2 shows the parts of the channel considered the estuary for the purposes of calculating the tidal prism. The river area is shown by the blue polygon and Breydon Water area has been shown by the red polygon. To calculate the tidal prism, the baseline model has been used to calculate the surface area of the water at the MHWS and the MLWS. The volume between the two surfaces is then calculated. To further understand how the estuary works, the tidal prism for only the River Yare channel has also been calculated. This helps to understand the impact of Breydon Water on the tidal dynamics in the area. Table 4-2 lists the tidal prism calculated in the estuary rounded to the nearest 1,000 m^3.

Plate 4.2 – Tidal Prism Boundary

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Plate 4-2: Tidal Prism Boundary

Table 4-2: Calculated Tidal Prism

MHWS Level	1mAOD
MLWS level	-0.6mAOD
Baseline Tidal Prism River Yare	617,000m^3
Baseline Tidal Prism Breydon Water	4,504,000m^3
Total Baseline Tidal Prism	5,121,000m^3

4.4 Bathymetry

4.4.1 Peel Ports Great Yarmouth have provided bathymetry data of the River Yare collected in 2017. The bathymetry collected is within the port's jurisdiction between the river mouth and Haven Bridge. Plate 4-3 shows a typical cross section in the River Yare channel at the Principal Application Site.

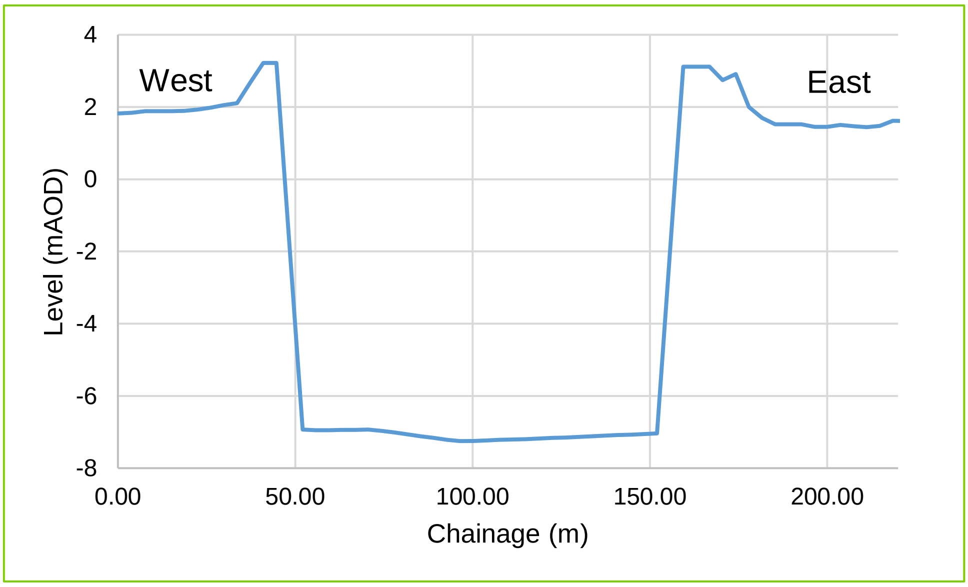

Plate 4-3: Typical River Cross Section: River Yare

4.4.2 Plate 4-3 shows that the channel bed is around -7mAOD. This is consistent along the full length of the channel through Great Yarmouth and is maintained by regular dredging undertaken by Peel Ports Great Yarmouth. No bathymetry data has been obtained for Breydon Water, however the 2011 Halcrow/EA flood model uses 1D cross sections to represent the lake. Plate *4-4* shows a typical cross section through Breydon Water, there is a deep central channel with slope sections either side representing the mudflats and saltmarsh of Breydon Water.

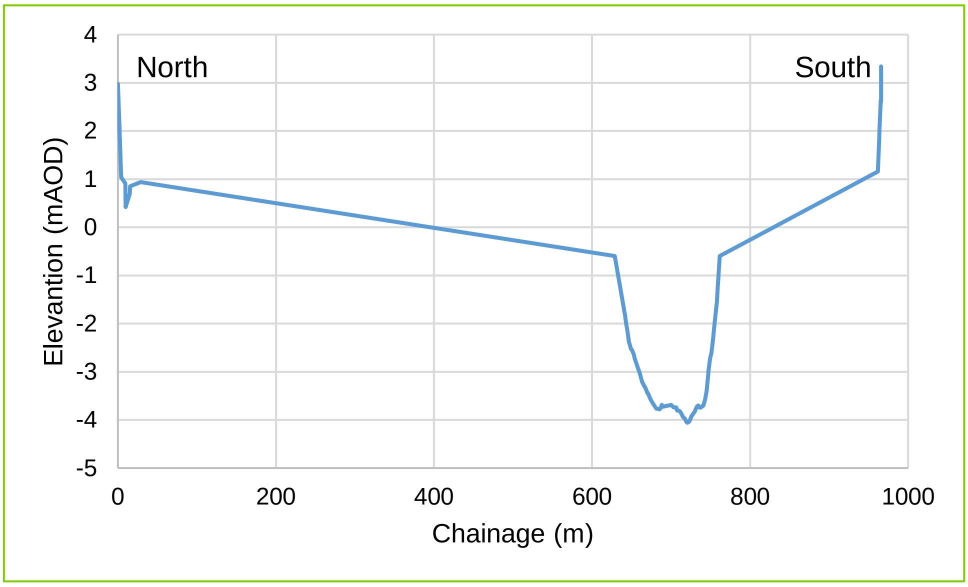

Plate 4-4: Typical Lake Cross Section - Breydon Water

4.5 Tidal Symmetry

4.5.1 Tidal symmetry compares speed against elevation to show whether a tidal system is ebb or flood dominant. For this assessment, the model results from the 13th-16th April 2018 tidal cycle simulation have been plotted on Plate 4-5 and Plate 4-6. This cycle has been obtained at the gauge at Gorleston-on-Sea and represents the period of time when the velocity survey was conducted.

4.5.2 Plate *4-5* shows the water level and speed plotted against time and Plate 4-6 shows the water level plotted against speed for the 13th-16th April 2018 tidal cycle in the channel near the Principal Application Site. The plots suggest that the estuary is almost tidally symmetrical (a perfectly symmetrical tide would be shown as a circle or an oval on the graph) in the engineered River Yare channel with a slight skew at high water. As there is a need for periodic dredging, it is assumed that sediment is deposited in the channel during slack water and is carried on both the ebb and flood tide.

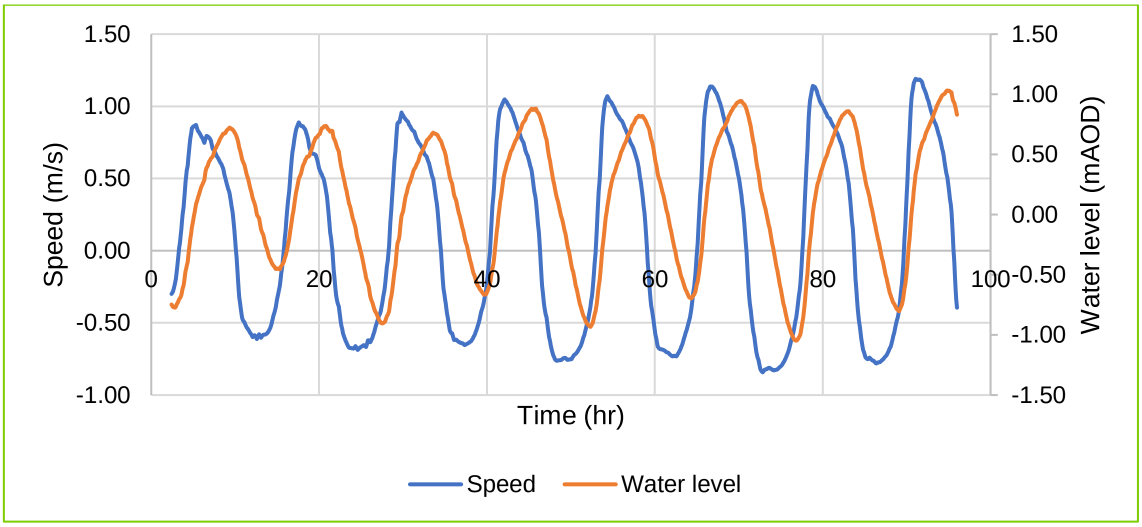

Plate 4-5: Tidal Boundary

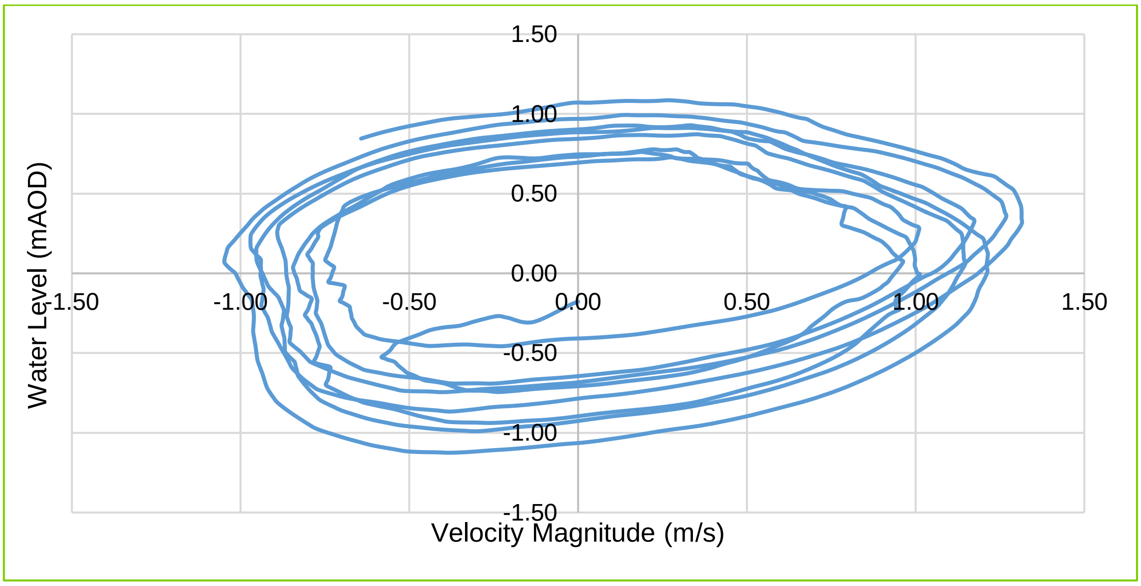

Plate 4-6: Velocity Magnitude against Water Level at the Scheme Site – Baseline Model

4.6 Dronker's Ratio and Estuary Type

4.6.1 The Dronker's Ratio is a measure of tidal dominance and is used to assign a type to an estuary. This is used here to assess the tidal dominance of the estuary as a whole. There are two types of estuary; Type I and Type II. A type I estuary is a deep, wide channel that is typically filling up with sediments. As the intertidal flats of the estuary develop, the sediment supply on the flood is reduced and new morphology is attained. Type II estuaries typically excrete sediment on the flood tide, which has the effect of eroding the intertidal plain and reverting the estuary to Type I. A typical estuary oscillates between Type I and Type II in a dynamic equilibrium.

4.6.2 The Dronker's Ratio provides a numerical measure of tidal dominance and is calculated using the surface area and volume of the high and low tidal levels in the estuary following EA guidance (Ref 11C.3). The estuary is defined as shown in Plate 4-7 and Plate 4-8 wetted areas. The high and low tide levels are 1mAOD and -0.6mAOD respectively.

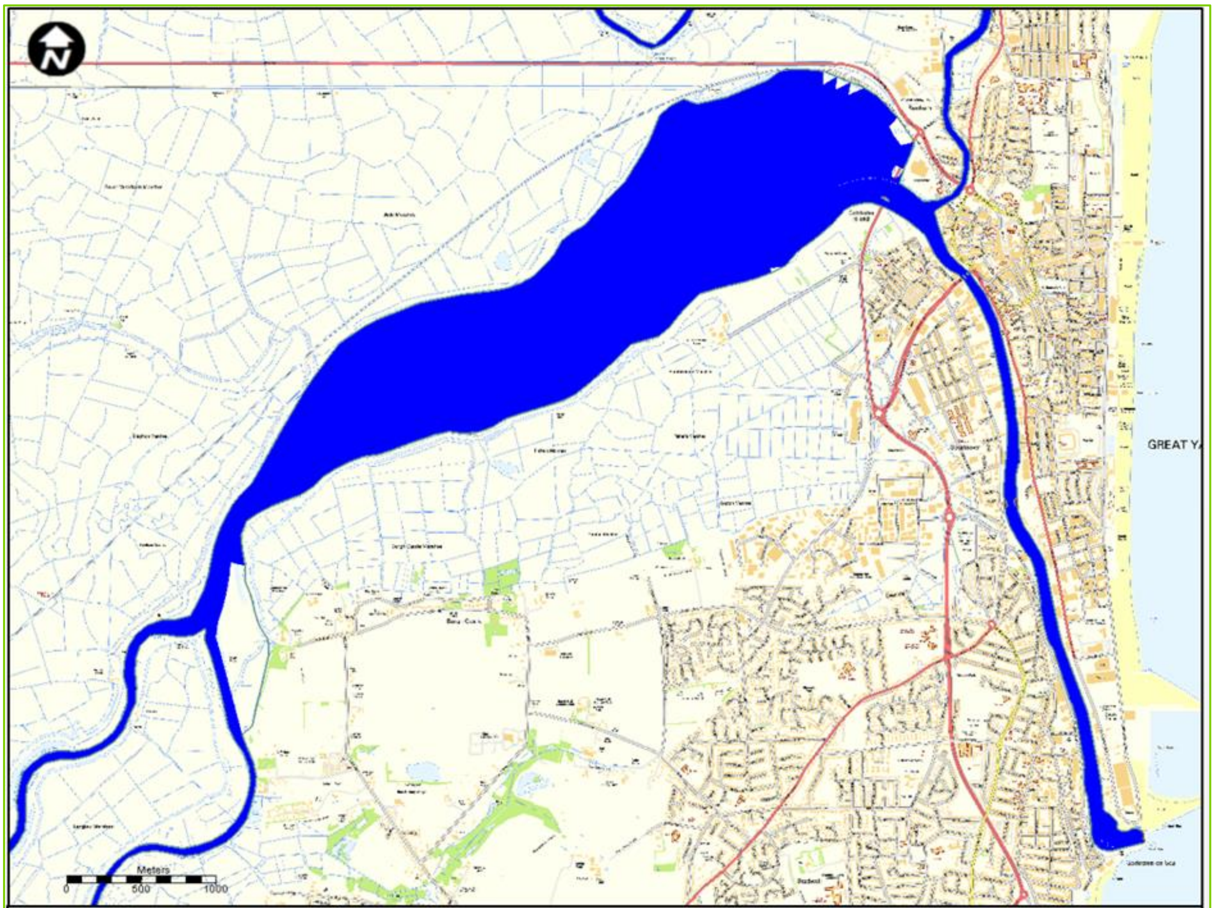

Plate 4.7 – Wetted Area, High Tide

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Plate 4-7: Wetted Area, High Tide

Plate 4.8– Wetted Area, Low Tide

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Plate 4-8: Wetted Area, Low Tide

Table 4-3: Baseline Dronker's Ratio Calculation

Measure	Baseline
Hydraulic depth, dh	3.88
Tidal Amplitude, a	0.58
Surface area at low water, Slw	1318636m^2
Surface area at high water, Shw	4916929m^2
Volume at high water, Vhw	9475544m^3
Volume at low water, Vlw	4357856m^3
Dronker's (dh)	0.49

4.6.3 The Dronker's Ratio shown in Table 4-3 shows that the estuary is an ebb dominated environment. The Dronker's Ratio of 1 shows no tidal dominance.

A value lower that one highlights an Ebb dominant environment and great than one shows a Flood dominant environment. However, Great Yarmouth is not a typical estuary because of the narrow channel through Great Yarmouth town centre. The engineered channel hydraulically controls the flow of the water and by extension the sediment transport in and out of Breydon Water. To that end, the impact of the engineered channel means that Breydon Water is excreting sediments at a slower rate than would otherwise be expected in such an estuary.

4.6.4 The combination of the cross section shown in Plate 4-4 which shows the shape of the lake and the Dronker's Ratio suggests the estuary is Type II and considered Ebb dominant.

5 Model Build

5.1 Overview

5.1.1 A 3D tidal model has been built in TUFLOW-FV to represent the River Yare including Breydon Water at Great Yarmouth. Baseline and Scheme versions of the model have been created. The model built for this study is detailed in Section 5.2. Section 5.3 describes the model calibration process that has been undertaken. TUFLOW-FV uses an unstructured grid to resolve the 3D flow characteristics of the watercourse. A 3D model can significantly increase the amount of information and detail compared to a 2D model.

5.1.2 In addition to the hydraulic calculations, the TUFLOW-FV model built for this assessment includes an explicit sediment transport module. This module explicitly calculates the bed load, erosion and deposition rates of sediment particles in the watercourse by using the velocity magnitude to calculate the bed shear stresses. The model provides detailed velocity magnitude results to be used in the sediment transport module. This is beneficial when considering sediment transport as it is the velocity magnitude in the lower section of the water column that drives sediment transport.

5.1.3 The unstructured grid (flexible mesh) method allows the user to efficiently use the computational power available by specifying a high resolution in areas of interest and lower resolution elsewhere. This is particularly useful when the results needed are focused in a small spatial area, as for the Scheme, for example, around bridge supports.

5.2 Model Build

Model Domain

5.2.1 The model domain extends from the harbour entrance at Gorleston-on-Sea to Breydon Water and includes representation of the River Yare and the River Bure upstream of Breydon Water. It is assumed that the worst-case scenario for the velocity magnitude will be before the water level exceeds the harbour walls therefore it is not considered necessary to include any floodplain representation within the model. The harbour entrance is approximately 2.5km from the Principal Application Site, which is sufficient distance to ensure that any boundary effects do not influence the area of interest. Plate 5-1 shows the model domain used in this assessment.

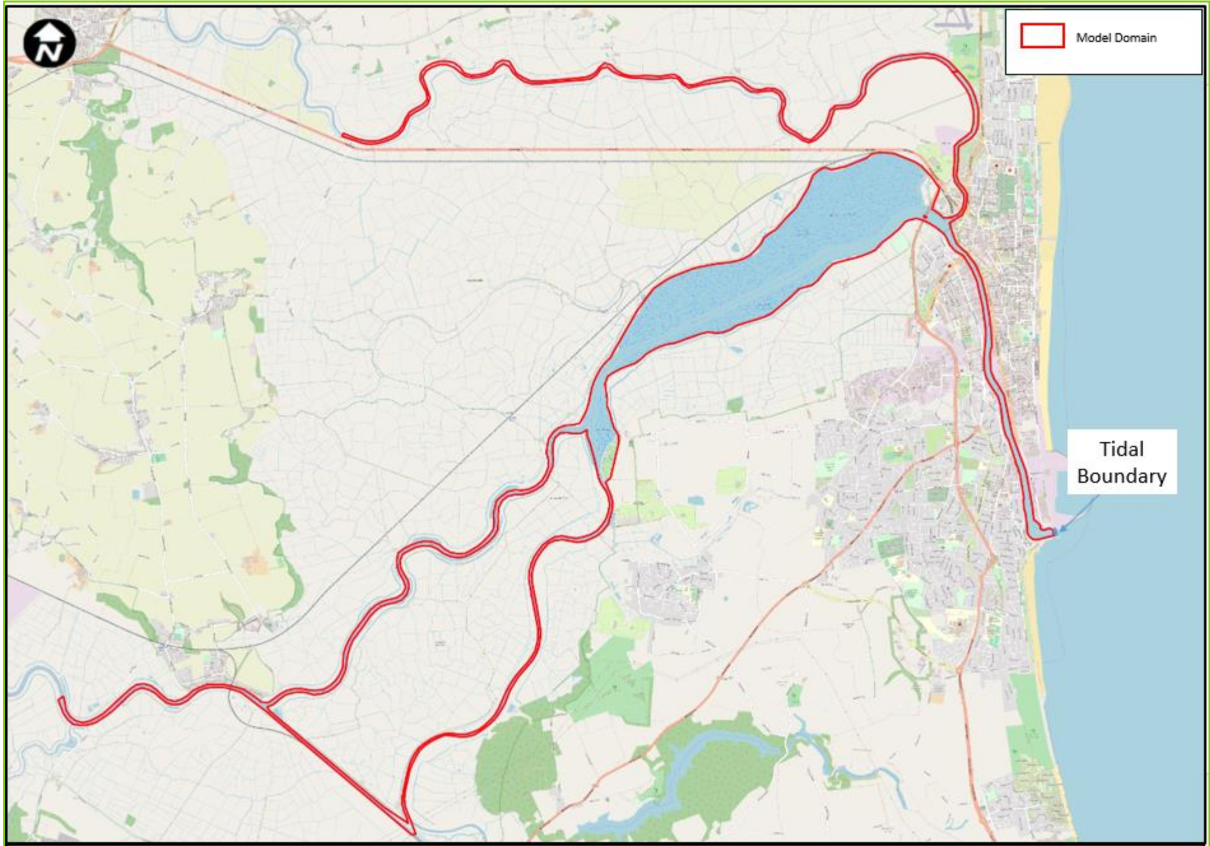

Plate 5.1 – Model Domain Boundary

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Plate 5-1: Model Domain Boundary

5.2.2 The major benefit of the flexible mesh is the ability to vary the resolution across the model domain. The cell size through the domain is dependent on the level of accuracy required in specific locations and computational time. In this model build, it was considered necessary to simulate the channel at the Principal Application Site at an ultra-high resolution (approximately 3m by 3m) to obtain the highest level of detail in the area where the largest impacts will occur. The cell size increases further away from the Scheme to approximately 5m by 5m in channel. Breydon Water and the reaches of the River Yare and River Bure upstream of this have been simulated at a lower resolution. The lower resolution is considered appropriate to simulate the areas that are a significant distance from the Principal Application Site. Plate 5-2 shows the resolution of various areas within the model domain. Plate 5-3 shows the Scheme representation in the model grid where the bridge knuckles extend into the channel from both quays leaving an approximately 50m wide channel between them.

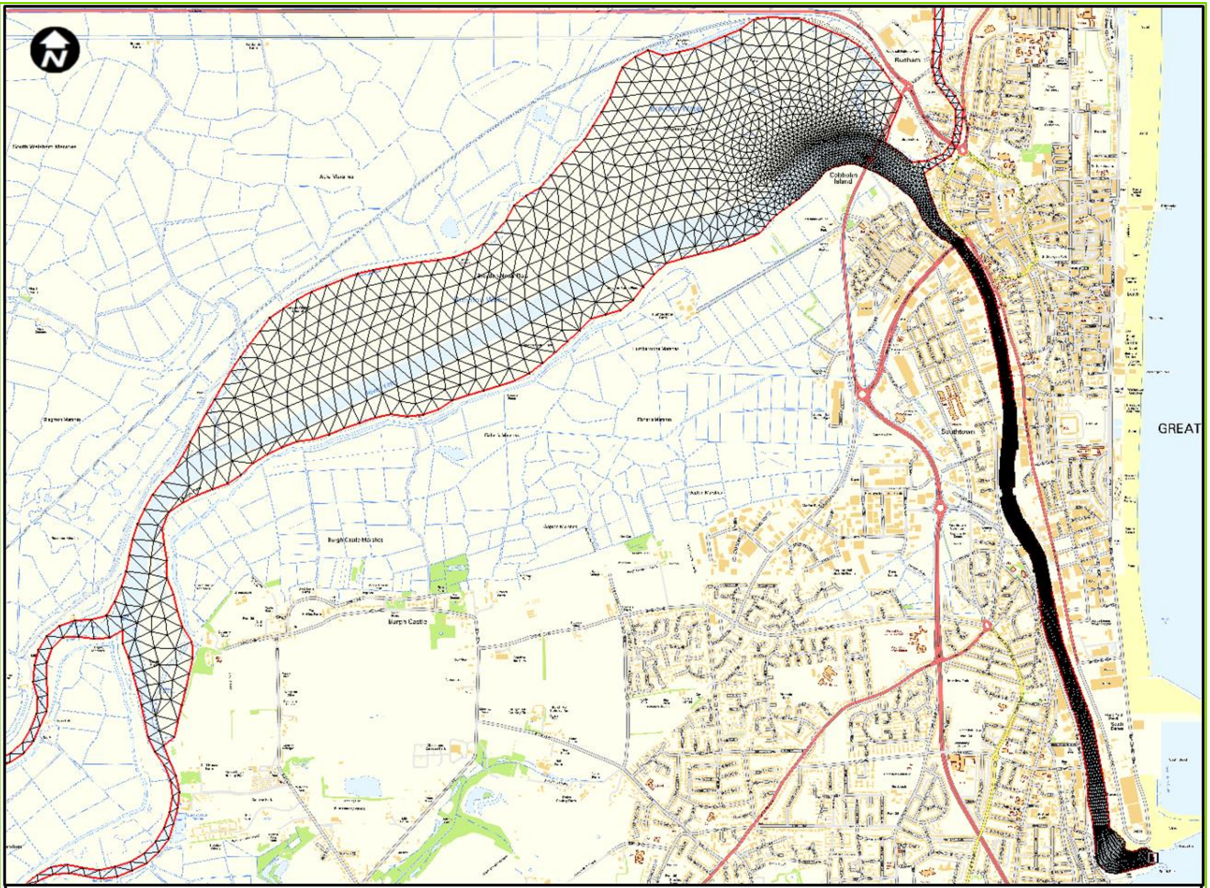

Plate 5.2 – Model Mesh

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Plate 5-2: Model Mesh

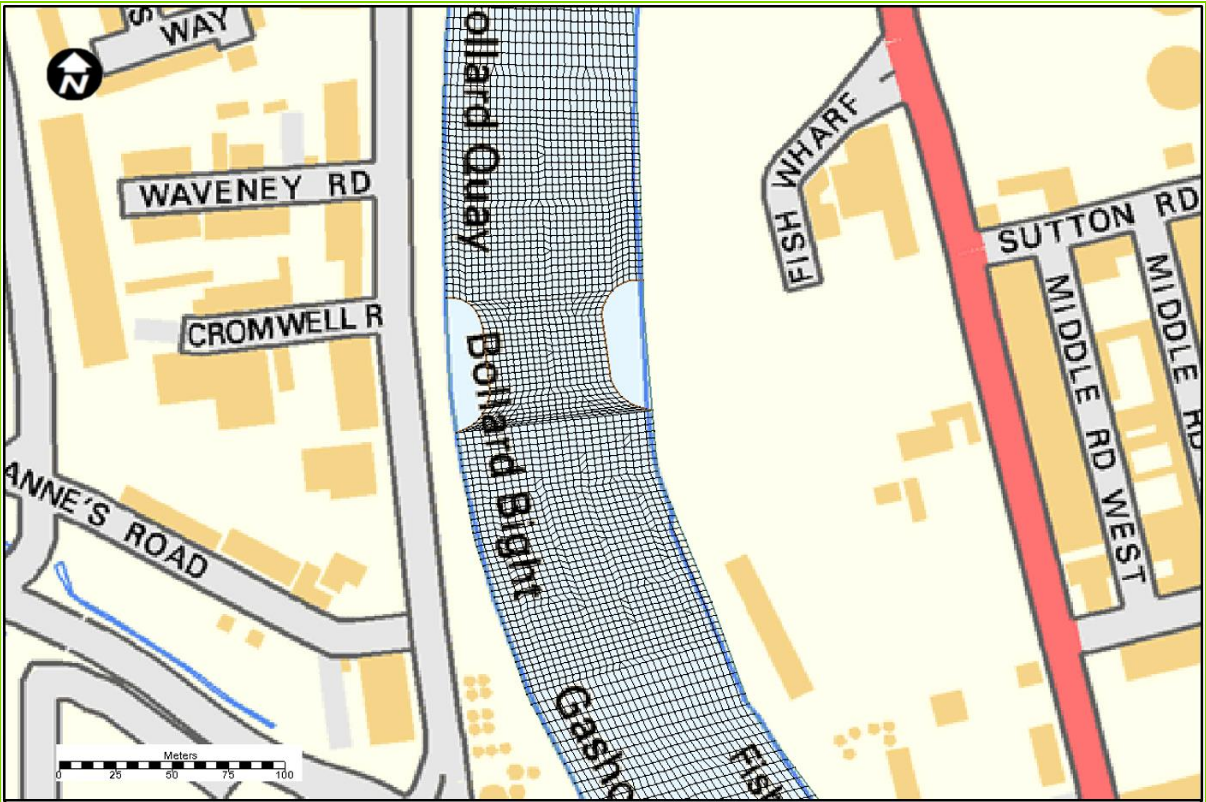

Plate 5.3 – Model Mesh at the Principal Application Site

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Plate 5-3: Model Mesh at the Principal Application Site

5.2.3 The benefit of the flexible mesh, finite volume method in TUFLOW-FV is that different sized polygons can be used with no connection/flux errors, which are possible in a finite difference model. This means triangles and quadrilaterals can be used alongside each other in the model mesh, however it is considered best practice to use quadrilaterals where possible because it improves run times. In addition, different sized polygons can be used next to each other providing they share two node connections without any impact on the calculations, a visual check of all the outputs was carried out to ensure connectivity. In this assessment, the best representation was to use predominantly triangular cells. Higher model run times have been accepted in order to improve the model calculations in this case.

5.2.4 There are currently two bridge crossings in Great Yarmouth; Haven Bridge and Breydon Bridge represented in the model. For the purpose of this assessment, the bridges have been represented by simulating the bridge knuckles in the mesh and no representation of the bridge decks. This is because both existing bridge decks are higher than the events simulated, therefore they will not interact with the water. It is the bridge support structures that have an impact on the sediment transport. Haven Bridge has two main support structures which have been explicitly modelled. Breydon Bridge has one large support and several smaller supports. The large support, which supports the bascule bridge section and lifting mechanism has been explicitly represented in the model. Due to the resolution of the model at Breydon Bridge, the smaller piers are not represented. This is considered suitable because the supports, when compared to the main structure are much smaller and the impacts of the supports will not affect the watercourse at the modelled resolution.

Roughness Values

5.2.5 As part of the model setup, initial roughness values have been applied to the model. Following review of the study area, it was considered appropriate to split the model up into three different environments, which each have a different roughness value. Table 5-1 shows the roughness values used in the model. The values have been selected using typical values and following engineering guidance.

Table 5-1: Roughness Values

Area	Roughness (Manning's *n*)
Smooth dredged Channel	0.03
Natural (un-dredged) river channel	0.04
Lake/mudflats	0.05

5.2.6 The domain was split into three roughness regions; smooth dredged channel, natural (un-dredged) river channel and lake/mudflats. The smooth dredged channel roughness has been applied to the channel through Great Yarmouth from the North Sea boundary at Gorleston-on-Sea to Haven Bridge. A Manning's *n* value of 0.03 has been used for this section because of the periodic dredging activity which will remove any vegetation growth on the river bed that causes additional drag. The channels of the River Bure and River Yare upstream of Haven Bridge have been defined as a natural (un-dredged) river channel. This is defined as an un-dredged channel where vegetation may grow and therefore cause increased energy losses, a Manning's *n* roughness value of 0.04 has been applied to these areas. Breydon Water has been defined as an area where vegetation can grow in large quantities, a Manning's *n* value of 0.05 has been applied in this area to simulate the energy losses associated with this.

Model Topography

5.2.7 The bathymetry data provided by Peel Ports Great Yarmouth has been used to define the bed levels in the River Yare. Peel Ports Great Yarmouth conducted the survey between the harbour entrance and Haven Bridge, as shown on Plate 5-4. The dataset, recorded in 2017, consists of data points taken from a boat traversing the harbour.

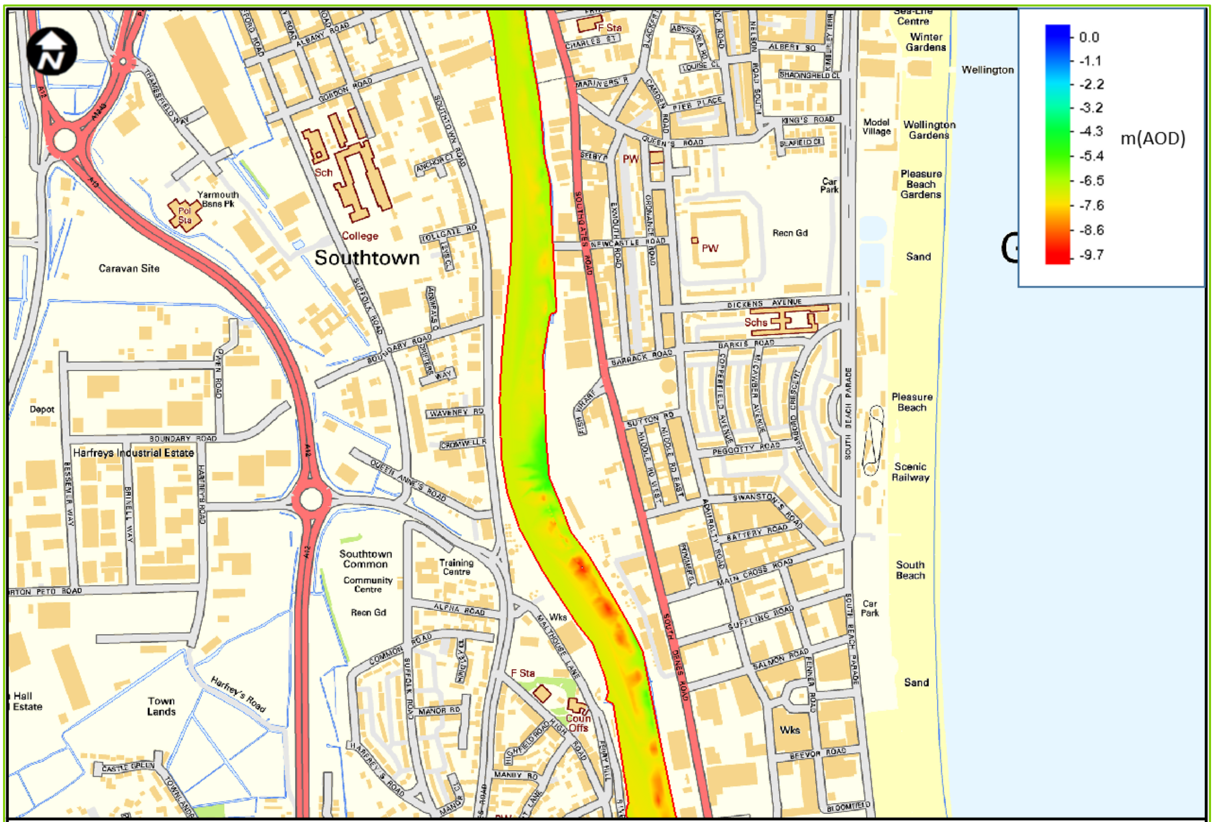

Plate 5.4 – Bathymetry at the Principal Application Site

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Plate 5-4: Bathymetry at the Principal Application Site

5.2.8 There is limited information available for the river bed upstream of Haven Bridge. The flood models received for use in this project, contain 1D cross-sections defining the river channels upstream of Haven Bridge, the bed levels in these sections range from -7mAOD to -4mAOD. It was not clear from the flood model supporting information where the data used to define the levels was from. In order to be conservative, the main channels of the River Yare and River Bure have been set at a constant depth of -7m AOD upstream of Haven Bridge. This approach has been adopted because the upper reach of the model has been included to provide sufficient storage within the system and there is not a need to represent the river sections in detail.

5.2.9 In order to represent Breydon Water, LiDAR levels have been used. The flights are often flown at or near low tide therefore the dataset can be used to set the bathymetry in the lake assuming the water levels will always be greater than this. Breydon Water has been represented using a coarse resolution approach, therefore LiDAR provides sufficient information for the bathymetry for this model.

Boundary Conditions

5.2.10 The North Sea tidal boundary is located to the south east of the Principal Application Site. The tidal curves derived for this assessment as summarised in Section 3 have been applied to this boundary in the model. The tidal boundary is applied at the river mouth and forces the water levels and flows in the model. No fluvial boundaries have been applied to the model because the catchment has a strong tidal dominance which can be seen on gauges much further upstream. To that end, it is unlikely that a small fluvial inflow will have a measurable impact on the hydraulics within the River Yare through Great Yarmouth.

Structures

5.2.11 There are two existing structures on the River Yare in Great Yarmouth, these are Haven Bridge and Breydon Bridge. Both the Haven Bridge support structures have been represented in the model, this creates a constriction in the channel simulating the impact of the bridge on the water flow. Breydon Bridge has been represented by explicitly simulating the main support for the bascule bridge span, the smaller support piles are not modelled because they are significantly smaller than the grid resolution. This means that any impact of the piles would not be seen in the calculation. This approach is considered appropriate because the impact of the piles on the hydraulics of the channel will be very small and highly unlikely to affect the Principal Application Site location, which is 2.5km away.

Salinity and Temperature

5.2.12 As the River Yare is tidally dominated, the water in the estuary is mostly saline, warm coastal ocean water. Salinity (35g/kg) and temperature (20°C) has been applied to water coming in through the tidal boundary in the model. TUFLOW recommends the use of these values as they represent typical value in the coastal oceans around the UK. The use of salinity and temperature values impact the density calculations undertaken by the model, therefore these parameters are considered important in the sediment transport modelling.

Sediment Parameters

5.2.13 A number of sediment samples have been collected from sample locations close to the Principal Application Site as reported in Section 4.2. The PSD assessment has been carried out detailing the size and type of the particles found. Using the D50 (the 50th percentile particle size passing through the sieve) value, the sediment found ranges from 0.03mm to 0.55mm in size with the larger particles typically found close to the eastern quay wall. The model has been set up to simulate silt and sand sediment types that are typically found in the River Yare channel.

5.2.14 TUFLOW-FV has the capability of simulating sediment deposition using a range of methods from applying a simple settling velocity to each particle type to a full salinity induced flocculation and hindering assessment. TUFLOW recommends the use of the simplest method (the settling velocity method) first. It is only when the expected results cannot be achieved that more complicated methods should be considered. As such, this assessment calculates sediment deposition by assigning each sediment type with a settling velocity. In this assessment, the sediment settling velocity has been obtained using the Ferguson and Church method (Ref 11C.4).

5.2.15 Erosion is dealt with by calculating the critical shear stress using the bed velocity magnitude. Each sediment type has an assigned critical erosion shear stress, which is used to determine when the sediment becomes mobile.

5.2.16 Following the sediment sample survey, the PSD survey concluded that there are two main sediment types in the channel; sand and silt. The model has been set up to simulate these sediment types using the parameters specified in Table 5-2.

Table 5-2: Sediment Type Model Parameters

Parameter	Sand	Silt
Settling Velocity (m/s)	$2x10^{-2}$	$1x10^{-5}$
Critical Shear for deposition (N/m^2)	Nan – special treatment for sand in Tuflow FV.	0.1
Material Density (kg/m^3)	2650	2650
Critical Shear for erosion	Top Layer: 0.12 Bottom Layers: 0.2	Top Layer: 0.12 Bottom Layers: 0.2

5.2.17 TUFLOW-FV uses a layered approach to simulate a river bed. For example, if a silt layer is found on top of a sand layer then it follows that the silt will be eroded first before the sand layer can be mobilised. All deposited material will always be on the top layer. For this model, it was appropriate to represent the bed initially using a two-layer approach; the first layer is silt dominant and the second layer sand dominant. Plate 5-5 shows a graphical representation of the bed as simulated in the model.

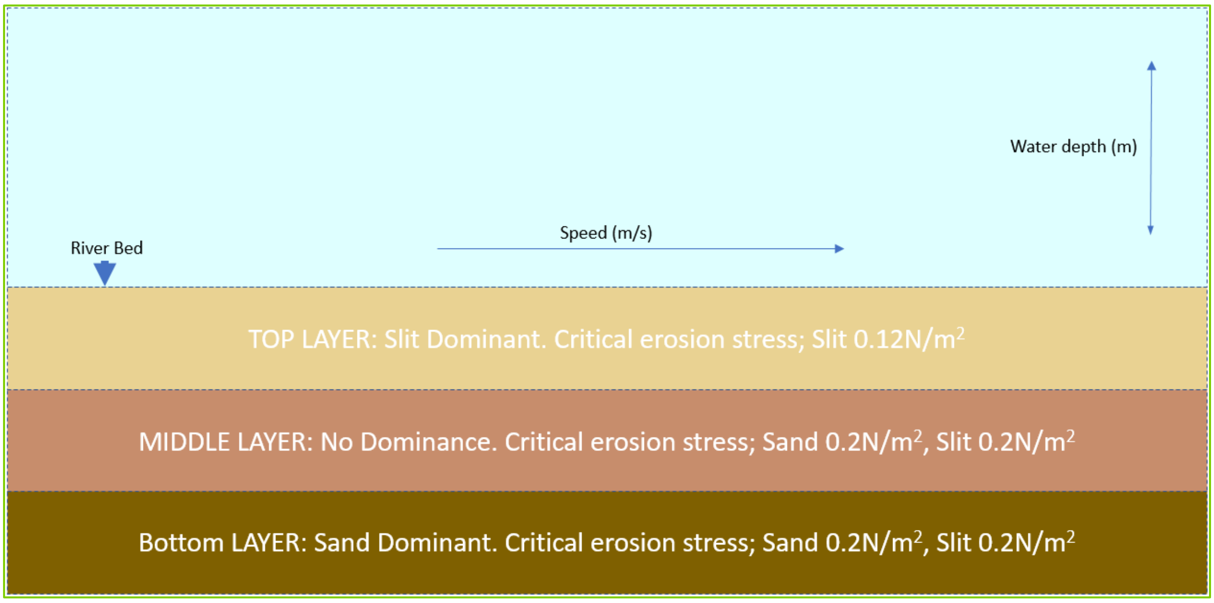

Plate 5-5: Sediment Model Layers Schematisation

5.2.18 In order to set up the model, the sediment has to be initially distributed around the model manually. The model is set up to have 1325kg/m^2 of silt in the top layer, 1325 kg/m^2 of sand and silt in the middle layer and 5300kg/m^2 Sand in the bottom layer. The purpose of this approach is to introduce sediment into the model with can be transported around the domain using the hydrodynamic calculations.

Baseline Model

5.2.19 Once the initial baseline model had been developed as described above, a series of calibration tests have been carried out to ensure the model is an accurate representation of the River Yare through Great Yarmouth. The calibration process has been carried out by comparing the model predicted velocities to the velocity survey outputs from 2018. The calibration process is discussed in Section 5.3.

Scheme Model

5.2.20 The Scheme has been represented by modelling the bridge knuckles as blocked out areas of the river channel as shown in Plate 5-3. As the water levels in this assessment will not exceed the defences, there is no requirement to represent any of the Scheme that is outside of the water channel including the embankments for the approach roads or any of the Satellite Application Sites.

Construction Phase Model

5.2.21 The construction method for the Scheme is expected to take up the same footprint as the finished Scheme knuckles. This means the results of the model created to assess the final Scheme arrangement is the worst possible case. As such, no additional modelling is required and the Scheme model results have been used to also assess the impact on the sediment regime during construction.

3D Representation

5.2.22 The model will be simulated using the hybrid 3D discretisation. The initial layer density has been set as 1m resolution to balance computational time and the accuracy of the calculations. The model has been simulated using the 1m vertical resolution at the bed. This resolution is considered appropriate for the assessment of the sediment in Breydon Water and the River Yare. The sediment transport model uses the velocity at the river bed to calculate the shear stress, which drives the sediment transport and therefore uses high resolution results

5.3 Model Calibration

5.3.1 The model described in Section 5.2 has been calibrated to a number of parameters. As part of the Scheme, a velocity survey has been carried out at nine locations in the River Yare through Great Yarmouth as shown in Plate 5-6.

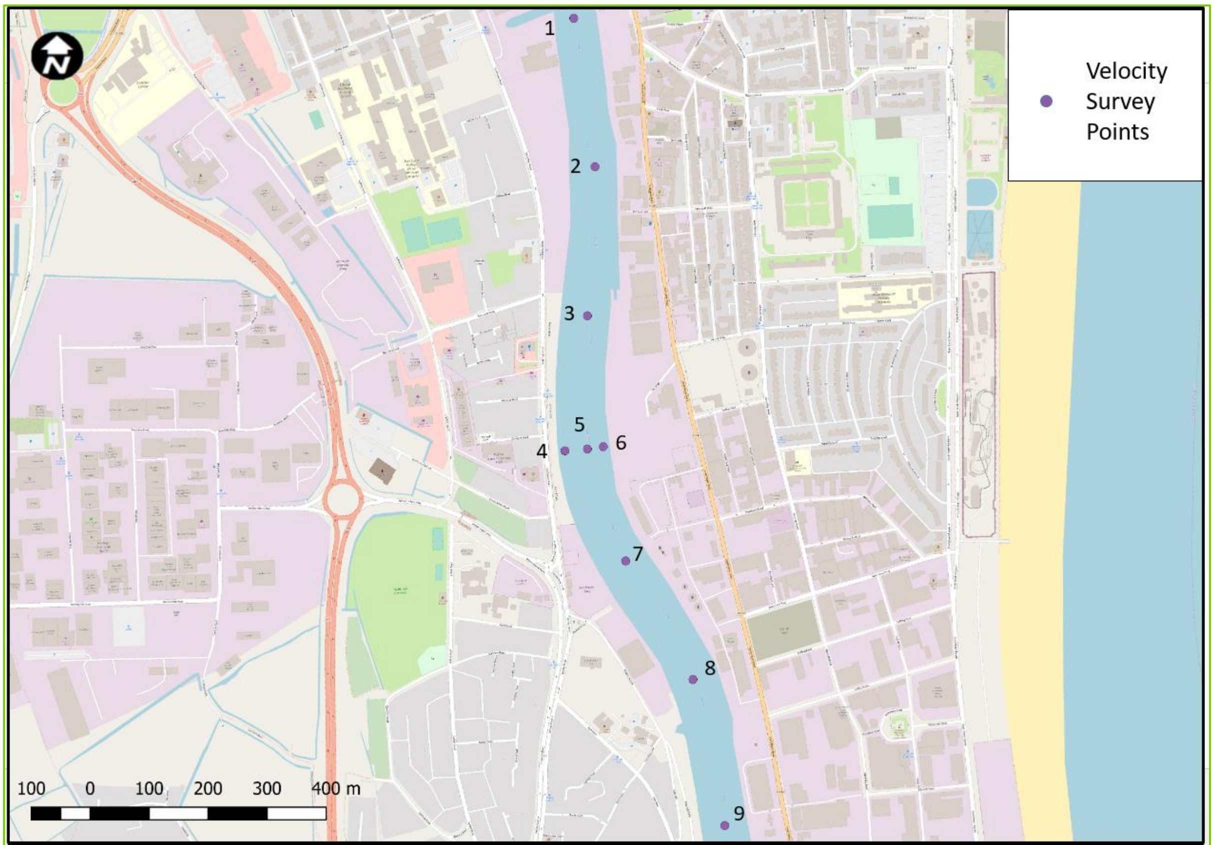

Plate 5.6– Velocity Survey Locations

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Plate 5-6: Velocity Survey Locations

5.3.2 At each location shown in Plate 5-6, an Acoustic Doppler Current Profiler (ADCP) has been used to obtain the velocity. The data has been recorded for a period of 5 minutes every hour for a day at each location and the velocity magnitude through the water column has been recorded. The model has been set up to simulate the same period of time (13^{th}-15^{th} April 2018) by obtaining the tidal levels from the Gorleston-on-Sea gauge for this period. To calibrate the model, predicted 2D velocity magnitude data has been exported from the model at each of the locations shown in Plate 5-6 and compared to the survey data. The model is calibrated to the 2D depth averaged velocity, this helps to negate the effect of specific differences in flows due to potential small sources of water such as drainage pipes or moving boats on the surface which the model cannot predict. This method is considered suitable for this model.

5.3.3 The calibration model run presented uses the tidal cycle for a weekend in April 2018 and simulates a four-day period (13th-16th). Plate 5-7 shows the water level plotted against hours used as the model boundary in the calibration event.

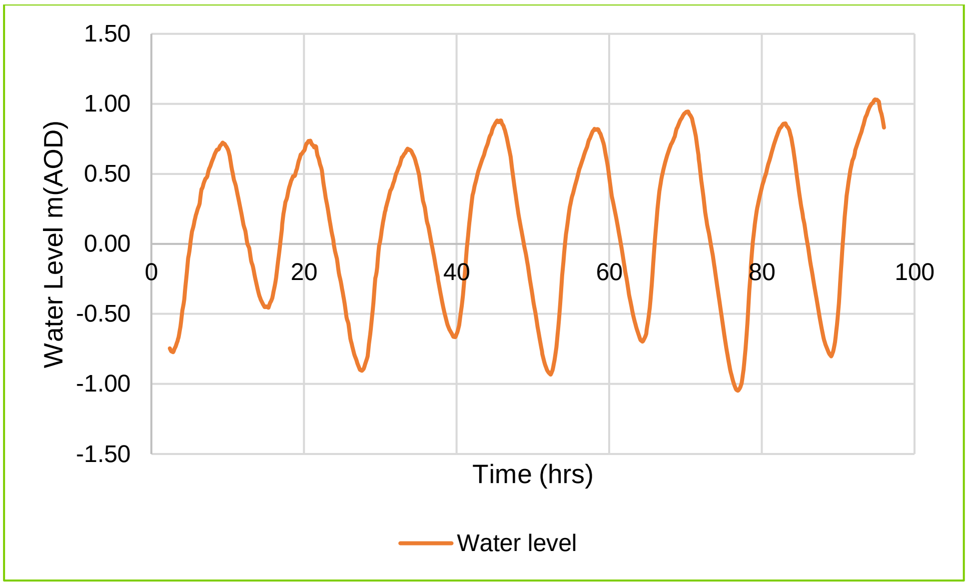

Plate 5-7: Gorleston-on-Sea Gauge Recorded Water Level - 13th-16th April 2018

5.3.4 The model has been simulated for the four day tidal period in April 2018 and Plate 5-8, Plate 5-9 and Plate 5-10 show a comparison of 2D depth averaged velocity magnitude between the model and the recorded data at velocity survey locations 4, 5 and 6 respectively. Plate 5-8 shows that the model predicts the peak velocity well at survey point 4. There are some differences between the model results and the survey data, which are likely due to local impacts such as vessel movements that can impact the survey results. It is not possible to replicate these impacts in the model. Plate 5-9 shows the model predicts velocity magnitudes well, although there are some discrepancies. Plate 5-10 shows that the model matches the survey data very well in this location. In the central section of the graph, the survey and speed match very closely.

