Net Zero Teesside Project

Planning Inspectorate Reference: EN010103

Land at and in the vicinity of the former Redcar Steel Works site, Redcar and in Stockton-on-Tees, Teesside

The Net Zero Teesside Order

Document Reference: 9.36 – Nutrient Nitrogen Briefing Paper

Planning Act 2008

Applicants: Net Zero Teesside Power Limited (NZT Power Ltd) & Net Zero North Sea Storage Limited (NZNS Storage Ltd)

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Author	Ian Campbell, Owen Tucker, James Riley		
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GLOSSARY

Abbreviation	**Description**
BEIS	The Department for Business, Energy and Industrial Strategy
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon dioxide
DCC	Direct Contact Cooler
DCO	Development Consent Order
dDCO	Draft DCO
DIN	Dissolved inorganic nitrogen
EA	Environment Agency
ECJ	European Court of Justice
EEC	European Economic Community
ES	Environmental Statement
ExA	Examining Authority
EQS	Environmental Quality Standard
FEED	Front End Engineering Design
HP	High Pressure
HRA	Habitats Regulations Assessment
HRSG	Heat Recovery Steam Generator
JNCC	Joint Nature Conservation Committee
km	Kilometres
NE	Natural England
NWL	Northumbrian Water Ltd.
NZT	The Net Zero Teesside Project
NZT Power	Net Zero Teesside Power Limited
NZNS Storage	Net Zero North Sea Storage Limited
PA 2008	Planning Act 2008
PCC	Power Capture and Compressor Site
PINS	Planning Inspectorate
SoS	Secretary of State

Abbreviation	Description
SPA	Special Protection Area
STDC	South Tees Development Corporation
WFD	Water Framework Directive
WwTW	Wastewater Treatment Works

CONTENTS

1.0 INTRODUCTION

1.1 Overview

1.1.1 This briefing paper has been prepared on behalf of Net Zero Teesside Power Limited and Net Zero North Sea Storage Limited (the ‘Applicants’). It relates to the application (the 'Application') for a Development Consent Order (a 'DCO'), that has been submitted to the Secretary of State (the ‘SoS’) for Business, Energy and Industrial Strategy (‘BEIS’), under Section 37 of ‘The Planning Act 2008’ (the ‘PA 2008’) for the Net Zero Teesside Project (the ‘Proposed Development’).

1.1.2 The Application was submitted to the SoS on 19 July 2021 and was accepted for Examination on 16 August 2021. A change request made by the Applicants in respect of the Application was accepted into the Examination by the Examining Authority (the ‘ExA’) on 6 May 2022. A further change request was submitted to the ExA at Deadline 6 on 23 August 2022.

1.2 Description of the Proposed Development

1.2.1 The Proposed Development will work by capturing CO_2 from a new the gas-fired power station in addition to a cluster of local industries on Teesside and transporting it via a CO_2 transport pipeline to the Endurance saline aquifer under the North Sea. The Proposed Development will initially capture and transport up to 4Mt of CO_2 per annum, although the CO_2 transport pipeline has the capacity to accommodate up to 10Mt of CO_2 per annum thereby allowing for future expansion.

1.2.2 The Proposed Development comprises the following elements:

- **Work Number (‘Work No.’) 1** – a Combined Cycle Gas Turbine electricity generating station with an electrical output of up to 860 megawatts and post-combustion carbon capture plant (the **‘Low Carbon Electricity Generating Station’**);
- **Work No. 2** – a natural gas supply connection and Above Ground Installations (‘AGIs’) (the **‘Gas Connection Corridor’**);
- **Work No. 3** – an electricity grid connection (the **‘Electrical Connection’**);
- **Work No. 4** – water supply connections (the **‘Water Supply Connection Corridor’**);
- **Work No. 5** – waste water disposal connections (the **‘Water Discharge Connection Corridor’**);
- **Work No. 6** – a CO_2 gathering network (including connections under the tidal River Tees) to collect and transport the captured CO_2 from industrial emitters (the industrial emitters using the gathering network will be responsible for consenting their own carbon capture plant and connections to the gathering network) (the **‘CO_2 Gathering Network Corridor’**);
- **Work No. 7** – a high-pressure CO_2 compressor station to receive and compress the captured CO_2 from the Low Carbon Electricity Generating Station and the CO_2

Gathering Network before it is transported offshore (the **'HP Compressor Station'**);

- **Work No. 8** – a dense phase CO_2 export pipeline for the onward transport of the captured and compressed CO_2 to the Endurance saline aquifer under the North Sea (the **'CO_2 Export Pipeline'**);
- **Work No. 9** – temporary construction and laydown areas, including contractor compounds, construction staff welfare and vehicle parking for use during the construction phase of the Proposed Development (the **'Laydown Areas'**); and
- **Work No. 10** – access and highway improvement works (the **'Access and Highway Works'**).

1.2.3 The electricity generating station, its post-combustion carbon capture plant and the CO_2 compressor station will be located on part of the South Tees Development Corporation (STDC) Teesworks area (on part of the former Redcar Steel Works Site). The CO_2 export pipeline will also start in this location before heading offshore. The generating station connections and the CO_2 gathering network will require corridors of land within the administrative areas of both Redcar and Cleveland and Stockton-on-Tees Borough Councils, including crossings beneath the River Tees.

1.3 The Purpose and Structure of this document

1.3.1 The purpose of this document is to explain the sources of effluent containing nitrogen to be discharged from the Proposed Development and set out the work done to date and the proposed approach to the continued assessment of the potential effects of these discharges on the Teesmouth and Cleveland Coast SPA/Ramsar site.

1.3.2 Computer modelling of the dispersion and dilution of nitrogen in effluent discharges from the Proposed Development is being undertaken. This modelling will be used to inform an assessment of the effects of nitrogen discharges on the qualifying features of the Teesmouth and Cleveland Coast SPA/Ramsar site. This assessment will set out the impacts of the nitrogen discharges and conclude whether or not the nitrogen discharges will have a likely significant effect on the habitats site. The results of this assessment will be documented in an updated Habitats Regulations Assessment (HRA) to be submitted at Deadline 9.

1.3.3 An assessment of the impact of nitrogen discharges on the Water Framework Directive status of the Tees Coastal Waterbody is also being conducted and will be reported in parallel at Deadline 9.

1.3.4 The document is structured as follows:

- Section 2 sets out the legislative background to the assessment of nutrient impact on habitat sites;
- Section 3 identifies potential sources of nitrogen in effluent arising from the NZT project;

- Section 4 summarises the engagement to date with Natural England and the Environment Agency in relation to nitrogen discharges;
- Section 5 summarises the scope of the discharge modelling being undertaken;
- Section 6 sets out the qualifying features of the Teesmouth and Cleveland Coast Special Protection Area (SPA) and Ramsar site and the approach to the nutrient neutrality assessment;
- Section 7 identifies the potential impacts that could affect the qualifying features of the SPA/Ramsar;
- Section 8 identifies the potential implications for Water Framework Directive compliance of nitrogen inputs to the Tees Coastal Waterbody; and
- Section 9 provides an action plan and identifies the next steps in the assessment of nitrogen discharges.

2.0 NUTRIENT IMPACTS ON HABITAT SITES

2.1.1 On 16 March 2022, Natural England published advice to Competent Authorities under the Habitats Regulations to advise that Competent Authorities must carefully consider the nutrient impacts of any new plans and projects on habitats sites and whether those impacts may have an adverse effect on the integrity of a habitats site that requires mitigation, including through ‘nutrient neutrality’.

2.1.2 In many designated estuarine and freshwater habitats sites, poor water quality due to nutrient enrichment is one of the main reasons for sites being in an unfavourable condition. Excessive levels of nutrients can cause the rapid growth of certain plants through the process of eutrophication. This in turn can lead to reduced biodiversity, and the condition of a site being considered ‘unfavourable’.

2.1.3 Nutrient neutrality has become an issue in many areas of the country, such as the Solent, Somerset Levels, the Wye catchment in Herefordshire, Derbyshire, Yorkshire and the North East of England. It stems from the ruling of the European Court of Justice (ECJ) in combined cases C-293/17 and C-294/17 (the Dutch Nitrogen case). That judgment refined the definition of plans and projects to include operations such as agriculture, confirming that agricultural inputs of nutrients (either from atmosphere or runoff) need to be covered in the ‘in combination’ requirements of the HRA process. This is significant because the traditional assessment process as applied for example by the Environment Agency distinctly separated treated wastewater from agricultural discharges, largely because the latter is effectively unconsented and outside the remit of the Environment Agency.

2.1.4 In addition, the ruling reaffirmed that if a European protected nature conservation site is in a deteriorating condition (such as due to excess nutrient levels that may also be forecast to increase) there are very limited circumstances under which further discharges of nutrients to a site can be permitted.

2.1.5 In this case the relevant Competent Authority is the Secretary of State and the relevant habitats site is the Teesmouth and Cleveland Coast SPA/Ramsar site. Excess baseline nitrogen from a range of diffuse and point sources is already contributing to aspects of this site being in unfavourable condition around the Seal Sands mud flats in particular.

2.1.6 Phosphorus (as phosphate) has been not identified as a concern for the Teesmouth and Cleveland Coast SPA/Ramsar site and does not require consideration.

2.1.7 As a result, in the absence of any empirically derived threshold by which additional aquatic inputs of nitrogen can be deemed de minimis, the implication of Natural England’s nutrient neutrality guidance is that any new development within the Teesmouth and Cleveland Coast SPA/Ramsar catchment that increases nutrients could have potential impacts on features of that SPA/Ramsar and could interfere with the ability of the site to achieve its conservation objectives and thus adversely affect the integrity of the European protected nature conservation site.

3.0 POTENTIAL SOURCES OF NITROGEN IN EFFLUENT

3.1 Overview

3.1.1 The Proposed Development will produce the following sources of effluent containing nitrogen:

- Cooling Water Return;
- Direct Contact Cooler (DCC) Blowdown;
- Heat Recovery Steam Generator (HRSG) Blowdown; and
- Foul waste (excluded hereafter as this will be sent to the Marske-by-the Sea WwTW which discharges out with the Ramsar/SPA boundary).

3.2 Cooling Water

3.2.1 The potential source of the water used for cooling is raw, untreated, River Tees water provided by Northumbrian Water Ltd (NWL) from three possible abstraction points – Low Worsall, Blackwell and Broken Scar. River water quality monitoring data have been provided by NWL for Broken Scar and a summary dataset of key substances has been provided for Low Worsall and Blackwell. Dissolved Inorganic Nitrogen (DIN) concentrations in the raw water have been calculated by converting nitrate, nitrite and ammonia concentrations recorded each sample.

3.2.2 Discussions with NWL have confirmed that although the Low Worsall abstraction point is currently out of use, it is expected to return to use as local water requirements increase, for example in response to development of the PCC site. It is also the closest abstraction point to the PCC site. It is therefore assumed that the development will receive the majority of its water supply from Low Worsall and this is used in the assessments as it has the highest concentrations of nitrogen (as nitrate) and it is therefore considered to represent the worst case.

3.2.3 Based on the use of the raw water in the DCC, nitrogen will then be further concentrated by up to five times as the DCC will evaporate a proportion of the water to atmosphere leaving nitrogen in the blowdown that will periodically be purged from the system.

3.2.4 It is worth noting that the Proposed Development will not introduce any new nitrogen into the water environment through this effluent stream. The nitrogen is already present in the raw water feed being abstracted from the River Tees. It will simply be passed through the site and returned back into Tees Bay, albeit in a more concentrated form, with the abstraction and discharge effectively reducing the quantity of nitrogen entering the Tees Estuary by 14 kgN/h. This concentrated discharge to Tees Bay will be assessed in the modelling outlined in Section 4.0 below.

3.3 DCC Blowdown

3.3.1 Blowdown from the DCC will contain ammonia which will require treatment either on-site or off-site to convert the ammonia to nitrate. The DCC Blowdown Water will make up the majority of the nitrogen containing effluent produced by the PCC site. This is estimated to contain up to 24.7 kgN/hr.

3.4 HRSG Blowdown

3.4.1 A small additional flow of Condensed Water arising from blowdown from the HRSG is expected to be discharged directly into Tees Bay without treatment. This water is expected to contain only one contaminant, ammonia, at concentrations of 5 mg/l equating to 0.015 kgN/hr. The HRSG Blowdown discharge will be diluted with surface water runoff.

3.5 Effluent Handling Options with the draft DCO

3.5.1 There are a number of options to handle the effluent containing nitrogen, namely:

- Direct discharge to the water environment;
- On-site treatment followed by discharge to the water environment;
- Off-site treatment (at Northumbrian Water Ltd.'s Bran Sands Waste Water Treatment Works (WwTW)) followed by discharge to the Dabholm Gut (Tees Estuary); or
- Off-site treatment (at Bran Sands WwTW) followed by discharge to the sea (Tees Bay).

3.5.2 The dDCO makes provision for all of the above options (including through parts of Work No. 1 (wastewater treatment plant and building, and effluent ponds) and Work No. 5 (wastewater disposal works including pipelines to Bran Sands WwTW and into the Tees Bay), and at this stage no final decisions have been made on how to handle the effluent containing nitrogen.

3.6 Discharge Scenarios

3.6.1 A number of discharge scenarios are considered in this paper:

- The pre-development baseline;
- The current Base Case approach to effluent management from the Proposed Development;
- Option A, whereby effluent is treated at Bran Sands WwTW and an effluent return line directs treated effluent to the outfall at the PCC Site for discharge into Tees Bay.

3.6.2 These are discussed in turn below.

Pre-Development Baseline

3.6.3 The pre-development baseline case is illustrated schematically in Figure 3.1. This shows that municipal and industrial effluent is treated at Bran Sands WwTW in three trains:

- Train A (industrial effluent);
- Train B (municipal waste); and

- Train C (municipal waste and industrial effluent from North Tees)

3.6.4 Train A is consented under its own Environmental Permit. Trains B and C are consented under a separate Permit.

Base Case

3.6.5 The Base Case is illustrated schematically in Figure 3.2. This illustrates the inflows to the PCC site as being:

- Raw Water from the River Tees; and
- Ammonia delivered for NOx removal.

3.6.6 Outflows from the PCC Site to the Dabholm Gut (Tees Estuary) are shown as:

- DCC Blowdown containing ammonia is exported to Bran Sands WwTW by pipeline for treatment in Trains B or C. This is treated to convert the ammonia to nitrate and the treated comingled effluent is discharged to the Dabholm Gut (Tees Estuary).

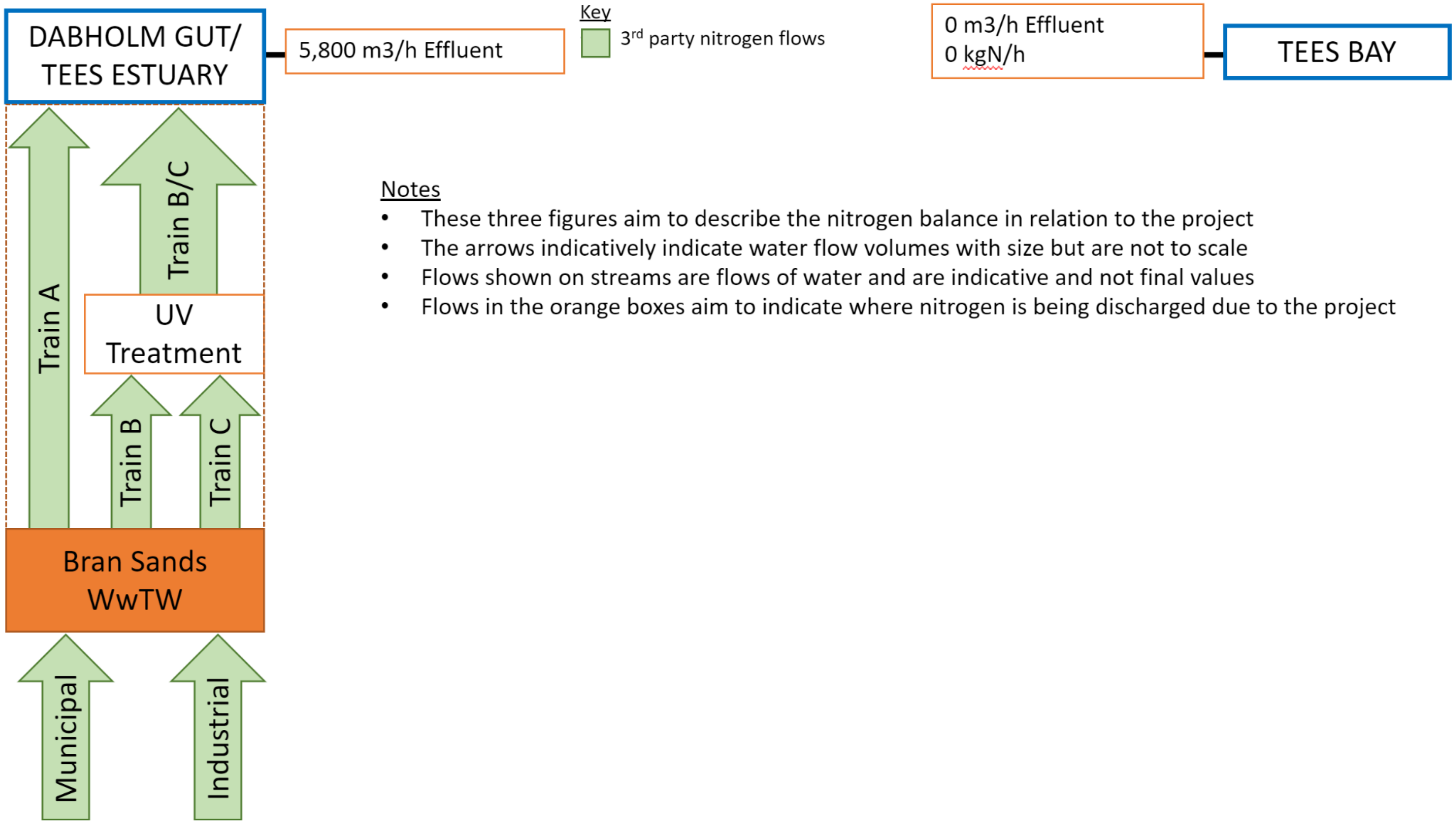
3.6.7 Outflows from the PCC Site directly to the Tees Bay are shown as being:

- Cooling Water Blowdown (i.e. concentrated Raw Water) plus raw water filtration backwash (unconcentrated) both containing nitrate;
- HRSG Blowdown containing ammonia; and
- Surface water run-off (clean)

Option A

3.6.8 Option A is illustrated schematically in Figure 3.3. This illustrates the inflows and outflows to the PCC site as being the same as for the Base Case with the exception that a volume of treated Train B/C effluent from Bran Sands WwTW containing an equivalent quantity of nitrogen (in kgN/h) to the DCC Blowdown would be returned to the PCC site for discharge to Tees Bay via the existing or replacement outfalls.

Figure 3.1 Pre-Development Discharges to Dabholm Gut/Tees Estuary



Notes

- These three figures aim to describe the nitrogen balance in relation to the project
- The arrows indicatively indicate water flow volumes with size but are not to scale
- Flows shown on streams are flows of water and are indicative and not final values
- Flows in the orange boxes aim to indicate where nitrogen is being discharged due to the project

Figure 3.2: Base Case – Discharges to Dabholm Gut/Tees Estuary and Tees Bay

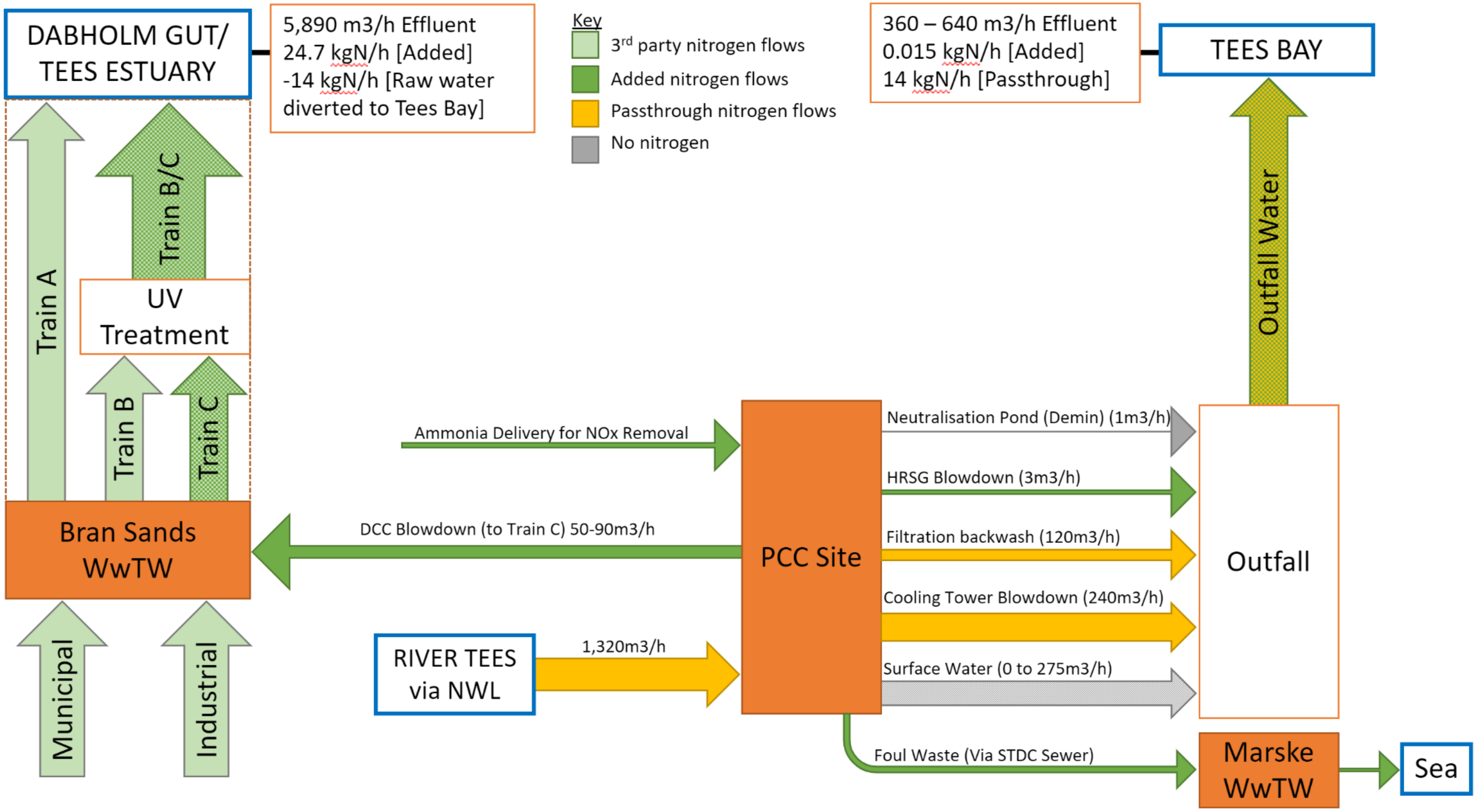
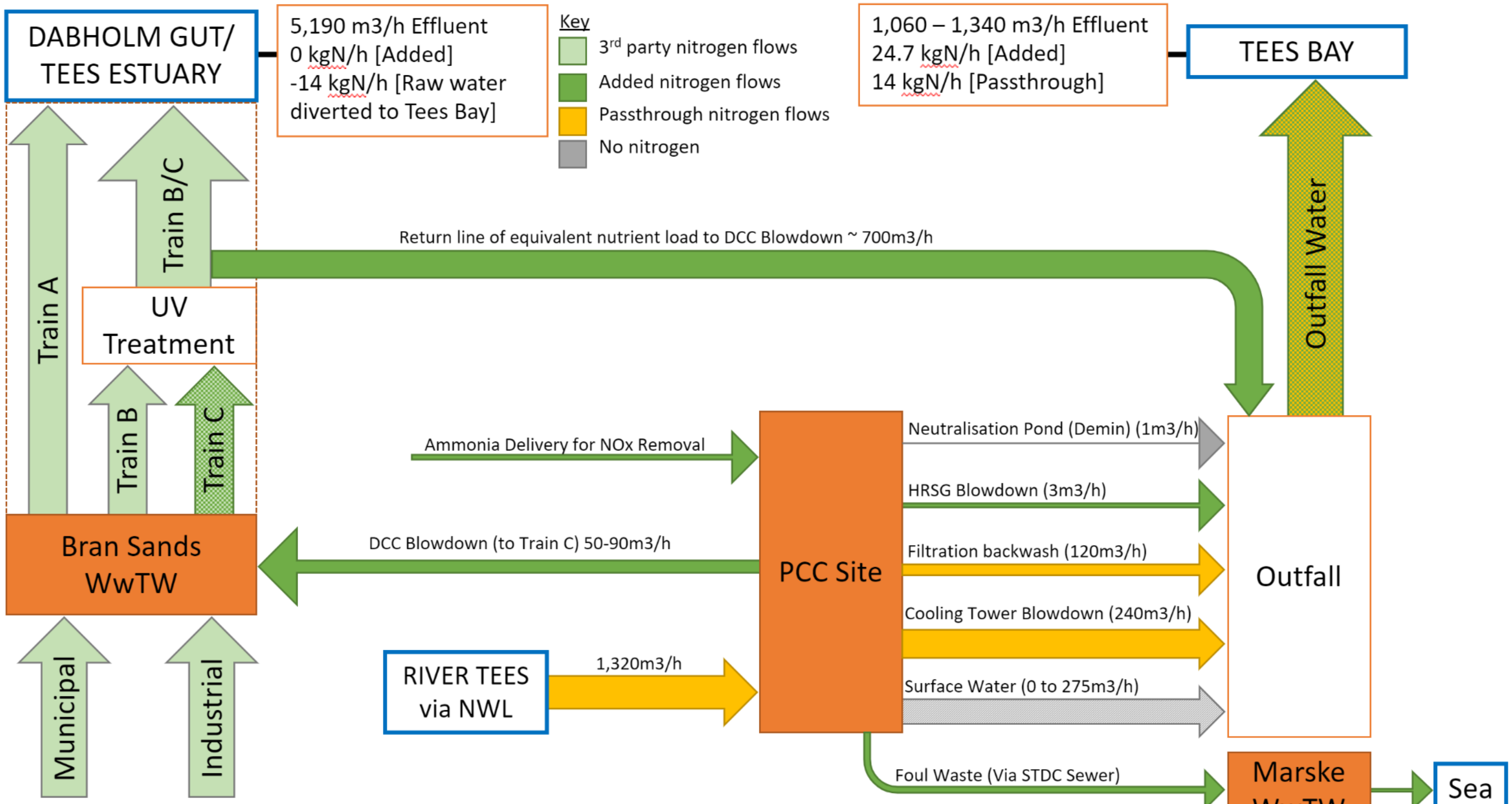


Figure 3.3: Option A – Discharges to Dabholm Gut/Tees Estuary and Tees Bay



4.0 ENGAGEMENT

4.1.1 As requested in Natural England's Relevant Representation [RR-026], the Applicants agreed to assess the impacts of the discharge of effluent containing nitrogen into the Tees Estuary.

4.1.2 Preliminary modelling was undertaken by the Applicants in June 2022. The results of the modelling were discussed with the EA and NE at meetings on 7th July 2022 and 13th July 2022 respectively, and the draft modelling report was shared with the NE and EA on 29th July 2022. Detailed comments on the preliminary modelling were received from the NE on 19th August 2022 and the EA on 22nd August 2022.

4.1.3 Further discussions have been held with Northumbrian Water Ltd. to obtain more accurate effluent concentrations for use in the model. This data was received in the week ending 12th August and modelling using this data is currently ongoing. The approach to modelling is explained in section 5.0 below.

4.1.4 A meeting was held with NE on 15th September to discuss the discharge of treated effluent containing nitrogen from the PCC site, amongst other issues. In that meeting NE confirmed that the features of the habitat currently in unfavourable condition are the mudflats in the vicinity of Seal Sands within the Tees Estuary. Several of the qualifying features of the SPA/Ramsar rely on those habitats and their wading and feeding grounds are being impacted by the growth of algal mats[1]. It was confirmed by Natural England that the focus of their concern is on nutrients reaching those habitat features. It was outlined that modelling of nutrient discharges from the Proposed Development was being updated, and the modelling and the potential for likely significant effects on the habitats site and specifically those features would be discussed with Natural England prior to submission at Deadline 9.

4.1.5 A meeting will also be held with the EA prior to Deadline 9 to discuss the modelling and the outcome of the assessment into the effect on the Water Framework Directive status of the Tees Coastal water body.

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[1] Site Improvement Plan Teesmouth & Cleveland Coast, Natural England, 2014.

5.0 DISCHARGE MODELLING

5.1.1 Modelling of discharges to Tees Bay will assess potential impacts on the qualifying features of the Teesmouth and Cleveland Coast SPA/Ramsar and the potential for effluent to disperse into the Tees Estuary e.g. by tidal effects. The modelling scenarios are summarised in Table 5.1 below:

5.1.2 The impacts on the Tees Estuary will be assessed on the basis of identifying whether there is a net increase or decrease in nitrogen discharged to the Dabholm Gut/Tees Estuary or if the discharge modelling identifies the potential for effluent return from Tees Bay to the estuary due to tidal effects.

Table 5.1: Summary of Modelling Scenarios

Scenario			Discharges to Tees Bay		
			Cooling Water (concentrated raw water)	**Returned treated effluent from Bran Sands**	**HRSG Blowdown (no treatment)**
Base Case	Direct Contact Cooler (DCC) blowdown treated at Bran Sands and discharged to Dabholm Gut.	Modelled and reported on in Preliminary Discharge Modelling Report (see Appendix A)	X		X
Option A	Direct Contact Cooler (DCC) blowdown treated at Bran Sands. Returned effluent to PCC discharged to Tees Bay.	Modelling of Option A ongoing and will be reported at Deadline 9	X	X	X

6.0 THE TEESMOUTH AND CLEVELAND COAST SPECIAL PROTECTION AREA AND RAMSAR

6.1 Introduction

6.1.1 The Teesmouth and Cleveland Coast SPA / Ramsar[2] is a 12,211 ha estuarine and coastal site located on the north-eastern coast of England as shown in the image below extracted from ES Figure 15-3 Statutory [ecological] Designated Sites. It comprises a range of coastal habitats, such as sand and mudflats, rocky shore, saltmarsh, freshwater marsh and sand dunes. The SPA / Ramsar lies along a stretch of coast that has been significantly modified by human activity. The site provides feeding and roosting opportunities for a significant number of waterfowl in winter and the passage period.

6.1.2 The site qualifies as a SPA under Article 4.1 of the Birds Directive (79/409/EEC) by supporting populations of the following features, as per the conservation objectives for the SPA updated in May 2020:

- *Recurvirostra avosetta*; Pied avocet (Breeding);
- *Calidris canutus*; Red knot (Non-breeding);
- *Calidris pugnax*; Ruff (Non-breeding);
- *Tringa totanus*; Common redshank (Non-breeding);
- *Sterna sandvicensis*; Sandwich tern (Non-breeding);
- *Sterna hirundo*; Common tern (Breeding);
- *Sterna albifrons*; Little tern (Breeding); and
- Waterbird assemblage.

6.1.3 The Teesmouth and Cleveland Coast SPA/Ramsar was extended in 2020 to improve seabird protection within the SPA network.

6.1.4 Ramsar qualifying features[3] include:

- Criterion 5 – Assemblages of international importance; species with peak counts in winter are 26,786 waterfowl (5 year peak mean 2011/12-2015/16); and
- Criterion 6 – Species/populations occurring at levels of international importance; qualifying species/populations (as identified at designation); species with peak counts in spring / autumn - common redshank *Tringa totanus*; 1,648 individuals representing an average of 1.1% of the East Atlantic population (1987-91); Species

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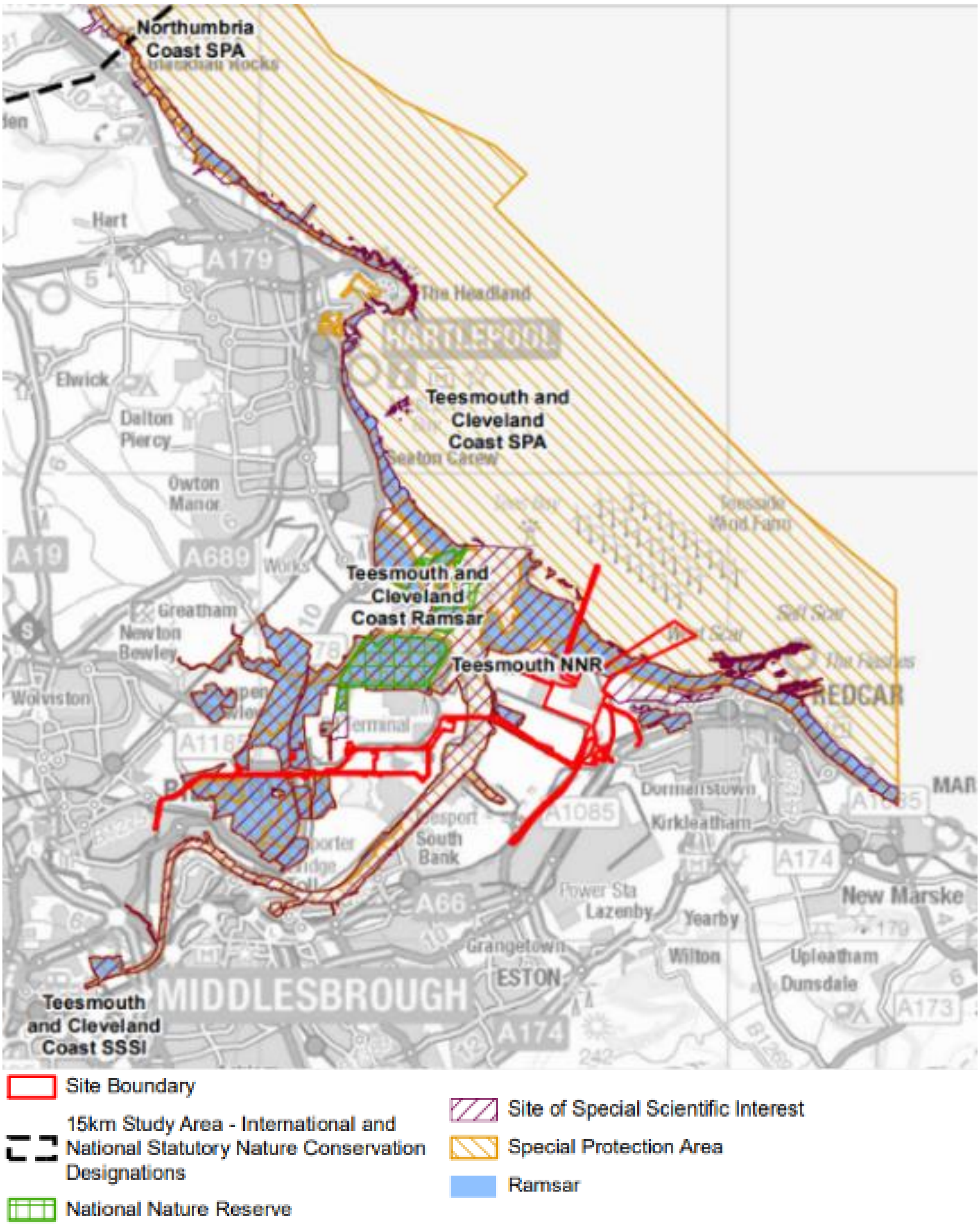
[2] JNCC Teesmouth and Cleveland Coast SPA Standard Data Form. Available at https://jncc.gov.uk/jncc-assets/SPA-N2K/UK9006061.pdf

[3] Ramsar Sites Information Service (2020) Teesmouth & Cleveland Coast Ramsar.

with peak counts in winter - red knot Calidris *Canutus islandica*; 5,509 individuals representing an average of 1.6% of the Canada/Greenland/Iceland/UK population (5 year peak mean 1991/92-1995/96), and Sandwich tern *Thalasseus sandvicensis* - 1,900 individuals representing an average of 4.3% of the GB population (1988-1992).



6.1.5 The Teesmouth and Cleveland Coast SPA/ Ramsar Nutrient Neutrality evidence pack provided in Annex E of the NE guidance from March 2022 states that the target for the site is to "restore water quality to mean winter dissolved inorganic nitrogen levels where biological indicators of eutrophication (opportunistic macroalgal and phytoplankton blooms) do not affect the integrity of the site and features."

6.1.6 A 'weight of evidence' approach adopted from the WFD is used to determine whether the site is meeting standards in terms of nutrient levels. Failure to achieve Good Ecological Status in dissolved inorganic nitrogen (DIN), macroalgae and phytoplankton indicate that the site would be in an unfavourable condition with regards to nutrients.

6.1.7 The Teesmouth and Cleveland Coast SPA / Ramsar covers two WFD water bodies, the Tees Estuary and the Tees Coastal ('Tees Bay' referred to herein is part of the Tees Coastal water body). The latest WFD classification data suggests that DIN and macroalgae are only at moderate status in the Tee Estuary (phytoplankton are good). However, none of these parameters are monitored and reported for the Tees Bay on the Environment Agency's Catchment Data Explorer website4, and a review of background Environment Agency water quality data suggests that mean DIN levels would be meeting high ecological status (which does not imply nutrient enrichment outside of the estuary area). In particular, the evidence pack goes on to state that "algal mats can be observed on intertidal mud and sandflats across the site during the summer months, particularly at Seal Sands, indicating excess nutrient levels.". Seal Sands lies to the northwest within the outer estuary area and is a shallower and wider area that is surrounded by heavy industry.

6.1.8 Correspondence with NE in March 2022 (via correspondence from an NE officer on 24/3/22) contains the following advice: "If [modelling] shows that the offshore discharges do not flow back into the [Tees] river, and there is therefore no pathway to add to the nutrient levels within the terrestrial or inter-tidal sections of the SPA then there is no issue…if the foul water does go to Marske for treatment it is very unlikely this will be an issue, as there is no pathway for impacts [as currents tend to flow away from the SPA and Tees Estuary]". NE also stated that if new emissions with a nitrogen load were to be discharged via Bran Sands Waste Water Treatment Works to the Dabholm Gut and ultimately the Tees Estuary, this would be introducing a new nutrient load direct to the SPA and mitigation to ensure nutrient neutrality would be required.

6.1.9 The effluent sources of nitrogen that have been considered are detailed in Table 6.1.

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[4] https://environment.data.gov.uk/catchment-planning/WaterBody/GB650301500005

Table 6.1. Sources of nitrogen and consideration as to whether they need to be considered by the assessment

Nitrogen source	Discussion	Include in assessment?
Cooling Water– Blowdown Waters from the gas fired power station cooling system	Cooling water will be provided by NWL from abstraction sources along the River Tees upstream of Middlesbrough near Darlington. This water contains DIN and will be concentrated due to operational processes prior to emission from the site to the Tees Bay. However, as the Proposed Development will not be adding to the nutrients that were already within the catchment of the Teesmouth and Cleveland Coast SPA / Ramsar, this is considered to be a neutral nutrient effect. Furthermore, water quality modelling of a range of scenarios for DIN has shown that, if the existing outfall continues to be used, DIN emissions at the predicted effluent concentrations are rapidly diluted within the Tees Bay and do not reach the Tees Estuary. Under some scenarios (i.e. alternative outfall) the effluent plume may interact with the intertidal shore areas along the Coatham Sands frontage, but the modelling does not take account of wave dispersion in line with Natural England advice. As described earlier, nitrogen levels within the Tees Bay are at high ecological status and Natural England have indicated that their concern is primarily within the Tees Estuary.	No – although a concentrated emission will be made as a result of the operational processes, the Proposed Development will not add any nitrogen to the receiving water and only nitrogen that was present in the original abstraction from the Tees upstream of the Site would be discharged (i.e. this is a neutral emission). The effluent will also not enter the Tees Estuary.
Process Water – Condensed Waters from the Carbon Capture Facility (HRSG)	The Condensed Water flows are significantly smaller than the Blowdown Water but this water may contain concentrations of ammonia up to 5 mg/l. Please refer to the summary of recent water quality modelling above.	Yes - The discharge of condensed water, diluted with surface water, will be to the Tees Bay and modelling will be used to identify whether it exceeds the EQS for high status and whether it will enter the Tees Estuary.
Process Water – DCC Blowdown	The DCC blowdown process effluent is proposed to be sent to Bran Sands Wastewater Treatment Works for treatment, and either discharged by Northumbrian Water through their licensed discharge to Dabholm Gut or an equivalent volume of treated effluent would be returned to the Proposed Development for discharge to Tees Bay via an existing or new outfall. Any amine production will be isolated for appropriate disposal off-site.	Yes – this discharge will contain ammonia generated by the Proposed Development and the treated effluent (i.e. a volume of treated effluent containing an equivalent quantity of DIN returned from Bran Sands WwTW) would be discharged to the Tees Estuary via the Dabholm Gut or to the Tees Bay via the selected outfall. Modelling of the discharge of process water to Tees Bay is on-going.
Surface water runoff	Nutrient load in surface water can be determined using the catchment specific calculator. This includes different leaching rates for different land uses. As the site is a former steel works, and will remain an industrial site, there will be no significant change in land use for the purposes of this	No – the proposed development does not constitute a significant change in land use and thus there is no potential for the development to alter the

Nitrogen source	**Discussion**	**Include in assessment?**
	assessment, and thus no change in leaching potential for nutrients.	nutrient load from existing site runoff.
Foul water	The nutrient neutrality assessment method from NE is intended to estimate the nutrient budget from all types of development that would result in a net increase in population served by a wastewater system. This is indicated by development that would include overnight accommodation. It states that "*other types of business or commercial development, not involving overnight accommodation, will generally not need to be included in the assessment unless they have other (non-sewerage) water quality implications*." In addition, foul wastewater is to be discharged to Marske-on-Sea Waste Water Treatment Works to the south. Given the direction of prevailing current from the Marske outfall to the south and based on initial hydrodynamic modelling, the prevailing direction of flow is away from the Tees Estuary, so there would therefore be no pathway to the Teesmouth and Cleveland Coast SPA/Ramsar site. Natural England have indicated during a meeting to discuss their Relevant Representation on the 4th of March 2022, that the use of this WwTW for foul effluent would alleviate their concerns with regards to foul drainage.	No – NE guidance assumes that staff will also live in the catchment and thus foul water generated is already part of the baseline. Foul water will also not be discharged to the Tees Estuary but from Marske-on-Sea WwTW to the Tees Bay to the south of the Proposed Development, where the prevailing flow would be away from the SPA/ Ramsar to the south.
Atmospheric deposition of nitrogen	Atmospheric emissions of nitrogen have been modelled and an estimation of the load across the Tees Bay has been made. Initial analysis suggests that this will have a negligible impact on ambient DIN concentrations. Annual loads of between 0.1 and 0.45 kg N/ha/yr have been determined, with the highest values restricted to relatively small areas just off Coatham Sands. Given the very small deposition rates nitrogen contributions from this source are very small and insignificant when considered alongside loads from other process sources. It will also only affect the Tees Bay and Natural England have indicated that they are primarily concerned by emissions of nitrogen to the Tees Estuary.	No – Due to the very small loads emitted by this source and its distribution and dilution across a wide area of Tees Bay it is considered not necessary to consider this emission any further.

6.2 Nutrient Neutrality Approach

6.2.1 Nutrient neutrality is an approach which enables decision makers to assess and quantify mitigation requirements of new developments. Natural England considers nutrient neutrality as an acceptable means of counterbalancing nutrient impacts from development to demonstrate no adverse effects on the integrity of habitats sites.

6.2.2 A generic nutrient neutrality calculation methodology and a catchment specific nutrient budget calculator have been developed by Natural England and these were issued alongside the guidance to LPAs in March 2022. Although primarily directed at residential developments, the guidance states that “other types of business or commercial development, not involving overnight accommodation, will generally not need to be included in the assessment unless they have other (non-sewerage) water quality implications”. Given the potential of the Proposed Development to impact on water quality in the Tees Estuary and/or Tees Bay a bespoke assessment is therefore required within the relevant areas of the designated site.

6.2.3 The main function of the nutrient budget calculators is to estimate the annual nutrient load from foul water and from changes in land use via surface water runoff. However, for the Proposed Development there are no overnight stays (and so foul wastewater is assumed to be neutral already) and for the purposes of this assessment the land use will effectively remain the same. Regardless of this, the principles of Natural England’s method decision tree presented in Appendix A of the March 2022 letter hold true and will be applied, and a similar approach to the determination of a nutrient budget for the Proposed Development will be undertaken (i.e. to estimate the annual nitrogen load from each source to provide a total development nitrogen budget per year plus a buffer of 20%). Assumptions may be required for how the nitrogen load from various sources is estimated and this will be detailed in the final report. Once the annual nitrogen load plus buffer has been estimated, options for mitigation may be considered. Table 6.2 provides a summary of the main assessment stages and steps of the Natural England Nutrient Neutrality Generic Guidance with the final column setting out the bespoke approach for determining the budget for the Proposed Development.

Table 6.2. Comparison of NE Nutrient Neutrality Generic Methodology Stages and Steps and bespoke approach from NZT

NE Nutrient Neutrality Generic Methodology Stages and Steps		**Proposed method for NZT**
Stage 1 The increase in nutrient loading to a Habitats Site that results from the increase in wastewater from a new development	Step 1 Calculate increase in population due to development	Estimate annual load of nitrogen from process water (other) discharges to the Tees Estuary in kg N/ yr.
	Step 2 Calculate the increase in wastewater production (from population increase) due to development	
	Step 3 Determine the concentration of nutrients in wastewater and calculate additional wastewater nutrient load	
Stage 2 The nutrient loading from the past/present land use of the development site	Step 1 Obtain nutrient export values from current land use	N/A as land use not changing.
	Step 2 Calculate the annual nutrient export from current land use(s)	
Stage 3 The nutrient loading from the future mix of land use on the development site	Step 1 Calculate the annual nutrient export from future land use(s)	
Stage 4 Calculate the net change in nutrient loading to a Habitats Site with the addition of a buffer (the net change in the nutrient loading + the buffer is the nutrient budget)	Step 1 Calculate the nutrient budget	There is no change in land use so the annual nitrogen load from process water discharges to the Tees Estuary equates to the nutrient budget.
	Step 2 Add the buffer to the nutrient budget	A precautionary buffer of 20% will be added to the Proposed Development Nutrient Budget.

7.0 POTENTIAL IMPACTS OF NITROGEN ON QUALIFYING FEATURES OF SPA/RAMSAR

7.1 Tees Bay

7.1.1 The Teesmouth and Cleveland Coast SPA / Ramsar (JNCC, 2001a) is a 12,211 ha estuarine and coastal site comprising a range of coastal habitats, such as sand- and mudflats, rocky shore, saltmarsh, freshwater marsh and sand dunes. The SPA / Ramsar lies along a stretch of coast that has been significantly modified by human activity. The site provides feeding and roosting opportunities for a significant number of waterfowl in winter and the passage period. Furthermore, little tern Sterna albifrons breed on beaches within the site during summer and sandwich tern Sterna sandvicensis use the SPA / Ramsar as a stop-over location on passage.

7.1.2 Tees Bay is included in the SPA designation to protect the open water areas of greatest foraging importance to the little terns at Crimdon Dene and the open water areas of greatest foraging importance to the common terns at Saltholme. The part of Tees Bay within the SPA designation is an area of c. 9,000 ha and neither tern species is a highly selective feeder, foraging on a wide range of fish and invertebrates. As a result, prey biomass is likely to be more important than diversity or species richness. Moreover, Warren (2018) and research reported in Econ (2014) identified that physical parameters such as tidal currents, wave height and wind speed, and biological factors such as the presence of predatory fish competing with the terns, all importantly influence prey available near the surface for both common and little tern, and the spatial and temporal predictability (or otherwise) of these processes may be more important than the absolute density of prey in a given area.

7.1.3 Whilst the discharge modelling is ongoing, it should be noted that although marine water clarity can be affected by pollution (such as by nutrients, including DIN, causing plankton blooms in the water column) spatial differences in water turbidity can have both negative effects (obscuring prey from the predator) and positive effects (making it less likely the prey detect the predator and increasing food for prey drawing more of them to the surface). Holbech et al (2018) found that water clarity had no effect on prey capture success by common terns, while Econ (2014) suggests turbid waters may be an essential prerequisite for foraging little terns.

7.1.4 Given the major role of physical and biological (competition) factors in influencing predation behaviour and success, the variability in some of these factors, and the 9,000 ha size of the designated part of Tees Bay compared to the population of terns (approximately 480 pairs based on the Defra departmental brief at the time the SPA was extended into the marine environment), it is considered unlikely that an increase in dissolved inorganic nitrogen to the Tees Bay as a result of the Proposed Development would materially affect its ability to provide adequate sustenance to maintain the tern populations.

7.1.5 Based on Natural England's advice that the concern is over the Tees Estuary, and specifically the Seal Sands mud flats, under Option A the Proposed Development redirects effluent containing an equivalent quantity of nitrogen away from Dabholm

Gut and to Tees Bay, specifically in order to avoid exacerbating existing nutrient issues in Tees Estuary.

7.2 Impacts on the Dabholm Gut/Tees Estuary

7.2.1 Under the Base Case, the discharge from Bran Sands to Dabholm Gut causes discharge of a net addition of nutrient nitrogen to Dabholm Gut and the Tees Estuary. At the meeting with the Applicants on 15th September 2022, Natural England confirmed that they considered that adopting the Base Case would not be acceptable from a nutrient nitrogen perspective.

7.2.2 Option A allows for taking an equivalent quantity of nitrogen back from Bran Sands to that exported for treatment for discharge to Tees Bay. There would therefore be no direct input of nitrogen from Bran Sands to the Dabholm Gut as a result of the Proposed Development under this option. In addition, raw water would be extracted from the Tees upstream of the Tees Barrage and discharged after use to Tees Bay via the existing or replacement outfall. This would effectively reduce the nutrient nitrogen flux in the estuary by 14 kgN/hr.

7.2.3 Modelling of Option A will confirm whether or not there would be an adverse effect on the dissolved inorganic nitrogen levels in the Estuary relating to discharges from the existing or replacement outfalls in Tees Bay (based on analysis of mixing zones) through dispersion of effluent back into the Tees Estuary. The results of the modelling will confirm whether there would be no adverse effect on the integrity of the SPA/Ramsar site due to an increase in nutrients to the Tees Estuary under this option.

8.0 WATER FRAMEWORK DIRECTIVE AND EQS COMPLIANCE

8.1.1 During the operational phase potential water environment impacts may occur associated with changes in water quality within Tees Bay from operational discharges from the PCC Site including the discharge of treated process wastewater and water from the cooling system.

8.1.2 On completion of the discharge modelling, an updated Water Framework Directive assessment will be prepared, considering water quality impacts from emissions to the Tees Bay and any effects on the WFD status of the Tees Coastal Water Body .

9.0 ACTION PLAN / NEXT STEPS

9.1.1 The Applicants intend to continue / undertake the following activities by Deadline 9.

- Modelling of Option A discharges to Tees Bay using CORMIX (near field) and Delft3D (far-field models);
- Update of the WFD Compliance Report and Habitat Regulations Assessment Report;
- Consultation with both Natural England and Environment Agency; and
- Address any comments from NE/EA.

These will be followed by submission at Deadline 9 of the final nitrogen discharges briefing paper to the ExA supported by:

- Effluent Discharge Modelling Report for Option A;
- Updated Water Framework Directive Compliance Report (Appendix 9C to the ES); and
- Updated Habitat Regulations Assessment report (DCO Document Ref. 5.13).

9.1.2 In addition, the Applicants intend to submit by Deadline 9 a paper which provides sufficient information, on a without prejudice basis, to demonstrate that the tests in Regulations 64 and 68 of the Habitats Regulations would be achieved. It will explain the mitigation measures that will be employed where possible to avoid adverse effects on the estuary from the discharge of effluent containing nitrogen. If appropriate, and if it cannot be demonstrated that effluent containing nitrogen cannot be prevented from reaching the estuary, the paper will further explain why the Proposed Development is justified by imperative reasons of overriding public interest; why there is an absence of alternatives; and set out the proposed compensation measures, all in accordance with the requirements of the Planning Inspectorate's updated Advice Note 10[5]. The paper will not assume that the derogating provisions will need to be relied upon to satisfy the requirements of the Habitats Regulations.

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[5] https://infrastructure.planninginspectorate.gov.uk/legislation-and-advice/advice-notes/advice-note-ten/

APPENDIX A PRELIMINARY DISCHARGE MODELLING REPORT

Net Zero Teesside - Water Quality Assessment

Intermediate Design Stage

BP

Project number: 60675797

14 June 2022

Quality information

Prepared by	Checked by	Verified by	Approved by
Sarah Waite Water Quality Scientist	Frans van Eeden Senior Coastal Modeller	Paul Norton Technical Director	

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Prepared for:

BP

Prepared by:

Sarah Waite
Water Quality Scientist

AECOM Limited
Royal Court, Basil Close
Chesterfield
Derbyshire S41 7SL
United Kingdom

T: +44 (1246) 209221
aecom.com

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1. Introduction

1.1 Background

The Power, Capture and Compression (PCC) site of the proposed Net Zero Teesside (NZT) development is located on part of the former Redcar Steel Works which operated until 2015. It is proposed to redevelop the site and construct a gas fired power station with carbon capture, as well as a high pressure compressor station, and in the surrounding Teesside are a CO2 Gathering Network and development associated with the power station will be constructed. During operations, it is proposed to discharge wastewater from on-site processes to Tees Bay. The outfall will also be used for disposal of surface water runoff. In their Relevant Representations, the Environment Agency and Natural England have asked for an assessment of the potential impacts of the proposed discharge on water quality in Tees Bay with specific focus on localised temperature impacts and wider impacts on Dissolved Inorganic Nitrogen (DIN) concentrations within Tees Bay and the River Tees Estuary. The results of this assessment will aid in the assessment of the impact of the Proposed Development on nutrient levels and how this may impact the Teesside and Cleveland Coast Special Protection Area/Ramsar site, including parts of Tees Bay and the Tees Estuary.

A preliminary study of near field and far field mixing of discharges from the site was carried out by ABPmer and was included in the DCO Application submitted in July 2021 as Appendix 14E [App-321]. Site design was at an earlier stage at this point (referred to throughout this report as the Initial Design Stage Assessment and included as Appendix A). The Initial Design Stage Assessment focussed on thermal impacts only and the assessment was limited in scope due to the earlier design stage of the proposed development at that time. ABPmer was aware that heated water and surface water runoff would need to be discharged from the site and were provided with an initial future discharge rate of 1.37 m^3/s which would be a combination of both. However, at the time of ABPmer's Initial Design Stage Assessment, there was no information concerning the likely design of the surface water system, the temperature of the heated water or the proportion of heated and surface water runoff present in the effluent. A worst case scenario in which the entire 1.37 m^3/s flow was heated to 30°C was assumed.

Details of the site design have now been progressed and better information on discharge rates and volumes is now available. The discharge rate of heated effluent is anticipated to be significantly lower at approximately 0.07 m^3/s. The addition of surface water runoff will increase this flow rate, but will also potentially produce a cooler discharged effluent and dilute any contaminants that may be present, as well as being intermittent and attenuated through on-site storage provision. In view of the progress in the design, it is necessary to update the assessment carried out by ABPmer to reflect the changes in effluent flow rates and to also include an assessment of DIN emissions to Tees Bay.