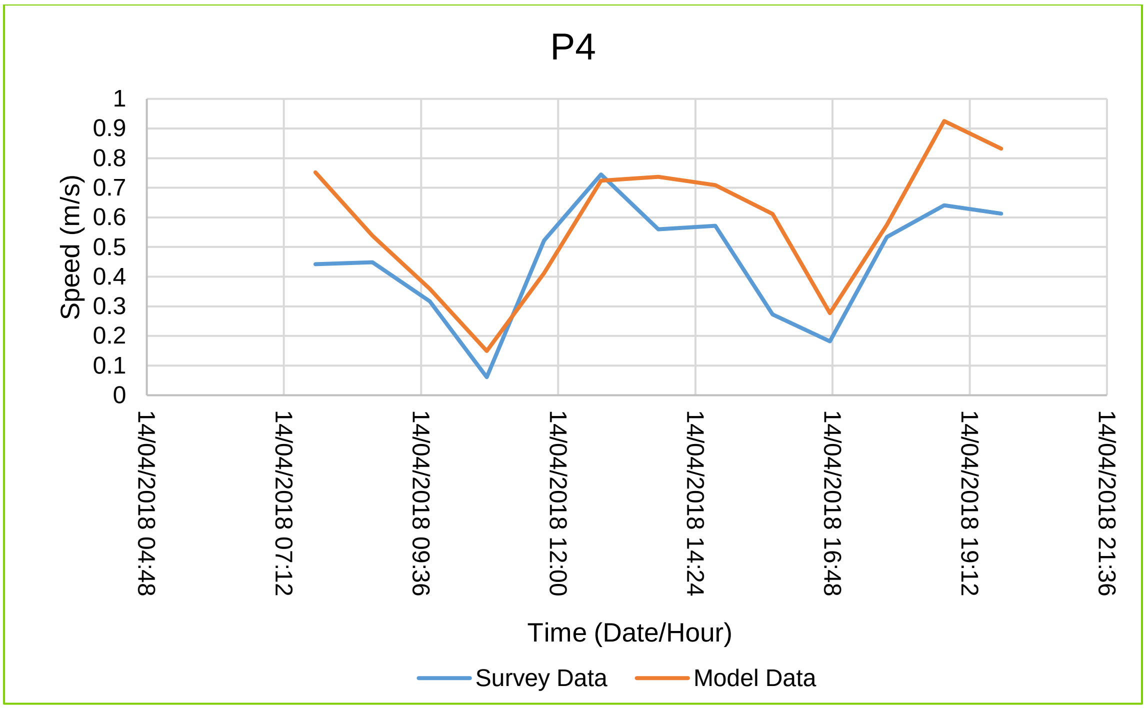

Plate 5-8: Comparison of Modelled and Recorded Water Speed at Survey Point 4

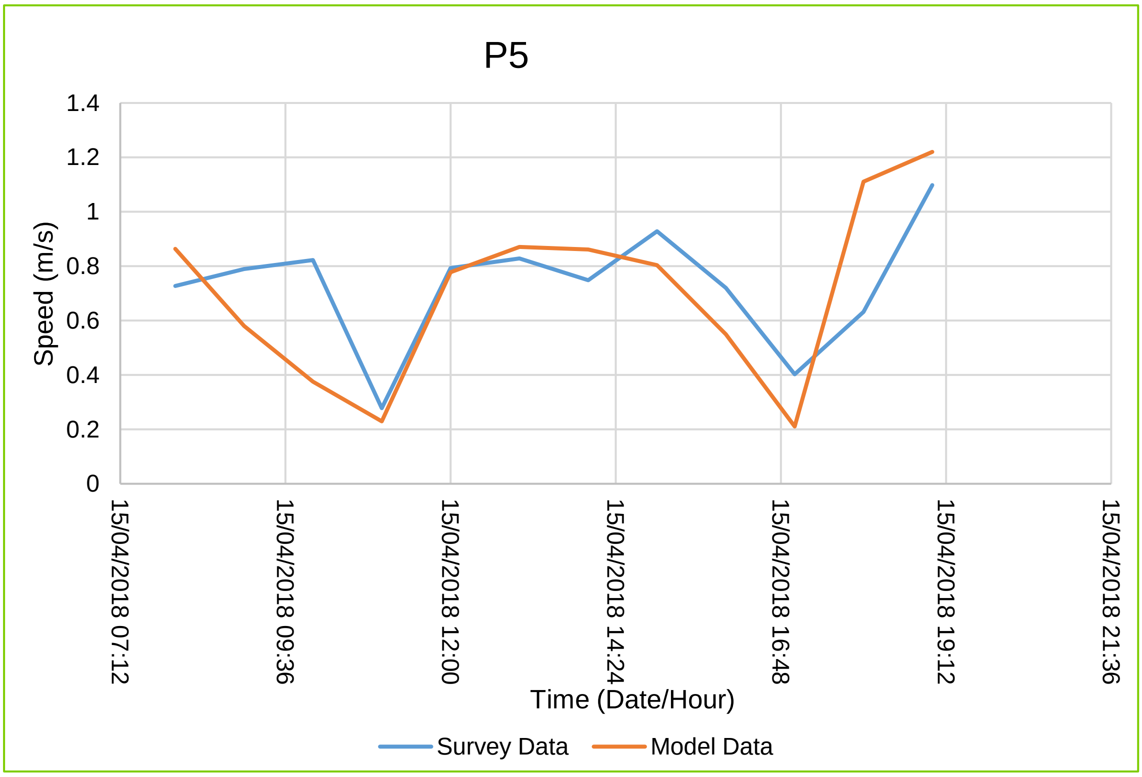

Plate 5-9: Comparison of Modelled and Recorded Water Speed at Survey Point 5

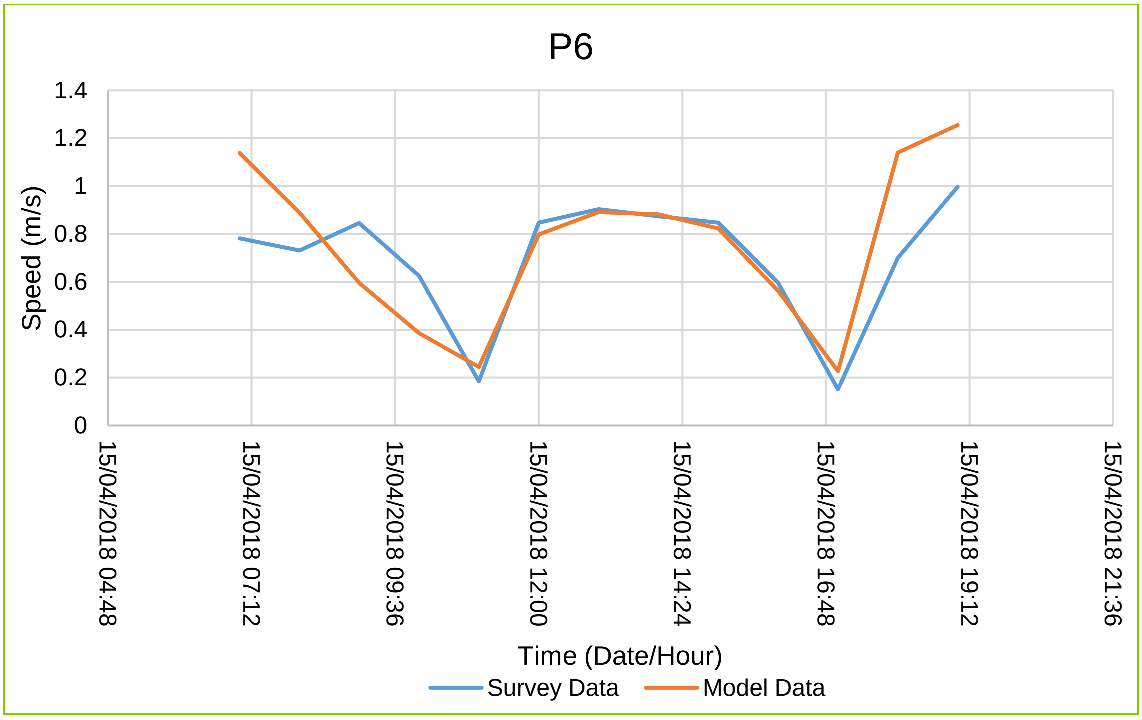

Plate 5-10: Comparison of Modelled and Recorded Water Speed at Survey Point 6

5.3.5 In addition to the plates shown, the model represents the depth average velocities well. The calibration process has shown that the model is capable of predicting the velocity magnitude in the River Yare near the Scheme well by matching the velocity magnitude of the recorded data well. Following the calibration process, the model is considered suitable for use in the sediment assessment.

6 Impacts of the Scheme

6.1 Model Runs

6.1.1 The model has been used to assess the sediment transport by simulating the four different tidal events described in Section 3 for the Baseline and the Scheme scenarios. For each tidal event, the impact of the Scheme has been determined by comparing the model results between the Baseline and Scheme scenarios. The events that have been simulated in the model are listed in Table 6-1.

Table 6-1: Model Simulations

Baseline	Scheme
Everyday Events	
Spring	Spring
Neap	Neap
Extreme Events	
MHWS to MLWS + 5% AEP sea surge	MHWS to MLWS + 5% AEP sea surge
MHWN to MLWN + 5% AEP sea surge	MHWN to MLWN + 5% AEP sea surge

6.1.2 The model has been simulated for a 75 hour tidal period for each event, the first 25 hours of each run is used to stabilise the model. In order to simulate the required resolution at the Principal Application Site in 3D, each model run takes approximately 30 hours to run 75 hours simulation time.

6.1.3 The model has been simulated using the setup described in Section 5. The results have been processed to produce plots and plates to show the difference in sediment transport due to the Scheme. The main driver for sediment transport is velocity magnitude which is used to calculate the bed stress. Bed stress is the parameter used to predict the sediment deposition and erosion therefore assessing the bed stress provides a good estimate of sediment transport.

6.1.4 In addition to the bed stress, the instantaneous average erosion/deposition rate has been calculated. This rate has been calculated to give a measure of sediment erosion and deposition and to show the areas that will be affected. The model does not include morphological updates because the changes in bathymetry are small and will not significantly change the hydrodynamics and is likely to increase the total time and instability of the model.

6.1.5 Whilst absolute values are used where appropriate, averages are used to provide a measure of erosion/deposition accounting for the influence of the ebb and flood tide and to understand the longer term impacts of the Scheme.

6.2 Results – Everyday Tide

6.2.1 The results presented in this section show the impact of the Scheme on the tidal environment and sediment transport processes using a simulation of 75 hours for the Spring and Neap tidal boundary. By using a Spring and a Neap tide, the upper and lower limits of impact can be assessed for a typical year without explicit simulation of a full tidal cycle as this would mean excessive run times. For the purposes of this assessment, the Baseline and Scheme model have been simulated using the same boundary and the results of each compared. Time series outputs of velocity magnitude, water level and bed stress from the model at four locations in the domain; Harbour Entrance, Scheme, Haven Bridge and Breydon Water are shown on Plate 6-1.

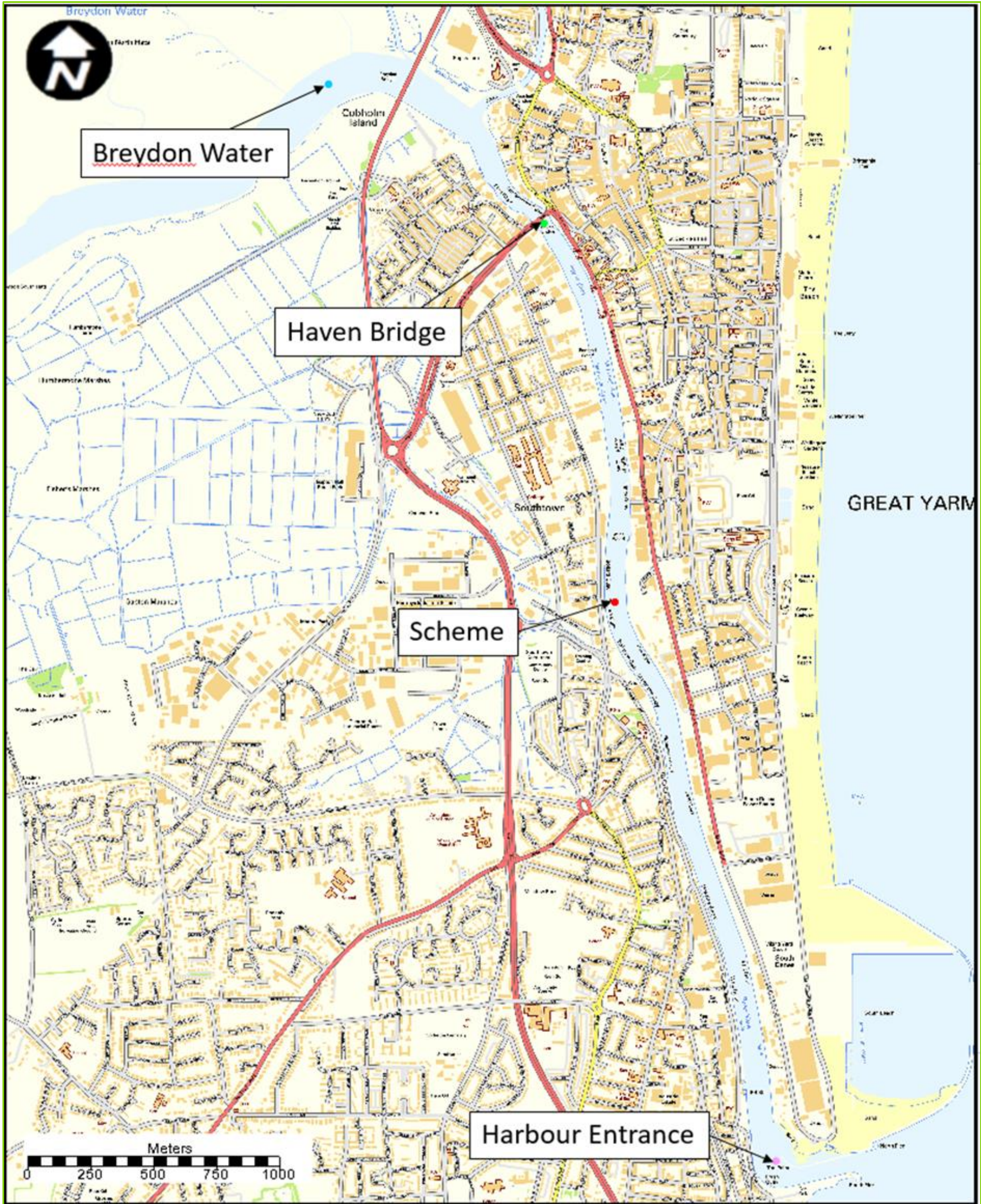

Plate 6.1 –Time Series Locations

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Plate 6-1: Time Series Locations

Velocity Magnitude and Elevation

6.2.2 The velocity magnitude and water level are fundamental to sediment movement. In narrowing the channel caused by the Scheme, the velocity magnitude will increase in order to retain the same capacity. In this section, the velocity magnitude and elevation impacts of the Scheme are discussed for the Spring and Neap tidal events.

Spring Tide Event

6.2.3 Plate 6-2 shows the depth-averaged velocity magnitude between the bridge knuckles for the Spring tidal simulation in the Baseline and Scheme scenarios. The plot shows the Baseline velocity magnitude at the Principal Application Site location peaks at approximately 1m/s as shown by the orange line on the plot. The plot shows that due to the presence of the Scheme (blue line), the water velocity magnitude increases by around 100% to up to 2m/s for the duration of the simulation. This is because the bridge knuckles constrict the change and in order for a similar volume of water to transit the channel, the velocity increases.

6.2.4 Plate 6-3,

6.2.5 Plate *6-4* and Plate 6-5 show the velocity magnitude at Haven Bridge, the harbour entrance and Breydon Water respectively. The plots show there is a negligible change in velocity magnitude due to the Scheme remote from the Principal Application Site.

6.2.6 Plate 6-6 shows the difference (Scheme – Baseline) in velocity magnitude for the four locations in the channel. What is clear from the plot is that the main difference in velocity magnitude is at the Principal Application Site. The plot shows that the constriction that the new bridge causes increases the Baseline velocity magnitude by up to 1m/s in between the bridge knuckles. There are a few times in the tidal event near the harbour entrance where the velocity is affected slightly however, the differences in velocity magnitude are typically less than 0.1m/s.

6.2.7 Plate 6-7 shows a 2D plot of the velocity magnitude for the Baseline and Scheme Spring simulation at 37hr which corresponds with the largest difference in Plate 6-6. The plate highlights the differences in velocity magnitude caused by the Scheme. There is a small change (approximately 1m/s increase) in velocity magnitude at Haven Bridge due to the presence of the Scheme. There is a negligible impact on velocity magnitude elsewhere in the domain.

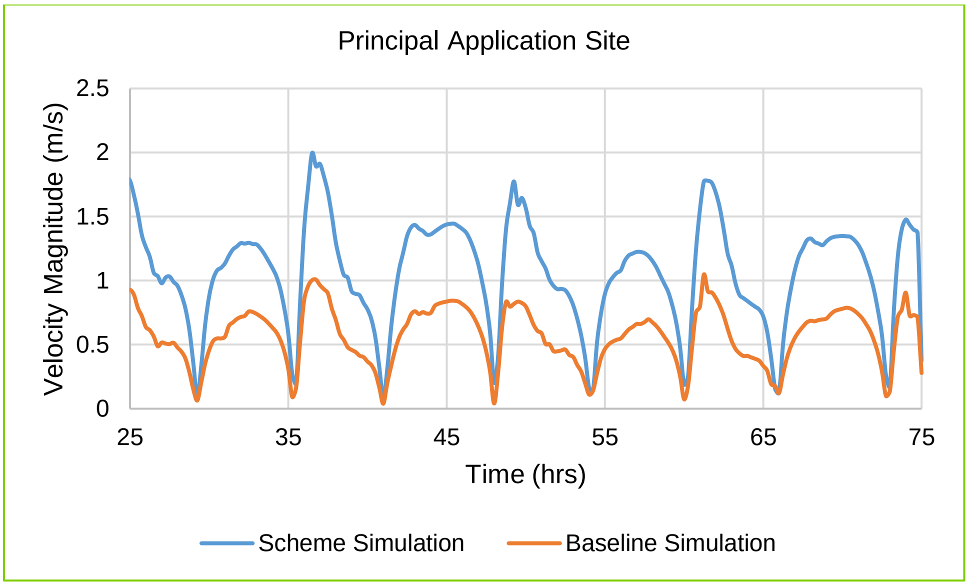

Plate 6-2: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at the Principal Application Site (between the bridge knuckles) for the Spring Tide

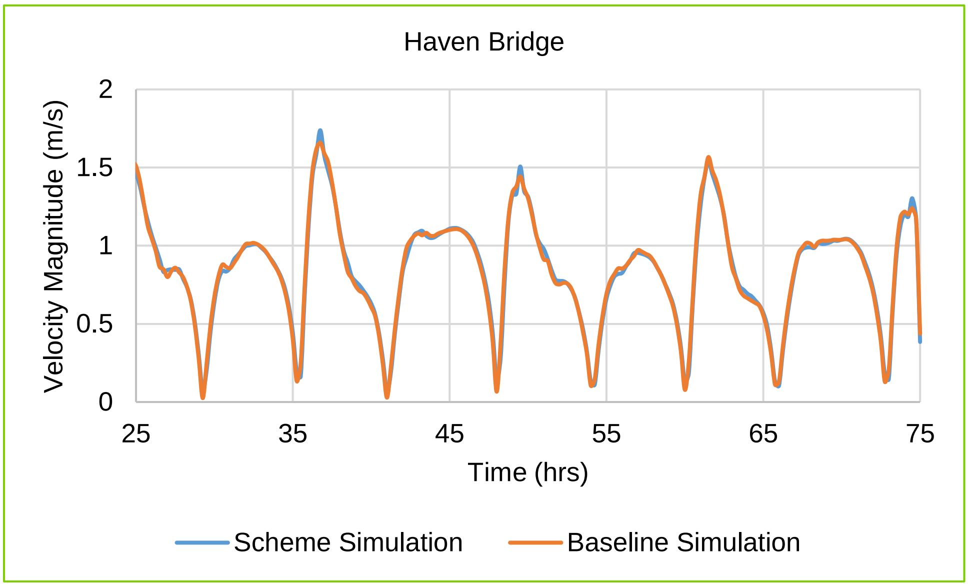

Plate 6-3: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at Haven Bridge for the Spring Tide

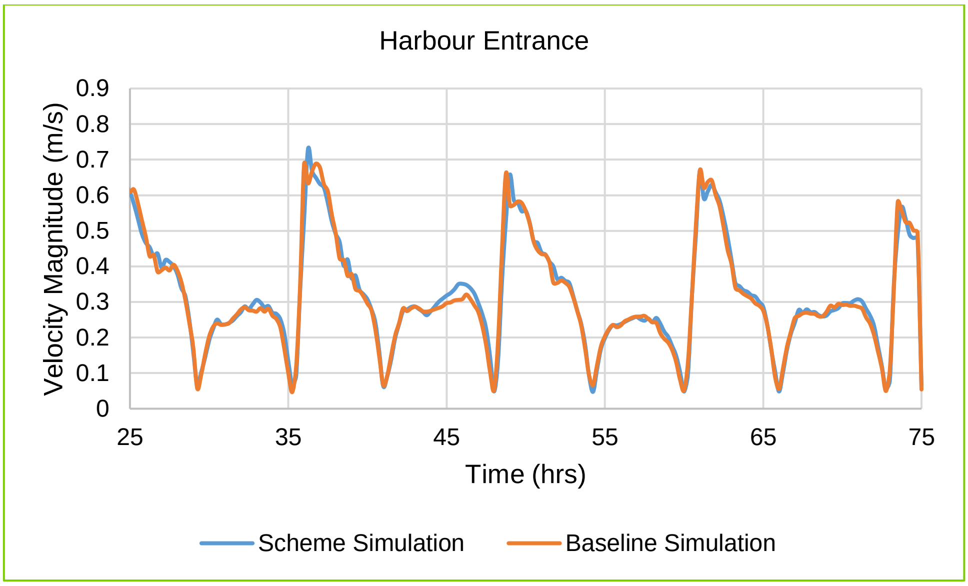

Plate 6-4: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at the Harbour Entrance for the Spring Tide

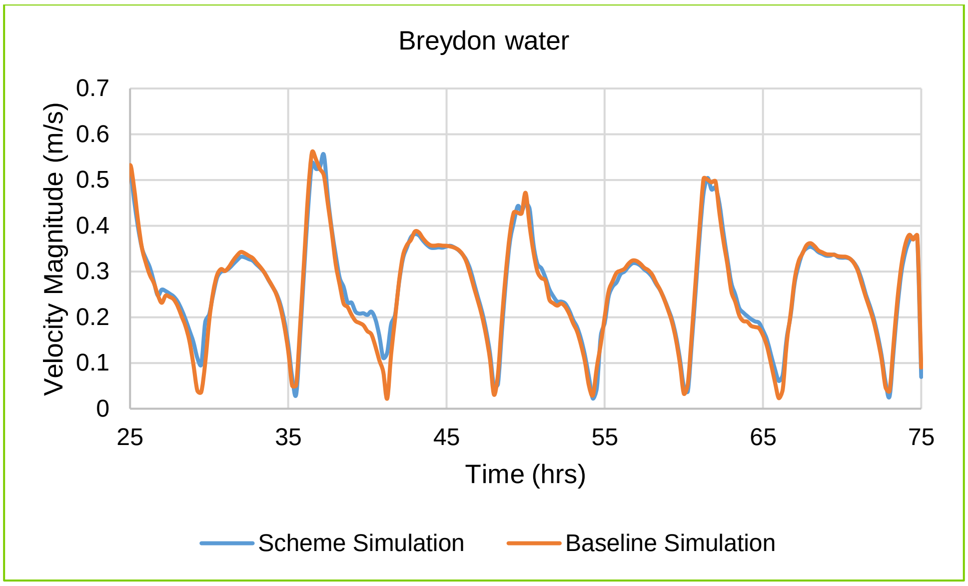

Plate 6-5: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at Breydon Water for the Spring Tide

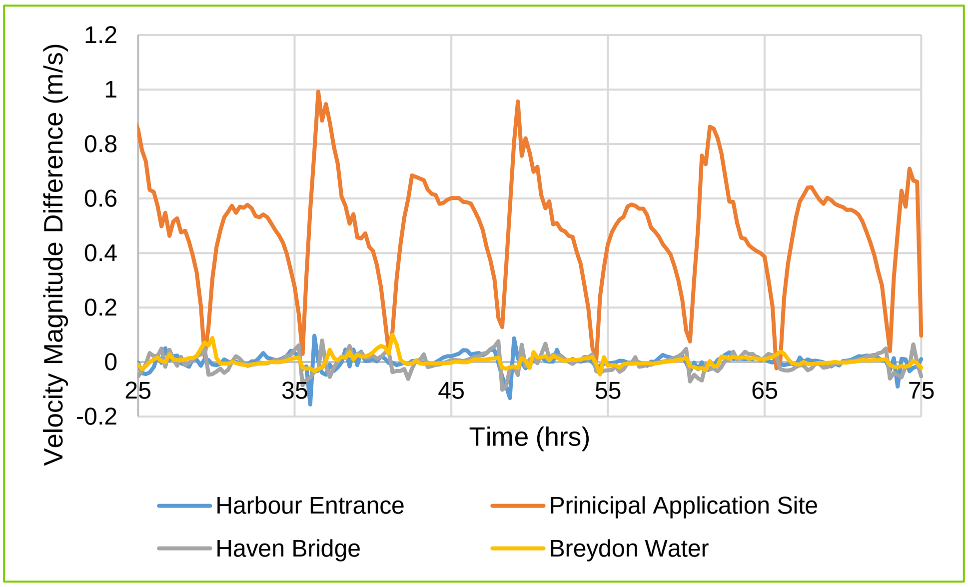

Plate 6-6: Velocity Magnitude Difference between the Baseline and Scheme Scenarios (Scheme-Baseline) for the Spring Tide

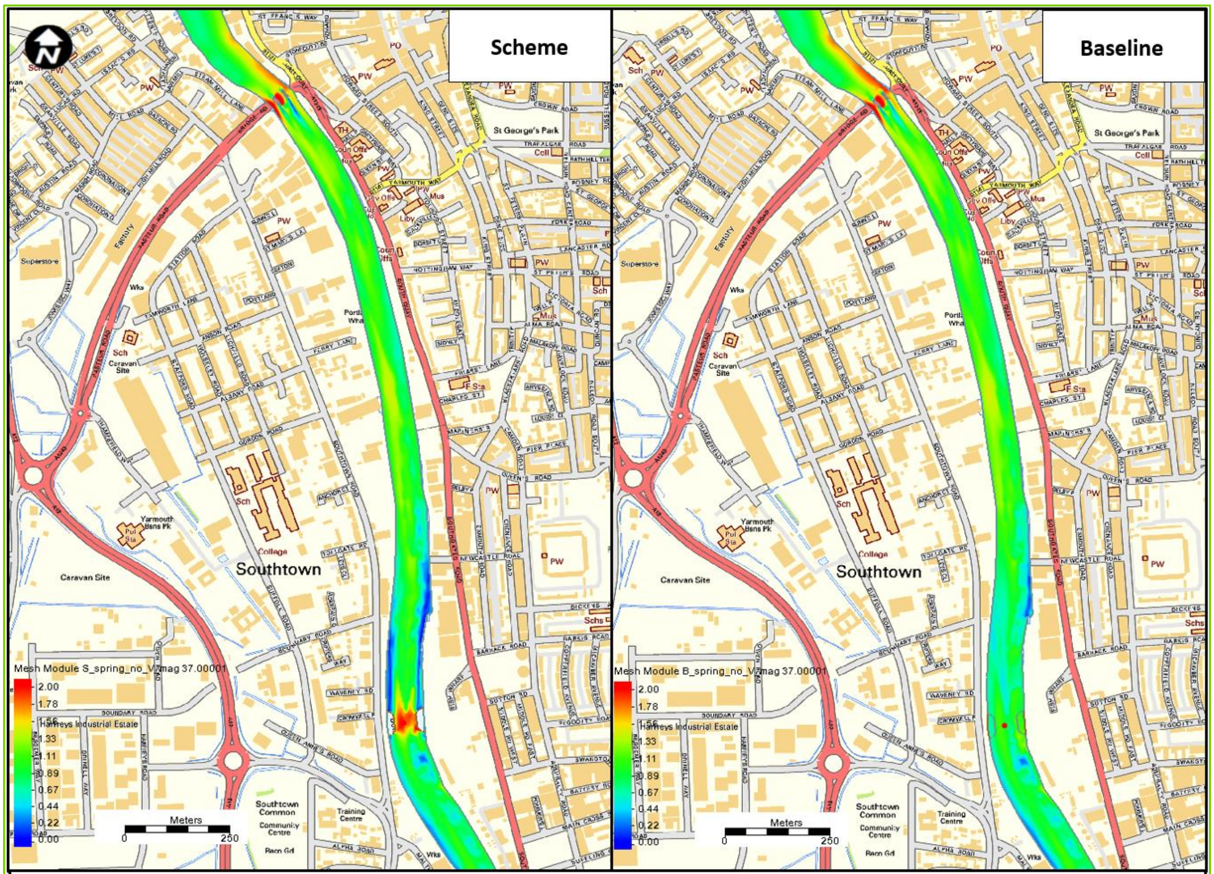

Plate 6.7– Spring Velocity Magnitude, Scheme and Baseline at 37hr

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Plate 6-7: Spring Velocity Magnitude

6.2.8 Plate 6-8, Plate 6-9, Plate 6-10 and Plate 6-11 show the water level at the Principal Application Site, Breydon Water, Harbour Entrance and Haven Bridge respectively. The plates show the Scheme has a negligible impact on the water level in the Spring tide event. Plate 6-12 shows the water level difference between the Scheme and Baseline at the four locations in the domain. There is a small difference in water levels at the Principal Application Site. This is a result of the increase in water velocity magnitude caused by the Scheme, which in turn slightly reduces the local water level. This can be seen on the flood tide where the blue line representing the Scheme is visible on Plate 6-8. The water level difference is less than 0.15m, considering the bed elevation at the Scheme is approximately -7mAOD giving a water depth of between 6m and 8.5m in the tidal cycle, this difference is negligible.

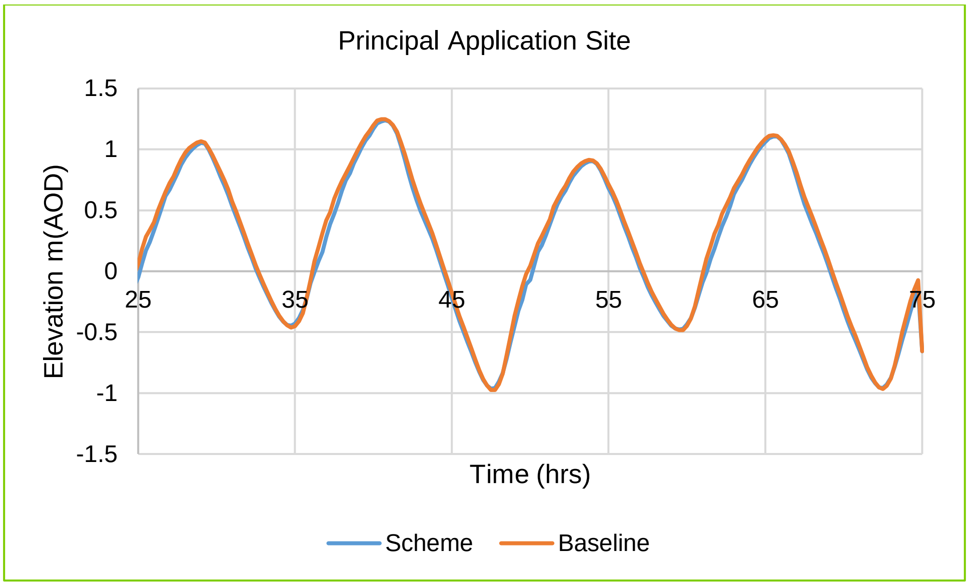

Plate 6-8: Comparison of Water Level between the Baseline and Scheme Scenarios at the Principal Application site (between the bridge knuckles) for the Spring Tide

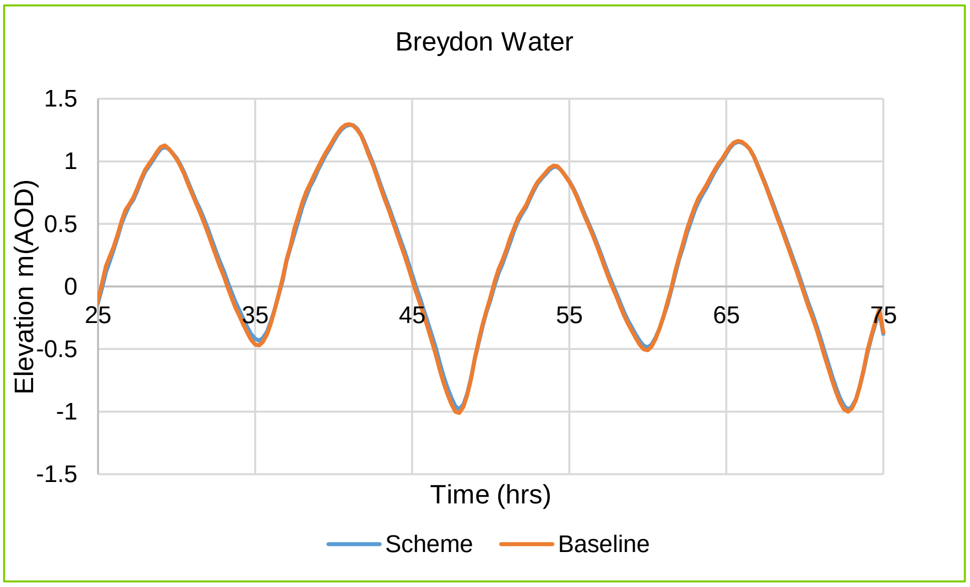

Plate 6-9: Comparison of Water Level between the Baseline and Scheme Scenarios at Breydon Water for the Spring Tide

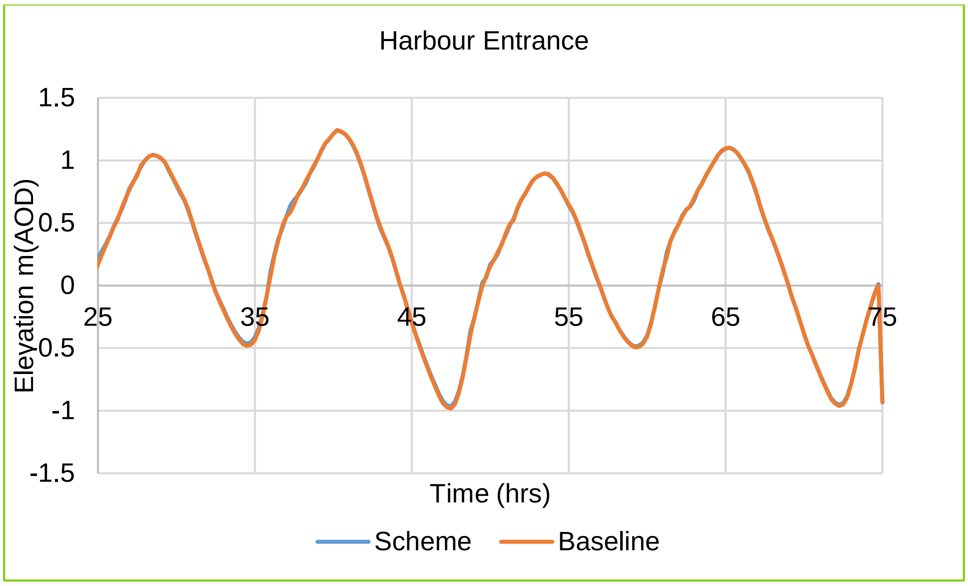

Plate 6-10: Comparison of Water Level between the Baseline and Scheme Scenarios at the Harbour Entrance for the Spring Tide

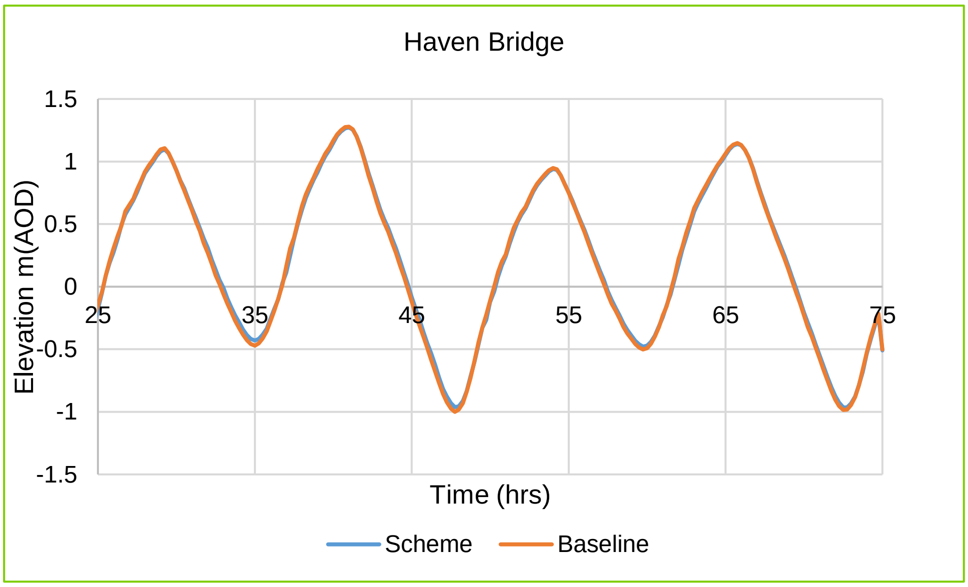

Plate 6-11: Comparison of Water Level between the Baseline and Scheme Scenarios at Haven Bridge for the Spring Tide

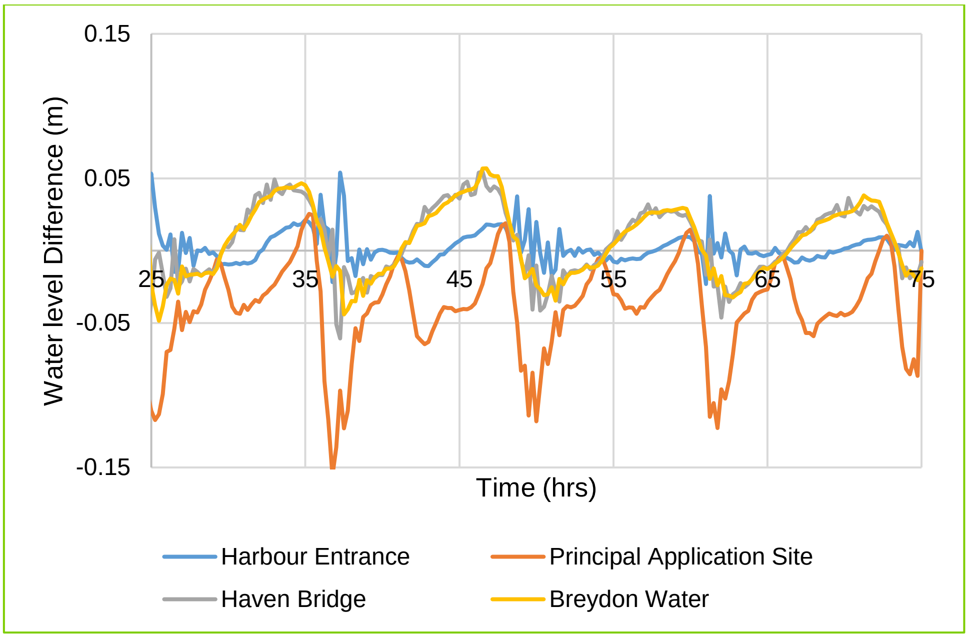

Plate 6-12: Water Level Difference between Baseline and Scheme Scenarios (Scheme – Baseline) for Spring Tide

6.2.9 The results show during the Spring tidal event, the Scheme has a negligible impact on the water level in the model domain. The main effect of the Scheme is to increase the local velocity magnitude by up to 1m/s at the Principal Application Site because of the constriction caused in the channel by the bridge knuckles. The differences in velocity magnitude in Breydon Water and at the Harbour Entrance are negligible.

Neap Tidal Event

6.2.10 Plate 6-13 shows the velocity magnitude between the bridge knuckles at the Principal Application Site for the Neap tidal profile. The Baseline velocity magnitude at the Principal Application Site location in the neap tide reaches a peak of approximately 0.7m/s during the simulation. The plot shows that due to the presence of the Scheme, the water velocity magnitude approximately doubles for the duration of the simulation. This is because the bridge knuckles cause a constriction the channel and in order for a similar volume of water to transit the channel, the velocity must increase. Plate 6-14, Plate 6-15 and Plate 6-16 show the velocity magnitude change is small elsewhere in the domain during the neap tide. Plate 6-15 shows a large difference in velocity magnitude at the harbour entrance during the model warm up time. This is considered a localised model error and likely due to the inflow boundary and initial conditions and therefore is not attributed to the Scheme. The difference is not seen in any of the other model runs and is not consistent with later tidal cycles in the simulation.

6.2.11 Plate 6-17 shows the difference (Scheme – Baseline) in velocity magnitude for the four locations in the channel. The plot shows the largest difference in velocity magnitude is at the Principal Application Site. With the exception of a peak near the harbour mouth at around 40 hours into the simulation, the differences in velocity magnitude elsewhere in the domain are less than 0.1m/s and considered negligible.

6.2.12 Plate 6-18 shows a 2D plot of the velocity magnitude for the Baseline and Scheme Neap simulation at 50 hours, which corresponds with the largest difference on Plate 6-17. The plate shows the localised increase in velocity magnitude due to the Scheme. The range of the impact on velocity is approximately 500m upstream and 500m downstream of the Principal Applications Site during the Neap tide simulation.

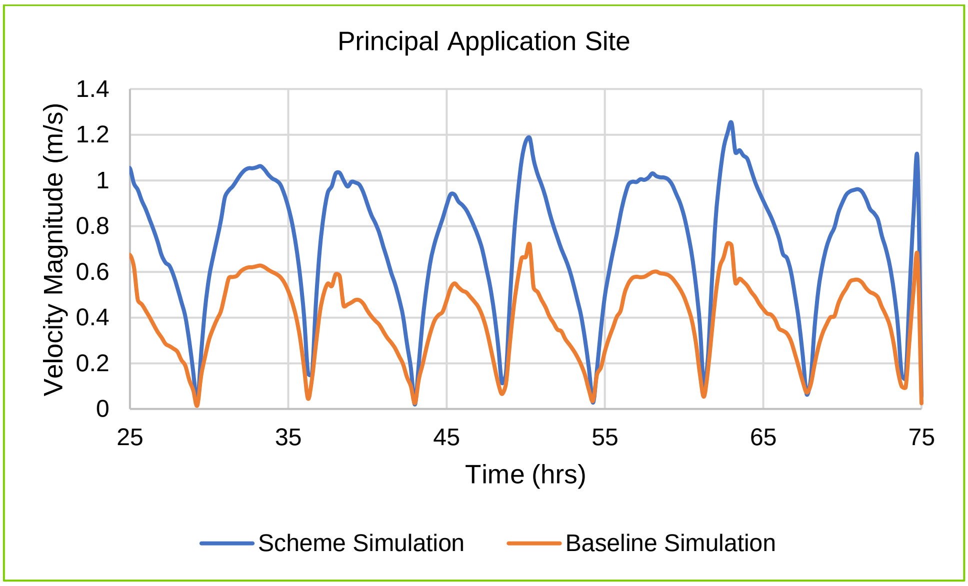

Plate 6-13: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at the Principal Application Site for the Neap Tide

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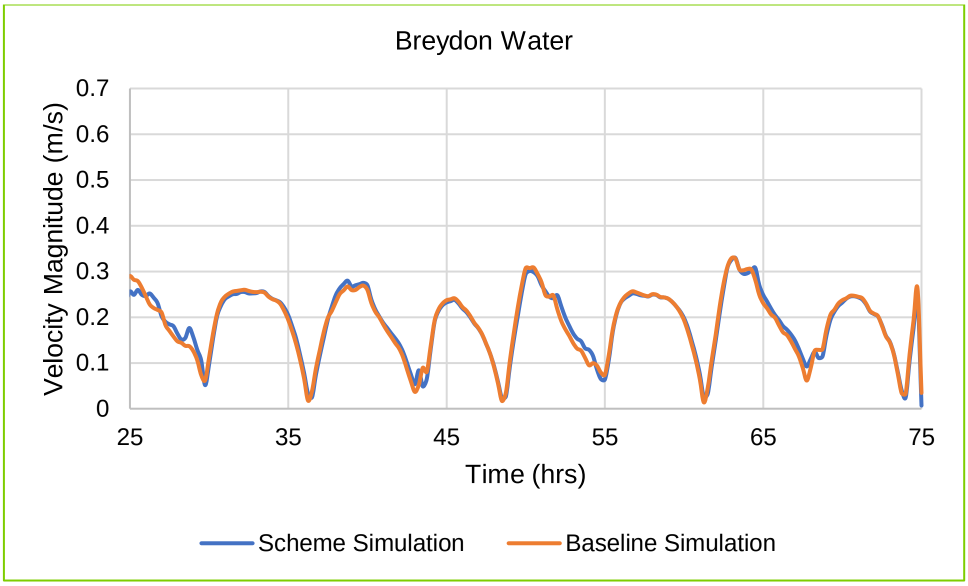

Plate 6-14: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at Breydon Water for the Neap Tide

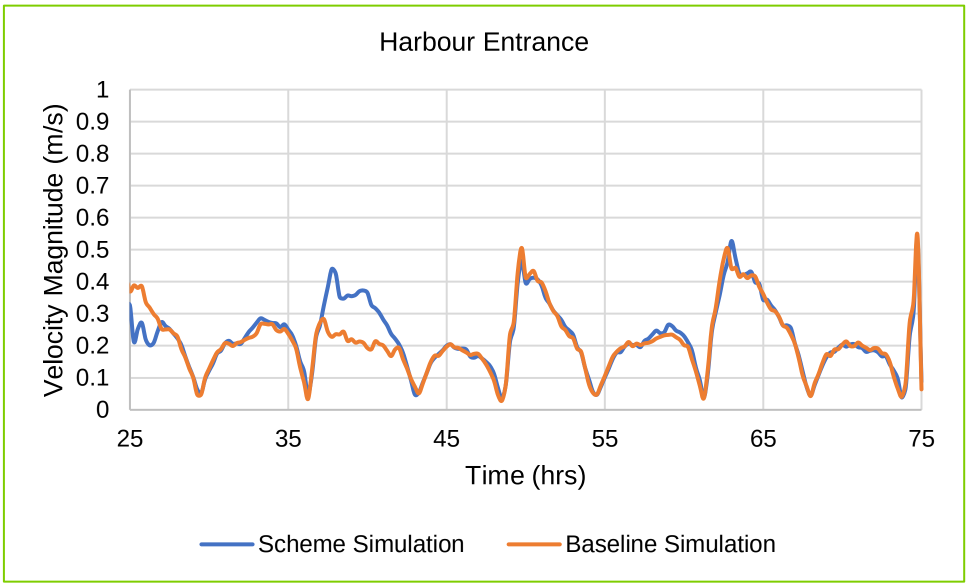

Plate 6-15: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at the Harbour Entrance for the Neap Tide

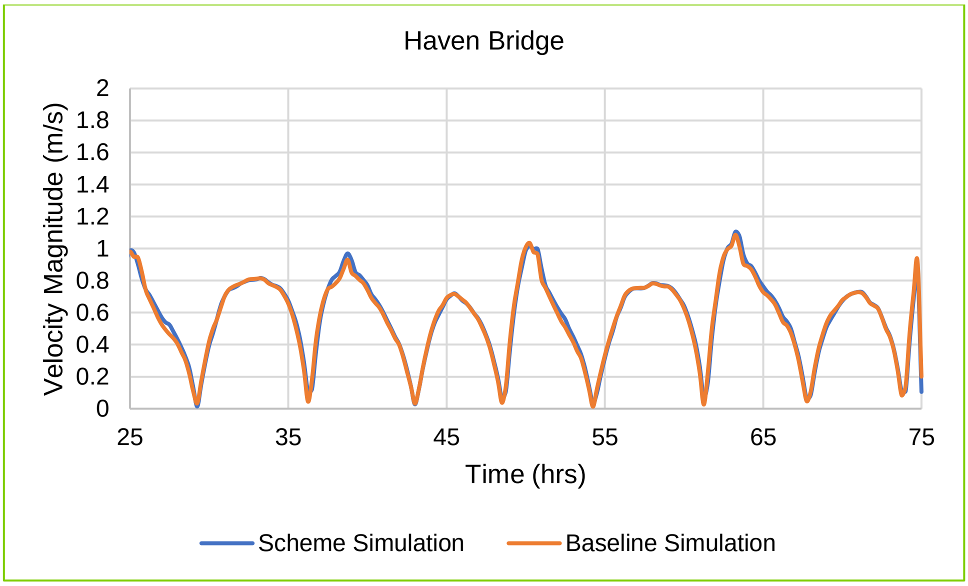

Plate 6-16: Comparison of Velocity Magnitude between the Baseline and Scheme Scenarios at Haven Bridge for the Neap Tide

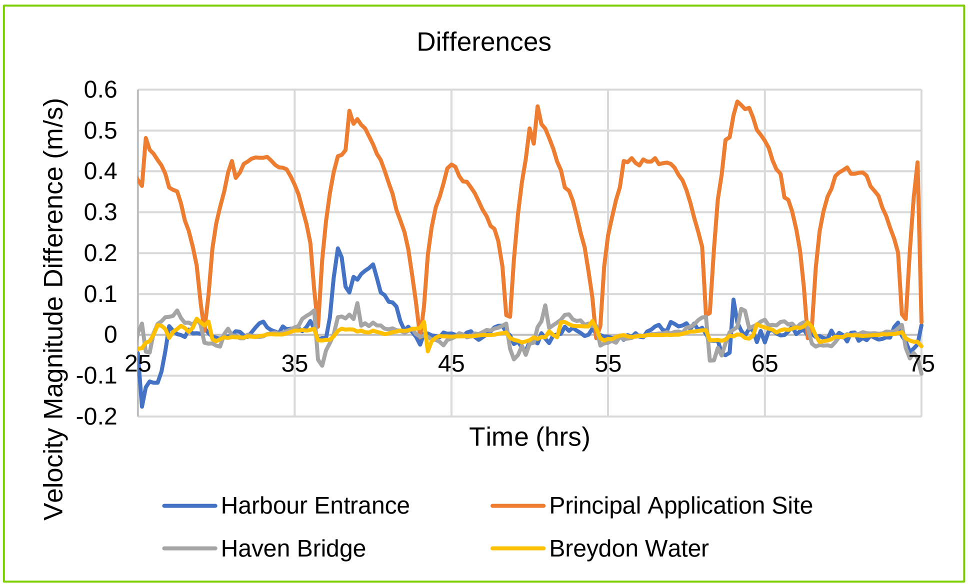

Plate 6-17: Difference in Velocity Magnitude between the Baseline and Scheme Scenarios for the Neap Tide

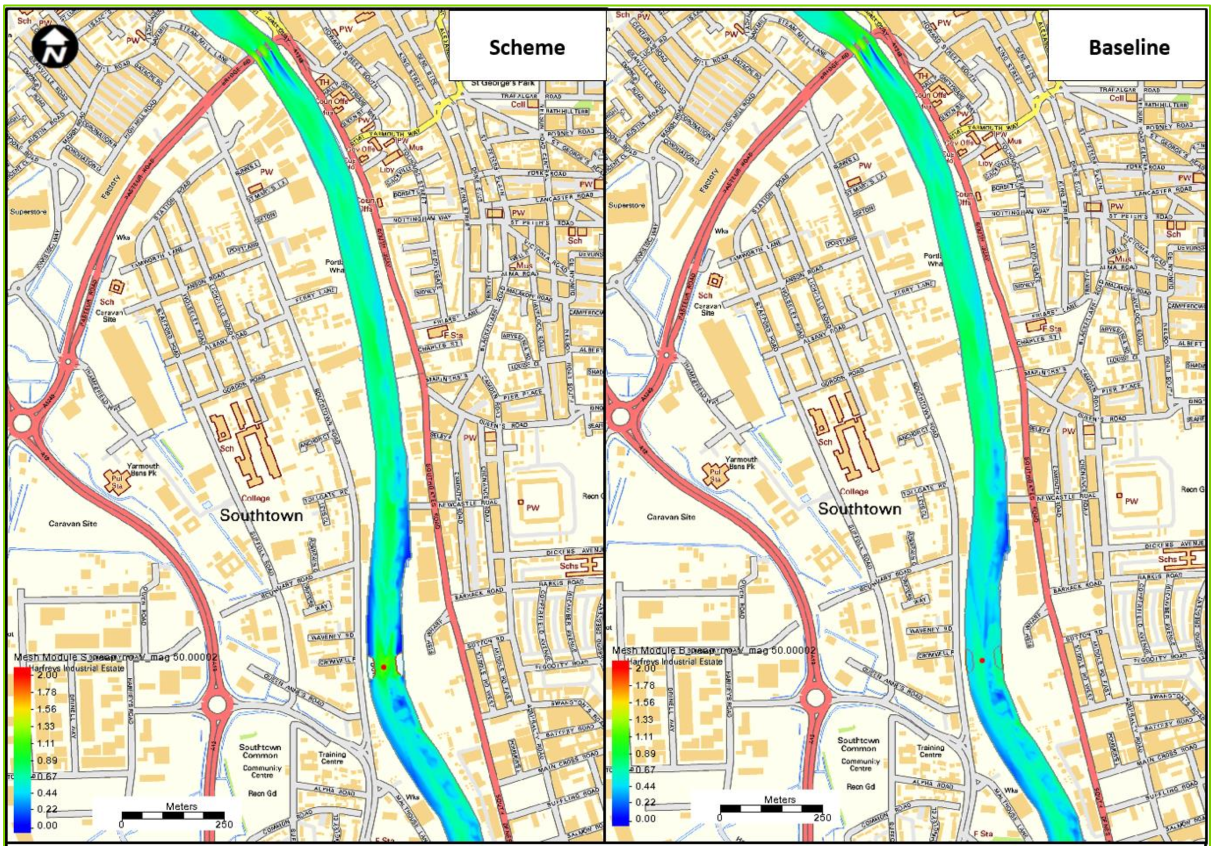

Plate 6.18– Neap Velocity Magnitude, Scheme and Baseline at 50hr

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Plate 6-18: Neap Velocity Magnitude

6.2.13 Plate 6-19, Plate 6-20, Plate 6-21 and Plate 6-22 show the water level at the Principal Application Site, Breydon Water, Harbour Entrance and Haven Bridge respectively. The plates show the Scheme has a negligible impact on the water level at the Scheme in the Neap event. There is a negligible impact on water level elsewhere in the domain. Plate 6-23 shows the water level difference between the Scheme and Baseline at the four points in the domain. The water level difference is less than 0.1m at the Principal Application Site, considering the bed elevation at the Principal Application Site is approximately -7mAOD giving a water depth of between 6m and 8m in the Neap cycle, this difference is considered negligible.

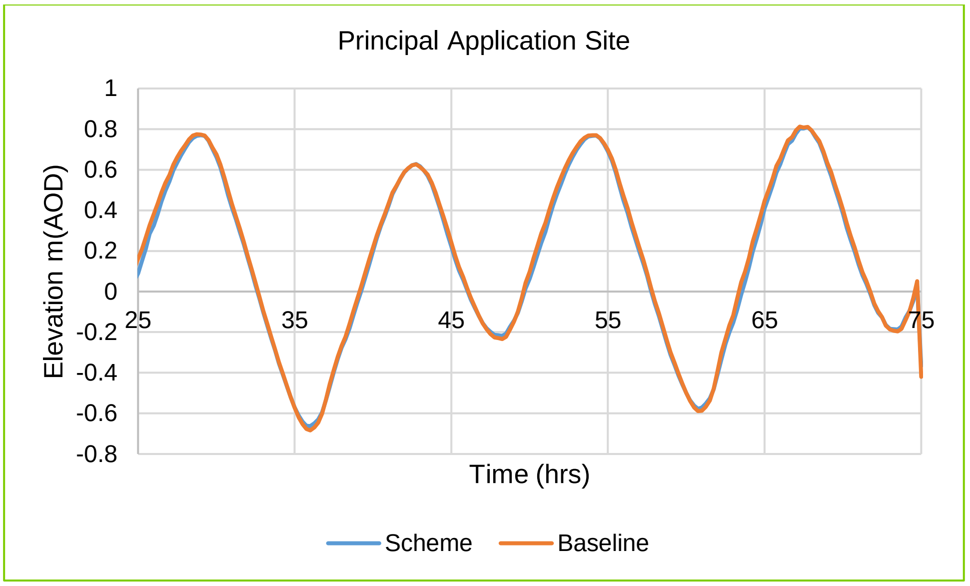

Plate 6-19: Comparison of Water Level between the Baseline and Scheme Scenarios at the Principal Application Site for the Neap Tide

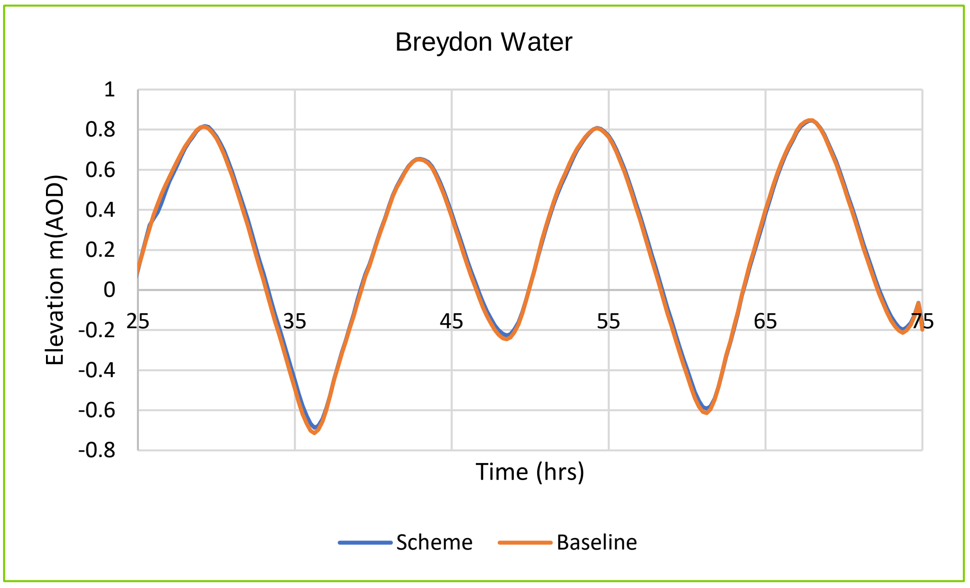

Plate 6-20: Comparison of Water Level between the Baseline and Scheme Scenarios at Breydon Water for the Neap Tide

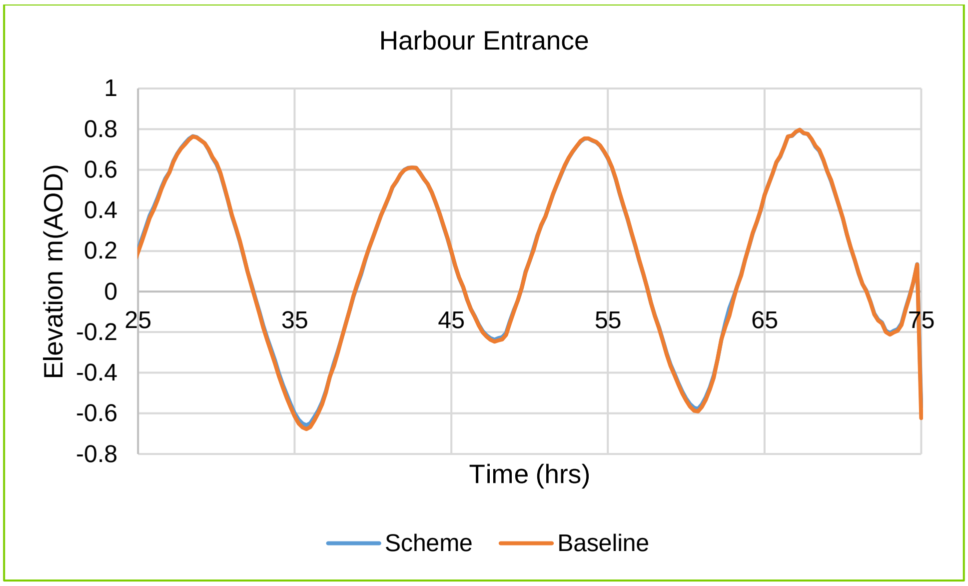

Plate 6-21: Comparison of Water Level between the Baseline and Scheme Scenarios at the Harbour Entrance for the Neap Tide

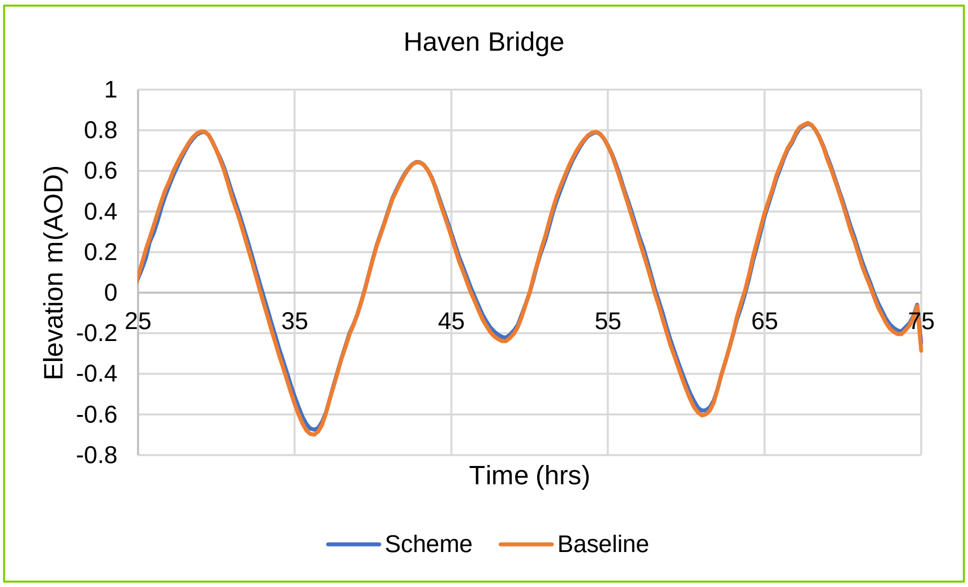

Plate 6-22: Comparison of Water Level between the Baseline and Scheme Scenarios at Haven Bridge for the Neap Tide

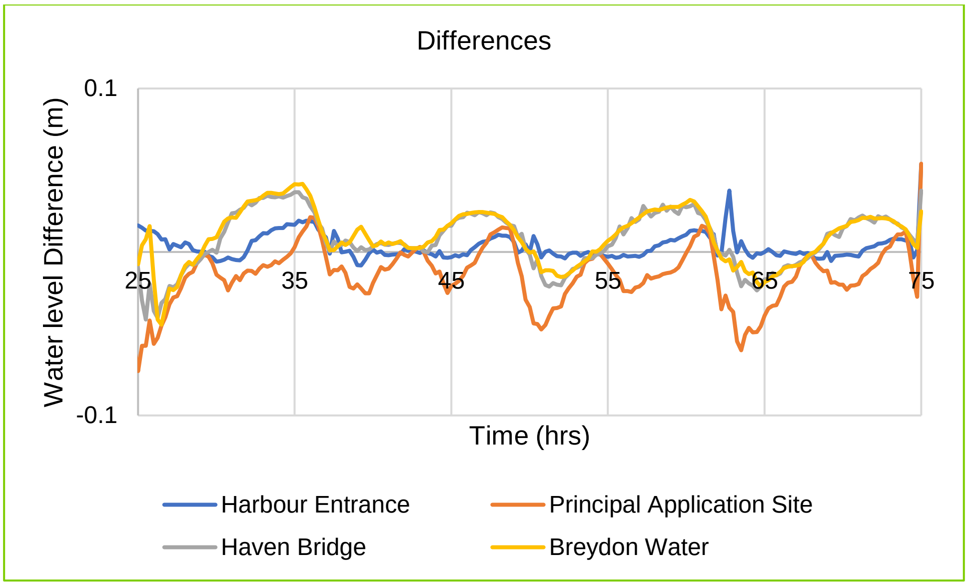

Plate 6-23: Difference in Water Level between the Baseline and Scheme Scenarios for the Neap Tide

6.2.14 The results show during the Neap tidal event, the Scheme has a negligible impact of the water level across the domain. The main effect of the Scheme is to increase the local velocity magnitude at the Principal Application Site because of the constriction caused in the channel by the bridge knuckles.

6.2.15 When comparing the Neap and Spring tide events, the Baseline velocity magnitude in the Neap event peaks at approximately 0.7m/s and the Baseline velocity magnitude over the Spring tide peaks at approximately 1m/s. The difference is driven by the increased water level and tidal amplitude in the Spring tide when compared to the Neap.

6.2.16 The velocity magnitude increase due to the Scheme is greater in the Spring tide event than the Neap event. This is because the velocity magnitude is dependent on the rate of change in water level, which is greater during the Spring tide than the Neap tide.

Bed Stress

6.2.17 Bed stress is the parameter that drives erosion and deposition. Therefore, assessing the bed stress predicted by the model highlights areas where erosion and deposition occurs. The bed stress is calculated using the bottom velocity magnitude in the model. The bed stress results for the Spring and Neap tide are presented below. To put the bed stress into context, the critical erosion rate for the top layer of material (silt) in the channel is 0.12Pa, therefore where the stress exceeds this value sediment erosion will occur.

Spring Tide Event

6.2.18 Table 6-2 shows the bed stress average and extremes for the Harbour Entrance, Principal Application Site, Haven Bridge and Breydon Water. The table shows that at all locations, the bed stress rates in the Baseline scenario are sufficient on average to erode material over the duration of the Spring tide event.

6.2.19 The results show that in the Spring tide event, on average across the simulation, the Scheme increases the localised bed stress, this is in line with the increased velocity magnitude. The results show that on average the bed stress is increased by 1.55Pa in the Scheme scenario compared to the Baseline at the Principal Application Site. When comparing the Scheme model to the Baseline model results at the Harbour Entrance, Haven Bridge and in Breydon Water, the Scheme has a negligible impact on average bed stress.

Table 6-2: Bed Stress – Spring Tide

Tide	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Average Baseline (Pa)	0.26	0.63	1.55	0.14
Average Scheme (Pa)	0.26	2.14	1.54	0.14
Average Difference (Pa)	0.00	1.55	-0.01	0.00
Baseline				
Maximum Baseline (Pa)	1.01	1.86	5.44	0.53
Minimum Baseline (Pa)	0.00	0.00	0.00	0.00
Scheme				
Maximum Scheme (Pa)	1.01	6.73	5.86	0.52
Minimum Scheme (Pa)	0.01	0.01	0.01	0.00
Difference				
Maximum Difference (Pa)	0.20	5.02	0.43	0.08
Minimum Difference (Pa)	-0.32	-0.01	-0.33	-0.05

6.2.20 Plate 6-24 and Plate 6-25 show the time series results for the bed stress at the four locations in the domain. This shows that the highest bed stress is seen on the flood tide as water is entering the estuary. A lower bed stress can be seen on the ebb tide. The impact of the Scheme approximately mirrors the impact of Breydon Bridge in the Spring tide. This result shows the Scheme will have a similar impact on the estuary as Breydon Bridge currently has during a Spring tide. Plate 6-26 shows the difference in bed stress through the timeseries. The plot shows the largest difference is at the Principal Application Site on the flood tide, as water is entering the estuary. The differences in bed stress elsewhere are negligible.

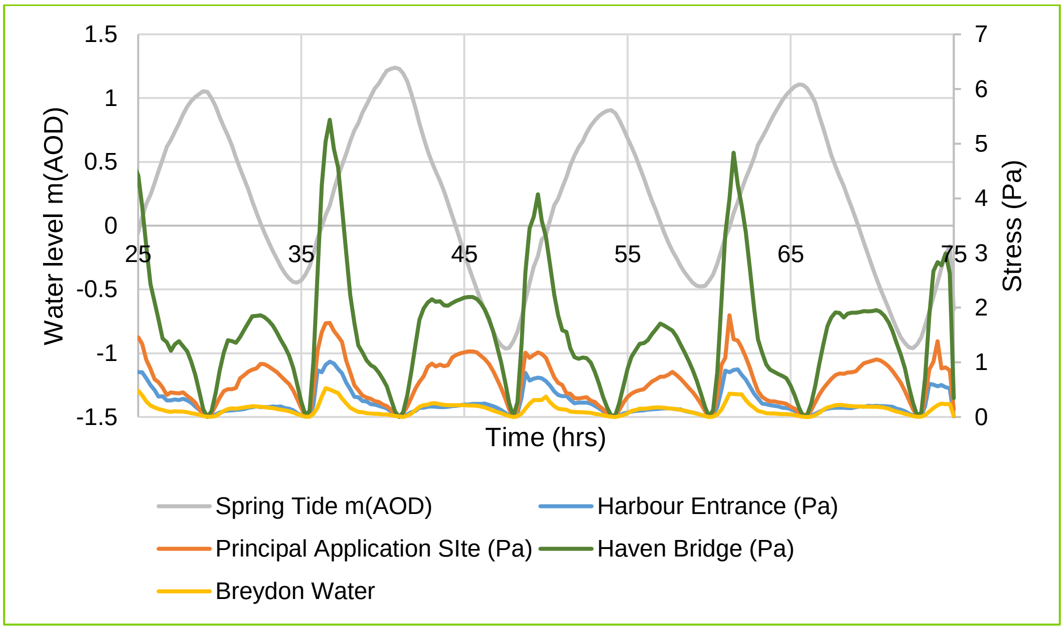

Plate 6-24: Model Predicted Baseline Bed Stress – Spring Tide

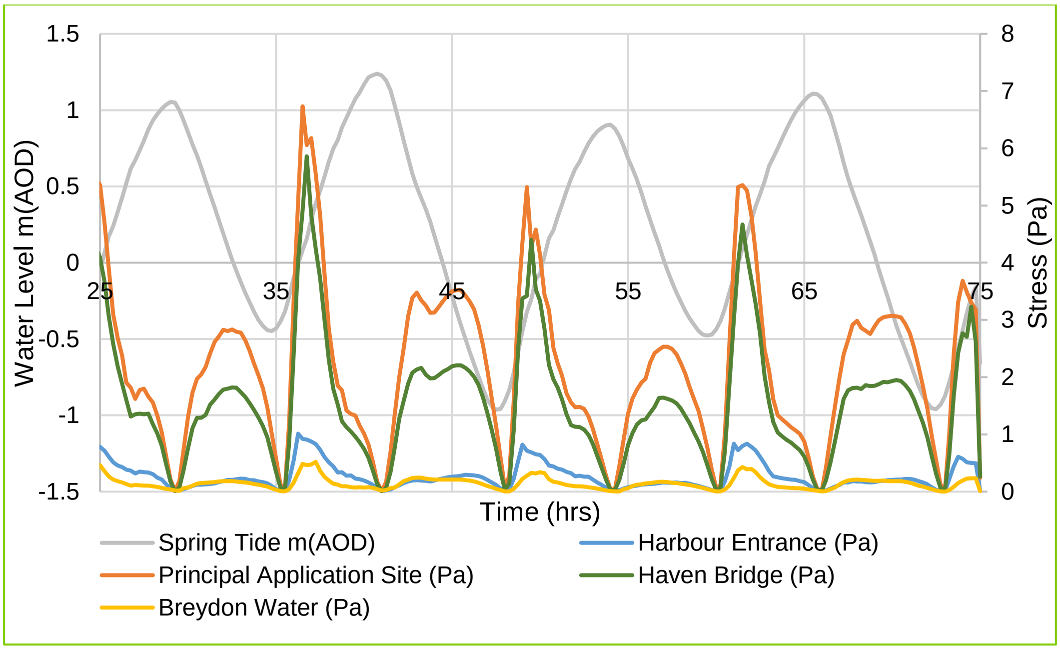

Plate 6-25: Model Predicted Scheme Bed Stress – Spring Tide

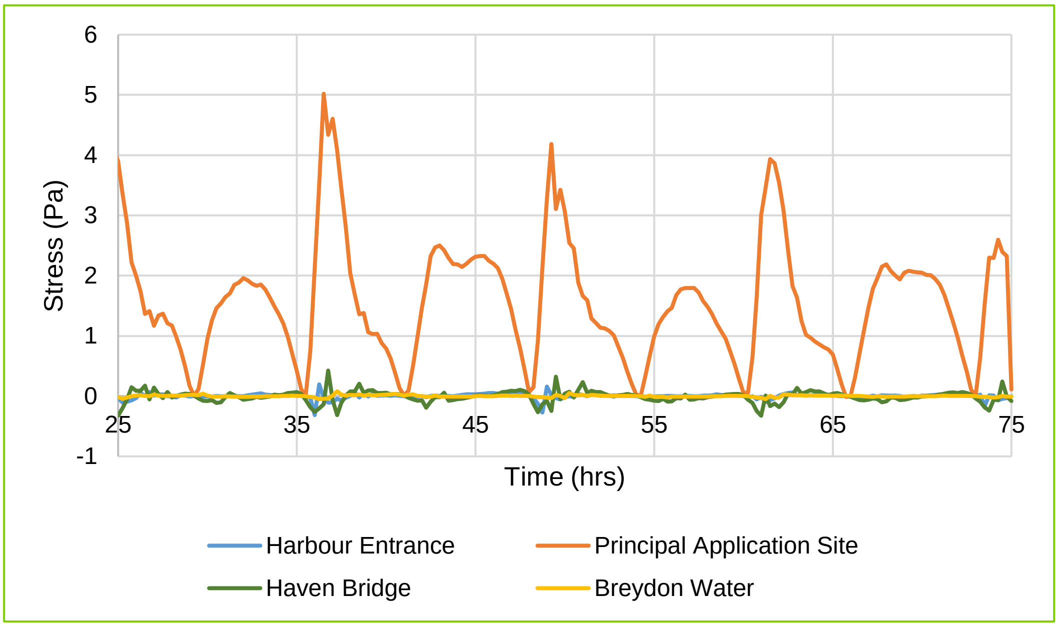

Plate 6-26: Bed Stress Difference (Scheme – Baseline) – Spring Tide

Neap Tide Event

6.2.21 Table 6-3 shows the bed stress average and extremes for the Harbour Entrance, the Principal Application Site, Haven Bridge and Breydon Water during the Neap tidal event. The table shows at all locations during the Baseline Scenario, the bed stress rates in the model domain are sufficient on average to erode material over the duration of the Neap event.

6.2.22 Table 6-3 shows that in the Neap tide event, on average across the model run, the Scheme increases the bed stresses due to the increase velocity magnitude. The main difference between the Baseline and Scheme scenarios is at the Principal Application Site where the bed shear is significantly increased due to the increase in velocity magnitude. The results show that on average the bed stress is increased by 0.74Pa at the Principal Application Site. When comparing the Scheme model to the Baseline model results at the Harbour Entrance, Haven Bridge and in Breydon Water there is a negligible impact on bed stress.

Table 6-3: Bed Stress - Neap Tide

	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Average Baseline (Pa)	0.12	0.32	0.73	0.07
Average Scheme (Pa)	0.13	1.06	0.74	0.07
Average Difference (Pa)	0.01	0.74	0.01	0.00
Baseline				
Maximum Baseline (Pa)	0.48	0.87	2.01	0.16
Minimum Baseline (Pa)	0.00	0.00	0.00	0.00
Scheme				
Maximum Scheme (Pa)	0.51	2.65	2.29	0.18
Minimum Scheme (Pa)	0.00	0.00	0.00	0.00
Difference				
Maximum Difference (Pa)	0.22	1.79	0.26	0.03
Minimum Difference (Pa)	-0.17	0.00	-0.18	-0.03

6.2.23 Plate 6-27 and Plate 6-28 show the time series results for bed stress at the Harbour Entrance, the Principal Application Site, Haven Bridge and Breydon Water. The plots show that the highest bed stress is seen on the flood tide as the water is entering the estuary. A lower increase in bed stress can be seen on the ebb tide. This result shows the Scheme will have a similar impact on the estuary as Breydon Bridge currently has during a Neap tide. Plate 6-29 shows the difference in bed stress between the Baseline and Scheme scenarios through the Neap tide simulation. This plot shows the largest difference is at the Principal Application Site on the flood tide, as water is entering the estuary.

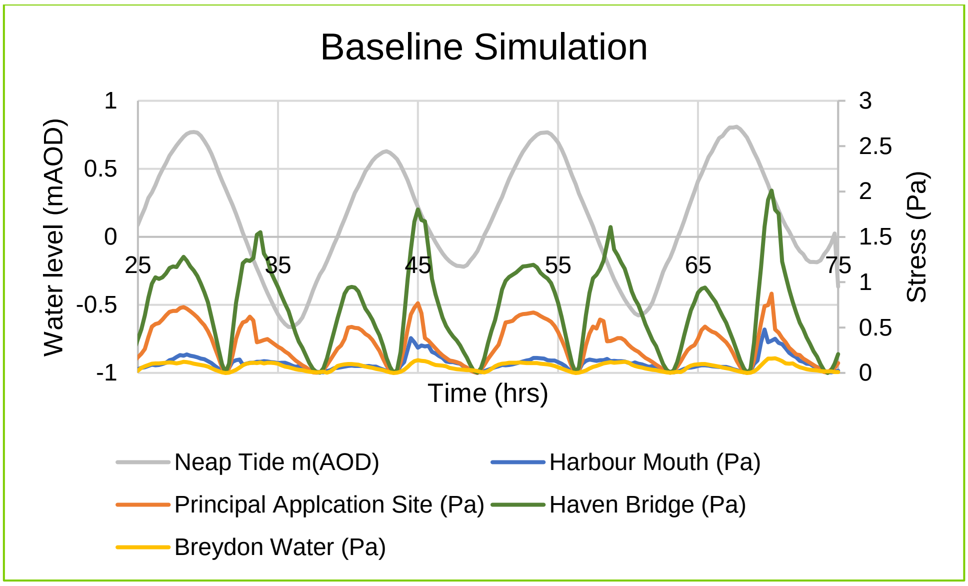

Plate 6-27: Model Predicted Baseline Bed Stress – Neap Tide

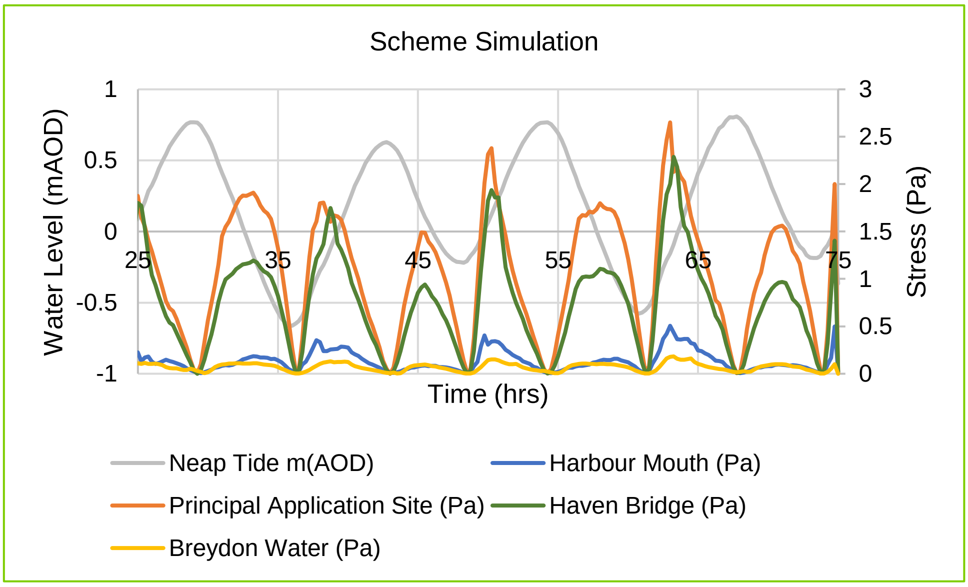

Plate 6-28: Model Predicted Scheme Bed Stress – Neap Tide

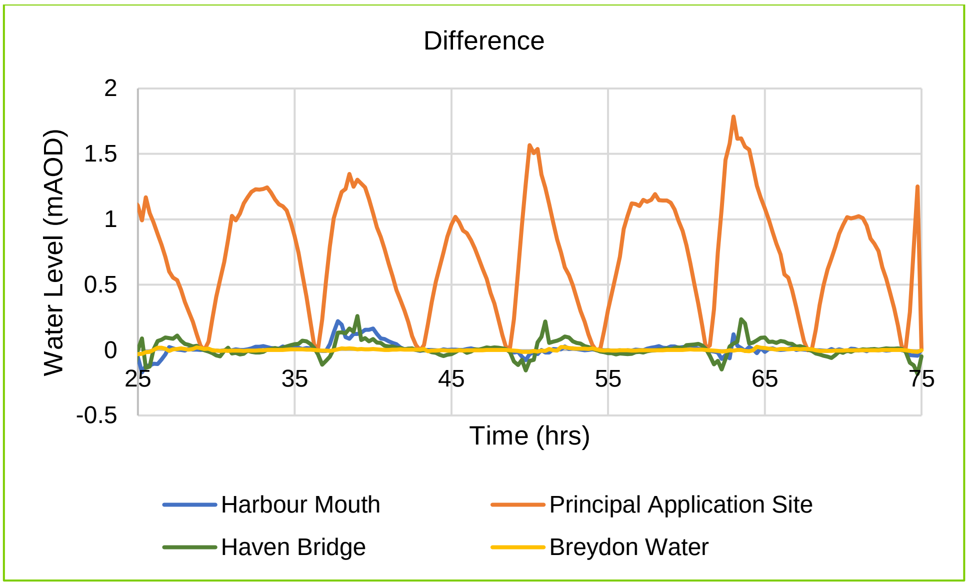

Plate 6-29: Bed Stress Difference (Scheme – Baseline) – Neap Tide

6.2.24 When comparing the impacts on bed stress in the Spring and Neap simulations, the Scheme causes a larger increase in bed stress during the Spring tide. This is because the velocity magnitude is greater during this simulation. In both simulations, the impact of the Scheme is mainly seen locally at the Principal Application Site with a negligible difference predicted elsewhere.

6.2.25 On average, throughout the year, the change in bed stress is likely to fall between the Spring and Neap values because of the approximately two weekly spring/neap cycle experience in the estuary.

Erosion Rate

6.2.26 In order to make an assessment of sediment transport, a calculation of the average erosion/deposition rate has been carried out. The purpose of this value is to give an understanding of the worst case impacts on the sediment regime, given that no bed morphology can be included in the calculation. The erosion/deposition rate takes into account both the scour and deposition occurring through the model simulations.

6.2.27 The average erosion rate has been calculated by taking the difference in bed material (kg/m^2) at the start and finish of the model simulation and dividing by the total simulation time. The calculation provides a number which can be extrapolated to give an estimation over a required period of time. It should be noted that long term changes in bed level will affect the velocity magnitude due to the continuity equation (Q=VA, where Q is flow rate, V is velocity magnitude and A is cross sectional area). For example, if sediment built up in a location, assuming flow remains the same, local velocity would increase because the cross-sectional area would decrease until it was sufficient to trigger erosion. Explicit modelling of these bed elevation changes cannot be undertaken given resolution of the model in this assessment as the model run times would be too long.

Spring Tide Event

6.2.28 Table 6-4 shows the calculated erosion rates for the Spring tide event. A positive rate shows scour and a negative rate shows deposition. In both the Scheme and the Baseline models, the Harbour entrance, the Principal Application Site, Haven Bridge and Breydon Water are found to be experiencing scour on average throughout the model run.

6.2.29 Table 6-4 shows that the Scheme reduces the scour rates in Breydon Water and at the Harbour Entrance compared to the Baseline scenario. As a result, the existing sediment does not erode as fast as predicted for the Baseline scenario and less material is moved around the model domain.

6.2.30 There is additional scour at the Principal Application Site in the Scheme scenario compared to the Baseline, this is due to the increase in velocity magnitude which drives higher bed stresses causing localised scour pits. The results also show that the rate of scour is slightly increased near Haven Bridge in the Scheme scenario compared to the Baseline, this is due to the small increase in velocity due to the Scheme at Haven Bridge.

Table 6-4: Spring Erosion Rate

Baseline	**Harbour Entrance**	**Principal Application Site**	**Haven Bridge**	**Breydon Water**
Average Erosion rate ($kg/m^2/hr$)	0.98	1.87	3.75	0.77
Average Erosion depth rate (m/hr)	0.00037	0.00071	0.00141	0.00029
Scheme				
Average Erosion rate ($kg/m^2/hr$)	0.74	7.35	5.75	0.28
Average Erosion depth rate (m/hr)	0.000277	0.002775	0.002170	0.000105
Differences				
Average Erosion rate ($kg/m^2/hr$)	-0.24	5.48	2.00	-0.49
Average Erosion depth rate (m/hr)	-0.00009	0.00207	0.00076	-0.00018

6.2.31 Plate 6-30 shows the 2D plot of the average erosion rate comparison (kg/m^2/hr) in the model domain. There are two areas which show higher erosion rates with the Scheme in place compared to the Baseline; the Principal Application Site and Haven Bridge. These are areas where the increase in velocity locally impacts the sediment regime. However, the plate shows there is little change elsewhere in the domain. The Scheme locally scours the material in the channel between the bridges and most of the material is deposited close to the Principal Application Site near to the quay walls, with a small amount deposited elsewhere upstream and downstream of the Principal Application Site in the engineered channel. The modelling shows there is a negligible decrease in the erosion rate when comparing the Scheme scenario to the Baseline scenario in Breydon Water, this has the effect of slowing down the ambient erosion occurring naturally in the lake.

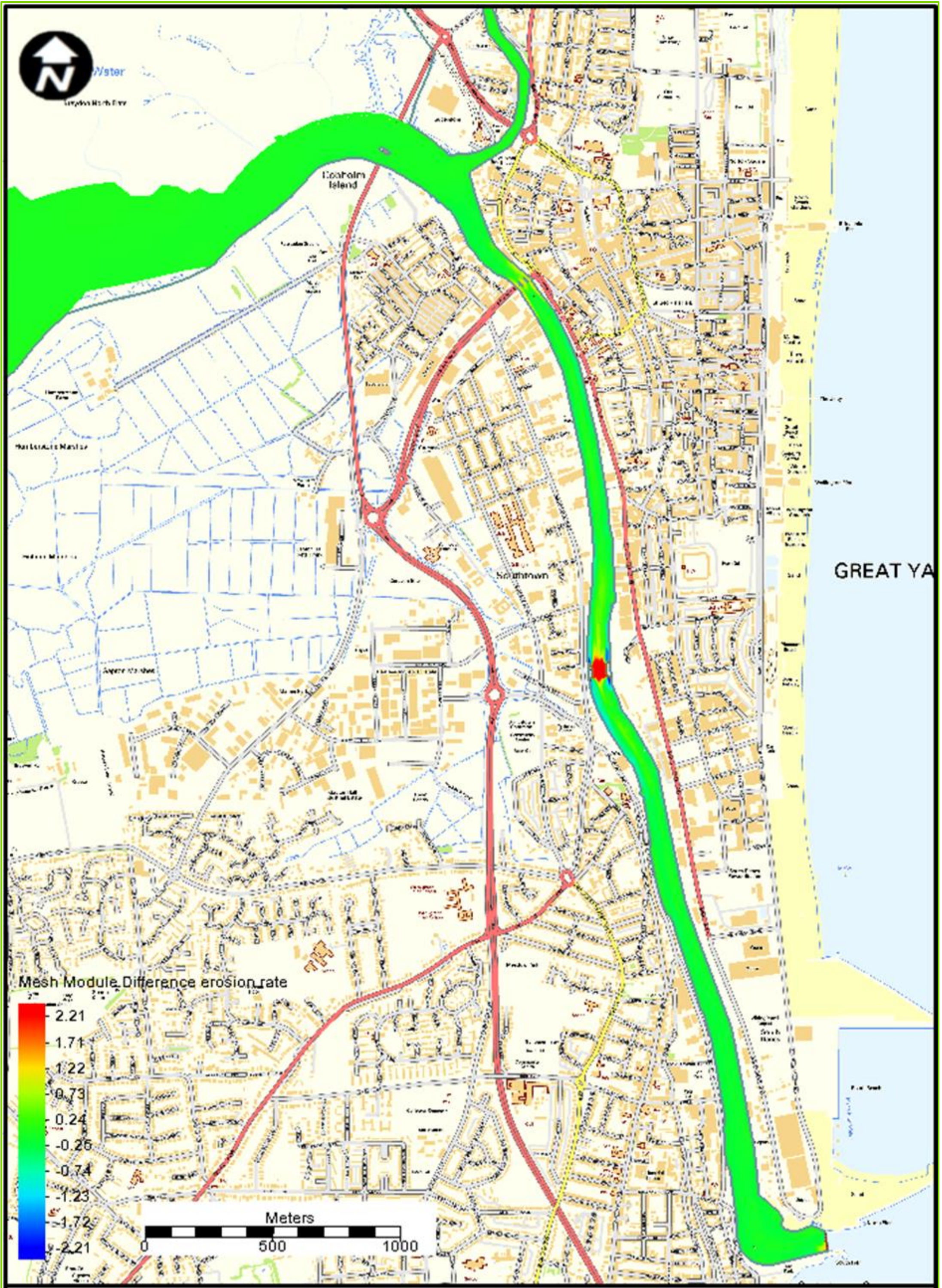

Plate 6.30 – Spring Average Erosion Rate Comparison

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Plate 6-30: Spring Average Erosion Rate Comparison

6.2.32 It should be noted that the rates presented here are rates calculated over a relatively short period of time and do not consider morphological changes therefore they should be considered worst case. In reality, bed levels would likely find an equilibrium before the scour is increased significantly as a result of the Scheme. Assuming the flow in the estuary remains the same, velocity magnitude will increase as a result of the continuity equation. The velocity magnitude on the Spring tide increases by up to 10%, therefore when sufficient scour has occurred to increase the cross-sectional area by 10%, the scour rates will likely return to pre-Scheme conditions. In this assessment, the channel is approximately 100m wide, Breydon Bridge is assumed to be 50% blockage and a water depth of 8m is assumed then the expected maximum scour depth would be 0.8m.

Neap Tide Event

6.2.33 Table 6-5 shows the calculated erosion rates for the Neap tide event. A positive rate shows scour and a negative rate shows deposition. In both the Scheme and the Baseline scenarios, scour is shown at the four locations in Table 6-5 as the velocity magnitudes are sufficient to erode the bed material.

6.2.34 When comparing the Baseline scenario to the Scheme scenario, the Scheme has a negligible impact on the scour rates in Breydon Water and at the Harbour entrance during the Neap event.

6.2.35 There is additional scour between the bridge knuckles at the Principal Application Site due to the increase in velocity magnitude, which drives higher bed stresses causing localised scour. The results also show that the rate of scour is slightly increased near Haven Bridge due to the change in velocity magnitude as a result of the Scheme.

Table 6-5: Neap Erosion Rate

Baseline	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Average Instantaneous Erosion rate (kg/m^2/hr)	0.10	1.13	2.75	0.01
Average Instantaneous Erosion depth rate (m/hr)	0.00004	0.00043	0.00104	0.00000
Scheme				
Average Instantaneous Erosion rate (kg/m^2/hr)	0.15	4.55	3.20	0.01
Average Instantaneous Erosion depth rate (m/hr)	0.000055	0.001716	0.001209	0.000003
Differences				

Baseline	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Average Instantaneous Erosion rate (kg/m^2/hr)	0.04	3.42	0.45	0.00
Average Instantaneous Erosion depth rate (m/hr)	0.00002	0.00129	0.00017	0.00000

6.2.36 Plate 6-31 shows the 2D plot of the average erosion rate comparison (kg/m^2/hr) in the domain. There is one area which show higher erosion rates with the Scheme in place; the Principal Application Site. This is where an increase in the velocity magnitude locally as a result of the Scheme impacts the sediment regime. However, the plate shows there is a negligible change elsewhere in the domain. The Scheme locally scours the material in the channel between the bridge knuckles and most of the material is deposited close to the Principal Application Site close to the quay walls, with a small amount deposited in the elsewhere upstream and downstream of the Principal Application Site in the engineered channel. The modelling shows there is a negligible decrease in the erosion rate when comparing the Scheme scenario to the Baseline scenario in Breydon Water, this has the effect of slowing down the ambient erosion occurring naturally in the Lake.

Plate 6-31: Neap Average Erosion Rate Comparison

6.2.37 In general, the modelling shows that there is change to erosion rate in both the Neap and Spring tides at the Principal Application Site as a result of the

Scheme and the increased velocity magnitude between the bridge knuckles, which causes scour. The model shows that the scoured material is deposited predominately locally near to the quay walls where the velocity magnitude is lower either side of each bridge knuckle. In the Spring tide simulation, there is a small increase in erosion rates at Haven Bridge. In both the Neap and Spring tide simulations the erosion rates in Breydon Water and at the harbour entrance are negligible.

Depth, Shape and Volume of Scour at the Scheme in a Typical Event

6.2.38 The model cannot be run for a long enough time to gain a full equilibrium in 3D to ascertain the full depth of the scour at the Principal Application Site. However, it is possible to estimate the depth of the scour using the continuity equation.

6.2.39 The model has shown that there is likely to be increased scour in the middle of the River Yare channel between the knuckles as a result of the Scheme. At the Principal Application Site, the width of the channel is 100m and the Scheme constricts the channel by approximately 50%, therefore the depth of the scour depth is likely to be limited to approximately double the average water depth. The average water level from the Gorleston-on-Sea gauge 2018 dataset shown in Plate 3-2 is 0.17mAOD. The bed level at the Principal Application Site is approximately -7mAOD, giving an average existing water depth of approximately 7m. This would mean in order to return to pre-Scheme conditions, the worst case depth of the scour pit would be approximately 7m below existing bed level between the Scheme knuckles. This depth should be considered a worst case scenario and a detailed assessment of scour should be carried out on the final design. Consideration is required to ensure the foundations are not compromised and scour protection will be required as part of the final design to reduce the depth of the scour pit at the Scheme.

6.2.40 Plate 6-7 shows the velocity magnitude between the Scheme and the Baseline scenarios in the Spring event at simulation time 37 hours. The figure shows the Scheme has localised impacts at the Principal Applications Site and negligible impacts at Haven Bridge. The impacts of the Scheme are reduced further away from the Principal Application Site. Plate 6-32 shows the average velocity magnitude difference, the figure shows on average, the velocity changes are localised to close to the Scheme. This plate shows the extent of the likely erosion in due to the Scheme.

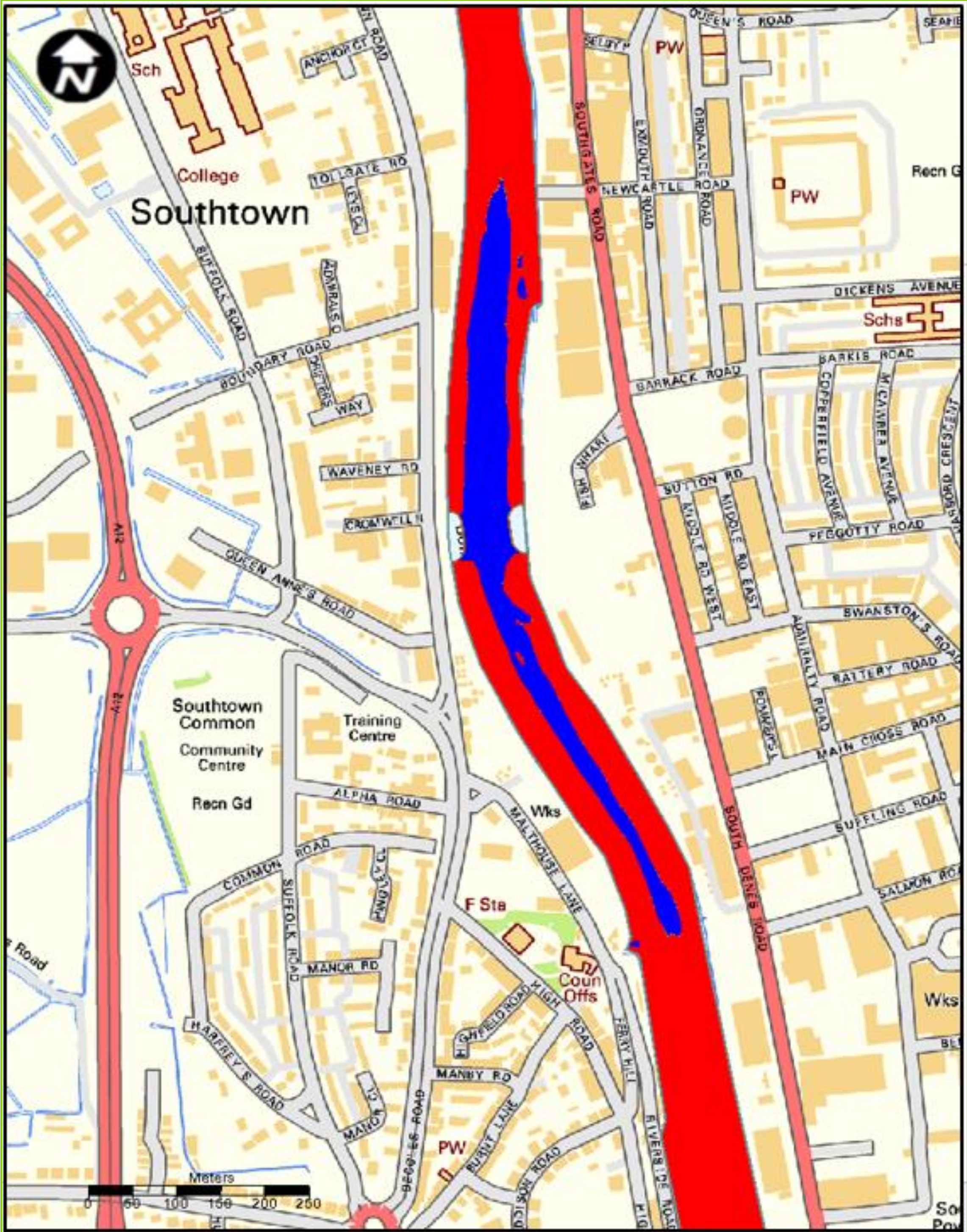

Plate 6.32–Extent of Average Velocity Magnitude Change

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Plate 6-32: Extent of Average Velocity Magnitude Change

6.2.41 Plate 6-33 shows the localised scour pattern with the Scheme in place. Assessing the volume of scoured material is difficult as it depends on many variables, however it is possible to provide a rough estimate assuming the worst case scour depth of 7mAOD. The area between the bridge knuckles is approximately 50m x 50m, which assuming a maximum scour depth of 7m would mean an estimated scour volume of 17,500m3. This value should be considered worst case as it does not take into account any engineered scour protection at the bridge and is a conservative estimation.

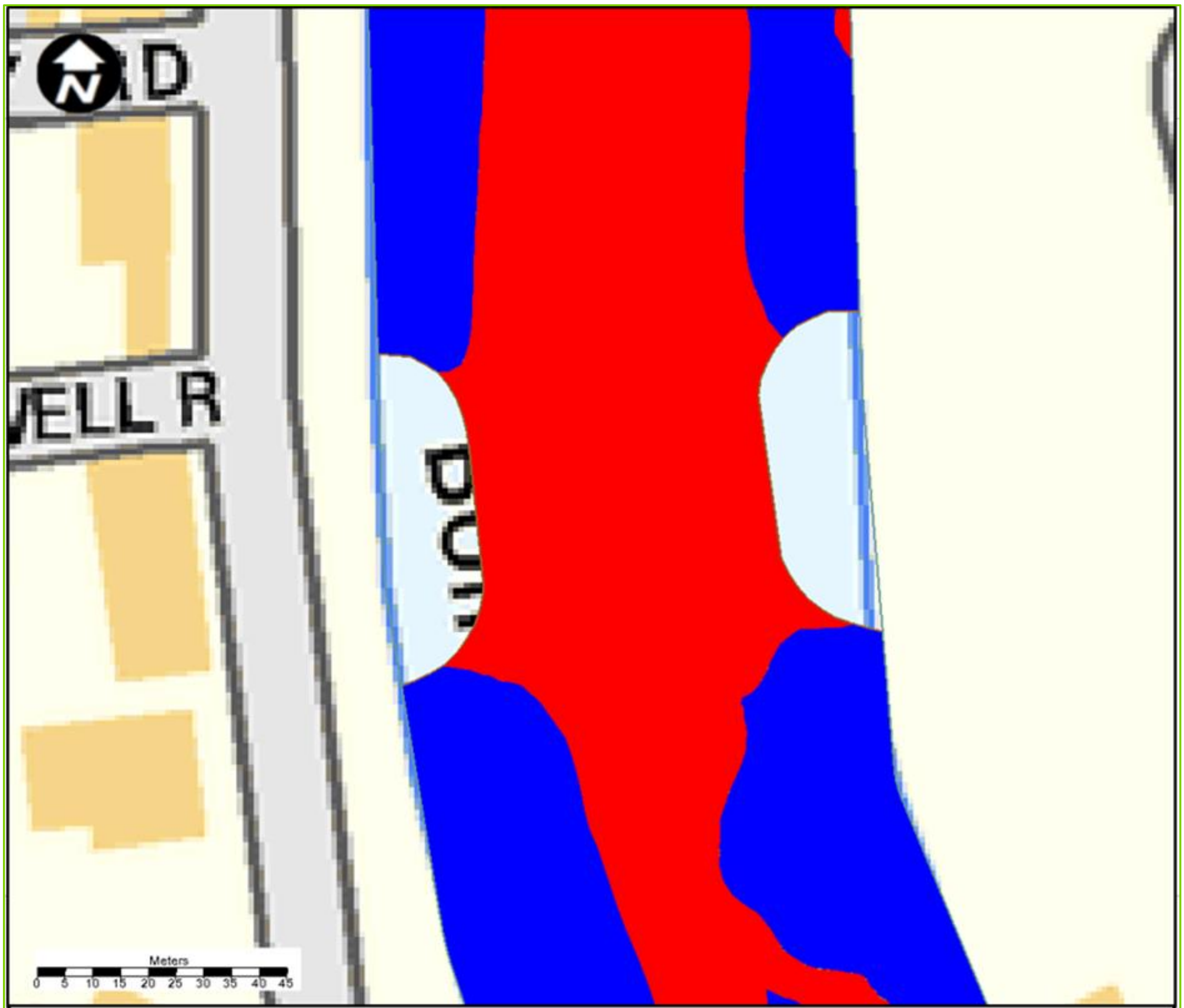

Plate 6.33 –Typical Scour Pattern

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Plate 6-33: Typical Scour Pattern

6.2.42 Plate 6-34 shows the likely areas of deposition and erosion, where red is erosion, blue is deposition, green shows a negligible change. The figure clearly shows the main impacts are localised near the Scheme where the eroded material typically moves towards the Quay walls. There is also increased deposition near the quay walls at Haven Bridge. This is likely to be from the small amount of additional scour at the Haven Bridge. There is a negligible elsewhere in the domain.