This Intermediate Design Stage Assessment sets out details of the near and far field modelling carried out on the basis of the information now available. This includes consideration of chemical pollutants using data which were not available to inform the Initial Design Stage Assessment. The assessment aims to represent worst case thermal and DIN impacts on Tees Bay and the Tees Estuary given current design philosophies and water management methods proposed for the PCC site. However, the Proposed Development is currently in the Front End Engineering Design (FEED) stage and as such proposals have yet to be finalised and proposed discharge rates and effluent quality may change in the future as the design progresses further and arrangements for water use are finalised (e.g. on or off site water treatment provision, water re-use on site, design of future outfalls). This Intermediate Design Stage Assessment therefore seeks to provide a worst case scenario assessment of water quality impacts based on the currently available information. It is envisaged that the modelling will be revisited and a Final Design Stage Assessment carried out as the development proposals are finalised. The purpose of this Intermediate Design Stage Assessment is to establish the worst case possible impacts on Tees Bay and the Tees Estuary and inform the design finalisation process.

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This Intermediate Design Stage Assessment builds on the work carried out for the Initial Design Stage Assessment, including work to characterise the receiving environment and construct a 3D hydrodynamic model of the tidal River Tees and Tees Bay. Full details of this work are provided in Appendix A and the same 3D model is used to provide input data to the near field modelling discussed below as well as to carry out the far field modelling.

1.2 Development Proposals

At this Intermediate Design Stage there are two main options for site design being developed. Given the nature of this intermediate assessment, with FEED works ongoing, full details of these designs are not yet available. However, the different design philosophies both include a supply of untreated raw water abstracted upstream of the tidal limit on the River Tees by Northumbrian Water Limited (NWL) and supplied to the site via NWL's network. This supply will be used as cooling water ("Blowdown Water") in the power station and will be discharged as effluent to Tees Bay. A small amount of additional effluent will be generated on site as steam condensate ("Condensed Water") and will also be discharged to Tees Bay. Where there is the potential for hydrocarbon contamination, surface water from the redeveloped site will be routed through oil interceptors before being discharged to Tees Bay via on-site attenuation storage facilities. Some additional effluent will be generated within the Carbon Capture Plant but this will be discharged to NWL's existing Wastewater Treatment Plant at Bran Sands which discharges to the Tees Estuary via the Dabholm Gut.

Water quality impacts in Tees Bay may occur because the Blowdown Water and Condensed Water will be generated, and may be discharged, at temperatures exceeding that of Tees Bay. Further, the origin of the Blowdown Water is untreated water from the River Tees and contains contaminants typical of a large lowland river draining a diverse catchment with extensive farming and industrial use including DIN. Abstracting and discharging this water could be considered maintaining the status quo, as without the abstraction these contaminants would remain in the flow and likely find their way to the estuary. However, these contaminants can be concentrated by up to five times by the on-site processes and this should be considered. The Condensed Water flows are significantly smaller than the Blowdown Water flows (see Section 2) but this water may contain concentrations of ammonia up to 5 mg/l.

Development Option Scenarios

At this stage, four scenarios for modelling the impact of wastewater discharges have been identified:

- **Option 1A** – Concentrated Blowdown Water and Condensed Water, excluding the re-use of wastewater from any process as Blowdown Water and excluding surface water runoff present in the discharged effluent.
- **Option 2A** – Concentrated Blowdown Water and Condensed Water, partial re-use of Condensed Water as Blowdown water, and no surface water runoff present in the discharged effluent.
- **Option 1B** – Concentrated Blowdown Water and Condensed Water, excluding re-use of wastewater from any process as Blowdown water, including average annual surface water runoff present in the discharged effluent.
- **Option 2B** – Concentrated Blowdown Water and Condensed Water, partial re-use of Condensed Water as Blowdown water, including average surface water runoff present in the discharged effluent.

Option 1A above will be worst case for effluent temperature and Option 2A will be worst case for effluent DIN concentrations. Scenario 1B will be worst case for effluent flow rates but the effluent will be cooler and contaminants will be diluted through addition of surface water.

There are also two alternative proposals under consideration for the location and geometry of the Tees Bay outfall. The first option is to re-use the existing former steelworks outfall located at Ordnance Survey National Grid Reference (OS NGR) 457108 E, 527563 N and constructed for discharge of effluent from the Teesside Integrated Iron and Steel Works. The second is to construct a new outfall at a location

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south-east of the existing outfall, with the precise location and outfall pipeline/diffuser design still to be determined. This Intermediate Design Stage Assessment examines the water quality impacts of both options over the tidal cycle. The current NZT DCO boundary outline and outfall locations are shown in Figure 1-1.

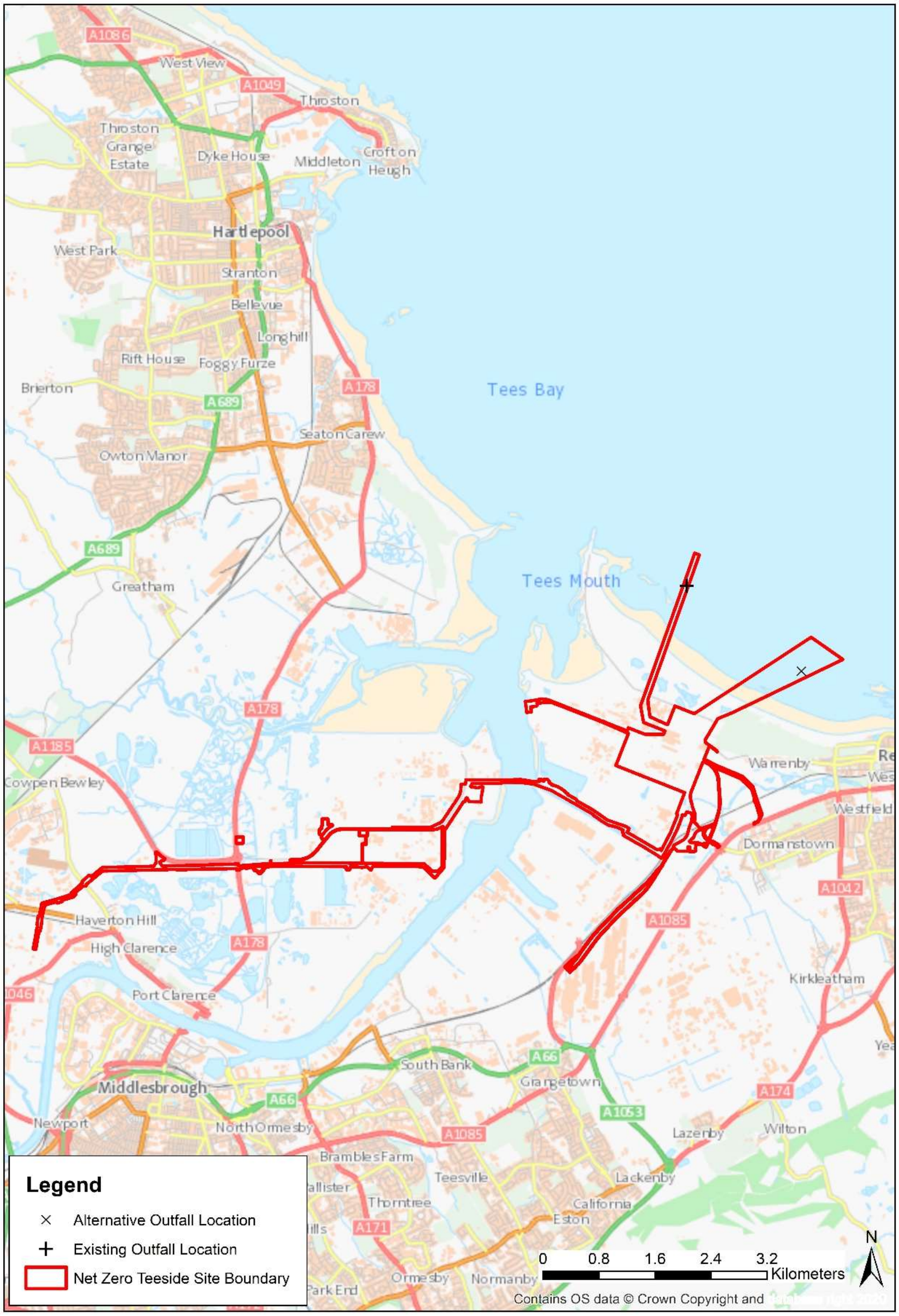

Figure 1-1: NZT Development Boundary and Potential Effluent Discharge Locations

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2. Discharged Effluent Quality

2.1 Environmental Quality Standards

Table 2-1 sets out Environmental Quality Standards (EQS) relevant to the Tees Bay coastal water under current UK legislation. These standards will be used to develop the list of pollutants which need to be assessed to determine the water quality impacts of the proposed discharge.

Table 2-1: Environmental Quality Standards for Tees Bay

Parameter	Environmental Quality Standard
Temperature	Less than 3°C increase in temperature outside the immediate mixing zone
Dissolved Inorganic Nitrogen (µmol/l)	Mean = 12 µmol/l (selected based on salinity and turbidity data)
Dissolved Oxygen	Mean = 5.74 mg/l (calculated from salinity)
Un-ionised Ammonia	Mean = 21 µg/l
Arsenic	Mean = 25 µg/l
Chlorine	95%ile = 10 µg/l
Cyanide	Mean = 1 µg/l, 95%ile = 5 µg/l
Hydrocarbons	
Benzyl butyl phthalate	Mean = 0.75 µg/l 95%ile = 10 µg/l
2,4-dichorophenol	Mean = 0.42 µg/l, 95%ile = 6 µg/l
3,4-dichloroaniline	Mean = 0.2 µg/l, 95%ile = 5.4 µg/l
Phenol	Mean = 7.7 µg/l, 95%ile = 46 µg/l
Toluene	Mean = 0.074 mg/l, 95%ile = 0.370 mg/l
Triclosan	Mean = 0.1 µg/l, 95%ile = 0.28 µg/l
Metals	
Chromium (VI)	Mean = 0.6 µg/l, 95%ile = 32 µg/l
Copper	Mean = 3.76 µg/l dissolved
Iron	Mean = 1 µg/l
Zinc	Mean = 6.8 µg/l dissolved plus ambient (1.1 µg/l) = 7.9 µg/l
Pesticides	
Cypermethrin	Mean = 0.1 µg/l, 95%ile = 0.4 µg/l
Diazinon	Mean = 0.01 µg/l, 95%ile = 0.26 µg/l
2,4-dichlorophenoxyacetic acid (2,4-D)	Mean = 0.3 µg/l, 95%ile = 1.3 µg/l
Dimethoate	Mean = 0.48 µg/l, 95%ile = 4 µg/l
Glyphosate	Mean = 196 µg/l, 95%ile = 398 µg/l
Linuron	Mean = 0.5 µg/l, 95%ile = 0.9 µg/l
Mecoprop	Mean = 18 µg/l, 95%ile = 187 µg/l
Permethrin	Mean = 0.2 ng/l, 95%ile = 1 ng/l

The EQS for DIN has been selected based on High Status EQS standards[1] for clear coastal waters containing less than 10 mg/l suspended particulate matter and with a salinity of 32 ppt. Environment Agency data show an average of 8 mg/l suspended solids and normal salinity of 30 ppt at Tees Mouth (see Section 3) and salinity of 32-35 ppt in Tees Bay.

The dissolved oxygen EQS is calculated for High Status from salinity for coastal waters with salinity less than 35 ppt. Dissolved oxygen discharges will not be modelled as a pollutant because concentrations in receiving waters will be controlled by temperature and nutrient (DIN) impacts.

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[1] For further information see https://www.legislation.gov.uk/uksi/2015/1623/pdfs/uksiod_20151623_en_auto.pdf

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2.2 Effluent Pollutant Concentrations

2.2.1 Blowdown Water Quality

The source of the Blowdown Water is untreated River Tees water from three abstraction points – Low Worsall, Blackwell and Broken Scar. River water quality monitoring data have been provided by Northumbrian Water for Broken Scar and a summary dataset of key substances has been provided for Low Worsall and Blackwell. Review of the data show significant differences in water quality at Low Worsall while water quality at Blackwell is similar to that at Broken Scar – average pollutant concentrations at each abstraction are shown in Table 2-2. Un-ionised Ammonia concentrations have been calculated from observed ammonia concentrations using the formula in Equation 2-1. DIN concentrations have been calculated by converting nitrate, nitrite and ammonia concentrations recorded in mg/l in each sample to µmol/l based on molecular mass, then calculating the average of the total µmol/l concentration.

Equation 2-1: Approximation for Calculating Un-ionised Ammonia Fraction from Total Ammonia[2]

$$\mathit{Unionised\ Ammonia\ (mg/l)} = \frac{\mathit{Total\ Ammonia\ (mg/l)} \times \frac{17}{14}}{1 + 10^{\left[0.09018 + \frac{2729.92}{273.15 + \mathit{Temp}\ (^\circ C)} - pH\right]}}$$

Table 2-2: Mean Pollutant Concentrations at River Tees Abstraction Points (2016-2022)

Parameter	Broken Scar	Blackwell	Low Worsall
Temperature (°C)	11.2	10.8	10.9
Dissolved Inorganic Nitrogen (µmol/l)	57	59	178
Un-ionised Ammonia (µg/l)	0.1	0.5	1.3
Arsenic (mg/l)	No data	No data	No data
Chlorine	No data	No data	No data
Cyanide	No data	No data	No data
Hydrocarbons			
Benzyl butyl phthalate	No data	No data	No data
2,4-dichorophenol	No data	No data	No data
3,4-dichloroaniline	No data	No data	No data
Phenol	No data	No data	No data
Toluene	No data	No data	No data
Triclosan	No data	No data	No data
Metals			
Chromium (VI) (mg/l)	0.5	No data	No data
Copper (mg/l)	No data	1.0	1.6
Iron (mg/l)	0.6	0.5	0.6
Zinc (mg/l)	No data	No data	No data
Pesticides			
Cypermethrin (µg/l)	Not detected	No data	No data
Diazinon (µg/l)	0.003	No data	No data
2,4-D (µg/l)	0.002	No data	No data
Dimethoate (µg/l)	No data	No data	No data
Glyphosate (µg/l)	0.012	No data	No data

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[2] https://floridadep.gov/sites/default/files/5-Unionized-Ammonia-SOP_1.pdf, accessed 10 May 2022

Linuron (µg/l)	No data	No data	No data
Mecoprop (µg/l)	0.002	No data	No data
Permethrin (µg/l)	No data	No data	No data

Discussions with NWL have confirmed that the Low Worsall abstraction point is currently out of use. However, it is expected to return to use as local water requirements increase, for example in response to development of the PCC site. In this case, the PCC site will receive the majority of its water supply from Low Worsall. Based on the current site design information, potential contaminants species in this raw water will then be further concentrated by up to five times as a result of its use as Blowdown Water.

The pollutant loads in the Blowdown Water have been calculated in this report based on the assumption that all Blowdown Water will be sourced from Low Worsall, with no supply from Broken Scar or Blackwell. This gives a worst case scenario for effluent DIN concentrations. However, a full analysis of hydrocarbons, arsenic, chlorine, cyanide and zinc cannot be made due to lack of data. Data are also missing for Dimethoate, Linuron and Permethrin, however these substances are not expected to be present in significant quantities in the River Tees because they were withdrawn from UK use in 2002, 2018 and 2002 respectively. Monitoring continues for Cypermethrin in the River Tees but this substance has not been detected in any sample in the dataset and is therefore considered to be absent. The impact of mixing and concentration on final effluent quality is discussed in Section 2.2.4.

2.2.2 Condensed Water Quality

The Blowdown Water will make up the majority of the process effluent produced by the PCC site. However, a small additional flow of Condensed Water is also expected to be discharged into Tees Bay. This water is expected to contain only one contaminant which is subject to an EQS, ammonia, at concentrations of 5 mg/l (294 µmol/l), which is limited through the DIN EQS. The Condensed Water may also contain dissolved carbon dioxide at concentrations sufficient to reduce the pH to a value of 6, however neither pH nor carbon dioxide concentrations are limited in coastal waters. The impact of mixing and re-use of Condensed Water on the final discharged effluent quality is discussed in Section 2.2.4.

2.2.3 Surface Water Runoff

Surface water runoff is not expected to be a significant source of contaminants to the discharged effluent. The surface water management proposals for the PCC site are still at an early stage, however they include installation of oil interceptors where there is a risk of surface water contamination. Sustainable drainage systems will be installed following redevelopment which will include surface water attenuation features which will allow settlement of solids and breakdown of contaminants. Therefore, it is assumed at this stage of the study that the addition of surface water runoff to the discharged effluent will serve to dilute contaminants rather than increase concentrations (see Section 2.2.4).

2.2.4 Final Mixed Effluent Discharge Scenarios

As discussed in Section 1.2, the final effluent discharged to Tees Bay will comprise a mixture of concentrated Blowdown Water and Condensed Water, with or without an aspect of Condensed Water re-use and surface water addition. The temperature of the discharged effluent will depend on the final development design because the current site designs include areas where Blowdown Water and Condensed Water will be stored prior to discharge, giving opportunity for cooling. Depending on the final development option selected, the site designs are expected to result in worst-case summer scenario temperature of the discharged effluent will be either 27 or 23°C. The addition of surface water runoff will significantly cool the discharged effluent.

Based on the available information, four scenarios for modelling the impact of wastewater discharges have been identified:

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- **Option 1A** - no re-use of wastewater from any process as Blowdown Water, no surface water runoff present in the discharged effluent. Effluent pollutant concentrations are taken from the River Tees Water data multiplied by 5, with an additional ammonia component then added to represent the Condensed Water. The effluent discharge temperature is taken as 27°C.

- **Option 2A** - Re-use of Condensed Water as Blowdown Water, no surface water runoff present in the discharged effluent. Effluent pollutant concentrations are taken from the River Tees water with an additional ammonia component added before the total concentrations of all pollutants are multiplied by 5. The effluent discharge temperature is taken as 23°C.

- **Option 1B** – Option 1 effluent concentrations are diluted by average annual surface water runoff volumes prior to discharge. Based on the current design documents, the effluent discharge temperature is taken as 15°C.

- **Option 2B** - Option 2 effluent concentrations are diluted by average annual surface water runoff volumes prior to discharge. The effluent discharge temperature is taken as 15°C based on the current design documents. Note that this design philosophy contains more measures to store and manage water flows on site in order to allow for water re-use. This includes using a single controlled discharge rate based on pumping of process flows only. The addition of surface water runoff will therefore dilute and cool the effluent but will not increase the effluent discharge flow rate.

Options 1 and 2 reflect different potential design philosophies at the site. The pollutant flows, effluent loads and temperatures in each scenario are set out in Table 2-3. Worst case scenario conditions are assumed where required, e.g. it is assumed that all Blowdown Water is sourced from Low Worsall as this is the worst case for DIN. Options 1B and 2B reflect the addition of surface water runoff from the redeveloped site to Option 1A and 2A effluent, respectively. The runoff volume has been estimated by allowing for 9 mm rainfall depth[3] (the rainfall depth expected during a rainfall event lasting 1 hour and occurring, on average, once per year, i.e. a moderately sized storm) over an area of 150,000 m^2 of hard standing surface, based on the area of the PCC site.

For each scenario, each chemical substance present in the effluent at concentrations greater than the EQS in Table 2-1 is highlighted in yellow. A water quality impact assessment is not required for those parameters which are not highlighted (2,4-D, glyphosate and mecoprop) because the discharge of these substances to Tees Bay at these concentrations does not risk exceeding the EQS.

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[3] Rainfall depth information taken from Flood Estimation Handbook 2013 model, accessed at https://fehweb.ceh.ac.uk/GB/map on 10 May 2022

Table 2-3: Flows and Pollutant Loads for Modelled Discharge Scenarios

Parameter	Option 1A	Option 2A	Option 1B	Option 2B
Description	Low Worsall water concentrated 5 times, condensed water added	Low Worsall water and condensed mixed, then concentrated 5 times	Option 1A with addition of 1350 m^3/hr surface runoff	Option 2A with addition of surface runoff
Flow Rate (m^3/s)	0.04	0.07	0.41	0.07
Temperature (°C)	27	23	15	15
DIN (µmol/l)	890[1]	989[3]	75	162[6]
Un-ionised Ammonia (µg/l)	2[2]	27[4]	0.2[5]	6[7]
Metals[8]				
Chromium (VI) (mg/l)	2.5	2.5	0.2	0.3
Copper (mg/l)	8.0	8.0	0.7	1.1
Iron (mg/l)	3.0	3.0	0.3	0.3
Pesticides[8]				
Diazinon (µg/l)	0.015	0.015	0.001	0.002
2,4-D (µg/l)	0.010	0.010	0.001	0.001
Glyphosate (µg/l)	0.060	0.060	0.005	0.009
Mecoprop (µg/l)	0.010	0.010	0.001	0.001

[1] Normal operating conditions, condensate collected on site and discharged to Tees Bay 1 hour per month, during which time DIN drops to 856 µmol/l

[2] Normal operating conditions, condensate collected on site and discharged to Tees Bay 1 hour per month, during which time un-ionised ammonia increases to 4 µg/l

[3] Worst case scenario, condensate collected on site and discharged into the Blowdown Water for 1 hour per month. Outside this time, DIN = 890 µmol/l

[4] Worst case scenario, condensate collected on site and discharged into the Blowdown Water for 1 hour per month. Outside this time, un-ionised ammonia = 2 µgl/l

[5] Normal operating conditions, condensate collected on site and discharged to Tees Bay 1 hour per month, during which time un-ionised ammonia increases to 0.3 µg/l when allowing for the addition of runoff

[6] Worst case scenario, condensate collected on site and discharged into the Blowdown Water for 1 hour per month. Outside this time, DIN = 124 µmol/l allowing for the addition of runoff

[7] Worst case scenario, condensate collected on site and discharged into the Blowdown Water for 1 hour per month. Outside this time, Un-ionised Ammonia = 5.8 µg/l, allowing for the addition of runoff

[8] All values for metals and pesticides are worst case scenarios, i.e. no dilution of blowdown water via addition of Condensate Water

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3. Receiving Environment

3.1 Model of the River Tees Estuary

Information on the physical environment of Tees Bay have been obtained for the study area from an existing, calibrated hydrodynamic model configured using the Delft3D (Deltares) software. This model was developed using the latest available data (ABPmer, 2019) and is provided in Appendix A. The model domain covers the River Tees Estuary and extends 10 km offshore and 30 km along the Hartlepool, Redcar and Cleveland coastline, as shown in Figure 3-1.

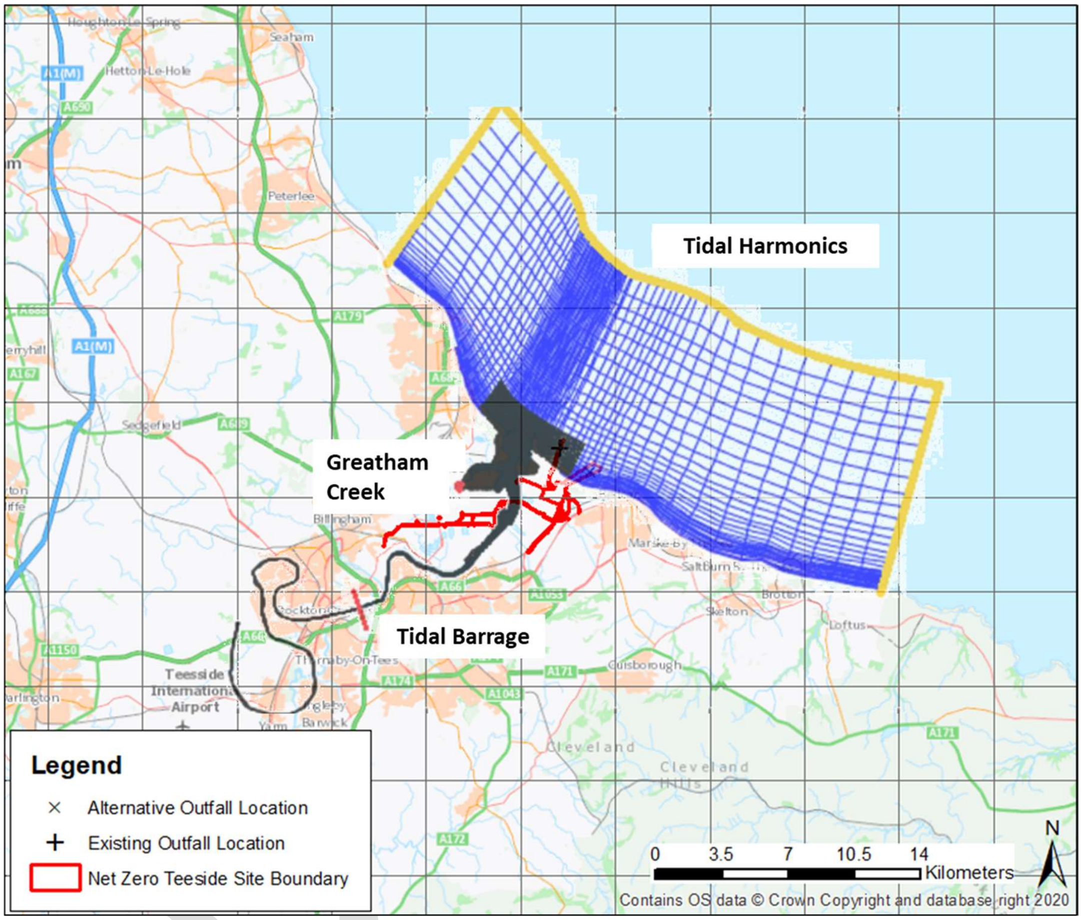

Figure 3-1: Delft3D hydrodynamic model extent

The model uses a curvilinear computational grid, which allows a grid composed of various sizes to be used throughout the model domain. A finer grid has been used for a section of the estuary west of the former steelworks (black shaded area in Figure 3-1) and a much coarser grid for the offshore region (blue grid lines in Figure 3-1).

Input flows to the model have been applied at three locations: tidal boundaries surrounding the offshore section of the model, Greatham Creek inflow and River Tees inflow represented at the location of Tees Barrage. These flows have been applied as follows:

- Three offshore boundaries have been used in the model (yellow lines in Figure 3-1) which are driven by tidal harmonics.
- The Tees Barrage has been represented as a “thin dam” structure which prevents saline water extending upstream in the River Tees. A non-continuous freshwater discharge has been added at this location which was calculated from flow data available from the National River Flow Archive

(NRFA). Peak discharge rates used in the model vary seasonally between 3 m^3/s (summer) and 74 m^3/s (winter).

- A continuous inflow of 1.8 m^3/s has been added to the model to represent the flow from Greatham Creek. This has been based on previous values used in prior modelling work.

The Delft3D hydrodynamic model was run for three simulation periods: calibration (20/04/2005 – 01/05/2005), verification (13/01/2001 – 27/10/2001) and 2019 seasonal runs (23/06/2019 – 08/07/2019). The period chosen for the 2019 seasonal run was selected to ensure that the mean spring and mean neap tidal conditions are captured in the model simulation period. The results from this simulation have been used in this study to simulate the tidal water variations and flows at the two outfall locations.

3.2 Outfall Locations

Effluent from the PCC site may be discharged via an existing outfall located at OS NGR 457108 E, 527563 N. An alternative option is to construct a new outfall at 458705 E, 526354 N, as indicated in Figure 1-1.

3.2 Bathymetry

The bathymetry data for the model has been compiled from a number of sources: PD Teesport Redcar Bulk Terminal Survey Data (29/01/2020), PD Teesport Survey Data (2019), LiDAR Contours, CMap, Admiralty Charts and survey data contained in previous models (2003). Where datasets overlapped, they were prioritised in the above order which has been dictated based on the quality of data. The bed profile extending from the shore towards the existing outfall is shown in Figure 3-2, where zero chainage is at the high tide shoreline (mean high water). The existing outfall is at approximately 750 m chainage and at -6.24 mAOD. Based on technical drawings supplied at the current design stage, the alternative outfall location is taken to be 500 m offshore and appears to be approximately -6 mAOD.

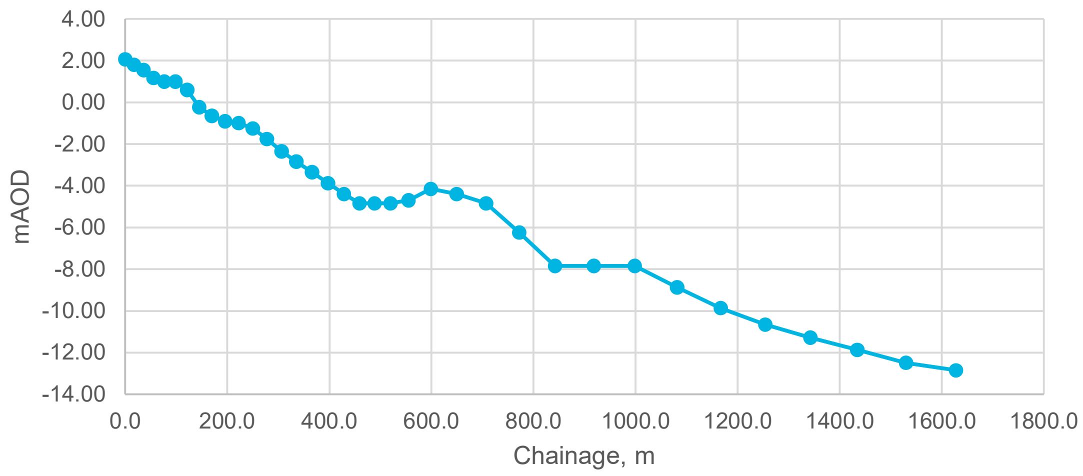

Figure 3-2: Bed Profile Extending Offshore at W3 Outfall Location

3.3 Tide Levels and Currents

Water level and current data have been extracted from the Delft3D model for the 2019 seasonal runs at the location of the existing outfall and are shown in Figures 3-3 to 3-5. An analysis of tidal conditions at the alternative outfall location were found to be not significantly different to those at the existing outfall location.

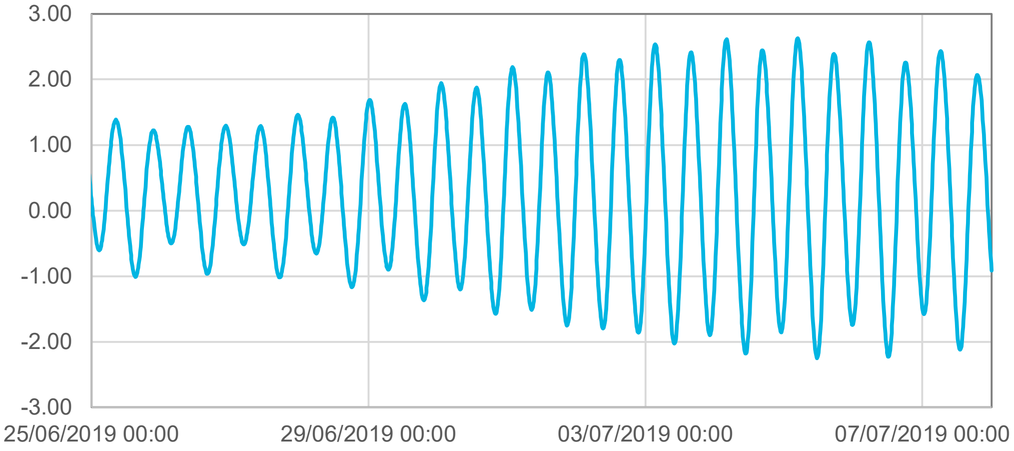

Figure 3-3: Water Levels at Existing Outfall

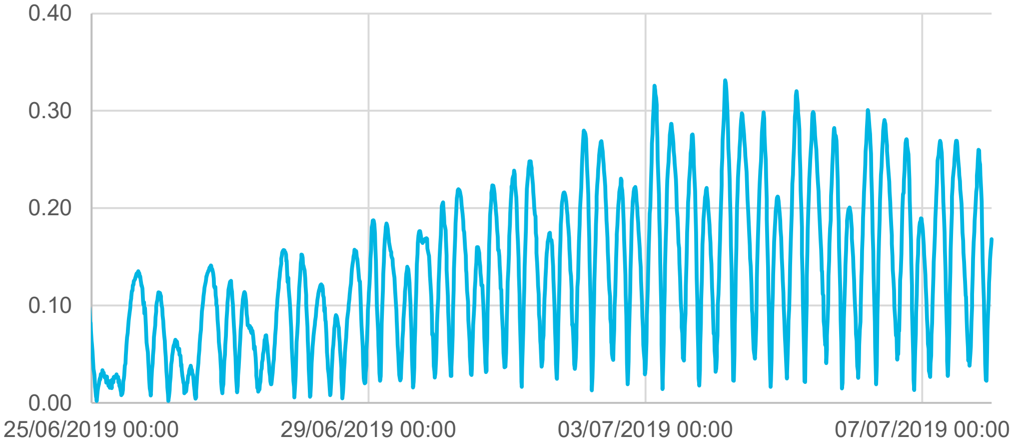

Figure 3-4: Current Speeds at the Existing Outfall Location

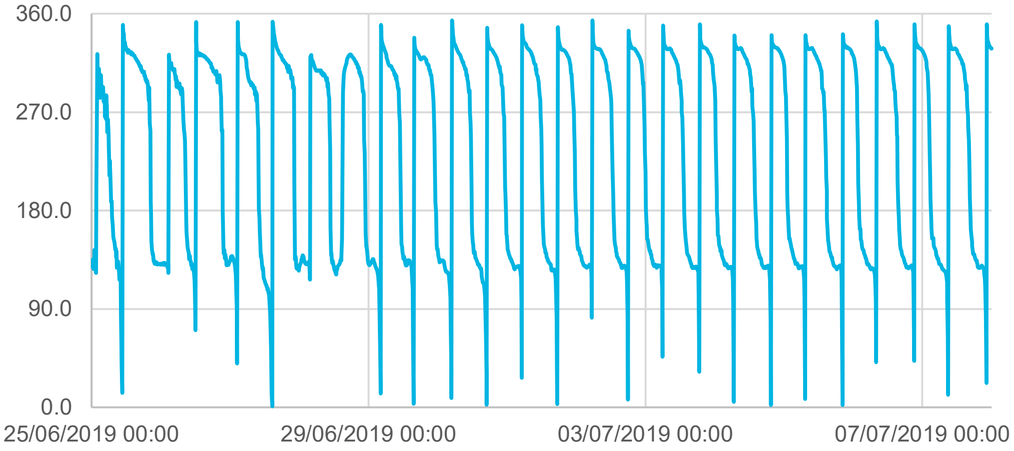

Figure 3-5: Current Directions at the Existing Outfall Location

Based on the above data, the values for water level, current speed and current direction, as listed in Table 3-1, have been used in the CORMIX modelling of the existing and alternative outfalls.

Table 3-1: Water Level and Current Conditions at Existing and Alternative Outfall Locations

Tidal Stage	Water Level (mAOD)	Current Speed (m/s)	Current Direction (°)
Minimum Tide Level	-2.24	0.25	319
Maximum Tide Level	2.61	0.31	131
Maximum Current Condition	2.54	0.33	131
Minimum Current Condition	0.77	0.013	82

3.4 Wind Conditions

Wind speed data has been obtained from the Durham Tees Valley Airport anemometer. Data is available for the years 2015 to 2019 at hourly intervals. This data was analysed as part of the Delft3D thermal discharge modelling exercise to calculate a monthly average wind speed and direction. From this, the highest (5.32 m/s) and lowest (4.08 m/s) average speeds were taken as the winter and summer condition in the Delft3D model. A value of 4.08 m/s has been applied in the CORMIX modelling as a worst case low wind speed scenario, however the Initial Design Stage modelling in Appendix A shows that the near field mixing zone is not sensitive to wind speeds over the observed range at Durham Tees Valley Airport.

3.5 Temperature and Salinity

Temperature and salinity are included in the Environment Agency ambient water monitoring data at the sample points shown in Figure 3-6. The salinity in Tees Bay (Sampling Point A in Figure 3-6) is shown to be relatively constant and varies between 31 and 34 ppt. A value of 32 ppt will be used in the near field modelling.

The temperature in Tees Bay is shown to vary between 5°C in winter and 16°C in summer. Given the significant variation in seawater temperatures, separate CORMIX model runs will be carried out to assess the seasonal variation in mixing zone extent.

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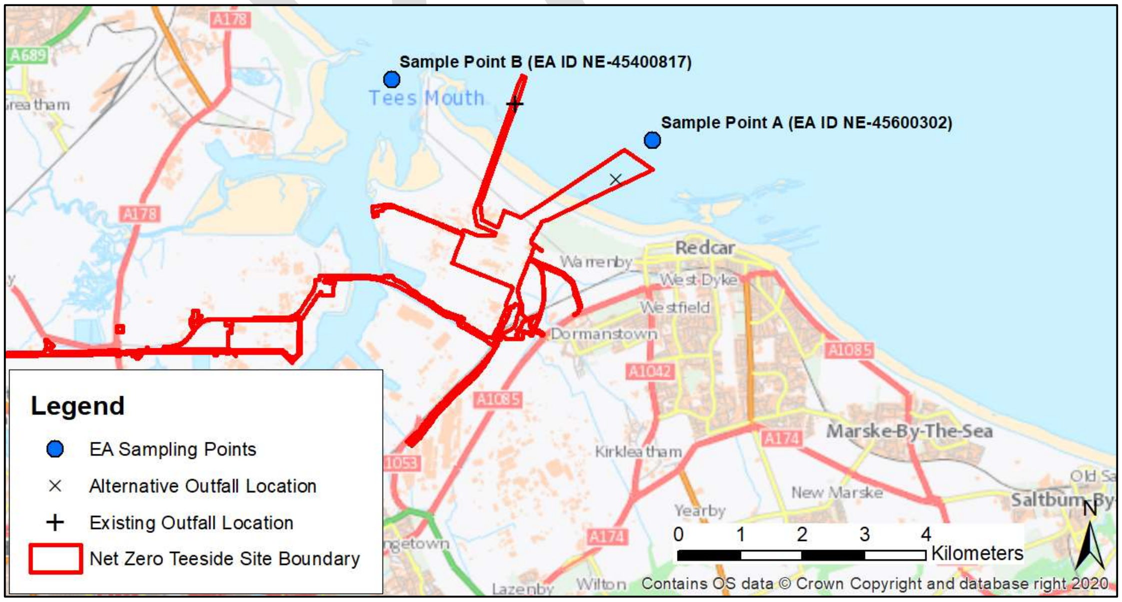

Figure 3-6: Environment Agency Ambient Water Quality Monitoring Locations

3.6 Ambient Water Quality

The Environment Agency data for two water quality sampling points, as shown in Figure 3-6, have been analysed to obtain suitable ambient water quality values for near field mixing zone modelling. Sample Point A is located within Tees Bay and records data from July 2019 to November 2021. This data shows an ambient DIN concentration within Tees Bay of 11.6 μmol/l and a calculated un-ionised ammonia concentration of 3.9 mg/l, but concentrations of chromium, copper, iron and diazinon are not monitored at this location. These substances are monitored at Sample Point B and this is considered to be the best available data for Tees Bay, although the location of Sample Point B may mean that water quality at this location is more influenced by flows from the River Tees. Sample Point B gives an average suspended solids concentration of 8.5mg/l.

Table 3-2 sets out ambient water quality values used in the near field CORMIX modelling and the location of the sample point. This data shows that DIN concentrations are close to the EQS (for high status in clear water with salinity 32) of 12 μmol/l (Table 2-1) and ambient chromium (VI) concentrations are above the EQS for mean values. The ambient chromium (VI) concentration is the same as the concentration in the PCC site effluent under Options 1A and 2A and higher than the effluent concentration under Options 1B and 2B (Table 2-3). Near field modelling is therefore not required for chromium (VI) because the discharge from the PCC site will either make no change to the Tees Bay concentrations or will locally reduce chromium (VI) concentrations.

Ambient concentrations of all other substances are all below the EQS and effluent concentrations under at least one discharge scenario.

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Table 3-2: Ambient Pollutant Concentrations in Tees Bay

Substance	Ambient Concentration	EQS	Sample Point
DIN[1]	11.6 μmol/l	12 μmol/l	A
Un-ionised Ammonia	3.9 μg/l	21 μg/l	A
Chromium (VI)	2.5 μg/l[2]	0.6 μg/l	B
Copper	0.8 μg/l[3]	3.76 μg/l	B
Iron	0.37 mg/l[4]	1.0 μg/l	B
Diazanon	0.0003 μg/l[5]	0.01 μg/l	B

[1] EQS value based on average suspended solids concentration of 8.5mg/l recorded at Sample Point B and average salinity of 32 PSU at Sample Point A

[2] Values for total chromium (VI) quoted as per UK water quality standards. Of 14 samples taken between 2008 and 2022, 5 contained measurable chromium VI however a further 14 contained concentrations below a limit of detection of 30 μg/l.

[3] Values for dissolved copper quoted as per UK water quality standards

[4] Value based on 6 samples containing measurable iron concentrations between 2008 and 2022. However, a further 53 samples contained iron concentrations below a limit of detection of 0.1 mg/l

[5] A total of 22 samples taken between 2008 and 2022, all but 5 below the limit of detection of 0.0001 μg/l

4. CORMIX Input Data

The Cornell Mixing Model software (CORMIX), developed and maintained by MixZon Inc., has been used to define the extent of the near field mixing zone at both the existing and alternative outfalls. CORMIX requires details of the effluent, the ambient conditions and the outfall geometry and the following sections outline how these aspects have been represented in the model for each of the modelled scenarios. Following analysis of the effluent and ambient water quality in Section 2 and 3.6 above, the near field mixing zone has been modelled for temperature, DIN, un-ionised ammonia, copper, iron and diazinon.

4.1 Outfall Representation

The available information for the existing outfall is provided in Appendix B. The plan shows a pipe extending offshore at a gradient of 1 in 500 ending in a double diffuser extending above the seabed. The outfall tunnel is extremely large because it was designed to convey heated water effluent from the steelworks when under full operating conditions – based on the drawing in Appendix B it appears to be approximately 3.4 m in diameter. However, there is insufficient information concerning the size of the diffuser heads. If the option to re-use this outfall is taken forward then a survey of the pipe and diffuser will be required to inform the Final Design Stage water quality modelling.

For this Intermediate Design Stage study, and for consistency with the Initial Design Stage modelling in Appendix A, the pipe size will be modelled based on the assumption that the final designed outfall will be sized based on the future effluent flow rate. This means that different pipe sizes will be specified for Options A and B. The pipe size calculations are set out below:

Option 1
Option 1 includes a large allowance for surface water drainage via gravity, with a discharge rate limited to approximately 0.41 m^3/s. The pipe diameter required to convey this flow at a gradient of 1 in 500 is 710 mm. A value of 800 mm will be used for consistency with the Initial Design Stage report.

Option 2
Option 2 includes a more limited discharge rate of 0.07 m^3/s following more extensive collection and management of site wastewater streams to facilitate water re-use as Blowdown Water. The pipe diameter required to convey this flow at a gradient of 1 in 500 is 315 mm.

For both discharge points, it is assumed that the pipes will terminate in a single diffuser head with a single port extending 1 m above the seabed. The diffuser is assumed to be vertical in line with the recommendations of the Initial Design Stage report. The use of a different pipe size, diffuser design (e.g. use of a multiport diffuser) and port orientation will have implications for the mixing zone size and shape, therefore the assumptions in this report will need to be checked against the preferred outfall design for the Final Design Stage water quality assessment.

4.2 Ambient Conditions

4.2.1 Ambient Geometry

The following parameters must be specified in CORMIX to characterise the ambient geometry at a coastal water outfall: average depth; depth at the discharge and seabed roughness (n, Manning's number or roughness coefficient). The parameters for each modelled scenario have been calculated based on information extracted from the Delft3D model and discussed in Sections 3.4 and 3.5 and are set out in Table 4-1.

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Table 4-1: Ambient Water Parameters Specified in CORMIX Modelling

Tidal Stage	Outfall	Minimum Tide Level	Maximum Tide Level	Maximum Current Condition	Minimum Current Condition
Water Level (mAOD)	Both	-2.24	2.61	2.54	0.77
Depth at outfall (m)	Existing	4.00	8.85	8.78	7.01
	Alternative	3.76	8.61	6.54	6.77
Average depth (m)	Existing	3.30	8.10	8.00	6.30
	Alternative	3.10	7.90	7.80	6.10
Seabed Roughness (Mannings n)	Both	0.025			
Distance from bank (m)	Existing	750			
	Alternative	500			

4.2.2 Ambient Density

The ambient water density is calculated within CORMIX based on temperature and salinity. The calculated densities used for each scenario have been summarised in Table 4-5.

Table 4-2: Ambient Water Density used in CORMIX

Scenario	Temperature (°C)	Salinity (ppt)	Density (kg/m3)
Winter	5	32	1025.3
Summer	16	32	1023.4

A winter heat loss coefficient of 42 W/m^{2},°C has been used in the modelling while the summer heat loss coefficient is 44 W/m^{2},°C. These values have been selected based on ambient water temperatures and wind speeds of 5.37 m/s in winter and 4.00 m/s in summer.

4.3 Presentation of Results

The CORMIX results for temperature will be presented in terms of the distance from the outfall over which the temperature in the mixing zone falls to less than 3°C and 1.5°C above ambient temperatures and when contaminant concentrations are diluted to below the EQS. The CORMIX modelling has shown that the mixing zone plume can take two different shapes depending on the current flow rate compared to the discharge velocity; the plume either forms a vertical mixing zone extending towards the water surface or a lateral plume extending along the direction of the current. The two plume shapes are shown in simplified form in Figure 4-1 and Figure 4-2. The size of a vertical rising mixing zone can be approximated with references to two distances – the height of rise and the maximum spreading area. The size of a deflected lateral mixing zone requires three parameters to approximate – the travel distance in the direction of the current, the spreading distance perpendicular to the current direction and the vertical thickness of the plume. These dimensions will be quoted in Section 5 to show the size of the near field mixing zone for temperature, copper, iron, diazinon and un-ionised ammonia for each scenario.

If a vertically rising plume reaches the water surface, then the effluent will spread horizontally at the surface as it mixes with the ambient surface water. For all scenarios, the density of the effluent is significantly less than that of the ambient seawater in Tees Bay, which will limit vertical mixing once the plume begins to spread at the surface level. The lateral extent of the surface mixing zone can become large under this scenario, although the vertical rising plume thickness remains small. The extent of any surface mixing zone will be mapped in Section 5 where surface spreading occurs.

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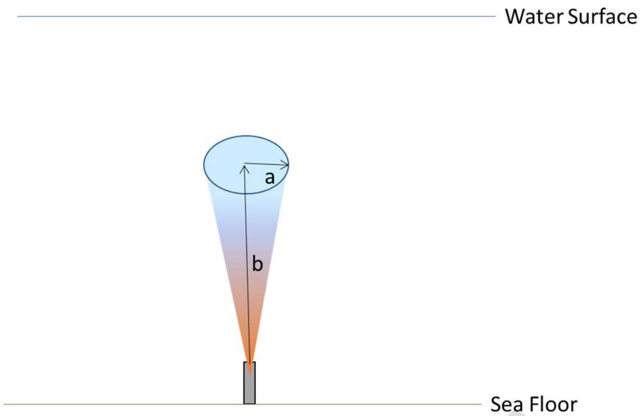

Figure 4-1: Vertical Rising Mixing Zone

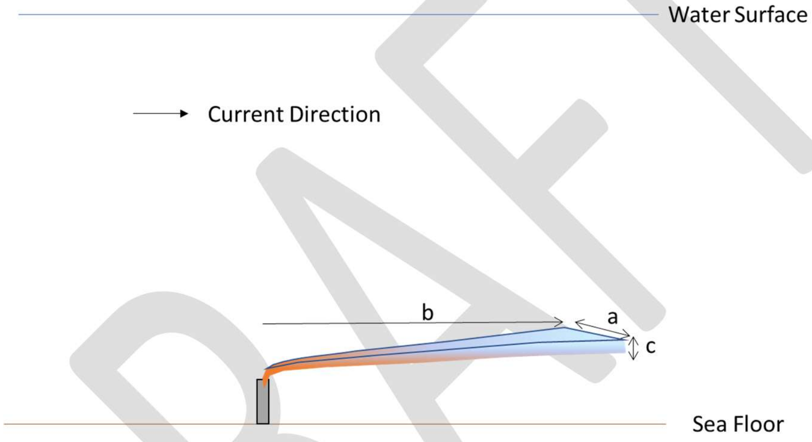

Figure 4-2: Deflected Lateral Plume Mixing Zone

The CORMIX modelling shows that the EQS concentration for DIN is not reached within the near field for any modelled scenario. In addition, the CORMIX model has difficulty producing reliable results at the limit of the near field for very low current conditions. For this reason, the mixing zones for DIN will be modelled using the far field model only (see Section 6) and the CORMIX model will not be used to inform the far field modelling to allow for consistency of approach for all current conditions.

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5. Near Field Modelling Results

5.1 Existing Outfall CORMIX Results

Table 5-1 describes the size of the near field mixing zones (see Section 4.3) for temperature and contaminant concentrations for summer and winter conditions under each discharge Option (Section 2.2.4) assuming ongoing use of the existing outfall. The effluent temperature is not significantly different from seawater temperatures in summer (15°C assumed effluent temperature, seawater temperatures up to 16°C) so thermal impacts under Options 1B and 2B only need to be assessed for winter conditions. Further, concentrations of pollutants in the effluent (except DIN) are diluted to below the EQS by the addition of runoff (see Table 2-3) so the mixing zone for copper, diazinon and iron also do not need to be assessed for Options 1B and 2B.

Table 5-1: CORMIX Near Field Modelling Results (Existing Outfall)

Discharge Option	Tide Condition	Description of Plume	Distance from outfall to reaching EQS		
			Temp (3°C)	Copper & Diazinon	Iron
1A Winter	Low Tide	Plume is deflected horizontally and does not reach water surface	a = 2.0 m b = 1.6 m c = 1.0 m	a = 1 m b = 0.5 m c= 0.8 m	a = 1.4 m b = 0.8 m c= 0.8 m
	High Tide		a = 1.8 m b = 1.4 m c = 0.9 m	a = 0.9 m b = 0.5 m c= 0.8 m	a = 1.3 m b = 0.7 m c= 0.8 m
	Max Current		a = 1.6 m b = 1.3 m c = 0.9 m	a = 0.8 m b = 0.5 m c= 0.7 m	a = 1.2 m b = 0.7 m c= 0.8 m
	Min Current	Plume rises vertically but does not reach water surface	a = 0.12 m b = 5 m	a = 0.03 m b = 2 m	a = 0.05 m b = 3 m
1A Summer	Low Tide	Plume is deflected horizontally and does not reach water surface	a = 1.4 m b = 0.8 m c = 0.8 m	a = 1 m b = 0.5 m c= 0.8 m	a = 1.4 m b = 0.8 m c= 0.8 m
	High Tide		a = 1.2 m b = 0.8 m c = 0.8 m	a = 0.9 m b = 0.5 m c= 0.8 m	a = 1.2 m b = 0.7 m c= 0.9 m
	Max Current		a = 1.2 m b = 0.7 m c = 0.8 m	a = 0.9 m b = 0.5 m c= 0.5 m	a = 1.3 m b = 0.7 m c= 0.8 m
	Min Current	Plume rises vertically but does not reach water surface	a = 0.05 m b = 3 m	a = 0.03 m b = 2 m	a = 0.05 m b = 3 m
2A Winter	Low Tide	Plume rises vertically and only spreads laterally at the water surface for scenarios marked *	a = 1.5 m b = 3.1 m	a = 0.3 m b = 1.9 m	a = 0.6 m b = 2.3 m
	High Tide		a = 1.5 m b = 2.6 m	a = 0.3 m b = 1.6 m	a = 0.6 m b = 1.9 m
	Max Current		a = 1.6 m b = 2.5 m	a = 0.3 m b = 1.6 m	a = 2.5 m b = 3.0 m
	Min Current		a = 0.1 m b = 7.0 m*	a = 0.02 m b = 3.2 m	a = 0.04 m b = 4.1 m
2A Summer	Low Tide	Plume rises vertically but does not reach water surface	a = 0.4 m b = 2.0 m	a = 1.9 m b = 0.3 m	a = 0.6 m b = 2.3 m
	High Tide		a = 0.4 m b = 1.7 m	a = 0.3 m b = 1.6 m	a = 0.6 m b = 1.9 m

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	Max Current		a = 1.8 m b = 12.4 m c = 1.5 m	a = 0.3 m b = 0.3 m c = 0.3 m	a = 0.4 m b = 0.6 m c = 0.3 m
	Min Current		a = 0.03 m b = 3.6 m	a = 0.01 m b = 3.3 m	a = 0.04 m b = 4.1 m
1B Winter	Low Tide	Plume rises vertically and spreads laterally at the water surface for scenarios marked *	a = 2.6 m b = 4.0 m*		
	High Tide		a = 1.5 m b = 3.9 m		
	Max Current		a = 1.6 m b = 3.3 m		
	Min Current		a = 28 m b = 7.0 m*		
2B Winter	Low Tide	Plume rises vertically and spreads laterally at the water surface for scenarios marked *	a = 0.7 m b = 2.4 m		
	High Tide		a = 0.7 m b = 2.0 m		
	Max Current		a = 0.8 m b = 2.0 m		
	Min Current		a = 0.05 m b = 4.4 m		

Un-ionised ammonia is diluted to below the EQS immediately on discharge under Option 2A for both summer and winter conditions.

The results in Table 5-1 show that the mixing zone is extremely small for thermal impacts and chemical contaminant concentrations under most scenarios. EQS concentrations for chemical contaminants are always met within a few metres of the outfall and before the plume meets the water surface. A thermal impact is seen at the water surface under three specific combinations of tide and discharge conditions, although the surface spreading zone remains extremely small in all scenarios.

5.2 Alternative Outfall CORMIX Results

Table 5-2 describes the size of the near field mixing zones for temperature and contaminant concentrations for summer and winter conditions under each discharge Option (Section 2.2.4) assuming that a new outfall is constructed to the southeast of the existing outfall location. As for the existing outfall, the effluent temperature is not significantly different from seawater temperatures in summer so thermal impacts under Options 1B and 2B are only assessed for winter conditions. Further, concentrations of copper, diazinon and iron in the effluent are diluted to below the EQS by the addition of runoff (see Table 2-3) so the mixing zones for these substances are not need assessed for Options 1B and 2B.