Plate 6.34– Erosion/Deposition Areas

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Plate 6-34: Erosion/Deposition Areas

6.2.43 The modelling of the everyday Spring and Neap events has shown that the impacts of the Scheme on sediment transport are local, creating some areas of additional sediment deposition and erosion near the Principal Application Site. There is no net change in sediment volume in the engineered section of the River Yare channel, therefore the Scheme has no impact on the volume of dredged material but will change the areas that will need to be dredged slightly. The modelling has shown that there is a negligible impact on the sediment regime at Breydon Water.

6.3 Results - Extreme Events

6.3.1 Two likely extreme events have been considered in this assessment, these are;

- MHWS to MLWS + 5% AEP Sea Surge Event; and
- MHWN to MLWN + 5% AEP Sea Surge Event.

6.3.2 The bed stress, peak velocity magnitude and bed erosion rates have been calculated for each event. This section provides an understanding of the likely impacts from a single surge event in the estuary to provide a likely worst case scour rate for an extreme event.

Peak Velocity

6.3.3 In order to assess the impact of the Scheme during an extreme tide, the peak velocity magnitudes at the Harbour Entrance, Principal Application Site, Haven Bridge and Breydon Water are presented in Table 6-6. The table shows that during the extreme Baseline simulation the peak velocities are greater than the velocities predicted by the model for the Spring and Neap events, which is to be expected. The MHWS-MLWS +5% event has a greater velocity magnitude than the MHWN-MLWN +5% event. This is because there is a larger difference between high and low tide during the Spring surge event, which causes higher velocity magnitudes.

6.3.4 The results show that the Scheme increases the velocity magnitude at the Principal Application Site in both the MHWS-MLWS +5% and MHWN-MLWN +5% events due to the constriction caused by the bridge knuckles. There is small decrease in velocity magnitude at Haven Bridge as a result of the Scheme, this is due to the slight delay in water arriving at the bridge on the flood tide. There is a negligible impact on velocity at the harbour entrance and Breydon Water in both events.

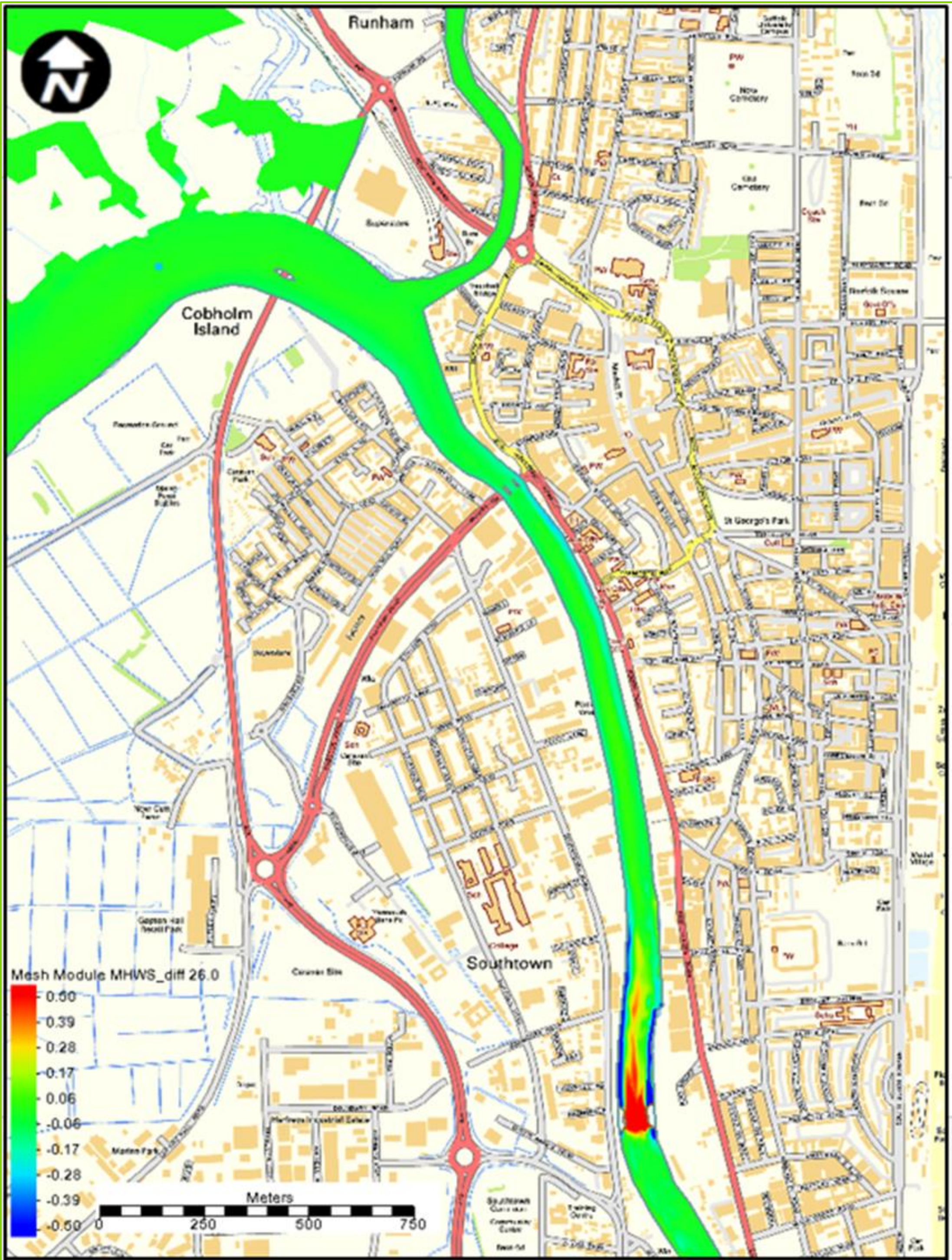

Plate 6.35– Velocity Magnitude at 26hr, MHWS to MLWS +5% AEP

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6.3.5 Plate 6-35 and Plate 6-36 show the velocity magnitude difference between the Baseline and Scheme scenarios in the MHWS-MLWS +5% AEP and MHWN-MLWN +5% AEP respectively. These figures show that velocity magnitude increases at the Principal Application Site between the bridge knuckles and decreases immediately upstream and downstream of the knuckles. There in a negligible impact within the River Yare channel between the Principal Application Site and Haven Bridge showing a slight reduction along the quay walls in both events. There is a negligible change at Breydon Water and the harbour entrance due to the Scheme.

Table 6-6: Extreme Tide, Peak Velocity

MHWS-MLWS + 5%	Harbour Entrance	Principal Application Site	Haven Bridge	Breydon Water
Baseline	0.87	1.35	2.19	0.76
Scheme	0.85	2.52	2.09	0.75
Difference	-0.02	1.17	-0.10	-0.01
MHWN-MLWN + 5%				
Baseline	0.73	1.15	1.74	0.60
Scheme	0.71	2.08	1.72	0.59
Difference	-0.03	0.93	-0.02	-0.01

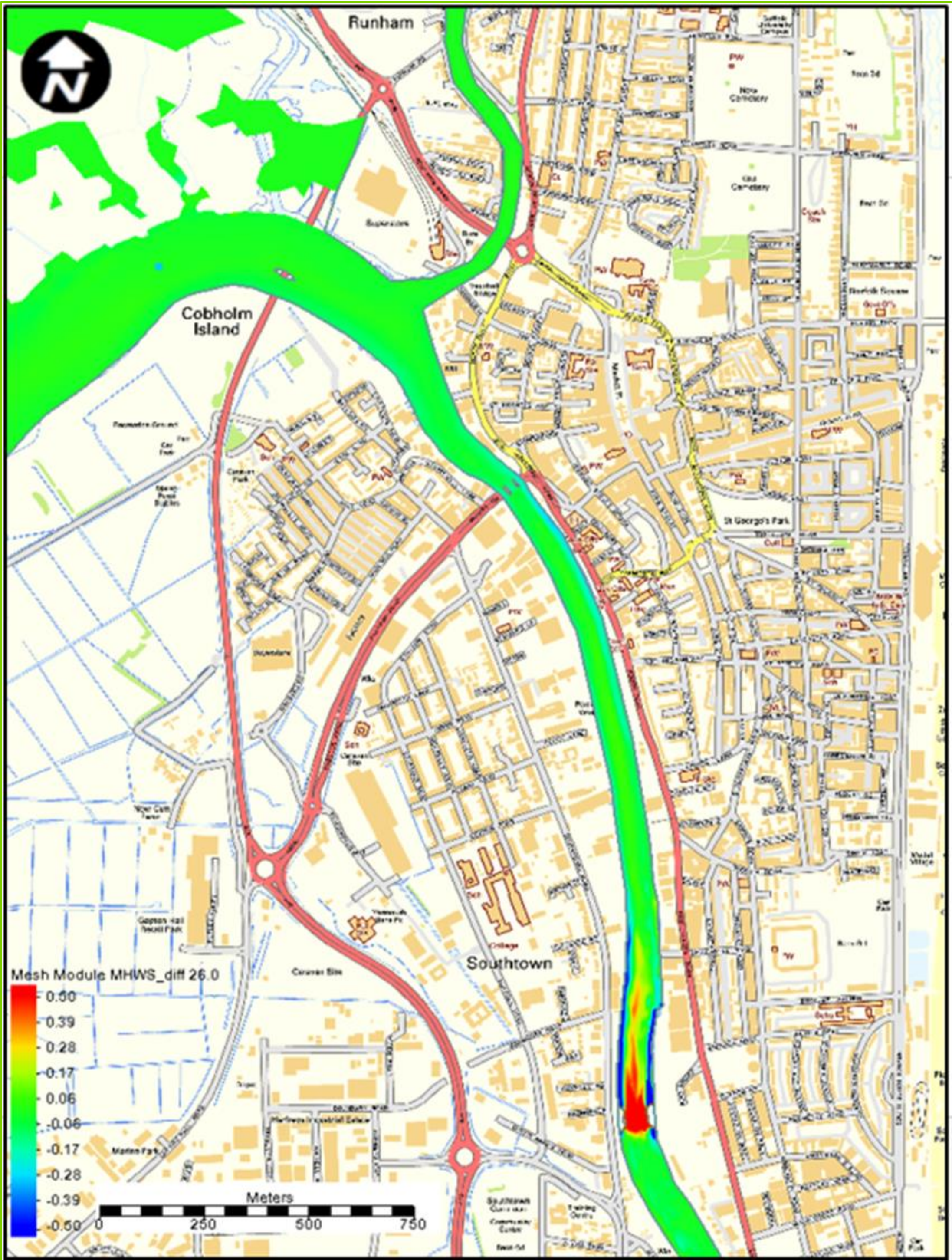

Plate 6.35– Velocity Magnitude at 26hr, MHWS to MLWS +5% AEP

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Plate 6-35: Velocity Magnitude, MHWS to MLWS

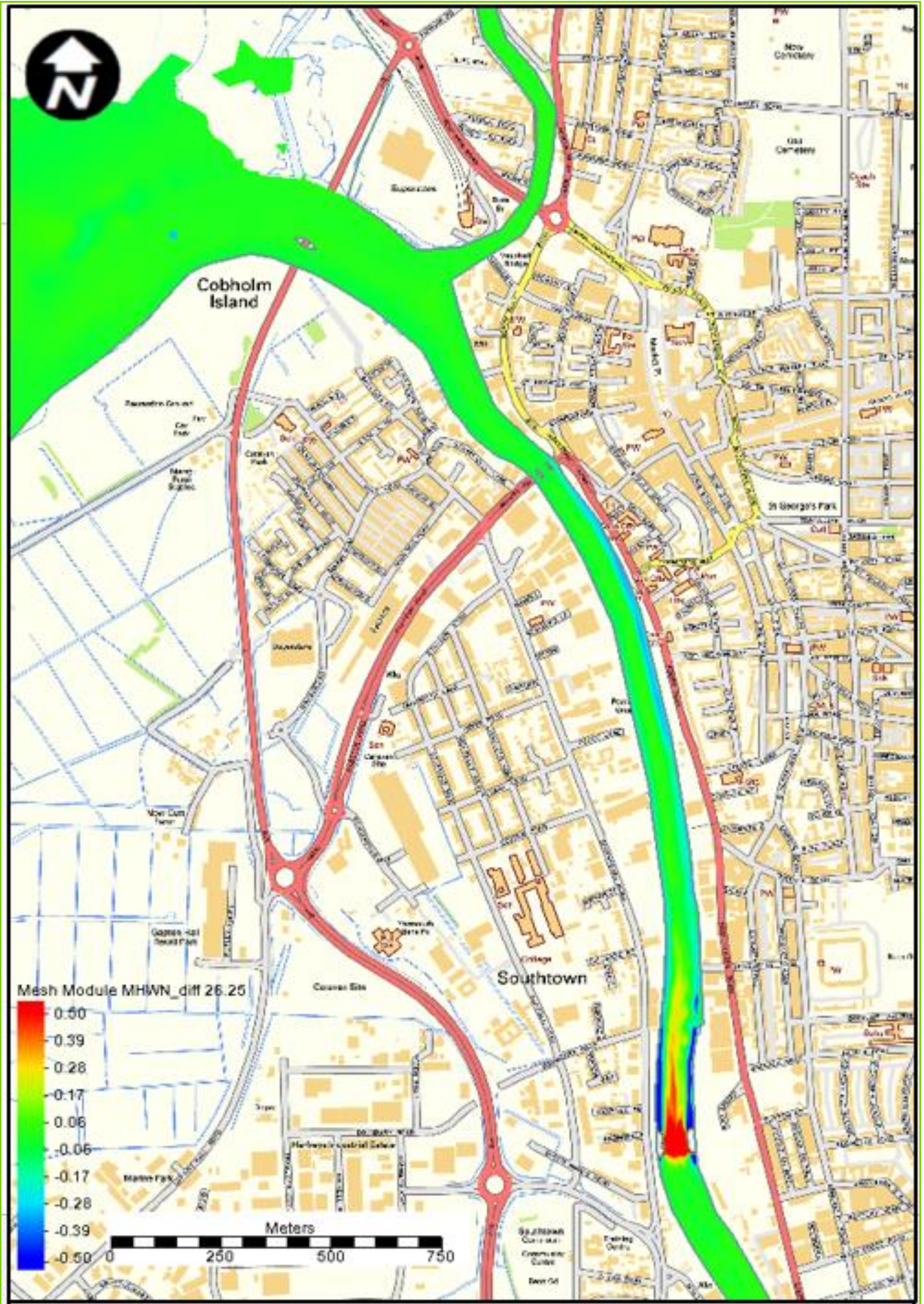

Plate 6.36– Velocity Magnitude at 26.25hr, MHWN to MLWN +5% AEP

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Plate 6-36: Velocity Magnitude, MHWN to MLWN

Bed Stress

6.3.6 Table 6-7 shows the bed stress for the Baseline and Scheme scenarios at the harbour entrance, Principal Application Site, Haven Bridge and Breydon Water for the MHWS-MLWS+ 5% AEP event. The average bed stress at the Principal Application Site is increased due to the Scheme. There is a negligible impact on bed stress elsewhere in the domain during the MHWS-MLWS+ 5% AEP event.

Table 6-7: Extreme Tide MHWS-MLWS+ 5% AEP, Bed Stress

MHWS-MLWS + 5%	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Baseline Average	0.39	0.81	2.19	0.17
Scheme Average	0.38	2.90	2.13	0.17
Average Difference	-0.01	2.10	-0.06	0.00
Baseline				
Maximum	1.63	3.11	9.28	0.97
Minimum	0.00	0.00	0.00	0.00
Scheme				
Maximum	1.57	10.74	8.54	0.95
Minimum	0.01	0.00	0.01	0.00

6.3.7 Table 6-8 shows the bed stress at the harbour entrance, Principal Application Site, Haven Bridge and Breydon Water for the MHWN-MLWN+ 5% AEP event. The average bed stress at the Principal Application Site is increased due to the Scheme. There is a negligible impact on bed stress elsewhere in the domain. The results for the MHWN-MLWN+ 5% AEP event are lower than the MHWS-MLWS+ 5% AEP as the overall velocity magnitudes are lower.

Table 6-8: Extreme Tide MHWN-MLWN+ 5% AEP, Bed Stress

MHWN-MLWN + 5%	Harbour Mouth	Scheme	Haven Bridge	Breydon Water
Baseline Average	0.27	0.50	1.29	0.11
Scheme Average	0.26	1.78	1.29	0.11
Average Difference	-0.01	1.28	0.00	0.00
Baseline				
Maximum	1.18	2.26	5.88	0.60
Minimum	0.00	0.00	0.00	0.00
Difference				
Maximum	1.07	7.33	5.66	0.59
Minimum	0.00	0.00	0.00	0.00

Bed Erosion Rate

6.3.8 To understand the instantaneous impact of the surge event, the bed erosion rates have been compared in

6.3.9 Table 6-9 and Table 6-10. Comparing the Scheme and Baseline values provides an understanding of the likely erosion and deposition due to a single surge event.

6.3.10 Table 6-9 shows the average erosion rate for the duration of the MHWS-MLWS+ 5% AEP surge event. The results show that the erosion rate at the Principal Application Site location increases because of the Scheme due to the increased velocity magnitude. This means additional scour at the Principal Application Site is likely. The average erosion rate at Haven Bridge decreases from the Baseline scenario to the Scheme scenario, this is because the velocity slightly lower in the Scheme scenario. This means the Scheme reduces the rate the material is being scoured at Haven Bridge during the surge events. The results show there is a negligible impact on sediment erosion elsewhere in the domain due to the Scheme.

Table 6-9: Extreme Tide MHWS-MLWS + 5% AEP, Bed Erosion

Baseline	Harbour Entrance	Principal Application Site	Haven Bridge	Breydon Water
Average Erosion rate (kg/m2/hr)	1.48	3.86	10.73	0.51
Scheme				
Average Erosion rate (kg/m2/hr)	1.44	14.10	10.46	0.51
Differences				
Average Erosion rate (kg/m2/hr)	-0.04	10.24	-0.27	0.00

6.3.11 Table 6-10 shows the average erosion rate for the duration of the MHWN-MLWN+ 5% AEP surge event. The results show that the erosion rate at the Principal Application Site is increased because of the Scheme due to the increased velocity magnitude. This means that during the surge event, additional scour at the Principal Application Site is likely. The results show that there is a negligible impact on sediment erosion/deposition elsewhere during the MHWN-MLWN + 5% AEP Surge event.

Table 6-10: Extreme Tide MHWN-MLWN+ 5% AEP, Bed Erosion

Baseline	Harbour Entrance	Principal Application Site	Haven Bridge	Breydon Water
Average Erosion rate (kg/m2/hr)	0.89	2.21	6.29	0.27
Scheme				
Average Erosion rate (kg/m2/hr)	0.85	8.71	6.28	0.27
Differences				
Average Erosion rate (kg/m2/hr)	-0.04	6.50	-0.01	0.00

6.3.12 In conclusion, the impact of a likely extreme event is that water flushes through the River Yare channel through Great Yarmouth at a higher ambient velocity magnitude than during the everyday events and the velocity magnitude increases locally at the Principal Application Site due to the presence of the Scheme. This in turn increases the instantaneous scour near the Principal Application Site for the short period over which the extreme tide occurs. The results show the impact on erosion/deposition elsewhere is negligible.

6.4 Construction Phase

6.4.1 To construct the Scheme, cofferdams will be installed that will be filled in to create the bridge Knuckles. There will be no additional increase in the footprint of the Scheme in the water during construction compared to the operational phase. This means there is no need to simulate a separate model for the construction phase as the results presented above for the operational phase will apply.

6.5 Impact of the Scheme on Tidal Parameters

6.5.1 In order to assess the wider impacts of the Scheme on the watercourse, the tidal parameters calculated in Section 4 has been assessed using the model for the Scheme scenario.

Tidal Asymmetry

6.5.2 Plate 6-37 shows the velocity magnitude against the water elevation at the Principal Application Site. The plot shows that when compared to the Baseline plot in Plate 4-6, the scheme does not have an impact on the tidal asymmetry in the model. The area taken up by the bridge knuckles is relatively small when compared to the estuary as a whole and the localised increase in velocity magnitude ensures that the same volume of water reaches the upper estuary and Breydon Water. The Scheme model shows that the tide is still almost symmetrical with a slight skewness at high water.

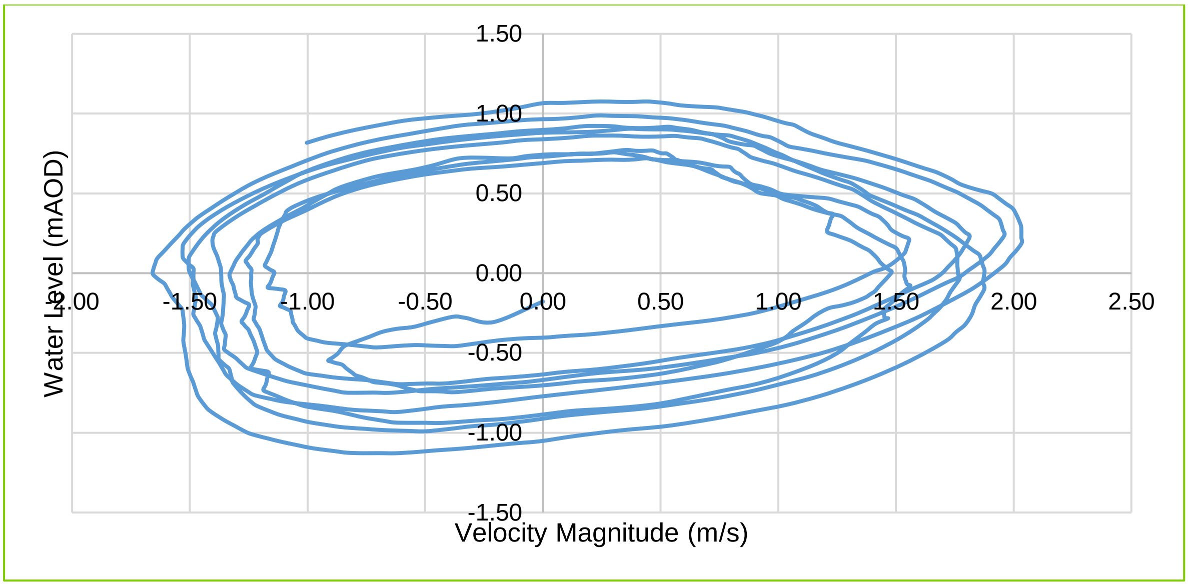

Plate 6-37: Velocity Magnitude against Water Level at the Principal Application Site in the Scheme Scenario

Tidal Dominance

6.5.3 Table 6-11 shows the Dronker's Ratio calculated for the Scheme scenario, the surface area and volume are slightly decreased due to the presence of the Scheme in the watercourse. However, this is no difference in the Dronker's Ratio when rounded to two decimal places. This shows that the Scheme does not change the estuary type which has been shown to be Type II and considered ebb dominant.

Table 6-11: Scheme Dronker's Ratio

	Baseline	Scheme
Hydraulic depth, dh	3.88	3.89
Tidal Amplitude, a	0.58	0.58
Surface area at low water, Slw	1318636	1318636
Surface area at high water, Shw	4916929	4916929
Volume at high water, Vhw	9475544	9489944
Volume at low water, Vlw	4357856	4369376
Dronker's	0.49	0.49

Tidal Dominance and Climate Change

6.5.4 In order to gain an understanding of the effects of climate change on the tidal dominance, The Dronker's Ratio has been calculated when the water level increases by 1.88m. This level has been obtained using the UK Climate Projections 18 (UKCP18) estimated sea level rise dataset and extrapolated for a 120 year design life. The increase of 1.88m creates an average high water level of 2.88mAOD. When considering the river cross-section in Plate 4-4, the 2.88mAOD water level is retained within both banks of the Breydon Water therefore the assumption is that the water will not overtop the defences and flow onto the floodplain.

6.5.5 Table 6-12 shows that with the increase in sea levels due to climate change, the Dronker's Ratio suggests that the estuary will change to a Type I, flood dominant Estuary. The Scheme is not shown to impact on the estuary type and tidal dominance.

Table 6-12: Climate Change, Dronker's Ratio

Measure	Climate Change - Baseline	Climate Change - Scheme
Hydraulic depth, dh	3.35	3.35
Tidal Amplitude, a	0.58	0.58
Surface area at low water, Slw	4916929	4915129
Surface area at high water, Shw	4916929	4915129
Volume at high water, Vhw	9253660	9253660
Volume at low water, Vlw	18743605	18729205
Dronker's	2.01	2.01

6.5.6 The results show that the Scheme has no impact on the tidal parameters when considering the estuary as a whole. This is because the relative size of the Scheme in the watercourse compared to the whole estuary is very small and the Scheme is not large enough to have a significant impact on the overall tidal regime of the estuary. The overall volume of sediment movement through the estuary will not be impacted significantly by the Scheme to cause a visible change in the estuary wide sediment regime.

7 Summary

7.1.1 A 3D flexible mesh hydraulic model of Great Yarmouth has been developed to assess the impact of the Scheme on sediment transport in the River Yare and Breydon Water. The tidal curve for the Spring and Neap has been extracted from Gorleston on Sea level gauge and used to force the model for the 'everyday' scenario. For 'extreme' events, the hydrology of Great Yarmouth has been analysed and the MHWS to MLWS +5% AEP Surge and the MHWN to MLWN +5% AEP Surge have been derived. The tidal boundaries have been applied at the boundary to the south of the Scheme at the North Sea.

7.1.2 Calibration testing has been carried out by comparing the model output to a velocity survey carried out using an ADCP device in April 2018. The model has been simulated using the levels extracted from Gorleston on Sea gauge and the velocity points compared to the model results. The 3D depth-averaged results show that the model can predict the velocity magnitude in the channel well. There are a few differences which are likely to be local impacts such as disturbances from vessel moves for example. The model is considered fit for use in the sediment assessment.

7.1.3 The D50 Sediment particle size ranges from 0.03mm to 0.55mm and defined as predominately silt and sand. The sediment model has been set up to simulate silt and sand and chart the evolution through the system. The model has been used to simulate the Spring and Neap tidal events to represent the everyday events and likely extreme events.

7.1.4 The Everyday tide results show that the Scheme locally increases the velocity magnitude because of the constriction of the Scheme knuckles in both the Spring and Neap simulations. This locally increases the scour in the centre of the channel and the material is typically moved the Quay walls where the velocity magnitude is decreased. During the Neap tide there is a negligible impact on velocity magnitude elsewhere in the domain. The Spring tide shows there is a small impact on scour rates at Haven Bridge which causes a small amount of erosion and deposition locally. There is a negligible impact in Breydon Water and at the Harbour entrance. There is a localised impact on bed stress and erosion rates due to the presence of the Scheme in the Spring and Neap tide.

7.1.5 The extreme tide events show that the velocity magnitude experiences an increase due to the presence of the Scheme in the water course. The localised impacts are greater at the Scheme when compared to the Everyday scenarios. There is a small reduction in velocity magnitude at Haven Bridge which means the bed erodes slower due to the presence of the Scheme. There is a negligible impact elsewhere in the domain during the extreme events. It should be noted that due to the low frequency of such events in the channel, the change in scour patterns are negligible.

7.1.6 The tidal parameters analysis has shown the Scheme has no change on the tidal prism, water level, asymmetry and Dronker's Ratio. This is because when considering the estuary, the area taken up by the knuckles is negligible therefore the increase in velocity magnitude ensures the same volume of the water transits the estuary. This means that the overall volume of sediment transport in the estuary is not affected by the Scheme simply because the volume taken up by the knuckles is negligible when compared to the estuary as a whole.

7.1.7 In conclusion, the modelling and tidal analysis has shown that the presence of the Scheme does increases the scour and deposition within the Principal Application Site. The modelling has shown there is small impacts in the engineered channel up to Haven Bridge, however the additional scoured material remains in the engineered channel. There is a negligible change in the sediment regime of Breydon Water due to the presence of the Scheme. The Scheme has no impact on the tidal parameters of the estuary.

7.1.8 There is no additional material transported into the engineered channel due to the presence of the Scheme. Therefore, there is no change to the overall dredging regime in the harbour needed. However, some dredging areas may change due to the physical presence of the Scheme in the channel. Engineering scour protection should be considered at the Scheme in order to reduce the impact of the increased velocity magnitude and reduce the volume of sediment scoured.

8 References

Ref 11C.1: General Port and Pilotage Information P16, Peel Ports Great Yarmouth, October 2014.

Ref 11C.2: SC060064/TR4: Practical Guidance Design Sea Levels and Open Coast (CFBD) Flood Risk Study (2014) JBA for the Environment Agency.

Ref 11C.3: Analysis and Modelling Guide, EA/ABPmer, 2008

Ref 11C.4: Ferguson, R & A. Church, M. (2004). A Simple Universal Equation for Grain Settling Velocity. Journal of Sedimentary Research - J SEDIMENT RES. 74. 933-937. 10.1306/051204740933.

Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11C, Annex A: Tidal Boundary Derivation – Sediment Assessment

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2) (a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11C, Annex A

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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Tables

Plates

1 Introduction

1.1.1 This note records the process and decision making that has been followed to generate the tidal boundaries for the Sediment Transport Assessment carried out as part of the Great Yarmouth Third Crossing (hereafter known as 'the Scheme').

1.1.2 The purpose of the assessment is to simulate an 'everyday' scenario and likely extreme scenarios which do not cause out of bank flooding to get an understanding of the impact of the Scheme on the existing sediment regime. Out of bank flooding is not considered in the Sediment Transport Assessment because the focus of this assessment is on in-channel everyday events where the water is predominately moving up and down the channel. The likely extreme scenarios consider the impact during of small tidal surges. The tidal boundary has been created using two different processes; firstly selecting a typical Spring/Neap tidal cycle from existing data to simulate the everyday event and secondly, deriving a tidal boundary for likely extreme tides.

1.1.3 The everyday Spring/Neap boundary has been extracted from the recorded gauge data at Gorleston-on-Sea level gauge located at the harbour mouth. The extreme tidal boundary derivation detailed here follows the recommendations set out in SC060064/TR4 (Ref 11C.2).

2 Everyday Scenario

2.1.1 In order to generate the "everyday" tidal boundary, the recorded tidal data was downloaded from the British Oceanography Data Centre (BODC) website for 2018. Plate 2.1 shows the water elevation recorded for the full year for 2018.

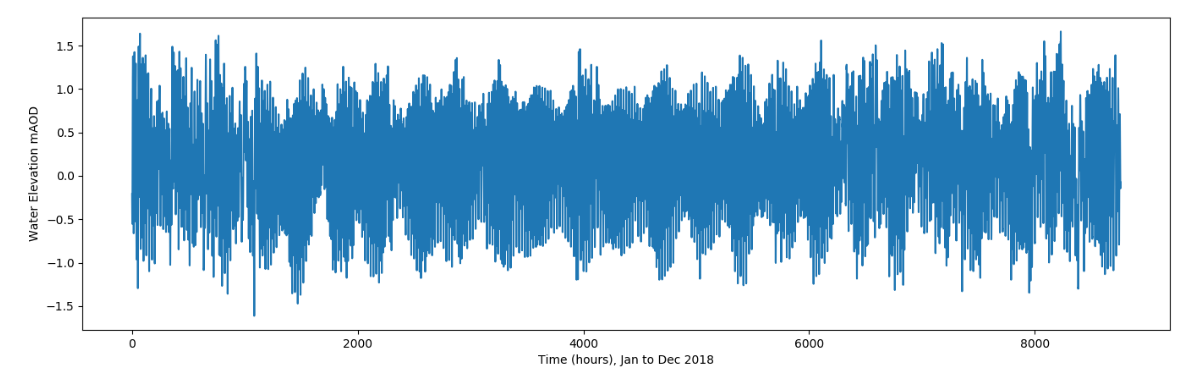

Plate 2.1: 2018 - January to December

2.1.2 Plate 2.1 shows the full year of recorded data at Gorleston-on-Sea for 2018. The time series plot shows the typical Spring/Neap cycle repeating approximately every 2 weeks throughout the year and several surge tides particularly around the early part of the year around January to February. For the purpose of this assessment a typical Spring/Neap tide cycle is required; therefore, the curve shown in Plate 2.2 has been extracted making sure no surge events are captured.

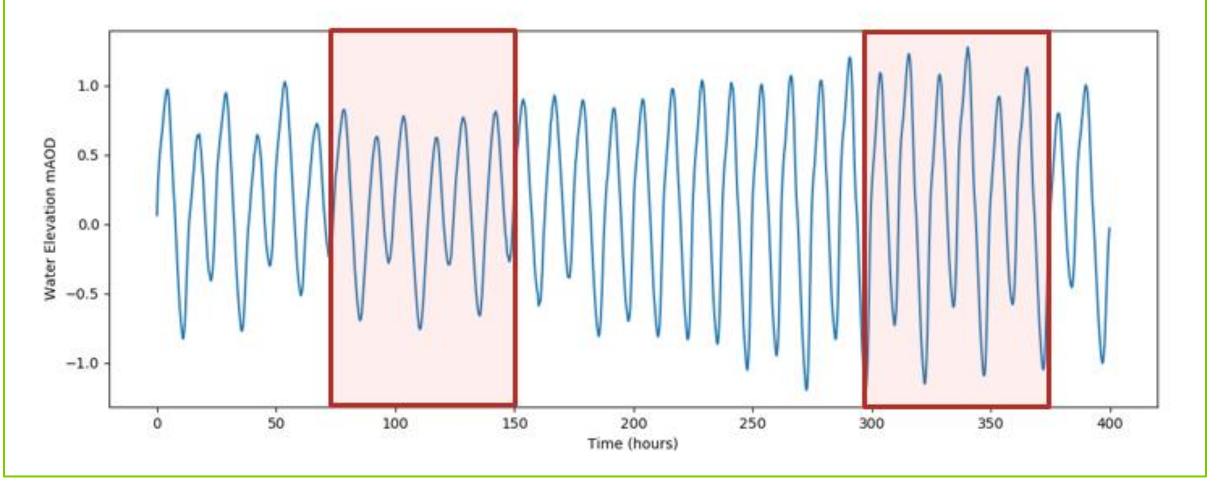

Plate 2.2: Extracted Tidal Curve

2.1.3 Plate 2.2 shows a typical water level time series ranging from a Neap to Spring tide which includes the shape of the tide which can be replicated in the model. The data has been selected from the yearly recorded data shown in Plate 2.1 to represent at typical tide with minimal surge events. At this point, the date of the profile is no longer relevant therefore the plate plots the tidal cycle against time in hours starting at zero hour. In an effort to reduce simulation time, the curve shown in Plate 2.2 has been split into two separate simulations (shown in the red boxes) of approximately 75 hours; one simulating a Spring tide and one simulating a Neap tide. These simulations will be used to approximate the amount of sediment movement on a typical Spring and Neap tide.

2.1.4 The aim of this event is to simulate a typical tidal profile and assess the impact of the Scheme on the sediment regime due to everyday flow. The tidal boundaries shown in Plate 2.2 will be simulated in the 3D model and the sediment transport will be assessed.

3 Extreme Tidal Curve Derivation

3.1.1 The purpose of this curve is to assess the impact of a sudden, likely extreme event on the sediment and what the impact of the Scheme is on sediment transport.

3.1.2 The section records the steps carried out to generate a number of sea surge events showing the peak of the 5% AEP event from the JBA 2014 has been applied to the base profiles. The extreme events are;

- MHWS to MLWS + 5% AEP sea surge;
- MHWN to MLWN + 5% AEP sea surge.

3.2 Extreme Tide Calculations

3.2.1 To investigate the impact of a likely extreme tide level, tidal curves have been derived using the SC060064/TR4 guidance (Ref 11C.2) to create curves with the peak water level of the 5% AEP level provided by JBA in Open Coast (CFBD) Flood Risk Study (Ref 11C.3). Table 3.1 lists all the steps set out in the Environment Agency guidance.

Table 3.1: Guidance Steps

Ten Step procedure
1. Check study location is outside of estuary boundaries
2. Select an appropriate chainage point for extreme sea levels
3. Select an annual exceedance probability peak sea level
4. Consider allowance for uncertainty
5. Identify base astronomical tide
6. Convert levels to Ordnance Datum
7. Identify surge shape to apply
8. Produce the resultant design tide curve
9. Sensitivity testing
10. Apply allowance for climate change

3.2.2 The guidance is part *of* the larger project, ‘Coastal flood boundary conditions for UK mainland and islands’ (Ref 11C.5) and is the best method currently available for tidal curve derivation in UK waters. As part of this project several additional datasets are also provided, as shown in Table 3.2.

Table 3.2: Additional Data Sets

Additional Data
Estuary Boundaries
Extreme Sea Levels
Gauge Sites
Confidence Interval
Surge Shapes

3.2.3 In following the guidance steps set out in Table 3.1 and using the datasets in Table 3.2 the extreme event tidal curves are generated.

Check Study Location in Outside of Estuary Boundaries

3.2.4 The guidance states that it is only valid for areas outside of estuaries, and as such the first check is to make sure the boundary is not in a major estuary. As part of the SC060064/TR4 guidance (Ref 11C.2), a shape file is provided with all major estuary locations highlighted.

3.2.5 On reviewing the Estuary Boundary dataset, the proposed location of the tidal boundary is outside any estuary.

Select the Appropriate Chainage Point for Extreme Sea Levels

3.2.6 The guidance recommends that the extreme sea level node nearest to a horizontal line drawn from the tidal boundary should be used to define the extreme sea levels for the site of interest. A horizontal line drawn from the Great Yarmouth tidal boundary passes closest to 4,150 chainage node.

Select an Annual Exceedance Probability Peak Sea Level

3.2.7 For each chainage node, an extreme sea level for the full range of return periods is provided in the additional data supplied alongside the guidance. The extreme sea levels modelled by JBA on behalf of the Environment Agency (Ref 11C.2) at node 4,150 are provided in Table 3.3 for the event considered in this study.

Table 3.3: Extreme Sea Level

AEP	Extreme Sea Levels (m AOD)
5%	2.84

Consider Allowance for Uncertainty

3.2.8 As part of the SC060064/TR4 project (Ref 11C.2), confidence in the extreme sea levels are provided as shown in Table 3.4 for the event considered in this study. The confidence levels are a measure of the potential error in the Environment Agency extreme sea level modelled results.

Table 3.4: Uncertainty Levels (node 4,150)

AEP	Uncertainty (+/-m)
5%	0.2

Identify a Base Astronomical Tide

3.2.9 Gauge data at the Great Yarmouth gauge has been made available however the MHWN and MLWN levels have not been obtained because Great Yarmouth is not a Primary Gauge on the network. In the interest of consistent, the tidal parameters should all be obtained from the same source. In this situation, EA guidance recommends using the properties of the nearest Primary Gauge to the site of interest. The nearest Primary Gauge is in Lowestoft harbour approximately 12km to the south. Table 3.5 shows the tidal properties from the Lowestoft harbour gauge that will be used to create the base tide profiles.

Table 3.5: Lowestoft Primary Gauge Properties

Property	Value (mAOD)
HAT	1.48
LAT	-1.38
MHWS	1.08
MLWS	-0.86
MHWN	0.74
MLWN	-0.34

3.2.10 As part of this assessment, Gauge data from the Great Yarmouth gauge at Gorleston-on-Sea has been obtained. The data has been recorded from December 1992 and continues to be in operation recording the sea level at the mouth of the River Yare. Plate 3.1 shows an extract from the gauge data.

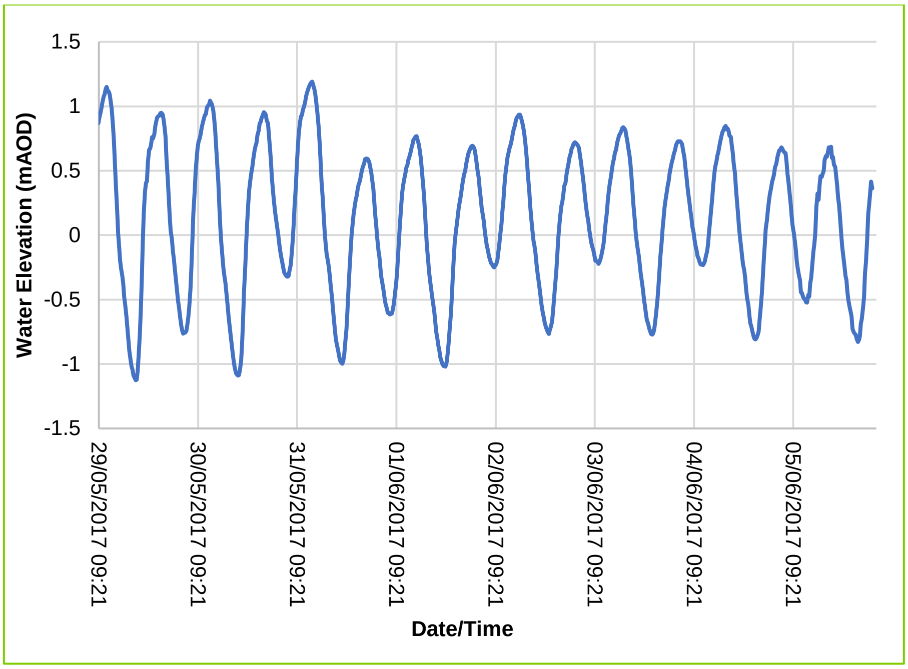

Plate 3.1: Extract from the Great Yarmouth Gauge

3.2.11 In order to properly represent the tidal curve shape, the gauge data has been reviewed and a typical tidal cycle has been extracted. This tidal cycle has then been scaled so the peak and trough matches the required water level. Plate 3.2 shows the typical tidal cycle extracted from the gauge.

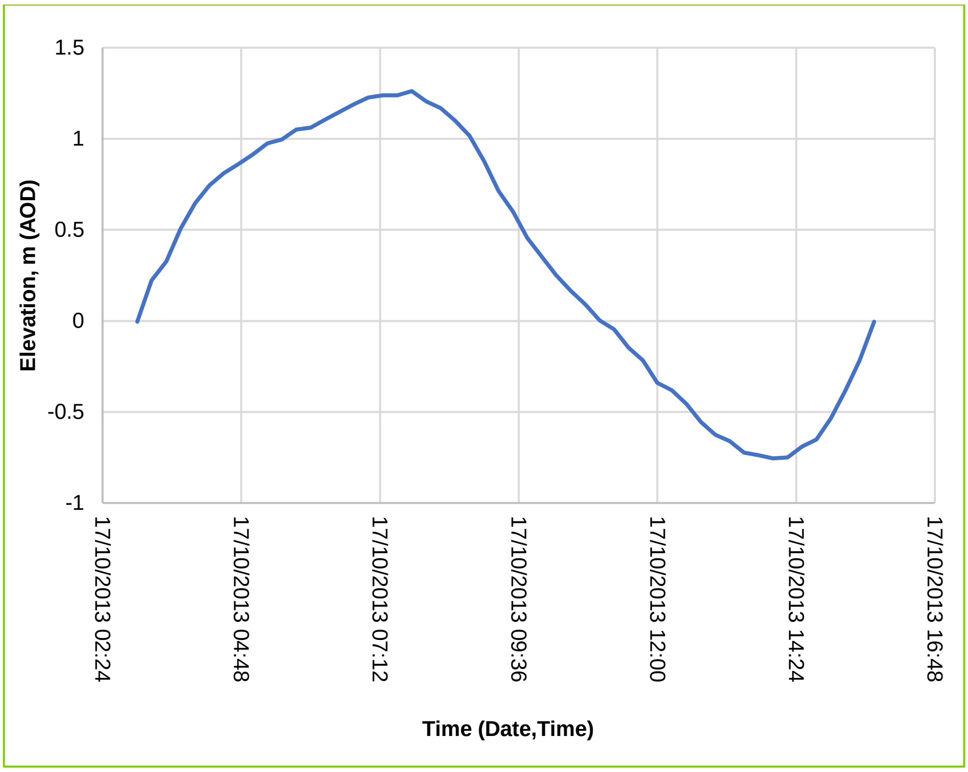

Plate 3.2: Typical Tidal Curve

3.2.12 Plate 3.2 shows a typical tidal curve extracted from the Gorleston-on-Sea Gauge. Extracting a typical tidal profile from the gauge accurately predicts the shape of the tide taking into account the skewness, symmetry and the period.

3.2.13 Following the extraction of the typical curve from the gauge data, the curve shown in Plate 3.2 has been extended by repeating the tidal cycle to create the base curve to run the model for 75 hours. At this point, the peak and trough for the curves have been scaled to the required levels in order to create the base tidal profiles for the assessment, as shown in Plate 3.3.

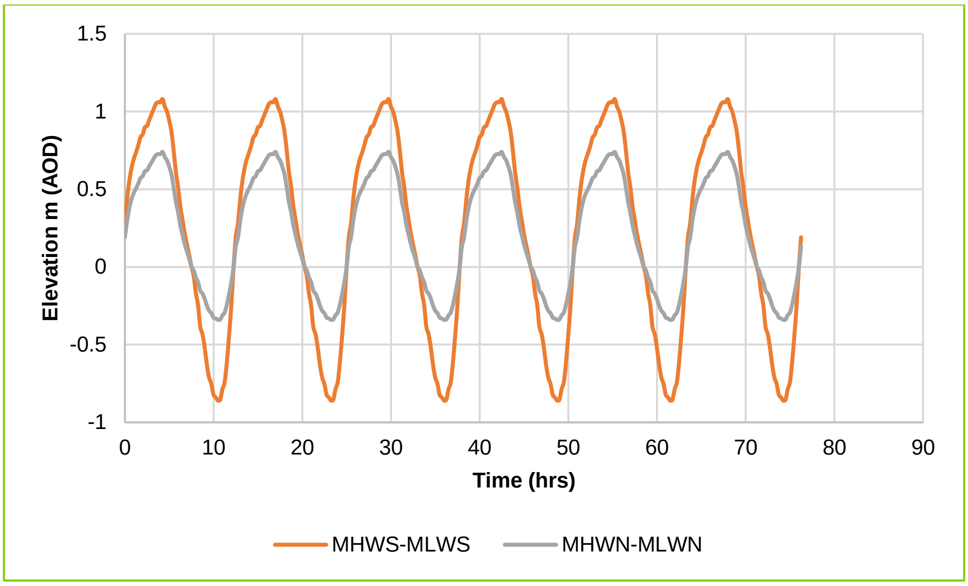

Plate 3.3: Base Tide Profiles

3.2.14 Plate 3.3 shows the base tidal profiles used to generate the extreme events simulated in the sediment model.

Convert Levels to Ordinance Datum

3.2.15 All levels are assessed with respect to Ordinance Datum. Any local levels may be recorded in Chart Datum and, for Great Yarmouth, the chart datum conversion is -1.56m.

Identify Surge Shape

3.2.16 As part of the SC060064/TR4 (Ref 11C.2) project surge shapes where derived for key locations around the UK. For this assessment the nearest surge shape is number 9 in the Design_Surge_Shapes.xls provided with the guidance documentation.

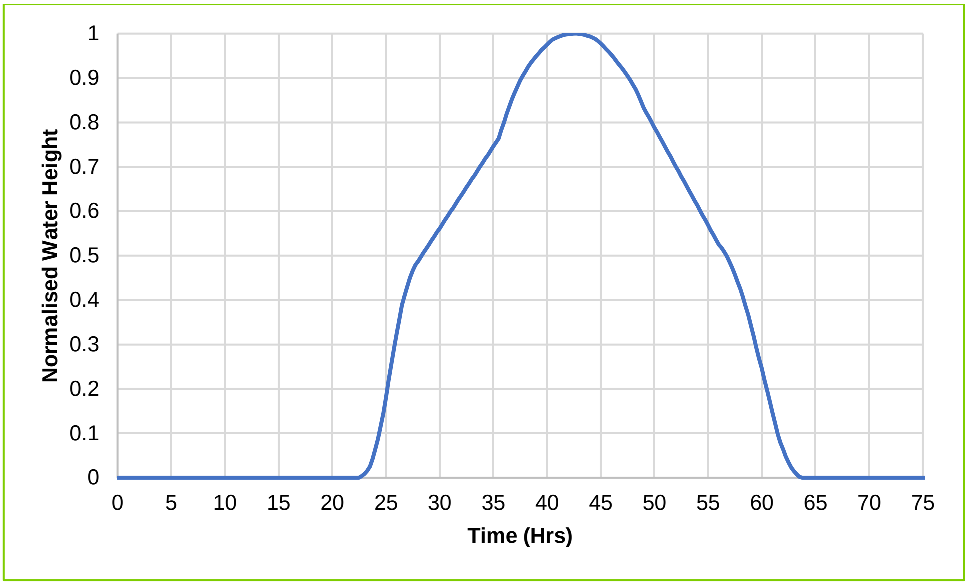

Plate 3.4: Shape 9 – Lowestoft Surge

3.2.17 Plate 3.4 shows the normalised surge shape which when combined with the base tidal profiles, the design tidal curves are derived.

Produce the Resultant Design Tide Curve

3.2.18 The guidance states that the resultant design tide curve is derived by combining the extreme sea level, base tide and surge shape. The first process is to align the base tide and surge shape peaks, in this case this is at 42.5 hours in line with the base tidal curve.

3.2.19 Once the base tide and surge shape are aligned, it is necessary to scale the base tide to the required extreme sea level. To explain this procedure, the HAT-LAT - 5% AEP event will be used as an example. Firstly, the difference between the required extreme sea level (2.84mAOD) and the base tide peak (1.48mAOD) is calculated, which in this example is 1.36m. As the surge shape is aligned with the peak water level time in the base tide, the maximum surge value of 1.0 occurs at the same time as the peak water level. The surge shape can now be scaled by the coefficient 1.36/1.0 = 1.36m AOD, thus creating a surge height which can be added to the base tide curve resulting in the required tidal profile for the event.

3.2.20 This procedure is carried out of each tidal profile to produce the three tidal boundaries required for this extreme scenario assessment as shown on Plate 3.5.