Table 5-2: CORMIX Near Field Modelling Results (Alternative Outfall)

Discharge Option	Tide Condition	Description of Plume	Distance from outfall to reaching EQS		
			Temp (3°C)	Copper & Diazinon	Iron
1A Winter	Low Tide	Plume is deflected horizontally and does not reach water surface	a = 2.0 m b = 1.6 m c = 1.0 m	a = 1 m b = 0.5 m c= 0.8 m	a = 1.4 m b = 0.8 m c= 0.9 m
	High Tide		a = 1.8 m b = 1.5 m c = 0.9 m	a = 0.9 m b = 0.5 m c= 0.8 m	a = 1.3 m b = 0.7 m c= 0.9 m
	Max Current		a = 1.6 m b = 1.3 m	a = 0.9 m b = 0.5 m	a = 1.2 m b = 0.7 m

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			c = 0.9 m	c= 0.7 m	c= 0.8 m
	Min Current		a = 0.12 m b = 5.1 m	a = 0.03 m b = 2.3 m	a = 0.05 m b = 3.0 m
1A Summer	Low Tide	Plume is deflected horizontally and does not reach water surface	a = 1.4 m b = 0.8 m c = 0.9 m	a = 1.0 m b = 0.5 m c= 0.8 m	a = 1.5 m b = 0.8 m c= 0.9 m
	High Tide		a = 1.2 m b = 0.8 m c = 0.8 m	a = 0.8 m b = 0.5 m c= 0.7 m	a = 1.2 m b = 0.7 m c= 0.8 m
	Max Current		a = 1.2 m b = 0.7 m c = 0.7 m	a = 0.8 m b = 0.5 m c= 0.7 m	a = 1.2 m b = 0.7 m c= 0.8 m
	Min Current	Plume rises vertically but does not reach water surface	a = 0.05 m b = 3.0 m	a = 0.03 m b = 2.3 m	a = 0.05 m b = 3.0 m
2A Winter	Low Tide	Plume rises vertically and only spreads laterally at the water surface for scenarios marked *	a = 1.4 m b = 3.8 m*	a = 0.3 m b = 1.8 m	a = 0.6 m b = 2.2 m
	High Tide		a = 1.5 m b = 2.6 m	a = 0.3 m b = 1.6 m	a = 0.5 m b = 1.9 m
	Max Current		a = 1.5 m b = 2.5 m	a = 0.2 m b = 1.5 m	a = 0.6 m b = 1.9 m
	Min Current		a = 0.1 m b = 6.0 m	a = 0.02 m b = 3.3 m	a = 0.04 m b = 4.1 m
2A Summer	Low Tide	Plume rises vertically but does not reach water surface	a = 0.4 m b = 1.7 m	a = 0.3 m b = 1.5 m	a = 0.6 m b = 1.9 m
	High Tide		a = 0.4 m b = 1.7 m	a = 0.3 m b = 1.6 m	a = 0.5 m b = 1.9 m
	Max Current		a = 0.4 m b = 1.7 m	a = 0.3 m b = 1.5 m	a = 0.6 m b = 1.9 m
	Min Current		a = 0.03 m b = 3.6 m	a = 0.02 m b = 3.3 m	a = 0.04 m b = 4.1 m
1B Winter	Low Tide	Plume rises vertically and spreads laterally at the water surface for scenarios marked *	a = 2.8 m b = 3.8 m*		
	High Tide		a = 1.5 m b = 3.1 m		
	Max Current		a = 1.6 m b = 3.7 m		
	Min Current		a = 30 m b = 6.8 m*		
2B Winter	Low Tide	Plume rises vertically but does not reach water surface	a = 0.7 m b = 2.3 m		
	High Tide		a = 0.6 m b = 1.9 m		
	Max Current		a = 0.7 m b = 2.0 m		
	Min Current		a = 0.05 m b = 4.4 m		

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Un-ionised ammonia is diluted to below the EQS immediately on discharge under Option 2A for both summer and winter conditions.

The results in Table 5-2 show that the mixing zone is extremely small for thermal impacts and chemical contaminant concentrations under most scenarios. EQS concentrations for chemical contaminants are always met within a few meters of the outfall and before the plume meets the water surface. A thermal impact is seen at the water surface three specific combinations of tide and discharge conditions, although the extent of the surface spreading zone remains small for all scenarios.

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6. Far Field Modelling Results

6.1 Far Field Model Scenarios

The Delft3D model has been used to carry out far field modelling of DIN mixing at the existing and alternative outfall locations. Far field modelling of thermal effects has not been carried out because the distance from the outfall over which a temperature difference of 3°C is observed is extremely small and contained in the near field only (Section 5). Full details of the far field model setup and representation of the outfalls and ambient conditions are provided in Appendix A – the model was used as set up by ABPmer without editing any of the model parameters or input data except for discharge flow rate and DIN concentration. DIN was modelled as a conservative tracer and the model was run to identify mixing zone concentrations through the water column and laterally within Tees Bay.

The Delft3D model was run for eight scenarios, the four discharge options (as summarised in Table 6-1) at the existing and alternative outfall locations. A continuous flow rate and DIN concentration (calculated as set out in Section 2.2) is assumed in each option. Note that the higher flow rate under Option 1B would not be sustained because this option allows for discharge of surface water runoff following rainfall and the effluent discharge rate would be lower during dry weather. The discharge for each scenario was modelled as a continuous discharge into the relevant model cell at full effluent concentrations – the model does not take account of mixing within the near field because the near field mixing zone is small and does not provide significant dilution of DIN in comparison to the far field dilution.

Table 6-1: Discharge Scenario Input Data for Delft3D Model

Parameter	Option 1A	Option 2A	Option 1B	Option 2B
Flow Rate (m^3/s)	0.04	0.07	0.41	0.07
Temperature (°C)	27	23	15	15
DIN (µmol/l)	890	989	75	162

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6.2 Far Field Model Results

The mixing zone extents predicted by the model for each outfall are discussed and mapped below. The figures show the maximum concentration found within each grid cell from the analysis of hourly data over the 14-day simulation period. Results are presented for three vertical layers within the water column: a surface layer (2% of the water column depth), a mid-layer (layer thickness of 10% of the water depth) and a lower layer (35% of the water depth measured from the sea bottom). The edge of the mixing zone is taken as the contour where DIN concentrations meet the High Status WFD EQS for DIN in coastal waters (Section 2.1). Since ambient DIN concentrations are at 11.6 µmol/l and the EQS is 12 µmol/l, the edge of the mixing zone is found where excess DIN concentrations fall below 0.4 µmol/l.

The model outputs represent a worst case scenario because the model does not currently take account of wave action. This is likely to be particularly important for mixing at the alternative outfall which is within the wave breaking zone and close to Coatham Rocks, a rocky outcrop extending into Tees Bay which is under water at high tide but will promote wave breaking and vertical mixing. If the final design for the PCC site includes use of the alternative outfall, then it is recommended that the Delft3D model is revised to include wave action to more appropriately represent mixing at this location as part of a Final Design Stage water quality assessment. The omission of wave action in this Intermediate Design Stage report allows for worst case scenario impact prediction for both outfalls based on the currently available information.

6.2.1 Existing outfall

The DIN mixing zone under Option 1A for the existing outfall only affects the lower 35% of the water column and modelled concentrations are above the EQS in area shown in Figure 6-1. The mixing zone is small in comparison to the overall size of Tees Bay and the DIN is rapidly diluted such that DIN concentrations are below the EQS in the mid and surface layers in the model.

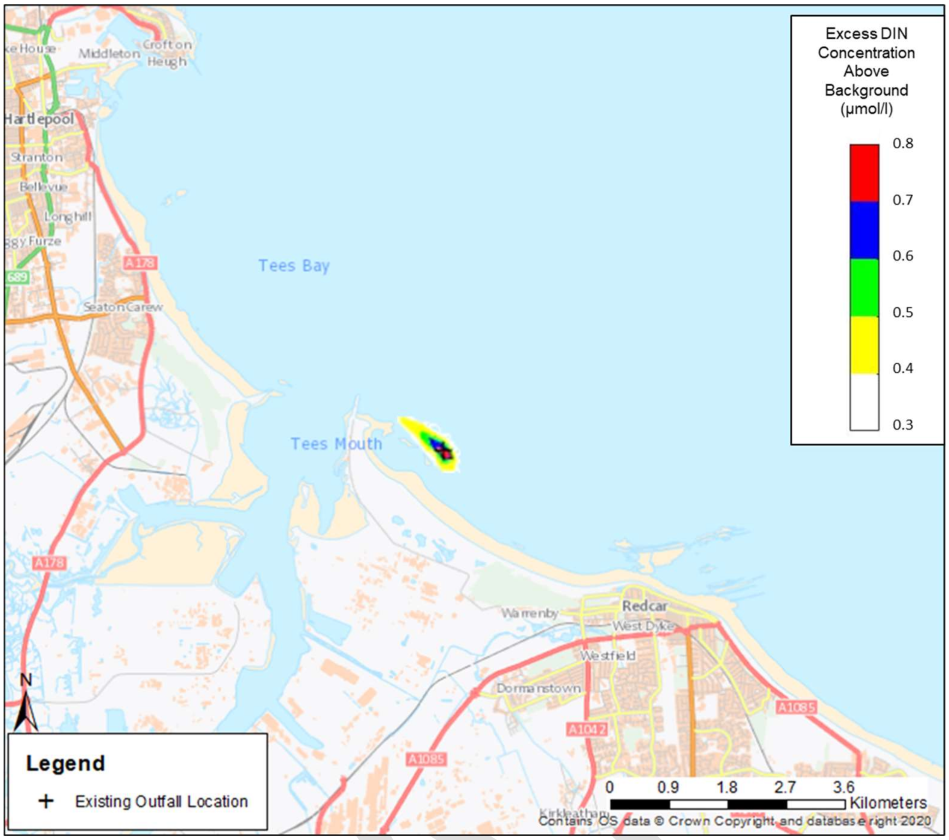

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Figure 6-1: DIN Mixing Zone: Existing Outfall Option 1A, Lower 35% of Water Column

Discharge rates and effluent DIN concentrations are higher under Option 2A, resulting in a mixing zone which can extend through the water column. The extent of the mixing zone in the lower section of the water column and at the surface are compared in Figures 6-2 and 6-3, the mixing zone is small at the water surface and does not extend into the River Tees at any water depth. A mixing zone of this size is not considered to be detrimental to the water quality of Tees Bay as a whole because it is unlikely to change the WFD status classification of the wider Tees Bay waterbody.

Mixing zone maps are not provided for Options 1B and 2B because dilution of DIN within the far field occurs extremely rapidly such that the EQS concentration is reached over an extremely small area. The effluent is diluted to an excess concentration of less than 0.4 µmol within the space of one model cell – these cells are 79 m x 168 m at the existing outfall. The model shows that the EQS standard is met within an area of 0.013 km^2 within the 35% of the lower water column.

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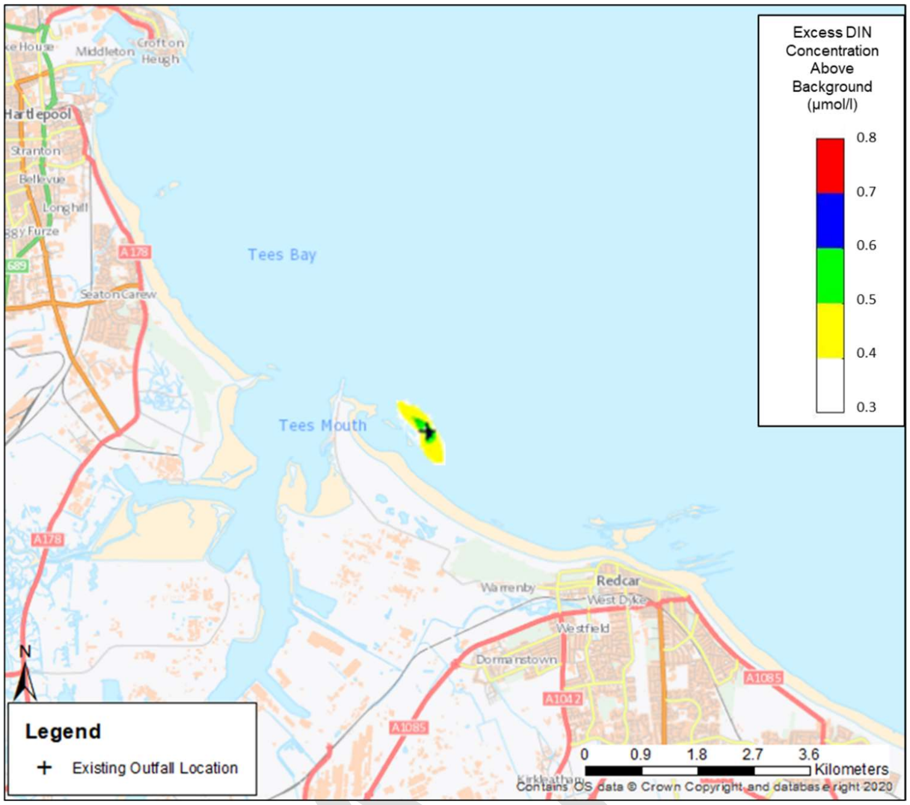

Figure 6-2: DIN Mixing Zone: Existing Outfall Option 2A, Upper 2% of Water Column

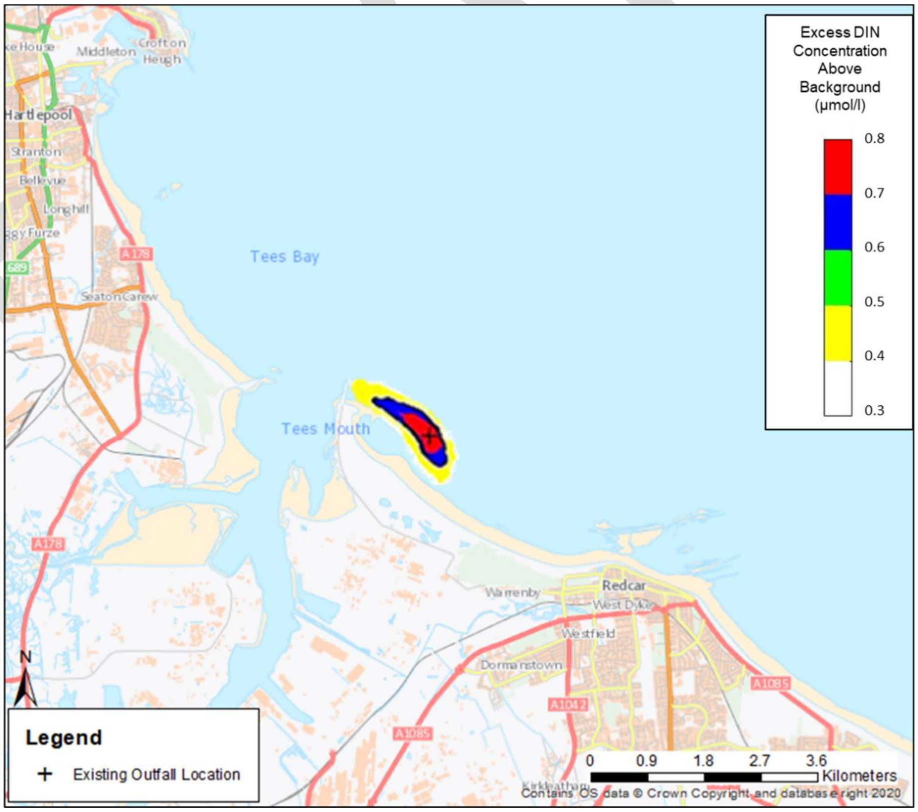

Figure 6-3: DIN Mixing Zone: Existing Outfall Option 2A, Lower 35% of Water Column

6.2.2 Alternative outfall

The DIN mixing zone under Option 1A for the alternative outfall location is shown for the lower, mid and upper water column layers in Figures 6-4 to 6-6. The mixing zone is relatively small, although it does reach the low tide shoreline. The mixing zone extent is similar in both the mid and surface water column layers.

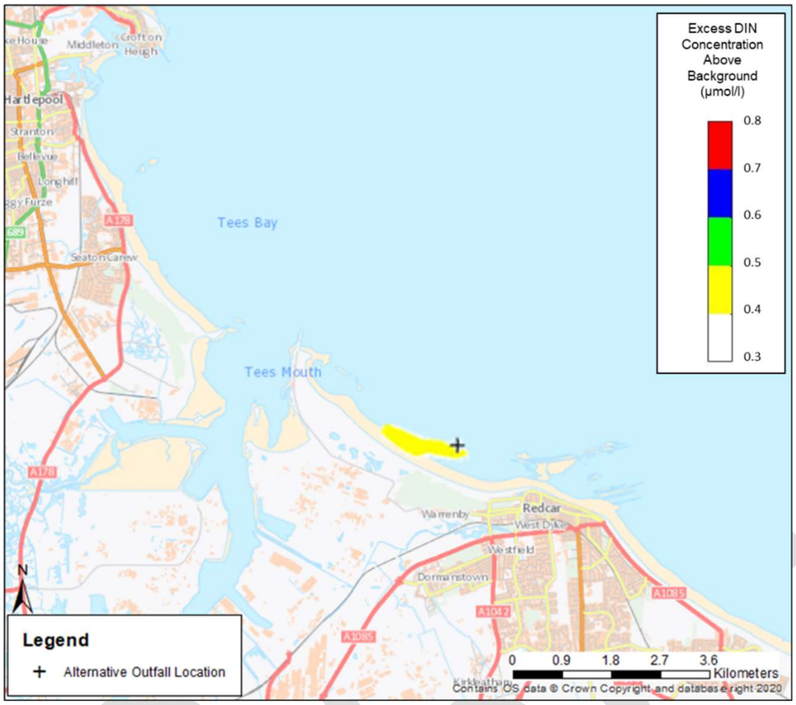

Figure 6-4: DIN Mixing Zone: Alternative Outfall Option 1A, Upper 2% of Water Column

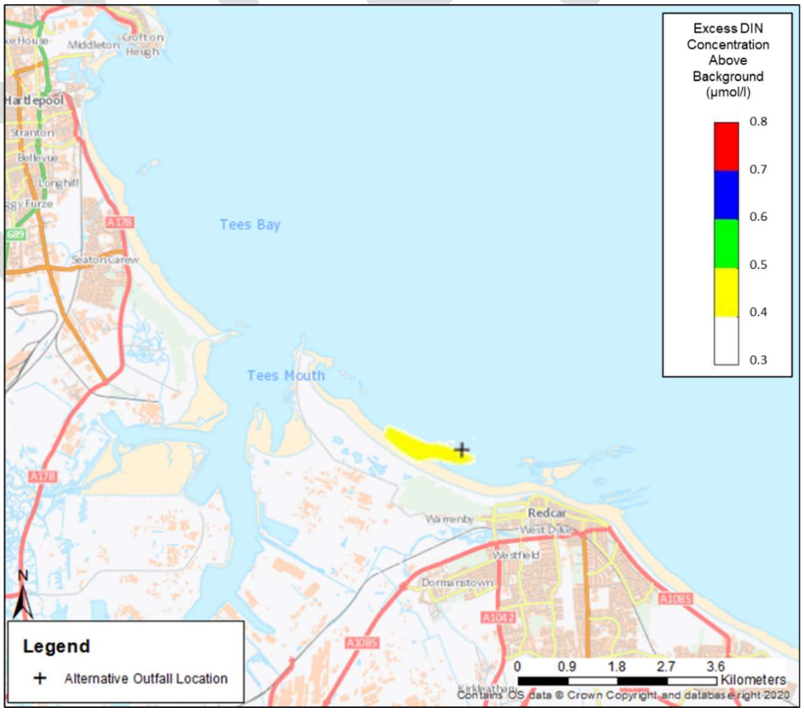

Figure 6-5: DIN Mixing Zone: Alternative Outfall Option 1A, Mid 10% of Water Column

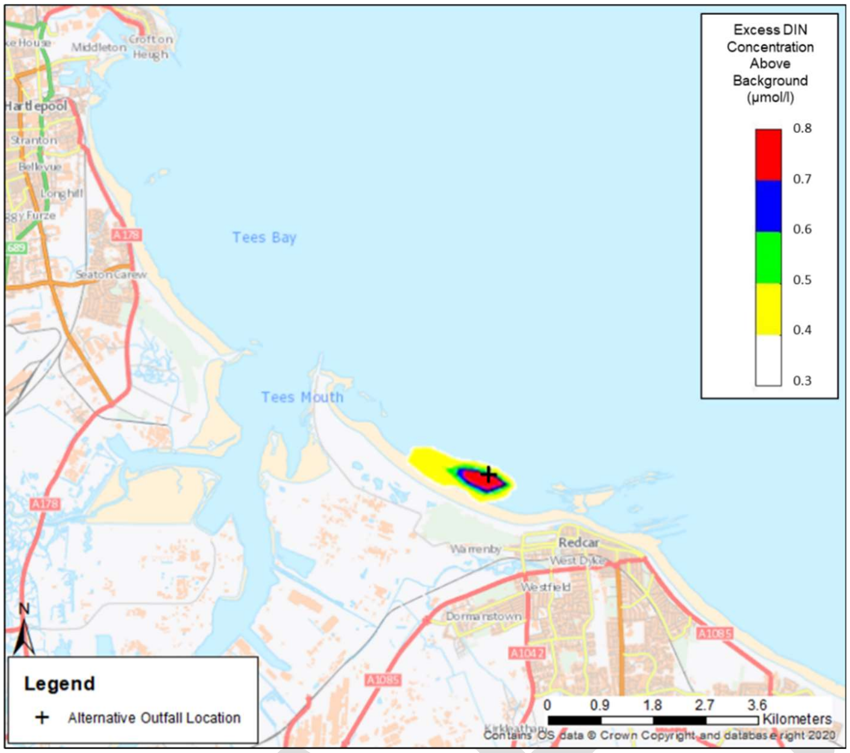

Figure 6-6: DIN Mixing Zone: Alternative Outfall Option 1A, Lower 35% of Water Column

The alternative outfall mixing zone under Option 2B is much larger and reaches the high tide shoreline as well as intersecting with Coatham Rocks (Figures 6-8 to 6-10). Given that wave action will significantly increase mixing along the shoreline and at Coatham Rocks, this mixing zone extent should be considered a worst case scenario.

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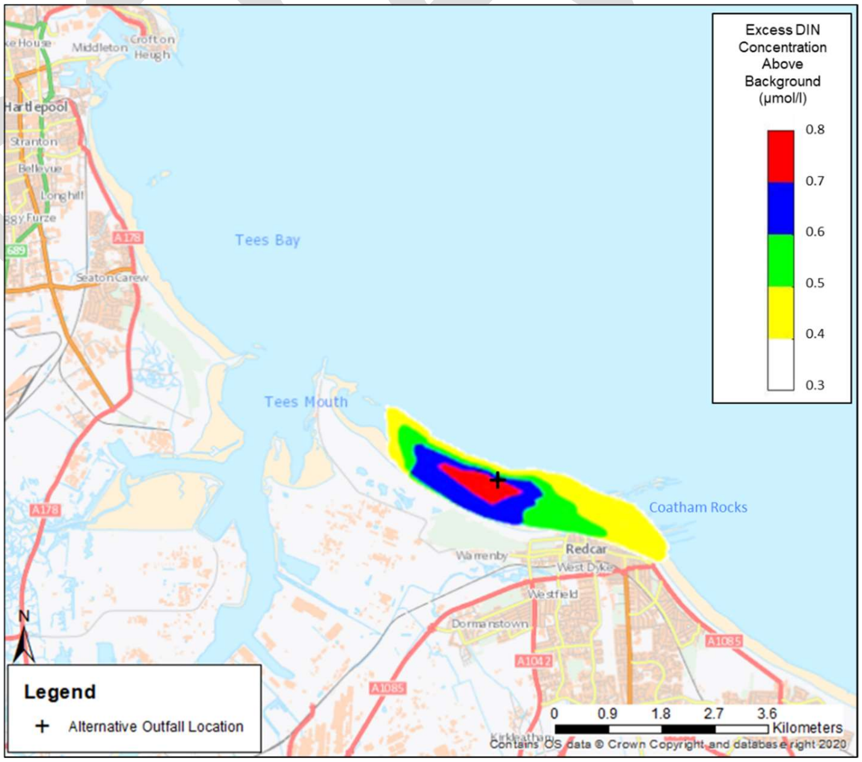

Figure 6-7: DIN Mixing Zone: Alternative Outfall Option 2A, Surface 2% of Water Column

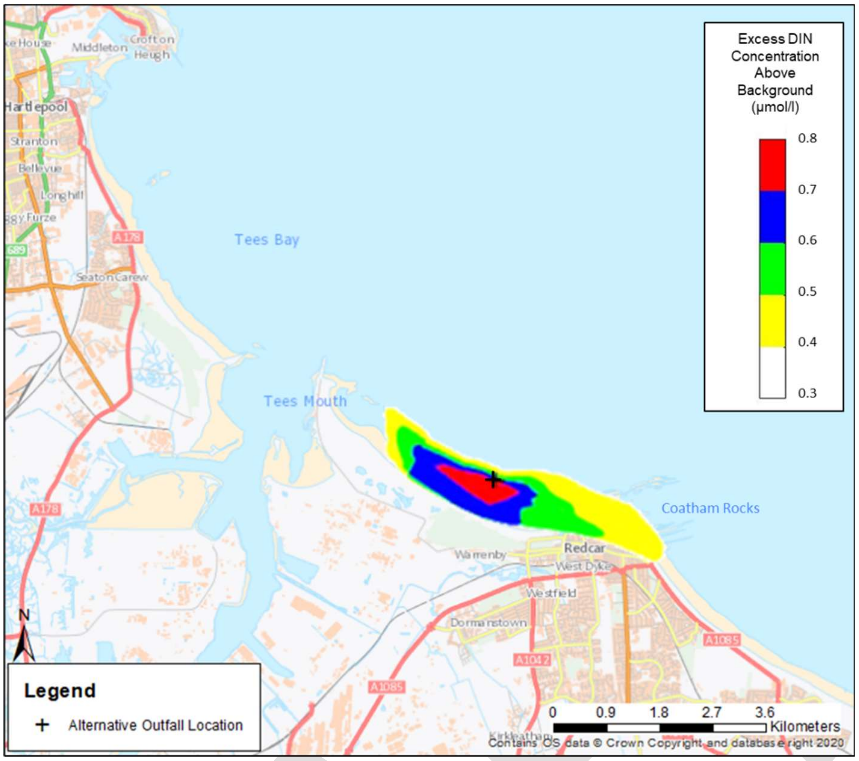

Figure 6-8: DIN Mixing Zone: Alternative Outfall Option 2A, Mid 10% of Water Column

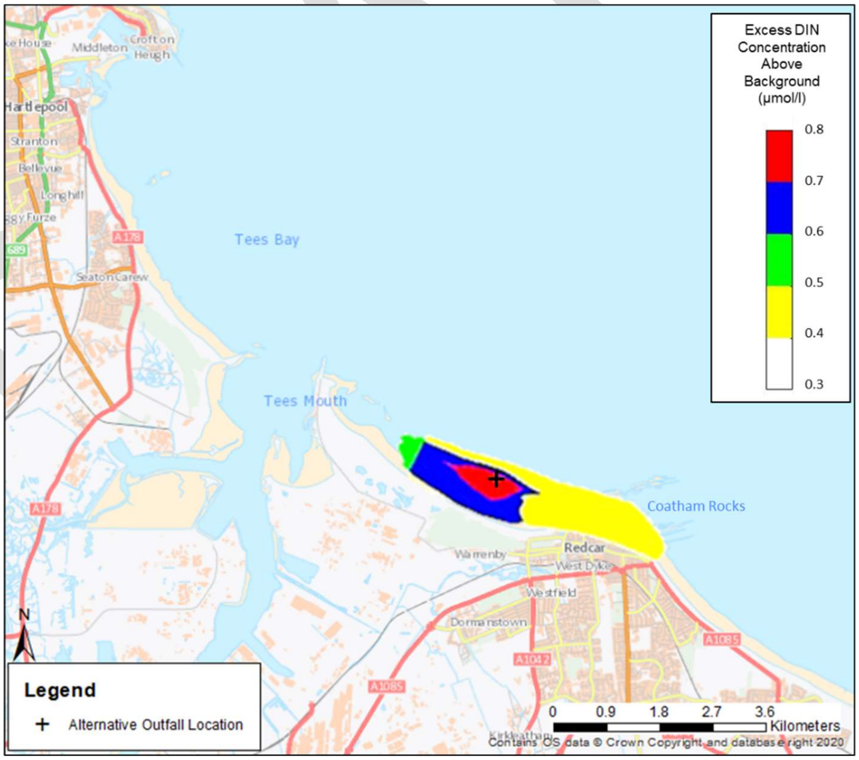

Figure 6-9: DIN Mixing Zone: Alternative Outfall Option 2A, Lower 35% of Water Column

As with the existing outfall, far field mixing zone maps are not provided for Options 1B and 2B for the alternative outfall because dilution of DIN within the far field occurs extremely rapidly such that the EQS concentration is reached over an extremely small area. The effluent is diluted to an excess concentration of less than 0.4 µmol within the space of one model cell – these cells are 108 m x 370 m

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at the alternative outfall. The model shows that the EQS standard is met within an area of 0.04 km^2 within the 35% of the lower water column.

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7. Summary and Conclusions

Near field and far field water quality modelling has been carried out to support the design of the PCC site in respect of surface water and process effluent management. This Intermediate Design Stage report utilises information available at the time of publication and draws on hydrodynamic water quality modelling carried out at the Initial Design Stage. There is now significant additional information available concerning the future design and operation of the PCC site which enables more refined estimates of future discharge rates, locations, pollutant loads and effluent discharge temperature compared to the previous assessment. However, there are different options for the final design and some aspects such as outfall details, pipe sizes and surface water drainage rates are still to be finalised. It is therefore envisaged that the water quality assessment will be revisited in future to check the likely water quality impacts of effluent discharges at the Final Design Stage. This Intermediate Design Stage report seeks to assess the likelihood of significant adverse impacts on the water environment arising from future discharges of wastewater from the PCC Site to Tees Bay.

This report does not at present contain an assessment of cumulative impacts from other discharges of DIN into Tees Bay. The report will be updated once data on such discharges is provided by the Environment Agency.

The discharged effluent at the PCC site will be comprised of blowdown water from a gas fired power station, condensed water from a carbon capture facility and surface water runoff. The blowdown water will be initially sourced from the River Tees and will contain river water contaminants which will be concentrated by up to 5 times as a result of its use as blowdown water. The condensed water is a much smaller stream but can contain up to 5 mg/l of ammonia and there is an option to use this as a source of blowdown water. The surface water runoff will be routed through oil interceptors to remove contamination prior to combining the runoff with the blowdown water and condensed water and discharging the combined streams to Tees Bay.

Water quality data for the River Tees has been provided by Northumbrian Water and combined with information on potential future water use and pollutant loads in the condensed water to produce four discharge scenarios for this Intermediate Design Stage Assessment (for the existing and an alternative outfall location):

- **Option 1A** - no re-use of wastewater from any process as Blowdown Water, no surface water runoff present in the discharged effluent. Effluent pollutant concentrations are taken from the River Tees Water data multiplied by 5, with an additional ammonia component then added to represent the Condensed Water. The effluent discharge temperature is taken as 27°C.

- **Option 2A** - Re-use of Condensed Water as Blowdown water, no surface water runoff present in the discharged effluent. Effluent pollutant concentrations are taken from the River Tees water with an additional ammonia component added before the total concentrations of all pollutants are multiplied by 5. The effluent discharge temperature is taken as 23°C.

- **Option 1B** – Option 1 effluent concentrations are diluted by average annual surface water runoff volumes prior to discharge. The effluent discharge temperature is taken as 15°C.

- **Option 2B** - Option 2 effluent concentrations are diluted by average annual surface water runoff volumes prior to discharge. The effluent discharge temperature is taken as 15°C. Note that this design philosophy contains more measures to store and manage water flows on site and to allow for water re-use. This includes using a single controlled discharge rate based on pumping of process flows only. The addition of surface water runoff will dilute and cool the effluent but will not increase the effluent discharge flow rate.

Pollutant concentrations within the effluent under each of the options listed above have been compared with EQS standards for Tees Bay under the WFD. An assessment of compliance with WFD standards

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for hydrocarbons could not be carried out due to lack of hydrocarbon concentration information for the River Tees Water. The available information does show that concentrations of iron, copper, diazinon, un-ionised ammonia and DIN in the effluent may exceed EQS concentrations under some discharge options. Concentrations of chromium (VI) may also be present in the effluent above the EQS, although ambient monitoring data show that concentrations would be at or below chromium (VI) concentrations in the North Sea at Tees Mouth, therefore further assessment of this parameter is not required. The effluent from the PCC site may also be discharged at temperatures exceeding ambient temperatures in Tees Bay, especially when surface water runoff is not mixed with the process effluent. On the basis of the available information, the near field mixing zone modelling has been carried out to assess the water quality impacts for iron, copper, diazinon, un-ionised ammonia and temperature using the flow rates and effluent temperatures and pollutant loads summarised in Table 7-1. Concentrations of DIN in the effluent are too high to be sufficiently diluted within the near field and DIN mixing has therefore been assessed using the far field model only.

Table 7-1: Flows and Pollutant Loads for Modelled Discharge Scenarios

Parameter	Option 1A	Option 2A	Option 1B	Option 2B
Flow Rate (m^3/s)	0.04	0.07	0.41	0.07
Temperature (°C)	27	23	15	15
DIN (µmol/l)	890	989	75	162
Un-ionised Ammonia (µg/l)	2	27	0.2	5.8
Copper (mg/l)	8.0	8.0	0.7	1.1
Iron (mg/l)	3.0	3.0	0.3	0.3
Diazinon (µg/l)	0.015	0.015	0.001	0.002

The near field modelling has been carried out for summer and winter conditions at four stages across the tidal cycle – low tide, high tide, maximum current velocity and minimum current velocity. Water level and current data at each stage in the tidal cycle have been extracted from a Delft3D hydrodynamic model of Tees Bay and the River Tees constructed and calibrated in 2019 and included as Appendix A of this report. Two potential outfall locations have been considered, one requiring re-use of an existing outfall and one requiring construction of an outfall at an alternative location to the southeast. Pipe dimensions and outfall configurations are still to be confirmed and have therefore been assumed based on the effluent flow rates for each option.

The near field modelling shows that the impacts of the discharge is small for all four assessed discharge Options at all stages of the tidal cycle. The chemical contaminants (excluding DIN) are diluted to below the EQS within a very short distance of the outfall and before the mixing plume reaches the water surface. Thermal effects are also extremely small, with the temperature of the mixing plume falling below 3°C above ambient condition within a very short distance and usually before the plume reaches the water surface. Surface temperatures are not increased by more than 3°C over a significant area for any combination of effluent discharge option and tidal stage at either outfall location.

The far field modelling for DIN shows that, if the existing outfall continues to be used, DIN emissions at the predicted effluent concentrations are not sufficient to cause major impacts on Tees Bay water quality and no impacts on water quality in the Tees Estuary. The mixing zone is larger if the alternative outfall location is used due to the shallower water depths in this area, especially under Option 2A, although the mixing zones predicted in this report should be considered as a worst case scenario because the far field model does not currently take account of wave action which will be important at the alternative outfall location. If the final design for the PCC site includes use of the alternative outfall location, then additional far field water quality modelling should be carried out which includes representation of wave action effects on mixing as well as the final proposed effluent discharge rates and pollutant concentrations. If this Final Design Stage report confirms that large mixing zone extents are possible within Tees Bay, then a limit on DIN concentrations in the final effluent may be required to protect

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receiving water quality. Based on the smaller mixing zones observed under Option 1A, restricting DIN effluent DIN concentrations to 890 µmol/l would result in a mixing zone of acceptable size.

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Appendix A Initial Design Stage Report

Presented as a seperate attachement

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Appendix B Existing Outfall Schematic

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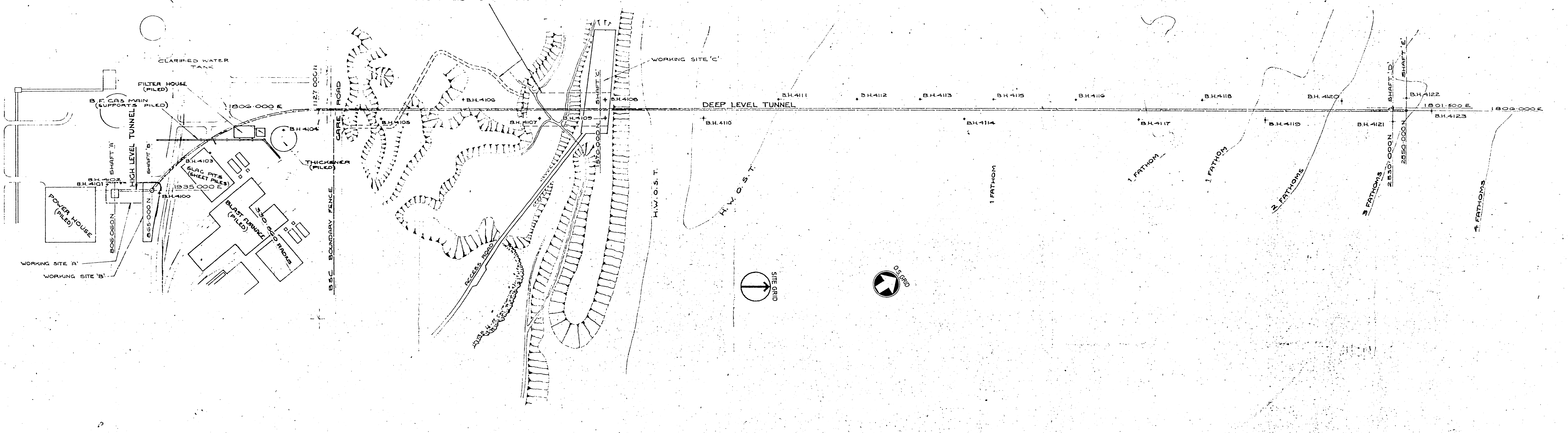

SCALE 1:2500

* HIGH LEVEL TUNNEL

BOREHOLE Nº.	LOG AVAILABLE	DATE AVAILABLE
4100		FEB. 75
4101	✓	JAN. 75
4102		FEB. 75
4103		"
4104		"
4105		"
4106		"
4107		"
4108	✓	JAN. 75
4109	✓	FEB. 75
4110		"
4111		"
4112		"
4113		APR.-MAY 75
4114		"
4115		"
4116		"
4117		"
4118		"
4119		"
4120		"
4121		"
4122		"
4123		"

SCALE 1:2500 HORIZONTAL
1:500 VERTICAL

NOTES

1. ALL LEVELS ARE IN METRES TO A TUNNEL DATUM 100m BELOW O.D. (NEWLYN)
2. ALL COORDINATES ARE IN METRES AND RELATE TO SITE GRID
3. FATHOM DATUM IS L.W.O.S.T. (98·0 ABOVE TUNNEL DATUM)
4. THE BOREHOLE POSITIONS MARKED ON THIS DRG ARE APPROXIMATE

FILE COPY

-5 MAR 1975

COST CODE Nº. 74. 51. 00.

suffix	REVISIONS	by	date	checked	suffix	REVISIONS	by	date	checked

DRAWING REFERENCES	
3420/74/MHA/4051	SITE ACCESS PLAN
3420/74/MHA/4053	LAYOUT OF WORKING SITE 'C'
3420/74/MHA/4054	LAYOUT OF WORKING SITES 'A'&'B'
3420/74/MHA/4055	GENERAL ARRANGEMENT SHAFT 'A'
3420/74/MHA/4056	GENERAL ARRANGEMENT SHAFT 'B'
3420/74/MHA/4057	GENERAL ARRANGEMENT SHAFT 'C'
3420/74/MHA/4058	GENERAL ARRANGEMENT SHAFTS D&E

ISSUED ONLY FOR	date	passed
PRELIMINARY		
TENDER	14/2/75	
APPROVAL	19/2/75	

drawn	JSF	January '75
checked	D. Stephens	Feb. '75
passed	T. W. Holme	Feb 5 '75

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CIVIL ENGINEERING WORKS — CONTRACT 'G'

W S Atkins & Partners in association with
Mott Hay & Anderson

British Steel Corporation
PLANNING & CAPITAL DEVELOPMENTS DIVISION
REDCAR DEVELOPMENTS

WORKS: REDCAR	PLANT: STAGE 2 PHASE B
SECTION OF PLANT: BLOWING & GENERATING STATION	
SUB SECTION: COOLING WATER OUTFALL	
DETAIL: PLAN AND LONGITUDINAL SECTION	
INDEX CODE: RBF/G/PH/1/1	B S C DRAWING No: RPS 111
Scale: AS NOTED	Drawing No.: 3420/74/MHA/4052

Net Zero Teesside – Environmental Statement

Planning Inspectorate Reference: EN010103

Volume III – Appendices

Appendix 14E: Coastal Modelling Report

The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (as amended)

Prepared by: AECOM

AECOM

Net Zero Teesside Project

Coastal Modelling – Final Integrated Report

April 2021

Innovative Thinking - Sustainable Solutions

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Net Zero Teesside Project

Coastal Modelling – Final Integrated Report

April 2021

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Prepared (PM)	Approved (QM)	Authorised (PD)
Helen Godwin	Adam Fulford	Gordon Osborn
[redacted]	[redacted]	[redacted]

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Contributing Authors

Catherine Merrix, Tom Finch

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ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
T: [redacted] [redacted]

Executive Summary

Numerical modelling has been undertaken to investigate the extent of thermal discharge resulting from an outfall from a new Carbon Capture, Utilisation and Storage (CCUS) project in the Tees Estuary.

Two potential scenarios for the discharge of treated effluent from the Proposed Development have been considered. The first option is for the re-use of the existing outfall with minor refurbishment; for the remainder of the report, this will be referred to as 'Outfall 1'. The second option is for a replacement outfall along the same corridor as the CO2 Export Route; for the remainder of the report, this is referred to as 'Outfall 2'. Under no circumstance will both Outfall 1 and Outfall 2 be progressed, however for completeness, both have been assessed as part of this report.

Results of near-field thermal plume modelling undertaken using the CORMIX modelling software show that, for Outfall 1 under spring conditions, the likely extent of a thermal plume (with a 15°C excess temperature at source) would be very localised: a 3°C temperature excess only extends approximately 45 m from the discharge point on the flood and 98 m on the ebb; for a 2°C temperature excess, the ebb extent of the plume increases to 140 m. Considering a further reduced excess temperature shows that a 0.1°C temperature excess is estimated to extend around 750 m from the origin on a spring flood tide, and 720 m on an ebb. In all cases tested, the mixing and plume dispersion appear to occur very rapidly from the origin with very little detectable change (>0.1°C) beyond ~800 m of the outfall location.

At Outfall 2, as a result of lower energy conditions leading to lower/slower rates of dissipation of the outfall plume, the neap tidal phases offer a larger plume, with the 2°C contour extending 600 m and 400 m from the outfall on the flood and ebb respectively, compared to the spring tide which extends 170 m and 270 m on the flood and ebb tide respectively, under normal discharge conditions.

Far field plume dispersion modelling using the Delft3D model shows a small impact of outfall discharge on the ambient water temperature. Depth averaged temperature differences of >0.02°C are detected up to ~9 km from the Outfall 2 site, however greater temperature excesses of up to 0.3°C are localised to within 1.5 km of the outfall in all simulations modelled.

This report has been developed with regular involvement from the Environment Agency, with meetings in March 2020 to discuss the thermal modelling approach and scope, and further meetings to discuss feedback from the initial modelling carried out for the project in January 2021. At the January meeting it was decided that far-field modelling is also required and therefore subsequently included in this re-issued report. The MMO has also been regularly informed at each stage of the project from September 2019 to February 2021.

Contents

Appendices

Tables

Figures

1 Introduction

AECOM Ltd. have commissioned ABPmer to undertake hydrodynamic and thermal plume modelling of the Tees Estuary and surrounding region. Numerical modelling is required to provide a description of baseline conditions and investigate potential marine environmental impacts associated with the construction and operation of a new Carbon Capture, Utilisation and Storage (CCUS) project located on the south bank of the Tees Estuary (Figure 1). This report is an update to the ABPmer (2020) report to include Outfall 2.

The purpose of the numerical modelling is to assess the near-field and far-field impact of thermal discharge at the location of Outfall 1 and Outfall 2. Locations are shown in Figure 1 below and Figure 2 on the following page.

Source: AECOM, 26/03/21

Figure 1. Development site boundary around the outfall locations: Outfall 1 (west) and Outfall 2 (east)

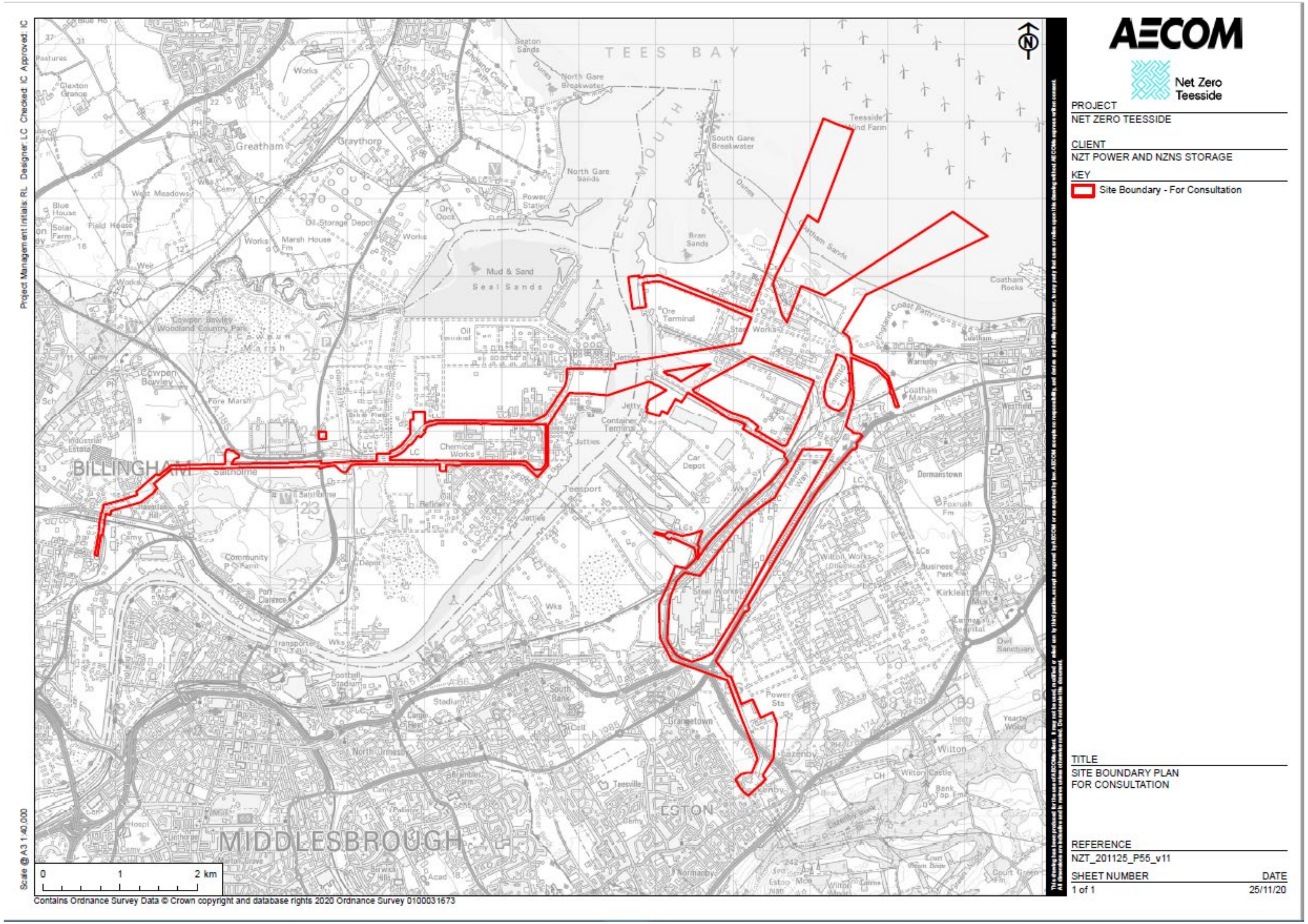


Figure 2. Net Zero Teesside – Site Boundary for Consultation

The site boundary outlining the outfall locations is shown in the previous figures. The positions of both outfall options are defined more accurately in Section 2 (Outfall 1) and Section 3 (Outfall 2)

Two stages of modelling have been undertaken for this phase of the work, which comprise the following:

- Near-field thermal plume modelling at two different outfall locations; and
- Far-field 3D thermal plume modelling.

1.1 Near-field thermal plume modelling

The first stage of the work uses the baseline outfall conditions established from the hydrodynamic model to construct thermal plume simulations using the MixZon Inc. CORMIX modelling software. Sensitivity to a range of environmental variables has been considered in order to better assess and quantify the possible extent of a plume from both outfall locations with particular thermal properties.

1.2 Far-field thermal plume modelling

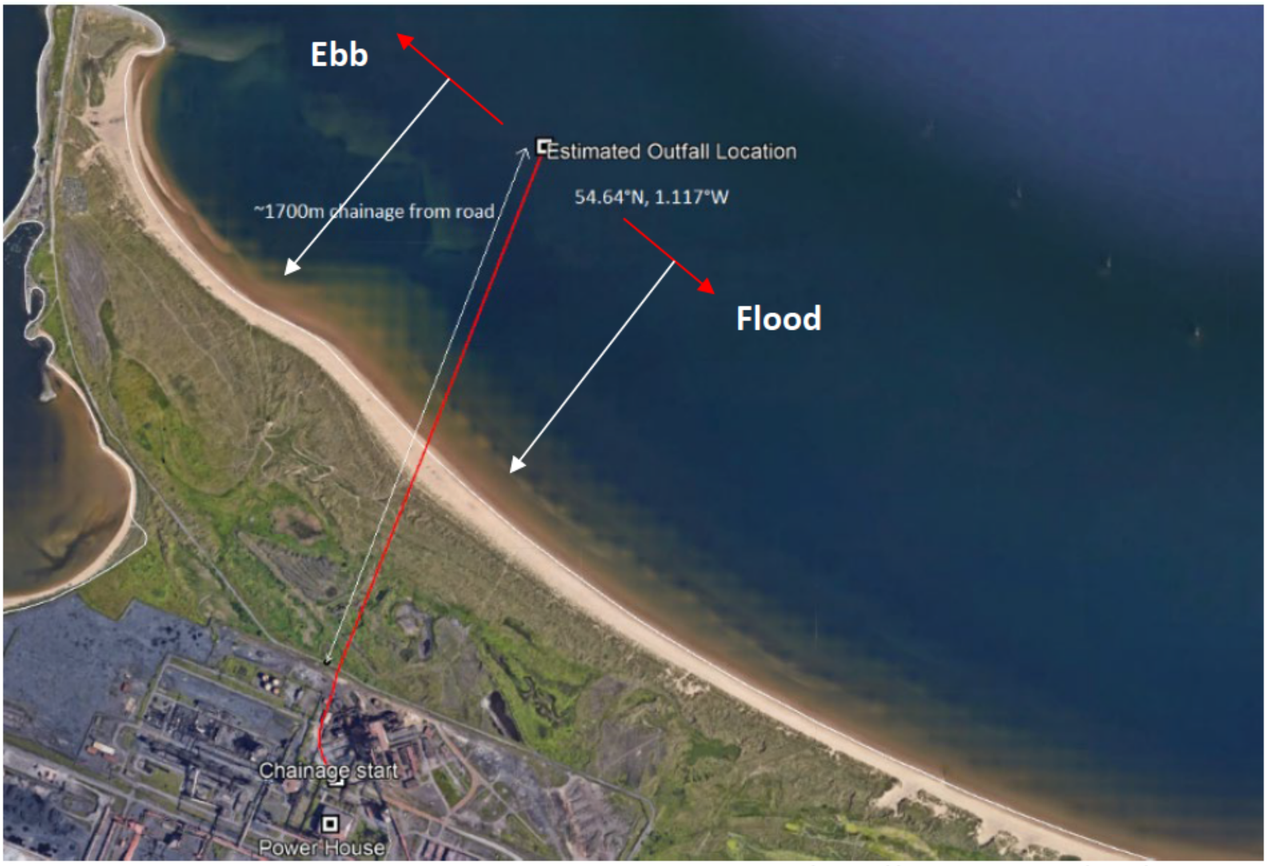
The second stage of work makes use of a Delft3D hydrodynamic model constructed to establish the flow conditions within the Tees estuary and offshore. The model extends approximately 10 km offshore and 30 km along the Hartlepool, Redcar and Cleveland coastline. This model has been updated to include temperature in the physical properties being modelled and to simulate a discharge with fixed thermal and saline properties at the outfall locations.

This report details the numerical modelling set up, calibration, and model results in the following report sections:

Section 2:	CORMIX Modelling – Outfall 1: Provides details of the thermal plume model setup and presentation of results.
Section 3:	CORMIX Modelling – Outfall 2: Provides details of the updated thermal plume modelling and presentation of results.
Section 4:	Far-field modelling provides details of the Delft3D model setup, scenarios run and results of the modelling
Appendix A:	Delft Model Setup
Appendix B:	Delft 3D Model Calibration
Appendix C:	CORMIX Extreme Discharge Modelling

2 CORMIX Modelling

The CCUS project uses a hybrid cooling system which results in a thermally uplifted effluent being discharged from the generating station through the planned outfall location (Figure 3). An investigation of 'near-field' mixing processes is required to establish the scale of the mixing zone for the thermal discharge. Thermal plume modelling for this study has been undertaken using the CORMIX modelling software. The methods and results from this thermal plume modelling are presented in the following report sections.



Background image source: Google Earth 2020

Figure 3. Location of Outfall 1

The CORMIX modelling software, produced by MixZon Inc., has been designed for the prediction and analysis of aqueous toxic or conventional pollutant discharges into diverse water bodies, with the latter being addressed in this study. The user-interface requires singular values to represent specific controlling parameters of geometries (e.g. discharge port) and water body characteristics (e.g. densities). The model uses these parameters to create the predicted plume, which is represented as an instantaneous snap-shot in time of the dispersion and dilution of the two specified water bodies.

CORMIX modelling, assessing the near-field impact of the of thermal plume, has been undertaken in two stages during this project. This first section considers a selection of discharge scenarios and sensitivity tests that were undertaken based upon an initial outfall location provided by AECOM (Outfall 1. Location detailed in Section 2.1). Results from these assessments are documented in Section 2.3.

2.1 Outfall location

An initial planned location of a thermal outfall has been provided to ABPmer via a technical drawing specifying chainage values from fixed onshore landmarks. The orientation of the planned outfall pipe has been estimated by determining the existing outfall orientation to shore from Admiralty Charts and measuring the appropriate distance from shore along the same bearing. Using this approach, the estimated location for the outfall is: 54.64°N, 1.117°W. The water depth in the model at this location is 7.75 m (ODN). Hydrodynamic conditions for this location have been extracted from the Delft3D model, for depth averaged conditions at the time of a mean spring and mean neap range to input into the CORMIX thermal plume modelling, as described in the following sections.

2.2 Model set-up

The CORMIX model set-up is composed of 3 main areas or tabs that require the input of specific parameters to represent geometries and aqueous characteristics within the model. The three tabs are individually outlined below, with the used input parameters stated. All parameters were chosen in consultation with AECOM and are representative of real world conditions.

2.2.1 Effluent

The software allows specification of the key characterises of the effluent water body that will be discharged from the outfall into the marine environment. Consideration is given to the type of effluent i.e. non/ conservative in which growth and decay rates can be applied. Additionally; heated, saline and sediment discharges can be simulated.

For this study, the effluent was characterised as a heated, conservative (no growth/ decay processes) effluent, which required the following input parameters:

- Temperature Excess: 15°C;
- Flow rate: 1.37 m^3/s; and
- Density: 1,018/ 1,020 kg/m^3 (summer/ winter representations).

It should be noted that the raw water intake is no longer required as the supply will be provided via a separate private supply, and therefore the higher densities modelled in this study represent a worst-case scenario.

2.2.2 Ambient

To represent the ambient ocean conditions that the outfall will disperse into, hydrodynamic conditions at the proposed outfall location (457108.31 E, 527562.69 N (OSGB)) were extracted from an existing Delft3D hydrodynamic model (See Appendix A and B) and analysed to determine key tidal characteristics; water levels (WL), current speed (CurSpd) and current direction (CurDir).

Following a series of sensitivity testing under mean spring and neap conditions, a mean spring tidal range (approximately 4.6 m) was isolated from the spring-neap cycle of the model output since a worse-case (spring tide) scenario will represent the greatest tidal excursion from the origin. Within this mean spring tide, the WL and CurDir that coincided with the peak CurSpd, for both the flood and ebb phases were obtained. Figure 4 highlights the tidal signal and its key characteristics, which have been isolated to represent the mean spring tide, with the value tabulated in Table 1. Additionally, seasonal wind speeds (m/s) were extracted from the analysis of Durham Tees Valley Airport measured data described in Appendix A.3.5 Wind speeds of 4.08 and 5.32 m/s were selected to represent summer and winter, respectively.

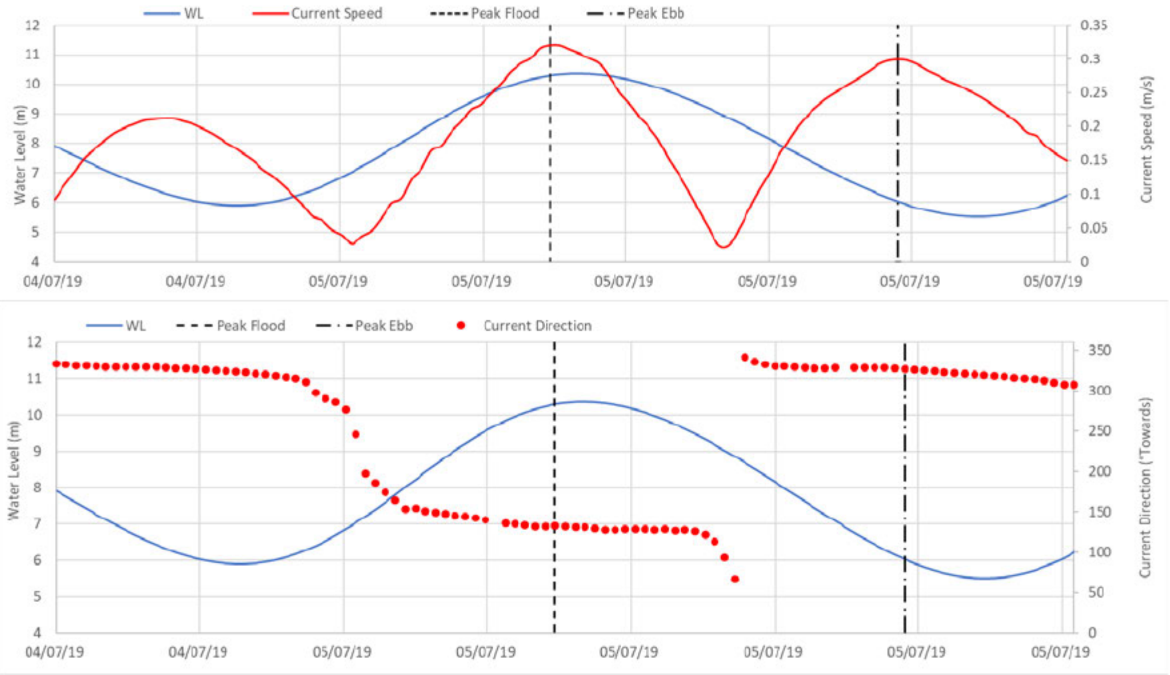


Figure 4. Tidal characteristics during a mean spring tide

Table 1. Tidal characteristics for a mean spring tide.

Tidal Characteristic	Peak Flood	Peak Ebb
Water Level (m)	10.3	6.0
Current Speed (m/s)	0.32	0.30
Current Direction (°N)	132	327

To conclude this tab, the ambient density of the receiving water (1,026 kg/m^3) and bed roughness (default of 0.04) parameters were also applied. Furthermore, the enabling of the model environment to be classified as 'Unbounded' is possible, which indicates that there is only one 'bank' in the model (consistent with outfalls into the open sea). This is opposed to a riverine environment, which would be classed as 'Bounded', in which the distance between banks would be required.

2.2.3 Discharge

For this study, the discharge has been represented as standard 'simple port' that is 860 m from the nearest bank, with a 90° (vertical) projection. The Current Direction (CurDir) is considered by determining the direction of the nearest bank – right or left, based on flood or ebb flow direction. The software assumes the user is looking downstream of the flow to determine this. By using the flood and ebb CurDir (132° and 327° as in Table 1), under ebb conditions the nearest bank is defined on the left and on the right under flood phases.

The specific port geometries are also specified within this tab which include:

- Port diameter: 0.8 m; and
- Port height above bed: 1 m.

2.3 CORMIX Outfall 1 results

Following a range of sensitivity tests under mean spring and neap conditions, it was concluded that the spring tidal range under summer conditions offered the largest plume extent, which included the following seasonal parameters;

- Effluent density of 1,018 kg/m^3; and
- A mean wind speed of 4.08 m/s.

This model setup has been used as a 'baseline' scenario to use as a comparison for a range of sensitivity tests. The tests completed to reach this conclusion are outlined below. A summary of the sensitivity tests presented in this report section are provided in Table 2.

Table 2. CORMIX Run Summary

Run no	Description
01	Spring flood tide (summer season) baseline case, this includes: ▪ Seasonal wind speeds ▪ 0.8 m pipe diameter ▪ Pipe orientation vertical
02	Spring flood tide (winter season)
03	Spring flood tide (summer season) no winds applied
04	Spring flood tide (winter season) no winds applied
05	Spring flood tide (summer season) 0.6 m pipe diameter
06	Spring flood tide (summer season) 1 m pipe diameter
10	Spring ebb tide (summer season)
16	Spring flood tide (summer season) 15 m/s wind speed
17	Spring flood tide (summer season) horizontal pipe orientation, directed offshore

2.3.1 Spring flood - Seasonal variation

Shown in Figure 5 is the spring flood tide, demonstrating the seasonal variation (summer/ winter). The winter variation is distinguished by applying different wind speeds (4.08 and 5.23 m/s) and effluent densities (1,018 and 1,020 kg/m^3) in separate runs. The seasonal variation is negligible with the summer plume extending very slightly further than the winter, highlighted at around 150 m and the red (summer) 2 and 3°C flags extending slightly further from the origin than the blue (winter).

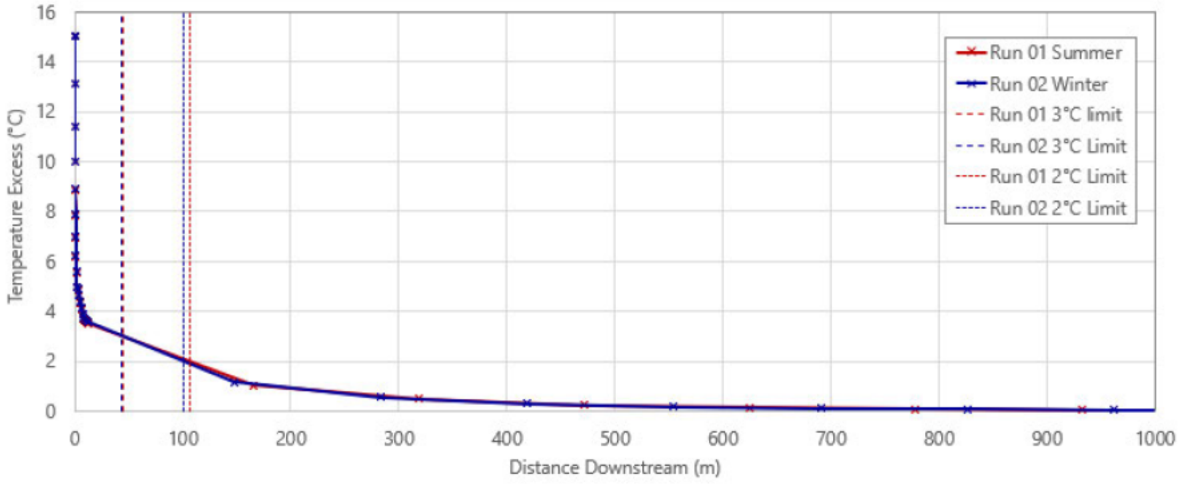


Figure 5. Spring flood seasonal variation

2.3.2 Summer season – Tidal variation

In Figure 6 the summer season has the ebb and flood phases compared against each other (variable for flood and ebb conditions as in Table 1) and shows the ebb plume (Run 10) to better maintain its excess temperature, especially within the first 100 m, which is also shown by the 2 and 3°C flags (blue) extending further than that of the flood (red). However, outside of the near-field region, around 300 m, the two runs converge.

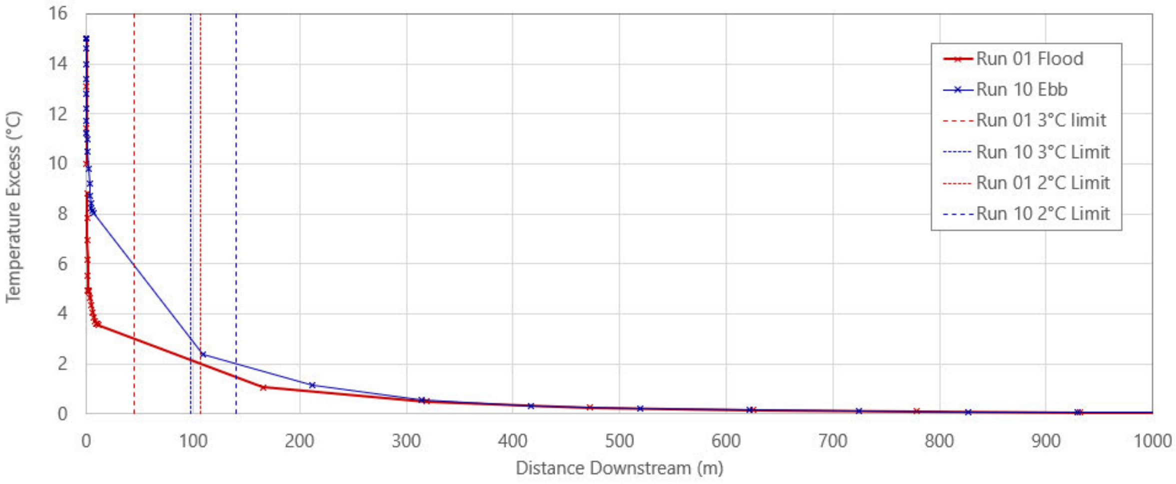


Figure 6. **Summer scenario, flood and ebb sensitivity**

2.3.3 Spring flood – Wind sensitivity

Shown in Figure 7 is the plume sensitivity to winds. The summer wind value of 4.08 m/s is a light wind and doesn't appear to have any influence on the plume when comparing runs 01 and 03. When a significantly stronger wind of 15 m/s is applied (Run 16), the plume is slightly affected causing the excess temperature to drop slightly quicker around the 100 m mark, also shown by the difference in the 2 and 3°C flags. However, it's to be noted that this wind speed of 15 m/s is approximately triple the speed of the faster mean winter wind speed of 5.32 m/s, and is considered here for sensitivity testing purposes only.

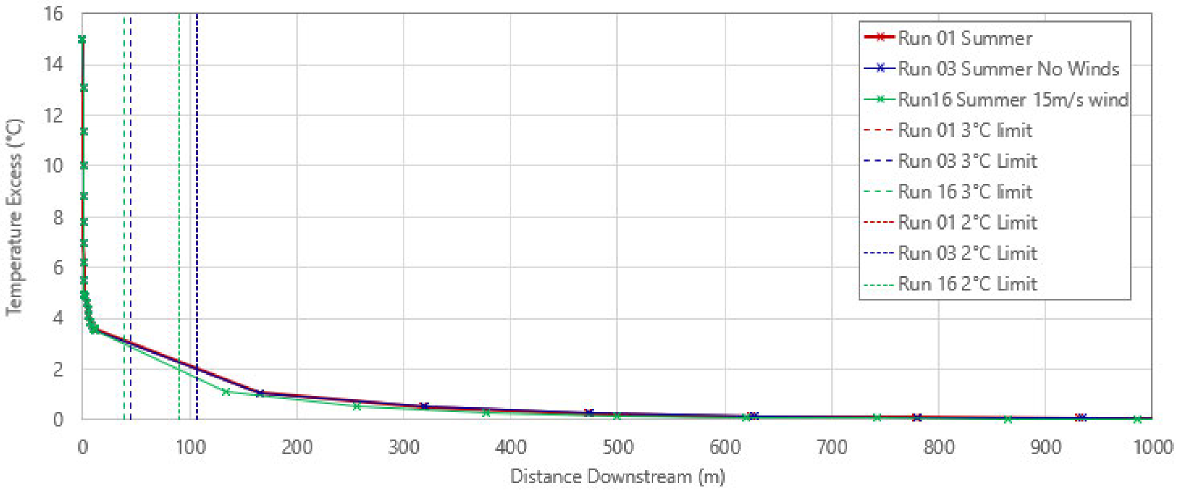


Figure 7. **Spring flood wind sensitivity**

2.3.4 Spring flood – Pipe diameter

Figure 8 shows the tests addressing the plume sensitivity to the discharge port diameter. The baseline run (Run 01 Summer) has a diameter of 0.8 m, with ±0.2 m applied in sensitivity runs; Run05 (0.6 m) and Run06 (1.0 m). The larger port diameter (Run 06) shows the excess temperature dilutes notably faster than the two smaller diameters in the near-field region, after which, at around 160 m all the runs converge.

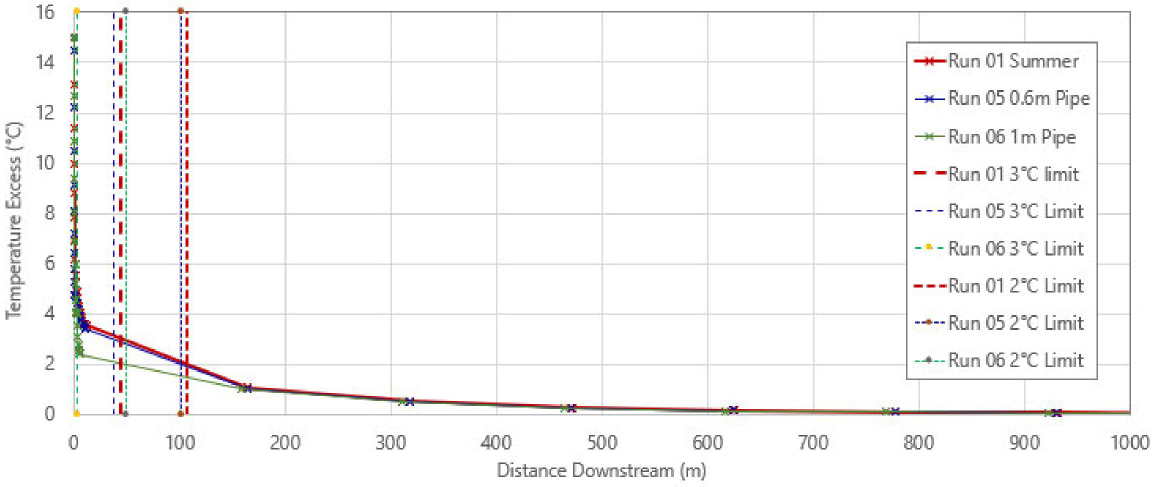


Figure 8. **Spring flood, pipe diameter sensitivity**

2.3.5 Spring flood – Pipe projection

Figure 9 shows the plume sensitivity to projection of the outfall port. Run 01 has a vertical projection off the seabed, contrasted by Run 17 having an offshore-aligned, horizontal projection, which shows dispersion of the excess temperature far more efficiently, with the 2°C being exceed at around 15 m, compared to approximately 105 m for the vertical projection in Run 01.

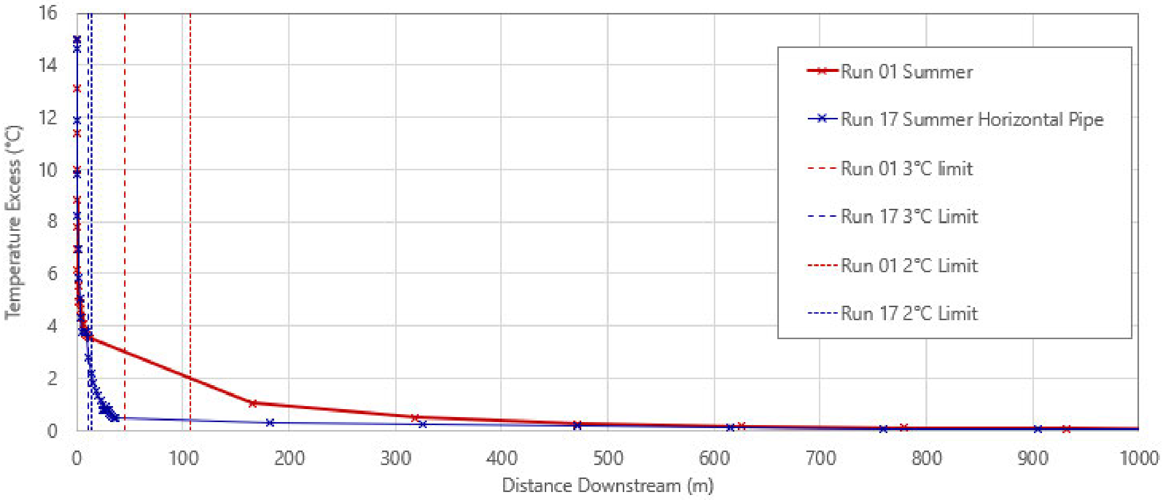


Figure 9. **Spring flood, outfall projection sensitivity**

2.3.6 Temperature excess isolines

The spring tidal range under summer conditions has also been utilised to demonstrate the plume extent for both the peak flood and ebb flow conditions (tidal characteristics as in Table 1). The plume shown in Figure 10 represents the extents of the excess temperatures isolines from +5°C to +0.1°C and have been overlaid on a map view to indicate the plume extent in relation to the site. A zoomed extent is also shown in Figure 11.

Figure 10. CORMIX excess temperature isolines (°C) under mean spring, peak flood (SE) and ebb (NW) tidal states

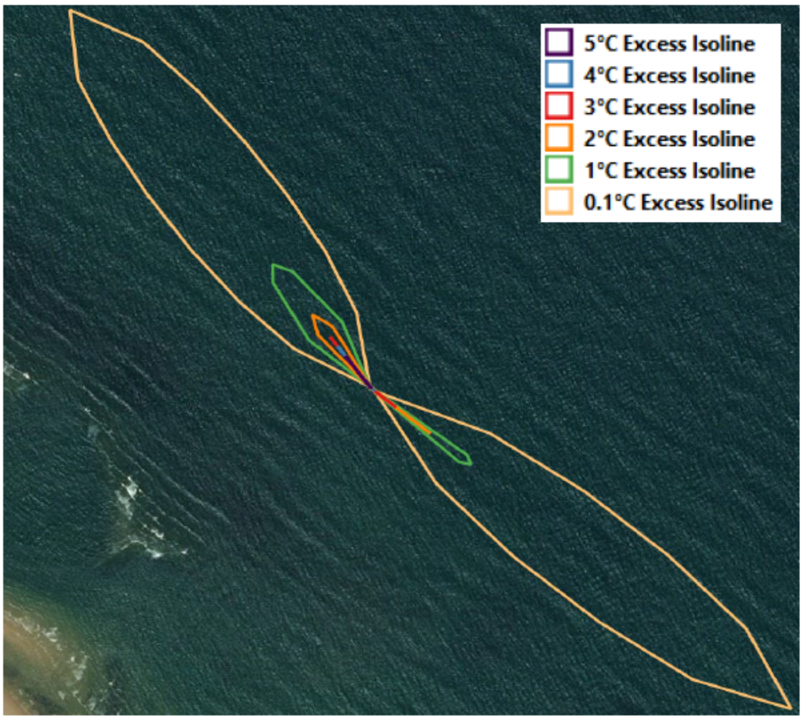


Figure 11. Zoomed extent of the CORMIX excess temperature isolines (°C) under mean spring, peak flood (SE) and ebb (NW) tidal states

Additionally, each isoline extent from the outfall is tabulated for both flood and ebb conditions in Table 3.

Table 3. **Excess temperature isoline extents from the outfall under peak ebb and flood for a mean spring tide**

Excess Temperature Isoline (°C)	Peak Flood (Run 01)		Peak Ebb (Run 10)	
	Isoline Extent from Outfall (m)	Area of Excess Temperature (m^2)	Isoline Extent from Outfall (m)	Area of Excess Temperature (m^2)
5.0	1.6	32	61.3	2
4.0	6.6	49	79.4	3
3.0	44.7	71	97.6	21
2.0	106.5	1,673	140.0	76
1.0	179.3	7,500	235.4	1,455
0.1	754.2	81,256	718.1	74,578

3 CORMIX Modelling – Outfall 2

3.1 Overview

As stated in Section 2, CORMIX modelling, assessing the near-field impact of the of thermal plume has been undertaken in two stages during this project. This section considers key scenarios that have been reproduced based upon a new outfall location and including an alternative 'extreme' flow scenario.

For this investigation, spring and neap tidal states have been compared during peak ebb and flood phases. In addition to this, a further case has been considered, in which the pipe diameter is increased to 2.4 m. This change in diameter is to account for a 1-in-30-year worst-case storm event to accommodate for the run off from the site. This scenario is considered across the same tidal states and phases as the initial scenarios and is representative of an extreme and anticipated to be a highly infrequent scenario. The setup and results of this scenario are presented separately in Appendix A.

3.2 Outfall 2 location

In February 2021 AECOM provided an update to the planned outfall location. Easting and Northings have been provided for three possible locations, in close proximity, named East, Mid and West. These sites are listed in Table 4 and the corresponding locations shown in the technical drawing provided by AECOM in Figure 12.

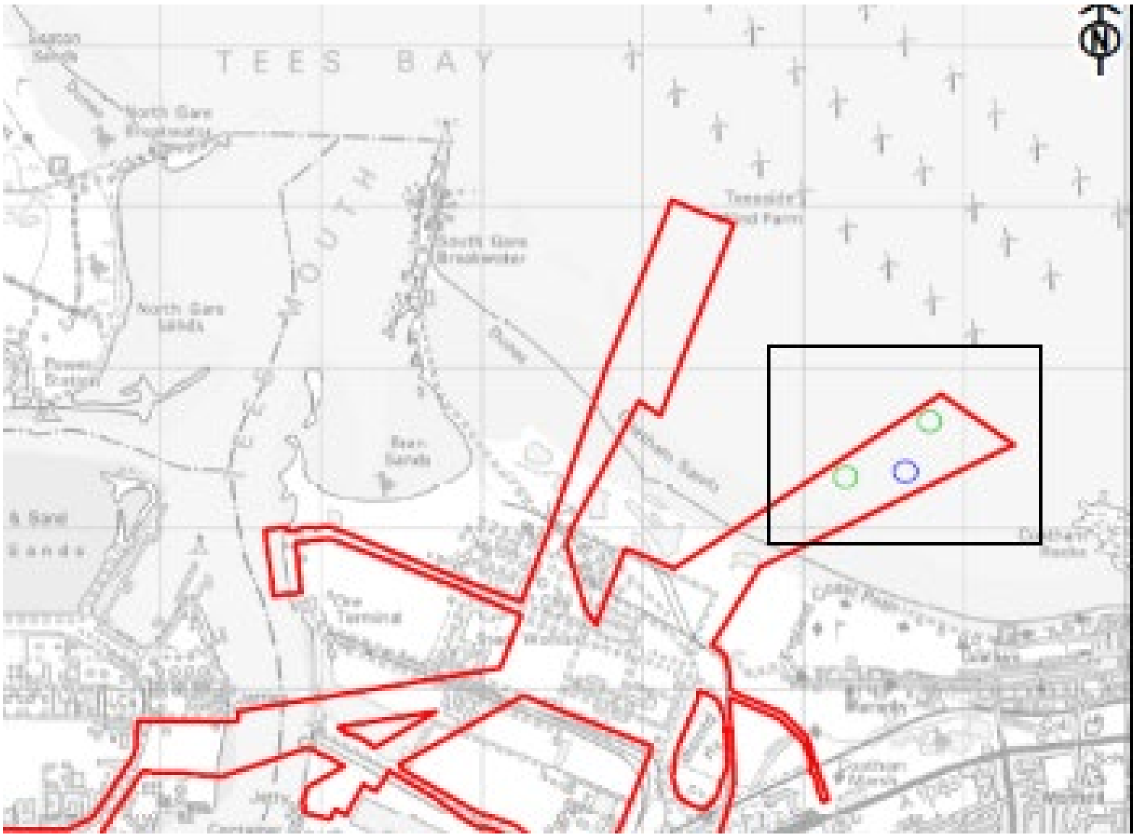


Figure 12. Outfall 2 location indicated by blue circle

Table 4. Outfall 2 location options

Location	Easting (m)	Northing (m)
Eastern-most	458737	526655
Mid (blue circle)	458622	526308
Western-most	458143	526315

3.3 Model set-up

The summer density of the effluent (1,018 kg/m^3) was carried over from the initial sensitivity tests since this offered a slightly greater plume compared to a winter equivalent. Tidal data at three locations provided by AECOM as potential sites for the outfall location were compared to determine any differences in tidal conditions. Differences were negligible and so the middle location was used. The site-specific tidal characteristics for Outfall 2 are presented in Table 5. All the runs (normal and extreme discharge events) completed and analysed for Outfall 2 (position shown in Figure 13) are outlined in Table 6.

Figure 13. Location of modelled Outfall 2

Table 5. Input tidal characteristics.

Tidal State	Tidal Characteristic	Peak Flood	Peak Ebb
Spring	Water Depth (m)	**8.1**	5.0
	Current Speed (m/s)	0.24	0.17
	Current Direction (°N)	119	**306**
Neap	Water Depth (m)	4.7	6.5
	Current Speed (m/s)	0.07	0.11
	Current Direction (°N)	111	292

Table 6. Outfall 2 CORMIX Run Summary.

Run no.	Description
18	Spring flood tide
19	Neap flood tide
26	Spring flood tide (extreme 1-in-30-year) *
28	Neap flood tide (extreme 1-in-30-year) *
22	Spring ebb tide
23	Neap ebb tide
27	Spring ebb tide (extreme 1-in-30-year) *
29	Neap ebb tide (extreme 1-in-30-year) *

*results presented in Appendix A.

3.4 CORMIX Outfall 2 results

Since the tests at this outfall focus on the variability across tidal states, the runs are presented by flood and ebb phases during both spring and neap tides.

3.4.1 Flood tide variation

Figure 14 shows the downstream temperature excess of the resultant plume during a spring (run 18) and neap (run 19) flood tide under normal discharge conditions, at Outfall 2. The neap tidal characteristics result in a larger, more extensive plume. The excess temperature is dispersed at a slower rate due to the slower tidal velocities when compared to spring equivalent as shown in Table 5. This is highlighted by the offset of the 2 and 3°C flag limits.

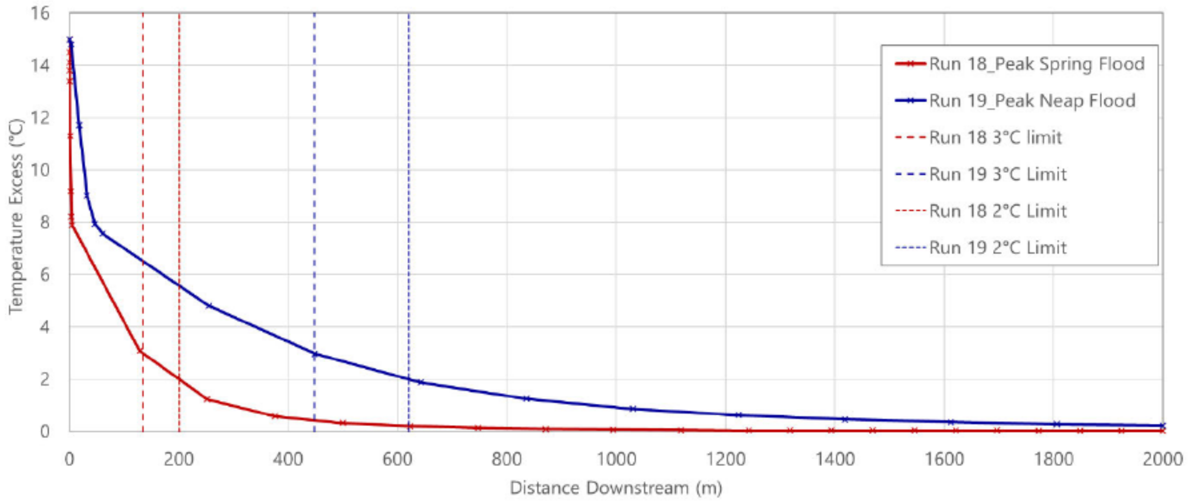


Figure 14. Spring and neap flood tide plume variations during normal discharge events.

3.4.2 Ebb tide variation

Figure 15 shows the downstream temperature excess of the resultant plume during a spring (run 22) and neap (run 23) ebb tide under normal discharge conditions, at Outfall 2. As with the flood tide, the neap plume is shown to have a larger extent under ebb conditions due to the slower tidal velocities resulting in a slower dispersion of the excess temperature, but both spring and neap plumes are dispersed by 1,200 m downstream of the origin.

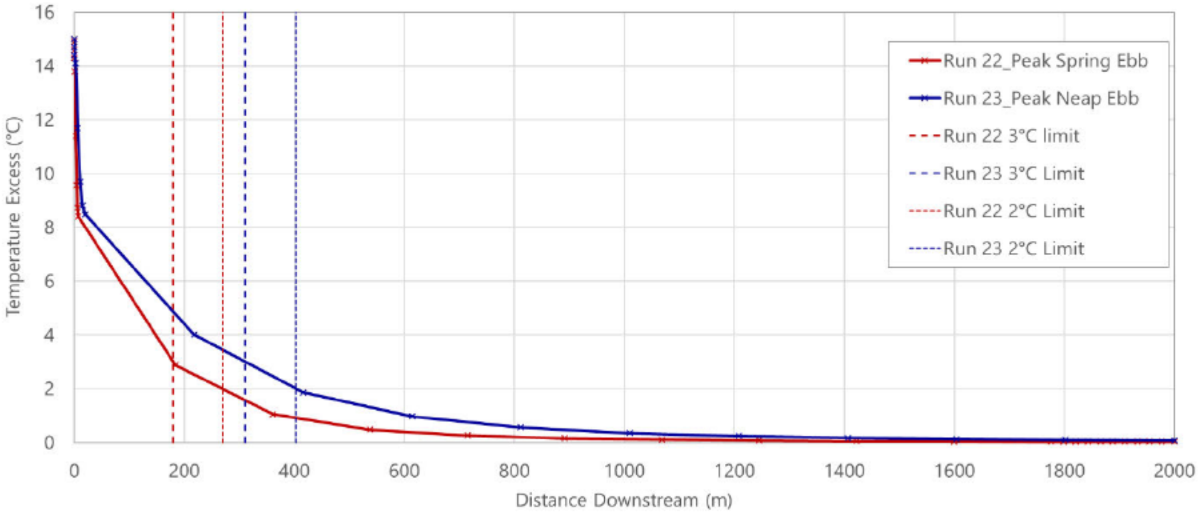


Figure 15. **Spring and neap ebb tide plume variations during normal discharge events.**

3.4.3 Temperature excess isolines

The tidal velocities that occur during the neap tide reduce the rate of dispersion of the excess temperature and therefore result in a larger plume. The extents of the 1-5 °C isolines for the neap tide are outlined in Table 7, with the isolines from the neap tidal states geo-referenced in Figure 16 which represent the 'worst-case' under normal discharge conditions. It should be noted that the CORMIX assessments assume constant ambient flow conditions and provide a prediction of the fully developed plume. In the tidal coastal waters at the Outfall locations, flow speeds and directions are constantly shifting with tidal phase, meaning that a fully developed plume will not experience the assumed constant flow regime. The results of the far-field thermal assessment (detailed in Section 4) take account of the changing tidal conditions and, as a result, are likely to give a more realistic representation of the thermal plume under the assessed conditions.

Table 7. **Isoline extents for all tidal states under normal discharge conditions.**

	Spring Flood Tide (Run 18)	Spring Ebb Tide (Run 22)	Neap Flood Tide (Run 19)	Neap Ebb Tide (Run 23)
Excess Temperature Isoline (°C)	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)
1	308	381	913	609
2	170	266	599	398
3	114	184	431	293
4	57	146	329	203
5	5	117	237	149

Figure 16. Excess temperature isolines during a neap tide under normal discharge conditions.

4 Delft3D Modelling – Far Field Impact

AECOM wish to assess the potential far-field impact of a thermal discharge produced by cooling water from the CCUS into the sea off the Teesside coastline. Far-field thermal plume modelling has been requested to satisfy the requirements of the Development Consent Order for the CCUS project.

The following section describe the Delft Far Field modelling undertaken to assess the impact of the thermal plume discharge through a simulated outfall and present the results from the scenarios which have been tested. A summary of observations from the far-field modelling is provided in each subsection of the results presentations (Section 4.3) and summary statements are provided in the modelling conclusions in Section 5.

4.1 Model setup

The far-field thermal plume modelling makes use of the existing Delft3D model, as described earlier in the report, constructed to assess the hydrodynamic conditions in the estuary. Details of the model setup are provided in Appendix A

This model has been updated to include temperature in the physical properties being modelled and to simulate a discharge with fixed thermal and saline properties at the outfall location.

A summary of the physical parameters applied in the Delft3D model is provided in Table 8. These parameters have been kept consistent with the hydrodynamic and near field thermal plume modelling undertaken in previous report sections. Their derivation is described earlier in this report.

Table 8. Physical properties of the Delft3D simulations

Parameter	Summer value	Winter value
Wind Speed (m/s)	4.08	5.32
Wind Direction (° from)	230	230
Ambient water temperature (°C)	14	5.8
Ambient salinity (ppt)	33.9	33.9

4.1.1 Outfall location

Two possible outfall locations have been (separately) simulated in this far-field assessment. The first is the original outfall location (Outfall 1) provided by AECOM during the original modelling scope (2020), the second is a revised location (Outfall 2) slightly further to the east of the original. Three possible 'updated' locations for the outfall were provided by AECOM in February 2021, the central location of the three has been used in the far field assessment. Further details for Outfall 1 and Outfall 2 have been provided in Section 2.1 and 3.2 of this report. For convenience the two locations modelled in the far field simulations are listed in Table 9 and their position in the Delft3D grid shown in Figure 17.

Table 9. Outfall locations for far-field modelling

Location	Easting (m)	Northing (m)
Outfall 1 (Original)	457088	527565
Outfall 2 (Updated - Mid)	458622	526308

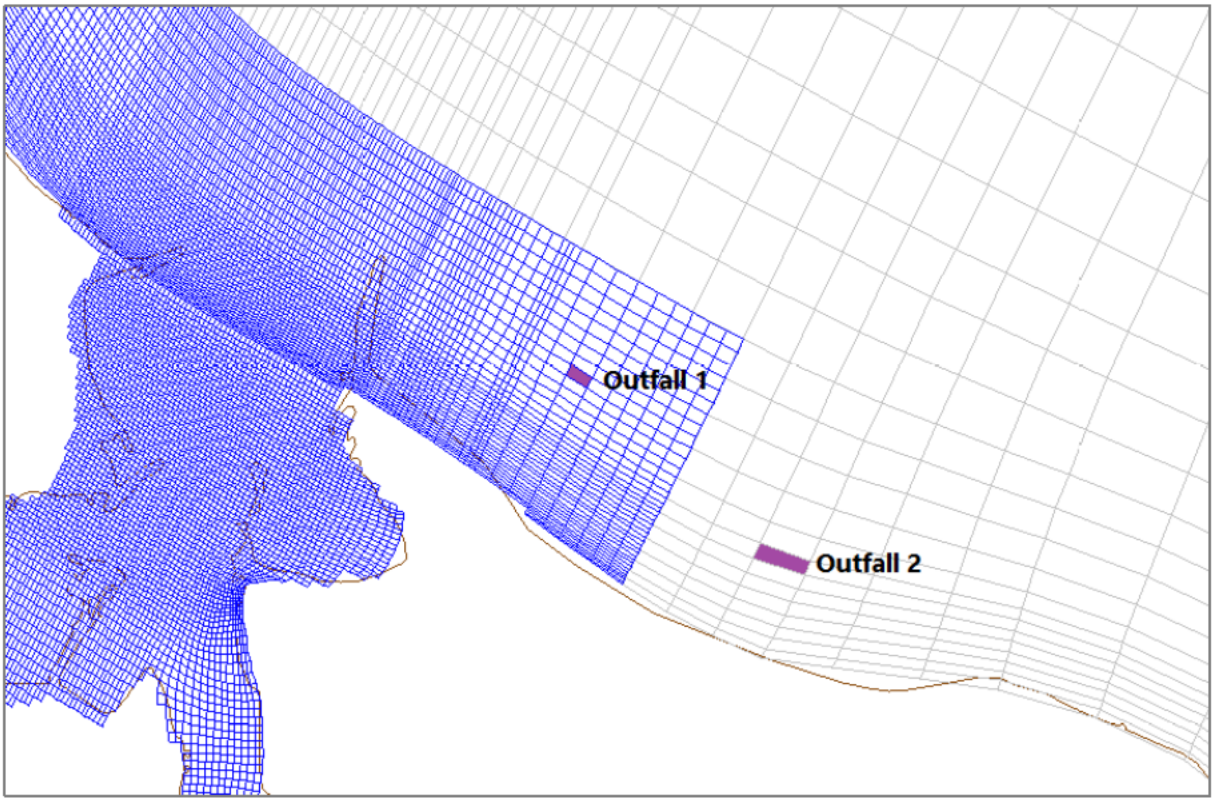


Figure 17. **Location of Outfalls in far-field (Delft3D) model grid**

4.1.2 Definition of the Outfall in Delft3D

Delft3D provides the option to include a 'discharge' in the flow model grid. In order to simulate the outfall a discharge has been defined in the applicable model grid cell (see Figure 17) in vertical layer 8 (nearest to the sea bed). The thermal and saline properties of the ambient and effluent water are shown in Table 10 below. A continuous flow rate of 1.37 m^3/s is specified for the thermal discharge.

Table 10. **Thermal plume properties in Delft3D, summer and winter case**

Input/Parameter	Summer		Winter	
	Ambient	Effluent	Ambient	Effluent
Salinity (ppt)	33.9	29.3	33.9	29.3
Temperature (°C)	14	29	5.8	20.8

4.2 Scenarios

Summer and winter scenarios have been simulated for a 14-day duration in 2019 covering a spring and neap period. These have been produced for both the outfall locations. The simulation time is the same as that modelled in the assessment of hydrodynamic conditions in Appendix A.

Sensitivity tests assessing the impact of wind direction and flow rate have been undertaken using the Outfall 2 location – this being the best current estimate of the likely discharge site.

A summary of model runs undertaken to assess the far-field thermal plume impact is provided in Table 11.

Table 11. Delft3D model runs for far-field assessment

Run	Description
Run 1	Summer conditions for a spring-neap period: Outfall 2
Run 2	Winter conditions for a spring-neap period: Outfall 2
Run 3	Summer conditions for a spring-neap period – Onshore wind: Outfall 2
Run 4	Summer conditions for a spring-neap period – Wind from south east: Outfall 2
Run 5	Summer conditions for a spring-neap period: Outfall 1
Run 6	Winter conditions for a spring-neap period: Outfall 1
Run 7	Summer conditions for a spring neap period – high flow rate scenario: Outfall 2

4.3 Results

Contour plots of excess temperature are presented in Figure 18 to Figure 35 showing the impact of the thermal discharge on the sea water temperature. Excess temperature is shown as a positive difference relative to the ambient temperature (14°C for the summer condition and 5.8°C in winter). Temperatures shown are depth averaged across all vertical layers in the model.

For the initial summer and winter model runs, contour plots are presented for four stages of the tide: a peak flood, peak ebb and the slack waters in between. For later sensitivity comparisons, the times of peak flow are sufficient to provide comparisons.

The times of peak flood and ebb have been selected from representative periods of mean spring and neap tidal range. These selected times also correspond to those used in the identification of CORMIX input parameters in the nearfield assessments.

For reference in the excess temperature contours:

- Temperature excess less than 0.02°C is not shaded in these plots;
- The first grey band of colour shows a temperature excess of between 0.02°C and 0.04°C; and
- The next light blue band shows a temperature excess of between 0.04°C and 0.06°C;

4.3.1 Runs 1 and 2: Summer and Winter Spring/Neap conditions using the Outfall 2 location

Figure 18 to Figure 21 on the following pages show the contour plots of excess temperature produced from simulating the thermal discharge at the updated outfall site for the summer and winter conditions.

Four stages of the tide are shown for each of the summer/winter spring/neap combinations.

For both the summer and winter scenarios the same spring vs neap observations are made:

- The thermal discharge over a spring tide tends to stay closer to the shore and extend further along the coastline in comparison to the neaps.
- The neap simulations show a higher temperature excess close to the point of discharge and a plume which extends further offshore than seen in the spring cases.
- Overall the distance from source over which a difference in temperature is observed is greater in the spring simulations than the neaps.
- In a spring scenario, the extent of the temperature excess between 0.02 and 0.04°C extends approximately 9 km to the south east of the outfall location.
- No temperature excess >0.02 degrees extends into the estuary mouth in these scenarios.

Summer Conditions: Spring Tide – Outfall 2 Location

15 °C excess temperature (14 °C ambient)
4.08 m/s wind speed from 230°
1.37 m³/s discharge rate

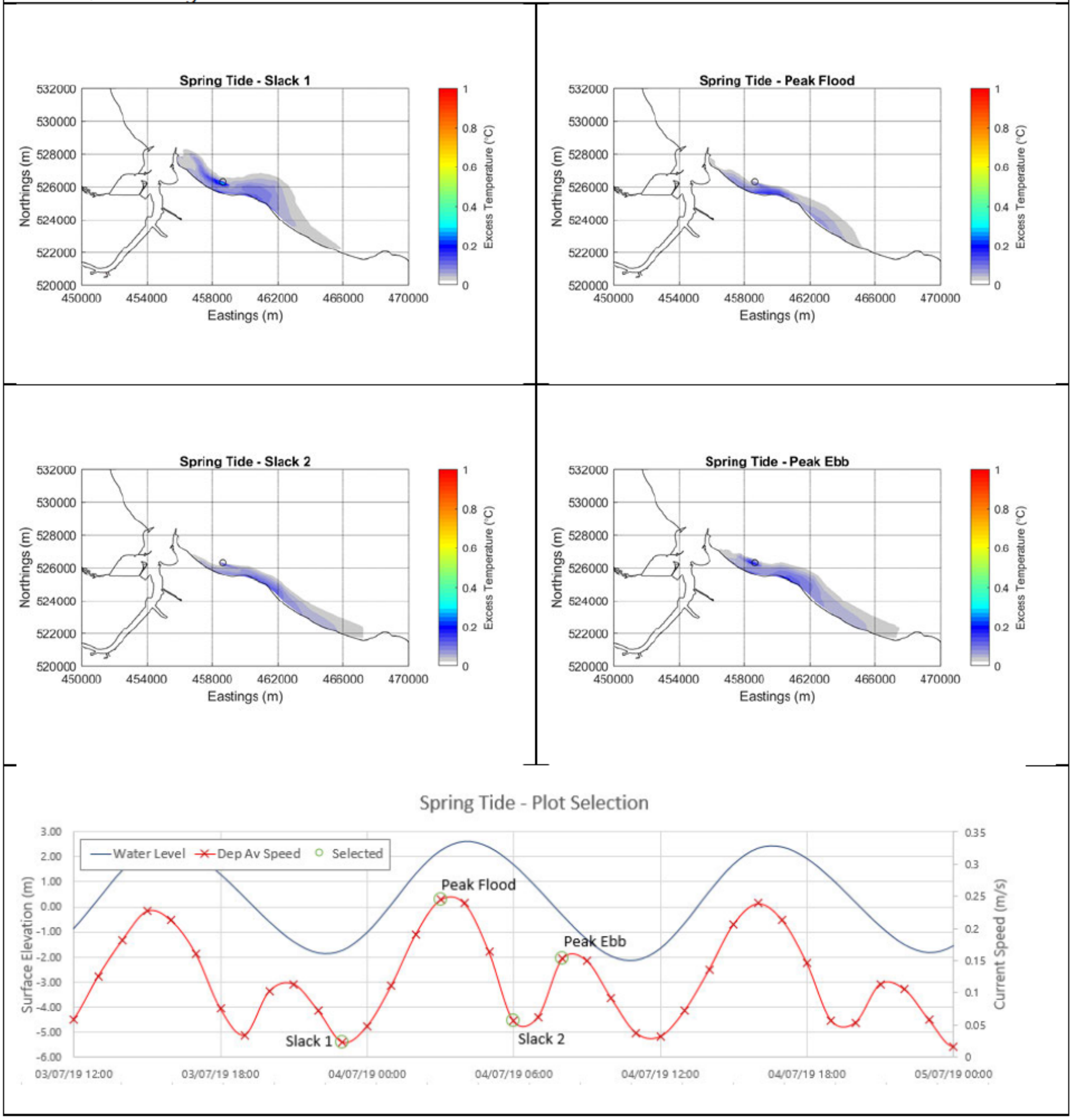
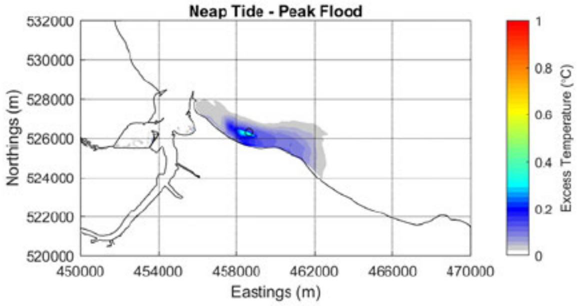
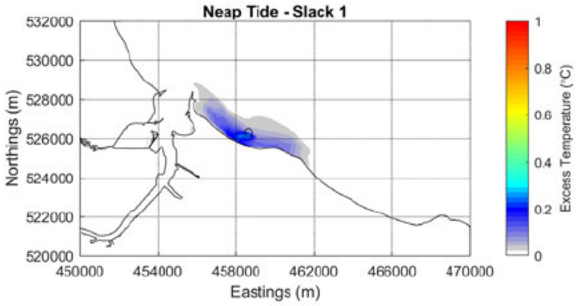


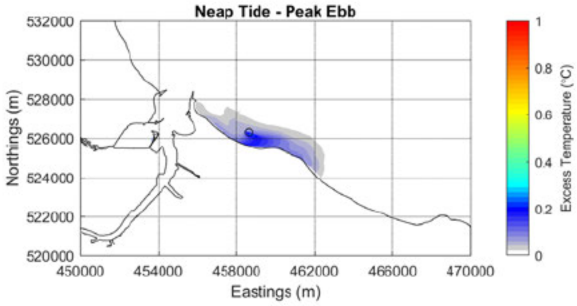
Figure 18. Temperature excess contour plots: Summer spring tide – Outfall 2 location

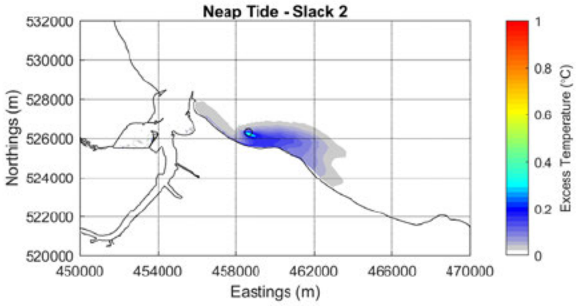
Summer Conditions: Neap Tide – Outfall 2 Location

15 °C excess temperature (14 °C ambient)
4.08 m/s wind speed from 230°
1.37 m³/s discharge rate









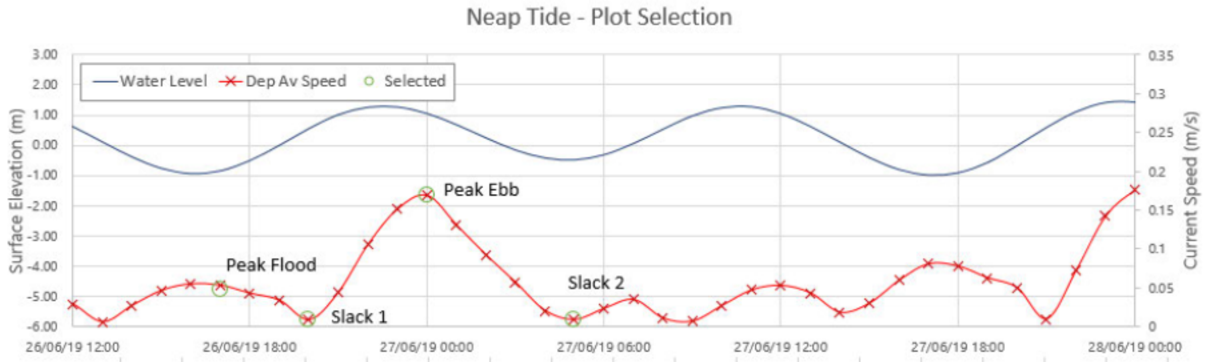


Figure 19. Temperature excess contour plots: Summer neap tide – Outfall 2 location

Winter Conditions: Spring Tide – Outfall 2 Location

15 °C excess temperature (5.8 °C ambient)

5.32 m/s wind speed from 230°

1.37 m^3/s discharge rate

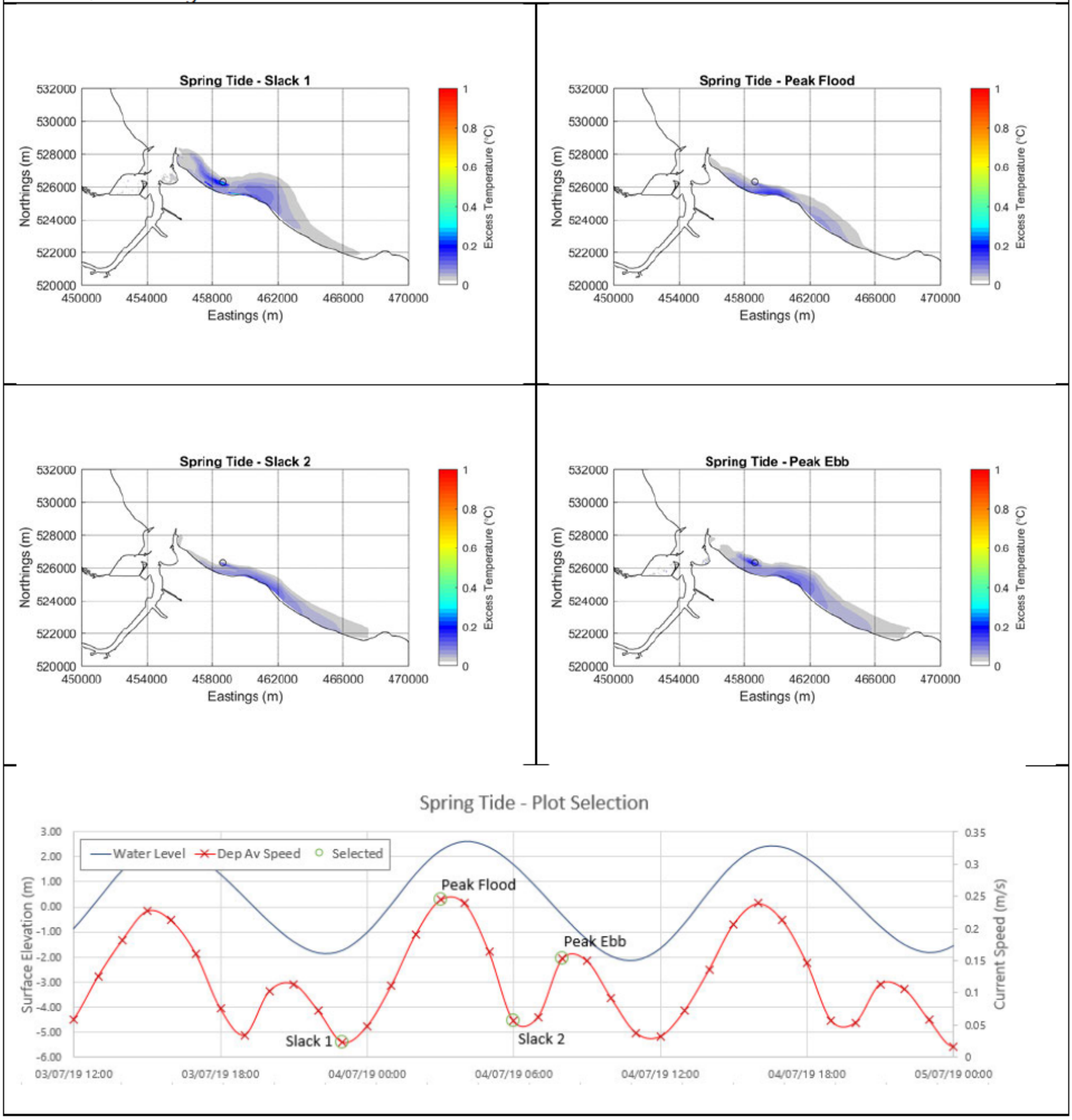


Figure 20. Temperature excess contour plots: Winter spring tide – Outfall 2 location

Winter Conditions: Neap Tide – Outfall 2 Location

15 °C excess temperature (5.8 °C ambient)

5.32 m/s wind speed from 230°

1.37 m^3/s discharge rate

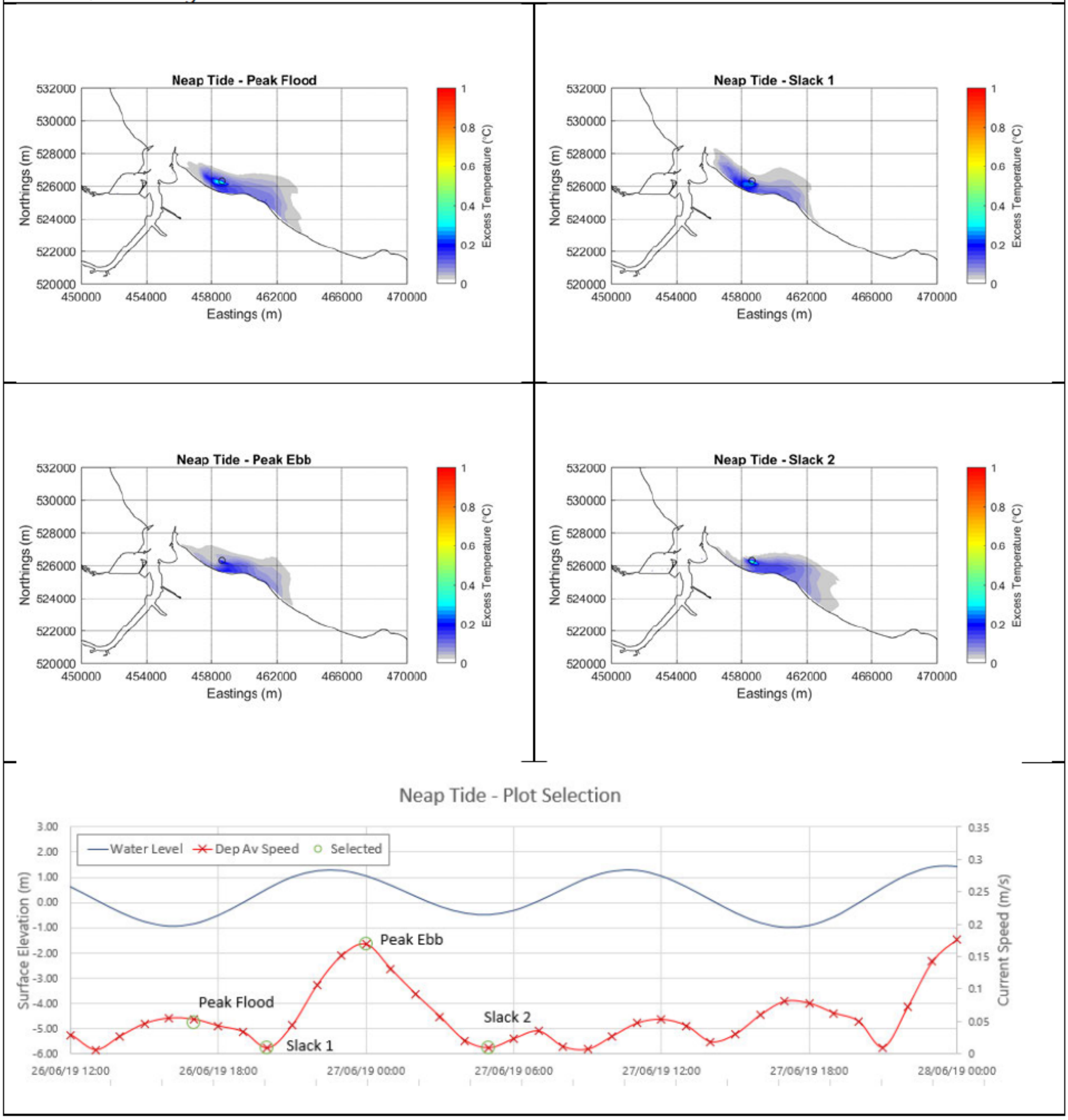


Figure 21. Temperature excess contour plots: Winter neap tide – Outfall 2 location

4.3.2 Runs 3 and 4: Sensitivity to Wind conditions

The Run 1 and 2 simulations applied the average seasonal wind conditions (derived during model calibration (Appendix A)), of 4.08 m/s for the summer and 5.32 m/s in the winter, both applied with a continuous direction of 230° from.