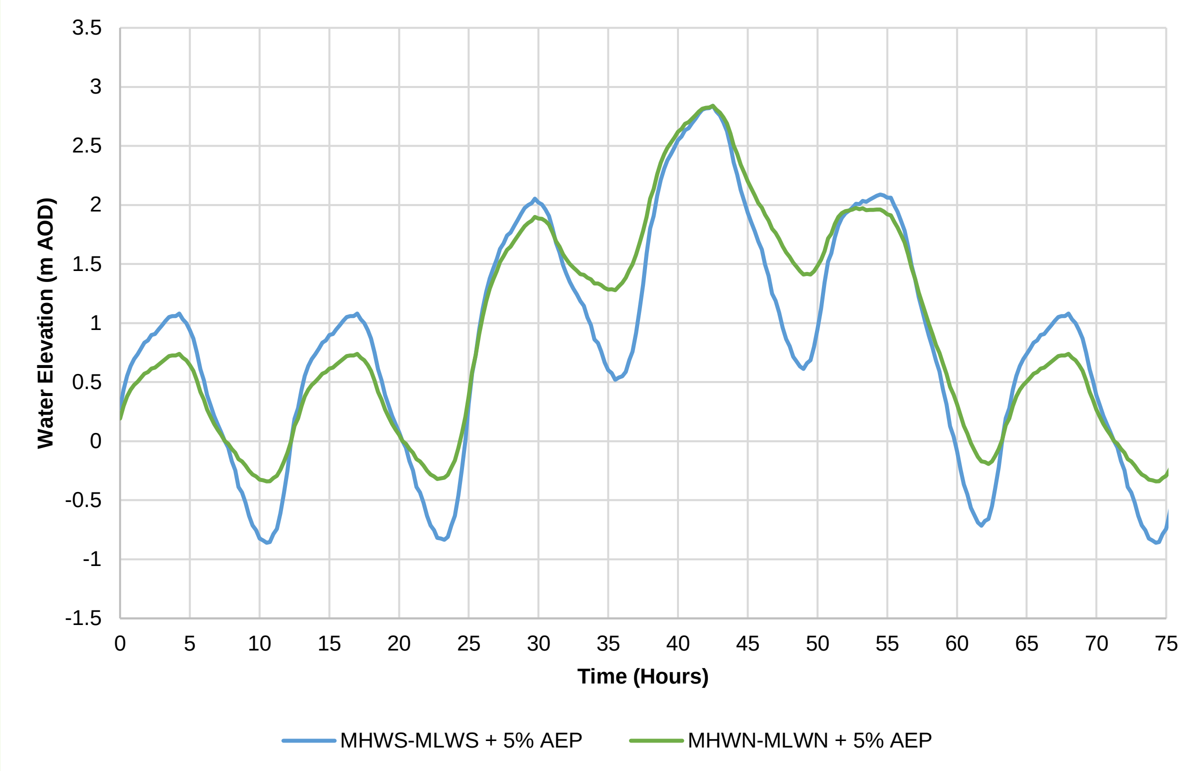

Plate 3.5: Tidal Curves for all Events

Sensitivity Testing

3.2.21 For this assessment, no additional curves are required for the sensitivity testing.

Climate Change Calculations

3.2.22 For this assessment, climate change scenario is not considered therefore no climate change curves have been created.

Conclusions

3.2.23 For the purpose of the sediment transport assessment, the tidal curves for each of the events have been created (Plate 3.5).The final curves generated will be used as the inflow boundary for the 3D hydraulic sediment model developed for the Scheme.

Limitations

3.2.24 There are a number of limitations highlighted in the guidance documents. These are presented in Plate 3.6.

Table 3.6: Limitations of the Tidal Curve Derivation Method

Limitation	Description
Extreme sea levels are considered accurate to one decimal place.	The extreme sea levels are considered accurate to one decimal place, two decimal places are provided only to differentiate between nodes on the chainage.
Extreme sea levels do not consider wave impacts.	The sea level values presented include effects from the storm surge but do not include any impact on local sea level due to onshore wave action.

3.2.25 The guidance document recognises flaws in the data used to produce the extreme sea levels, this is due to difficulty recording long-term sea level data. However, it is stated that this is the best possible method currently available and uses the most accurate initial conditions available. The limitations are considered acceptable for the accuracy required in a flood risk assessment therefore the extreme sea level curves will be used to assess flooding in Great Yarmouth due to the Scheme.

Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11D: HAWRAT Assessment

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11D

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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1 HAWRAT Assessment

1.1 Introduction

1.1.1 The assessment informs Chapter 11: Road Drainage and the Water Environment of the Environment Statement (ES) in relation to potential impacts of the Great Yarmouth Third River Crossing ("the Scheme"), specifically highway runoff, on water quality.

1.1.2 The Scheme will increase impermeable road surface and alter the current traffic flow regime. This has the potential to affect the volume and quality of surface water runoff from the road surface that in turn may affect the quality of the receiving water environment. The purpose of this assessment is to assess the potential impact of the Scheme on the chemical quality of the water environment.

1.1.3 The approach that has been adopted follows the approach promoted in Method A and Method D of the Design Manual for Roads and Bridges (DMRB) Volume 11, Part 10, Section 3 (Ref 11D.1):

- Method A is used to assess pollution impacts from routine runoff to surface waters; and
- Method D is used to assess pollution impacts from accidental spillage.

1.1.4 The methods are implemented using the DMRB HAWRAT assessment tool.

1.1.5 Method C is used to assess pollution impacts from routine runoff to groundwater. However, the disposal of road runoff via infiltration is not proposed in the Drainage Strategy (Appendix 12C (document reference 6.2)) due to high groundwater levels in the Principal Application Site and any drainage features will be lined to limit any infiltration of polluted runoff to the underlying groundwater. As such the effects of routine runoff on groundwater are considered negligible, therefore Method C has not been undertaken as part of the HAWRAT assessment.

1.1.6 The HAWRAT assessment focusses on permanent risks during the operational phase of the Scheme and does not consider risks during the construction phase as the methodology is not appropriate for assessing impacts associated with construction traffic. Potential impacts to chemical water quality during construction are qualitatively assessed within Section 11.8 of Chapter 11: Road Drainage and the Water Environment.

1.2 Assessment Parameters

1.2.1 The Scheme involves the construction, operation and maintenance of a new crossing of the River Yare in Great Yarmouth. The Scheme consists of a new dual carriageway road, including a road bridge across the river, linking the A47 at Harfrey's Roundabout on the western side of the river to the A1243 South Denes Road on the eastern side.

1.2.2 The Scheme aims to relieve traffic that at present must travel through the town centre and will increase traffic flows in the immediate vicinity of the Principal Application Site. The forecast with-Scheme 24-hour two-way Annual Average Daily Traffic (AADT) flow for the 2038 scenario is estimated as 18,195 for the existing William Adams Way adjacent to Harfrey's Roundabout, compared with 15,608 under the baseline condition. The forecast AADT traffic flows for the new bridge crossing and highway (including the new roundabout) are estimated as 23,041. Both the baseline and forecast with-Scheme traffic flows are in the lowest range assessed using the HAWRAT tool, $\geq$ 10,000 to $<$ 50,000. Approximately 4% of this will comprise Heavy Goods Vehicles (HGVs).

1.2.3 New highway drainage is proposed for the Scheme and the key principles of the Drainage Strategy (Appendix 12C (document reference 6.2)) are stated as follows:

The western side of the Scheme - the section of the Scheme due west of the bridge mid-point (Total area = 3.3ha)

- Runoff from the western side of the Scheme will be attenuated and discharged either via gravity into the existing Internal Drainage Board (IDB) ordinary watercourse network adjacent to the Scheme or via a pumped system into the River Yare. This assessment investigates the potential effects of both discharge options.
- Runoff to be attenuated to as close as practical to greenfield runoff rates for the 1 in 100-year event, including climate change. Where this is not achievable, the post development runoff rates and volumes should not exceed existing scenario values. The required attenuation storage will, as a minimum, consist of an underground storage tank and a pond/wetland feature.
- Runoff will be treated before discharge. Pollution control measures will include proprietary treatment devices (vortex separator) and natural treatment in the form of wet pond/wetland feature. Penstocks are also proposed as control of spillages.

The eastern side of the Scheme - the section of the Scheme due east of the bridge mid-point (Total area=0.9ha)

- Runoff from the eastern side of the Scheme will be discharged into existing Anglian Water combined sewer.
- Runoff to be attenuated, via oversized pipes and/or underground storage tanks, to achieve the restricted discharge rate of 10l/s as agreed with Anglian Water.
- Runoff to be treated, via proprietary devices, before discharge into the Anglian Water combined sewer.

1.2.4 The proposed drainage areas for the western and eastern side of the Scheme were estimated based on the General Arrangement Plans (document reference 2.2), which include a combination of permeable and impermeable area that contribute to the respective outfalls. In order to account for the limits of deviation that will allow for minor changes to the highway design and subsequently the drainage areas for the Scheme, the HAWRAT assessment has investigated the potential effects of increasing the impermeable surface area by 15%. Given the limited space within the Principal Application Site, it is not expected that the drainage areas would deviate by more than 15%.

1.3 Assessment Approach: Method A

Scope of the Assessment

1.3.1 Method A assesses the risks of water pollution within the receiving watercourse associated with the proposed routine discharges from the Scheme. The assessment has only been completed for the western side of the Scheme, which is currently known to discharge into the IDB watercourse network adjacent to the Scheme. The drainage catchment for this side of the Scheme has an impermeable area of 2.5ha based on the General Arrangement Plans (document reference 2.2). The assessment has also considered the potential impacts of increasing the impermeable area by 15% (i.e. up to 2.88ha) to allow for the limits of deviation provided for in the DCO.

1.3.2 Highway runoff from the eastern part of the Scheme will undergo two stages of treatment; first via proprietary devices installed as part of the Scheme Drainage Strategy (Appendix 12C (document reference 6.2)), prior to discharge into Anglian Water combined sewer, and second where discharged runoff will be treated alongside existing flows as part of Anglian Water's treatment processes. Given discharges from the eastern side of the Scheme will be incorporated into Anglian Water's treatment system, and Anglian Water has confirmed this will not affect the performance of their sewage treatment works, the effects have not been considered further in this assessment.

1.3.3 Two separate HAWRAT assessments have been completed:

- Scenario 1: Discharge to the existing IDB watercourse network adjacent to the Scheme. This IDB network, which forms part of the surface water drainage for the urban areas of Great Yarmouth, is connected to the wider network of dykes and drains within the Waveney, Lower Yare & Lothingland IDB district. Water level within the IDB district is managed by pumping, which removes excessive runoff from the marshes, urban area and the upland catchment to the River Yare.
- Scenario 2: Discharge to the River Yare. The River Yare is a transitional tidal waterbody through Great Yarmouth. The HAWRAT tool, used in this assessment, was designed to assess the impacts to freshwater bodies and is therefore not directly applicable to the assessment of impacts to transitional waters. Furthermore, given the size of the River Yare catchment at the Principal Application Site (estimated to be around 3,130km^2), its current use for commercial and recreational navigation, and the regular dredging activities to remove accumulated sediment, it is considered highly unlikely that the Scheme would pose a notable risk to water quality. However, in order to quantify and therefore better understand the scale of potential impact, the HAWRAT assessment process has been applied to a freshwater scenario to enable consideration of likely pollutant concentrations and dilution requirements.

1.3.4 Two types of assessment are undertaken within the HAWRAT tool:

- Short-term impacts on aquatic ecology related to the intermittent nature of road runoff. For an individual outfall to pass the HAWRAT assessment it must pass both the soluble pollutant and sediment pollutant impacts.
- Long-term impacts based on annual average concentration of certain hazardous pollutants, as defined under the Water Framework Directive (WFD). The long-term risks over the period of one year are assessed through comparison of the annual average concentration of pollutants discharged with the published Environmental Quality Standards (EQS) for those pollutants.

1.3.5 HAWRAT is a tiered consequential system which involves up to three assessment stages, outlined as ‘steps’ within the assessment spreadsheet. These are detailed as follows:

- Step 1 uses statistical models to determine pollutant concentrations in raw road runoff prior to any treatment or dilution in the receiving watercourse;

- Step 2 assess pollutant concentrations after dilution and dispersion in the receiving watercourse, but without active mitigation; and
- Step 3 considers the pollutant concentrations with active mitigation. Pollution control measures proposed as part of the Drainage Strategy (Appendix 12C (document reference 6.2)) will include a vortex separator to treat runoff that discharges into the underground storage tank and natural treatment in the form of wet pond/wetland feature. However, the proportion of the Scheme (western side) contributing to the underground storage via the vortex separator and the proportion contributing to the pond/wetland feature are currently unknown. Hence, it is assumed that the entire western side of the Scheme will contribute to the underground storage via the vortex separator to provide the worst-case scenario. A vortex separator is effective in the removal of fine sediment, sediment-bound pollutants and hydrocarbons. However, its ability to remove soluble metals is considered limited.

Assessment Parameters

1.3.6 Information used to complete the HAWRAT assessments for both discharge scenarios are summarised in Table 1.1

Table 1.1: Summary of Input Data for HAWRAT Assessments

Input Data	Discharge Locations	
	IDB Watercourse	River Yare
Impermeable area drained to outfall (ha)	2.5 (and 2.88 to allow for limits of deviation)	2.5 (and 2.88 to allow for limits of deviation)
Permeable area drained to outfall (ha)	0.8	0.8
Standard Average Annual Rainfall (SAAR)	550mm based on rain gauges from nearby stations	550mm based on rain gauges from nearby stations
Base Flow Index (BFI)[1]	0.73	0.64
Water hardness	A low value of < 50mg $CaCO_3$/L was selected as a reasonable worst case as this information is uncertain	A low value of < 50mg $CaCO_3$/L was selected as a reasonable worst case as this information is uncertain
Estimated river width (m)	2	100

[1] Derived using the LowFlows 2 software based on characteristics of the catchment.

Input Data	Discharge Locations	
	IDB Watercourse	River Yare
Is the discharge in or within 1km upstream of a protected site for conservation?	No international / national designated conservation sites have been identified within 1km downstream from the point of discharge (the Breydon Water SSSI is located approximately 2km from the point of discharge)	Yes, the River Yare is included in the Outer Thames Estuary Special Protection Area (SPA)
Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge?	The IDB watercourse network is culverted in many places and a culvert structure is found within 100m of the point of discharge.	No - although on flood tides reverse flow occurs in the Yare at the point of discharge, the assessment has been undertaken assuming minimal flow (i.e. periods of slack tide when fluvial flow dominates).

Determining the Annual 95% River Flow

1.3.7 The HAWRAT tool requires an estimation of the 95 percentile (%) river flow to represent likely low flow conditions (and therefore potential for greatest impact). Consultation with the Environment Agency and the IDB has confirmed that they do not carry out or hold any flow measurements for the IDB watercourse network adjacent to the Scheme. It is expected that flows would be intermittent due to tidal influences and the largely urbanised nature of the catchment. Hence it is difficult to produce representative annual 95 percentile (%) river flows (Q95s) that feed into the assessment to determine the pollutant concentrations after dilution and dispersion in the receiving watercourse. Furthermore, given the potential ephemeral nature of the watercourse, the dilution capacity is likely to be limited with Q95s close to zero at times, in particular for the drier summer months.

1.3.8 According to the guidance provided in the DMRB (Ref 11D.1), if the Q95 value is less than $0.001m^3/s$, a figure of $0.001m^3/s$ should be used in the assessment. Due to the uncertainties associated with the flow rates and duration of the receiving watercourse, the assessment has been carried out based on a Q95 value of $0.001m^3/s$, i.e. the lowest value that should be used in the assessment, to reflect the limited dilution capacity of the watercourse and therefore the worst case.

1.3.9 Estimating an appropriate Q95 for the River Yare is equally problematic due to the transitional nature of the waterbody as it is influenced by both fluvial flows from the upper catchment and tidal inflows from the North Sea. The fluvial Q95 value has been used for this assessment, with no consideration of tidal inflows. This is considered a reasonable worst-case scenario as it represents the lowest flow rate in the River Yare, during periods of slack tide, when the dilution capacity is at its lowest. The river has a catchment area of around 3,130km^2 at the Principal Application Site and the Q95 flow was estimated to be approximately 4.5m^3/s.

Summary of Assessment

Scenario 1: Discharge to existing IDB watercourse network

1.3.10 The Scheme failed Step 1 of the HAWRAT assessment, which is the assessment of pollutant concentrations in raw road runoff prior to any treatment or dilution in the receiving watercourse. The findings of Step 2 and Step 3 of the HAWRAT assessment, which assess pollutant concentrations after dilution and dispersion in the receiving watercourse without and with active mitigation, respectively, are summarised in Table 1.2 (details provided in Annex A), with a review of this assessment provided below.

Table 1.2: Summary of HAWRAT Assessment of Pollution Risks to IDB Watercourse

Assessment stage	Impermeable area (ha)	Short Term Pollutant Impacts			Long Term Pollutant Impacts	
		Acute impact assessment of Copper	Acute impact assessment of Zinc	Sediment (chronic impact)	Annual average concentration of Copper (µg/l) due to road runoff	Annual average concentration of Zinc (µg/l) due to road runoff
Step 2 (no mitigation)	2.5	FAIL	FAIL	FAIL	0.79	1.79
Step 3 (with mitigation)	2.5	FAIL	FAIL	PASS* (but alert due to presence of downstream structure)	0.79	1.79
Step 2 (no mitigation)	2.88	FAIL	FAIL	FAIL	0.86	1.95
Step 3 (with mitigation)	2.88	FAIL	FAIL	PASS* (but alert due to presence of downstream structure)	0.86	1.95
* The vortex separator is assumed to have 80% removal capability for fine sediment.[2]						

[2] Percentage removal is based on industry design standard for a hydrodynamic vortex separator - information provided by Hydro International for their product, Downstream Defender, which is an advanced hydrodynamic vortex separator (Ref 11D.2).

1.3.11 The HAWRAT tool indicates the acute concentration of pollutants generated by the Scheme would exceed the acceptable threshold values for both Copper and Zinc set by the DMRB methodology (Ref 11D.1), thus failing the assessment of short-term pollutant impacts. Due to the presence of culvert structures along the IDB watercourse, which could potentially lower the flow velocity, the HAWRAT tool also indicates there would be extensive settlement of sediments, causing the watercourse to fail the assessment of sediment-bound pollutants. Given the ephemeral nature of the IDB watercourse, there is insufficient dilution to pass the HAWRAT assessment without active mitigation.

1.3.12 With the incorporation of the vortex separator as pollution control, the Scheme would pass the assessment of sediment-bound pollutants, but there remains a risk of impact due to the presence of a culvert structure downstream from the point of discharge, which could potentially reduce flow velocity and encourage the deposition of sediment. However, the volume of sediment entering the receiving watercourse following mitigation would be small, hence the effect of the downstream structure is considered to be insignificant.

1.3.13 The Scheme still fails the assessment of short-term pollutant impacts due to the limited capability of the vortex separator to remove soluble metals. However, it is important to note that the current assessment assumed the worst case whereby the entire western part of the Scheme was assessed to contribute to the underground storage via the vortex separator. It is understood that a proportion of the Scheme would discharge into a wet pond, which has the potential to remove up to 50 - 80% of soluble heavy metals, according to Table 3.7 of CIRIA C609, Sustainable drainage systems – Hydraulic, structural and water quality advice (Ref 11D.3). Furthermore, the CCTV survey conducted as part of the Drainage Strategy (Appendix 12C (document reference 6.2)) and consultation with the IDB has confirmed that the majority of the existing highway in the vicinity of the Scheme drains into the same IDB watercourse with no known treatment measures incorporated. Given the risk of pollution already exists in this waterbody due to existing highway discharges, runoff from the Scheme is not expected to cause significant deterioration in water quality in the IDB watercourse, even if runoff is discharged untreated.

1.3.14 As shown in Table 11D.2, the outcomes and subsequently the conclusion of the assessment of short-term pollutants in the IDB watercourse would remain unchanged with the increase in impermeable road area to account for deviation in highway design for the western side of the Scheme.

1.3.15 HAWRAT also provides an assessment of long-term pollution impacts to the receiving water environment, which considers the annual average pollutant concentrations associated with the Scheme against the EQS that inform the WFD. The threshold values in the DMRB (Ref 11D.1) are 1 µg/l in the water hardness band of < 50mg/l $CaCO_3$ for Copper and 7.8 µg/l in all water hardness bands for Zinc. The results of the HAWRAT assessment indicate annual average concentrations of Copper and Zinc are below these threshold values. With the increase in impermeable area, the concentrations would increase but only marginally and the values are still below the threshold. Therefore, in themselves, discharges from the Scheme would not result in the EQS values being exceeded at the point of discharge. The EQS values may be exceeded when taking into account existing discharges to the local IDB drains, however the estimated topographical catchment to the point of discharge is approximately 2 km^2, comprising large areas of urban development and highway. The drained area from the Scheme (~ 3.3 ha based on current highway design and ~3.7 ha that allows for deviation) represents less than 2% of this catchment, therefore discharges from the Scheme will not significantly affect the water quality in these drains.

1.3.16 Contaminants released into the IDB watercourse network adjacent to the Scheme could be transported downstream to impact on the water quality of the wider network of dykes and drains within the IDB district, in particular the more sensitive marshland south of Breydon Water. However, a comparison of the catchment areas at the point of discharge (approximately $2km^2$) and at the marshland (approximately $12km^2$), suggests the contaminants would have been sufficiently diluted and dispersed before reaching the main dyke system within the marshes (Plate 1.1). It is therefore highly unlikely that highway discharges from the Scheme would have any significant effect on the water quality of the wider IDB catchment.

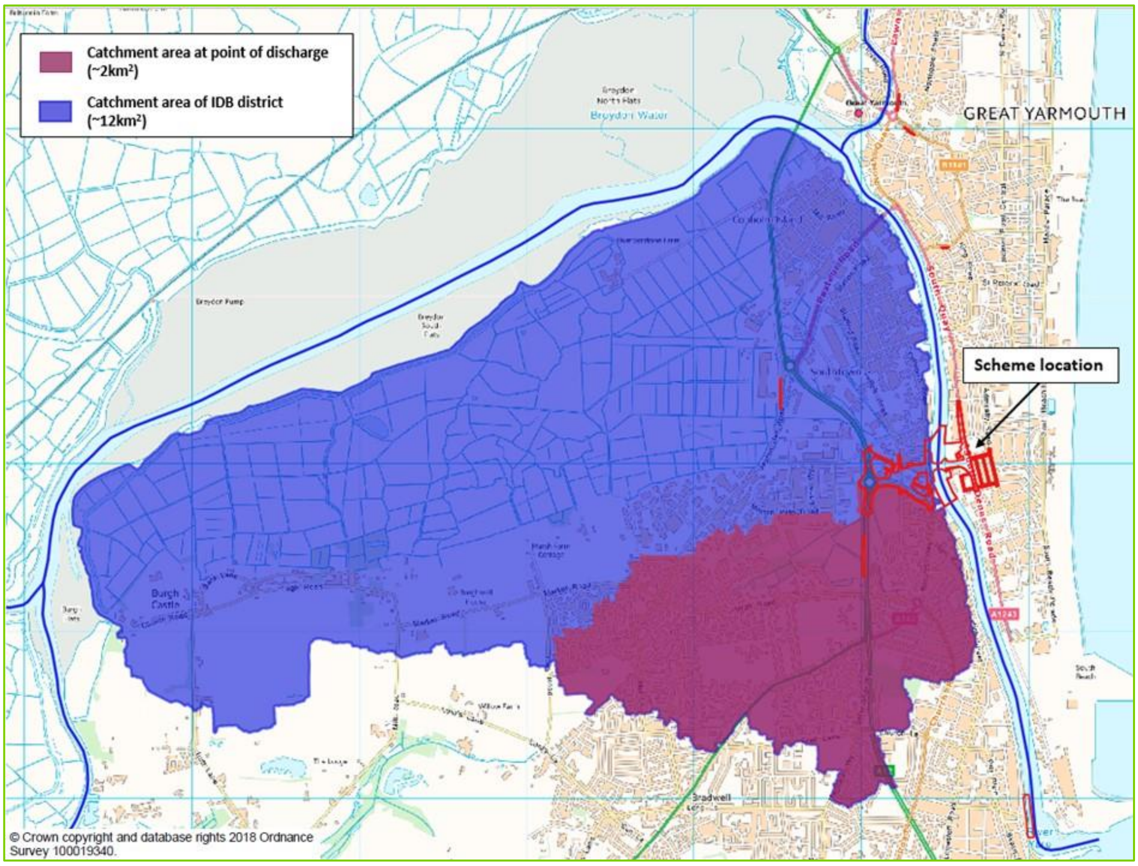


Plate 1.1: A Comparison of the Wider IDB Catchment and the Catchment at the Point of Discharge

Scenario 2: Discharge to the River Yare

1.3.17 With the option of discharging into the River Yare, the Scheme would pass Step 2 of the HAWRAT assessment, which takes into account dilution and dispersion in the river, without active mitigation being necessary. Table 1.3 summarises the findings of the Step 2 assessment (details provided in Annex A), with a review of this assessment provided below.

Table 1.3: Summary of HAWRAT Assessment of Pollution Risks to the River Yare

Assessment stage	Impermeable area (ha)	**Short Term Pollutant Impacts**			**Long Term Pollutant Impacts**	
		Acute impact assessment of Copper	Acute impact assessment of Zinc	Sediment (chronic impact)	Annual average concentration of Copper (µg/l) due to road runoff	Annual average concentration of Zinc (µg/l) due to road runoff
Step 2 (no mitigation)	2.5	PASS	PASS	PASS (but alert as runoff is discharged into a protected area)	0.00	0.00
Step 2 (no mitigation)	2.88	PASS	PASS	PASS (but alert as runoff is discharged into a protected area)	0.00	0.00

1.3.18 The HAWRAT tool indicates the acute concentration of pollutants generated by the Scheme would be below the acceptable threshold values set by the DMRB methodology (Ref 11D.1), with consideration of the dilution potential within the River Yare. It is anticipated that the dilution capacity of the river would be significantly greater than that assessed in the HAWRAT, due to tidal flows which were not considered in the assessment. Hence, the Scheme is not expected to pose a short term pollution risk to this waterbody. The results for the assessment of sediment deposition indicate there would be limited settlement of sediment and associated sediment-bound pollutants in the River Yare. However, the assessment still alerted a potential risk of impact because the River Yare is included in the Outer Thames Estuary SPA. Given the river is already regularly dredged for navigation, the potential increase in sediment and sediment-bound pollutants associated with highway discharges from the Scheme is not considered to pose a notable impact.

1.3.19 With respect to long-term pollution impacts, the results of the HAWRAT assessment indicate annual average concentrations of Copper and Zinc associated with the Scheme would be zero. This is to be expected given the significant dilution capacity of the River Yare. Highway runoff discharges from the Scheme represent a very small proportion of the flow in the Yare and will therefore not have any notable effect on existing pollutant concentrations.

1.3.20 It can be seen from Table 11D.3 that the increase in impermeable road area within the limits of deviation has not altered the results of the HAWRAT assessment for the River Yare.

1.3.21 Consultation has been carried out with the Environment Agency to request relevant water quality sampling data for the River Yare waterbody. The data showed that both the maximum and annual mean concentrations of the sampled elements, including Arsenic, Ammonia, Mercury, heavy metals such as Cadmium, Lead, Copper, Zinc, and Nonylphenol, are all below the transitional waters EQS used to inform the WFD. This suggests the waterbody is not at pressure relating to these elements, which are contaminants that could be found in road runoff. The HAWRAT assessment shows the Scheme discharges will not lead to a change in existing pollutant concentrations and therefore discharges from the Scheme will not affect the water quality in the River Yare.

1.3.22 Step 3 of the HAWRAT assessment was not completed for this scenario as the Scheme passes the HAWRAT assessment at Step 2.

1.4 Assessment Approach: Method D

Scope of the Assessment

1.4.1 Method D of the DMRB assesses the risk of pollution from spillages occurring during operation of the Scheme – i.e. if an accident were to occur. The assessment considers likely spillage rates based on the nature of the road (i.e. presence of slip roads, roundabouts, junctions, etc. that can increase risk) and the percentage of the AADT that comprises HGVs.

1.4.2 The assessment is designed to consider spillage risks to motorways and A-roads and, as such, is not directly applicable to this Scheme given the slower speeds of vehicles using these roads. The assessment will, however, give an indication of potential risks should an accident occur. Similar to the Method A assessment, this assessment has only been completed for the western side of the Scheme. The length of road considered in this assessment measures approximately 645m.

Assessment Parameters

1.4.3 The following information has been used to complete the HAWRAT Method D assessment:

- Outfall will drain to a surface watercourse;
- The road type was selected as an A-road in an urban area;
- Response time taken as <20 minutes as the site is urban;
- Two-way AADT of 23,041 vehicles for the new bridge crossing and highway;
- 4% HGV traffic.

1.4.4 The DMRB (Ref 11D.1) provides spillage rates for different types of junctions and for lengths of road within 100m of these junctions.

Summary of Assessment

1.4.5 A summary of this information is provided in Table 1.4, noting that only new junctions have been considered and that the assessment (details provided in Annex B) has been completed without and with the consideration of mitigation.

Table 1.4: Summary of HAWRAT Assessment of Pollution Impacts from Spillages

Assessment type	Type of junction	Length of carriageway within 100m of junction	Spillage rates (Table D1.1 (Ref 11D.1),)	Annual probability of a serious pollution incident
No mitigation	New five-arm roundabout	420	5.35	0.00034 (0.034%)
	Carriageway not within 100m of junction	225	0.31	0.00001 (0.001%)
With mitigation (spillage control penstocks with a pollution reduction factor of 0.4 (60%))	New five-arm roundabout	420	5.35	0.00014 (0.014%)
	Carriageway not within 100m of junction	225	0.31	0.00000 (0.0%)

1.4.6 The DMRB (Ref 11D.1) recommends that an annual probability of a serious pollution incident occurring of less than 1% would be acceptable. The results of the HAWRAT assessment without the consideration of mitigation indicate a total annual probability of 0.035%, which is well below this threshold.

1.4.7 Although the estimated spillage risk is below the DMRB threshold, it is considered good practice to incorporate mitigation measures of spillage containment. The use of penstocks has been proposed as part of the Drainage Strategy (Appendix 12C (document reference 6.2)) to control spillage. According to Table 8.1 of DMRB Volume 11, Part 10, Section 3 (Ref 11D.1), this has the potential to reduce the risk by 60%, which subsequently reduces the annual probability of a serious pollution incident to 0.014%.

2 References

Ref 11D.1: Design Manual for Roads and Bridges Volume 11, Section 3, Part 10 (HD 45/09) Road Drainage and the Water Environment, former Highways Agency, November 2009.

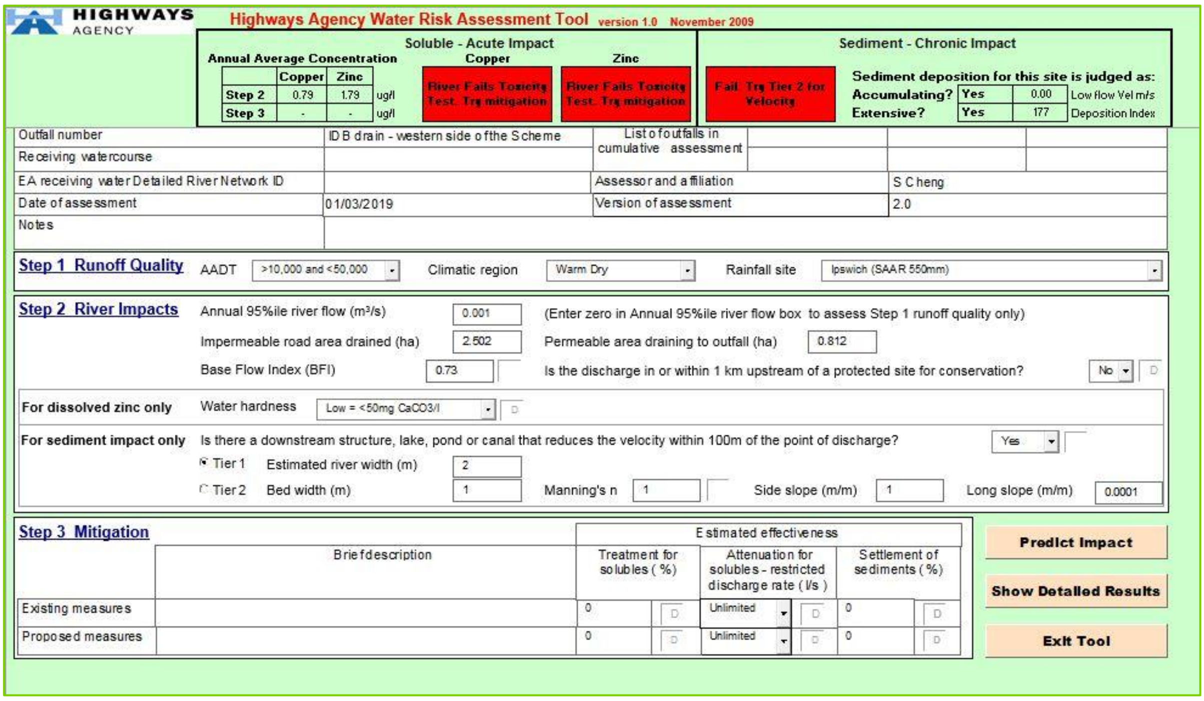
Ref 11D.2: Hydro International (2016, online). Downstream Defender Design Data Sheet.

Ref 11D.3: CIRIA (2004). CIRIA C609, Sustainable Drainage Systems – Hydraulic, structural and water quality advice.

Annex A: Details of the Method A Assessment

Scenario 1: Discharge to existing IDB watercourse (2.5ha impermeable area)

Without Active Mitigation



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Summary of predictions

	Soluble - Acute Impact		Sediment - Chronic Impact							
	Copper	Zinc	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Prediction of impact – Step1										
Step2										
Step3										

DETAILED RESULTS

In Runoff

Step 1 – Soluble

RST24	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	**33.60**	**21.80**
No. of exceedances/worst year	41	29

RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	**10.70**	**7.50**
No. of exceedances/worst year	17	13

	Copper (ug/l)	Zinc (ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	25.75	60.02
90%ile	49.14	126.87
95%ile	62.68	162.41
99%ile	86.03	300.69

Step 1 – Sediment (Toxicity Threshold)

	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Allowable Exceedances/year	1	1	1	1	1	1	1	1
No. of exceedances/year	**42.60**	**53.10**	**0.30**	**8.10**	**27.50**	**8.10**	**6.60**	**15.00**
No. of exceedances/worst year	52	58	1	15	36	15	11	22
Units	(mg/kg)	(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
Toxicity	197	315	3.5	16770	875	2355	245	515
Event Statistics Mean	367	1308	1	10016	1733	1663	106	469
90%ile	776	3117	1	22387	3873	3716	237	1048
95%ile	1027	3835	2	56234	9729	9335	596	2632
99%ile	1453	7397	3	112202	19411	18626	1189	5251

In River (no mitigation)

Step 2

RST24	Copper	Zinc
Allowable Exceedances/year	2	2
No. of exceedances/year	**2.8**	**2.8**
No. of exceedances/worst year	6	4
No. of exceedances/summer	1.9	1.5
No. of exceedances/worst summer	4	4

RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	**0.4**	**0.6**
No. of exceedances/worst year	3	2
No. of exceedances/summer	0.4	0.3
No. of exceedances/worst summer	3	2
Annual average concentration (ug/l)	0.79	1.79

	Copper (ug/l)	Zinc (ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	6.47	15.44
90%ile	14.73	36.06
95%ile	20.08	53.48
99%ile	32.92	109.56

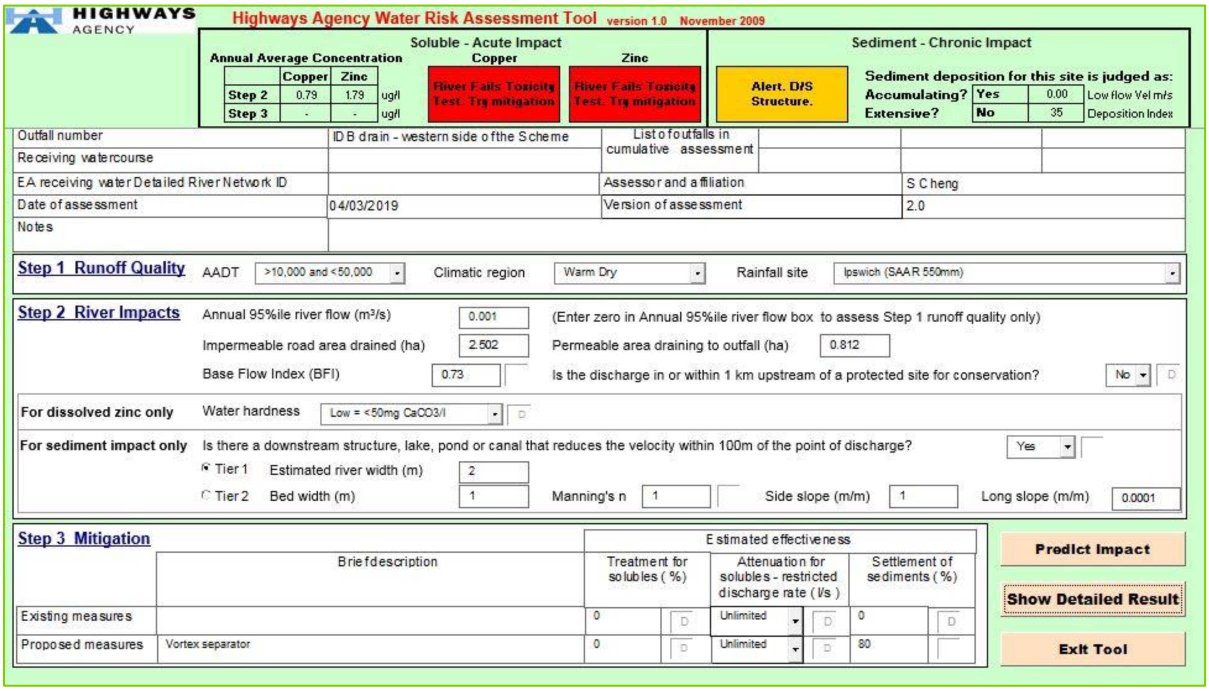
Step 2

Velocity 0.00 m/s — Tier 1 is used for the calculation

DI 177.25

% settlement needed 44 %

With Active Mitigation (vortex separator with assumed 80% removal of fine sediment)



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Soluble - Acute Impact

Annual Average Concentration	Copper	Zinc	
Step 2	0.79	1.79	ug/l
Step 3	-	-	ug/l

Copper: River Fails Toxicity Test. Try mitigation
Zinc: River Fails Toxicity Test. Try mitigation

Sediment - Chronic Impact
Alert. D/S Structure.
Sediment deposition for this site is judged as:
Accumulating? Yes 0.00 Low flow Vel m/s
Extensive? No 35 Deposition Index

Outfall number	IDB drain - western side of the Scheme	List of outfalls in cumulative assessment	
Receiving watercourse			
EA receiving water Detailed River Network ID		Assessor and affiliation	S Cheng
Date of assessment	04/03/2019	Version of assessment	2.0
Notes			

Step 1 Runoff Quality AADT >10,000 and <50,000 Climatic region Warm Dry Rainfall site Ipswich (SAAR 550mm)

Step 2 River Impacts
Annual 95%ile river flow (m³/s) 0.001 (Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)
Impermeable road area drained (ha) 2.502 Permeable area draining to outfall (ha) 0.812
Base Flow Index (BFI) 0.73 Is the discharge in or within 1 km upstream of a protected site for conservation? No

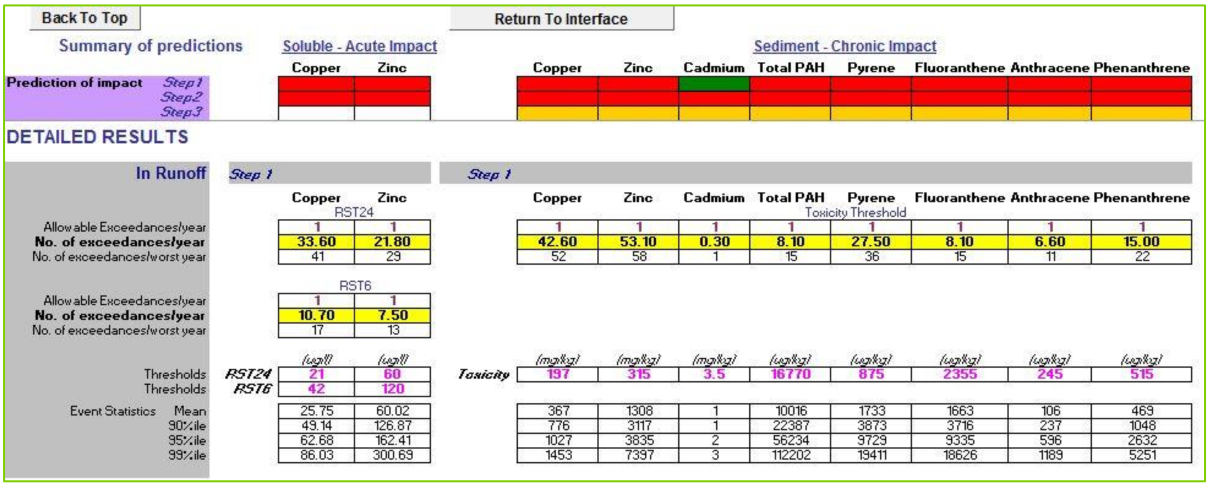
For dissolved zinc only: Water hardness Low = <50mg CaCO3/l

For sediment impact only: Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? Yes
Tier 1 Estimated river width (m) 2
Tier 2 Bed width (m) 1 Manning's n 1 Side slope (m/m) 1 Long slope (m/m) 0.0001

Step 3 Mitigation

	Brief description	Estimated effectiveness: Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures	Vortex separator	0	Unlimited	80

Predict Impact
Show Detailed Result
Exit Tool



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Summary of predictions: Soluble - Acute Impact (Copper, Zinc); Sediment - Chronic Impact (Copper, Zinc, Cadmium, Total PAH, Pyrene, Fluoranthene, Anthracene, Phenanthrene)

Prediction of impact: Step 1, Step 2, Step 3

DETAILED RESULTS

In Runoff — Step 1 (Soluble)

	Copper	Zinc
RST24		
Allowable Exceedances/year	1	1
No. of exceedances/year	33.60	21.80
No. of exceedances/worst year	41	29
RST6		
Allowable Exceedances/year	1	1
No. of exceedances/year	10.70	7.50
No. of exceedances/worst year	17	13
	(ug/l)	(ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	25.75	60.02
90%ile	49.14	126.87
95%ile	62.68	162.41
99%ile	86.03	300.69

Step 1 (Sediment) — Toxicity Threshold

	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Allowable Exceedances/year	1	1	1	1	1	1	1	1
No. of exceedances/year	42.60	53.10	0.30	8.10	27.50	8.10	6.60	15.00
No. of exceedances/worst year	52	58	1	15	36	15	11	22
	(mg/kg)	(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
Toxicity	197	315	3.5	16770	875	2355	245	515
Event Statistics Mean	367	1308	1	10016	1733	1663	106	469
90%ile	776	3117	1	22387	3873	3716	237	1048
95%ile	1027	3835	2	56234	9729	9335	596	2632
99%ile	1453	7397	3	112202	19411	18626	1189	5251

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Summary of predictions

Prediction of impact	Soluble - Acute Impact: Copper	Soluble - Acute Impact: Zinc	Sediment - Chronic Impact: Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Step1										
Step2										
Step3										

In River (no mitigation)

Step 2

RST24	Copper	Zinc
Allowable Exceedances/year	2	2
No. of exceedances/year	**2.8**	**2.8**
No. of exceedances/worst year	6	4
No. of exceedances/summer	1.9	1.5
No. of exceedances/worst summer	4	4

RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	**0.4**	**0.6**
No. of exceedances/worst year	3	2
No. of exceedances/summer	0.4	0.3
No. of exceedances/worst summer	3	2
Annual average concentration (ug/l)	0.79	1.79

		Copper (ug/l)	Zinc (ug/l)
Thresholds	RST24	21	60
Thresholds	RST6	42	120
Event Statistics	Mean	6.47	15.44
	90%ile	14.73	36.06
	95%ile	20.08	53.48
	99%ile	32.92	109.56

Step 2

Velocity 0.00 m/s — Tier 1 is used for the calculation

DI 177.25

% settlement needed 44 %

In River (with mitigation)

Step 3

RST24	Copper	Zinc
Allowable Exceedances/year	2	2
No. of exceedances/year	-	-
No. of exceedances/worst year	-	-
No. of exceedances/summer	-	-
No. of exceedances/worst summer	-	-

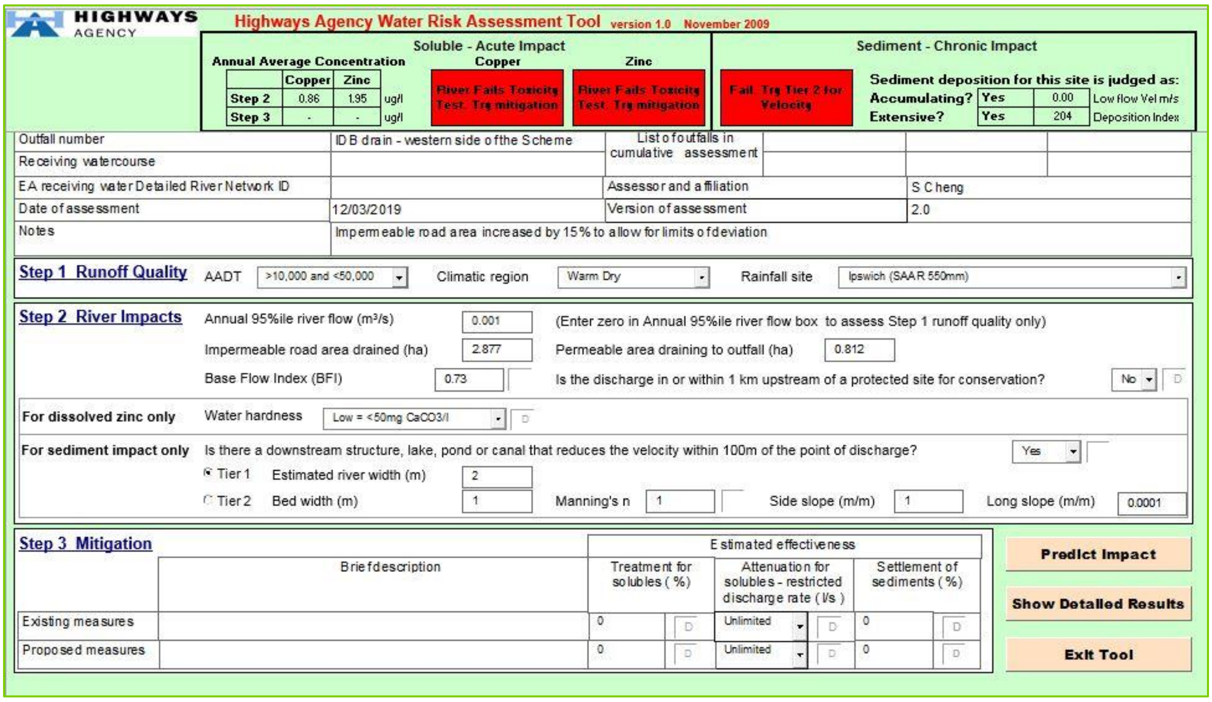
RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	-	-
No. of exceedances/worst year	-	-
No. of exceedances/summer	-	-
No. of exceedances/worst summer	-	-
Annual average concentration (ug/l)	-	-

		Copper (ug/l)	Zinc (ug/l)
Thresholds resholds	RST24	21	60
Thresholds	RST6	42	120
Event Statistics	Mean	-	-
	90%ile	-	-
	95%ile	-	-
	99%ile	-	-

DI 35.45

Scenario 1: Discharge to existing IDB watercourse (2.88ha impermeable area)

Without Active Mitigation



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Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.86	1.95	ug/l
Step 3	-	-	ug/l

Copper: River Fails Toxicity Test. Try mitigation

Zinc: River Fails Toxicity Test. Try mitigation

Sediment - Chronic Impact

Fail. Try Tier 2 for Velocity

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	Yes	204	Deposition Index

Outfall number	IDB drain - western side of the Scheme	List of outfalls in cumulative assessment	
Receiving watercourse			
EA receiving water Detailed River Network ID		Assessor and affiliation	S Cheng
Date of assessment	12/03/2019	Version of assessment	2.0
Notes	Impermeable road area increased by 15% to allow for limits of deviation		

Step 1 Runoff Quality AADT: >10,000 and <50,000 Climatic region: Warm Dry Rainfall site: Ipswich (SAAR 550mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.001 (Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.877 Permeable area draining to outfall (ha): 0.812

Base Flow Index (BFI): 0.73 Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only — Water hardness: Low = <50mg CaCO3/l

For sediment impact only — Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? Yes

Tier 1 (selected) Estimated river width (m): 2

Tier 2 Bed width (m): 1 Manning's n: 1 Side slope (m/m): 1 Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Estimated effectiveness: Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0

Predict Impact

Show Detailed Results

Exit Tool

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Summary of predictions

	Soluble - Acute Impact		Sediment - Chronic Impact							
	Copper	Zinc	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Prediction of impact *Step1*										
Step2										
Step3										

DETAILED RESULTS

In Runoff

Step 1

	Copper	Zinc
RST24		
Allowable Exceedances/year	1	1
No. of exceedances/year	33.60	21.80
No. of exceedances/worst year	41	29
RST6		
Allowable Exceedances/year	1	1
No. of exceedances/year	10.70	7.50
No. of exceedances/worst year	17	13
	(ug/l)	(ug/l)
Thresholds *RST24*	21	60
Thresholds *RST6*	42	120
Event Statistics Mean	25.75	60.02
90%ile	49.14	126.87
95%ile	62.68	162.41
99%ile	86.03	300.69

Step 1

	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Toxicity Threshold								
Allowable Exceedances/year	1	1	1	1	1	1	1	1
No. of exceedances/year	42.60	53.10	0.30	8.10	27.50	8.10	6.60	15.00
No. of exceedances/worst year	52	58	1	15	36	15	11	22
	(mg/kg)	(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
Toxicity	197	315	3.5	16770	875	2355	245	515
Event Statistics Mean	367	1308	1	10016	1733	1663	106	469
90%ile	776	3117	1	22387	3873	3716	237	1048
95%ile	1027	3835	2	56234	9729	9335	596	2632
99%ile	1453	7397	3	112202	19411	18626	1189	5251

In River (no mitigation)

Step 2

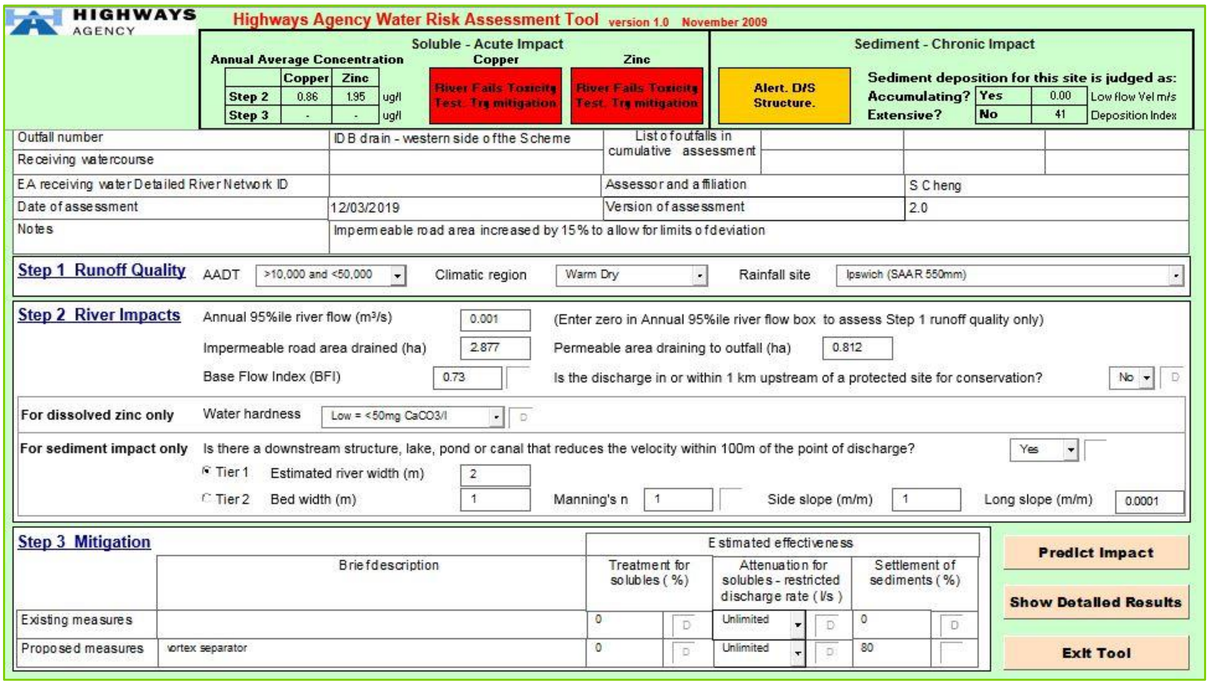
	Copper	Zinc
RST24		
Allowable Exceedances/year	2	2
No. of exceedances/year	3.7	3.2
No. of exceedances/worst year	8	5
No. of exceedances/summer	2.4	1.7
No. of exceedances/worst summer	4	5
RST6		
Allowable Exceedances/year	1	1
No. of exceedances/year	0.4	0.7
No. of exceedances/worst year	3	3
No. of exceedances/summer	0.4	0.3
No. of exceedances/worst summer	3	2
Annual average concentration (ug/l)	0.86	1.95
	(ug/l)	(ug/l)
Thresholds *RST24*	21	60
Thresholds *RST6*	42	120
Event Statistics Mean	7.01	16.74
90%ile	15.54	37.90
95%ile	21.21	56.65
99%ile	34.90	115.47

Step 2

Velocity	0.00	m/s
DI	203.82	
% settlement needed	51	%

Tier 1 is used for the calculation

With Active Mitigation (vortex separator with assumed 80% removal of fine sediment)



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Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.86	1.95	ug/l
Step 3	-	-	ug/l

Copper: River Fails Toxicity Test. Try mitigation

Zinc: River Fails Toxicity Test. Try mitigation

Sediment - Chronic Impact

Alert. D/S Structure.