In order to test the sensitivity of the plume discharge to wind directions, two further simulations have been run. These both use the baseline summer condition: ambient temperature of 14° and wind speed of 4.08 m/s, but with altered wind directions as follows:

- Run 3: Onshore wind. A forcing direction of 30° (from) has been applied to simulate a continuous wind perpendicular to the coast (onshore).
- Run 4: South East. A forcing direction of 120° (from) has been applied to simulate a continuous wind running parallel to the coastline from approximately a south east direction.

Results from these simulations have been compared with the summer scenario with a 230° wind in Figure 22 to Figure 25. The following observations are made:

- Comparison of the south westerly (230°) vs the onshore (30°) wind direction show small differences in the distribution of the thermal plume:
    - During the spring tides, when flows are relatively higher, very little change in the excess temperature plots is seen as a result of the change in wind direction.
    - During the neap tide a more discernible difference is seen, with the discharge being held closer to the coast in the presence of an onshore wind.
- When a south easterly (120°) wind is applied to the summer thermal plume discharge scenario the effect is to reduce the eastern extent of the thermal plume. This is more pronounced in the neap comparisons where flow speeds are lower and the along-coast extent of the plume is already smaller compared with the spring case.

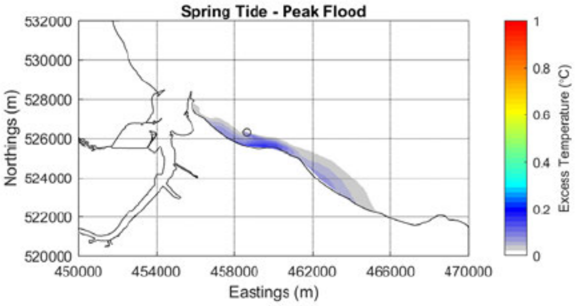
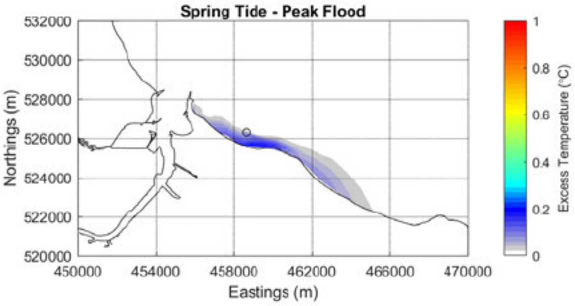
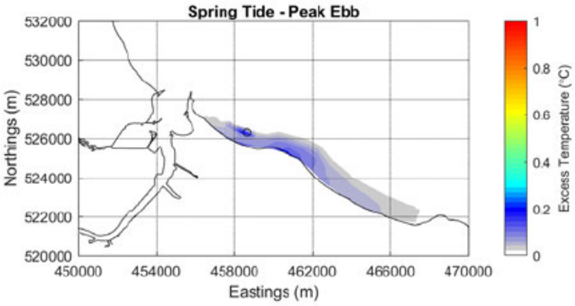
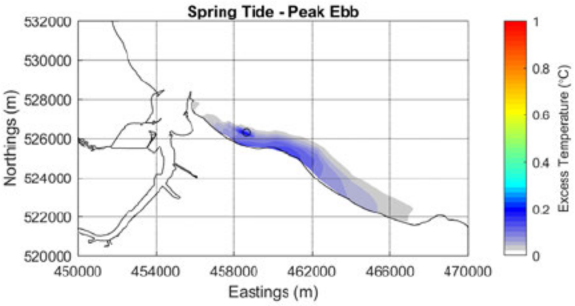
Comparison of wind direction sensitivity: Summer Spring Tide – Outfall 2 Location	
15 °C excess temperature (14 °C ambient) 1.37 m^3/s discharge rate	
South westerly wind	**Onshore wind**
4.08 m/s wind speed from 230°	4.08 m/s wind speed from 30°
	
	

Figure 22. **Temperature excess contour plots: Comparison of spring summer conditions with a 230° wind direction (left) vs onshore wind (right)**

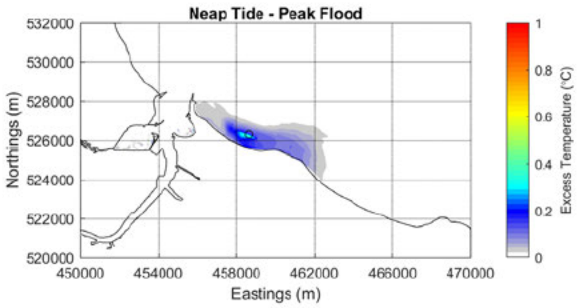
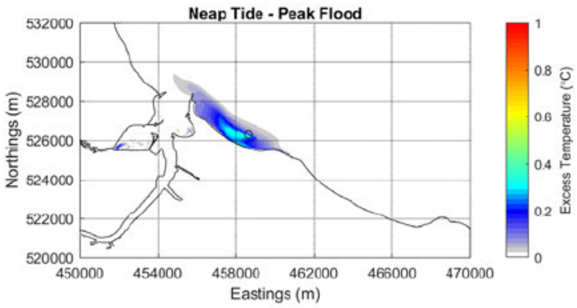
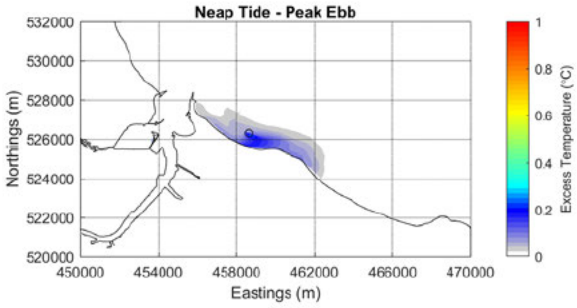
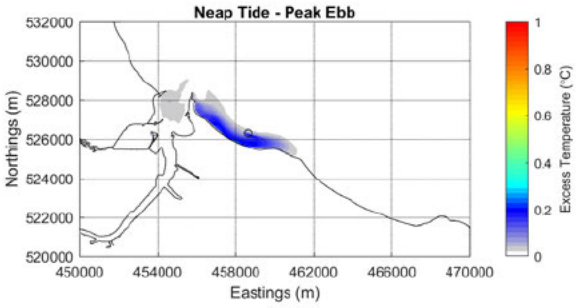
Comparison of wind direction sensitivity: Summer Neap Tide – Outfall 2 Location	
15 °C excess temperature (14 °C ambient) 1.37 m^3/s discharge rate	
South westerly wind	**Onshore wind**
4.08 m/s wind speed from 230°	4.08 m/s wind speed from 30°
	
	

Figure 23. **Temperature excess contour plots: Comparison of neap summer conditions with a 230° wind direction (left) vs onshore wind (right)**

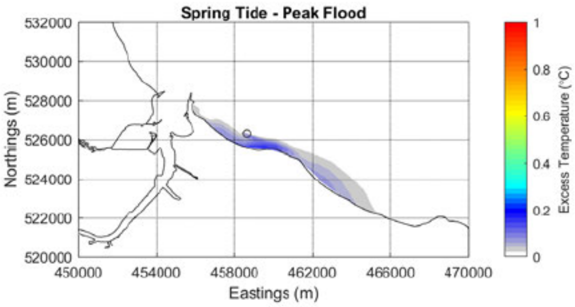
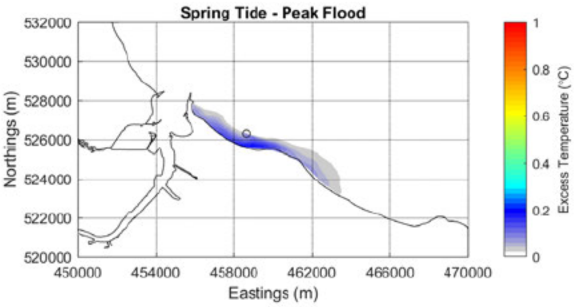
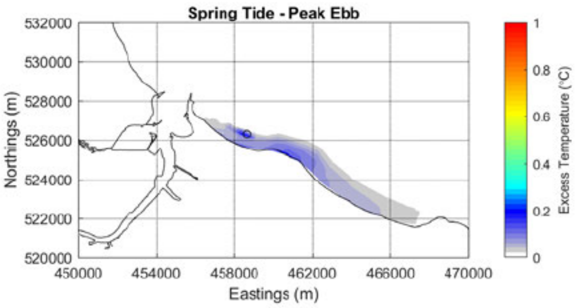
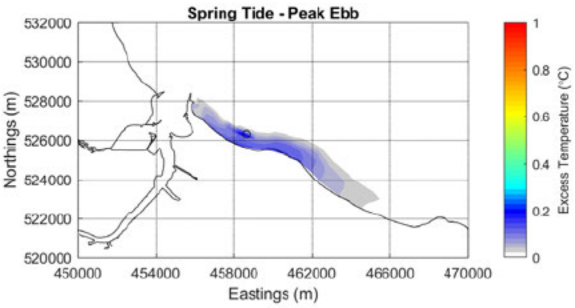
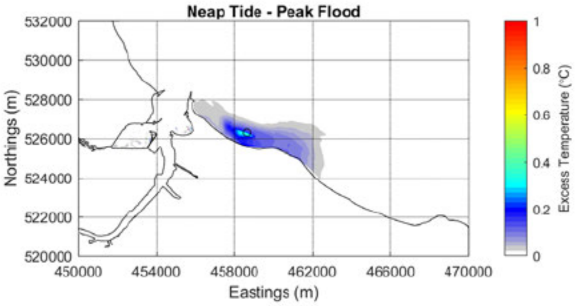
<table>
<tr><th colspan="2">Comparison of wind direction sensitivity: Summer Spring Tide – Outfall 2 Location</th></tr>
<tr><td colspan="2">15 °C excess temperature (14 °C ambient)
1.37 m^3/s discharge rate</td></tr>
<tr><th>South westerly wind</th><th>South easterly wind</th></tr>
<tr><td>4.08 m/s wind speed from 230°</td><td>4.08 m/s wind speed from 120°</td></tr>
<tr><td> </td><td> </td></tr>
<tr><td> </td><td> </td></tr>
</table>

Figure 24. **Temperature excess contour plots: Comparison of spring summer conditions with a 230° wind direction (left) vs 120° wind direction (right)**

<table>
<tr><th colspan="2">Comparison of wind direction sensitivity: Summer Neap Tide – Outfall 2 Location</th></tr>
<tr><td colspan="2">15 °C excess temperature (14 °C ambient)
1.37 m^3/s discharge rate</td></tr>
<tr><th>South westerly wind</th><th>South easterly wind</th></tr>
<tr><td>4.08 m/s wind speed from 230°</td><td>4.08 m/s wind speed from 120°</td></tr>
<tr><td>



Neap Tide - Peak Flood

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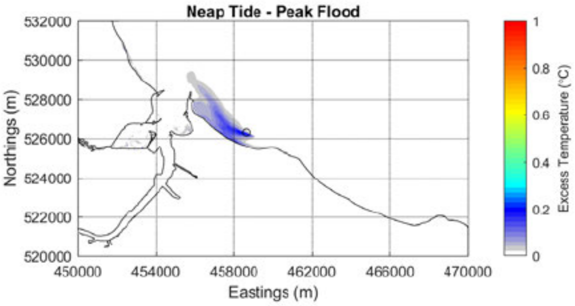
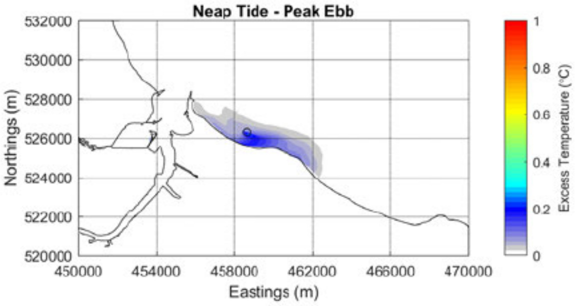


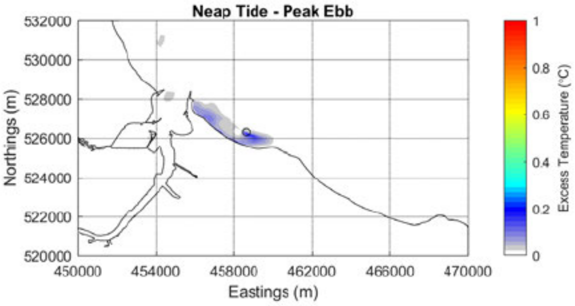
Neap Tide - Peak Flood

</td></tr>
<tr><td>



Neap Tide - Peak Ebb

</td><td>



Neap Tide - Peak Ebb

</td></tr>
</table>

Figure 25. **Temperature excess contour plots: Comparison of neap summer conditions with a 230° wind direction (left) vs 120° wind direction (right)**

4.3.3 Runs 5 and 6: Outfall location assessment

Runs 5 and 6 simulate the summer and winter conditions over a spring/neap cycle with the discharge specified at the Outfall 1 site (Figure 17). These are compared for selected tidal conditions with the discharge modelled from the Outfall 2 location. The following observations are made:

- During the summer cases, the extent of the thermal discharge (up to 0.04°C) from the updated location is greater than that simulated in the original location.
- Using the Outfall 1 location: during the summer some of the temperature impact is seen inside the estuary in the neap simulations. This temperature excess does not exceed 0.06°C within the estuary mouth.
- During the winter period a temperature difference is seen extending into the Tees Estuary, particularly noticeable in the spring tide scenarios. It should be noted that the excess temperatures seen are very small (< 0.04°C excess) compared with the background of 5.8°C.

These scenarios have been examined in more detail in order to explain the differences seen between the two different outfall scenarios. It should be noted that the flow speeds vary between the two sites despite their close proximity. This has been illustrated in Figure 26 and Figure 27 below for a representative spring and neap flow. The selected times peak ebb and flood tide for the Outfall 2 assessment are shown on these plots (the timings of these will vary slightly from those selected for the Outfall 1 flow data. The flow differences seen between the two sites, particularly on the neap tide, are relatively large compared with the magnitude of the flow speed. It can be seen that the flow speeds at the Outfall 1 site are consistently higher which may be contributing to faster dispersion of the plume as well as the widened extent in some cases.

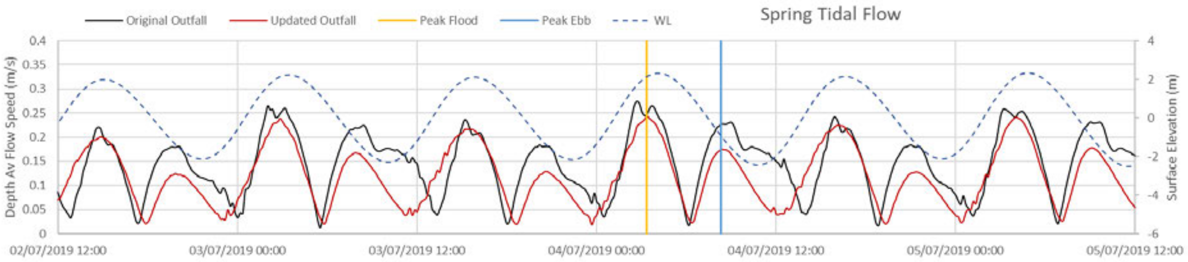


Figure 26. **Flow speeds over a spring tide at Outfall 1 and Outfall 2 positions**

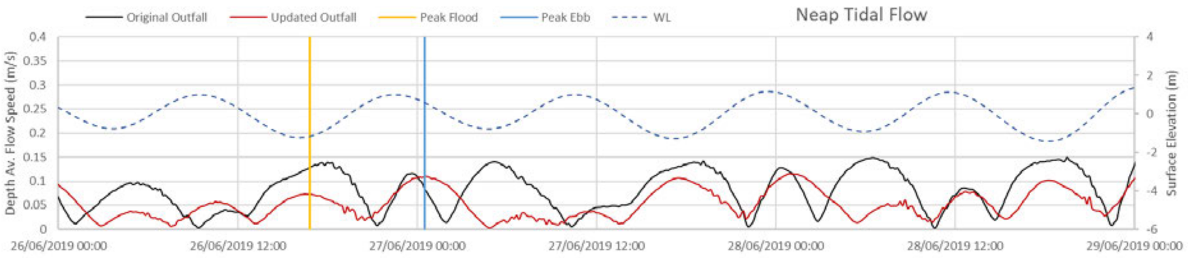


Figure 27. **Flow speeds over a neap tide at Outfall 1 and Outfall 2 positions**

Figure 28 below shows flow vectors during a spring period where flow direction is towards the north west. The underlying colour contours show the sea temperature, in which the outfall impact is evident. This plot shows the along shore flow directing the plume discharge into the estuary. Plot Figure 29 shows the same time with the vectors removed to better illustrate the temperatures within the estuary. It should be emphasised that the colour scales on these plots have been stretched to illustrate this effect (showing a range of 0.4°C) and that the temperature differences observed are very small.

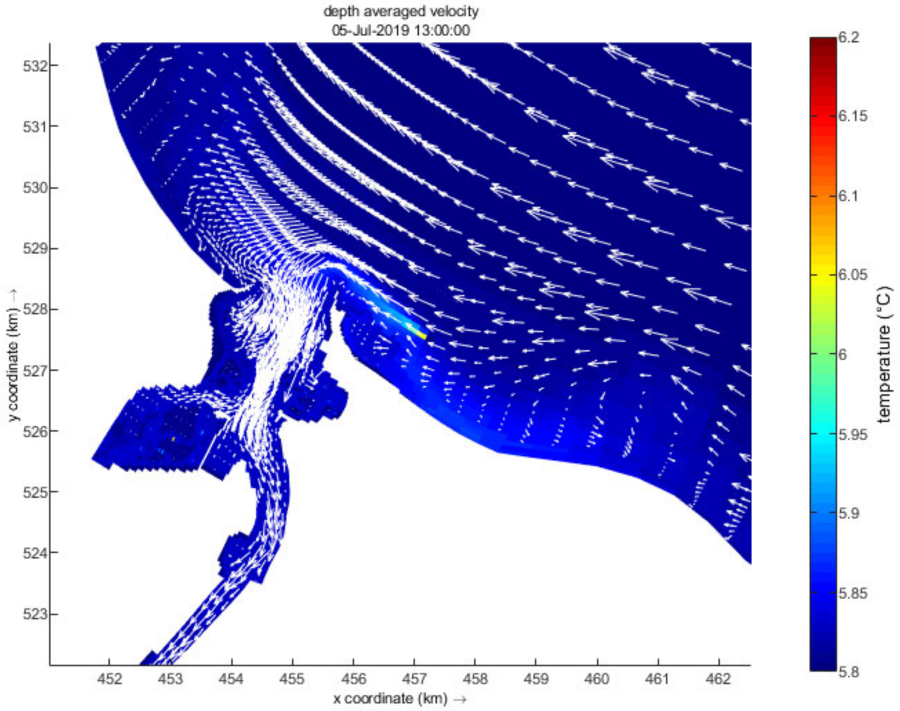


Figure 28. Temperature contours and Flow Speed Vectors from Run 6: Winter – Outfall 1

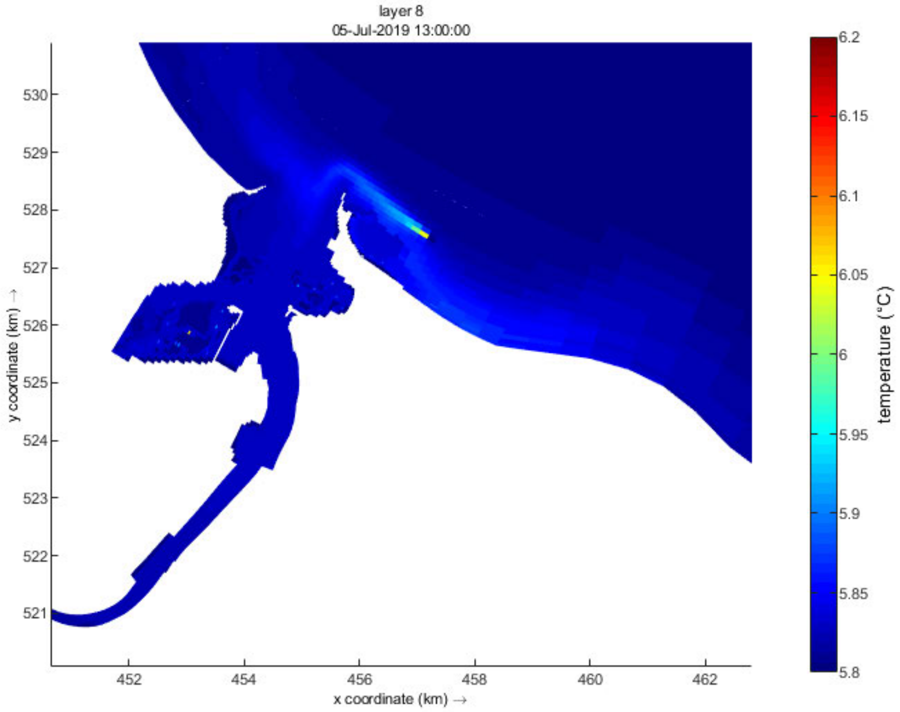


Figure 29. Temperature Contours from Run 6: Winter – Outfall 1

Comparison of outfall location: Summer Spring Tide	
15 °C excess temperature (14 °C ambient) 4.08 m/s wind speed from 230° 1.37 m^3/s discharge rate	
Outfall 2 location	**Outfall 1 location**

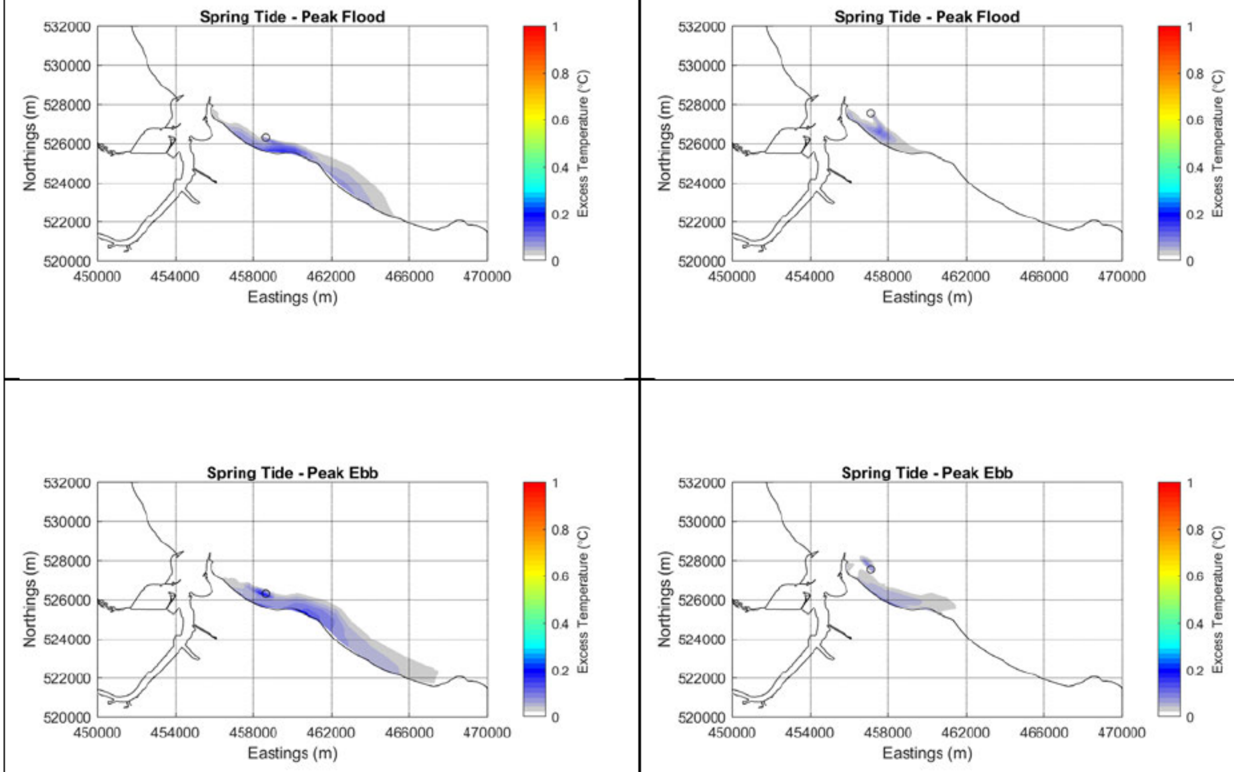
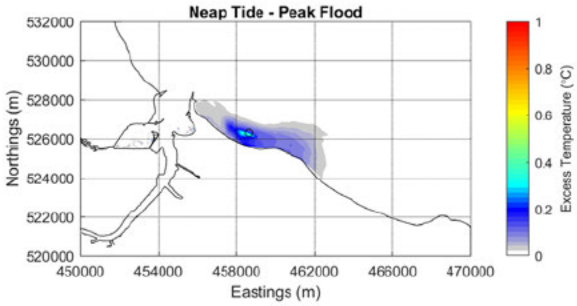


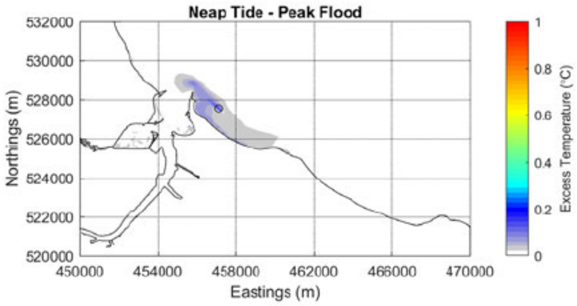
Figure 30. Temperature excess contour plots: Comparison of spring summer conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

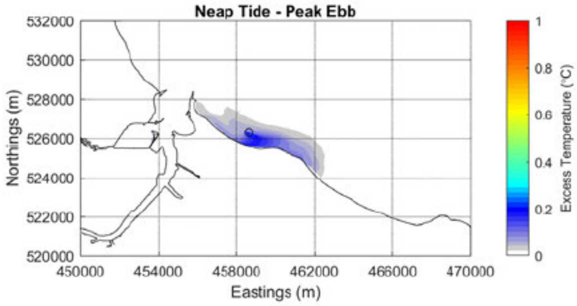
Comparison of outfall location: Summer neap Tide

15 °C excess temperature (14 °C ambient)
4.08 m/s wind speed from 230°
1.37 m³/s discharge rate

Outfall 2 location | **Outfall 1 location**







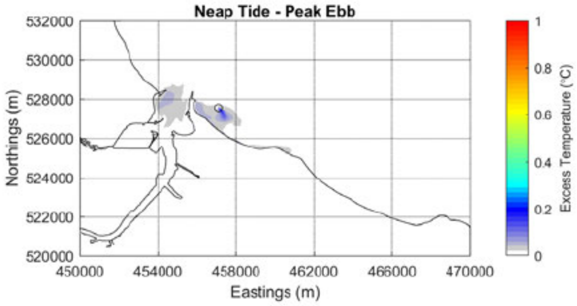


Figure 31. **Temperature excess contour plots: Comparison of neap summer conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)**

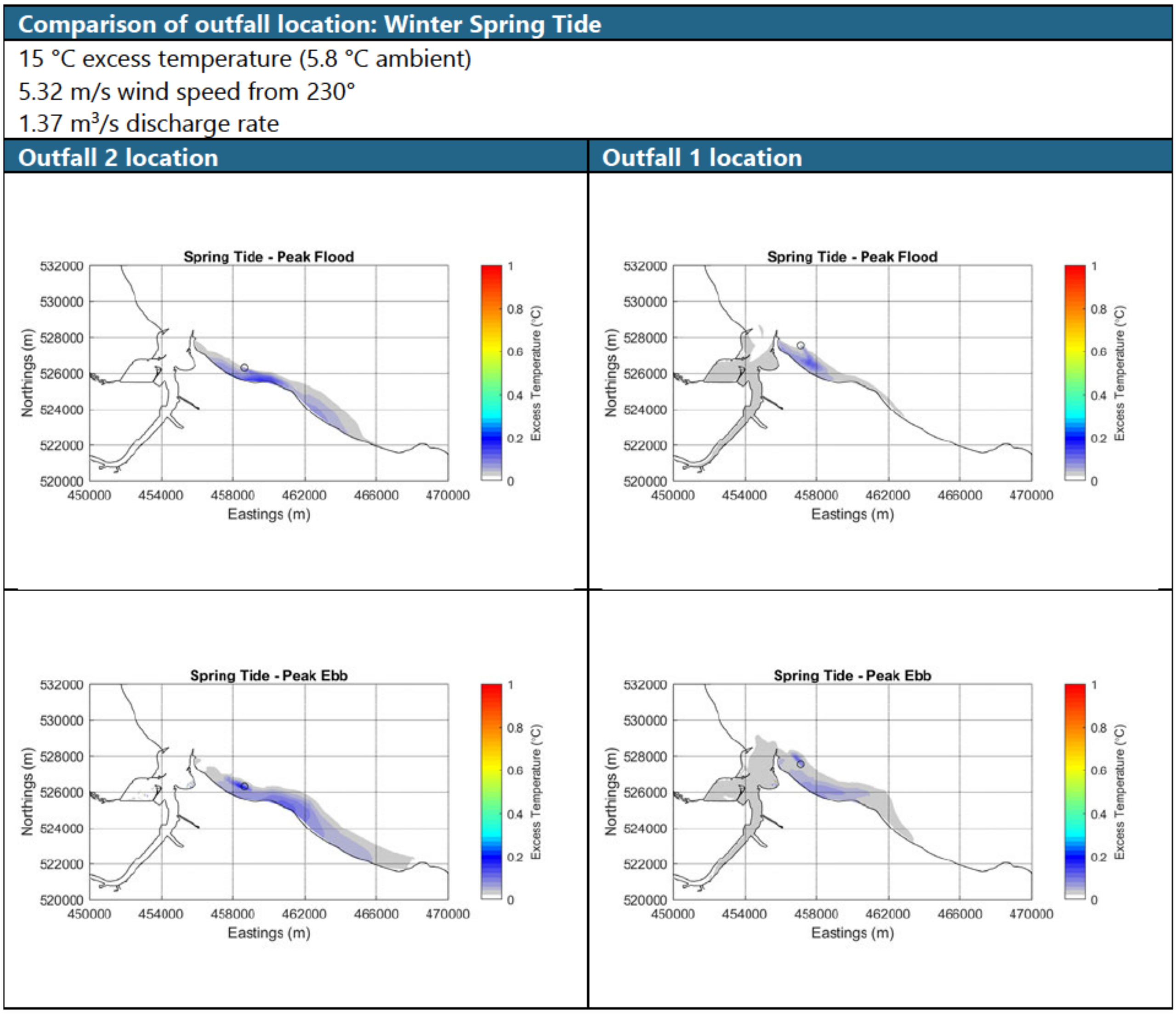


Figure 32. Temperature excess contour plots: Comparison of spring winter conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

Comparison of outfall location: Winter neap Tide

15 °C excess temperature (5.8 °C ambient)
5.32 m/s wind speed from 230°
1.37 m^3/s discharge rate

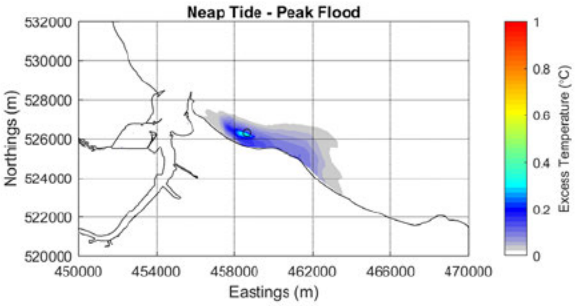
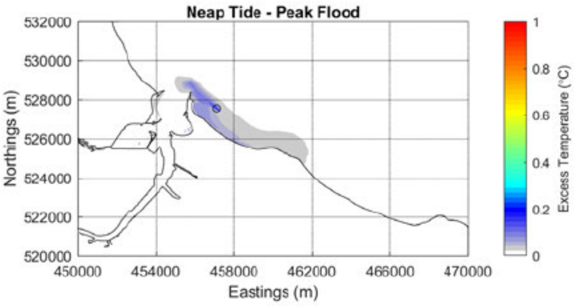
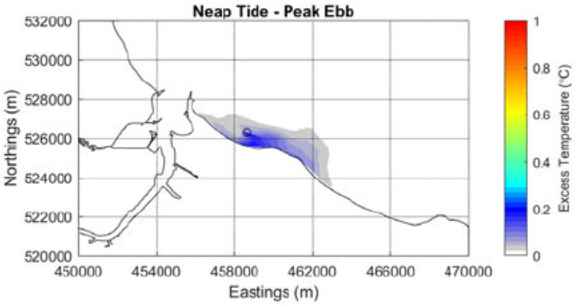
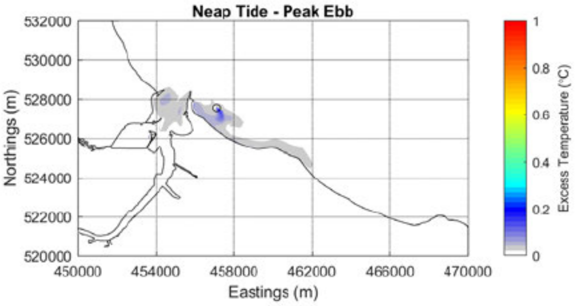
Outfall 2 location	**Outfall 1 location**
 Neap Tide - Peak Flood	 Neap Tide - Peak Flood
 Neap Tide - Peak Ebb	 Neap Tide - Peak Ebb

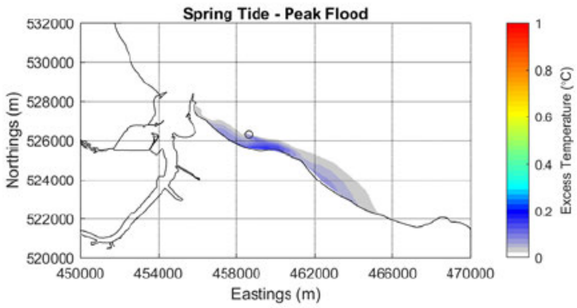
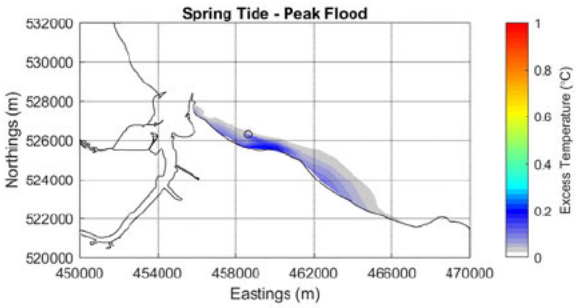
Figure 33. **Temperature excess contour plots: Comparison of neap winter conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)**

4.3.4 Run 7: Comparison of high flow scenario

The nearfield thermal plume modelling considered an extreme 1 in 30-year flow rate discharge through the pipe, with a specified rate of 5.75 m³/s. This discharge would consist of a portion of heated water combined with land run-off water at ambient temperature. Information provided by AECOM anticipates an approximate ratio of 31% warm and 69% ambient water would be discharged during this type of extreme event resulting in a combined temperature excess of approximately 5°C. Effluent salinity has also been calculated to reflect the mixture of warmed and ambient water.

This 1 in 30-year high flow event has been simulated in the Deflt3D far field model and compared over summer spring and neap conditions in this section.

Comparisons in Figure 34 and Figure 35 show that the thermal plume distribution over both the normal and extreme discharge case are largely similar. A slightly larger area of excess temperature is seen in the high flow case compared with the normal case in both the spring and neap tide conditions. A greater temperature excess is seen at the point of the plume discharge in the neap scenarios.

<table>
<tr><th colspan="2">Comparison of normal and extreme flow scenario: Summer Spring Tide – Outfall 2 Location</th></tr>
<tr><td colspan="2">4.08 m/s wind speed from 230°</td></tr>
<tr><th>Normal flow rate</th><th>Extreme flow rate</th></tr>
<tr><td>1.37 m³/s discharge rate
15°C excess temperature (14°C ambient)</td><td>5.75 m³/s discharge rate
5°C excess temperature (14°C ambient)</td></tr>
<tr><td>
</td><td>
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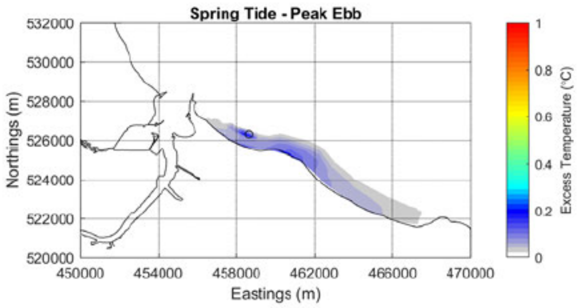
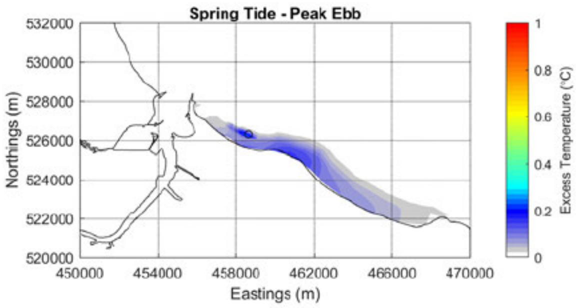
<tr><td>
</td><td>
</td></tr>
</table>

Figure 34. Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates

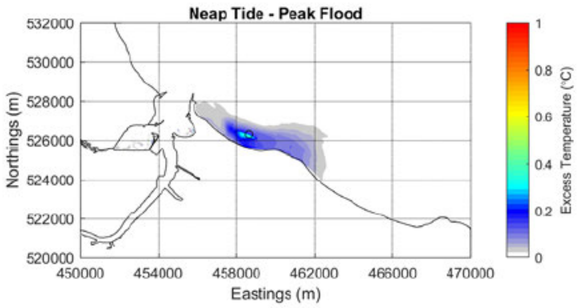
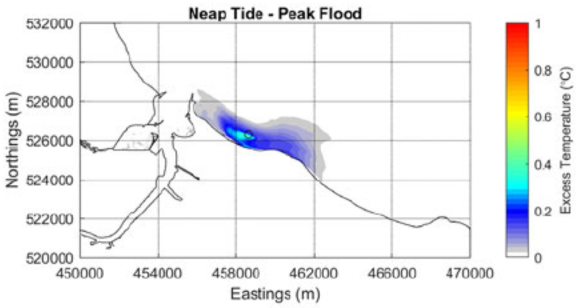
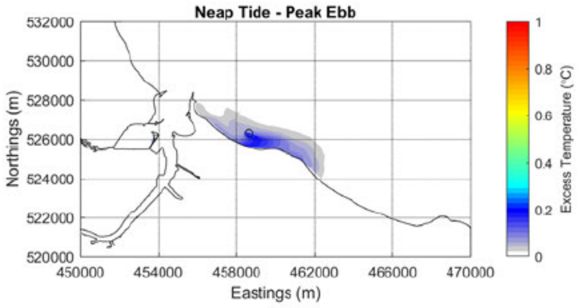
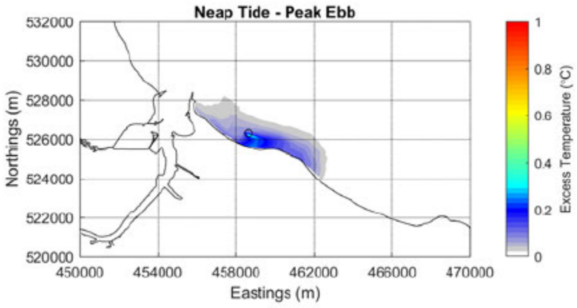
<table>
<tr><th colspan="2">Comparison of normal and extreme flow scenario: Summer Neap Tide – Outfall 2 Location</th></tr>
<tr><td colspan="2">4.08 m/s wind speed from 230°</td></tr>
<tr><th>Normal flow rate</th><th>Extreme flow rate</th></tr>
<tr><td>1.37 m^3/s discharge rate
15°C excess temperature (14°C ambient)</td><td>5.75 m^3/s discharge rate
5°C excess temperature (14°C ambient)</td></tr>
<tr><td> </td><td> </td></tr>
<tr><td> </td><td> </td></tr>
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Figure 35. **Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates**

5 Conclusion

Hydrodynamic modelling has been undertaken using the Delft3D flow modelling software to create a representative baseline condition of the Tees Estuary which produces a good comparison of flow, water level and vertical water column structure in the estuary in comparison with available measurements. Implementing the proposed cofferdam within the model run suggests that the impacts on flow speeds around the construction site will be very limited and restricted to within approximately 150 m of the structure when considering flow speed differences of >0.05 m/s. Changes in flow will be felt mostly in the faster flowing surface and mid water layers and less so nearer to the bed where flow speeds are lower. Flow directions will alter as flows are redirected around the new structure, extending further from the coastline than the original infrastructure. The proposed cofferdam structure is only temporary whilst enabling works are completed. Once finished, the cofferdam will be removed, and the orientation of the coastline will revert to the existing (baseline) condition.

Near-field thermal plume modelling has been undertaken using the CORMIX modelling software to trace the likely extent of thermal discharge at two proposed outfall locations. At Outfall 1, under spring conditions, the likely extent of a thermal plume (of the properties modelled) would be very localised: a 3°C temperature excess only extends approximately 45 m from the discharge point on the flood and 98 m on the ebb. Considering a 2°C temperature excess the ebb extent of the plume increases to 140 m, and then 235 m to the 1°C excess temperature contour, which still represents a very limited excursion from the original discharge point.

To examine the wider plume dispersion a 0.1°C temperature excess contour was exported from CORMIX. This shows that a 0.1°C temperature excess is estimated to extend around 750 m from the origin on a spring flood tide, and 720 m on an ebb. At lower speeds (e.g. near slack water), reduced mixing could allow the plume to stay buoyant for longer, however the excursion from the plume would be limited by the speeds and mixing with subsequent dispersion occurring as speeds increase through the tidal cycle. Sensitivity testing showed only a small influence on plume extent due to wind and seasonal variations, while the outfall orientation (horizontal or vertical) has a relatively larger impact on the dispersion of the plume.

At Outfall 2, as a result of lower energy conditions leading to lower/slower rates of dissipation of the outfall plume, the neap tidal phases offer a larger plume, when compared to the spring tide, under normal discharge conditions. In particular, the neap flood tide offers the largest plume extent as highlighted in Table 7 (run 19).

However, it is to be noted that the CORMIX model assumes full plume development under the given conditions and, in reality, the ambient flows (defined as constant in the model) will not persist long enough for a fully developed plume (as defined) to form. As the flows reduce, either side of the peak conditions modelled, and turn with the tidal phase, further dissipation of the plume is expected before it can fully develop to the state portrayed by the CORMIX outputs. The results of the far-field thermal modelling (using the Delft3D model) better represents the influence of the shifting tidal conditions on the discharge.

Far field plume dispersion modelling has been undertaken using the Delft3D modelling software using both the original and updated planned outfall locations for a range of environmental conditions. Temperature excess plots of the plume impact have shown a small impact of the outfall discharge on the ambient water temperature. Depth averaged temperature differences of >0.02°C are predicted up to ~9 km of the Outfall 2 site, however greater temperature excesses of up to 0.3° are localised to within 1.5 km of the outfall in all simulations modelled.

In order to ensure a robust assessment of the likely significance of the environmental effects of the Proposed Development, the Environmental Impact Assessment (EIA) for NZT is being undertaken adopting the principles of the 'Rochdale Envelope' approach, where appropriate. This involves assessing the maximum (or where relevant, minimum) parameters for the elements where flexibility needs to be retained (such as the building dimensions or operational modes for example).

Justification for the need to retain flexibility in certain parameters is also outlined in Chapter 4: The Proposed Development and Chapter 6: Alternatives and Design Evolution (ES Volume I (Document Ref. 6.2)). As such, the NZT ES represents a reasonable worst-case assessment of the potential impacts of the Proposed Development at its current stage of design.

In terms of coastal modelling, the reporting is highly precautionary for several specific reasons. For example, the parameters defined at the start of the modelling process were based on three CCGT trains; as the Proposed Development is now only for a single CCGT train, the modelling assumptions are highly precautionary. Furthermore, any performance benefits from the presence of a terrestrial mixing zone (i.e. surge pit / outfall retention pool) before discharge of treated effluent to the outfall have not been factored in. For this reason, no losses of heat to the atmosphere or through mixing with other water sources (i.e. surface water) were factored in (again, highly precautionary).

6 References

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NFRA: [redacted]

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Wood (2020). Gas Power – Cooling System Analysis Report 13430-01-8110-RP-3001 REV F1 DRAFT report. Selected data shared by AECOM, access to full report not provided to ABPmer.

7 Acronyms/Abbreviations

2D	Two Dimension(al)
3D	Three Dimension(al)
ADCP	Acoustic Doppler Current Profiler
AECOM	AECOM Ltd
CCGT	Combined Cycle Gas Turbines
CCUS	Carbon Capture, Utilisation and Storage
CD	Chart Datum
CFSR	Climate Forecast System Reanalysis
CTD	Conductivity-Temperature-Depth
CurDir	Current Direction
CurSpd	Current Speed
dd	Domain Decomposition
DHI	Danish Hydraulic Institute
Dir	Direction
EIA	Environmental Impact Assessment
ES	Environmental Statement
HD	Hydrodynamic
HW	High Water
ITT	Invitation to Tender
JBA	JBA Consulting
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
MMO	Marine Management Organisation
NFRA	National River Flow Archive
NRFA	National River Flow Archive
NZT	Net Zero Teesside
ODN	Ordnance Datum Newlyn
OSGB	Ordnance Survey Great Britain
Q	Quartile
RORO	Roll-on/Roll-Off
THPA	Tees and Hartlepool Port Authority
UK	United Kingdom
UKHO	United Kingdom Hydrographic Office
WL	Water Levels
WS	Wind Speed

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices

Innovative Thinking - Sustainable Solutions

A Delft Model Setup

For the present study a three-dimensional hydrodynamic model has been run using the Delft3D software package developed by Deltares. The version of the software used for this study is version 4.03.01 The software is designed for complex applications within oceanographic, coastal and estuarine environments. The Delft3D-FLOW module has been used to simulate the tidal water variation and flows in the area of interest.

ABPmer holds an existing Delft3D model of the Tees Estuary, calibrated and validated against various datasets within the area (ABPmer 2003). This existing model forms the basis for the current study: The original model has been refined across the region of interest and updated with recent bathymetric data with high resolution coverage across key areas. The model performance has been cross checked against previous simulations and the calibration re-assessed against measured data available for this study. The setup of the Delft3D model is detailed in this section; the performance of the model is then demonstrated in Appendix B of this report.

A.1 Model grid

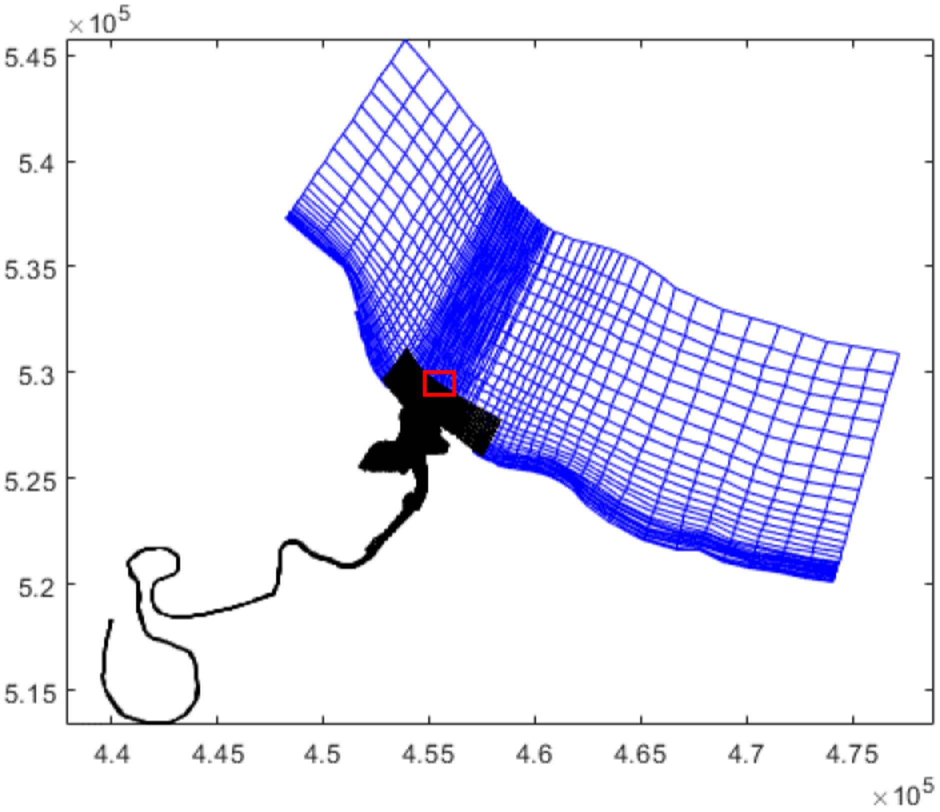
The Delft3D model uses a curvilinear computational grid, which allows a grid composed of various sizes to be used throughout a model domain. In addition to this, the original hydrodynamic model has been further refined using a 'domain decomposition' (dd) approach. This approach allows the creation of higher resolution grids which can be nested within the wider area domain, and dynamically coupled using defined dd boundaries. Two domains have been created in the Tees Estuary hydrodynamic model.

These are shown in Figure 36, with the outer grid shown in blue, and the nested (finer resolution) inner grid in black. A refinement factor of 1:3 was applied in the nested grid, in line with Deltares guidance, illustrated in Figure 37

Beyond the Tees barrage the river section of the HD model does not align with the Tees River Channel. This part of the model was altered during the calibration phase of the previous modelling work (ABPmer 2003) to accurately represent the correct water volumes up to the tidal limit of the estuary when simulating pre-barrage conditions in the Tees. For the present study the barrage is in included in all simulations as a barrier which does not allow the movement of saline water upstream, and the flow across the barrage is represented as a time varying discharge (details of the of these are provided in Section A.3.2). The upstream part of the Delft3D model is therefore effectively excluded from the hydrodynamic computations beyond the Tees Barrage.

Table 12. Model grid resolution

Area	Average Dimensions (m)
Offshore boundary	1,000 x 1,000
Outfall location	160 x 80
Central Estuary	30 x 30
Upper Tees	12 x 150



Red box shows extent of zoomed view (Figure 37)

Figure 36. Delft3D hydrodynamic model grid

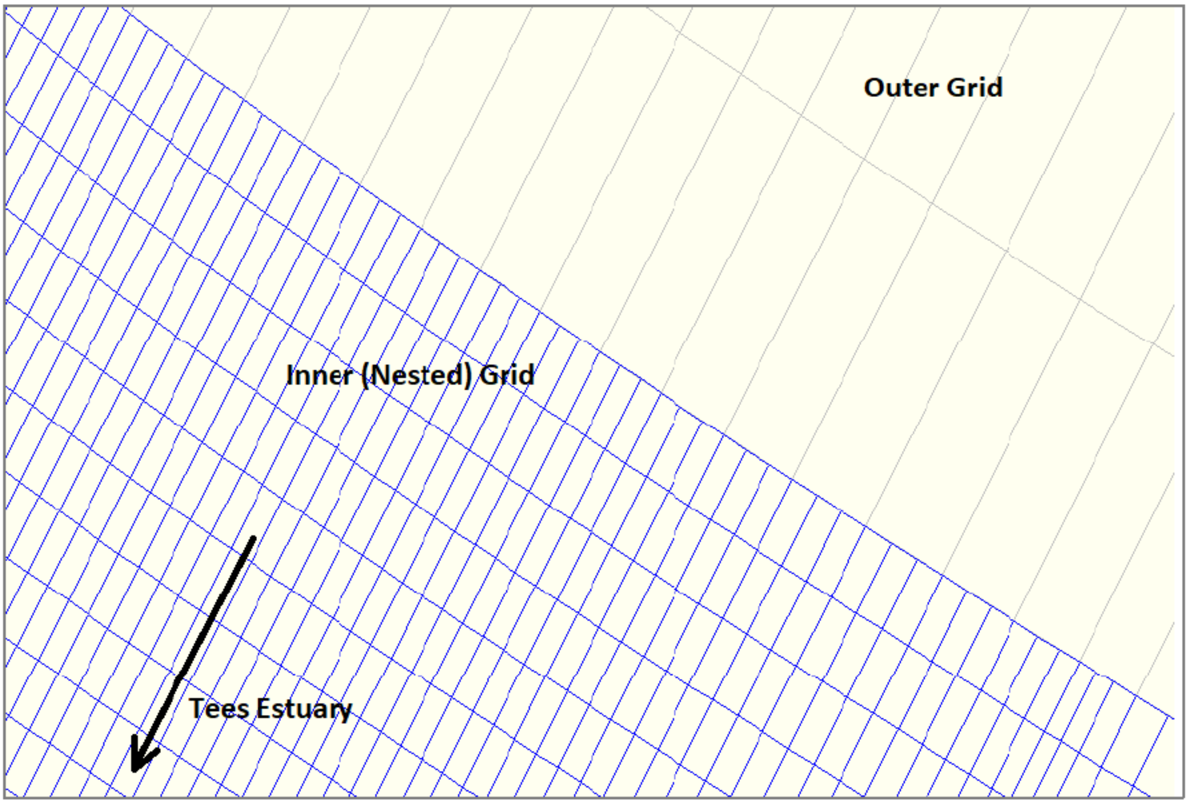


Figure 37. Delft3D hydrodynamic model grid – Refinement of nested grid

A.1.1 Vertical structure

The hydrodynamic model is three-dimensional (3D) with eight layers through the vertical representing 2, 3, 5, 7, 10, 15, 23 and 35% of the water column, respectively, from surface to bed. This configuration gives enhanced focus in the upper part of the water column, making the model suitable for any ongoing thermal plume or contamination modelling.

A.2 Bathymetry

The bathymetric data for the model grid construction has been compiled from the following sources:

PD Teesport Redcar Bulk Terminal Survey Data: Provided by AECOM as a digital .pdf drawing. This provides surveyed depths around the Redcar Bulk Terminal from soundings taken on 29/01/2020. Depths are provided to LAT.

PD Teesport Survey Data: xyz bathymetry data were provided by AECOM from PD Teesport surveys dating from 2019. Depth information has been provided relative to chart datum. These data cover the main channel to approximately 3.5 km beyond the estuary mouth and upstream to 2 km beyond the Tees Dock Tide Gauge.

LiDAR Contours: LiDAR data have been downloaded from the Defra survey download portal[1], to provide coverage of the intertidal areas within the Tees Estuary and outer coastline. Data have been downloaded from the available composite catalogue of the Tees area which means that sampling dates from the data may not be coincident across the spatial extent. However, the data is considered adequate for the purpose of model construction to achieve the correct volumes of water movement across the intertidal zones. The data have been cleaned to remove the water surface from the measurements and the data imported in 0.5 m depth contours up to the +3 m ODN level.

CMap: AECOM have provided bathymetry data for Tees Mouth and Tees Bay from the CMap database. Data were provided relative to chart datum and ODN. CMap is an electronic chart database managed by the Danish Hydraulic Institute (DHI) as part of their Mike software modelling provision. Spatial coverage provided by this database is adequate in the offshore region of the model but sparse within the estuary relative to the spatial resolution of the model grid.

Admiralty Charts: Admiralty charts of the Tees Estuary[2] have been used to inform the water depth in areas where alternative data were sparse. Chart depths were manually digitised for the areas of interest which included the Philips Inset Dock and dredged areas of the Tees river channel.

River Data: Beyond the region of the Teesport survey the depths in the Tees river have been extracted from previous ABPmer models of the Tees (ABPmer 2003). These originated from Tees and Hartlepool Port Authority surveys and Admiralty chart depths.

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[1] https://environment.data.gov.uk/DefraDataDownload/?Mode=survey

[2] Admiralty Chart 2566 Tees and Hartlepool Bays

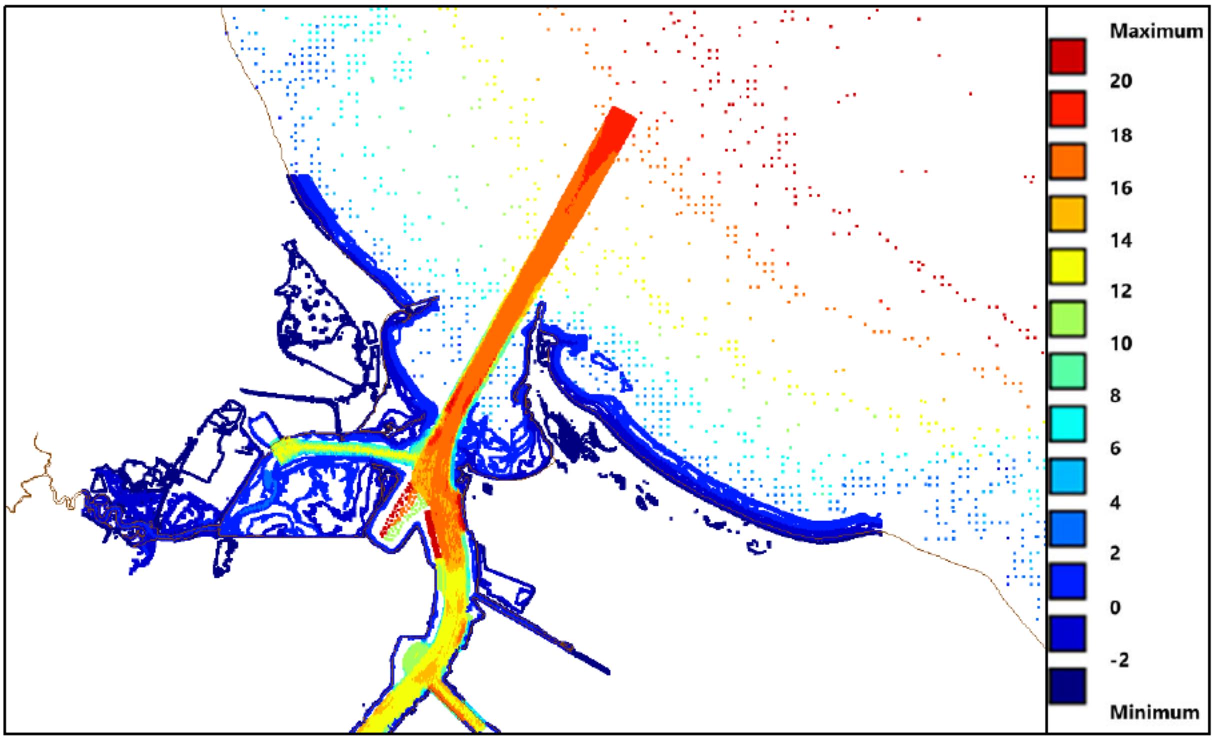


Figure 38. Scatter plot showing available bathymetry data resolution and coverage. All values are depth positive and referenced to meters below ODN.

A.2.1 Bathymetry data processing

All bathymetry datasets were converted to Ordnance Datum Newlyn (ODN) using the values stated on the Admiralty Tide Tables for the Tees: ODN = CD +2.85 m. This relationship is consistent with the CMap conversions already supplied by AECOM.

Where bathymetry data from different sources overlapped, these datasets were cropped to consider only a single dataset for any spatial area and allow smooth interpolation of bathymetry through the model: prioritising the best quality datasets. In order of priority these were:

- PD Teesport Survey;
- LiDAR Contours;
- CMap;
- Admiralty Chart; and
- Previous model depths in the upper section for rivers.

The bathymetry interpolation across the model grid was visually assessed to ensure contours appeared smooth and consistent, particularly across the interface between the nested grids and in key areas of interest.

A.3 Model Setup

A.3.1 Offshore tidal boundaries

The hydrodynamic model is defined by three offshore boundaries driven by tidal harmonics, shown in Figure 39.

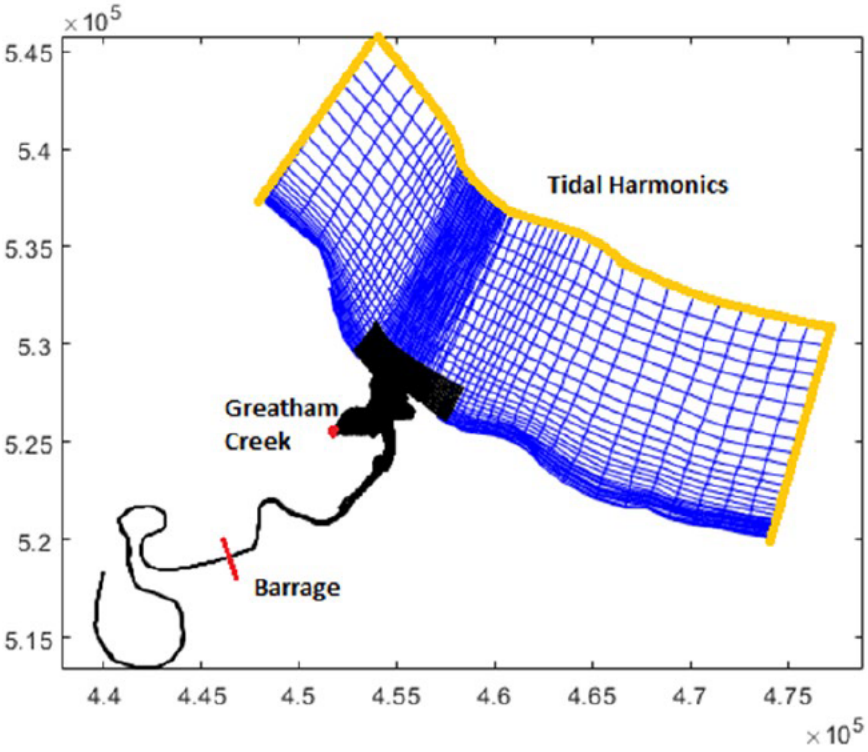


Figure 39. HD model domain and boundary positions (shown by yellow lines)

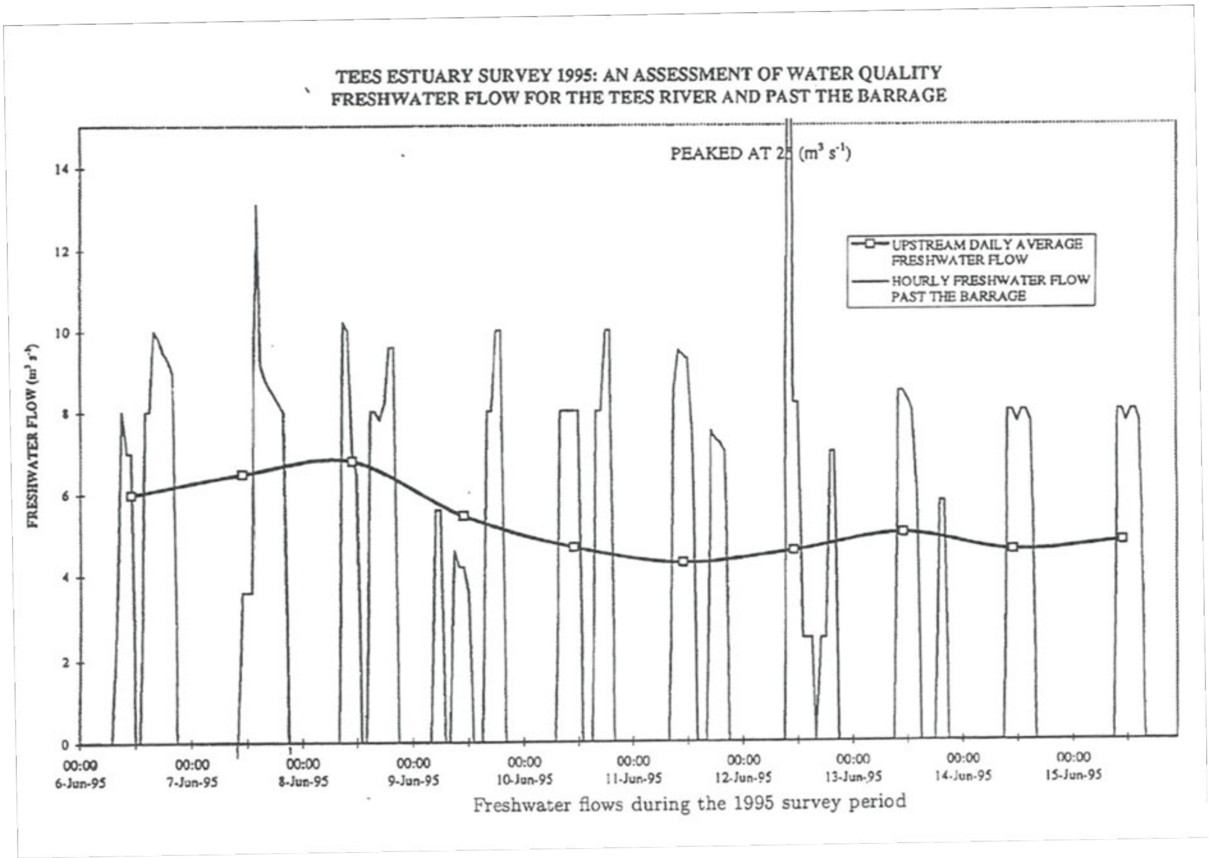
The harmonic constituents defined at these boundaries have been extracted from a wider area model (ABPmer 2003) previously constructed by ABPmer which has previously been calibrated and verified against three data sets. This data has been derived from TIDECALC (a programme for generating tidal predictions for and time period), Admiralty charts and THPA fixed current meter observations. The tidal constituents included in each boundary are given in Table 13. The amplitude and phase of each constituent is defined along the model boundaries. Each boundary is described using more than one set of tidal harmonics to allow any gradient in surface elevation along the boundary to be replicated.

Table 13. Tidal constituents in the numerical model

Harmonic	Brief Description
A0	Initial constituent
M2	Main lunar semidiurnal constituent
S2	Main solar semi-diurnal constituent
N2	Lunar constituent due to monthly variation in the Moons distance
K2	Solar-lunar constituent due to changes in declination of the sun and the moon throughout their orbital cycle
O1	Main lunar diurnal constituent
K1	Solar-lunar constituent
L2	Elliptical lunar semi-diurnal constituent
Q1	Elliptical lunar diurnal constituent
P1	Main solar diurnal constituent
EPSILON2	Lunar semi-diurnal constituent
NU2	Lunar semi-diurnal constituent
LABDA2	Evectional semi-diurnal constituent
M4	Shallow water component
MS4	Shallow water component

A.3.2 Inclusion of the Tees Barrage

At the upstream boundary of the model the Tees barrage is included in the model as a ‘thin dam’ structure, which acts as a barrier to saline water to extend upstream of this point. In addition, a freshwater discharge was added at the section of the barrage. The setup of the discharge takes into consideration that the barrage acts as a barrier to the upstream movement of the tide. The freshwater release from the barrage is not continuous. Survey data available from previous studies indicates that the release of water typically occurs at mid-day, regardless of tidal state (Figure 40). Whilst the survey data is for a period of time in 1995, it is not expected that this will have changed considerably over the years and is therefore suitable for this type of assessment.



Extracted from: ABPmer 2003

Figure 40. **Tees Estuary survey, 1995: Freshwater flow past the barrage**

Freshwater discharges from the barrage have been calculated from flow data available from the National River Flow Archive (NRFA)[3]. Data from gauging stations at Leven Bridge and Low Moor have been assessed to derive the annual mean flow for the combined stations as well as the 5% and 95% exceedance values which have been extracted to represent the winter and summer conditions, respectively. These have been chosen to provide the highest and lowest discharges of the year. Data from the measurement stations (Figure 41 are presented in Table 14, and the derived mean, summer and winter flows across the barrage in Table 15. The discharge from the barrage is defined in the model as a time varying input of fresh water, peaking at each mid-day in the simulation at the values calculated in Table 15.

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[3] [redacted]

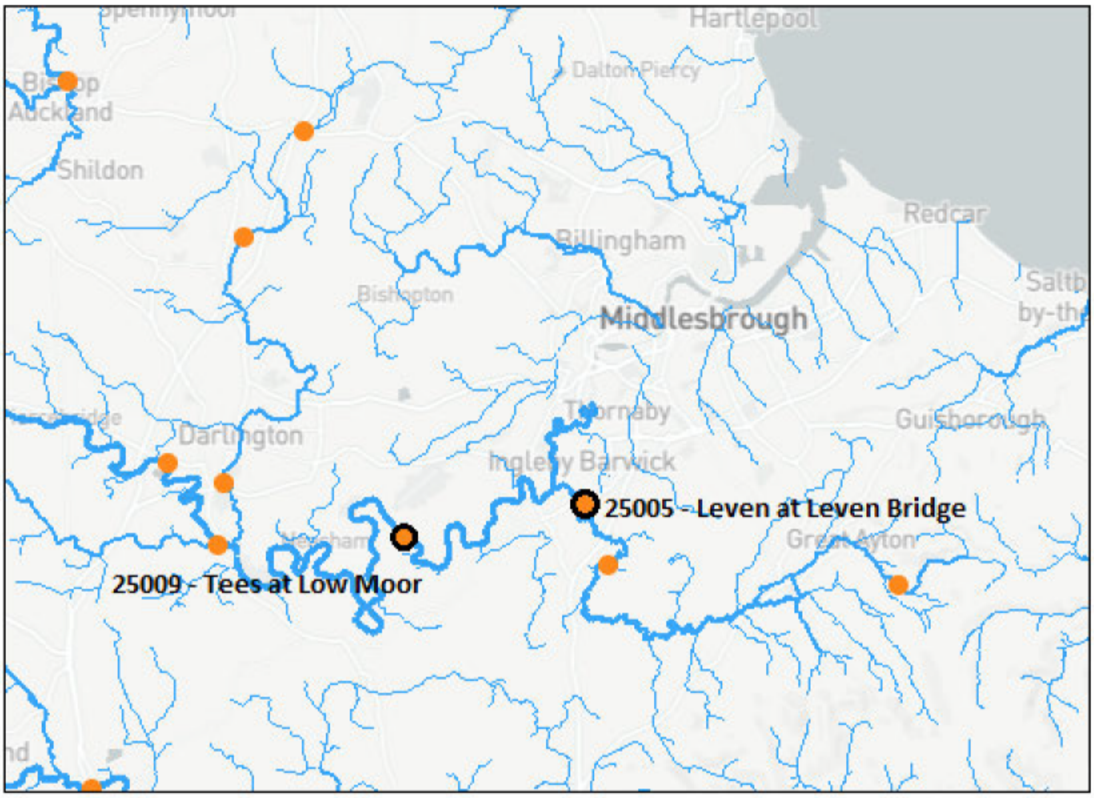


Figure 41. Flow data stations assessed for Tees Barrage discharge calculations

Table 14. Flow data from the Leven and Tees

	25005 - Leven at Leven Bridge	25009 - Tees at Low Moor
Period of Record:	1959 - 2008	1969 - 2018
Percent Complete:	>99 %	0.98
Base Flow Index:	0.42	0.39
Mean Flow:	**1.892 m^3/s**	**20.528 m^3/s**
95% Exceedance (Q95):	**0.249 m^3/s**	**3.07 m^3/s**
70% Exceedance (Q70):	0.517 m^3/s	6.15 m^3/s
50% Exceedance (Q50):	0.873 m^3/s	10.9 m^3/s
10% Exceedance (Q10):	4.248 m^3/s	46.5 m^3/s
5% Exceedance (Q5):	**6.78 m^3/s**	**67.7 m^3/s**

Source: National River Flow Archive, March 2020

Table 15. Peak discharge rates at the barrage for flow modelling

Parameter	Flow rate (m^3/s)
Mean Flow	22
Summer	3
Winter	74

A.3.3 Greatham Creek

A discharge has been defined in the model where freshwater enters the estuary at Greatham Creek. No local flow data has been forthcoming in the project, discharges have therefore been based on values adopted by JBA Consulting in previous modelling work (JBA, 2011) and set at a constant 1.8 m^3/s freshwater input for all modelled scenarios.

A.3.4 Salinity

Salinity was included in the hydrodynamic model because the Tees has both a vertical and lateral salinity distribution.

Salinity values have been defined at all existing boundaries and discharge locations: The seaward boundary salinities were set to 35 ppt whilst at Greatham Creek and the Tees Barrage the discharges were defined as completely fresh (0 ppt).

An initial salinity value of 33.9 ppt was defined across the whole model domain based on values provided by AECOM from the Wood Draft Report (Wood, 2020) for seawater properties.

A.3.5 Wind speed

Wind speed data have been provided by AECOM to ABPmer from the location of the Durham Tees Valley airport anemometer. Data are available between 01/01/2015 and 31/12/2019 at hourly intervals, providing wind speed and direction.

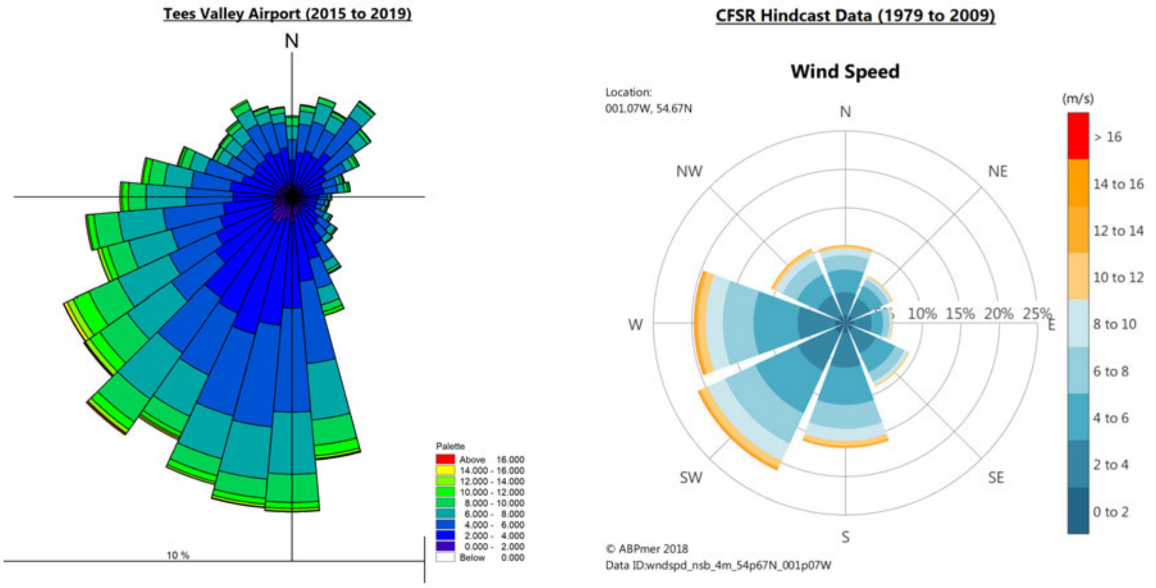


Figure 42. **Wind rose of Tees Valley Airport wind data (left) and CFSR Hindcast data (right).**

The wind speed and direction data have been analysed to calculate the monthly average wind speeds and direction across the five-year record (Table 16).

From these averages, the highest and lowest average speeds were taken as the winter and summer peak values and the annual average used for the mean condition runs. The direction was sufficiently consistent that a value of 230°N was selected for all model runs. This was checked against the wind rose created from the data, along with data from CFSR Hindcast data obtained from ABPmer's database.

The measurement height of the records is 10 m above ground level and therefore require no further adjustment before being applied in the model.

The wind field was applied as a constant speed and direction across the model domain throughout each model simulation

Table 16. Monthly average wind speeds (m/s) from Durham Tees Valley Airport

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average WS	5.14	5.16	**5.32**	4.50	4.55	4.42	**4.08**	4.64	4.35	4.47	4.91	5.05	**4.72**
Average Dir	228	217	**236**	262	271	253	**234**	218	221	230	231	210	**227**

A.3.6 Bed roughness

The sediment type in the Tees Estuary varies between silt and gravel in the upper estuary, to sands at the estuary mouth. The majority of material moving at the bed is sand sized (ABPmer, 2003), and the bed roughness in the Delft3D HD model has, therefore, been set to a constant value throughout the model. The roughness formulation has been changed from Chezy to Manning (n) as the latter is designed for use in an environment where depths are shallow. A constant value of 0.025 ($m^{-1/3}s$) has been defined in both the U and V direction.

A.4 Model run period

The Delft3D hydrodynamic model was run for three simulation periods, described in the following paragraphs. The model takes approximately 24 hours of simulated time to 'warm up': where the flows and water levels stabilise to allow the hydrodynamic processes in the estuary to be simulated in a realistic way.

Calibration period: 20/04/2005 to 01/05/2005: The model was run for a 12-day period, including one day of warm up time, to coincide with the ADCP and CTD data available from PD Teesport (see Appendix B). The model duration is centred on a spring tide, with a maximum tidal range of 4.80 m (mid estuary). This is slightly larger than the mean spring range of 4.6 m for the River Tees Entrance reported in the Admiralty tide tables (UKHO, 2020).

Validation period: 13/10/2001 to 27/10/2001: This model period was selected to duplicate the run period of the previous hydrodynamic model (ABPmer 2003). This 14-day run period includes a period of mean spring and mean neap range. The tidal range also reaches a 5.5 m at the peak of the spring tide. Repeating this model run time also allows flow speed and direction comparisons to be made against the previous project model runs and measured data available from the previous project.

2019 Seasonal Runs: 23/06/2019 to 08/07/2019: Following calibration and validation the model was simulated for a period in 2019 to generate outputs for summer, winter and average conditions, described in the model setup paragraphs in A.3. These model runs were used to extract flow conditions for the CORMIX thermal plume modelling (Section 2) The model was run for a 14-day simulation period, which was selected to ensure that mean spring and mean neap tidal conditions were captured within the model run time.

B Delft3D Model Calibration

A calibration and validation exercise are required to provide a measure of confidence in the numerical model performance. Model data from the three run periods (Section A.4) were used to undertake calibration and validation of the model, selected to coincide with the available calibration datasets, details of which are provided in the following sections.

B.1 Flow model calibration

B.1.1 Water levels

Measured water level data are available from two tide gauges in the Tees Estuary; Tees Dock and Riverside RORO, detailed in Table 17. All water level measurements were transformed to mODN using the 2.85 m adjustment sourced from the Admiralty tide tables for the Tees.

Table 17. Tide gauge data summary

Name	Dates	Location (OSGB)	Description
Riverside RORO	20/11/2018 to 21/01/2020	454922 524424	Water level measurements relative to Chart Datum
Tees Dock	08/06/2009 to 14/08/2019	454311 523508	Water Level measurements relative to Ordnance Datum

Time series data of water levels were extracted from the numerical models for the nearest appropriate model grid cell to the measured locations (shown in Figure 43).

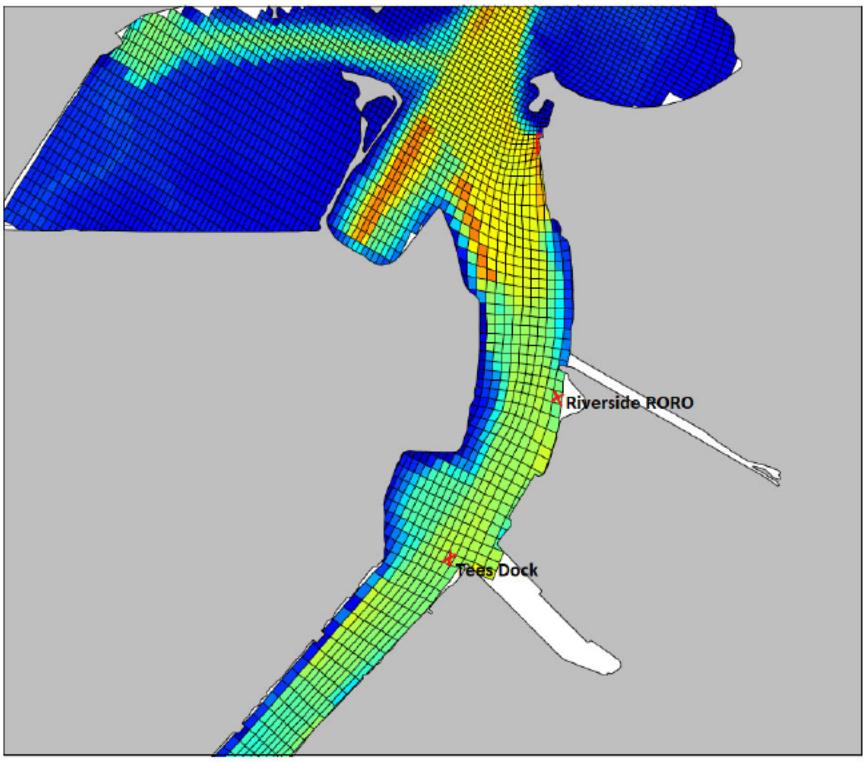


Figure 43. Location of model extraction points for tide gauge calibration overlaid onto model grid and underlying bathymetry.

Time series comparisons of the measured and modelled datasets are shown in Figure 44 and Figure 45.

It can be seen that there is good agreement in the phasing and amplitude between the two datasets at both locations. It is worth noting that the measured gauge data will also include any residual water variations driven by meteorological forcing at the time of measurements, while the modelled data represent only the tidal component of water level.

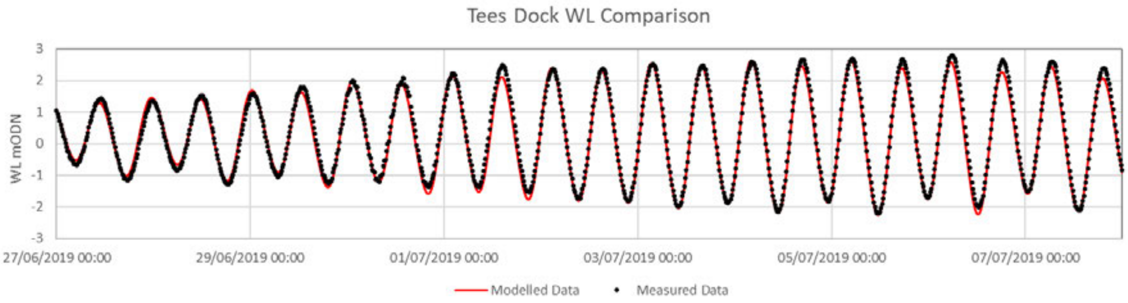


Figure 44. Water level comparison: Model vs measured data (Tees Dock)

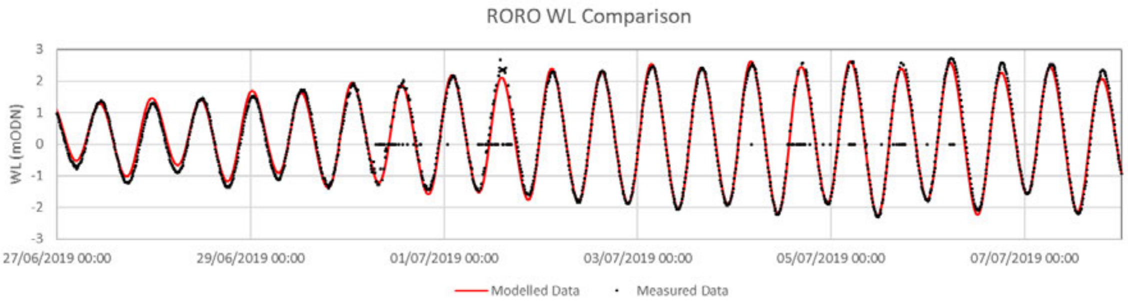


Figure 45. Water level comparison: Model vs measured data (Riverside RORO)

B.1.2 Flow speeds and direction

ADCP flow data 2005

ADCP survey data has been provided by AECOM from PD Teesport. These consist of field data and plots from a measurement campaign undertaken between 21/04/2005 and 30/04/2005. Flow data have been measured across 11 transects between the entrance to Philips Inset Dock and the bend in the Tees at Middlesbrough. For the purposes of model assessment, visual comparisons have been made between the transect plots provided by AECOM in the data files, and flow cross section data extracted from the model presented in a similar way for comparison. These comparisons are shown in Figure 46 to Figure 75. The following points should be considered when viewing these comparisons:

- Colour maps of speed and direction in the modelled outputs have been matched, visually, as closely as possible to the PD Teesport plots, however some small variation may exist between the two.
- The horizontal axis of the modelled transects represent model grid cells. These are plotted as being of equal width across the channel. This is a reasonable approximation across the transects considered – however it does mean that the X axis of the plots are not directly comparable and transect start and end points may not exactly align with the model cells.

- The vertical structure in the model is split into 8 layers, each representing a fixed percentage of the water column (see Section A.1.1). The absolute depth of each of these layers will vary with position in the estuary (depending on water depth) as well as through time as the water level rises and falls. The model data layers have been plotted to visualise this variation.
- Modelled flow data across the transects are exported from the model at hourly intervals. When comparing against available measurements the nearest hourly record has been identified and plotted. The tidal state relative to high water has also been checked against the notes in the ADCP data files.
- Flow data comparisons have been presented for two transects at different stages of the tide to provide a selection of visual assessments within this report.

Throughout the comparison of flow speeds and direction in Figure 46 to Figure 75. there appears to be good visual agreement between the measured ADCP transects and the modelled outputs. The variation in surface flows and the main water column at various stages of the tide appears to be well simulated in the model and in agreement with the measured data. Variations in flow direction with depth also appear to correlate between the measurements and modelled data which lends confidence in the model's ability to simulate the flow through the vertical water structure.

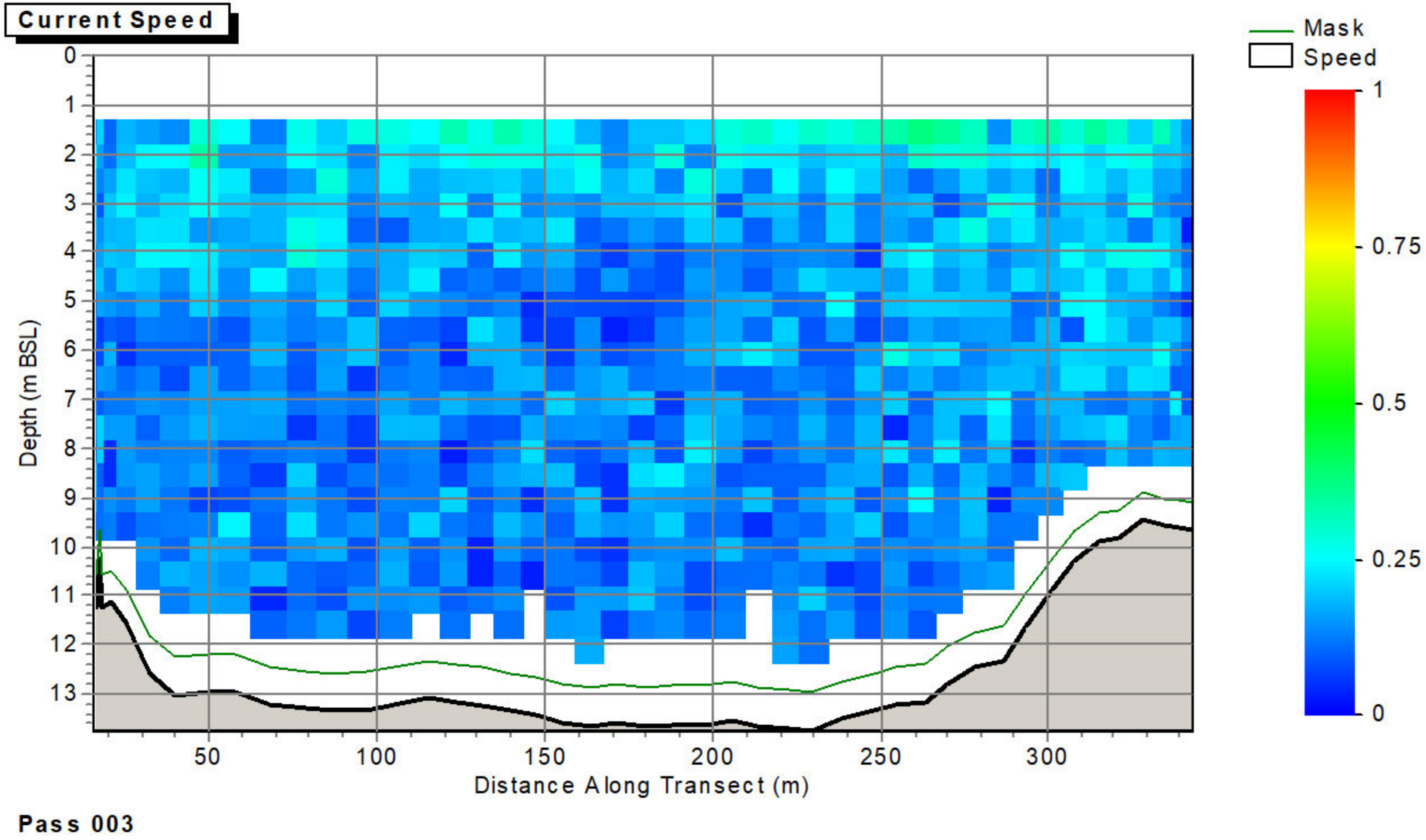


Figure provided by PD Teesport

Figure 46. Measured flow speeds, Transect 1, Pass 3: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

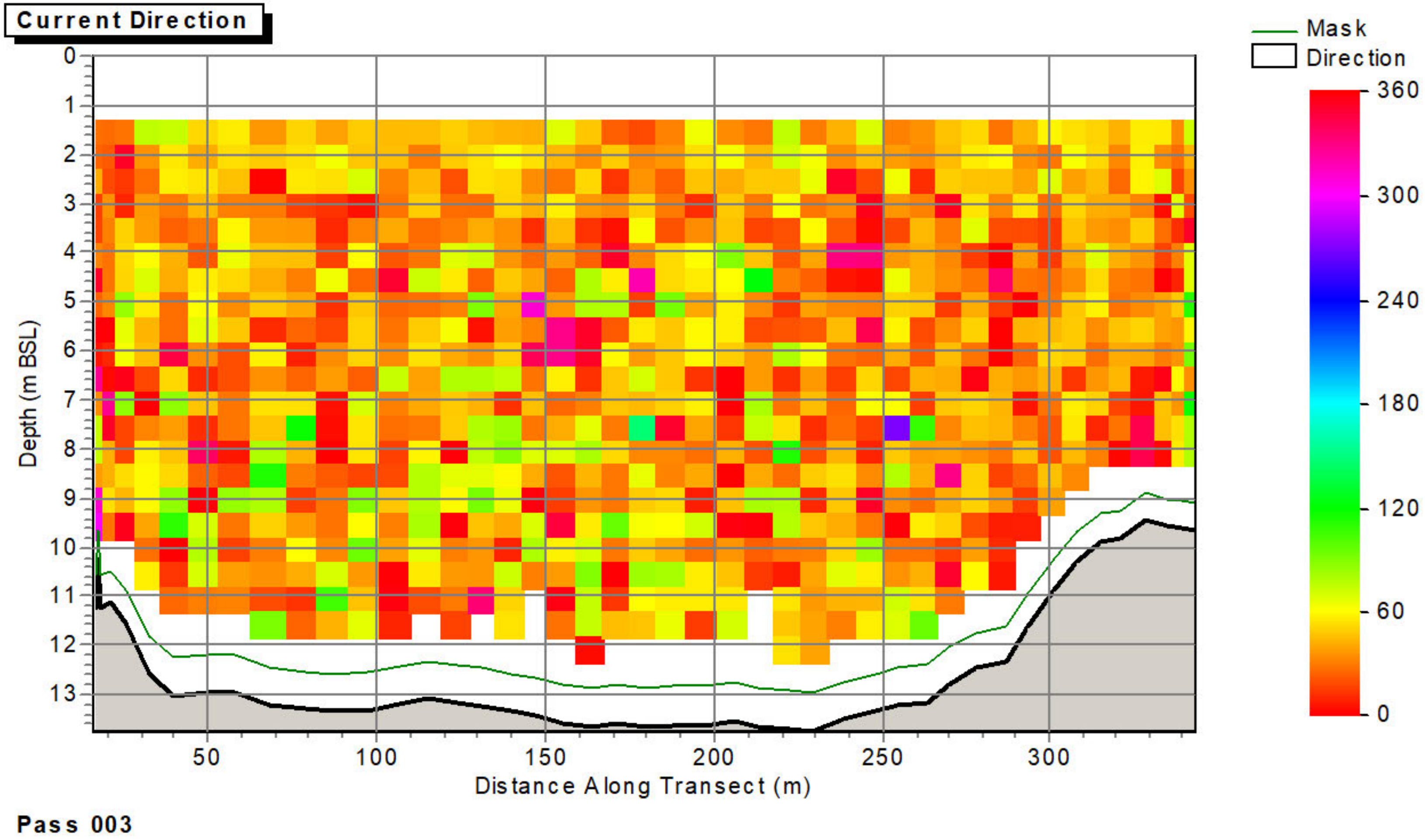


Figure provided by PD Teesport

Figure 47. Measured flow direction, Transect 1, Pass 3: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

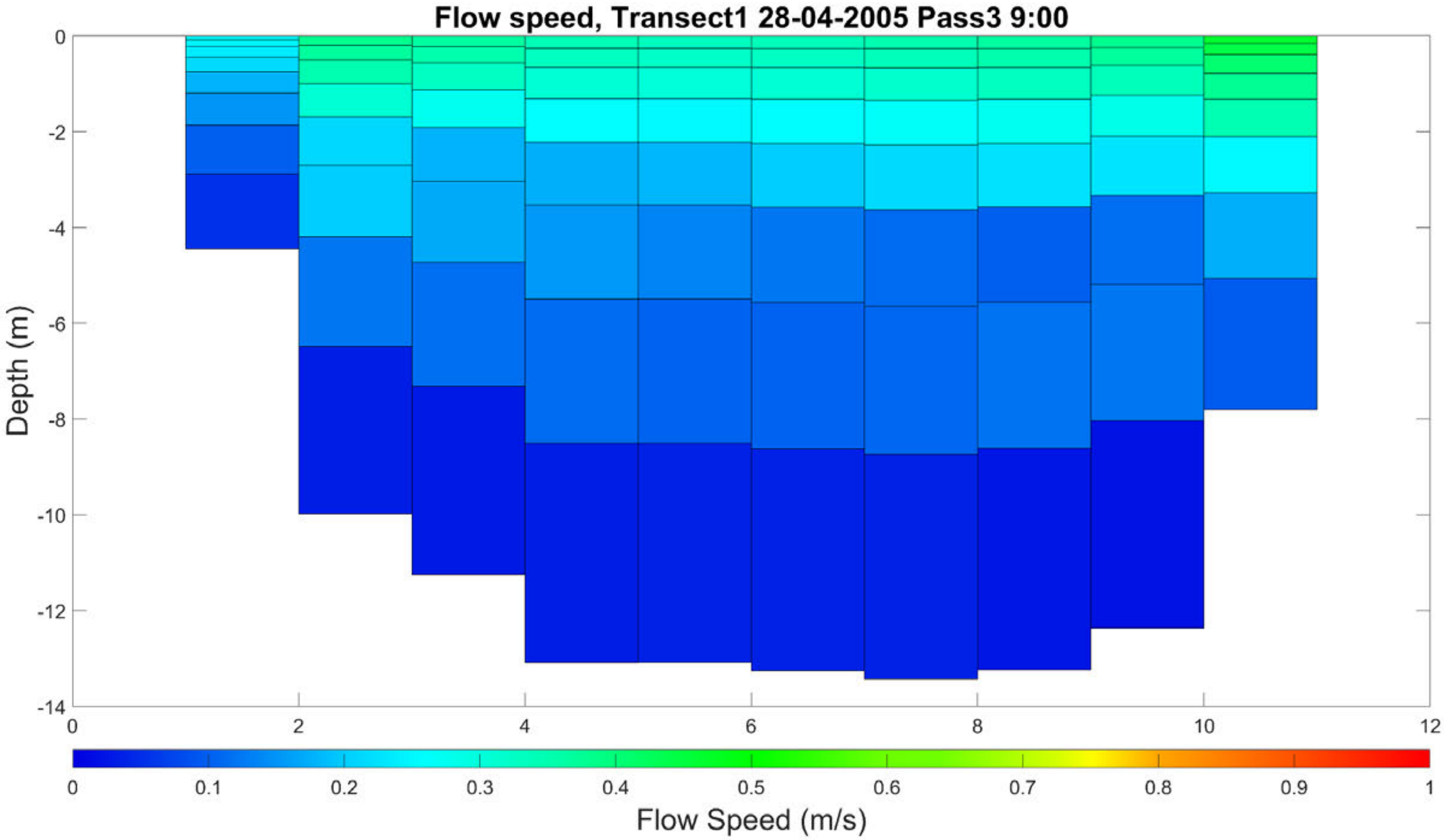


Figure 48. Modelled flow speed, Transect 1: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

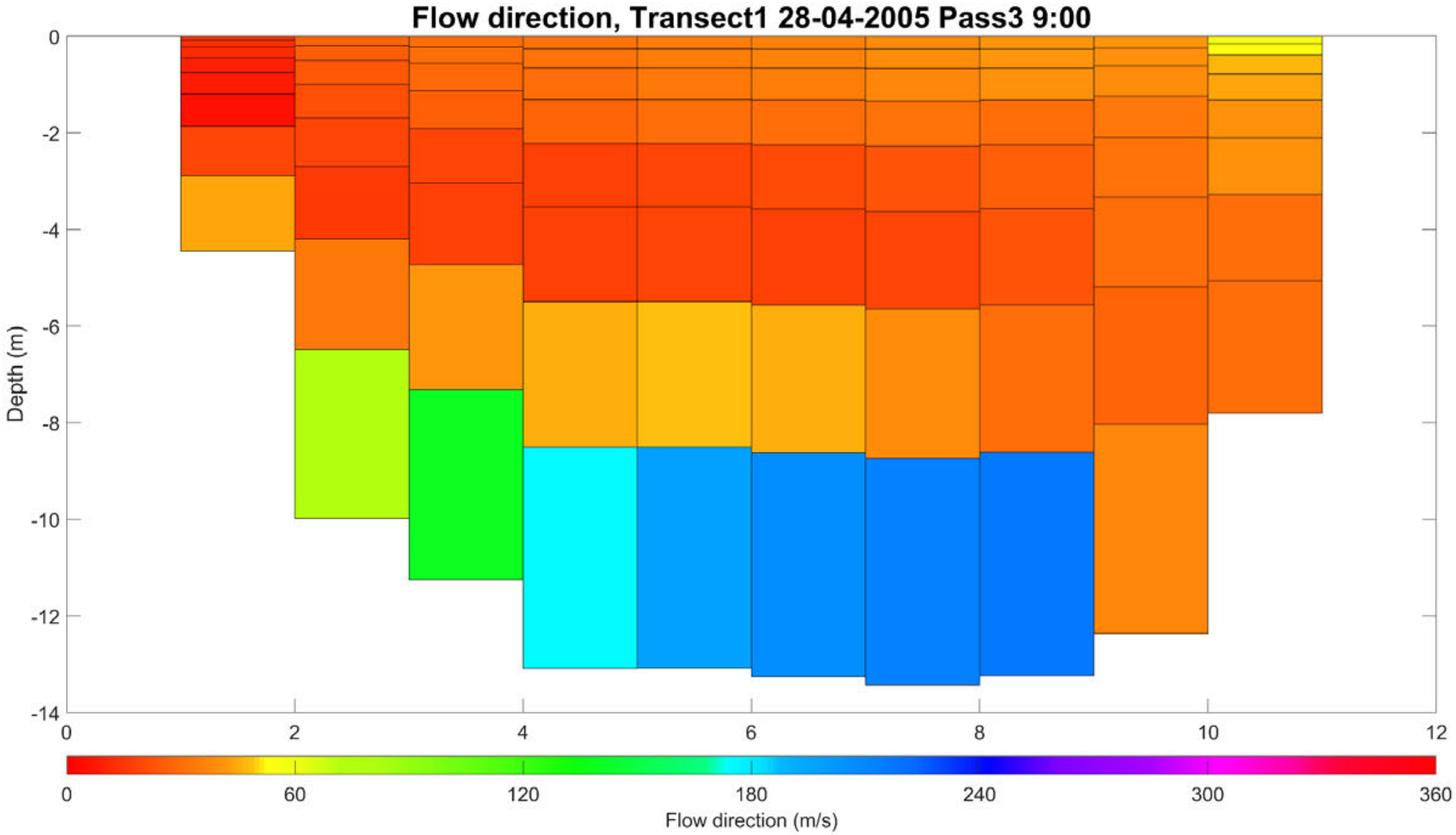


Figure 49. Modelled flow direction, Transect 1: Ebb tide, cross section of direction with depth shown from west (left) to east (right)

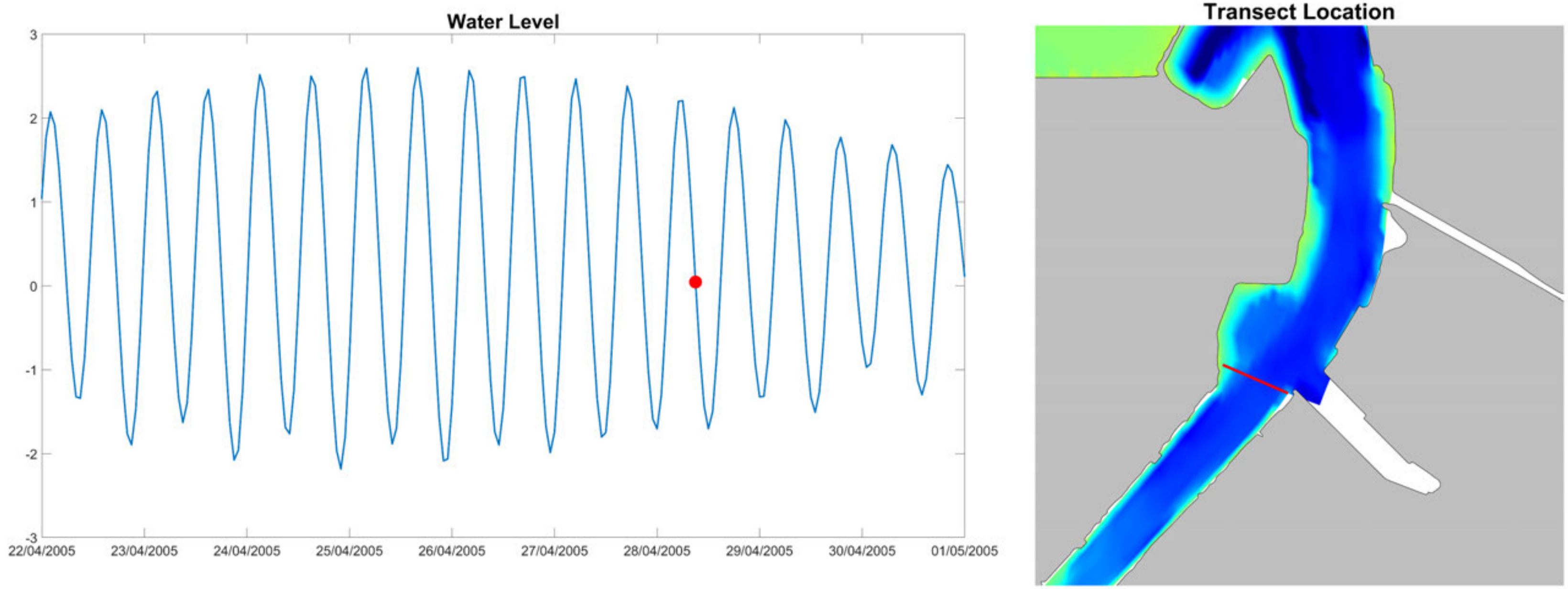


Figure 50. Tidal state and transect location extracted from the model for Transect 1 Pass 03: 28/04/2005

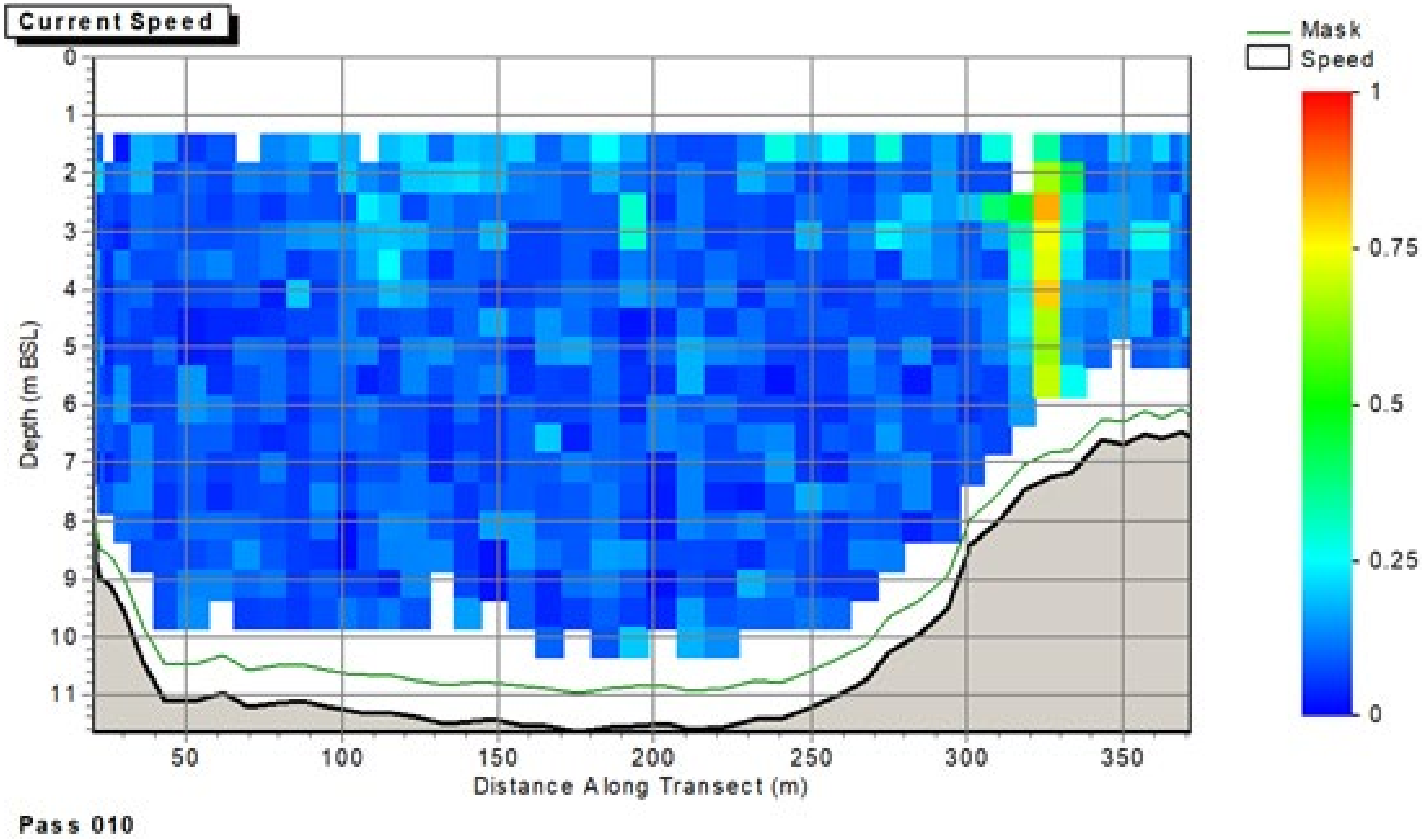


Figure provided by PD Teesport

Figure 51. Measured flow speeds, Transect 1, Pass 1: Low water, cross section of speed with depth shown from west (left) to east (right)

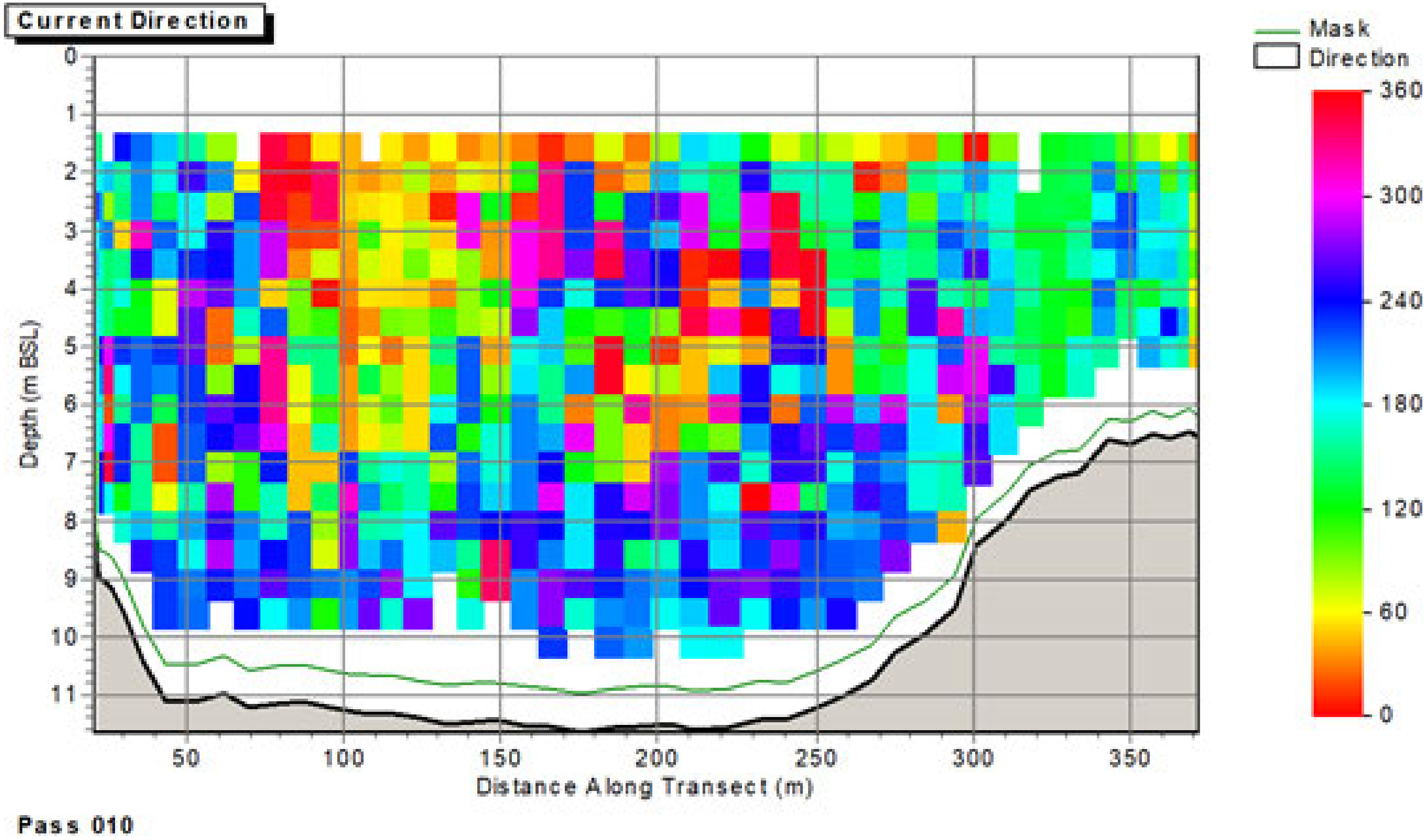


Figure provided by PD Teesport

Figure 52. Measured flow directions, Transect 1, Pass 1: Low water, cross section of speed with depth shown from west (left) to east (right)