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	No	41	Deposition Index

Outfall number	IDB drain - western side of the Scheme	List of outfalls in cumulative assessment	
Receiving watercourse			
EA receiving water Detailed River Network ID		Assessor and affiliation	S Cheng
Date of assessment	12/03/2019	Version of assessment	2.0
Notes	Impermeable road area increased by 15% to allow for limits of deviation		

Step 1 Runoff Quality AADT >10,000 and <50,000 Climatic region Warm Dry Rainfall site Ipswich (SAAR 550mm)

Step 2 River Impacts

Annual 95%ile river flow (m³/s) 0.001 (Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha) 2.877 Permeable area draining to outfall (ha) 0.812

Base Flow Index (BFI) 0.73 Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only: Water hardness Low = <50mg CaCO3/l

For sediment impact only: Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? Yes

Tier 1 Estimated river width (m) 2

Tier 2 Bed width (m) 1 Manning's n 1 Side slope (m/m) 1 Long slope (m/m) 0.0001

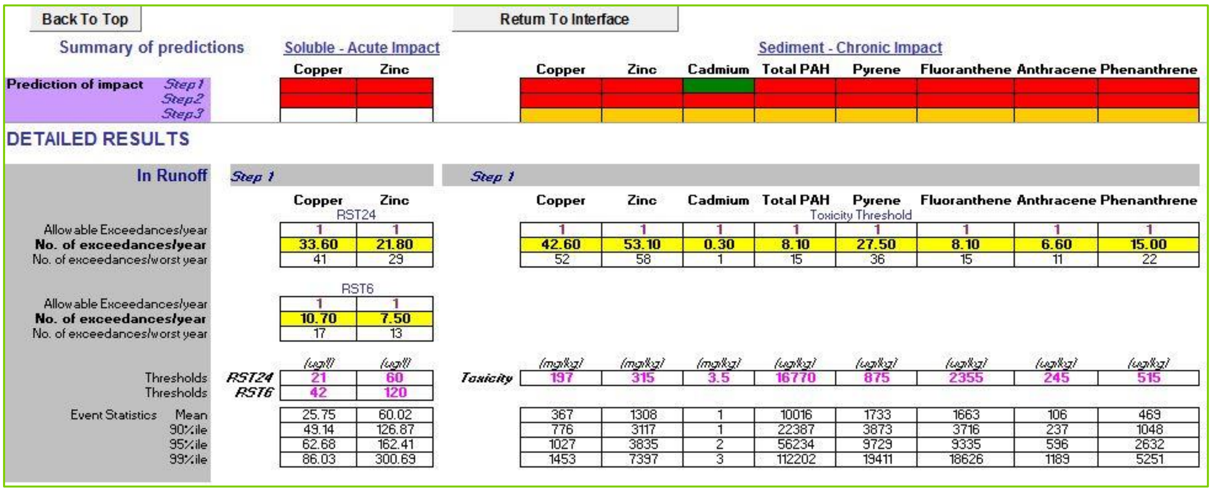
Step 3 Mitigation

	Brief description	Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures	vortex separator	0	Unlimited	80

Predict Impact

Show Detailed Results

Exit Tool



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Summary of predictions

Soluble - Acute Impact / Sediment - Chronic Impact

Prediction of impact: Step 1, Step 2, Step 3

DETAILED RESULTS

In Runoff

Soluble - Step 1

	Copper	Zinc
RST24		
Allowable Exceedances/year	1	1
No. of exceedances/year	33.60	21.80
No. of exceedances/worst year	41	29
RST6		
Allowable Exceedances/year	1	1
No. of exceedances/year	10.70	7.50
No. of exceedances/worst year	17	13
	(ug/l)	(ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	25.75	60.02
90%ile	49.14	126.87
95%ile	62.68	162.41
99%ile	86.03	300.69

Sediment - Step 1

	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Toxicity Threshold								
Allowable Exceedances/year	1	1	1	1	1	1	1	1
No. of exceedances/year	42.60	53.10	0.30	8.10	27.50	8.10	6.60	15.00
No. of exceedances/worst year	52	58	1	15	36	15	11	22
	(mg/kg)	(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
Toxicity	197	315	3.5	16770	875	2355	245	515
Event Statistics Mean	367	1308	1	10016	1733	1663	106	469
90%ile	776	3117	1	22387	3873	3716	237	1048
95%ile	1027	3835	2	56234	9729	9335	596	2632
99%ile	1453	7397	3	112202	19411	18626	1189	5251

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Summary of predictions

	Soluble - Acute Impact		Sediment - Chronic Impact							
	Copper	Zinc	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Prediction of impact *Step1*										
Step2										
Step3										

In River (no mitigation)

Step 2

RST24	Copper	Zinc
Allowable Exceedances/year	2	2
No. of exceedances/year	3.7	3.2
No. of exceedances/worst year	8	5
No. of exceedances/summer	2.4	1.7
No. of exceedances/worst summer	4	5

RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	0.4	0.7
No. of exceedances/worst year	3	3
No. of exceedances/summer	0.4	0.3
No. of exceedances/worst summer	3	2
Annual average concentration (ug/l)	0.86	1.95

		(ug/l)	(ug/l)
Thresholds	*RST24*	21	60
Thresholds	*RST6*	42	120

Event Statistics	Copper	Zinc
Mean	7.01	16.74
90%ile	15.54	37.90
95%ile	21.21	56.65
99%ile	34.90	115.47

Step 2

Velocity 0.00 m/s — **Tier 1** is used for the calculation

DI 203.82

% settlement needed 51 %

In River (with mitigation)

Step 3

RST24	Copper	Zinc
Allowable Exceedances/year	2	2
No. of exceedances/year	-	-
No. of exceedances/worst year	-	-
No. of exceedances/summer	-	-
No. of exceedances/worst summer	-	-

RST6	Copper	Zinc
Allowable Exceedances/year	1	1
No. of exceedances/year	-	-
No. of exceedances/worst year	-	-
No. of exceedances/summer	-	-
No. of exceedances/worst summer	-	-
Annual average concentration (ug/l)	-	-

		(ug/l)	(ug/l)
Thresholds resholds	*RST24*	21	60
Thresholds	*RST6*	42	120

Event Statistics	Copper	Zinc
Mean	-	-
90%ile	-	-
95%ile	-	-
99%ile	-	-

DI 40.76

Scenario 2: Discharge to the River Yare (2.5ha impermeable area)

HIGHWAYS AGENCY — Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.00	0.00	ug/l
Step 3	-	-	ug/l

Copper: Pass — Zinc: Pass

Sediment - Chronic Impact

Alert. Protected Area.

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.02	Low flow Vel m/s
Extensive?	No	2	Deposition Index

Outfall number	River Yare - western side of the Scheme	List of outfalls in cumulative assessment	
Receiving watercourse			
EA receiving water Detailed River Network ID		Assessor and affiliation	S Cheng
Date of assessment	01/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality — AADT: >10,000 and <50,000 — Climatic region: Warm Dry — Rainfall site: Ipswich (SAAR 550mm)

Step 2 River Impacts

- Annual 95%ile river flow (m³/s): 4.549 — (Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)
- Impermeable road area drained (ha): 2.502 — Permeable area draining to outfall (ha): 0.812
- Base Flow Index (BFI): 0.64 — Is the discharge in or within 1 km upstream of a protected site for conservation? Yes

For dissolved zinc only — Water hardness: Low = <50mg CaCO3/l

For sediment impact only — Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

- Tier 1 — Estimated river width (m): 100
- Tier 2 — Bed width (m): 1 — Manning's n: 1 — Side slope (m/m): 1 — Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0

Predict Impact — Show Detailed Results — Exit Tool

Back To Top — Return To Interface

Summary of predictions

Prediction of impact: Step1, Step2, Step3 — Soluble - Acute Impact (Copper, Zinc); Sediment - Chronic Impact (Copper, Zinc, Cadmium, Total PAH, Pyrene, Fluoranthene, Anthracene, Phenanthrene)

DETAILED RESULTS

In Runoff — Step 1

	Copper	Zinc
RST24		
Allowable Exceedances/year	1	1
No. of exceedances/year	33.60	21.80
No. of exceedances/worst year	41	29
RST6		
Allowable Exceedances/year	1	1
No. of exceedances/year	10.70	7.50
No. of exceedances/worst year	17	13
	(ug/l)	(ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	25.75	60.02
90%ile	49.14	126.87
95%ile	62.68	162.41
99%ile	86.03	300.69

Step 1 — Toxicity Threshold

	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Allowable Exceedances/year	1	1	1	1	1	1	1	1
No. of exceedances/year	42.60	53.10	0.30	8.10	27.50	8.10	6.60	15.00
No. of exceedances/worst year	52	58	1	15	36	15	11	22
	(mg/kg)	(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
Toxicity	197	315	3.5	16770	875	2355	245	515
Mean	367	1308	1	10016	1733	1663	106	469
90%ile	776	3117	1	22387	3873	3716	237	1048
95%ile	1027	3835	2	56234	9729	9335	596	2632
99%ile	1453	7397	3	112202	19411	18626	1189	5251

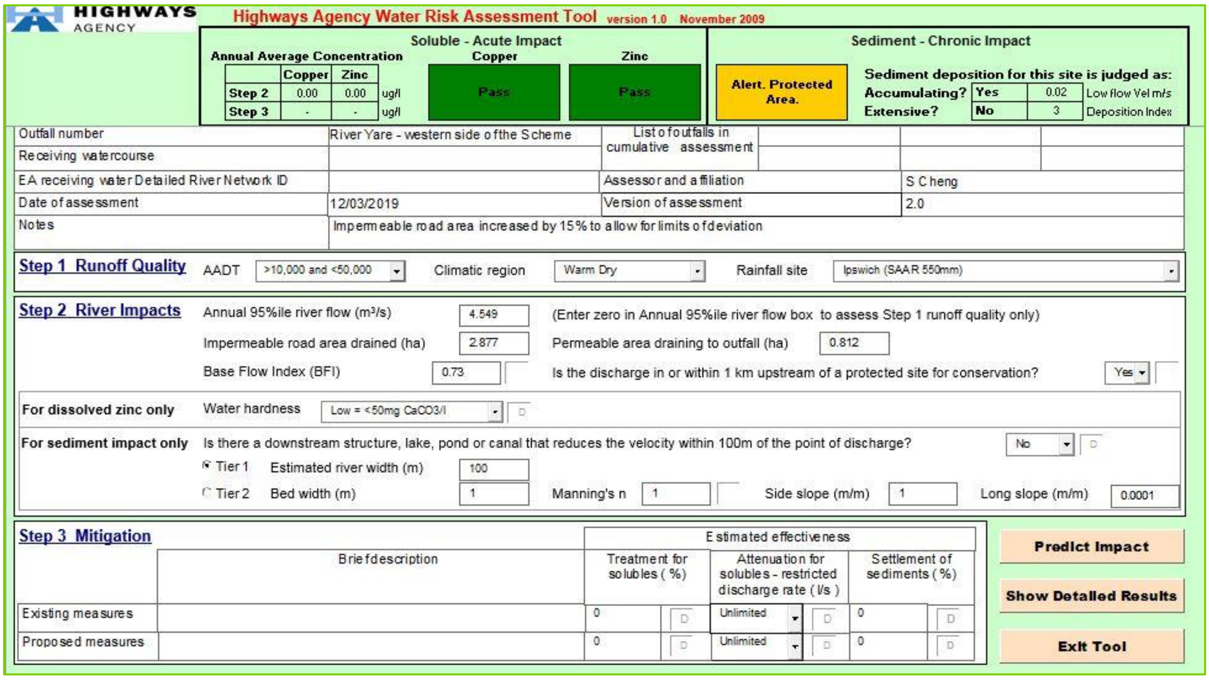
In River (no mitigation) — Step 2

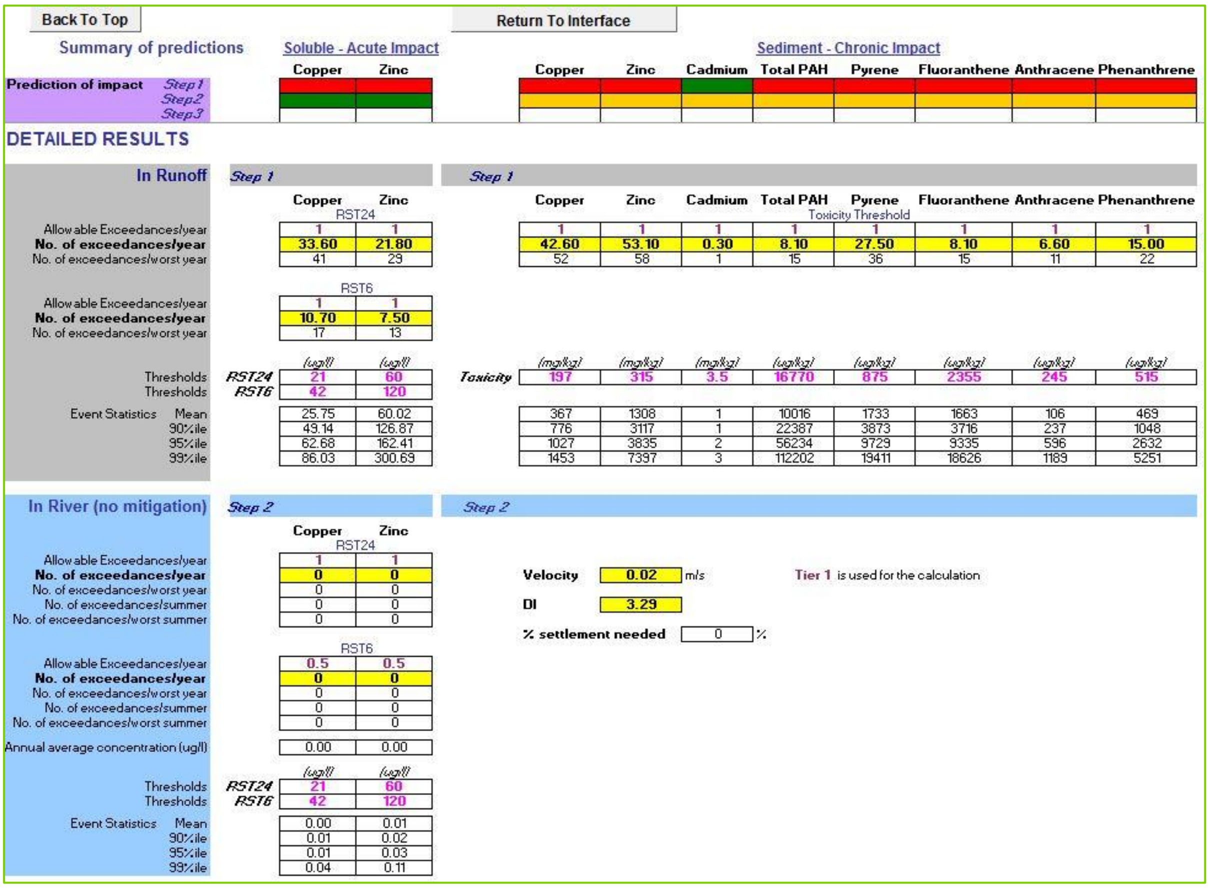
	Copper	Zinc
RST24		
Allowable Exceedances/year	1	1
No. of exceedances/year	0	0
No. of exceedances/worst year	0	0
No. of exceedances/summer	0	0
No. of exceedances/worst summer	0	0
RST6		
Allowable Exceedances/year	0.5	0.5
No. of exceedances/year	0	0
No. of exceedances/worst year	0	0
No. of exceedances/summer	0	0
No. of exceedances/worst summer	0	0
Annual average concentration (ug/l)	0.00	0.00
	(ug/l)	(ug/l)
Thresholds RST24	21	60
Thresholds RST6	42	120
Event Statistics Mean	0.00	0.01
90%ile	0.01	0.02
95%ile	0.01	0.03
99%ile	0.03	0.10

Step 2

- Velocity: 0.02 m/s — Tier 1 is used for the calculation
- DI: 2.71
- % settlement needed: 0 %

Scenario 2: Discharge to the River Yare (2.88ha impermeable area)





Annex B: Details of the Method D Assessment

Without Active Mitigation

HIGHWAYS AGENCY | View Spillage Assessment Parameters | Reset | Go To Runoff Risk Assessment Interface

Assessment of Priority Outfalls

Method D - assessment of risk from accidental spillage

			Additional columns for use if other roads drain to the same outfall						
		A (main road)	B	C	D	E	F	**Totals**	**Return Period (years)**
D1	Water body type	Surface watercourse	Surface watercourse						
D2	Length of road draining to outfall *(m)*	225	420						
D3	Road Type *(A-road or Motorway)*	A	A						
D4	If A road, is site urban or rural?	Urban	Urban						
D5	Junction type	No junction	Roundabout						
D6	Location	< 20 minutes	< 20 minutes						
D7	Traffic flow (AADT two way)	23,041	23,041						
D8	% HGV	4	4						
D8	Spillage factor *(no/10^9 HGVkm/year)*	0.31	5.35						
D9	Risk of accidental spillage	0.00002	0.00076	0.00000	0.00000	0.00000	0.00000		
D10	Probability factor	0.45	0.45						
D11	Risk of pollution incident	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000		
D12	Is risk greater than 0.01?	**No**	**No**						
D13	Return period without pollution reduction measures	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000	0.0004	2851
D14	Existing measures factor	1	1						
D15	Return period with existing pollution reduction measures	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000	0.0004	2851
D16	Proposed measures factor	1	1						
D17	Residual with proposed Pollution reduction measures	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000	0.0004	2851

With Active Mitigation (Spillage control penstocks)

HIGHWAYS AGENCY | View Spillage Assessment Parameters | Reset | Go To Runoff Risk Assessment Interface

Assessment of Priority Outfalls

Method D - assessment of risk from accidental spillage

			Additional columns for use if other roads drain to the same outfall						
		A (main road)	B	C	D	E	F	**Totals**	**Return Period (years)**
D1	Water body type	Surface watercourse	Surface watercourse						
D2	Length of road draining to outfall *(m)*	225	420						
D3	Road Type *(A-road or Motorway)*	A	A						
D4	If A road, is site urban or rural?	Urban	Urban						
D5	Junction type	No junction	Roundabout						
D6	Location	< 20 minutes	< 20 minutes						
D7	Traffic flow (AADT two way)	23,041	23,041						
D8	% HGV	4	4						
D8	Spillage factor *(no/10^9 HGVkm/year)*	0.31	5.35						
D9	Risk of accidental spillage	0.00002	0.00076	0.00000	0.00000	0.00000	0.00000		
D10	Probability factor	0.45	0.45						
D11	Risk of pollution incident	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000		
D12	Is risk greater than 0.01?	**No**	**No**						
D13	Return period without pollution reduction measures	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000	0.0004	2851
D14	Existing measures factor	1	1						
D15	Return period with existing pollution reduction measures	0.00001	0.00034	0.00000	0.00000	0.00000	0.00000	0.0004	2851
D16	Proposed measures factor	0.4	0.4						
D17	Residual with proposed Pollution reduction measures	0.00000	0.00014	0.00000	0.00000	0.00000	0.00000	0.0001	7128

Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11E: Water Framework Directive Assessment

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11E

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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1 Water Framework Directive Assessment

1.1 Introduction

Project Background

1.1.1 This Water Framework Directive (WFD) assessment has been prepared to assess the impacts of the Great Yarmouth Third River Crossing scheme (hereafter referred to as the 'Scheme') in support of the Development Consent Order (DCO) application. This WFD assessment has been prepared as an appendix to ES Chapter 11: Road Drainage and the Water Environment and draws upon information and assessment described in that report.

1.1.2 The WFD assessment investigates whether the Scheme will result in deterioration of the current quality status of relevant WFD waterbodies or prevent improvement in the status of waterbodies in accordance with the objectives and measures set out in the Anglian River Basin Management Plan (RBMP) (Ref 11E.1). The relevant WFD waterbodies are illustrated in the Water Bodies in a 'River Basin Management Plan' Plan (document reference 6.4B). The WFD assessment is provided to assist the Secretary of State in carrying out his duties under the WFD and The Water Environment (Water Framework Directive (England and Wales) Regulations 2017).

1.1.3 This assessment has been undertaken with reference to published Environment Agency guidance relating to WFD assessments in estuarine and coastal waterbodies (Ref 11E.2) and the Planning Inspectorate (PINS) advice note 18 on WFD assessments (Ref 11E.3).

1.1.4 The Scheme involves the construction, operation and maintenance of a new crossing of the River Yare in Great Yarmouth. The Scheme consists of a new dual carriageway road, including a road bridge across the river, linking the A47 at Harfrey's Roundabout on the western side of the river to the A1243 South Denes Road on the eastern side. A full description of the Scheme is included in the ES Chapter 2: Description of the Scheme.

1.1.5 The Study Area for this assessment comprises the extent of the Scheme and the area within 1km of the Application Site, which incorporates the Principal Application Site area and the Satellite Application Sites, for the assessment of impacts on surface water and 2km for the assessment of impacts on groundwater. The surface water Study Area has been extended along the River Yare to its outfall to the North Sea. Figure 11-1 shows the location of the Scheme and Study Area.

1.1.6 The Study Area for the assessment of impacts has incorporated the Principal Application Site and the Satellite Application Sites, but given that no surface water features are found within the Satellite Application Sites (for the installation of VMS), and that physical works associated with these will be minimal, their effects on the waterbodies have not been assessed further in the WFD assessment.

The Water Framework Directive

1.1.7 The Water Framework Directive (WFD) (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000) is a European Union directive which aims to bring about the effective co-ordination of water environment policy and regulation across Europe. The main aims of the legislation are to ensure that all surface water and groundwater reaches "good" status (in terms of ecological and chemical quality and water quantity as appropriate). Under the Directive "waterbodies" are defined as all ground and surface waters, including rivers, lakes, transitional waters and coastal waters (up to one nautical mile from shore).

1.1.8 As detailed in the PINS Advice Note 18, the overall aims and objectives of the WFD are to:

- Enhance the status and prevent further deterioration of surface water bodies, groundwater bodies and their ecosystems;
- Ensure progressive reduction of groundwater pollution;
- Reduce pollution of water, especially by Priority Substances and Certain Other Pollutants;
- Contribute to mitigating the effects of floods and droughts;
- Achieve at least good surface water status for all surface water bodies and good chemical status in groundwater bodies by 2015 (or good ecological potential in the case of artificial or heavily modified water bodies); and
- Promote sustainable water use.

1.1.9 Article 4 of the Water Framework Directive sets out the default environmental objectives that all surface waters and groundwaters should aim to meet.

1.1.10 With regard to surface waters these objectives include:

- Prevention of deterioration in the status of waterbodies;
- Protect, enhance and restore waterbodies with the aim of achieving good status for all waterbodies by 2015. In the case of artificial or heavily modified waterbodies the aim is to achieve good ecological potential and

good chemical status. Where this is not possible and subject to the criteria set out in the Directive, aim to achieve good status by 2021 or 2027 or set a less stringent objective;

- Progressive reduction in pollution from specified priority substances and cessation of discharges of priority hazardous substances.

1.1.11 With regard to groundwaters these objectives include:

- To prevent or limit the input of pollutants into groundwater receptors and prevent deterioration in status i.e. groundwater quality;
- Protect, enhance and restore groundwater waterbodies with the aim of achieving good status for all groundwater waterbodies by 2015. Where this is not possible and subject to the criteria set out in the Directive, aim to achieve good status by 2021 or 2027 or set a less stringent objective;
- Reversal of any significant and sustained upward trends in pollutant concentrations in groundwater receptors i.e. groundwater quality.

1.1.12 In addition, measures should be implemented to achieve compliance with standards and objectives for designated “protected areas”. These include areas designated for drinking water abstraction, the protection of economically significant aquatic species, designated recreational waters, nutrient sensitive areas and relevant areas designated for the protection of habitats or species (e.g. Natura 2000 sites).

1.1.13 For surface waters, the ‘good status’ is determined from the combined ecological and chemical status of surface waters. Ecological status is determined from a number of individual quality elements, as follows. The specific measures vary depending on the type of waterbody.

- Biological quality elements (e.g. fish, benthic invertebrates, aquatic flora);
- Supporting hydromorphological quality elements (e.g. flow regime, river continuity and substrate of the river bed); and
- Supporting physical-chemical quality elements (e.g. temperature, oxygenation and nutrient conditions).

1.1.14 The chemical quality refers to environmental quality standards for river basin specific pollutants and the priority substances specified under the WFD. These standards specify maximum concentrations for specific water pollutants. The WFD works on a ‘one out, all out’ basis, so if one such concentration is exceeded, then the waterbody will not be classed as having a ’good status’.

1.1.15 The ecological status of surface waters is classified as being ‘high’, ‘good’, ‘moderate’, ‘poor’ or ‘bad’, whilst waterbodies that have been modified (e.g. canals or which contain significant flood defences) are classed as ‘Heavily Modified Waterbodies’ (HMWB) and have to reach at least ‘good ecological potential’ by their objective year.

1.1.16 Groundwater waterbodies are classified as either ‘good’ or ‘poor’ and their status is determined from the combined quantitative and chemical status of groundwater. The quantitative status considers elements such as impacts of saline intrusion, ability to serve groundwater and surface water abstractions, and ability to support groundwater dependent terrestrial ecosystems. The chemical status refers to the environmental quality standards for river basin specific pollutants and the priority substances specified under the WFD.

1.1.17 Plates 1.1 and 1.2 overleaf illustrate the classification approach for surface water and groundwater respectively.

1.1.18 The WFD introduced River Basin Districts (RBDs) in order to better manage waterbodies without administrative and political boundaries. Each river basin is managed to achieve the objectives of the WFD through the development River Basin Management Plans (RBMP), which provide a clear indication of the way the objectives set for the river basin are to be reached within the required timescale and set out a programme of measures.

1.1.19 Article 4.7 of the WFD sets out reasons why physical modifications or activities may be allowed to cause deterioration in quality status or prevent good status being achieved (for example where activities are in the overriding public interest). If a scheme or activity is predicted to cause deterioration in waterbody status or prevent the waterbody from meeting any of its objectives, then assessment is required against the conditions listed in WFD Article 4.7, all of which must be met for the scheme to proceed without contravening the WFD. The impact of the scheme / activity on other waterbodies within the River Basin District must also be considered (Article 4.8) and protection given by existing Community Legislation to any Protected Areas must also be maintained (Article 4.9).

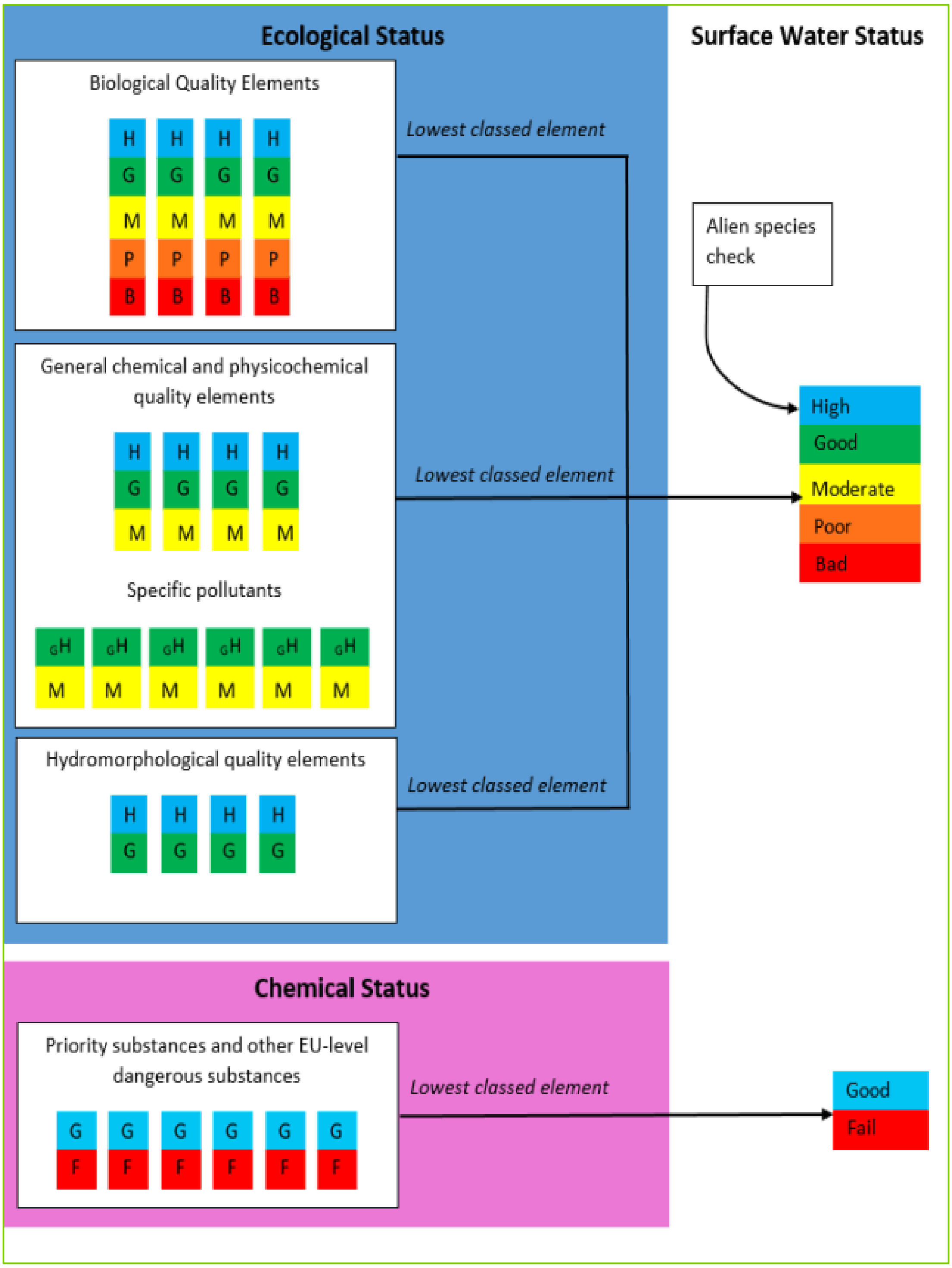

Plate 1.1: Surface Water Classification (Ref 11E.4)

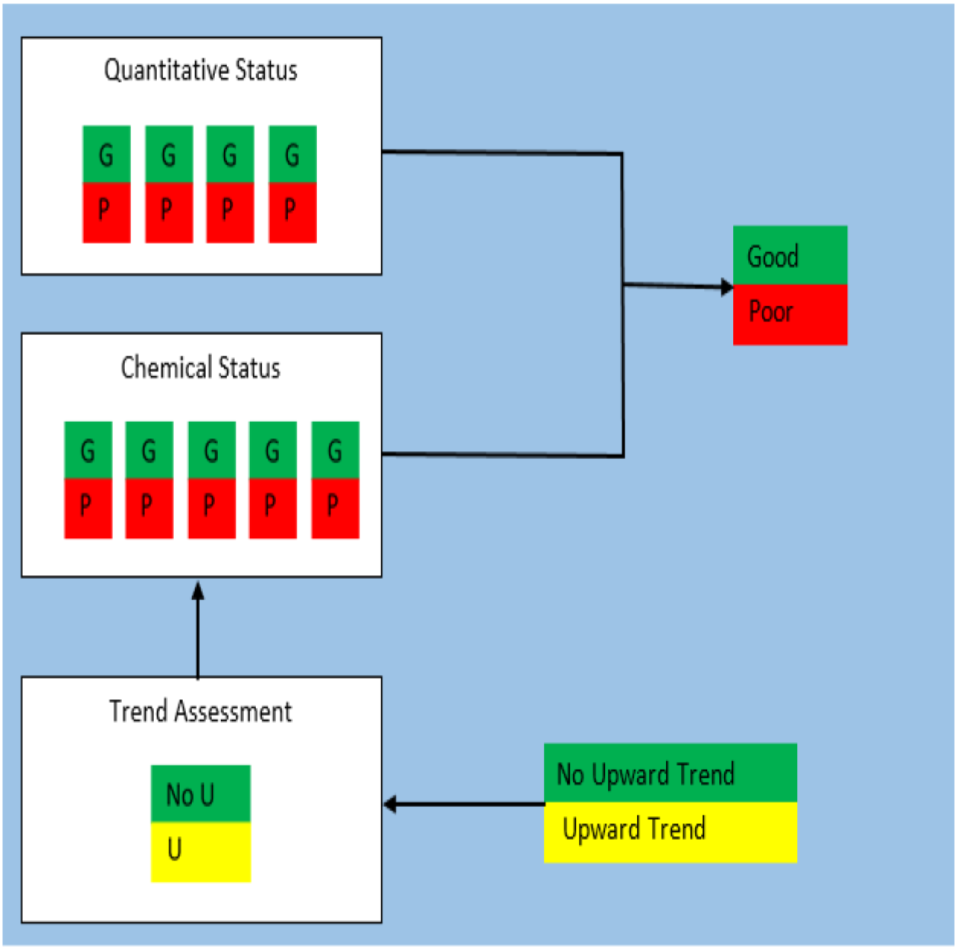

Plate 1.2: Groundwater Classification (Ref 11E.4)

1.2 Assessment Methodology

1.2.1 Determination of WFD compliance for this Scheme comprises a series of steps intended to establish the potential impacts of the Scheme at an appropriate level of detail using available information, and then to examine whether the identified impacts contravene the objectives of the WFD.

1.2.2 The PINS Advice Note 18 sets out a three-staged approach to the WFD process:

- Stage 1 – WFD screening to identify the extent to which the Scheme is likely to affect the waterbodies (i.e. defining the Scheme's zone of influence) and to determine if there are any activities associated with the Scheme that could be screened out;

- Stage 2 – WFD scoping to identify risks from the Scheme's activities to receptors based on the relevant waterbodies and their water quality elements (including information on status, objectives, and the parameters of each waterbody) and to identify waterbodies where a more detailed impact assessment is required; and

- Stage 3 – WFD impact assessment (this document) which is a detailed assessment of the waterbodies and activities carried forward from the WFD screening stage.

1.2.3 At each stage the WFD impact assessment should be set within the context of the appropriate RBMPs and should include the following, with an appropriate level of detail at each stage:

- Identification of WFD waterbodies in the Study Area with potential to be affected by the Scheme;

- Obtain information to identify the current status and objectives for the waterbodies, important features such as linked protected areas and relevant habitats, and improvement measures set out in the RBMP;

- A description of the Scheme and the aspects of the development considered within the scope of the WFD assessment;

- Identification of aspects of the Scheme with potential to affect WFD waterbodies, mitigation included in the Scheme proposals and consideration of further mitigation where necessary;

- For those criteria where a potential adverse effect has been identified, assessment of the Scheme (including relevant mitigation) against the individual quality elements to determine if these effects are sufficient to cause a deterioration in the quality status of each element;

- Assessment of the Scheme (including relevant mitigation) to determine if the Scheme will impact upon the proposed mitigation measures and objectives for the waterbodies and objectives for individual quality elements;

- Assessment of the Scheme against the wider catchment objectives and aims of the WFD; and

- Where applicable, application of the Article 4.7 test.

1.2.4 Formal screening and scoping assessments (Stage 1 and 2 above) have not been completed for this Scheme as it was established at an early stage that a detailed (Stage 3) assessment would be required. The Stage 3 detailed assessment incorporates the elements of both Stage 1 and Stage 2 of the WFD process.

1.2.5 This assessment is a qualitative assessment of potential impacts of the Scheme against WFD quality elements and measures. The data sources used for this assessment are as follows:

- Anglian River Basin Management Plan (Ref 11E.1)
- Catchment Data Explorer for Cycle 2 waterbody status and objectives (Ref11E.5);
- Published Ordnance Survey topographic maps (Ref 11E.6);
- British Geological Society (BGS) Geology of Britain viewer (Ref 11E.7);
- Burgh Castle District Water Level Management Plan 2014 (Ref 11E.8);
- DEFRA MAGIC Map portal (Ref 11E.9)
- Flood Estimation Handbook (FEH) web service portal (river catchment boundaries) (Ref 11E.10)
- UK Estuaries Database (Ref 11E.11)
- Assessments undertaken for the Scheme:
  - ES Chapter 11: Road Drainage and the Water Environment;
  - ES Chapter 8: Nature Conservation;
  - ES Chapter: 16 Geology and Soils;
  - Drainage Strategy (document reference 6.2, Technical Appendix 12C);
  - Piling Risk Assessment (document reference 6.2, Technical Appendix 16D);
  - Sediment Transport Assessment (Appendix 11C);
- Scheme proposals:
  - Engineering Section Drawings and Plans (document reference 2.10)
  - General Arrangement Plans (document reference 2.2)
  - Work Plans (document reference 2.6)

1.2.6 The following factors have been considered when determining whether the potential adverse effects of the Scheme are likely to lead to a deterioration in status or prevent objectives being met:

- Whether the impact is temporary (such as short-term construction impacts) or permanent / long term;
- The characteristics and sensitivity of the specific water features affected by the Scheme (which may be different to the designated WFD waterbody);
- The scale and importance of the specific water features affected by the Scheme to the designated WFD waterbody;
- The nature, scale and extent of potential impact in the context of the existing pressures and proposed measures for the waterbody.

1.3 Waterbody Details

Background

1.3.1 The Scheme lies within the Anglian River Basin District (RBD), which covers an area of 27,900km^2 and extends from Lincolnshire southwards to Essex and from Northamptonshire at its westernmost point to the East Anglian coast. Major urban centres include Lincoln, Northampton, Milton Keynes, Norwich and Chelmsford. The Anglian RBD has a rich diversity of wildlife and habitats, supporting many species of global and national importance. It is recognised as a rich region for wetland wildlife, with the Norfolk Broads being Britain's largest nationally protected wetland, and is important for wintering wildfowl. The management catchments that make up the river basin district include many interconnected rivers, lakes, groundwater and coastal waters. These range from chalk and limestone ridges to the extensive lowlands of the Fens and East Anglian coastal estuaries and marshes.

1.3.2 According to the Anglian River Basin Management Plan (2015) (Ref 11E.1) 42% of the surface water bodies in this river basin district have an objective of maintaining or aiming to achieve good ecological status between 2015 and 2027, whilst all the surface water bodies in the river basin district are expected to achieve good chemical status by 2027. With respect to groundwater bodies, 84% are expected to maintain or achieve good quantitative status by 2027, while 58% are predicted to achieve good chemical status by 2027. The main reasons for not achieving good status and for deterioration are related to physical modifications to rivers, lakes and estuaries, which have the potential to alter natural flow levels, cause excessive build-up of sediment in surface water bodies and the loss of habitats and recreational uses; diffuse and/or point source pollution from waste water, from towns, cities and transport and from rural areas; reduced flow and water levels in rivers and groundwater receptors; and negative effects of invasive non-native species. Mitigation measures have been identified in the RBMP to tackle these issues as follows:

- Water company investment programme to address point source impacts from sewage treatment works and discharges from the sewer network, with further investment to tackle abstraction and flow pressures.
- Countryside Stewardship scheme to address soil management and reduce the effects of nutrients, sediment and faecal contamination with the aim to reduce the impact of eutrophication and benefit bathing waters, shellfish waters and drinking water.
- Highways England's environment fund to tackle pollution from highway runoff through the use of sustainable drainage systems (SuDS) and to address physical modification pressures by adopting techniques such as fish and eel passes to allow fish migration.
- The Environment Agency's Flood and Coastal Erosion Risk Management investment programme to reduce the risks of flooding and erosion to homes and the economy. The programme will promote the use of natural/sustainable flood risk management measures to reduce the impact on the condition of waterbodies and, where possible, contribute towards improving the status of waterbodies, protecting wildlife sites and creating new habitats.
- Catchment level government funded improvement schemes to reduce the impact of pollution from rural and urban areas along with habitat improvement measures to increase biodiversity.
- Water resources sustainability measures to address current abstraction and flow pressures and to support sustainable supplies of water for the future.

Surface Water Bodies

1.3.3 The Environment Agency's catchment data explorer shows the Study Area to be contained within the Broadland Rivers Management Catchment, which includes the Waveney Operational Catchment covering the Waveney, Lower Yare & Lothingland Internal Drainage Board (IDB) drainage district, and the Bure Operational Catchment. The Study Area also covers land within the Anglian Transitional and Coastal (TraC) Management Catchment, which includes the Norfolk East TraC Operational Catchment incorporating the tidal section of the River Yare, the River Bure, Breydon Water and the coastal waters of Great Yarmouth.

1.3.4 Surface waterbodies located within and in the vicinity of the Study Area have been identified from the catchment data explorer website and are summarised in Table 1.1.

Table 1.1: WFD Surface Waterbodies

	Inland		Transitional & Coastal	
Management catchment	Broadland Rivers		Anglian TraC	
Operational catchment	Waveney	Bure	Norfolk East TraC	
Waterbody	Waveney (Ellingham Mill – Burgh St. Peter) (closest to Scheme)	Muck Fleet (closest to Scheme)	Bure & Waveney & Yare & Lothing (transitional water)	Norfolk East (coastal water)

1.3.5 The Waveney, Lower Yare & Lothingland IDB drainage district to the west of the Scheme is located within the Waveney Operational Catchment, a freshwater operational catchment under the WFD. However, based on the IDB's watercourse network plan, it is understood that the IDB catchment ultimately drains into Breydon Water and then into the River Yare. Hence it is more likely to contribute to the water quality of these surface water features, which form part of the Bure & Waveney & Yare & Lothing transitional waterbody, rather than the water quality of any freshwater bodies located within the Waveney Operational Catchment. The closest freshwater body within this operational catchment is the Waveney (Ellingham Mill – Burgh St. Peter) waterbody, which is located approximately 24km upstream from the Scheme. This distance is such that no impact on this waterbody is likely to result from the Scheme and the Scheme is not located within the hydrological catchment of this waterbody. Furthermore, the Scheme is not expected to have any effects on the measures identified for the Waveney Operational Catchment, which are mainly related to waste water treatment and habitat restoration (Waveney Habitat Project). As such, no detailed assessment has been undertaken for this freshwater catchment.

1.3.6 The Environment Agency's catchment data explorer also shows the Study Area to be contained within the Bure Operational Catchment. However, the closest freshwater body (Muck Fleet) is located approximately 18km upstream from the Scheme. Inspection of OS mapping indicates there is no direct hydraulic connection between the Scheme and this waterbody and that the Scheme is located outside of the hydrological catchment of this waterbody. For these reasons, the Scheme is not considered likely to have any impact on Muck Fleet waterbody or the objectives and measures identified with the Bure Operational Catchment, which mainly focus on reducing diffuse pollution pathways (Broadland Slow the Flow Project), and this has not been assessed further.

1.3.7 The tidal section of the River Yare, the River Bure and Breydon Water are all part of the Bure & Waveney & Yare & Lothing waterbody within the Norfolk East TraC Operational Catchment. This transitional waterbody is linked with several protected areas, including the Breydon Water Special Protection Area (SPA), but is also heavily modified, consisting of engineered flood protection, bridge and navigational infrastructure. This waterbody was assessed by the Environment Agency to have an overall status of Moderate in 2016. The reasons for not achieving Good status are primarily related to sewage discharge and also some unknown activities which are pending investigation. The objective for this waterbody is to achieve/maintain Moderate status by 2027, however no known measures have been identified at present to achieve this objective. Details of the current status of this waterbody are provided in Table 1.2.

1.3.8 The coastal waters of Great Yarmouth, which incorporate part of the North Sea, are included in the Norfolk East coastal waterbody within the Norfolk East TraC Operational Catchment. This waterbody is located approximately 3km downstream of the Scheme and covers the coastal area of Sheringham to Great Yarmouth and was assessed by the Environment Agency to have an overall status of Moderate in 2016. The reasons for not achieving Good status are related to diffuse and point source pollution associated with poor nutrient management and sewage discharge. The objective for this waterbody is to maintain Moderate status, however no known measures have been identified at present to maintain this objective. Details of the current status of this waterbody are provided in Table 1.3.