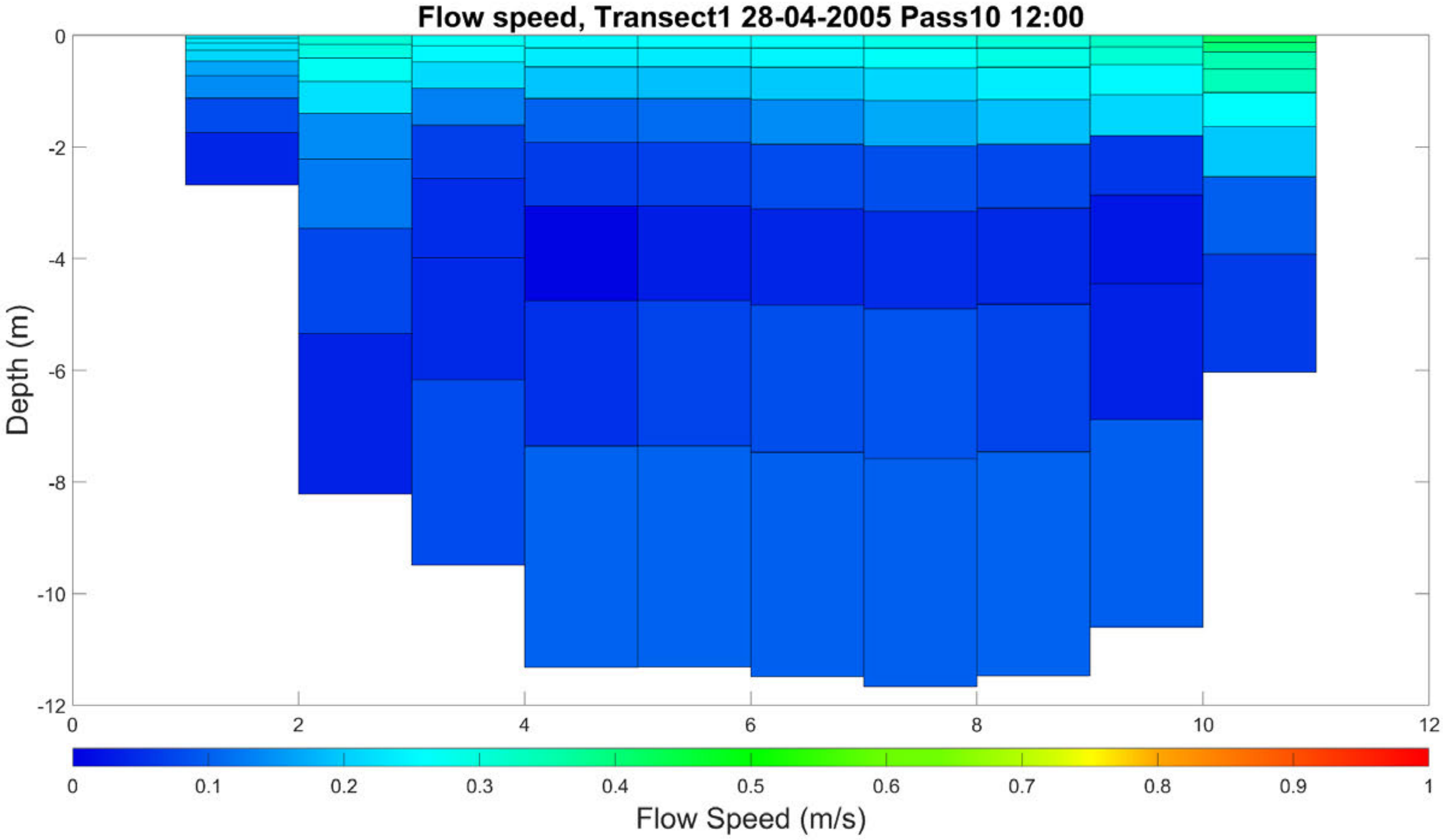


Figure 53. Modelled flow speed, Transect 1: Low tide, cross section of speed with depth shown from west (left) to east (right)

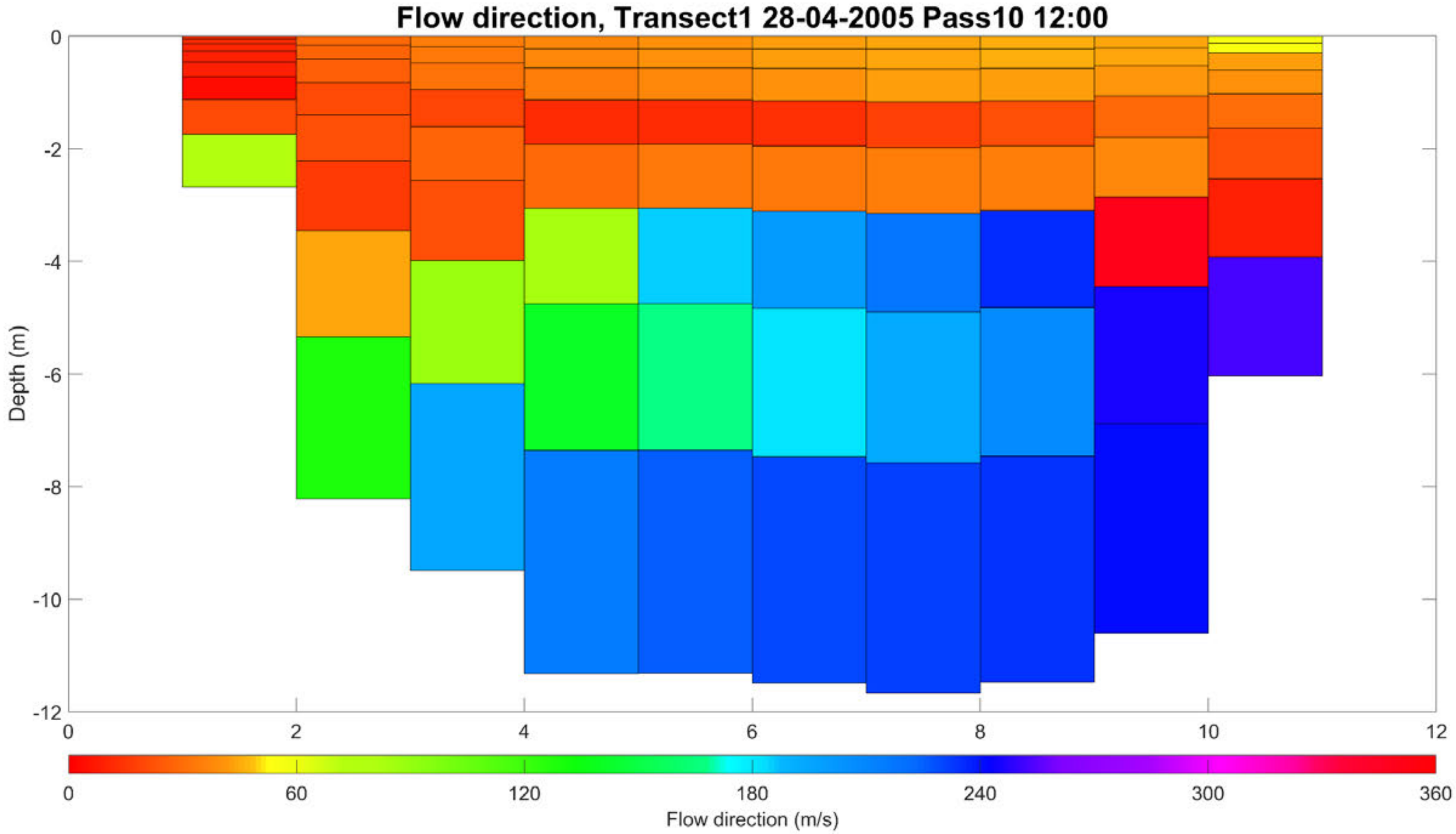


Figure 54. Modelled flow direction, Transect 1: Low tide, cross section of direction with depth shown from west (left) to east (right)

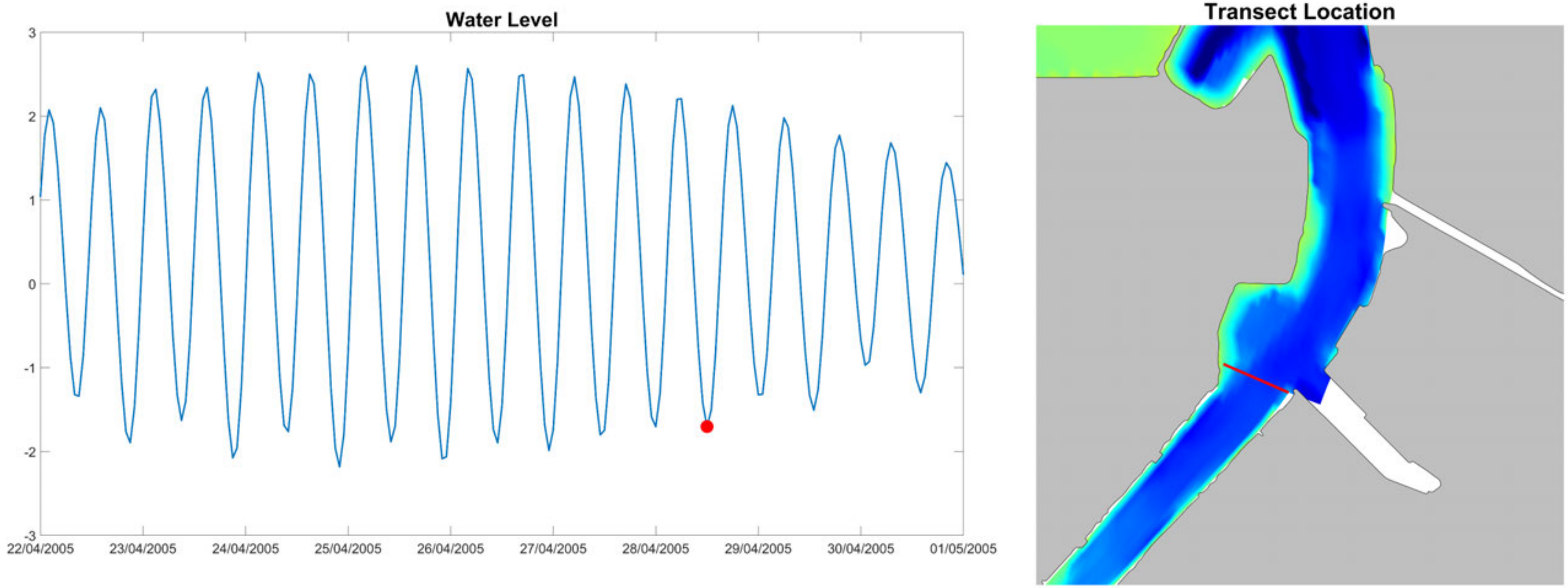


Figure 55. **Tidal state and transect location extracted from the model for Transect 1 Pass 01: 28/04/2005**

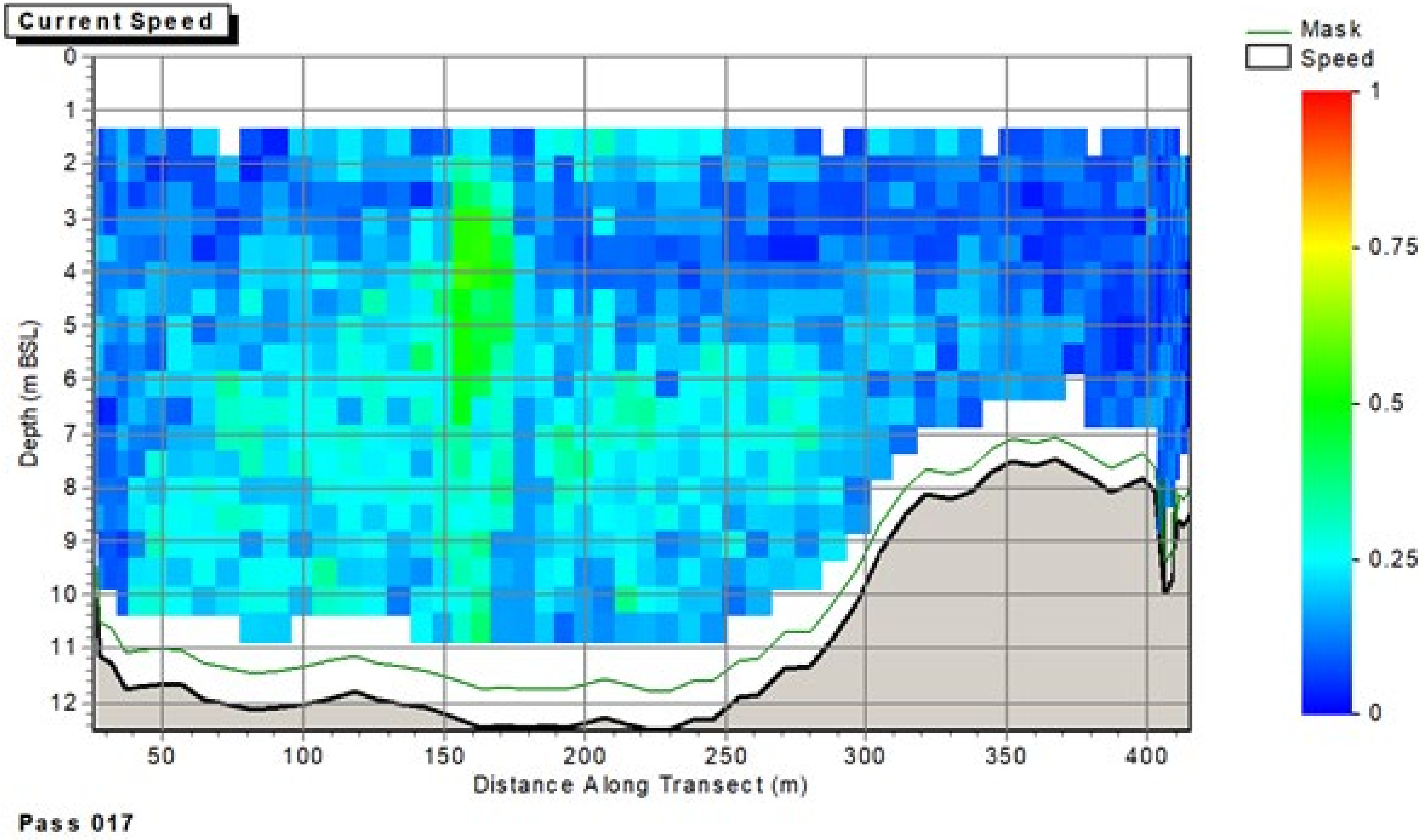


Figure provided by PD Teesport

Figure 56. Measured flow speeds, Transect 1, Pass 17: Flood tide, cross section of speed with depth shown from west (left) to east (right)

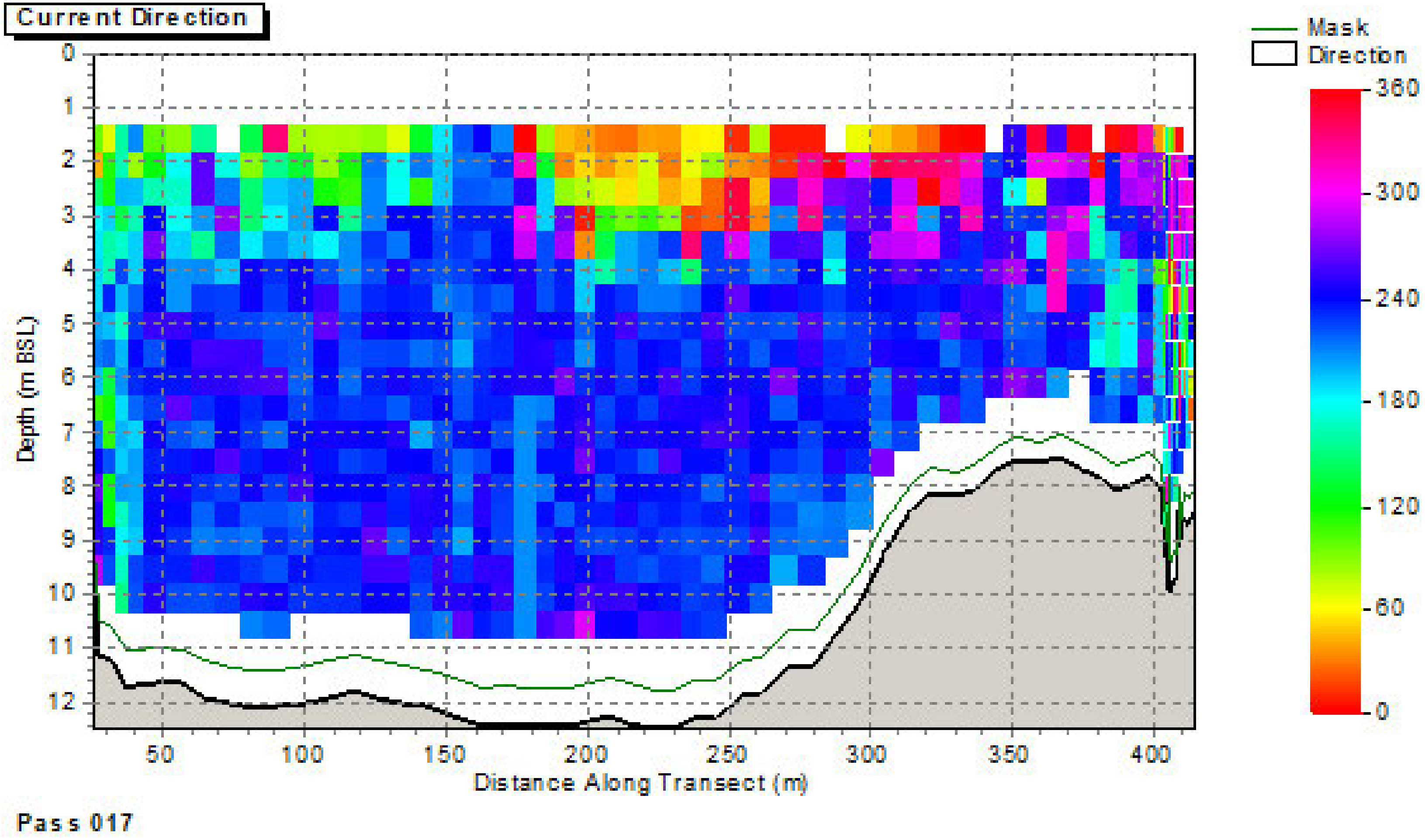


Figure provided by PD Teesport

Figure 57. **Measured flow directions, Transect 1, Pass 17: Flood tide, cross section of speed with depth shown from west (left) to east (right)**

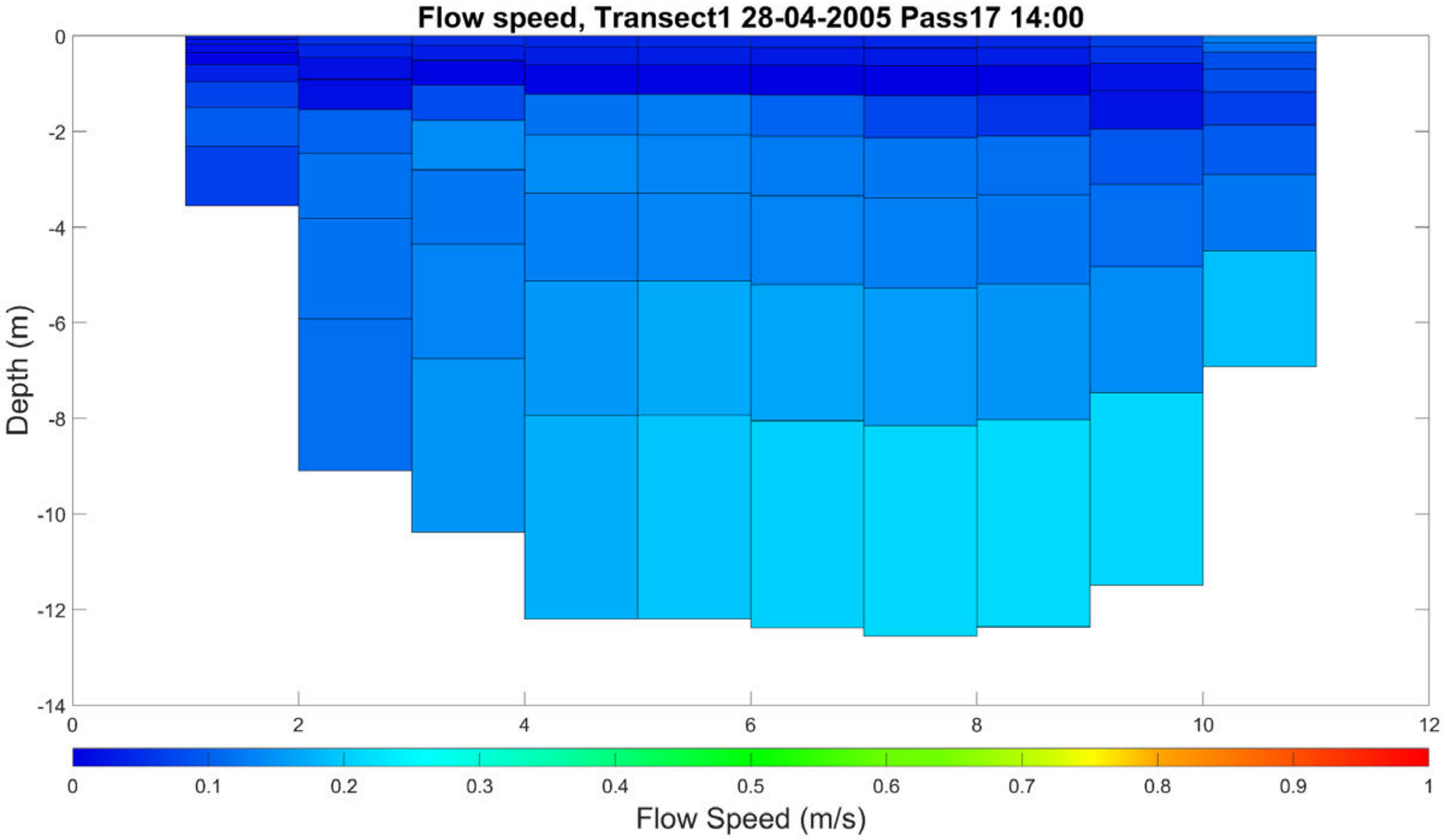


Figure 58. Modelled flow speed, Transect 1: Flood tide, cross section of speed with depth shown from west (left) to east (right)

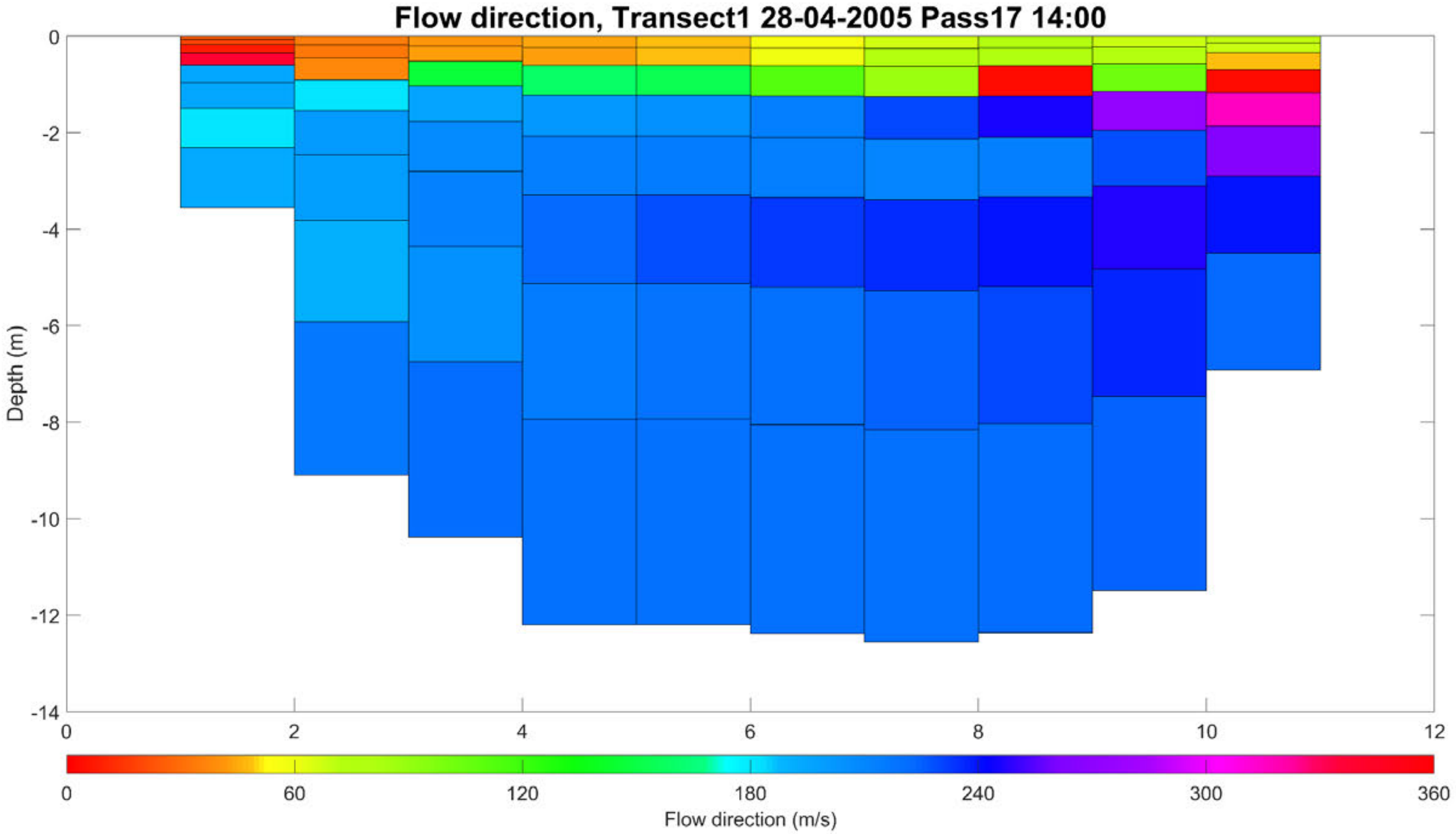


Figure 59. Modelled flow direction, Transect 1: Flood tide, cross section of direction with depth shown from west (left) to east (right)

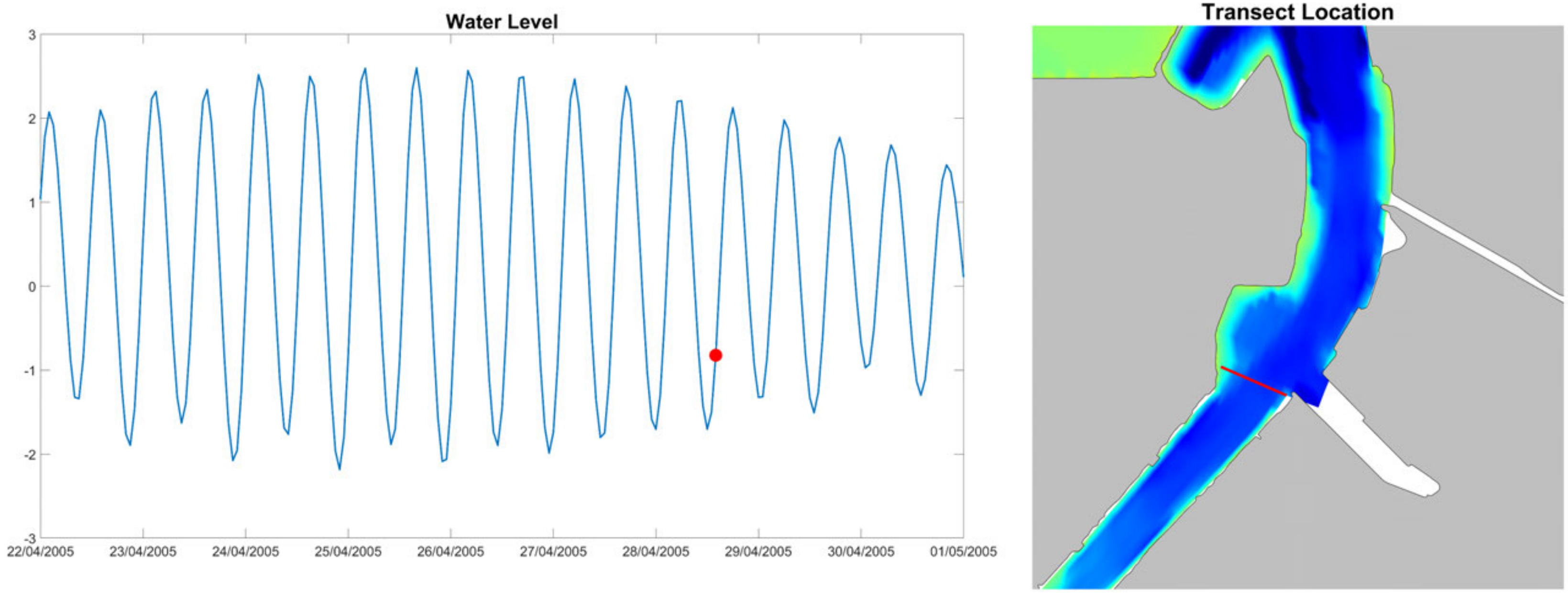


Figure 60. Tidal state and transect location extracted from the model for Transect 1 Pass 17: 28/04/2005

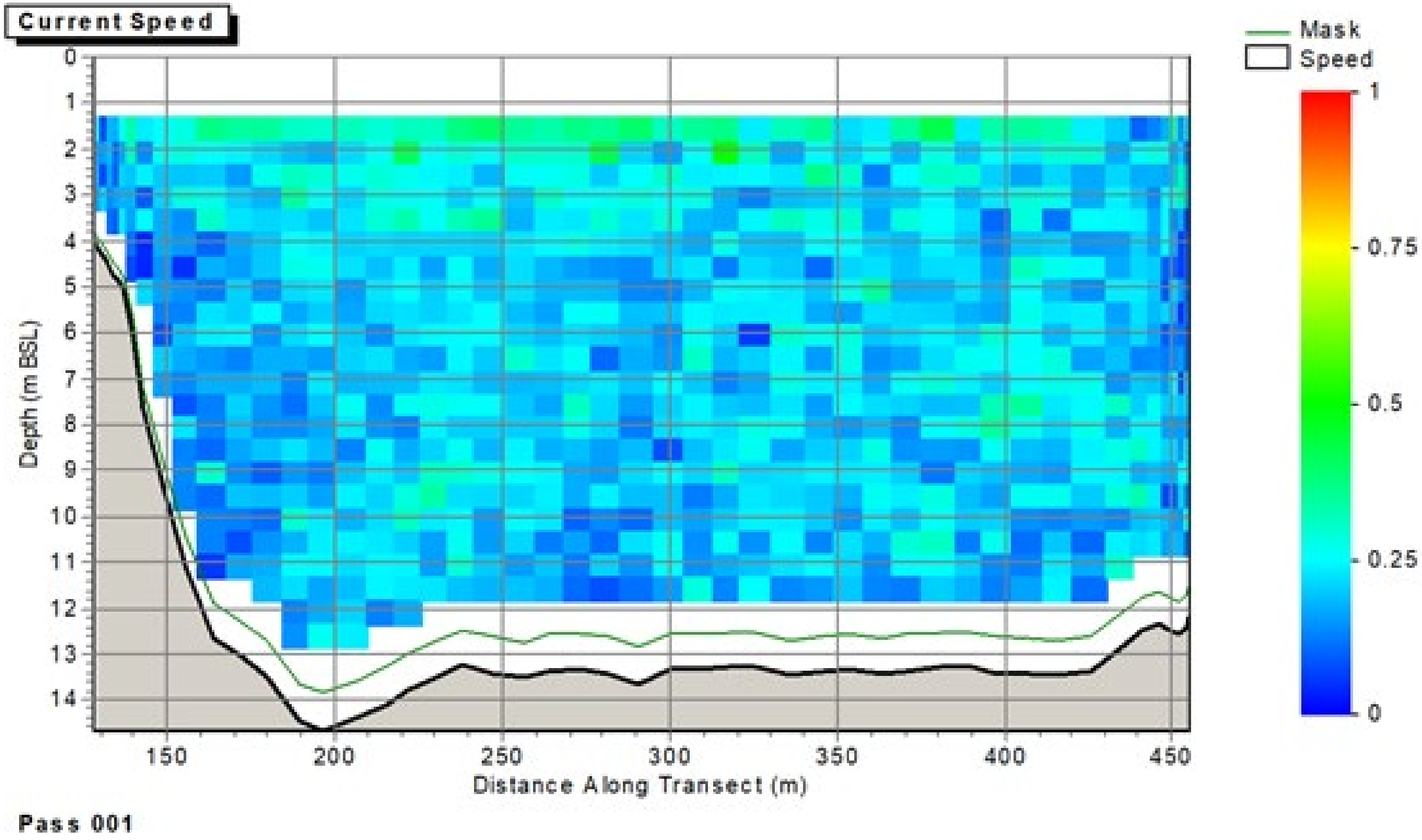


Figure provided by PD Teesport

Figure 61. **Measured flow speed, Transect 7, Pass 1: Ebb tide, cross section of speed with depth shown from west (left) to east (right)**

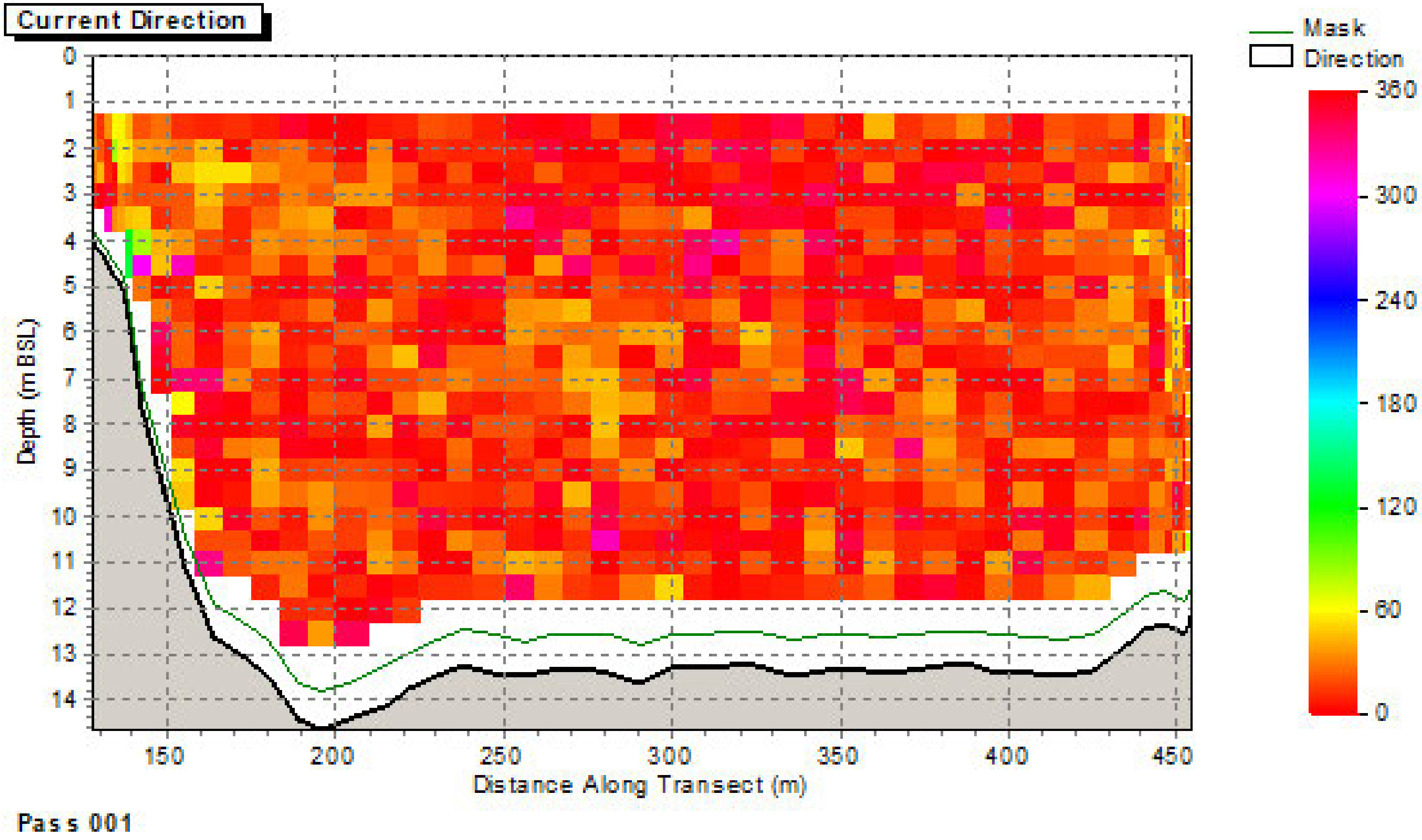


Figure provided by PD Teesport

Figure 62. **Measured flow direction, Transect 7, Pass 1: Ebb tide, cross section of direction with depth shown from west (left) to east (right)**

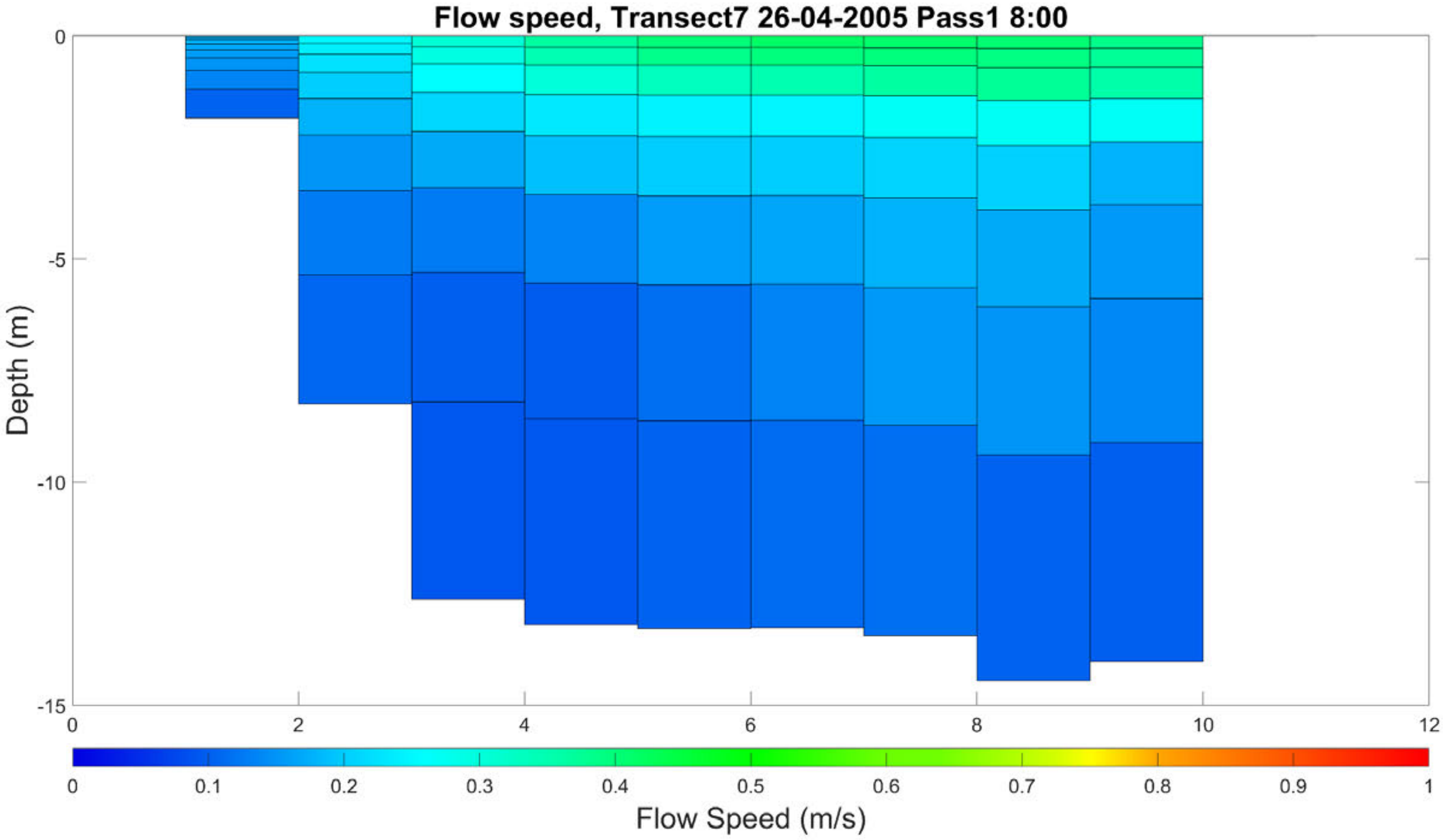


Figure 63. **Modelled flow speed, Transect 7: Ebb tide, cross section of speed with depth shown from west (left) to east (right)**

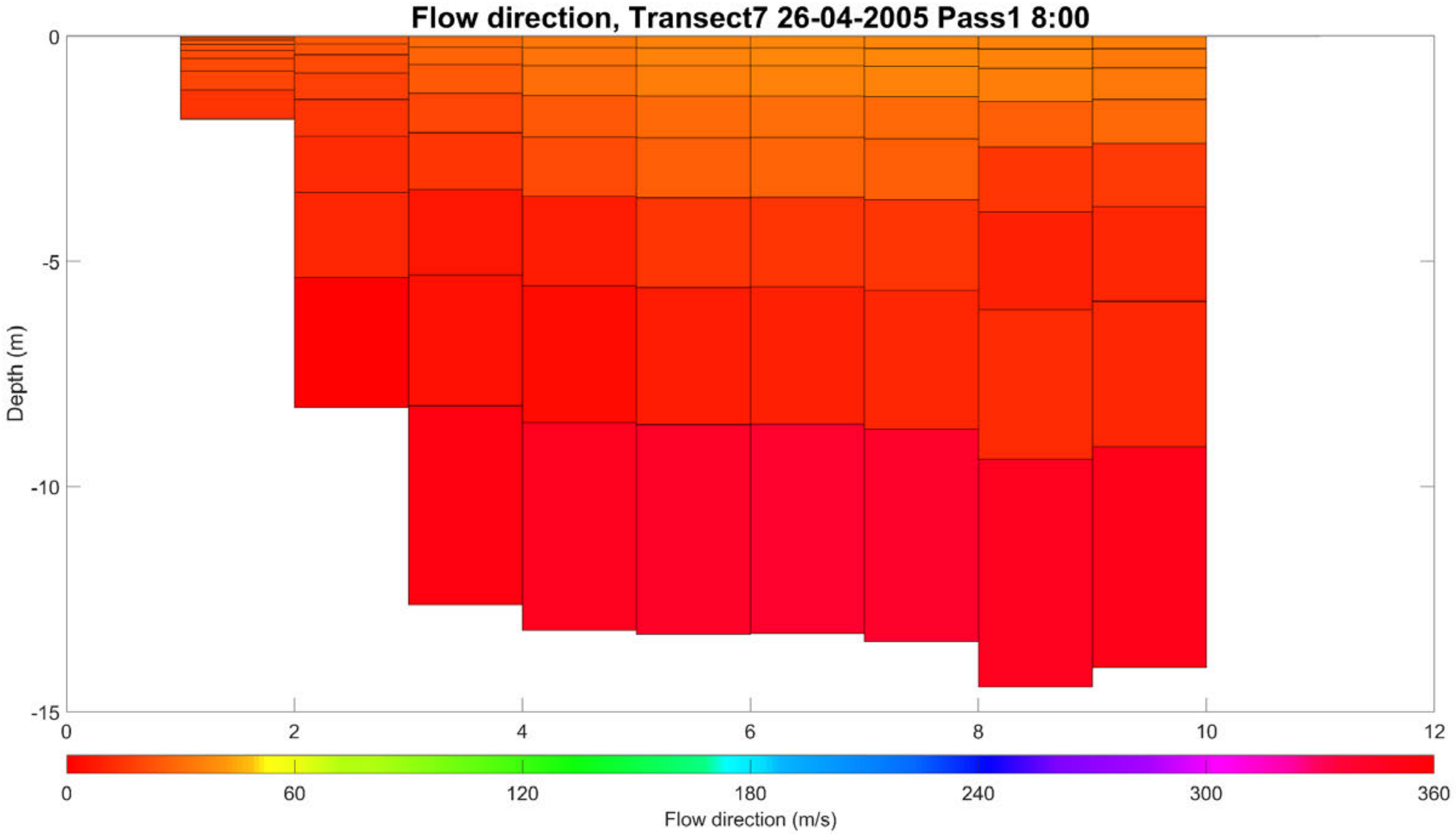
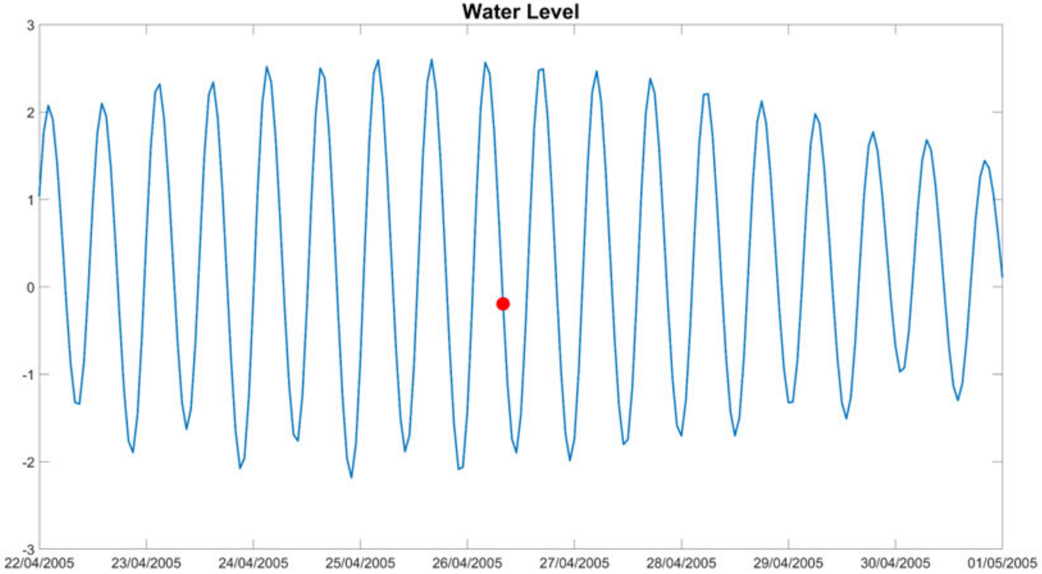


Figure 64. Modelled flow direction, Transect 7: Ebb tide, cross section of direction with depth shown from west (left) to east (right)



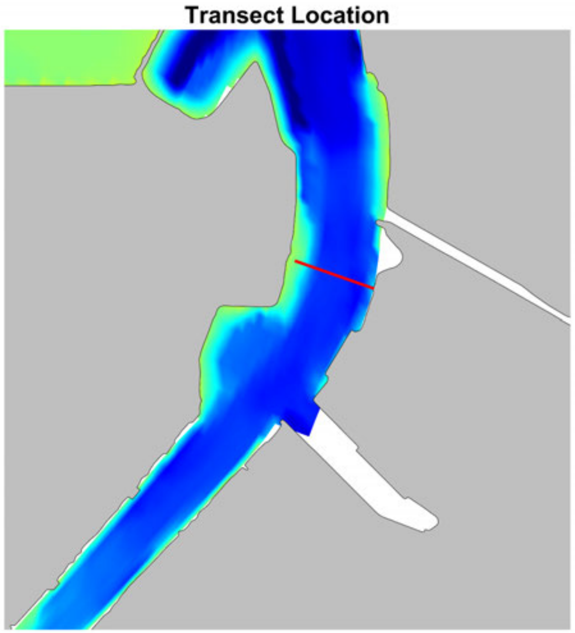


Figure 65. Tidal state and transect location extracted from the model for Transect 7 Pass 1: 26/04/2005

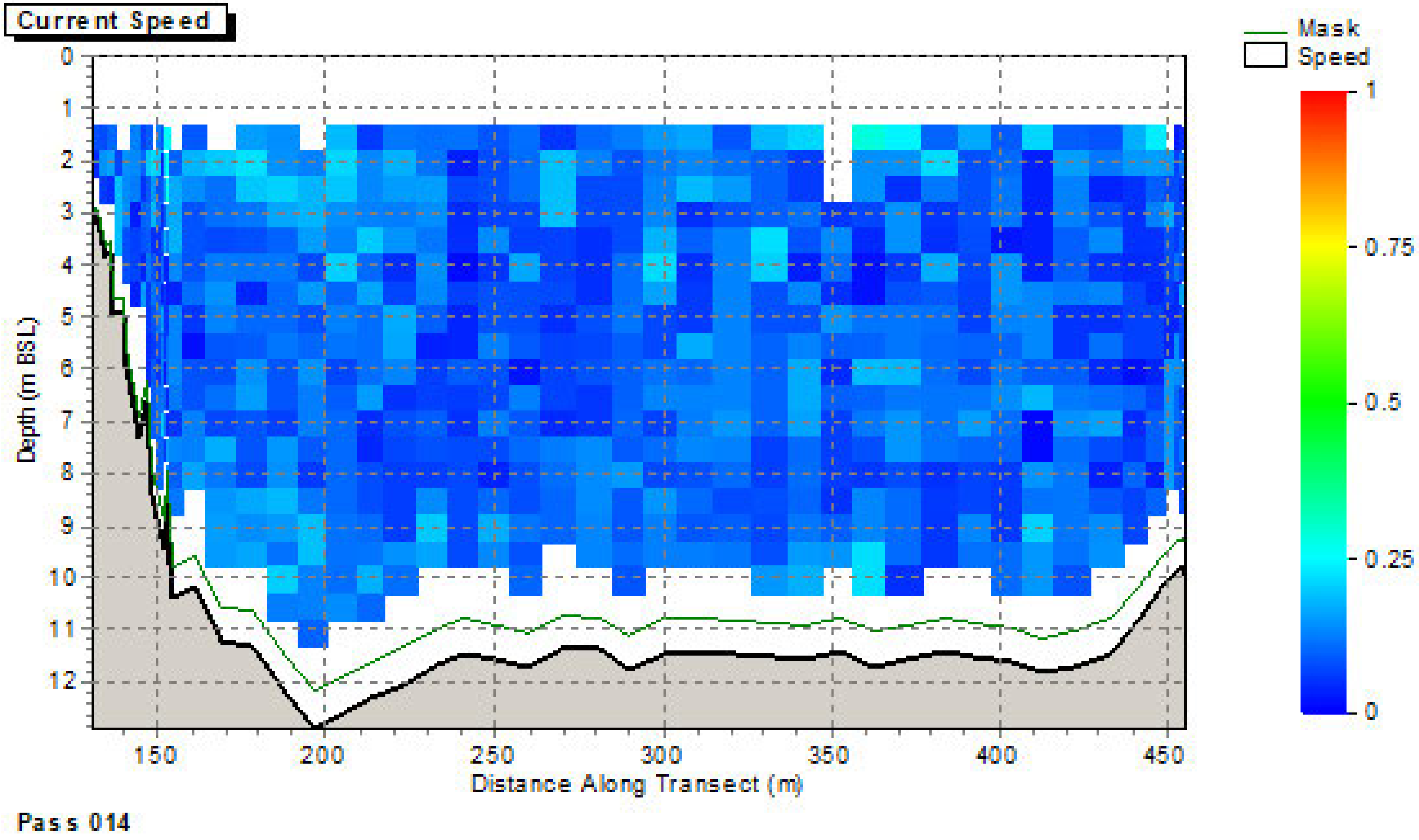


Figure provided by PD Teesport

Figure 66. Measured flow speed, Transect 7, Pass 14: Low water, cross section of speed with depth shown from west (left) to east (right)

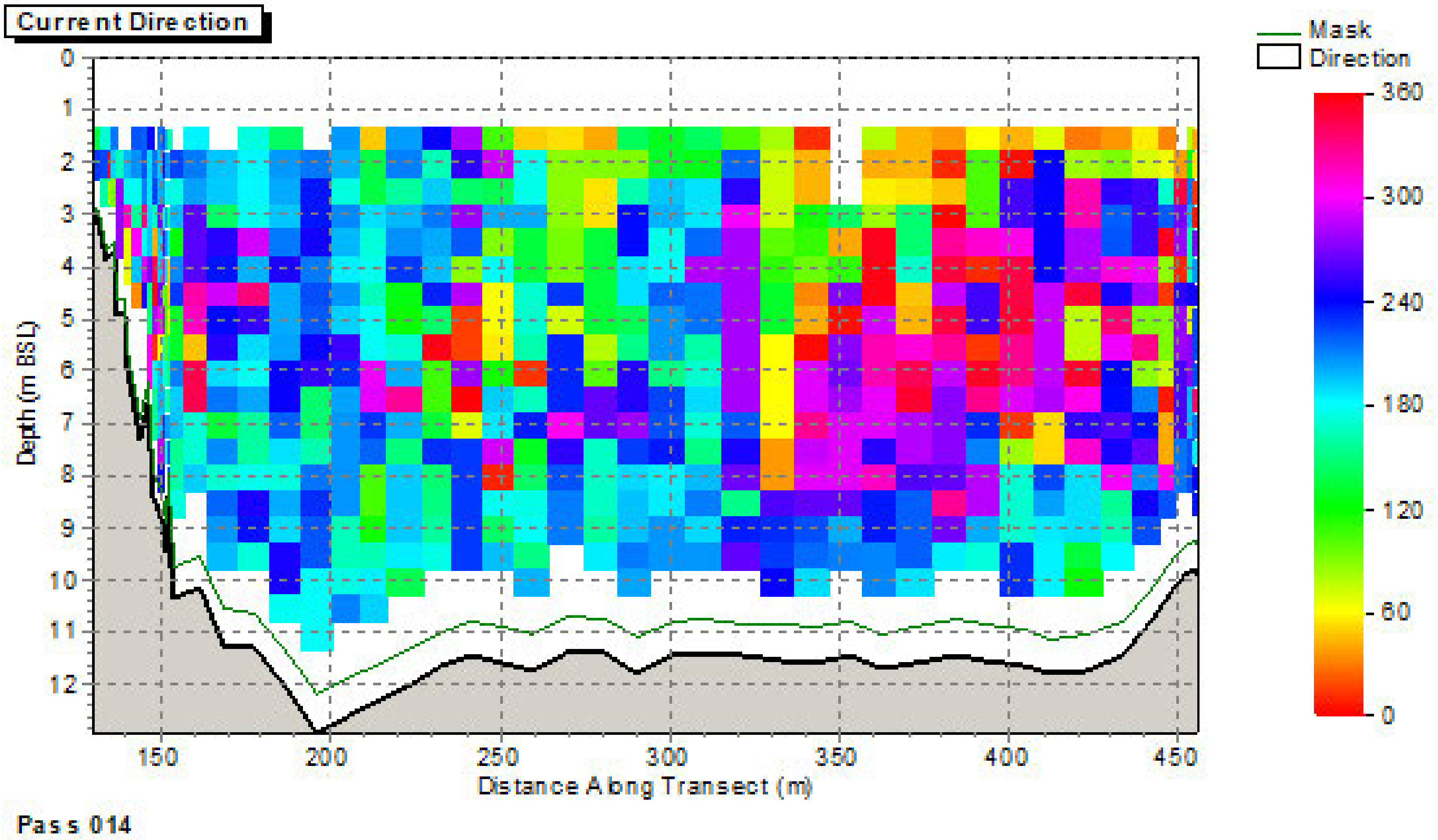


Figure provided by PD Teesport

Figure 67. Measured flow direction, Transect 7, Pass 14: Low water, cross section of direction with depth shown from west (left) to east (right)

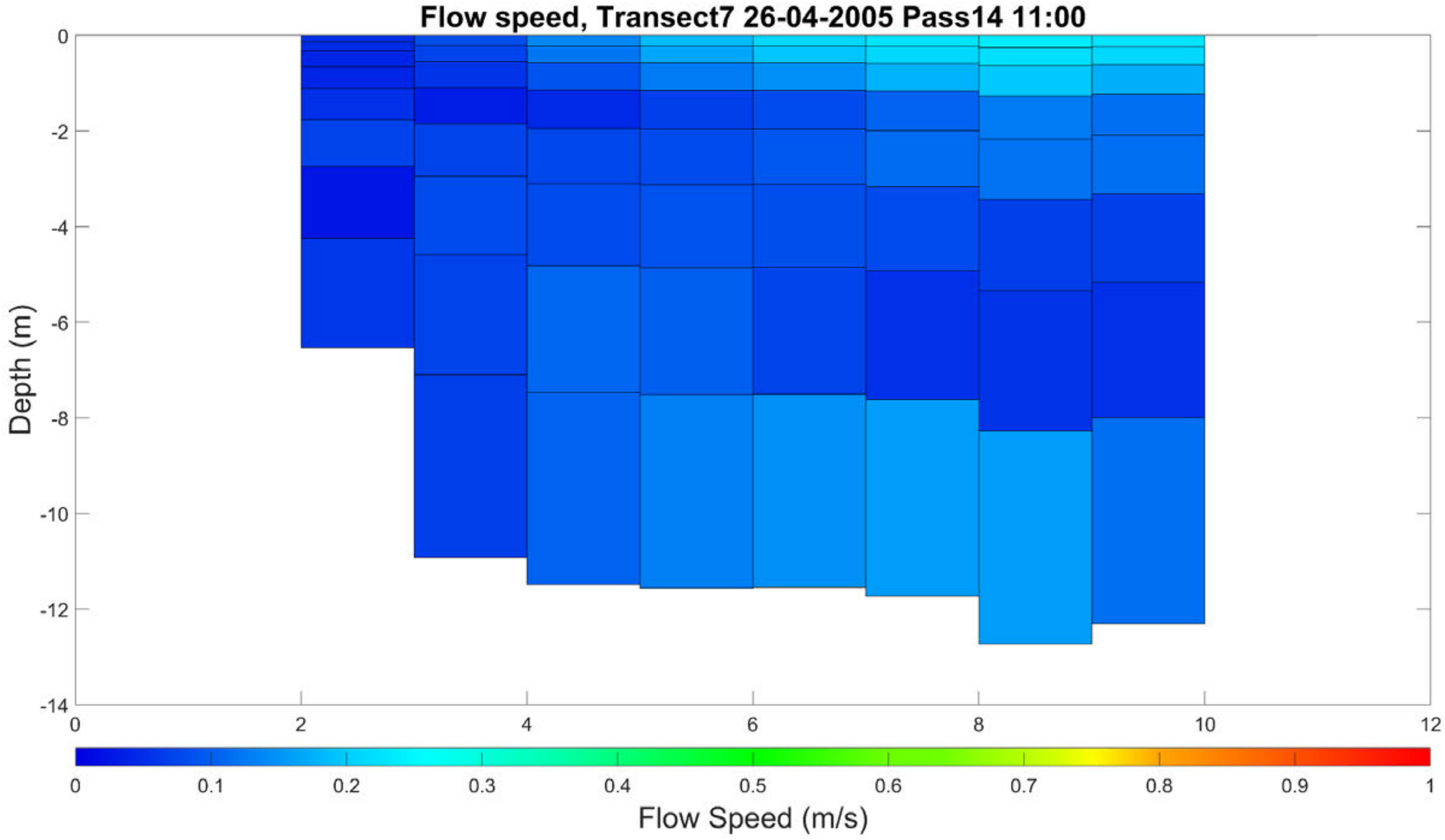


Figure 68. Modelled flow speed, Transect 7: Low water, cross section of speed with depth shown from west (left) to east (right)

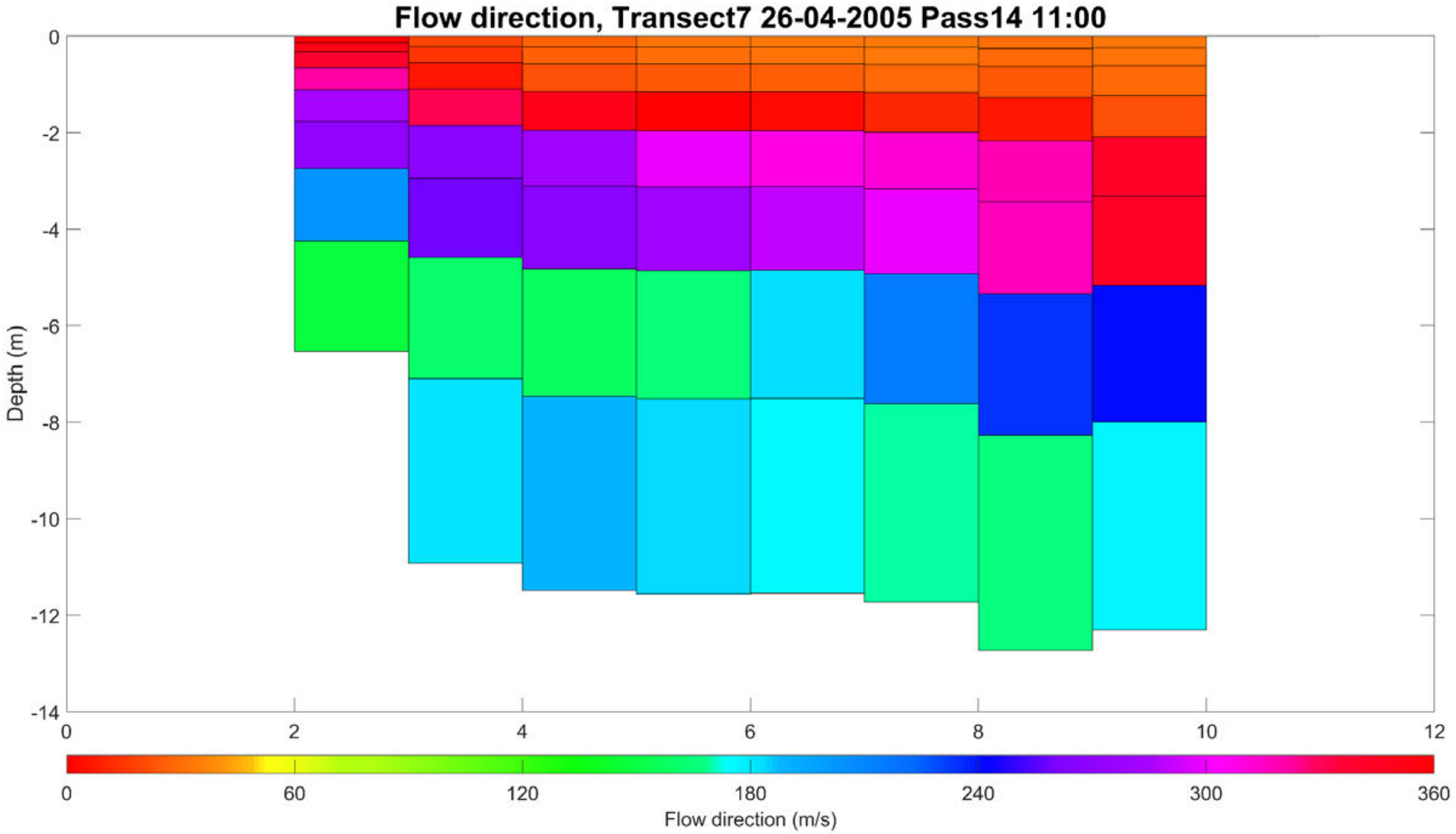


Figure 69. Modelled flow direction, Transect 7: Low water, cross section of direction with depth shown from west (left) to east (right)

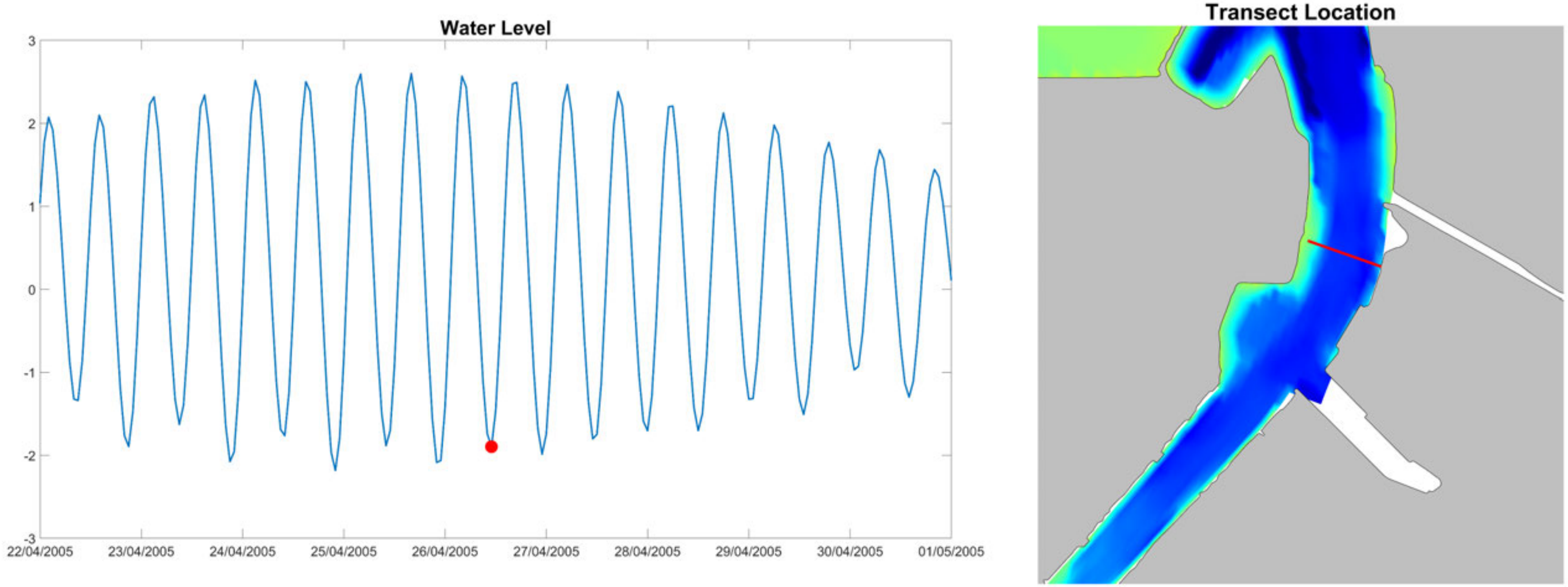


Figure 70. Tidal state and transect location extracted from the model for Transect 7 Pass 14: 26/04/2005

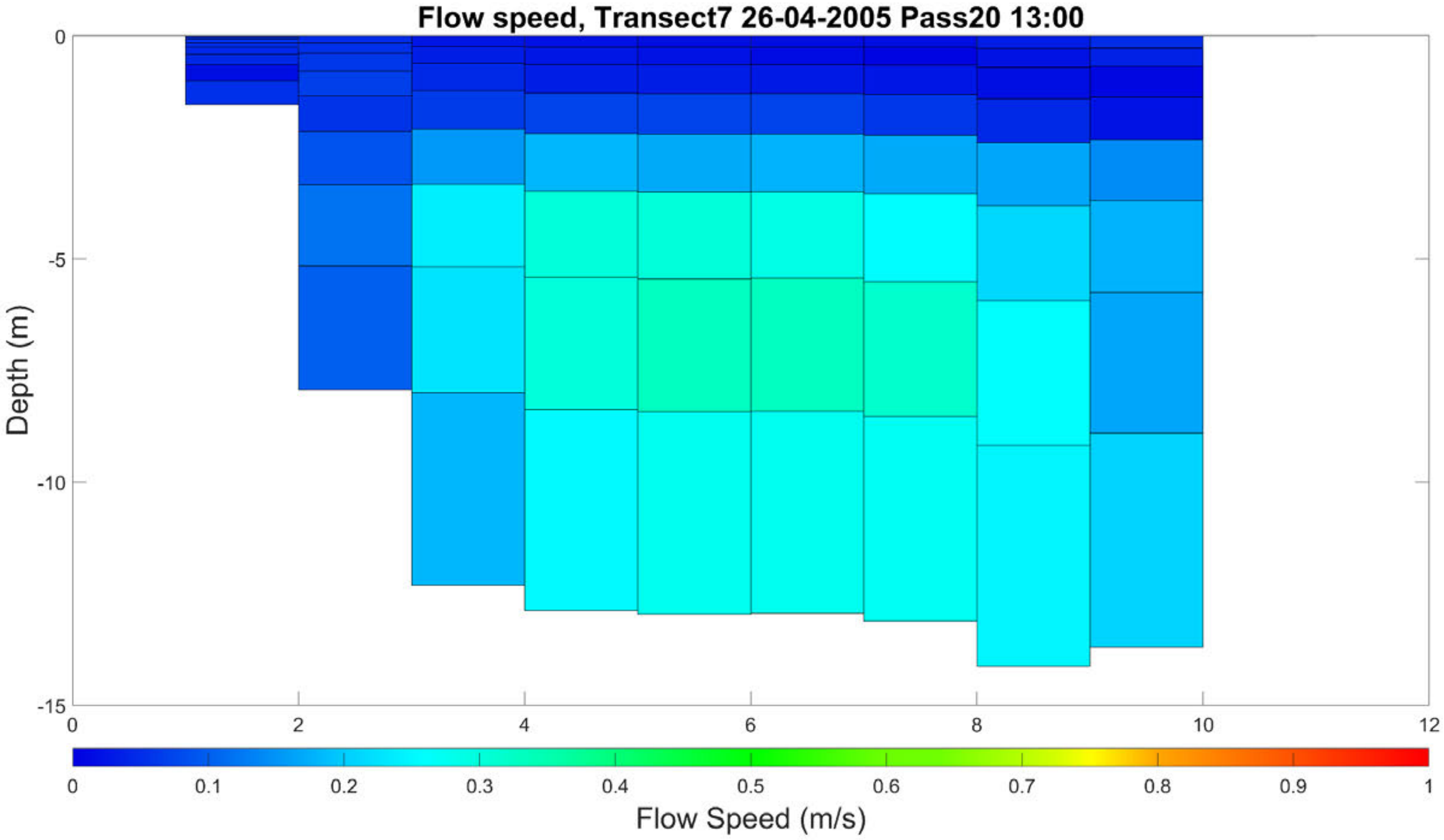


Figure 73. Modelled flow speed, Transect 7: Flood tide, cross section of speed with depth shown from west (left) to east (right)

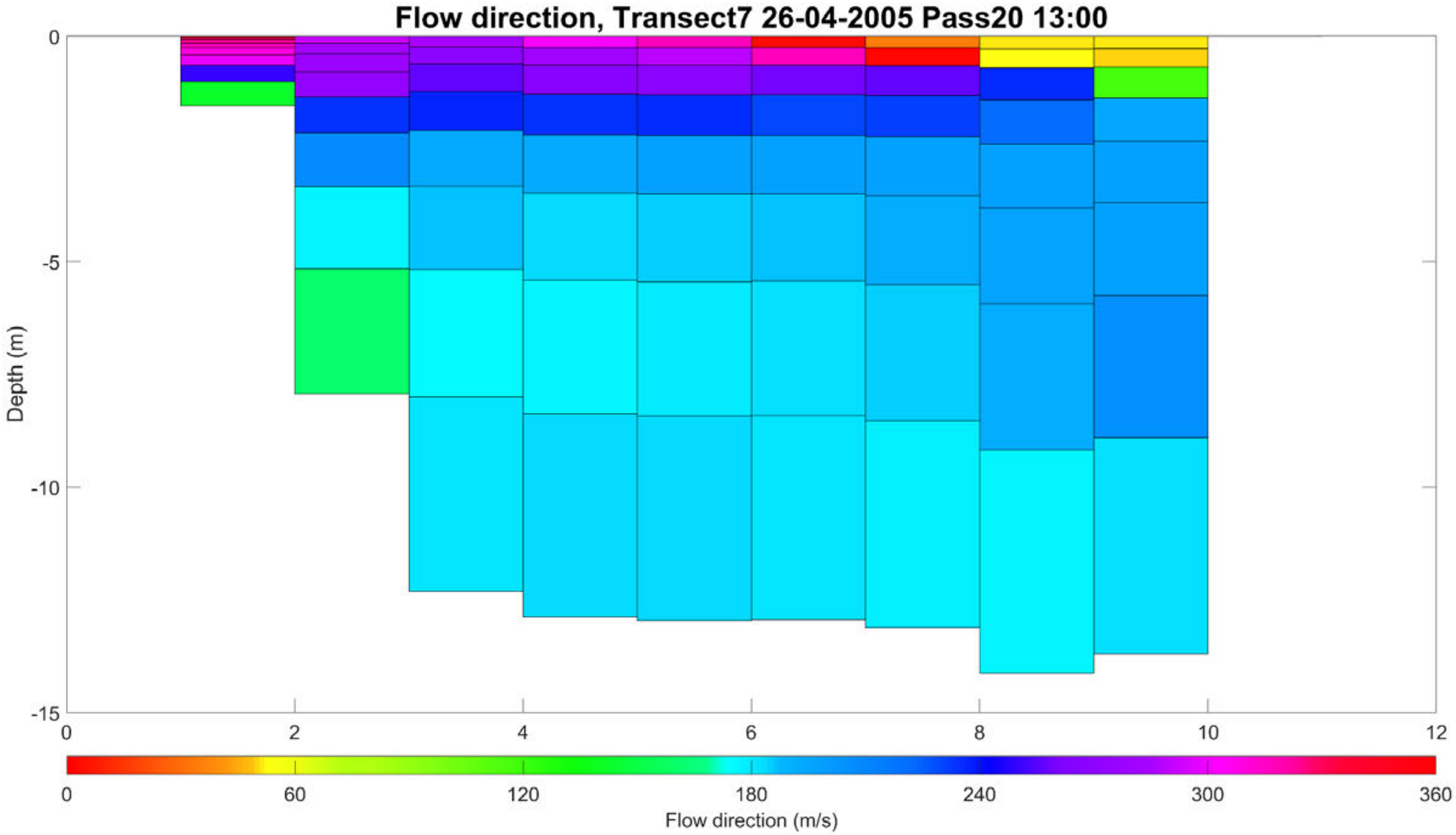
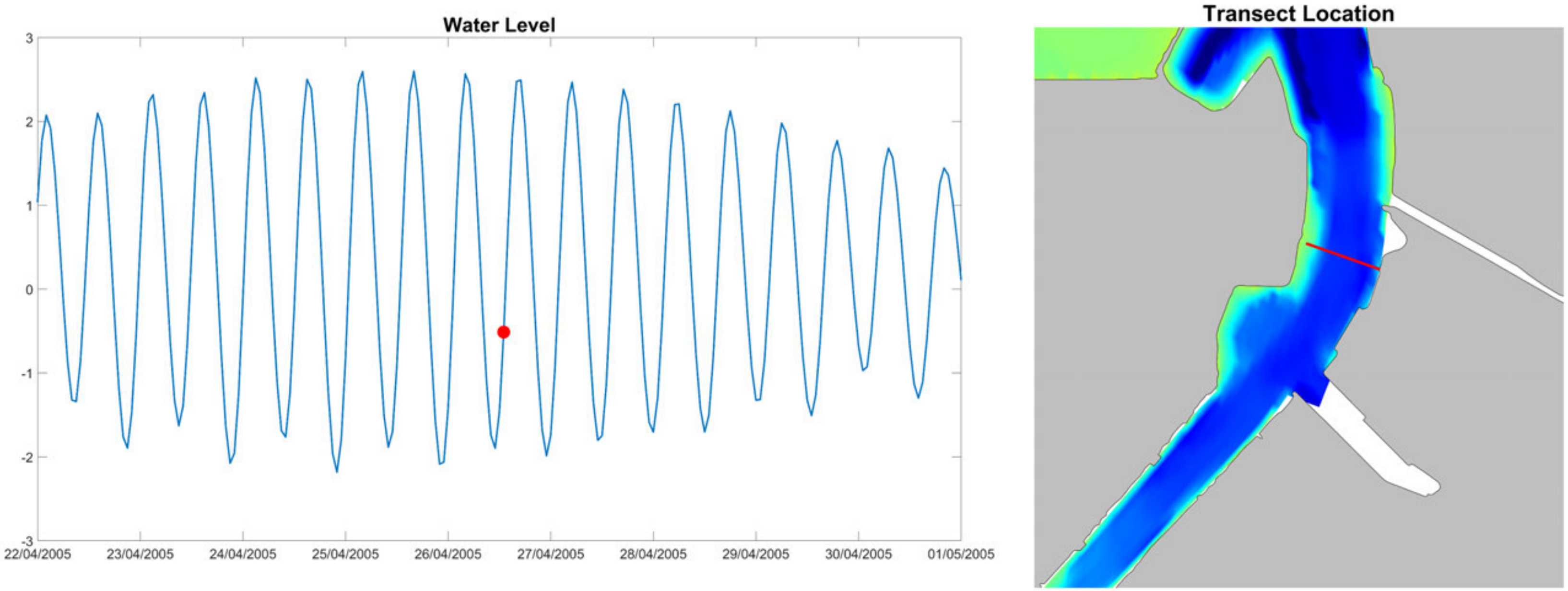


Figure 74. Modelled flow direction, Transect 7: Flood tide, cross section of direction with depth shown from west (left) to east (right)


Water Level

Transect Location

Figure 75. Tidal state and transect location extracted from the model for Transect 7 Pass 20: 26/04/2005

Timeseries flow data

Tees and Hartlepool Port Authority (THPA) previously provided measured flow speed and direction data from fixed current meter observations at a central location in the Tees Estuary. The location of the fixed current meter is data is shown in Figure 76 with the label Buoy 10. These data were processed in the previous study and assessed to identify spring and neap data periods of comparable magnitude to the model run period. The processed data for selected spring and neap tidal periods, have been utilised in this study to produce an equivalent comparison of measured and modelled data using the new modelled outputs. As an initial sense check, the modelled data were also compared against the previous modelled results.

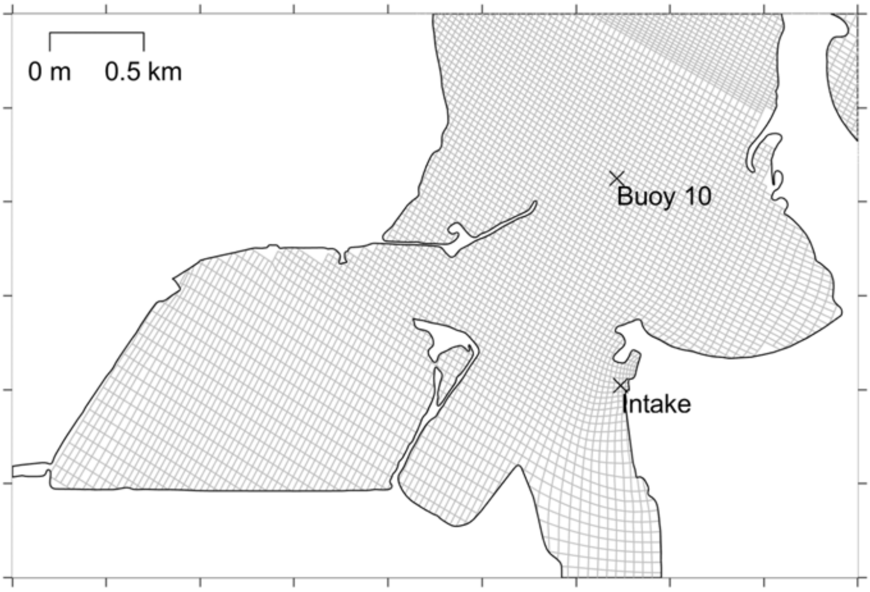


Figure 76. **Fixed current meter location: Buoy 10**

Comparison of the modelled and measured datasets are shown in Figure 77 for spring tides and Figure 78 for a neap condition. It should be remembered when examining the comparisons that:

- The layers in the model may not correspond exactly to the elevation of the instrument deployed in the field and none of the measurements would have been made for the exact tidal conditions, bathymetry and location being modelled. Hence a perfect calibration would not be expected.;
- The time period of the observations and model output is different. Comparison is between two data sets which have similar tidal ranges only. Due to this difference in data periods, as well as the small amount of measured data available, it has not been possible to carry out a statistical analysis.
- Field observations are represented by a poor temporal resolution of data points within the period of measurement. Hence variation within this period may have occurred which is not shown in the data.
- Freshwater regime during the collection period may be different from that specified in the model, which itself represents mean conditions.
- Time between the field observations and the present means that there could be differences in local bathymetry at and around the measured site compared to that modelled.

Comparisons were made at three layers within the water column: surface, middle and bed. There is generally good agreement between the phasing and magnitude in the datasets.

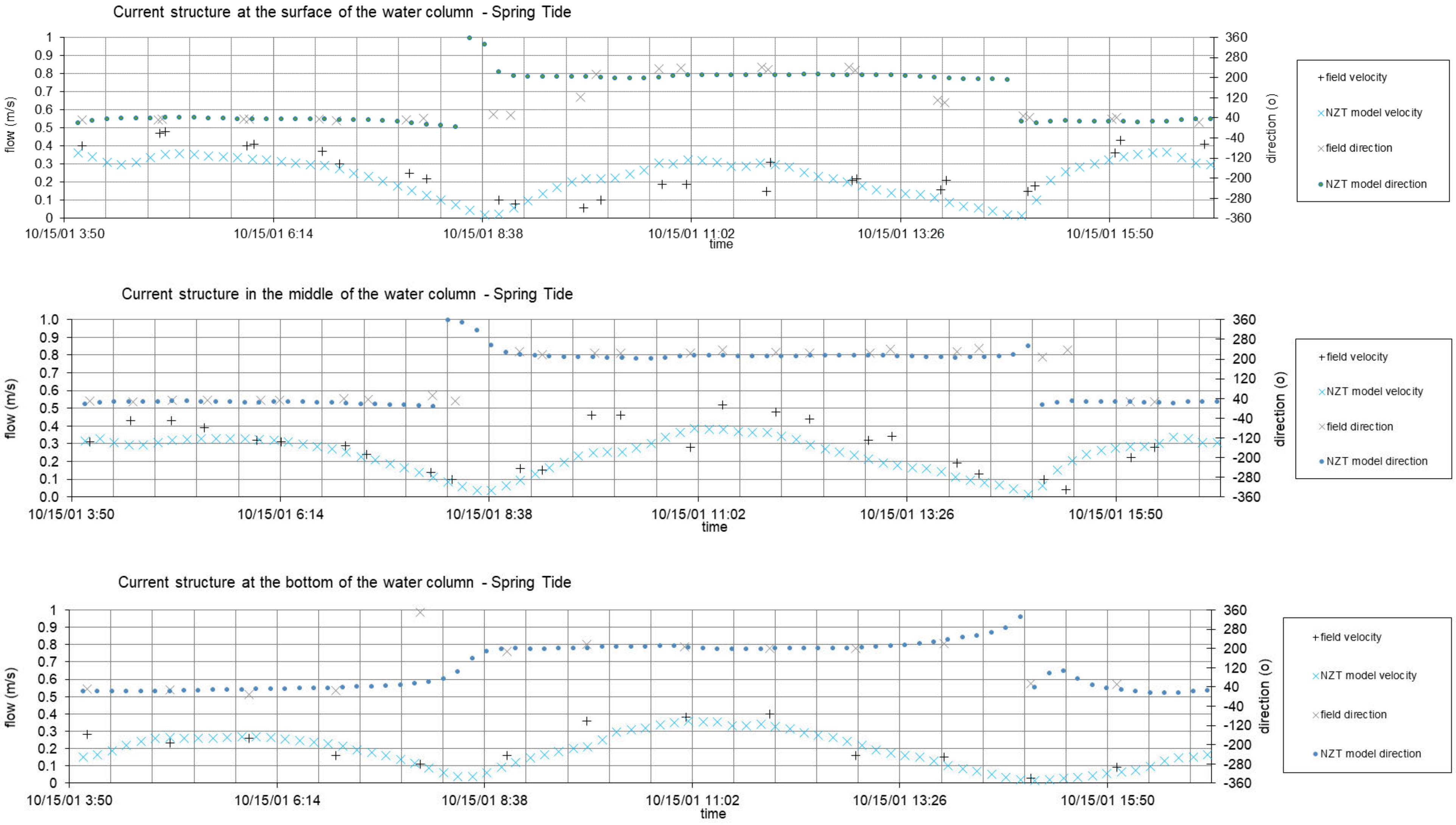


Figure 77. Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Spring tide

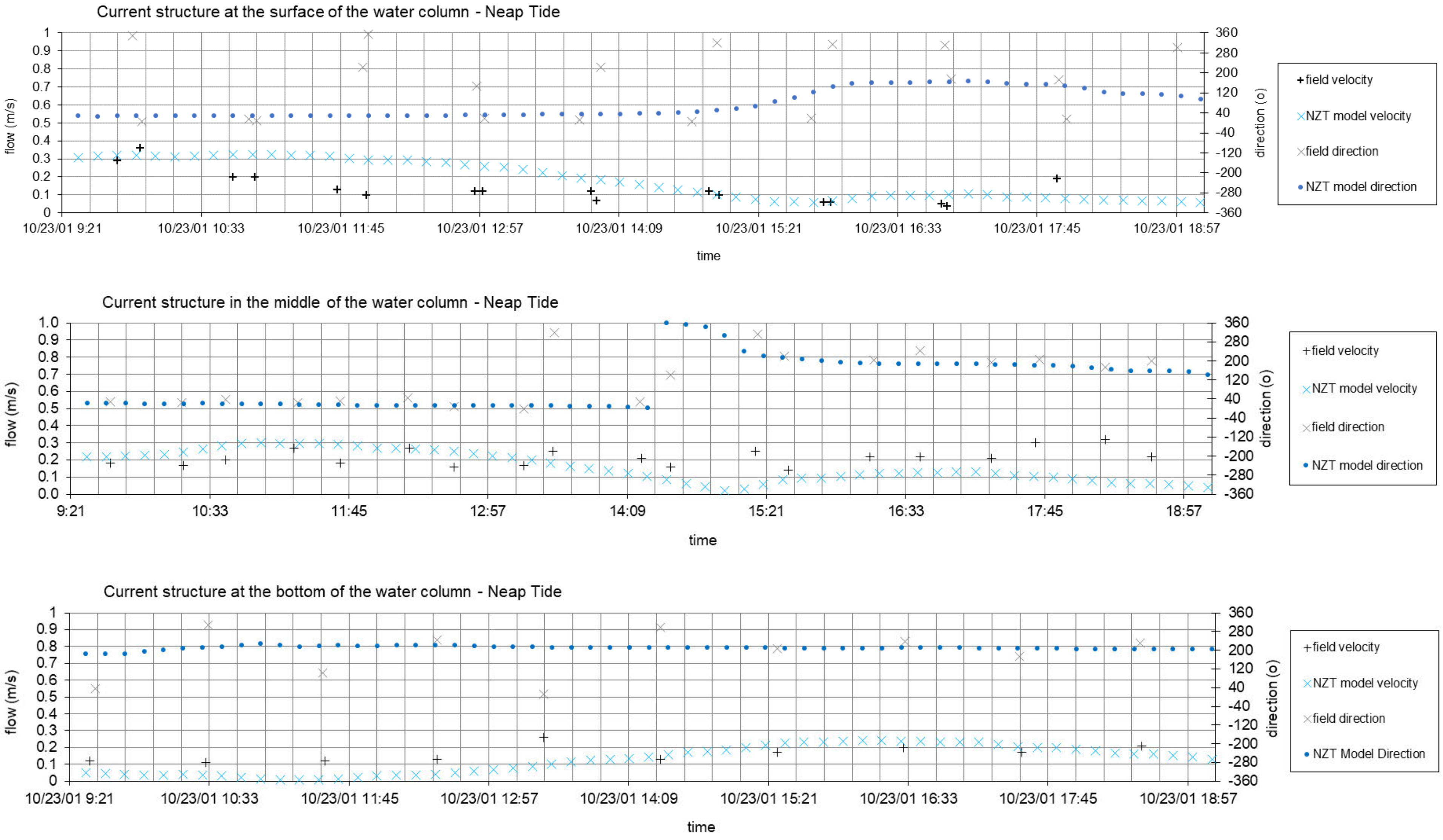


Figure 78. **Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Neap tide**

Offshore flow conditions

The above sections compare the model outputs against conditions within the Tees Estuary. There is limited measured data within the offshore coastal region, so comparison of the modelled flows has been undertaken against predicted tides using the UKHO Admiralty tide tables.

Modelled flow speeds and directions, over a mean spring tide, are compared in Table 18 which show the model is generally in good agreement with the variation in speed and direction across the flood and ebb tidal phases.

Table 18. Modelled and predicted flows speeds and directions within the offshore coastal region.

	Model		TT	
	Direction (°)	Speed (m/s)	Direction (°)	Speed (m/s)
HW-6	309	0.46	291	0.62
HW-5	305	0.46	296	0.57
HW-4	304	0.40	303	0.41
HW-3	307	0.28	303	0.21
HW-2	333	0.10		0
HW-1	96	0.17	111	0.41
HW	112	0.38	112	0.67
HW+1	115	0.47	109	0.57
HW+2	116	0.43	107	0.46
HW+3	116	0.28	110	0.36
HW+4	118	0.12	97	0.1
HW+5	274	0.04	278	0.1
HW+6	287	0.16	288	0.36

CTD data

AECOM have provided measurements of temperature and salinity from individual CTD (Conductivity, Temperature, Depth) casts deployed across the ADCP transects during the PD Teesport survey, conducted between 21/04/2005 to 30/04/2005.

All available CTD measured profiles have been plotted and compared against the model data available from the nearest model grid cell and coincident time. Sensitivity testing during the model build demonstrated that the salinity structure of the water column is sensitive to the starting salinity and to the discharge volume through the Tees Barrage. Three variations of the model have therefore been run for this data comparison to represent three alternative barrage discharges: Annual mean, summer and winter (as described in Table 15). The starting salinity of the model controls the resulting salinity of the bulk of the water column. The nature of the model setup (i.e. reasonably short duration with averaged discharge values across the barrage) means that the model will not reach a naturally stable point representative of a particular point in history: this would require a longer model duration and time varying discharges over a longer period, not felt necessary for the present study. Instead, it represents the conditions over a period of time rather than matching to specific day. The most appropriate starting value for the model salinity has been selected as 33.9 ppt based on values provided by AECOM from the Wood Draft Report (Wood, 2020) for seawater properties. This provides consistency throughout all modelled simulations (hydrodynamic and near-field thermal plume).

Figure 79 to Figure 81 present selected comparisons of CTD measurements and modelled profiles which are generally representative of the full set of profile comparisons.

It can be seen that the winter simulation (with higher freshwater flow discharges) creates the greatest variation in vertical structure, with the surface layer being significantly fresher for most states of the tide. This pattern is most consistent with the structure seen in the measured data. The salinity of the model tends to be fresher than the measurements for the bulk of the water column for all time periods and locations assessed, which tend to be closer to 35 ppt in most of the measured profiles. However, the measured salinity for this particular short period is more saline than other sources suggest for ‘typical’ conditions in the Tees Estuary, such as the Wood Draft Report (Wood, 2020), which documents 29.3 ppt for the Tees at Redcar Jetty and the Gares, and 32.8 ppt in the ‘River Water’.

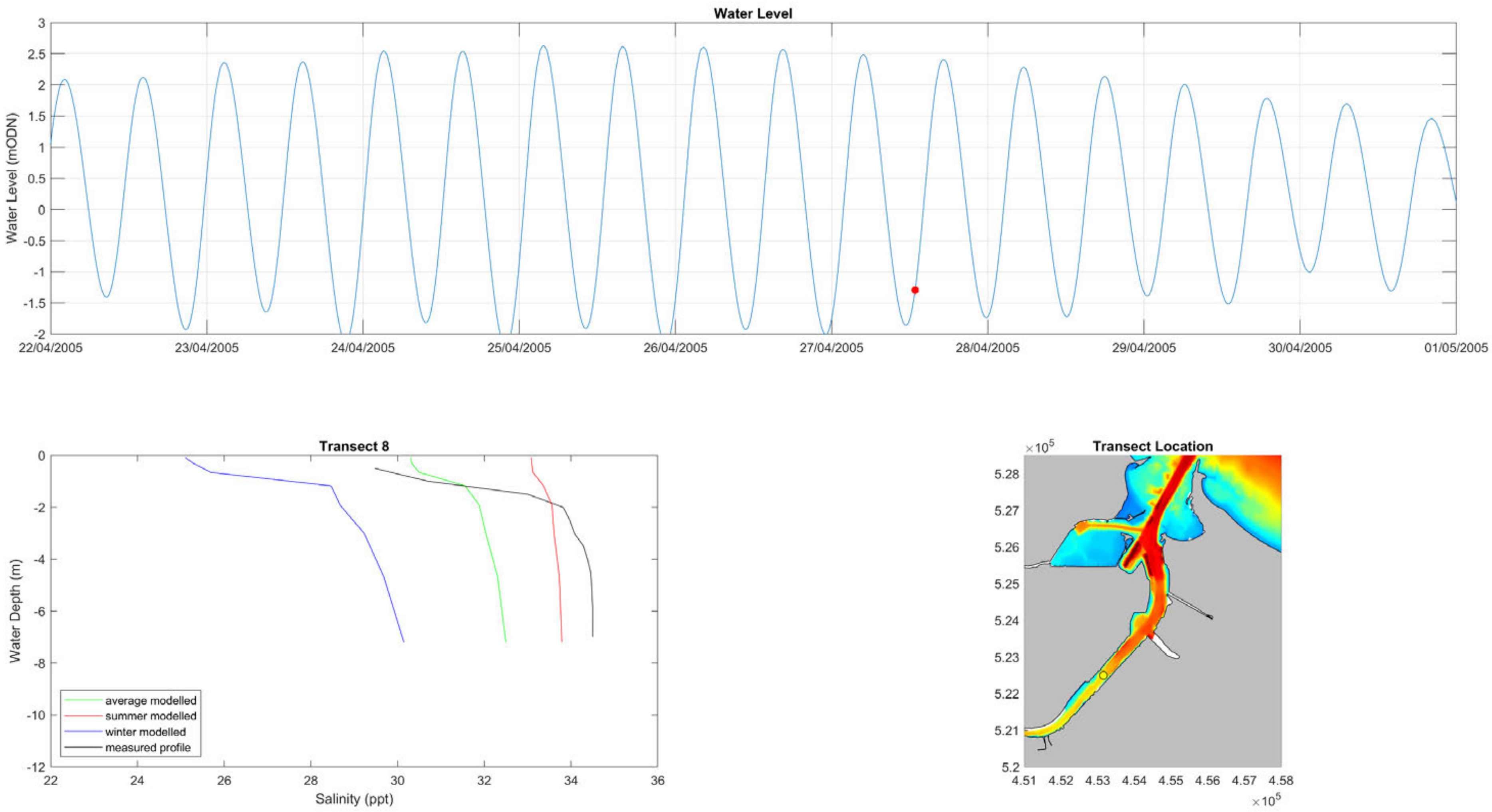


Figure 79. Comparison of measured and modelled salinity with depth: Transect 8 (red dot on top water level plot indicates point of the tide).

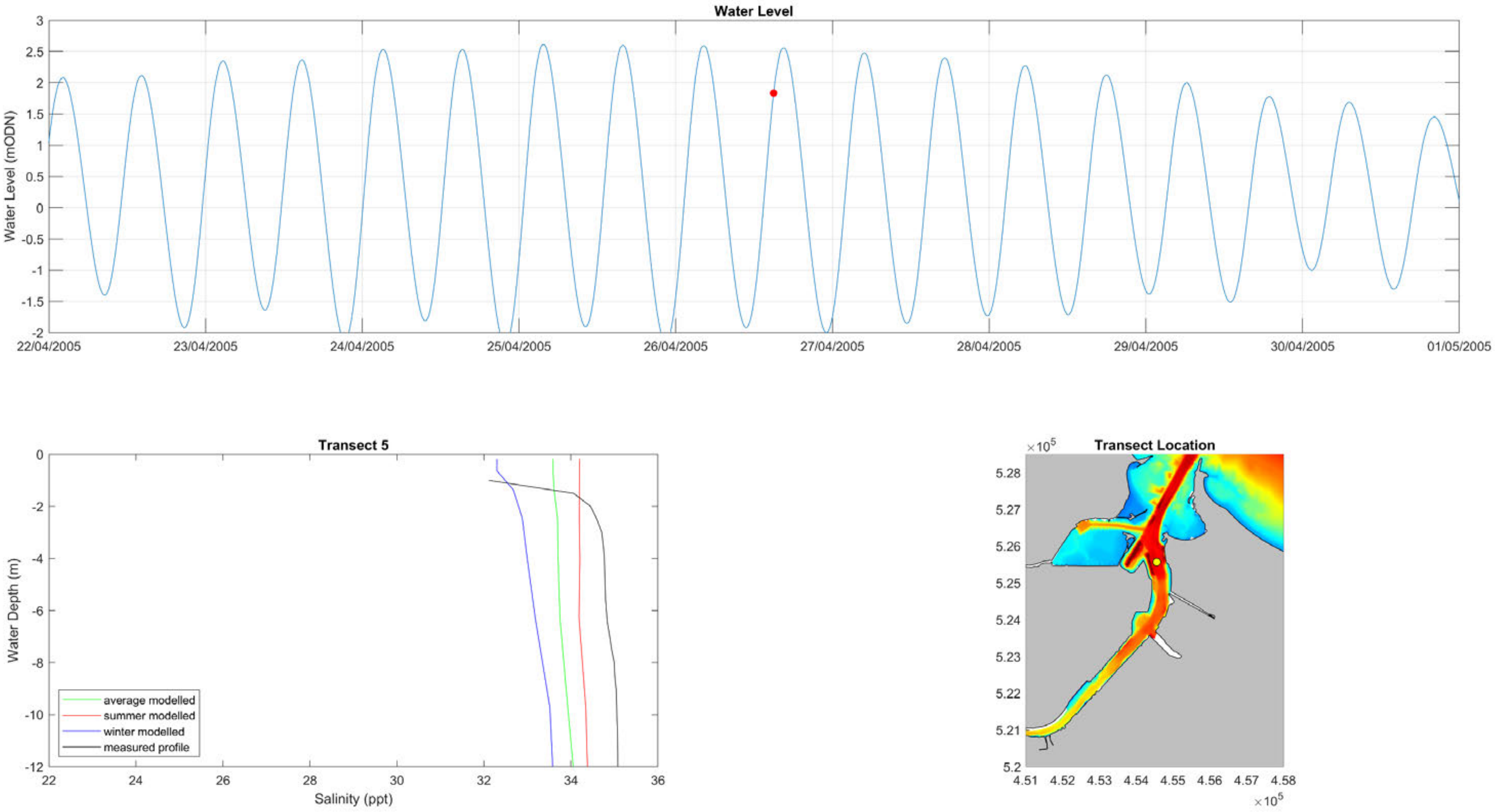


Figure 80. Comparison of measured and modelled salinity with depth: Transect 5, closest transect location to the cofferdam (red dot on top water level plot indicates point of the tide).

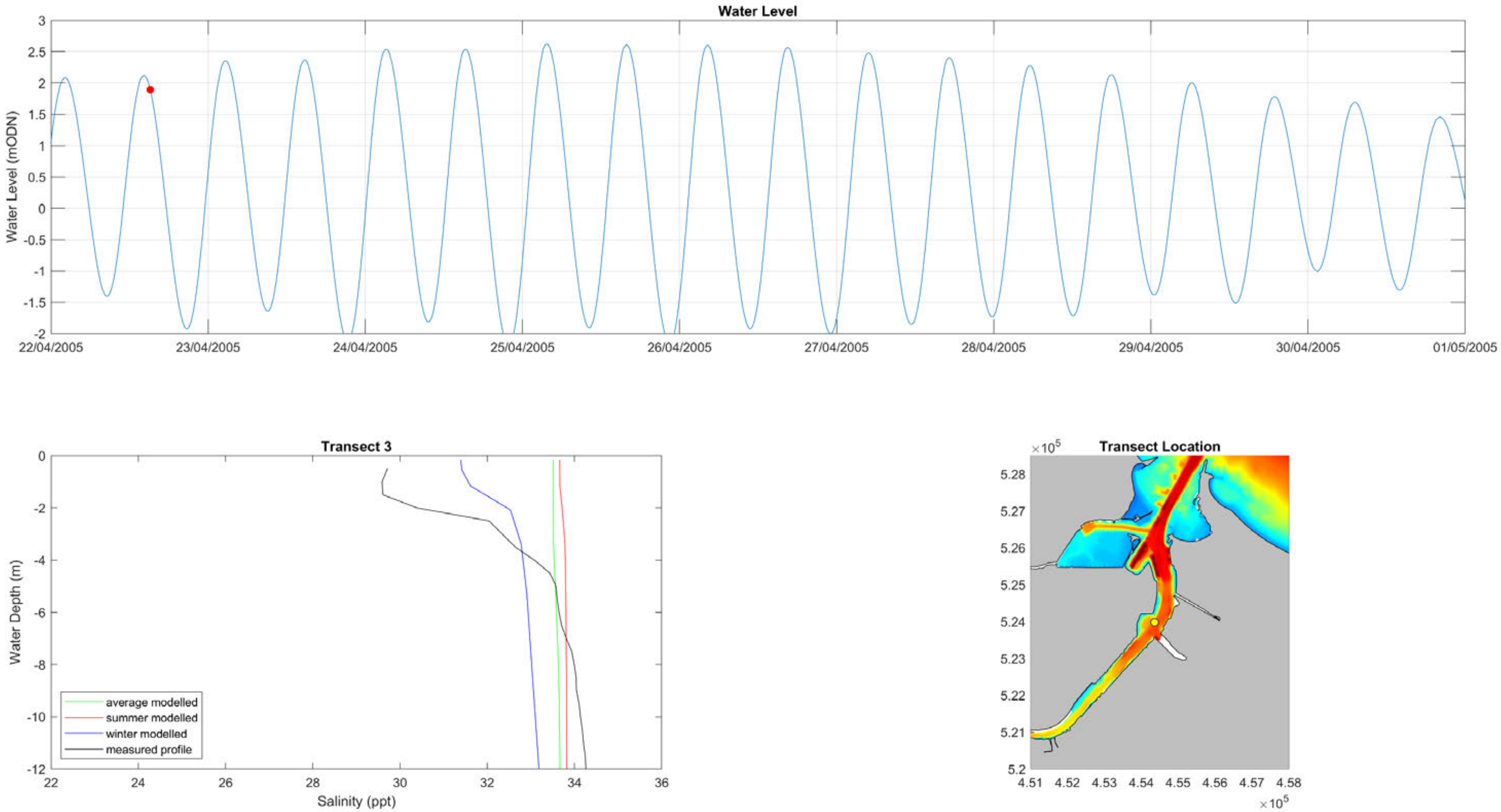


Figure 81. Comparison of measured and modelled salinity with depth: Transect 3 (red dot on top water level plot indicates point of the tide

C CORMIX Extreme discharge event

During an extreme discharge event, the volume of effluent water that will be discharged through the outfall is estimated to be 5.75 m^3/s. However, only a portion of the discharge (1.81 m^3/s) will be heated and have an excess temperature, compared to the rest of the discharge and the ambient sea that it's being discharged into. In turn, this will result in the heated portion of the discharge mixing and diluting with the rest of the effluent prior to its discharge out of the outfall. To account for this, a percentage representation of the heated proportion of the discharge has been applied to the original excess temperature of 15°C. This has resulted in a combined excess temperature of 5°C being used to represent the discharge during an extreme event.

C.1 Flood Tide Variation

Figure 82 shows the downstream temperature excess of the resultant plume during a spring (run 26) and neap (run 27) flood tide under extreme discharge conditions, at Outfall 2. The neap tidal characteristics again result in a more extensive plume, reducing the excess temperature at a slower rate due to the slower tidal velocities compared to spring equivalent. This is highlighted by the offset of the 2 and 3°C flags which also indicate both flood states to have dispersed the excess temperature below 2°C by around 168 m downstream of the outfall.

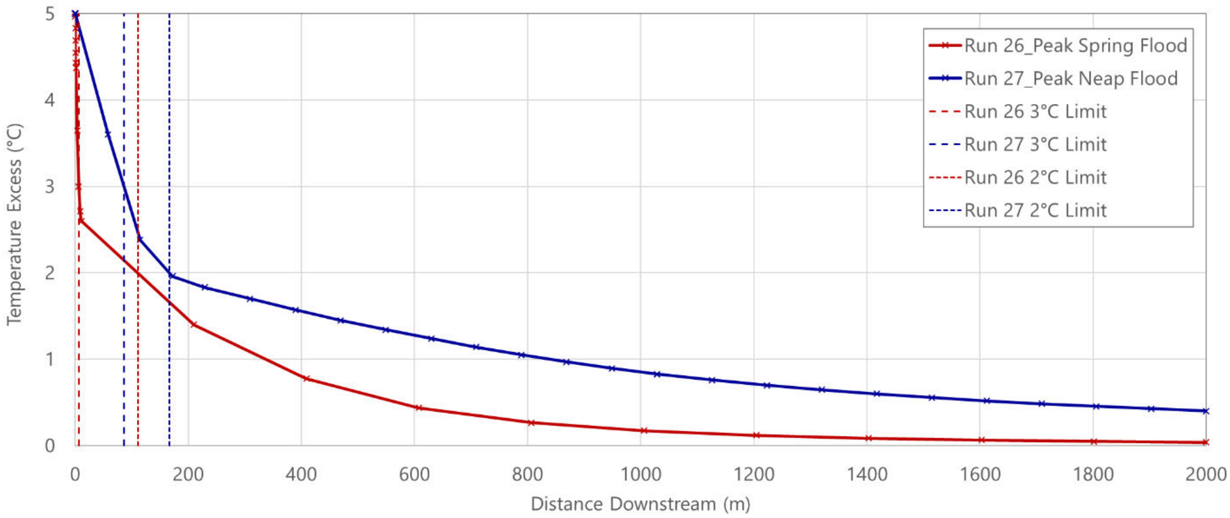


Figure 82. **Spring and neap flood tide plume variations during extreme discharge events.**

C.2 Ebb Tide Variation

Figure 83 shows the downstream temperature excess of the resultant plume during a spring (run 28) and neap (run 29) ebb tide under extreme discharge conditions, at Outfall 2. The ebb plume is shown to a larger extent under both spring and neap conditions due to the flood tidal velocities being slower for both spring and neap tides causing a slightly slower dispersion. Although the ebb tidal states exceed those on the flood, both ebb scenarios show for the excess temperature to be dispersed below 2°C excess by 235 m downstream of the outfall.

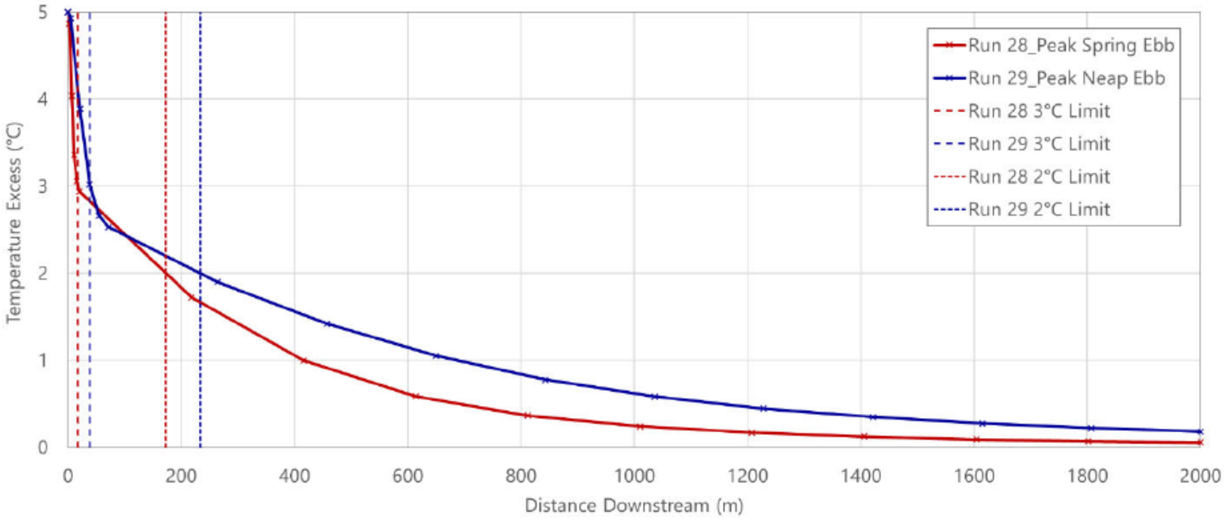


Figure 83. **Spring and neap ebb tide plume variations during normal discharge events.**

C.3 Temperature Excess Isolines

The extents of the 1-4 °C isolines for each scenario are outlined below in Table 19 summarising the excess temperatures for the 1-in-30-year event. Due to the reduced excess temperature used to represent the extreme event, there aren't any isolines representing an excess temperature of 5°C (as in the equivalent for the standard discharge event), as this is the input excess temperature which is instantly reduced upon dispersion into the sea.

Each of the isolines from the neap tidal states have been geo-referenced in Figure 84 as these extents exceed the corresponding extents during the spring tidal states. The plot highlights how the extreme discharge results in a greater plume with the excess temperatures being dispersed landward during the flood phase. It is to be noted that the 1°C contour has been clipped at the local coastline.

Table 19. **Isoline extents for all tidal states under 1-in-30-year discharge conditions.**

Excess Temperature Isoline (°C)	Spring Flood Tide (Run 26)	Spring Ebb Tide (Run 28)	Neap Flood Tide (Run 27)	Neap Ebb Tide (Run 29)
	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)	Isoline Extent from Outfall (m)
1	338	416	839	685
2	111	173	167	234
3	6	18	86	38
4	3	7	42	19

Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
[redacted]