Table 1.2: Bure & Waveney & Yare & Lothing Transitional Waterbody

Water Body ID	**GB510503410700**	**Water Body Name**	**Bure & Waveney & Yare & Lothing**
Water Body Type	Transitional Water	**Water Body surface area**	8.878km^2
Hydromorphological Designation	Heavily modified - flood protection and navigation, ports and harbours		
Description	One of the main surface water features within this TraC waterbody is the River Yare, which flows from north to south through the Scheme. The River Yare has a catchment area estimated at around 3,000km^2. The river flows in a generally eastward direction, along the southern fringes of the city of Norwich before entering into The Broads, a significant area of low-lying land drained by a network of ditches and channels. At the village of Burgh Castle, it is joined by the River Waveney before discharging into the inland tidal estuary of Breydon Water. Beyond Breydon Bridge, which marks the		

Water Body ID	GB510503410700	Water Body Name	Bure & Waveney & Yare & Lothing
	downstream extent of Breydon Water, the River Yare confluences with the River Bure before turning south, flowing through the town of Great Yarmouth, and discharges into the sea at Gorleston-on-Sea. Through the Study Area, the river is around 100m wide, with banks consisting of engineered quay walls. Bathymetry data provided by Peel Ports (collected in 2017) suggests that the River Yare channel through Great Yarmouth is affected by regular dredging activity, where the channel bed is dredged to around -7mAOD with steep banks. The River Yare is a tidal river and the estuary boundary incorporates the section of the Yare through Great Yarmouth and Breydon Water. According to the UK Estuaries Database the estuary has a spring tidal range of 1.9m, indicating it is microtidal as characterised by the small tidal range (<3m). A sediment transport assessment (Appendix 11C) has been undertaken for the Scheme to assess the existing regime of the estuary and the results confirm the narrow tidal range of the estuary, where the Mean High-Water Spring (MHWS) was estimated to be 1mAOD and the Mean Low-Water Spring (MLWS) -0.6mAOD. Based on the above and the general profile of the River Yare channel through Great Yarmouth, which is deep due to dredging, the channel bed and associated habitat will not be exposed during low tide. The results of the assessment also suggest that the estuary is ebb dominant i.e. there is a net export of sediment from the system. However, the engineered channel through Great Yarmouth has the potential to restrict sediment movement through the estuary, hence sediment is transporting out of Breydon Water at a slower rate than would be expected in an ebb dominant system. Results of sediment sampling completed for the Scheme indicate that majority of the sediment in the River Yare channel is made up of a combination of fine to coarse sand, with the D50 particle size ranges from 0.03mm to 0.55mm diameter. Chemical analysis of the sediment samples generally suggests high levels of heavy metals, but the contaminated sediments within the river are not significantly affecting the water quality and chemical status of this waterbody, which is classified as Good for all chemical status elements and High for specific pollutants, such as Copper and Zinc. The River Yare is included in the Outer Thames Estuary SPA, which extends from Caister on Sea south to the Thames Estuary. Connecting upstream is the Breydon Water SPA, an		

Water Body ID	GB510503410700	Water Body Name	Bure & Waveney & Yare & Lothing
	internationally important RSPB nature reserve, and also a designated Ramsar and Site of Special Scientific Interest (SSSI). Within Breydon Water, extensive areas of mud are exposed at low tide and these intertidal mudflats support diverse species of flora and fauna. Based on the findings of the aquatic survey provided in Chapter 8: Nature Conservation, the subtidal environment of the River Yare supports a range of fish and benthic communities but they are considered of limited conservation value. Habitat modification, as a result of existing dredging activities, means there are existing pressures on aquatic species. The River Bure joins the Yare approximately 2km upstream from the Scheme. It is one of the largest tributaries of the River Yare, with a catchment area estimated at around 1000km^2. The lower Bure, from downstream of Runham to the confluence with the River Yare, is also included in the Outer Thames Estuary SPA. There are a number of smaller drains and watercourses located within the Application Site and within the 1km Study Area, which are contained within the Waveney, Lower Yare & Lothingland IDB drainage district. These form part of the surface water drainage for the urban areas of Great Yarmouth, and they are connected to the main dyke system within the marshes in the western part of the IDB district by a series of culverts underneath the main A47 road. Water level within the IDB district is managed by pumping, which removes excessive runoff from the marshes, urban area and the upland catchment to the River Yare.		
Overall Status	Moderate	**Status Objective**	Moderate by 2027 – unfavourable balance of costs and benefits; cause of adverse impact unknown
Overall Ecological Status	Moderate	**Status Objective**	Moderate by 2027 – unfavourable balance of costs and benefits; cause of adverse impact unknown
Overall Chemical Status	Good	**Status Objective**	Good by 2015
Protected Area Designation	Breydon Water SPA; nutrient sensitive areas		

Water Body ID	GB510503410700	Water Body Name	Bure & Waveney & Yare & Lothing
Reasons for not achieving Good status	Sewage discharge (continuous); unknown (pending investigation)		
Waterbody measures	None identified		
Supporting Elements			
Mitigation measures assessment (dredging **disposal strategy; r**educe **impact of dredging; s**ediment **management; d**redge **disposal site selection; m**anage **disturbance; r**etain **habitats**)		Good	
Biological Quality Elements			
Overall biological quality elements	Poor	**Objective**	Good by 2027 – cause of adverse impact unknown
Angiosperms	Poor	**Objective**	Good by 2027 – cause of adverse impact unknown
Fish	Good (2012)	**Objective**	n/a
Invertebrates	Good	**Objective**	Good by 2015
Microalgae	High	**Objective**	Good by 2015
Phytoplankton	Good	**Objective**	Good by 2015
Biology: Higher Sensitivity Habitats			
Chalk reef		n/a	
Clam, cockle and oyster beds		n/a	
Intertidal seagrass		n/a	
Maerl		n/a	
Mussel beds, including blue and horse mussel		n/a	
Polychaete reef		n/a	
Saltmarsh		13.63 ha (Breydon Water, approximately 3km upstream from the Scheme; River Bure, approximately 4km upstream from the Scheme)	
Subtidal kelp beds		n/a	
Subtidal sea grass		n/a	

Water Body ID	GB510503410700	Water Body Name	Bure & Waveney & Yare & Lothing
Biology: Lower Sensitivity Habitats			
Cobbles, gravel and shingle		n/a	
Intertidal soft sediments like sand and mud		453.78 ha (Breydon Water and isolated areas along the right bank of the River Yare approximately 700m downstream from the Scheme; no intertidal habitat has been identified within the Application Site).	
Rocky shore		n/a	
Subtidal boulder fields		n/a	
Subtidal rocky reef		n/a	
Subtidal soft sediments like sand and mud		3.46 ha (coastline)	
Physico-chemical Quality Elements			
Overall physico-chemical	Moderate	**Objective**	Moderate – Unfavourable balance of costs and benefits
Dissolved inorganic Nitrogen	Moderate	**Objective**	Moderate – Unfavourable balance of costs and benefits
Dissolved Oxygen	High	**Objective**	Good by 2015
Specific pollutants	High	**Objective**	High by 2015
Hydromorphological Quality Elements			
Overall hydromorphological	Supports Good	**Objective**	Supports Good by 2015
Hydrological regime	Supports Good	**Objective**	Supports Good by 2015
Chemical Quality Elements			
Overall chemical	Good	**Objective**	Good by 2015
Priority substances	Good	**Objective**	Good by 2015
Other pollutants	Does not require assessment (Good in 2014)	**Objective**	Does not require assessment
Priority hazardous substances	Good	**Objective**	Good by 2015

Table 1.3: Norfolk East Coastal Waterbody

Water Body ID	**GB650503520003**	**Water Body Name**	**Norfolk East**
Water Body Type	Coastal Waterbody	**Water Body surface area**	211.2km^2
Hydromorphological Designation	Heavily modified – flood and coastal protection		
Description	The River Yare discharges to the North Sea at Gorleston-on-Sea. Under the WFD, this is included in the Norfolk East coastal waterbody. This waterbody is classified as heavily modified due to physical modifications for flood and coastal protection. It is also linked with several protected areas, including a number of bathing waters protected areas along the beach of Great Yarmouth. The entire waterbody is included in the Outer Thames Estuary SPA and a proportion, from Caister-on-Sea to the suburb of Newton in Great Yarmouth is included in the Great Yarmouth North Denes SPA.		
Overall Status	Moderate	**Status Objective**	Moderate by 2015 – unfavourable balance of costs and benefits
Overall Ecological Status	Moderate	**Status Objective**	Moderate by 2015 – unfavourable balance of costs and benefits
Overall Chemical Status	Good	**Status Objective**	Good by 2015
Protected Area Designation	Outer Thames Estuary SPA; Great Yarmouth North Denes SPA; Great Yarmouth South and Great Yarmouth Pier bathing waters		
Reasons for not achieving Good status	Poor nutrient management; sewage discharge (continuous); unknown (pending investigation)		
Waterbody measures	None identified		
Supporting Elements			
Mitigation measures assessment (Sediment management; dredge disposal site selection; manage disturbance)		Good	
Biological Quality Elements			
Overall biological quality elements	Good	**Objective**	Good by 2015
Angiosperms	n/a	**Objective**	n/a
Fish	n/a	**Objective**	n/a
Invertebrates	n/a	**Objective**	n/a

Water Body ID	GB650503520003	Water Body Name	Norfolk East
Microalgae	n/a	**Objective**	n/a
Phytoplankton	Good	**Objective**	Good
Biology: Higher Sensitivity Habitats			
Chalk reef		2893.73ha (off coastline)	
Clam, cockle and oyster beds		n/a	
Intertidal seagrass		n/a	
Maerl		n/a	
Mussel beds, including blue and horse mussel		n/a	
Polychaete reef		40.09ha	
Saltmarsh		n/a	
Subtidal kelp beds		n/a	
Subtidal sea grass		n/a	
Biology: Lower Sensitivity Habitats			
Cobbles, gravel and shingle		12971.88ha (off coastline)	
Intertidal soft sediments like sand and mud		718.96ha (coastline)	
Rocky shore		n/a	
Subtidal boulder fields		n/a	
Subtidal rocky reef		2019.66ha (off coastline)	
Subtidal soft sediments like sand and mud		7840.13ha (off coastline)	
Physico-chemical Quality Elements			
Overall physico-chemical	Moderate	**Objective**	Moderate by 2015 - unfavourable balance of costs and benefits
Dissolved inorganic Nitrogen	Moderate	**Objective**	Moderate by 2015 - unfavourable balance of costs and benefits
Dissolved Oxygen	High	**Objective**	Good by 2015
Specific pollutants	High for Toluene; Moderate (2014) for Zinc	**Objective**	High by 2015
Hydromorphological Quality Elements			
Overall hydromorphological	n/a	**Objective**	n/a
Hydrological regime	n/a	**Objective**	n/a

Water Body ID	GB650503520003	Water Body Name	Norfolk East
Chemical Quality Elements			
Overall chemical	Good	**Objective**	Good by 2015
Priority substances	Good	**Objective**	Good by 2015
Other pollutants	Does not require assessment	**Objective**	Does not require assessment
Priority hazardous substances	Good	**Objective**	Does not require assessment

Groundwater Waterbodies

1.3.9 The Environment Agency's catchment data explorer shows that the Scheme overlies the Broadland Rivers Chalk & Crag groundwater waterbody within the Anglian Groundwater Management Catchment. Details of the current status of this waterbody are provided in Table 1.4.

Table 1.4: Broadland Rivers Chalk and Crag Waterbody

Water Body ID	GB40501G400300	Water Body Name	Broadland Rivers Chalk & Crag
Water Body Type	Groundwater	**Water Body surface area**	3076km^2
Description	This waterbody underlies the Broadland Rivers catchment and is characterised by Chalk (to the west) and Crag (to the east) bedrock geology. This is largely covered by superficial glacial deposits of sand, silt and clay. According to the British Geological Survey and the findings from the ground investigation completed between September 2017 and March 2018, the bedrock geology underlying the entirety of the Scheme is the Crag Group Formation consisting of sands, gravels, silts and clays. This formation is classified as a Principal Aquifer by the Environment Agency, i.e. permeable strata capable of supporting water supplies at a regional scale, and is within a *Major Aquifer High* Groundwater Vulnerability Zone. The London Clay Formation, Thanet Formation and the Chalk Group underlie the Crag Group. The Chalk Group is also classified as a Principal Aquifer but no direct interaction between this aquifer and the Scheme is anticipated due to the overlying London Clay Formation, a substantially thick low permeable layer, which acts as a barrier. The most prevalent superficial deposits underlying the Principal Application Site comprise the North Denes		

Water Body ID	GB40501G400300	Water Body Name	Broadland Rivers Chalk & Crag
	Formation (quaternary sand and gravel deposits) and Breydon Formation (peat and clay and silts). These are low productivity aquifers of limited or local potential, where borehole yields are expected to be small. The Environment Agency designates the North Denes Formation as Secondary A Aquifers and the Breydon Formation as Unproductive Strata. The superficial deposits are not considered to be in hydraulic continuity (locally) with the underlying Crag Group due to the variable lithology of the superficial deposits which comprise a mixture of clayey, gravel, silt and sand and presents an inconsistent multi-layered aquifer. Hydraulic continuity may exist where non-laterally extensive clay lenses exist. The waterbody is designated as a Drinking Water Protected Area and is protected under the Nitrates Directive. It is at Poor status mainly due to groundwater abstraction associated with agriculture and rural land management. The objective for this waterbody is to achieve Good status by 2027, however no known measures have been identified at present to achieve this objective. Groundwater quality sampling was carried out across the boreholes sunk as part of the intrusive ground investigation (2017-2018). The results were screened against annual average EQS concentrations of potentially hazardous chemicals as defined under the WFD for freshwater waterbodies. Exceedances were recorded in contaminants such as arsenic, mercury, zinc, and polyaromatic hydrocarbons (PAHs). The groundwater quality results also conclude that there is some influence from seawater within the Principal Application Site with higher concentrations of electrical conductivity (EC) recorded on the western banks of the River Yare. The River Yare is a tidal river and EC concentrations are expected to increase near the coast and tidal reaches of the river due to saline infiltration.		
Overall Status	Poor	**Status Objective**	Good by 2027 – Groundwater status recovery time
Overall Quantitative Status	Poor	**Status Objective**	Good by 2021
Overall Chemical Status	Poor	**Status Objective**	Good by 2027 – Groundwater status recovery time
Protected Area	This waterbody is protected under the Nitrates Directive and		

Water Body ID	GB40501G400300	Water Body Name	Broadland Rivers Chalk & Crag
Designation	Drinking Water Protected Area (location and extent unknown)- the Study Area is not in a Source Protection Zone (SPZ).		
Reasons for not achieving Good status	Groundwater abstraction (Quantitative Groundwater Dependent Terrestrial Ecosystems (GWDTEs) test)		
Waterbody measures	None identified		
Supporting Elements			
Quantitative Status Elements			
Saline Intrusion	Good	**Objective**	Good by 2015
Water Balance	Good	**Objective**	Good by 2015
Groundwater Dependent Terrestrial Ecosystems (GWDTE) test	Poor	**Objective**	Good by 2021
Dependent Surface Water Body Status	Good	**Objective**	Good by 2015
Chemical Status Elements			
Drinking Water Protected Area	Poor	**Objective**	Good by 2027 – Groundwater status recovery time
General Chemical Test	Good	**Objective**	Good by 2015
GWDTE test	Good	**Objective**	Good by 2015
Dependent Surface Water Body Status	Good	**Objective**	Good by 2015
Saline Intrusion	Good	**Objective**	Good by 2015
Trend Assessment			Upward trend

1.4 Potential Impacts and Mitigation

1.4.1 This assessment addresses the potential construction and operational impacts of the Scheme on the waterbodies (both surface water and groundwater) identified in Section 1.3. Details of the Great Yarmouth Scheme are provided in Chapter 2: Description of the Scheme in the ES.

1.4.2 The key elements of the Scheme that could potentially impact on the WFD status of the surrounding surface and groundwater bodies are provided below:

- Construction of a new double-leaf bascule bridge providing an opening span to facilitate vessel movement within the river. This would include structures to support and accommodate the operational requirements of the bridge-opening mechanism, including counterweights below the level of the bridge deck. The bridge would be supported on driven piles;
- New substructures, supported by driven piles, to support the double leaf bascule bridge within the existing quays either side of the river and within the river itself, requiring new permanent "knuckle" walls, creating cofferdams in the waterway;
- Dredging may be required during operation to remove any sediment build up within the navigation channel. Any operational dredging will be incorporated into the current dredging regime along the River Yare and is not expected to significantly alter the current dredging regime;
- Associated changes, modifications and/or improvements to the existing local highway network;
- The relocation of existing allotments to compensate for an area to be lost as a result of the Scheme and other accommodation works, including those at the MIND Centre and Grounds; and
- New highway drainage. The key principles of the Drainage Strategy (document reference 6.2, Technical Appendix 12C) are stated as follows:

The western side of the Principal Application Site (the section of the Scheme due west of the bridge mid-point)

- Runoff from the western side of the Scheme will be attenuated and discharged either via gravity into the existing Internal Drainage Board (IDB) ordinary watercourse network adjacent to the Scheme or via a pumped system into the River Yare.
- Runoff to be attenuated to as close as practical to greenfield runoff rates for the 1 in 100-year event, including climate change. Where this is not

achievable, the post development runoff rates and volumes should not exceed existing scenario values. The required attenuation storage will, as a minimum, consist of an underground storage tank and a pond/wetland feature.

- Runoff will be treated before discharge. Pollution control measures currently proposed include proprietary treatment devices (vortex separator) that treat runoff that discharges into the underground storage and natural treatment in the form of wet pond/wetland feature. Penstocks are also proposed as control of spillages.

- Realignment of existing IDB watercourse and extension and/or replacement of existing culverts in the vicinity of the new roundabout.

The eastern side of the Principal Application Site (the section of the Scheme due east of the bridge mid-point)

- Runoff from the eastern side of the Scheme will be discharged into existing Anglian Water combined sewer.

- Runoff to be attenuated, via oversized pipes and/or underground storage tanks, to achieve the restricted discharge rate of 10l/s as agreed with Anglian Water.

- Runoff to be treated, via proprietary devices, before discharge into the Anglian Water combined sewer.

1.4.3 Works to facilitate the construction of the above elements will include:

- Construction of cofferdams to facilitate in-channel works within the River Yare. The cofferdams will eventually be integrated into the permanent works bridge foundation. Temporary works associated with the construction of the bridge substructures will occur within the cofferdams. No dredging is proposed.

- Temporary groundwater control systems and associated water disposal arrangements to facilitate the construction of the bascule pit cofferdams.

- Creation of temporary construction compounds adjacent to the River Yare.

- Temporary drainage arrangements and temporary works associated with the IDB drains and ordinary watercourses within the Principal Application Site, such as temporary culverting or diversion to maintain existing drainage routes.

- Provision of small vessel waiting facilities to the north and south of the new crossing, either as floating pontoons or additional fendering to the existing berths.

1.4.4 Table 1.5 and Table 1.6 summarise the potential impacts of the Scheme on the waterbodies, including details of embedded mitigation incorporated into the proposals and Outline Code of Construction Practice (document reference 6.16).

Table 1.5: Potential Construction Impacts and Mitigation

Potential Impact	Description and Mitigation
Impacts on water quality of receiving waterbodies, from mobilised suspended solids, spillage of fuels, lubricants, hydraulics fluids and cements from construction, and from dust/debris associated with demolition works.	An Outline Code of Construction Practice (CoCP) (document reference 6.16) has been prepared for the construction phase. The Outline CoCP includes details regarding the management of accidental spillages, the control of runoff from temporary construction compounds, areas of stockpiling, the disposal of contaminated sediments, as well as information regarding training and monitoring procedures during construction to reduce the likelihood of contaminants, sediment laden runoff and dust/debris entering surface waterbodies. Measures include restrictions on the siting of stockpiles and timing of certain works; bunded storage areas and leak-proof containers for waste fuels; silt barriers and settlement areas; barriers to screen off receptors from dust producing activities and adequate water supply for dust suppression. Temporary works associated with the construction of the bridge substructures will occur within the cofferdams. This will exclude work areas from the main waterbody of the River Yare, thus reducing the likelihood of contaminants entering the main water flow during construction. Whilst these measures will not eliminate the risk entirely, particularly where works take place within or immediately adjacent to watercourses, it will significantly reduce the likelihood and impacts of a pollution incident should it occur. Furthermore, any potential effects will be temporary as the pollutants entering the receiving watercourses will be diluted and dispersed over time via natural tidal and/or fluvial processes.
Pollution to surface water due to disturbance of	All temporary works associated with the construction of the bridge substructures will occur within the cofferdams, which will be integrated into the permanent works bridge

Potential Impact	Description and Mitigation
contaminated sediments within the River Yare during construction of the bridge substructures	foundation. No additional temporary works are proposed outside of the cofferdams and no dredging is planned during construction. Furthermore, soft start piling techniques will be employed to minimise the disturbance of contaminated sediment within the River Yare. Hence the construction of the cofferdams is not expected to disturb any sediments additional to that assessed under Operational impacts. An Outline Code of Construction Practice (CoCP) (document reference 6.16) has been prepared for the construction phase, which details the above mitigation measures to be implemented for the construction of the bridge substructures.
Impact to surface water due to dewatering and discharge of abstracted water from the cofferdams	Temporary groundwater control systems i.e. dewatering will be required to facilitate the construction of the bascule pit cofferdams, but the method of discharge of the abstracted water has yet to be determined. If the water is to be discharged into the River Yare or the IDB watercourse, there may be detrimental effects on the receiving watercourse in relation to the quantity and quality of the discharges. Results from the groundwater modelling of the bascule pit groundwater control system (Appendix 11F) suggest that the total abstractions rates for each cofferdam will be in the range of 0.16l/s to 15.5l/s. These rates are negligible compared with the flow rates in the River Yare. The groundwater modelling also indicates a potential reduction in baseflow in the River Yare of between 6 and 31 l/s due to the dewatering. These rates are also insignificant compared with the flows in the River Yare. Therefore, no impact is expected on the hydrological regime of the River Yare. Groundwater quality sampling undertaken across the Principal Application Site suggests hydraulic connection between the local groundwater system and the River Yare, it is therefore expected that the groundwater quality of the groundwater discharge would be similar to that in the river. As the discharge volume is very small any differences will not affect the water quality in the Yare. However, discharges into surface waterbodies will be subject to relevant permitting and consent requirements from relevant authorities, as detailed in the Consents and Agreements Position Statement

Potential Impact	Description and Mitigation
	(document reference 7.3) The rates and volume of groundwater discharge are also considered too small to significantly influence the hydrological regime of the IDB watercourses within the Principal Application Site and the wider IDB catchment. Given these watercourses are already ephemeral with levels and flows influenced by tide levels and local urban runoff, impacts caused by the reduction in groundwater level due to dewatering are also negligible. Any potential effects resulted from groundwater dewatering and discharge will be temporary and the hydrological regime of these watercourses will return to its current state when dewatering and discharge ceases. Given the risk of pollution already exists in the IDB catchment due to existing highway discharges and saline intrusion, any contaminants and/or elevated salinity in the discharge water are not expected to cause a significant deterioration in water quality.
Temporary alterations to the tidal and hydromorphological regime of the River Yare, such as changes to the tidal prism and erosion, deposition and channel migration processes associated with the construction of coffer dams to facilitate in-channel works within the River Yare.	All temporary works associated with the construction of the bridge substructures will occur within the cofferdams, which will be integrated into the permanent works bridge foundation. No additional temporary works are proposed outside of the cofferdams and no dredging is planned during construction. Furthermore, soft start piling techniques will be employed to minimise the disturbance of contaminated sediment within the River Yare. Hence the construction of the cofferdams is not expected to cause any significant changes to the tidal and hydromorphological regime of the River Yare, in terms of the tidal prism, erosion/deposition pattern and channel migration processes, additional to that assessed under Operational impacts. An Outline (CoCP) (document reference 6.16) has been prepared for the construction phase, which details the mitigation measures to be implemented for the construction of the bridge substructures.
Temporary alterations to the hydrological and morphological regime of the ordinary watercourses/IDB drains, such as	During the construction phase, existing ordinary watercourses/IDB drains within the Principal Application Site may be temporarily diverted, culverted or blocked to facilitate the construction of the channel realignments and new culverts. This may temporarily alter the hydrological regime, such as flow path and rate, and morphological characteristics of these watercourses.

Potential Impact	Description and Mitigation
changes to the flow path and rate, associated with the construction of the channel realignments and new culverts.	The Outline CoCP (document reference 6.16) in line with usual good practice, includes measures to maintain appropriate drainage arrangements at all stages of construction, with temporary diversions, culverts or over pumping used as required. It is therefore unlikely that the works will have any significant effect on these watercourses as existing drainage routes and outfall locations will be maintained wherever possible through construction.
Potential impacts on the groundwater regime due to disturbance of geological strata resulting from piling and dewatering activities.	The toe level of the cofferdam piles is expected to extend to the underlying Crag Group Aquifer (Principal Aquifer) and therefore may lead to localised disruptions in groundwater flow paths, which could result in adverse impacts to the principal groundwater receptor and aquifers. However, the piles will only occupy a very small cross sectional area and given they will be positioned parallel to groundwater flow to the river, the impacts to the groundwater regime (groundwater quantity and flow) will be negligible. Temporary groundwater control systems i.e. dewatering will be required to facilitate the construction of the bascule pit cofferdams. Modifications to groundwater conditions (locally) including groundwater level and flow by excavations and dewatering during the construction phase may cause alteration to groundwater receptors such as groundwater fed water supplies and/or local abstractions (water users). Appendix 11F: Groundwater Modelling Study of the Bascule Pit Groundwater Control System quantifies the impacts to local groundwater abstractor receptors and determines a dewatering zone of influence. The modelling suggests a zone of influence of approximately 400m from the cofferdam dewatering source with the change in groundwater levels diminishing rapidly with distance from the cofferdams. The nearest groundwater water user is located approximately 700m from the Principal Application Site, hence no impacts are predicted on groundwater abstraction, i.e. groundwater fed water supplies, within the Study Area due to dewatering of the cofferdams.
Potential introduction	The Outline CoCP (document reference 6.16) will include

Potential Impact	Description and Mitigation
of contaminants to groundwater receptors, through surface infiltration or through piling and dewatering activities	measures to reduce risks of contamination to surface water and groundwater. This will include measures such as lining of storage areas and drainage ponds where necessary to prevent significant infiltration of potentially contaminated water. It has been identified that driven piles are most appropriate for the ground conditions (predominantly granular soils) present across the Principal Application Site. The use of driven piles reduces geotechnical risks associated with 'blowing sands' and avoids the need for disposal of pile arisings and spillages entering the River Yare. However, driven piles can introduce preferential pathways for pollutants to migrate to the underlying aquifer due to the smooth surface of the piles and allow contaminated soils to be dragged along the shaft of the pile or be pushed ahead of the pile toe while driving. A Piling Works Risk Assessment has been completed as part of Chapter 16: Geology and Soils (document reference 6.2, Technical Appendix 16D) which considers these risks. The assessment suggests that piling activities are unlikely to cause an unacceptable pollution risk to the underlying groundwater system given limited contamination has been identified in the soil and sediment samples obtained across the Principal Application Site. Furthermore, the assessment states that vertical hydraulic continuity is likely to already exist between the superficial deposits and the underlying Crag Group Aquifer, hence piling is not expected to introduce new contamination. During construction of piled foundations and groundwater dewatering, water pumped from excavations may introduce or laterally expand any existing saline intrusion to fresh groundwater sources. However, groundwater quality sampling has confirmed the influence of saline intrusion in groundwater across the Principal Application Site, indicating hydraulic connection between the local groundwater system and the River Yare. In addition, the groundwater modelling has predicted a localised impact whereby the zone of influence only extends approximately 400m from the dewatering source. Based on the above, the impacts of dewatering-induced saline intrusion are considered marginal.

Potential Impact	Description and Mitigation
	The Outline CoCP (document reference 6.16) includes measures to avoid cross contamination and aquifer deterioration during construction of the piled foundations.
Disturbance through noise and vibration from piling and other construction related sources.	Installation of the cofferdams within the River Yare has the potential to disturb or harm fish, birds and invertebrates during piling. Birds and fish are likely to move away from the area into adjacent parts of the River Yare, or elsewhere during the disturbance, which will be temporary. It is unlikely that fish will be significantly affected within the River Yare as the river is large enough for fish to migrate away from the source of the noise and vibration during the works. Findings from the benthic and fish survey suggest that aquatic communities identified within the River Yare are of limited conservation value, therefore noise and vibration from construction works are considered to have limited impact on these communities in relation to the pressures already present due to habitat modification as a result of existing dredging activities (see Chapter 8: Nature Conservation). The Outline CoCP (document reference 6.16) sets out the framework to produce a noise and vibration management plan, which will be implemented and will control noise emissions from the construction site through the delivery of the Scheme. In addition, soft start pilling techniques will be employed to minimise noise and vibration during construction of the bridge substructures.
Disturbance/loss of inter-tidal and aquatic habitat through siting of the cofferdams.	No intertidal habitat has been identified within the Application Site, and based on the tidal regime of the estuary and available bathymetry data provided for the River Yare, the channel through the Application Site is unlikely to support intertidal habitat as the river bed and habitat will not be exposed during low tide due to the narrow tidal range and the deep channel profile through the Application Site. Aquatic communities identified in the benthic ecology and fish survey are of limited conservation value and are subject to habitat modification due to existing dredging activities along the River Yare. Therefore, any disturbances or losses due to siting of the cofferdams are considered negligible.

1.4.5 The construction impacts are expected to be temporary and localised with affected water features recovering over time as any residual pollutants settle and disperse through natural processes and following the removal of any temporary works or diversions. The construction impacts are therefore not assessed to have a permanent or long-term effect on the quality elements of the waterbodies (with respect to the waterbody objective timescales), which would affect the status of the quality elements sufficient to cause a deterioration or meeting the WFD objectives. Potential construction impacts have therefore not been considered further in this report.

Table 1.6: Potential Operation Impacts and Mitigation

Potential Impact	Description and Mitigation
Release of contaminants into surface waterbodies from routine road runoff and through spillage.	The Drainage Strategy for the Scheme (document reference 6.2, Technical Appendix 12C) will include some level of treatment of road runoff prior to discharge. Pollution control measures currently proposed include vortex separator and natural treatment in the form of wet pond/wetland feature. Penstocks are also proposed as control of spillages. A HAWRAT assessment (Appendix 11D) has been completed for the western part of the Scheme to investigate the potential impacts of discharging into the IDB watercourse network adjacent to the Scheme and into the River Yare. Results of the assessment suggest that impacts to the River Yare will be negligible due to the significant dilution capacity of the waterbody. Greater impacts are predicted on the immediate IDB watercourse network due to the ephemeral nature of these features. However, it has been confirmed that these watercourses already receive existing highway discharges with no known treatment. Therefore, runoff from the Scheme is unlikely to cause significant deterioration in water quality of the IDB network, particularly with pollution control measures implemented as part of the Scheme Drainage Strategy. The impacts to the wider IDB catchment are also considered to be insignificant as contaminants released into the watercourses in vicinity of the Scheme would have been sufficiently diluted and dispersed before reaching the main dyke system within the marshes south of Breydon Water. With consideration of spillage containment, the HAWRAT assessment indicates that the risks of contamination through spillages would be negligible with the annual probability of a serious incident occurring estimated at 0.014%, which is well below the 1% threshold set by the

Potential Impact	Description and Mitigation
	DMRB.
Pollution to surface water due to disturbance of contaminated sediments within the River Yare due to increased scour and erosion caused by the bridge substructures	The sediment transport assessment (Appendix 11C) has shown that the Scheme will create areas of additional sediment erosion and deposition near the Principal Application Site. Additional erosion is predicted around the bridge substructures, where potentially contaminated sediments would be mobilised and re-suspended in the water column. However, the volume of disturbed sediments only represents a very small proportion of the volume of water that transits through the estuary. Hence, any contaminants released would be quickly dispersed/diluted through the tidal flow regime and are unlikely to cause significant deterioration in the water quality in the River Yare. The sediment transport modelling indicates disturbed sediments will deposit close to the Scheme, and will not settle out in any significant quantity elsewhere in the estuary. The benthic communities and fish identified in the River Yare are considered of limited conservation value (see Chapter 8: Nature Conservation). Considering only a small volume of sediments would be mobilised and the significant dilution capacity of the River Yare, the impacts to aquatic ecology as a result of the release of sediment-bound contaminants would be negligible. Findings from the sediment transport assessment also suggest that the effects on the hydromorphological regime of the River Yare are local and do not extend up or downstream to impact on receptors, such as Breydon Water, the River Bure and the North Sea, that are hydraulically linked to the Yare. Any sediment bound contaminants released in the River Yare would be sufficiently diluted before reaching these receptors. Therefore, no impacts are predicted on these surface water features.
Alterations to the tidal and hydromorphological regime of the River Yare, such as changes to the tidal prism and erosion, deposition and channel migration processes due to	The sediment transport assessment (Appendix 11C) has shown that the presence of the new crossing and associated bridge substructures will have negligible impacts on the tidal regime, in relation to the tidal prism, tidal symmetry and water level, of the River Yare estuary. With respect to the hydromorphological regime, the assessment predicts localised changes to the erosion/deposition pattern in the engineered channel of the River Yare close to the Principal Application Site for both the

Potential Impact	Description and Mitigation
channel modifications and in-channel structures associated with the new bridge crossing.	everyday and extreme tidal events. However, the changes will not lead to significant modifications to the morphological characteristics of the river, which is already heavily engineered and subject to regular dredging. There is no net change in sediment volume in the channel, meaning the Scheme will not impact on the volume of dredged material, but may alter the locations where dredging is required. The sediment transport assessment also predicts a negligible change in the tidal prism resulting from the Scheme. Based on findings from the sediment transport assessment, the predicted changes in hydromorphological regime in the River Yare will not extend up and downstream to impact on the River Bure, Breydon Water and the North Sea. This means the Scheme will have negligible impacts on the sediment transport regime of these surface water features.
Increase in runoff from the Scheme leading to changes in the hydrological regime of receiving watercourses	The Scheme Drainage Strategy (document reference 6.2, Technical Appendix 12C) will ensure runoff is attenuated to as close as practical to greenfield rates for the 1 in 100-year event, including climate change. Where this is not achievable, the post development runoff rates and volumes should not exceed existing scenario values. Therefore, the Scheme is not expected to result in significant changes to existing flows (hydrological regime) in receiving watercourses.
Alterations to the hydrological and morphological regime of the ordinary watercourses/IDB drains, such as changes to the flow path and rate, associated with the channel realignments, new drainage outfalls and culvert extensions.	The Scheme will include channel realignment and culvert extensions of the IDB watercourse network within the Principal Application Site. However, the proposals will maintain existing drainage routes and catchments, therefore significant changes in the hydrological regime are not expected. Increased lengths of culvert and new discharge outfalls into the IDB drains could impact on the morphological quality of the watercourses; however, the drains are already culverted in many places and form part of urban and highway drainage infrastructure. Thus, the effects are unlikely to significantly impact on the morphological characteristics of these watercourses or migrate downstream to impact on the wider IDB catchment. The outfalls will require some localised engineering and scour protection however, the scale of works will be small and is unlikely to significantly affect the morphological characteristics of the watercourses.
Release of	The Drainage Strategy for the Scheme (document reference

Potential Impact	Description and Mitigation
contaminants into groundwater waterbodies from routine road runoff and through spillage (via infiltration).	6.2, Technical Appendix 12C) will include some level of treatment of road runoff prior to discharge. Pollution control measures currently proposed include a vortex separator and natural treatment in the form of wet pond/wetland feature. Penstocks are also proposed as control of spillages. These will reduce the likelihood of contaminants infiltrating into the underlying groundwater downstream of the Scheme. The disposal of road runoff via infiltration (e.g. soakaway) is not proposed in the Drainage Strategy due to high groundwater levels in the Principal Application Site and any drainage features will be lined where necessary to limit any infiltration of polluted runoff to the underlying groundwater.
Potential impacts on the groundwater regime and water quality due to introduction of piles	The piles are expected to extend to the underlying Crag Group Aquifer (Principal Aquifer) and therefore may lead to localised disruptions in groundwater flow paths. However, the piles will only occupy a very small cross sectional area and given they will be positioned parallel to groundwater flow, the impacts to the groundwater regime will be negligible. The Principal Application Site only represents a very small proportion of the catchment of the Crag Group Aquifer, which receives recharge from multiple sources within the wider catchment. Furthermore, the Crag Group Aquifer underlies an inconsistent multi-layered superficial aquifer, which already limits recharge locally to the underlying Crag Group Aquifer where clay occurs. Hence changes to groundwater recharge to the Crag Group Aquifer as a result of the piles are considered negligible. There is the potential for increased saline intrusion pathway due to the introduction of piles. However, the effects will be localised and groundwater quality sampling has confirmed the influence of saline intrusion in groundwater across the Principal Application Site, indicating hydraulic connection between the local groundwater receptors and the River Yare. Hence the Scheme is not expected to cause any additional changes that would increase saline intrusion at a catchment scale.
Disturbance/loss of Inter-tidal and aquatic habitat through placement of the bridge	No intertidal habitat has been identified within the Application Site, and based on the tidal regime of the estuary and available bathymetry data provided for the River Yare, the channel through the Application Site is unlikely to support intertidal habitat as the river bed and habitat will not

Potential Impact	Description and Mitigation
substructures.	be exposed during low tide. Aquatic communities identified in the benthic ecology and fish survey are of limited conservation value and are subject to habitat modification due to existing dredging activities along the River Yare. Therefore, any disturbances or losses due to the bridge substructures are considered negligible.

1.5 Assessment against individual Quality Elements

1.5.1 The following tables provide an assessment of the potential impacts of the Scheme on each of the respective waterbody quality elements, associated features, and the ability to meet the waterbody objectives as set out in the RBMP.

1.5.2 The key aspects of the Scheme have been consolidated into three elements in the assessment tables. The assessment considers the impacts and embedded mitigation incorporated into the proposals described in Section 1.4 against each of the quality elements (status and objectives) but does not repeat the detail. The consolidated Scheme elements are as follows:

1. River Yare bridge crossing:
    - Bridge substructures and channel modifications associated with the new bridge crossing – these could have potential impacts on the hydromorphological, physico-chemical, biological and chemical quality elements of the Bure & Waveney & Yare & Lothing Transitional and Norfolk East Coastal waterbodies
    - Introduction of piles to facilitate the construction of the cofferdams – this could have potential impacts on the quantitative and chemical quality elements of the Broadland Rivers Chalk & Crag groundwater waterbody.
2. Highway drainage across the whole Scheme:
    - Changes in runoff and the construction of new outfalls – these could have potential impacts on the hydromorphological and biological quality elements of the Bure & Waveney & Yare & Lothing Transitional and Norfolk East Coastal waterbodies with respect to discharge of highway runoff into the IDB watercourse network within the Principal Application Site or into the River Yare.

- Potential contaminants in highway runoff - these could have potential impacts on the physio-chemical, biological and chemical quality elements of the Bure & Waveney & Yare & Lothing Transitional and Norfolk East Coastal waterbodies with respect to discharge of highway runoff into the IDB watercourse network within the Principal Application Site or into the River Yare.

- Potential contaminants in highway runoff infiltrating into the underlying groundwater– this element could have potential impacts on the quantitative and chemical quality elements of the Broadland Rivers Chalk & Crag groundwater waterbody.

3. Channel realignments and culvert extensions of the IDB watercourse network within the Principal Application Site – this element of the Scheme could have potential impacts on the hydromorphological and biological quality elements of the Bure & Waveney & Yare & Lothing Transitional and Norfolk East Coastal waterbodies; this element is not expected to impact on the Broadland Rivers Chalk & Crag groundwater waterbody.

Table 1.7: Bure & Waveney & Yare & Lothing Transitional Waterbody Assessment

Water body Name & ID	**Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700**		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Ecological status (current status: Moderate; Objective: Moderate)			
Hydromorphological quality elements **Current status: Supports Good** **Objective: Supports Good** - **Hydrological Regime**	Negligible change on the tidal / fluvial hydrological regime. Some localised effects on the hydromorphological regime of the River Yare where the Scheme will create areas of additional sediment erosion and deposition near the Principal Application Site. These localised effects will not lead to significant modifications to the morphological characteristics of the River Yare. Any changes to the	Slight change in runoff rates to receiving watercourses but runoff will be attenuated to greenfield rates wherever possible and where not possible will be limited to existing rates. Some detrimental effects on the morphological quality of the IDB watercourse where new discharge outfalls are proposed but effects considered insignificant as the watercourses already receive runoff from existing drainage system. On the other hand,	Slight effect on specific IDB watercourses affected but existing drainage routes and catchments maintained. Some detrimental effects on the morphological quality of the IDB watercourses due to increased lengths of culvert but effects considered insignificant as the watercourses are already culverted in many places and represent a very small proportion of the wider network. No effects expected on the

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	hydromorphological regime along the River Yare will not extend upstream to impact on the River Bure or Breydon Water within the waterbody. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the hydromorphological quality (hydrological regime) of the waterbody nor prevent the waterbody from meeting the objective of this element.	new discharge outfalls are not expected to impact on the morphological quality of the River Yare. Effects insignificant to hydrological regime of the waterbody as only a very small area affected. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the hydromorphological quality (hydrological regime) of the waterbody nor prevent the waterbody from meeting the objective of this element.	hydrological regime. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the hydromorphological quality (hydrological regime) of the waterbody nor prevent the waterbody from meeting the objective of this element.
Physico-chemical quality elements	Some potential for the mobilisation of contaminated	Some potential for increased contaminants in receiving	N/A – this aspect of the Scheme will not alter the

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Current status: Moderate **Objective: Moderate** - **Dissolved inorganic Nitrogen** - **Dissolved Oxygen** - **Specific pollutants**	sediments in the River Yare due to additional erosion caused by the flow constriction at the crossing. Volume of disturbed sediments would be very small compared to the tidal flows hence any contaminants released will be quickly dispersed/diluted and unlikely to cause significant impacts. Any changes to water quality in the River Yare will not extend upstream to impact on the River Bure or Breydon Water within the waterbody. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the	watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the waterbody. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the physico-chemical quality of the waterbody, with respect to Dissolved inorgnanic Nitrogen, Dissolved Oxygen and Specific pollutants, nor prevent the waterbody from meeting the objective of this	concentrations of Dissolved inorganic Nitrogen, Dissolved Oxygen and Specific pollutants in the waterbody.

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	physico-chemical quality of the waterbody, with respect to Dissolved inorganic Nitrogen, Dissolved Oxygen and Specific pollutants, nor prevent the waterbody from meeting the objective of this element.	element.	
Biological Quality Elements **Current status: Poor** **Objective: Good by 2027** - **Angiosperms** - **Invertebrates** - **Microalgae** - **Phytoplankton**	Some detrimental effects on morphological characteristics and water quality in the River Yare due to mobilisation of potentially contaminated sediments at the crossing but unlikely to affect the ability of the watercourse to support existing aquatic ecology. Similar pressures already exist due to existing dredging operations.	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality and subsequent aquatic ecology in the waterbody due to relative size and existing sources of contamination affecting the waterbody.	Slight effect on morphological characteristics of local IDB drains but unlikely to significantly affect their ability to support existing aquatic ecology and only a small area of the waterbody would be affected. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the biological quality of the

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	No intertidal habitat has been identified within the Application Site and the Scheme is not predicted to impact on any intertidal habitation upstream and downstream of the Scheme. Effects of the Scheme are considered insignificant to the waterbody as only a small area affected. Any changes to the morphological regime and water quality in the River Yare at the crossing are not expected to impact on the wider catchment. Aquatic ecology assessment confirms no significant impacts resulting from the Scheme.	Therefore, this aspect of the Scheme is not expected to cause a deterioration to the biological quality of the waterbody, with respect to Angiosperms, Invertebrates, Microalgae and Phytoplankton, nor prevent the waterbody from meeting the objective of this element.	waterbody, with respect to Angiosperms, Invertebrates, Microalgae and Phytoplankton, nor prevent the waterbody from meeting the objective of this element.

Water body Name & ID	**Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700**		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	Therefore, this aspect of the Scheme is not expected to cause a deterioration to the biological quality of the waterbody, with respect to Angiosperms, Invertebrates, Microalgae and Phytoplankton, nor prevent the waterbody from meeting the objective of this element.		
Biology: Higher sensitivity habitats - **Saltmarsh**	No impact expected. The identified habitat (Saltmarsh) is found within Breydon Water and along the River Bure approximately 3 to 4km upstream from the Application Site. Given the distance from the Scheme, any changes to the hydromorphological characteristics and water quality in the surface water features at the crossing, including the River Yare which is in hydraulic connection with Breydon Water and the River Bure, are not expected to have any discernible impact on the identified habitat.		
Biology: Lower sensitivity	The identified intertidal habitats (Intertidal soft sediments and Subtidal soft sediments) are found		

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
habitats - **Intertidal soft sediments** - **Subtidal soft sediments**	within Breydon Water and in isolated areas along the west bank of the River Yare approximately 700m downstream from the Scheme. No intertidal habitat has been identified within the Application Site. Any changes to surface water features resulting from the Scheme are not expected to have any discernible impact on the identified habitat. The identified subtidal habitat is found along the coastline and given the distance from the Scheme, any changes to surface water features at the crossing are not expected to impact on this habitat.		
Chemical status (current status: Good; Objective: Good)			
Priority substances **Current status: Good** **Objective: Good**	Some potential for the mobilisation of contaminated sediments in the River Yare due to additional erosion caused by flow constriction as a result of the Scheme. Volume of disturbed sediments would be very small compared to the tidal flows hence any	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations highly unlikely to affect water quality in the waterbody due to relative size and existing	N/A - this aspect of the Scheme will not alter the concentration of Priority substances in the waterbody.

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	contaminants released will be quickly dispersed/diluted and unlikely to cause significant impacts. Any changes to water quality in the River Yare will not extend upstream to impact on the River Bure or Breydon Water within the waterbody. Given the Good chemical status, the waterbody is not identified as being at pressure related to sediment-bound contaminants. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority substances quality of the waterbody nor prevent the	sources of contamination affecting the waterbody. Given the Good chemical status, the waterbody is not identified as being at pressure related to contaminants contained in road runoff. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	waterbody from meeting the objective of this element.		
Other pollutants **Current status: Does not require assessment** **Objective: Does not require assessment**	N/A – no Other pollutants have been identified in the sediment sampling undertaken as part of the Scheme, therefore the mobilisation of contaminated sediments in the River Yare will not affect the Other pollutants quality of the waterbody.	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations highly unlikely to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the waterbody. Given the Good chemical status, the waterbody is not identified as being at pressure related to contaminants	N/A – this aspect of the Scheme will not alter the concentration of Other pollutants in the waterbody.

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
		contained in road runoff. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Other pollutants quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	
Priority hazardous substances **Current status: Good** **Objective: Good**	Some potential for the mobilisation of contaminated sediments in the River Yare due to additional erosion caused by flow constriction as a result of the Scheme. Volume of disturbed sediments would be very small compared to the tidal flow regime hence any contaminants released will be quickly dispersed/diluted	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations highly unlikely to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the waterbody.	N/A - this aspect of the Scheme will not alter the concentration of Priority hazardous substances in the waterbody.

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	and unlikely to cause significant impacts. Any changes to water quality in the River Yare will not extend upstream to impact on the River Bure or Breydon Water within the waterbody. Given the Good chemical status, the waterbody is not identified as being at pressure related to sediment-bound contaminants. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority hazardous substances quality of the waterbody nor prevent the waterbody from meeting the objective of this	Given the Good chemical status, the waterbody is not identified as being at pressure related to contaminants contained in road runoff. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority hazardous substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	element.		
Protected Areas **Breydon Water SPA; nutrient sensitive areas**	Due to the distance from the Scheme, any changes to the hydromorphological regime and water quality in the River Yare, which is in hydraulic connection with the Breydon Water SPA, will not extend upstream to impact on the protected area. No impacts expected on protected area which relates to nitrate sensitivity.		
Mitigation measures to achieve objectives	No impacts expected. No specific mitigation measures identified for waterbody.		

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Mitigation measures for heavily modified water designated use (Flood protection; navigation, ports and harbours) - **Dredging disposal strategy** - **Reduce impact of dredging** - **Sediment management** - **Dredge disposal site selection** - **Manage disturbance** - **Retain habitats**	The Scheme will not impact upon existing flood protection measures or alter the existing requirements for navigation, ports and harbours. Changes to these would likely require wide ranging measures throughout the urban area that far outweigh the scale of the Scheme. The Scheme will not affect the identified mitigation measures for heavily modified water designated use.		
Compliant with WFD objectives?	Yes – while there may be some localised effects on the watercourses directly affected by the Scheme these are not sufficient to affect the status of any of the quality elements of the Bure &		

Water body Name & ID	Bure & Waveney & Yare & Lothing (Transitional Waterbody) GB10503410700		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	Waveney & Yare & Lothing waterbody. Similarly, they will not affect the ability to meet the objectives for the waterbody set out in the RBMP. In conclusion, the Scheme would not lead to a deterioration to the current overall status (Moderate) of the waterbody. In addition, the Scheme would not prevent the waterbody from achieving its objective, which is to achieve/maintain Moderate status by 2027. No known specific waterbody measures have been identified.		

Table 1.8: Norfolk East Coastal Waterbody Assessment

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Ecological status (current status: Moderate; Objective: Moderate)			
Hydromorphological quality elements – n/a	N/A – Hydromorphological quality is not a measured supporting element for this waterbody type. Effects on the hydromorphological regime at the crossing will not extend to the coast to impact on this waterbody.		
Physico-chemical quality elements **Current status: Moderate** **Objective: Moderate** - **Dissolved inorganic Nitrogen** - **Dissolved oxygen** - **Specific pollutants (Toluene, Zinc)**	Some potential for the mobilisation of contaminated sediments in the River Yare due to additional erosion caused by flow constriction at the crossing. Volume of disturbed sediments would very small compared to the tidal flow regime hence any contaminants released will be quickly dispersed/diluted and area highly unlikely to cause significant impacts to water	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality in the Norfolk East waterbody due to relative size and existing sources of contamination affecting the waterbody. Therefore, this aspect of the	N/A - no direct connectivity to this waterbody.

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	quality in the coastal waterbody. Only indirect connectivity exists between the Scheme and the Norfolk East waterbody. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the physico-chemical quality of the waterbody, with respect to Dissolved inorgnanic Nitrogen, Dissolved Oxygen and Specific pollutants, nor prevent the waterbody from meeting the objective of this element.	Scheme is not expected to cause a deterioration to the physico-chemical quality of the waterbody, with respect to Dissolved inorgnanic Nitrogen, Dissolved Oxygen and Specific pollutants, nor prevent the waterbody from meeting the objective of this element.	
Biological Quality Elements **Current status: Good**	Some detrimental effects on local morphological characteristics and water	Some potential for increased contaminants in receiving watercourses but will be	N/A – no direct connectivity to this waterbody

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Objective: Good - **Phytoplankton**	quality in the River Yare due to mobilisation of potentially contaminated sediments at the crossing but unlikely to affect the ability of the watercourse to support existing aquatic ecology. Effects of the Scheme are considered insignificant to the Norfolk East waterbody as only indirect connectivity to the Scheme. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the biological quality of the waterbody, with respect to Phytoplankton, nor prevent the waterbody from meeting	reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality and subsequent aquatic ecology in the waterbody due to relative size and existing sources of contamination affecting the water body. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the biological quality of the waterbody, with respect to Phytoplankton, nor prevent the waterbody from meeting the objective of this element.	

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	the objective of this element.		
Biology: Higher sensitivity habitats **Chalk reef** **Polychaete reef**	No impact expected. Scheme has only indirect connectivity to the identified habitats (Chalk reef and Polychaete) via the Bure & Waveney & Yare & Lothing waterbody. Any changes to surface water features resulting from the Scheme are not expected to have any discernible impact on the Norfolk East waterbody and therefore on the identified habitats.		
Biology: Lower sensitivity habitats **Cobbles, gravel and shingle** **Intertidal soft sediments** **Subtidal rocky reef** **Subtidal soft sediments**	No impact expected. Scheme has only indirect connectivity to the identified habitats (Cobbles, gravel and shingle; Intertidal soft sediments; Subtidal rocky reef and Subtidal soft sediment) via the Bure & Waveney & Yare & Lothing waterbody. Any changes to surface water features resulting from the Scheme are not expected to have any discernible impact on the Norfolk East waterbody and therefore on the identified habitats.		
Chemical status (current status: Good; Objective: Good)			
Priority substances **Current status: Good**	Some potential for the mobilisation of contaminated sediments in the River Yare	Some potential for increased contaminants in receiving watercourses but will be	N/A - no direct connectivity to this waterbody.

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Objective: Good	due to additional erosion caused by flow constriction as a result of the Scheme. Volume of disturbed sediments would very small compared to the tidal flows hence any contaminants released will be quickly dispersed/diluted and unlikely to cause significant impacts. Effects are considered insignificant to the Norfolk East waterbody as only indirect connectivity to the Scheme and contaminants will be sufficiently diluted and dispersed prior to reaching this waterbody. Therefore, this aspect of the	reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the water body. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	Scheme is not expected to cause a deterioration to the Priority substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.		
Other pollutants **Current status: Does not require assessment** **Objective: Does not require assessment**	N/A - no Other pollutants have been identified in the sediment sampling undertaken as part of the Scheme, therefore the mobilisation of contaminated sediments in the River Yare will not affect the Other pollutants quality of this waterbody.	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the water body. Therefore, this aspect of the Scheme is not expected to	N/A - no direct connectivity to this waterbody.

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
		cause a deterioration to the Other pollutants quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	
Priority hazardous substances **Current status: Good** **Objective: Does not require assessment**	Some potential for the mobilisation of contaminated sediments in the River Yare due to additional erosion caused by flow constriction as a result of the Scheme. Volume of disturbed sediments would very small compared to the tidal flow regime hence any contaminants released will be quickly dispersed/diluted and unlikely to cause significant impacts.	Some potential for increased contaminants in receiving watercourses but will be reduced by road drainage treatment. Runoff volumes and concentrations insufficient to affect water quality in the waterbody due to relative size and existing sources of contamination affecting the water body. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the	N/A - no direct connectivity to this waterbody.

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	Effects insignificant to the Norfolk East waterbody as only indirect connectivity to the Scheme and contaminants will be sufficiently diluted and dispersed prior to reaching this waterbody. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Priority hazardous substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	Priority hazardous substances quality of the waterbody nor prevent the waterbody from meeting the objective of this element.	
Protected Areas **Great Yarmouth South and Great**	No impacts expected on protected areas. Some potential for increased contaminants due to mobilisation of contaminated sediments in the River Yare but further treatment by natural		

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
Yarmouth Pier bathing waters, Outer Thames Estuary SPA; Great Yarmouth North Denes SPA	processes will occur prior to discharge to the coast. Highway runoff will be treated before discharge. Runoff volumes and concentrations insufficient to affect water quality in the Norfolk East waterbody due to relative size.		
Mitigation measures to achieve objectives	No impacts expected. No specific mitigation measures identified for waterbody.		
Mitigation measures for heavily modified water designated use (Flood and coastal protection) - **Sediment management** - **Dredge disposal site selection** - **Manage disturbance**	The Scheme will not impact upon existing flood and coastal protection measures or provide an opportunity to alter these. Changes to these would likely require wide ranging measures that far outweigh the scale of the Scheme. The Scheme will not affect the identified mitigation measures for heavily modified water designated use.		
Compliant with WFD objectives?	Yes – while there may be some localised effects on the watercourses directly affected by the Scheme these are not sufficient to affect the status of any of the quality elements of the Norfolk East waterbody. Similarly, they will not affect the ability to meet the objectives for the waterbody set out in the RBMP. In conclusion, the Scheme would not lead to a deterioration to the current overall status (Moderate) of the waterbody. In addition, the		

Water body Name & ID	Norfolk East (Coastal Waterbody) GB650503520003		
Scheme design element:	**River Yare bridge crossing (bridge substructures; channel modifications)**	**Highway drainage (changes in runoff, potential contaminants and new outfalls associated with discharge into the IDB watercourse or into the River Yare)**	**Channel realignments and culvert extensions of IDB watercourse within the Principal Application Site**
	Scheme would not prevent the waterbody from achieving its objective, which is to maintain Moderate status. No known measures have been identified at present to maintain this objective.		

Table 1.9: Broadland Rivers Chalk & Crag Groundwater Waterbody Assessment

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
Quantitative Status (current status: Poor; Objective: Good by 2021)		
Saline intrusion **Current status: Good** **Objective: Good**	Some potential for increased saline intrusion pathway due to piling but effects will be localised. Groundwater quality sampling has confirmed the existing influence of saline intrusion in groundwater receptors across the Principal	N/A – the disposal of highway runoff via infiltration (e.g. soakaway) is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and drainage features will be lined where necessary to prevent mixing with groundwater,

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
	Application Site. The Scheme is not expected to cause any significant changes that would increase saline intrusion at the waterbody scale. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Quantitative Saline intrusion element of the waterbody nor prevent the waterbody from meeting the objective of this element.	therefore this aspect of the Scheme will not affect the Quantitative status (Saline intrusion) of this waterbody.
Water balance **Current status: Good** **Objective: Good**	Some potential for localised effects on groundwater pathways but insufficient to affect wider groundwater flows and availability. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Water balance element of the waterbody nor prevent the waterbody from meeting the objective of this element.	N/A – the disposal of highway runoff via infiltration (e.g. soakaway) is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and drainage features will be lined where necessary to prevent mixing with groundwater. The scale of the Scheme is insufficient to affect groundwater recharge therefore this aspect of the Scheme will not affect the Quantitative status (Water balance) of this waterbody.

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
GWDTE tests **Current Status: Poor** **Objective: Good by 2015**	Some potential for localised effects on groundwater pathways but insufficient to affect wider groundwater flows and quantity to groundwater receptors. No known GWDTEs identified in the vicinity of the Scheme. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Quantitative GWDTE element of the waterbody nor prevent the waterbody from meeting the objective of this element.	N/A – the disposal of highway runoff via infiltration (e.g. soakaway) is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and drainage features will be lined where necessary to prevent mixing with groundwater, therefore this aspect of the Scheme will not affect the Quantitative status (GWDTE tests) of this waterbody.
Dependent surface waterbody status **Current status: Good** **Objective: Good**	Some potential for localised effects on groundwater pathways but insufficient to affect wider groundwater flows and quantity to groundwater receptors. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Quantitative Dependent surface waterbody status of the waterbody nor prevent the waterbody from meeting the objective of this element.	N/A – the disposal of highway runoff via infiltration (e.g. soakaway) is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and drainage features will be lined where necessary to prevent mixing with groundwater, therefore this aspect of the Scheme will not affect the Quantitative status (Dependent surface waterbody status) of this waterbody.

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
Chemical Status (current status: Poor; Objective: Good by 2027)		
Drinking Water Protected Area **Current status: Poor** **Objective: Good by 2027**	Some potential for ground based contaminants to enter through piling however the Scheme is not expected to cause any significant changes that would deteriorate groundwater quality at the waterbody scale. The Study Area does not lie within a SPZ. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Drinking Water Protected Area of the waterbody nor prevent the waterbody from meeting the objective of this element.	Some potential for contaminants to enter groundwater via infiltration however, disposal of highway runoff via infiltration is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and the likelihood will be reduced as any drainage features will be lined where necessary to limit any infiltration of polluted runoff to the underlying groundwater receptors. The Study Area does not lie within a SPZ. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Drinking Water Protected Area of the waterbody nor prevent the waterbody from meeting the objective of this element.
General Chemical Test **Current Status: Good** **Objective: Good**	Some potential for ground based contaminants to enter through piling however the Scheme is not expected to cause any significant changes that would deteriorate groundwater quality at the	Some potential for contaminants to enter groundwater via infiltration however, disposal of highway runoff via infiltration is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
	waterbody scale. Waterbody not currently under pressure. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the General Chemical element of the waterbody nor prevent the waterbody from meeting the objective of this element.	and the likelihood will be reduced as any drainage features will be lined where necessary to limit any infiltration of polluted runoff to the underlying groundwater receptor. Waterbody not currently under pressure. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the General Chemical element of the waterbody nor prevent the waterbody from meeting the objective of this element.
GWDTE test **Current Status: Good** **Objective: Good**	Some potential for ground based contaminants to enter through piling however the Scheme is not expected to cause any significant changes that would deteriorate groundwater quality at the waterbody scale. No known GWDTEs identified in the vicinity of the Scheme. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Chemical GWDTE element of the waterbody	Some potential for contaminants to enter groundwater via infiltration however, disposal of highway runoff via infiltration is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and the likelihood will be reduced as any drainage features will be lined where necessary to limit any infiltration of polluted runoff to the underlying groundwater receptors. No known GWDTEs identified in the vicinity of the Scheme.

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
	nor prevent the waterbody from meeting the objective of this element.	Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Chemical GWDTE element of the waterbody nor prevent the waterbody from meeting the objective of this element.
Dependent surface waterbody status **Current Status: Good** **Objective: Good**	Some potential for ground based contaminants to enter through piling however the Scheme is not expected to cause any significant changes that would deteriorate groundwater quality at the waterbody scale. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Chemical Dependent surface waterbody status element of the waterbody nor prevent the waterbody from meeting the objective of this element.	Some potential for contaminants to enter groundwater via infiltration however, disposal of highway runoff via infiltration is not proposed in the Drainage Strategy (document reference 6.2 Appendix 12C) due to high groundwater levels and the likelihood will be reduced as any drainage features will be lined where necessary to limit any infiltration of polluted runoff to the underlying groundwater receptor. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Chemical Dependent surface waterbody status element of the waterbody nor prevent the waterbody from meeting the objective of this element.

Waterbody Name & ID	**Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)**	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
Saline intrusion **Current Status: Good** **Objective: Good**	Some potential for increased saline intrusion pathway due to piling but effects will be localised. Groundwater quality sampling has confirmed the influence of saline intrusion in groundwater across the Principal Application Site. The Scheme is not expected to cause any significant changes that would increase saline intrusion at the waterbody scale. Therefore, this aspect of the Scheme is not expected to cause a deterioration to the Chemical Saline intrusion element of the waterbody nor prevent the waterbody from meeting the objective of this element.	This aspect of the Scheme will not introduce saline intrusion in the groundwater and therefore no impacts are expected on this quality element.
Trend assessment **Upward trend**	No impacts expected. Existing pressures relate to groundwater abstraction associated with agriculture and rural land management.	
Protected Areas **Nitrate Directive, Drinking Water Protected Area**	No impacts expected on protected areas. Some potential for increased contaminants via infiltration of road runoff or through piling. Existing waterbody pressures relate to groundwater abstraction. The Study Area of the Scheme is not located within a SPZ.	

Waterbody Name & ID	Broadland Rivers Chalk & Crag (Groundwater Waterbody ID GB40501G400300)	
Scheme design element:	**River Yare bridge crossing (piled foundations)**	**Highway drainage (potential contaminants)**
Mitigation measures	No impacts expected. No specific mitigation measures are identified for groundwater waterbody.	
Compliant with WFD objectives?	Yes – while there may be some localised effects these are not sufficient to affect the status of any of the quality elements of the Broadland Rivers Chalk & Crag groundwater waterbody. Similarly, they will not affect the ability to meet the objectives for the waterbody set out in the RBMP. In conclusion, the Scheme would not lead to a deterioration to the current overall status (Poor) of the waterbody. In addition, the Scheme would not prevent the waterbody from achieving its objective, which is to achieve Good status by 2027, however no known measures have been identified at present to achieve this objective.	

1.6 Summary and Conclusion

1.6.1 This WFD assessment on behalf of the Applicant to assess the impacts and to identify appropriate mitigation measures for the proposed works associated with the Scheme.

1.6.2 The WFD waterbodies potentially affected by the Scheme were identified as the Bure & Waveney & Yare & Lothing (transitional), Norfolk East (coastal) and Broadland Rivers Chalk & Crag (groundwater). Although the Study Area of the Scheme is located within the designated boundary of the Waveney Operational Catchment and the Bure Operational Catchment, it is not considered to form part of the actual catchment for these fresh waterbodies or associated tributaries. The Scheme is therefore not considered to have any impact on these catchments.

1.6.3 The potential impacts of the Scheme, including relevant mitigation, have been assessed against each of the individual quality elements of the affected waterbodies to determine whether the Scheme will lead to any detriment in the current status of the waterbody and/or the ability to meet the stated objectives for the waterbody. The assessment has also considered potential effects on associated Protected Areas and planned mitigation measures.

1.6.4 The assessment has concluded that whilst the Scheme may have some localised effects on watercourses directly affected by the Scheme, and the local groundwater aquifer, these are insufficient to lead to any deterioration in status or ability to meet the objectives of the respective waterbodies. The Principal Application Site represents a very small proportion of the waterbody catchments and the works are relatively small in the context of the infrastructure and development already present. The potential impacts of the Scheme do not affect or alter the existing pressures on the waterbodies, which are largely due to flood and coastal protection; navigation, ports and harbours; continuous sewage discharge; poor nutrient management and groundwater abstractions.

1.6.5 Furthermore, the Scheme will not prevent the achievement of the wider WFD objectives in the Anglian River Basin District and is not predicted to have an impact on any other waterbody within the Anglian River Basin District or the proposed mitigation measures to achieve Good status.

1.7 References

Ref 11E.1: Environment Agency (2015). Anglian River Basin Management Plan.

Ref 11E.2: Environment Agency (2016 updated 2017). Water Framework Directive assessment: estuarine and coastal waters and EA.

Ref 11E.3: The Planning Inspectorate (2017). Advice note eighteen: The Water Framework Directive.

Ref 11E.4: Environment Agency (2011 updated 2015). The Water Framework Directive classification method statement.

Ref 11E.5: Environment Agency (2019, online). Catchment Data Explorer.

Ref 11E.6: Ordnance Survey (2018, online). Ordnance Survey Online Mapping.

Ref 11E.7: British Geological Society (2019, online). Geology of Britain viewer.

Ref 11E.8: The Waveney, Lower Yare & Lothingland Internal Drainage Board (2014). Burgh Castle District Water Level Management Plan.

Ref 11E.9: Department for Environmental and Rural Affairs, Natural England, Environmental Agency, Historic England, Forestry Commission and Marine Management Organisation (2019, online). Magic.

Ref 11E.10: Centre for Ecology & Hydrology (2019, online). Flood Estimation Handbook (FEH) web service portal.

Ref 11E.11: Department for Environment Food and Rural Affairs and Environment Agency (2015, online). UK Estuaries Database.

Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11F: Groundwater Modelling Study of the Bascule Pit Groundwater Control System

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

APFP regulation Number: 5(2)(a)

Planning Inspectorate Reference Number: TR010043

Author: Norfolk County Council

Document Reference: 6.2 – Technical Appendix 11F

Version Number: 0 – Revision for Submission

Date: 30 April 2019

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1 Introduction

1.1.1 Temporary works dewatering is required to lower groundwater pressures within and below cofferdams for the construction of the proposed bascules. The potential impact of the dewatering on the water environment needed to be assessed as part of the Great Yarmouth Third River Crossing Application for the Development Consent Order.

1.1.2 Environment Agency Report, SC040020/SR1 (Ref 11F.1), provides guidance on how to appraise the hydrogeological impacts of dewatering. The approach is risk based, matching the level of effort to the level of risk to the Environment. Three tiers, (levels of assessment), are identified, with the level of complexity and effort increasing from Tier 1 to Tier 3 in line with the level of risk. The guidance includes a scoring mechanism to identify the level of assessment required (the Tier of the assessment).

1.1.3 The scoring system is described below along with a summary of its application to the proposed dewatering and the resulting score, indicated in bold:

1. The aquifer characteristics: Principal Aquifer (Crag Group) will be impacted. **Weighted score = 6**
2. The presence of water dependent conservation sites: There are no groundwater dependent ecosystems near the Principal Application Site, but the River Yare is a SSSI. **Weighted score = 4 to 12**
3. The water resources availability status: There is no water availability map for groundwater, as a precaution, we have assumed that groundwater is not available. **Weighted score = 2**
4. The dewatering quantity: Maximum predicted by contractors was 15.3 L/s (1,300 m^3/d), which puts the quantity into the medium category (in the worst-case scenario). **Weighted score = 6**

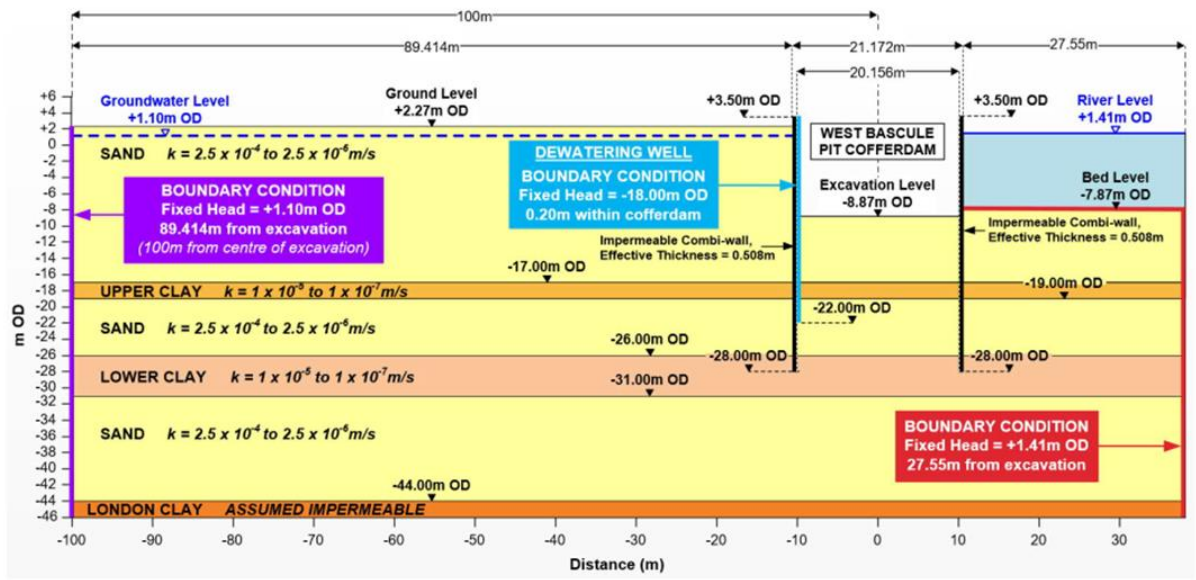
1.1.4 Total score is, therefore, between 18 and 26, which would indicate that a Tier 2 tool is appropriate. Tier 2 tools include analytical solutions, spreadsheets and basic numerical models.

1.1.5 The requirement to simulate the River Yare, the adjacent layered geological system and the cofferdam including piles meant that the adopted approach needed to be capable of representing different boundary conditions as well as spatially variable parameters.

1.1.6 A steady state MODFLOW model was considered the most appropriate for the assessment. The model was based on the Designer's conceptual model of the site presented below for reference (Plate 1.1).

1.1.7 Symmetry of the ground conditions is assumed either side of the River Yare. Therefore, the model results are considered applicable to the assessment of potential impacts on both the west and east banks of the River Yare.

Plate 1.1: Copy of the Designer's Conceptual Model



2 Groundwater Flow Model Set Up

2.1 Modelling Approach and Modelling Code

2.1.1 A 3D distributed numerical modelling approach was selected as the most appropriate way to investigate the groundwater system close to the western bascule pit cofferdam. A model was constructed to represent groundwater flow through simplified geological layers of sand and clay, as described by the Design team. The modelling code selected was MODFLOW-2015, an industry standard code, with Groundwater Vistas V7 selected as the graphical user interface for building and viewing the model and results.

2.1.2 Construction dewatering is estimated to be required over a 21-month period, a potentially long enough time period for a new ‘equilibrium’ also known as ‘steady state’ to establish. Steady state computations were considered appropriate to the conditions and allowed for the investigation of the maximum extent of the cone of depression formed by dewatering.

2.2 Model Domain/Extents

2.2.1 The groundwater flow model covers an area of 1 km^2. The eastern boundary of the model is a simplified representation of the River Yare running directly north-south for the purposes of the modelling. The western bascule pit cofferdam is therefore located close to the eastern boundary of the model. The western model boundary was assigned a constant head value and set at 1km from the cofferdam to ensure dewatering estimations are not significantly influenced by the boundary condition. The north and south model boundaries were located to form a uniform square area of 1km^2 and set as no flow boundaries. The boundaries are thought to be significantly far enough away not to influence model results.

2.2.2 The top of the model was set at 2.27m OD to be consistent with the ground level presented as per information provided by the Design team. For the purposes of this modelling, the top of the model is assumed to be flat. The bottom of the model is at an elevation of -44.0m OD, which is understood to be the top of the impermeable London Clay Formation, as per information provided by the Design team.

2.3 Model Vertical and Horizontal Discretisation

2.3.1 The model grid was set up with a minimum grid refinement of 0.5 x 0.5 m along the impermeable combi-wall of the west bascule pit cofferdam, increasing to 1 x 1 m within the cofferdam. Model cell size increases gradually with distance from the cofferdam to a maximum cell size of 50 x 50 m at the model extents.

2.3.2 The model layers were set up to correspond to the conceptual hydrogeological units as per information provided by the Design team. The model consists of six layers, detailed in Table 2.1 below. Model layers were assumed to be flat and homogenous for the purposes of this study.

Table 2.1: Groundwater Flow Model Layers

Model Layer Number	Design Team Assigned Hydrogeological Unit (and Interpreted Geology)	Top Elevation (m OD)	Bottom Elevation (m OD)	Additional Information
1	Sand (North Denes Formation, Breydon Formation and the Happisburgh Glaciogenic Formation undifferentiated)	2.27	-17.0	
2	Upper Clay (Crag Group Aquifer)	-17.0	-19.0	
3	Sand (Crag Group Aquifer)	-19.0	-26.0	
4	Lower Clay (Crag Group Aquifer) – penetrated by the sheet pile wall	-26.0	-28.0	Impermeable wall penetrates the lower clay to -28.0m OD. In order to include this in the model the lower clay layer was divided
5	Lower Clay (Crag Group Aquifer) –	-28.0	-31.0	Thickness of lower clay which

Model Layer Number	Design Team Assigned Hydrogeological Unit (and Interpreted Geology)	Top Elevation (m OD)	Bottom Elevation (m OD)	Additional Information
	below the sheet pile wall			is below the bottom of the impermeable wall
6	Sand (Crag Group Aquifer)	-31.0	-44.0	The base of the model was set at -44.0m OD, corresponding to the top of the London Clay

2.4 Model Boundary Conditions and Initial Conditions

2.4.1 River boundary conditions are used on the eastern boundary of the model to represent the River Yare. The river bed level was set at -7.87m OD and the river level was defined as 1.41m OD (as per information provided by the Design team). Representation is simplified for the purposes of this model and the river is assumed to run north south along the eastern edge of the model.

2.4.2 The western model boundary was set as a constant head boundary condition, with a head of 1.1m OD assigned. This is based on the conceptual pre dewatering groundwater level as provided by the Design team. The development of a recharge function was considered beyond the level of complexity required and recharge was not applied to the model. Instead a constant head boundary was used as a surrogate for recharge to maintained groundwater levels. The significance of the constant head boundary is discussed in the results section.

2.4.3 In the information provided by the Design team, six deep groundwater control dewatering wells were proposed with a target dewatering level of -22.0m OD, to be located within the sheet pile wall of the west bascule pit cofferdam. Ten passive dewatering wells were distributed around the remaining walls of the cofferdam. For this model, drain boundary conditions were chosen to represent the dewatering wells so that groundwater heads could be lowered to the level as specified by the Design team; the deep wells were assigned a drain elevation equal to the target dewatering level (-22.0m OD) and the passive dewatering wells were assigned an elevation of -8.87m OD to represent the excavation level within the cofferdam. The resulting drain flow rates were then verified against proposed pumping rates and the flow rates simulated by the Design team's groundwater model.

2.5 Model Hydraulic Properties

2.5.1 A sensitivity analysis was conducted to consider a range of hydraulic properties for the sand and clay units. The ranges of hydraulic conductivity modelled were consistent with the conceptual model outlined by the information provided by the Design team. Table 2.2 presents the ranges of hydraulic conductivity (K) values modelled. A minimum, maximum and average value was chosen for each unit and the upper and lower clay units were assigned the same permeability.

2.5.2 Horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) were assumed to be equal for the purposes of this study as there was no data to suggest otherwise. This assumption means water will flow as easily in the vertical direction as it will in the horizontal within a given model layer and builds in a conservative (worst case) prediction of the effects of dewatering for each scenario.

2.5.3 The proposed impermeable pile wall was represented in the model by assigning a very low hydraulic conductivity to a 0.5 m wide area where the wall is to be located.

Table 2.2: Simulated Hydraulic Conductivity Values

Unit	Hydraulic Conductivity (m/s)
Sand	2.5×10^{-4} to 2.5×10^{-6}
Upper and Lower Clay	1.0×10^{-5} to 1.0×10^{-7}
Impermeable combi-wall	1×10^{-15}

2.6 Model Sensitivity Analysis

2.6.1 Sensitivity analysis was completed to understand the significance to the model predictions of the uncertainties in the hydraulic parameters assigned. Nine model sensitivity analysis scenarios were run with different combinations of hydraulic conductivity (K). The model properties for each model run are summarised in Table 2.3.

Table 2.3: Hydraulic Conductivity Sensitivity Analysis Model Runs

Scenario	Sand K (m/s)	Clay K (m/s)
1	2.5×10^{-5}	1.0×10^{-6}
2	2.5×10^{-5}	1.0×10^{-5}
3	2.5×10^{-5}	1.0×10^{-7}
4	2.5×10^{-4}	1.0×10^{-6}
5	2.5×10^{-4}	1.0×10^{-5}
6	2.5×10^{-4}	1.0×10^{-7}
7	2.5×10^{-6}	1.0×10^{-6}
8	2.5×10^{-6}	1.0×10^{-5}
9	2.5×10^{-6}	1.0×10^{-7}

3 Groundwater Flow Model Results

3.1 Simulated Flow to Groundwater Control Wells

3.1.1 The model results agree extremely well with the dewatering flows predicted in the Design team's groundwater model. Theoretical flow rates to all the groundwater control dewatering wells are within the range 0.16 L/s to 15.53 L/s. Table 3.1 summarises the dewatering flows predicted in all modelled scenarios. For reference the flow rates determine by the Design team are also provided.

Table 3.1: Simulated Total Flow Rate from Dewatering Wells for each Modelled Scenario

Scenario	Sand K (m/s)	Clay K (m/s)	Predicted Total Flow Rate to Wells (L/s)	Design Team Modelling Study Predicted Total Flow Rates (L/s)
1	2.5×10^{-5}	1.0×10^{-6}	1.59	1.53
2	2.5×10^{-5}	1.0×10^{-5}	6.07	5.45
3	2.5×10^{-5}	1.0×10^{-7}	0.21	0.21
4	2.5×10^{-4}	1.0×10^{-6}	2.06	2.10
5	2.5×10^{-4}	1.0×10^{-5}	15.53	15.28
6	2.5×10^{-4}	1.0×10^{-7}	0.21	0.22
7	2.5×10^{-6}	1.0×10^{-6}	0.62	0.55
8	2.5×10^{-6}	1.0×10^{-5}	1.24	1.12
9	2.5×10^{-6}	1.0×10^{-7}	0.16	0.15
Median			1.24	1.12
Mean			3.08	2.96

These results are presented graphically in Plate 3.1.

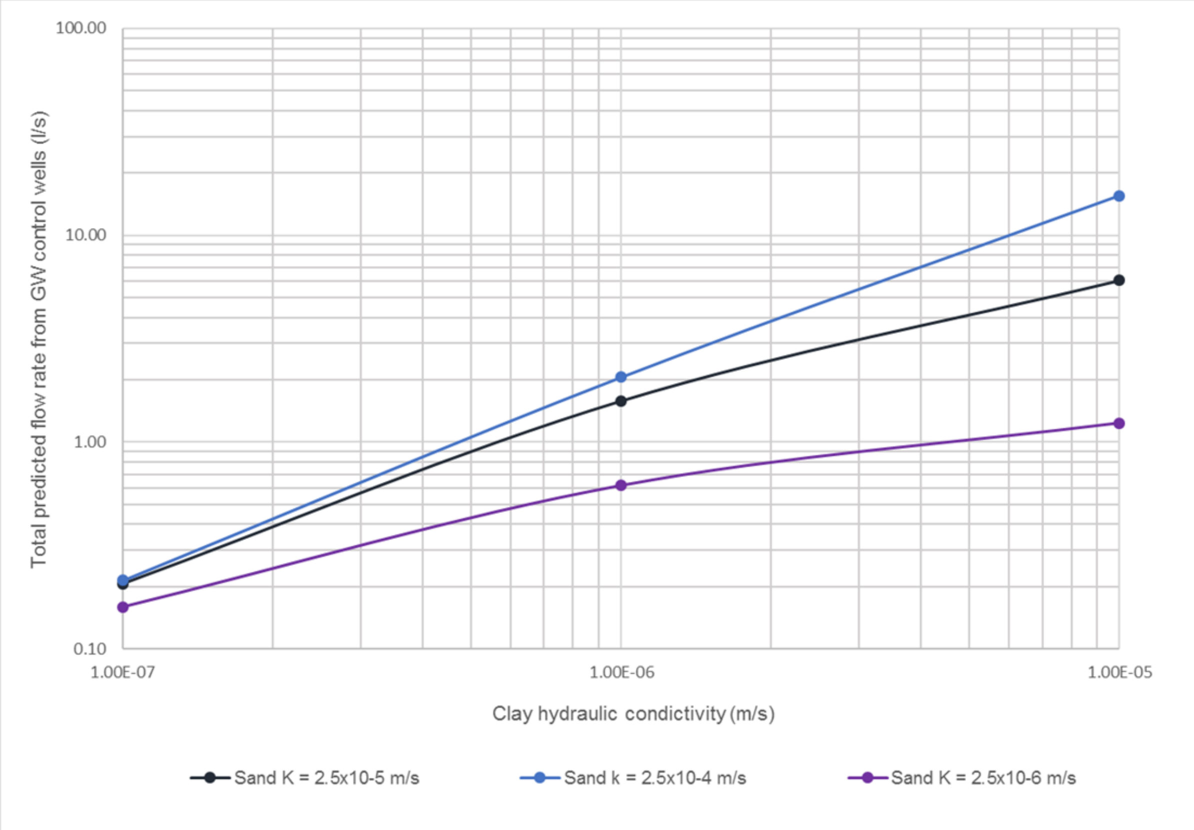


Plate 3.1: Sensitivity Analysis of Clay and Sand Hydraulic Conductivity

3.2 Impact of Dewatering on Local Groundwater Levels

3.2.1 The lateral impact of dewatering at the cofferdam varies depending on the hydraulic properties used in the model. Plate 3.2 shows drawdown from east to west in model layer 6, the thickest layer within the Crag Group Aquifer, for each scenario modelled.

3.2.2 Drawdown is greatest in Scenario 8 (worst case), which represents the impact in a low sand hydraulic conductivity and a high clay hydraulic conductivity setting. In this scenario the ‘clays’ are more permeable than the ‘sands’ and the effect of drawdown in the sands will propagate relatively easily across the clay layers.

3.2.3 The low sand hydraulic conductivity means a steeper cone of depression is formed and there is a greater impact on water levels near the cofferdam.

3.2.4 Plate 3.3 shows the drawdown predicted in model Scenario 8 (worst case) for all model layers. Immediately adjacent to the cofferdam the predicted drawdown is approximately 5.0m in the lower clay layer (model layer 5) and about 1.5m in the shallowest sand layer (model layer 1) reflecting the vertical attenuation of drawdown caused by the geological layering.

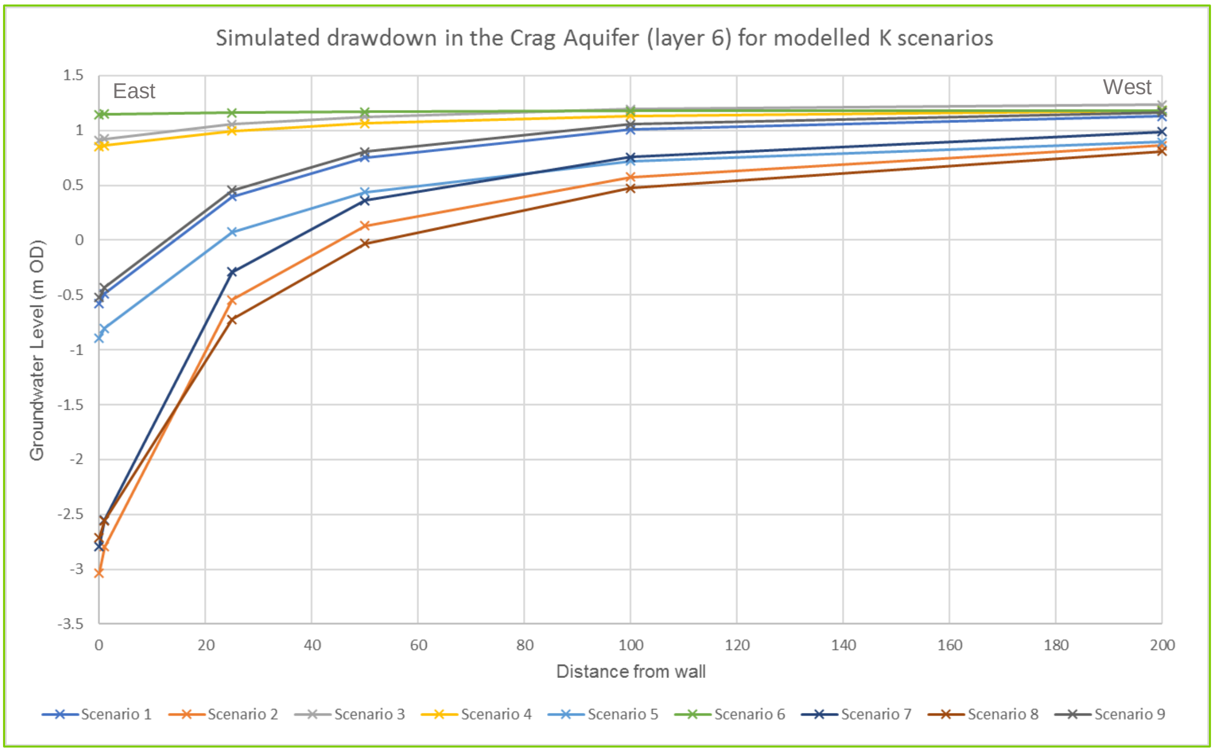


Plate 3.2: Simulated Drawdown in the Crag Group Aquifer (Layer 6) for all Scenarios Modelled

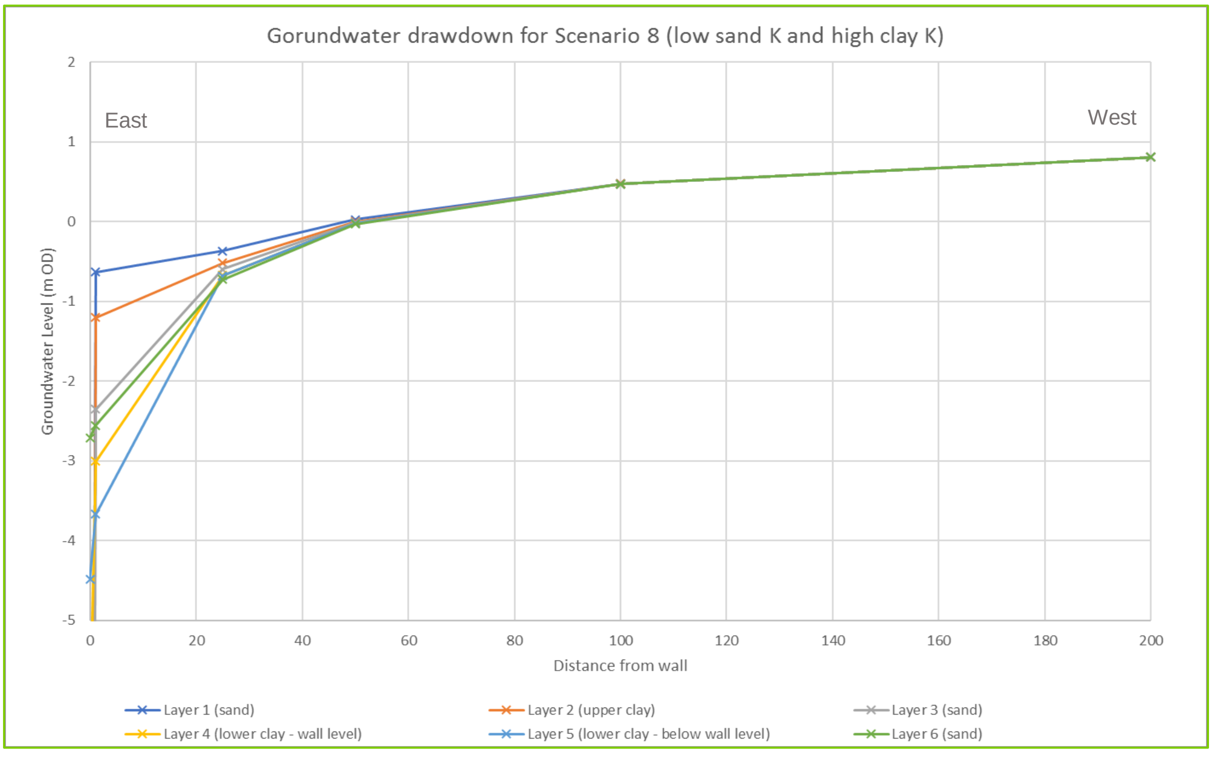


Plate 3.3: Worst Case Groundwater Drawdown (Scenario 8) with Distance from Cofferdam for each Model Layer

3.2.5 Drawdown will decrease exponentially with distance away from the cofferdam. The model simulates a drawdown of up to 5.0m close to the cofferdam, 1.8m at 25.0m distance, 0.6m at 100.0m distance, 0.3m at 200.0m distance, and 0.1m at 400.0m distance from the cofferdam (compared to the starting groundwater level of 1.1m OD).

3.2.6 The absence of a rainfall recharge model boundary condition means that the model recharge is sourced via the western constant head boundary, and to a lesser extent the river boundary condition to the east, providing a constant replenishment of groundwater to be dewatered at the cofferdam location. A hydraulic gradient will extend from the cofferdam simulated in the east to the constant head boundary in the west, albeit the gradient is extremely shallow and the drawdown insignificant at the constant head boundary. A consequence of the model set up is that there is no point in the model where zero drawdown occurs.

3.2.7 The model simplification and the propagation of drawdown that results are not significant by comparison with uncertainties within the conceptual model (Plate 1.1) e.g. geological layering and hydraulic properties. The results should be viewed as an umbrella that contains a realistic scenario within it. Scenario 8 (worst case) is very unlikely given the potentially unrealistic combination of hydraulic properties assigned to the clay and sand layers. Professional judgement suggests a maximum accuracy of 0.1m, and that 400.0m represents an effective limit of future drawdown.

3.2.8 Attachment A (Figure 11.2A and 11.2B from the Environmental Statement report) is a plan view illustrating model Scenario 8 (worst case) extent of drawdown – the 0.1m contour for Layer 1 (the North Denes, Breydon and Happisburgh Glaciogenic Formations) and Layer 6 (the lower Crag Group Aquifer) to the western side of the river. As described in Section 1, the model results are considered applicable to the assessment of potential impacts on both the west and east banks of the River Yare. An alternative and probably more realistic scenario where the clays and the sands have lower and higher hydraulic conductivities, respectively, would result in significantly less drawdown.

3.3 Potential Impact of Dewatering

3.3.1 Four potential receptors and three potential impacts are recognised. The receptors are the Crag Group Principal Aquifer, the North Denes Formation Secondary A Aquifer, (which is grouped in the model with the Breydon Formation and the Happisburgh Glaciogenic Formation in accordance with information provided by the Design team, nearby groundwater abstractions the closest of which is approximately 0.7km from the proposed cofferdam, and the River Yare. The potential impacts relate to changes in groundwater storage which include to the lowering of the water table and reducing the amount of water in the aquifer(s), changes in groundwater flow, and changes in groundwater quality.

3.3.2 Groundwater quality was not simulated within the groundwater flow model, however, groundwater flow directions may be interpreted in the context of groundwater mixing and potential changes in salinity.

Crag Group Aquifer

3.3.3 The Crag Group Aquifer, which is recognised as a Principal Aquifer, comprises sands, gravels, silts and clays. The aquifer properties of the Crag Group vary greatly depending upon the grain size of the sediments, degree of sedimentation and presence of semi-confining glacial sediments (i.e. the Happisburgh Glaciogenic Formation), although it is largely unconfined (Jones et al., 2000).

Groundwater Storage

- Maximum change to the groundwater level (drawdown) is predicted in the Crag Group Aquifer. The effect decreases rapidly with increasing distance, from a maximum of approximately 5.0m drawdown just 1.0m from the dewatering wells to less than 0.1m at 400.0m distance, under the worst case scenario simulated (Scenario 8).
- The modelled dewatering does not differentiate between water removed from the Crag Group Aquifer and that removed from overlying aquifers (North Denes, Breydon and Happisburgh Glaciogenic Formations). An estimate of the loss of storage may be based on the thickness of the respective aquifers (Table 2.1). The Crag Group Aquifer will contribute approximately 50% of water abstracted. The average (mean) dewatering rates simulated was 3.0 L/s, therefore half of this (1.5 L/s) is assumed to be from the Crag Group Aquifer, which is equivalent to 0.13 M L/day.
- There are no public water supply abstractions from the Crag Group Aquifer in the Principal Application Site and actual abstraction information (opposed to licensed limits) for the Crag Group Aquifer is difficult to find.
- A joint report produced by the British Geological Survey and the Environment Agency, (Ref 11F.2), refers to National Rivers Authority abstraction data from 1994 for the Lowestoft and Saxmundham area. It is unclear whether the data includes Great Yarmouth, but it nonetheless indicates the potential level of abstraction from the Crag Group Aquifer, which is reported as 4.5M m^3/year or 12.3M L/day. Based on this comparison, the average simulated dewatering rate is equivalent to approximately 2% of the total Aquifer abstraction (when dewatering simultaneously at both the western and eastern cofferdams is considered).

Groundwater Flow

3.3.4 Groundwater flow in the Crag Group Aquifer would naturally be towards the River Yare (locally) and more regionally towards the coast. The modelling study indicates a capture zone for the cofferdam of up to 400.0m, although the exact capture zone depends on recharge, which was not simulated in the groundwater flow model. All groundwater within the capture zone will migrate towards the cofferdam at the expense of discharge to the River Yare or overlying aquifers (and eventually to the coast).

Groundwater Quality

3.3.5 The groundwater flow model did not simulate groundwater quality. However, model results indicate that vertical flow will be induced from shallow layers (the North Denes, Breydon and Happisburgh Glaciogenic Formations) into the Crag Group Aquifer as it flows eventually to the cofferdam (Plate 3.4). This will occur to varying degrees depending on the scenario modelled.

3.3.6 Drawdown in the upper layers and groundwater flow vectors indicates that there is significant potential for mixing of groundwater within the cone of depression for the range of conceptual models simulated within the groundwater flow model. The amount of mixing depends on the contrasts between the hydraulic conductivities and the extent of layering. Continuous layers were simulated at a range of hydraulic conductivities, as per the Design team’s conceptual model. The more homogenous the ground the more mixing that will occur. In reality ground conditions are more variable than those simulated and the amount of mixing will be more influenced by the vertical and lateral changes in the geology.

3.3.7 The impact is dependent on the baseline groundwater quality, which is described in Chapter 11: Road Drainage and the Water Environment of the Environmental Statement Section 11.4.

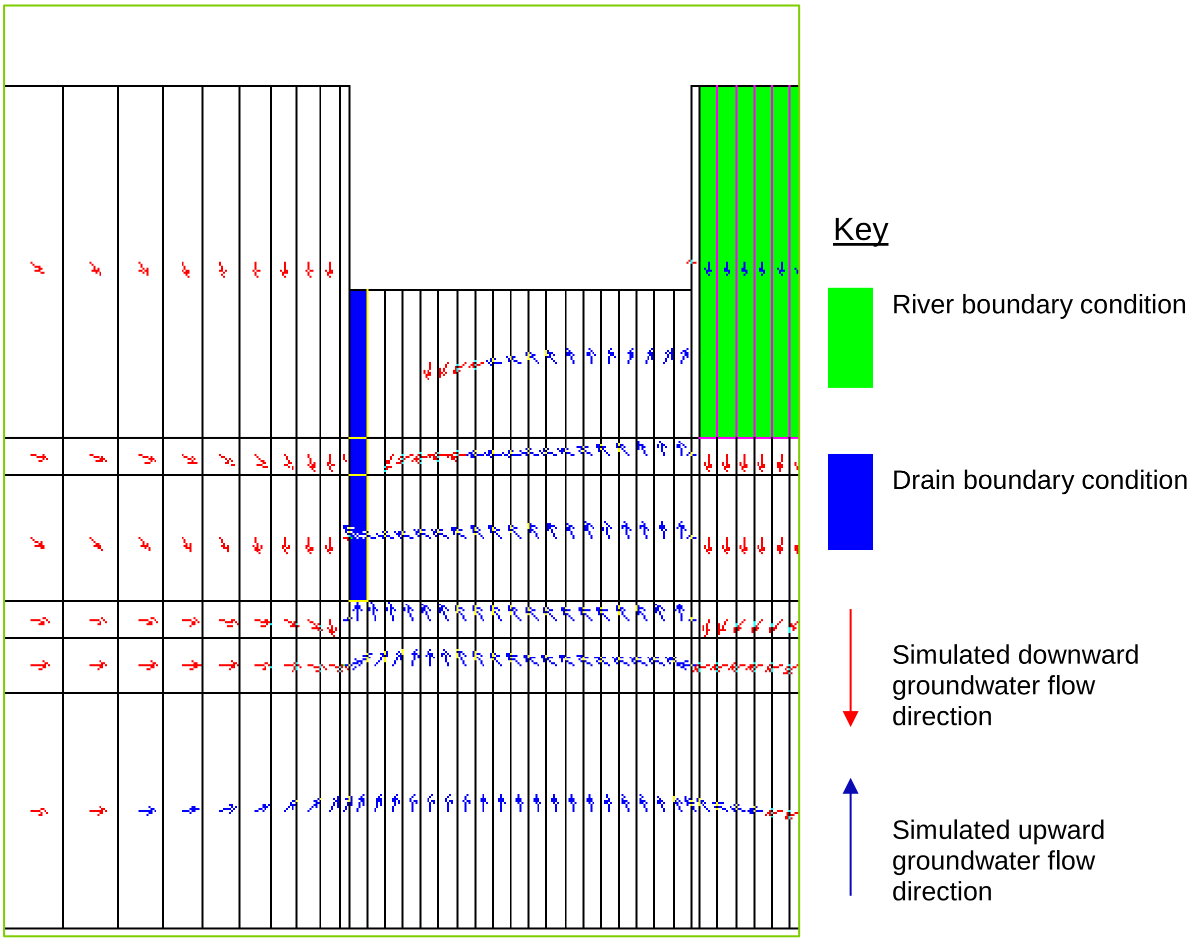


Plate 3.4: Groundwater Flow Vectors for Model Scenario 8. Groundwater moves through the Aquifer Layers and up inside the Cofferdam towards the Dewatering Wells

North Denes, Breydon and Happisburgh Glaciogenic Formations

3.3.8 The three superficial geological units may broadly be summarised as an upper sand (North Denes Formation) and lower gravel unit (Happisburgh Glaciogenic Formation) separated by clays of the Breydon Formation. More geological information may be found on the online British Geological Survey (BGS) Lexicon (Ref 11F.3). Of the three formations, the North Denes Formation is recognised as a Secondary A Aquifer. However, lateral and vertical variations in composition, i.e. the distribution and respective ratio of sand to clay, will result in a degree of connectivity across all three formations.

Groundwater Storage

- Groundwater drawdown reduces towards ground surface due to the layering within the geological sequence. In the worst-case scenario

(Scenario 8), drawdown 1m from the cofferdam is predicted to be approximately 1.8m and at 400.0m the drawdown will be approximately zero.

- The joint report produced by the British Geological Survey and the Environment Agency (Ref 11F.2) also includes data for the superficial deposits. Total abstractions were 5.4M m^3/year. Based on this information, dewatering from the three formations would represent less than 1% of abstraction. The abstractions and dewatering rates quoted are indicative and the presented in support of what is a qualitative assessment.

Groundwater Flow

3.3.9 The groundwater flow assessment described above for the Crag Group Aquifer applies equally to these three formations.

Groundwater Quality

3.3.10 The groundwater flow model did not simulate groundwater quality. However, construction dewatering is going to lower water levels in these three formations. The resulting drawdown is going to induce flow from the River Yare into the formations. The impact is dependent on the baseline groundwater quality, which is described in Chapter 11: Road Drainage and the Water Environment.

3.3.11 With reference to the geological description on the BGS Lexicon, the North Denes Formation is described as consisting of an elongate, wedge-shaped body of sand with subordinate gravel and thin layers of silty clay. The Breydon Formation is dominated by unconsolidated silt and clay with a shelly marine fauna. Sand is generally a minor component. The Happisburgh Glaciogenic Formation consists of a range of diamictons, sands and gravels, sands and laminated silts and clays. The superficial geology formations contain variable amounts of clays, however, the formations are anticipated to be hydraulically connected on a regional, and potentially local scale depending on heterogeneity (that was not simulated in the model), meaning groundwater quality should be consistent across all three formations unless stratification has occurred.

Groundwater Users

Groundwater Availability

3.3.12 The nearest licensed groundwater user is Camplings Ltd located approximately 0.7km from the west cofferdam. Modelling indicates that drawdown is unlikely to extend as far as this abstraction borehole. The drawdown simulated in the worst case scenario (Scenario 8), which is considered to be unlikely, indicates 0.1m drawdown at 400m, tending towards zero drawdown at 1km. As discussed above, the point of zero drawdown is influenced in the model by the constant head boundary and the 0.1m drawdown contour represents an effective limit to drawdown. The results indicate that that there could be minimal interference between the Camplings Ltd abstraction and the cone of dewatering required for temporary works under unlikely hydrogeological conditions. The magnitude of drawdown that occurs at the Camping Ltd well, if indeed there is any, is very likely to be within the seasonal range of groundwater levels and therefore natural changes in groundwater level. There is unlikely to be any significant impact at the further two abstractions sites identified.

Groundwater Quality

3.3.13 The Camplings Ltd source is further inland than the cofferdam and groundwater mixing local to the cofferdam caused by local changes in flow path is very unlikely to lead to any impact on water quality at the abstraction for the duration of the temporary works (construction stage). The temporary works dewatering is likely to capture groundwater from the River Yare and inland, this will therefore not propagate any pre-existing saline intrusions towards the groundwater abstraction. If dewatering wells are screened across multiple geological layers then groundwater quality mixing could occur.

3.3.14 Dewatering at the cofferdam is likely to induce groundwater exchange between layers, potentially affecting water quality locally. After the cessation of dewatering (in the operational stage of the scheme) the groundwater that has mixed in the area of the cofferdam may migrate towards Camplings Ltd source, depending on its area of influence. Consequently, there is a slight risk of longer term deterioration of water quality at the abstraction until the groundwater system returns to its pre-construction state. It is worth noting that the impact of this medium to long-term change in water quality is related to the baseline water quality, which is described in Chapter 11: Road Drainage and the Water Environment Section 11.4. Please note that the abstraction well capture zones have not been modelled as this was beyond the scope of this study, therefore the impacts described are inferred rather than explicitly modelled.

River Yare

3.3.15 The model was not designed to investigate groundwater surface water interactions and any changes in the hydraulic relationship in response to dewatering. However, results indicate a number of potential impacts are possible on the River Yare:

- Changes in baseflow. The conceptual model developed by Design team indicates that the hydraulic gradient is from the river to the adjacent aquifers. However, this is likely to vary seasonally and with tidal changes. Although not investigated by the model the dewatering activities are likely to reduce groundwater baseflow to the River Yare by the amount of water predicated to flow into the cofferdam when the river is gaining from groundwater. The groundwater flow model is assumed to apply to the temporary works on both the western and eastern banks. Flow to the river is, therefore, anticipated to be reduced by 6 L/s to 31 L/s for the 'average' and worst-case scenarios, which would represent an insignificant change in such a large river.

- River losses. The dewatering associated with the proposed cofferdam will induce flow from the River Yare. Although the pile walls will prevent flow directly into the cofferdam, small amounts of water will migrate into the shallow geological formations. Modelling indicates a maximum flow from the River Yare of 0.1M L/day.

3.3.16 Both potential impacts on the river may be mitigated by recirculating the water removed during dewatering into the River Yare, subject to the necessary Environmental Permit.

4 Summary and Conclusions

4.1.1 This report presents a dewatering impact assessment for the temporary works dewatering that would be associated with the proposed cofferdam and bascule construction. The level of risk was reviewed prior to modelling, in accordance with Environment Agency Report, SC040020/SR1 (Ref 11F.1), to determine the level of detail required in the modelling study. A simple 3D groundwater flow model was constructed in MODFLOW 2015 based on the conceptual model provided by the Design team. The model assumes homogenous flat layering, a simplified geology and no vertical anisotropy. The model was run in steady state with no recharge. The model was used to investigate the sensitivity of drawdown impacts to hydraulic conductivity.

4.1.2 The simulated dewatering rates at the proposed groundwater control wells agree well with those predicted during a previous modelling study (as completed by the Design team), giving a range of total flow rates between 0.16 l/s to 15.53 l/s. Nine scenarios were modelled to perform a sensitivity analysis on the range of hydraulic conductivity values provided for sand and clay. Of these model runs, results from Scenario 8 (low sand hydraulic conductivity and high clay hydraulic conductivity) were presented as these were considered the worst-case results in terms of dewatering impacts.

4.1.3 The impacts of the proposed dewatering on the water environment are summarised as follows:

- Negligible drawdown beyond 400.0m during the worst-case scenario modelled.
- Minor but insignificant loss of aquifer resource in both the Crag Group Principal Aquifer and North Denes Formation Secondary A Aquifer.
- Groundwater mixing will occur as water moves towards the cofferdam. The degree of mixing is dependent on the hydraulic properties of the geological formations. Mixing is likely under natural conditions and the resulting impact is therefore likely to be negligible.
- Potential interference between the cone of depression that will develop around the proposed cofferdam and the nearest licensed abstraction, Camplings Ltd, approximately 0.7km away, which could result in a minor but insignificant impact on borehole yield.

- Upon the cessation of dewatering there is potential for changes in groundwater quality to eventually impact on the Camplings Ltd borehole. The potential impact of the change cannot be assessed without information on the quality of water currently abstracted by Camplings Ltd, but given the location of the abstraction close to the coast (in and area of high salinity groundwater), it is considered that the impact will be minor and insignificant at worst and potentially negligible.
- The development of a steeper hydraulic gradient between the River Yare and the dewatered aquifer material will lead to an increase in the ingress of river water. Two potential impacts follow: the loss of river water at minor, but insignificant rate, and the change in groundwater quality, the impact of which depends on the baseline groundwater conditions.
- The proposed dewatering could result in a reduction of baseflow, (groundwater discharge), to the River Yare by a minor but insignificant amount. The impact of the change in baseflow regime could potentially be offset by discharging water from the dewatering activities into the River Yare, subject to conditions set out in an environmental permit.

5 References

Ref 11F.1: Boak R, Bellis L, Low R, Mitchell R, Hayes P, McKelvey P, Neale S. (2007). Hydrogeological impact appraisal for dewatering abstractions. Environment Agency Science Report SC040020/SR1.

Ref 11F.2: Ander, E. L., Shand, P. and Wood, S. (2006). Baseline Report Series: 21. The Chalk and Crag of north Norfolk and the Waveney Catchment Groundwater Systems and Water Quality. Commissioned Report CR/06/043N

Ref 11F.3: British Geological Survey Lexicon, 2019.