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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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. Change requests made by the Applicants in respect of the Application were accepted into the Examination by the Examining Authority on 6 May 2022 and 6 September 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 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 has been undertaken. This modelling has been 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 concludes that the Proposed Development will not give rise to nitrogen discharges that will have a likely significant effect on the Teesmouth and Cleveland Coast SPA/Ramsar.

1.3.3 This 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 sets out the qualifying features of the Teesmouth and Cleveland Coast Special Protection Area (SPA) and Ramsar site;
- Section 6 summarises the scope of the discharge modelling undertaken;

- Section 7 identifies the potential impacts that could affect the qualifying features of the SPA/Ramsar;
- Section 8 sets out the position on nutrient neutrality;
- Section 9 identifies the potential implications for Water Framework Directive compliance of nitrogen inputs to the Tees Coastal Waterbody; and
- Section 10 provides an action plan and identifies the next steps to be taken.

1.3.4 In addition to this document, the Habitats Regulations Assessment (Document Ref. 5.13) [REP8-009] and the Water Framework Directive Assessment (Appendix 9C to the ES) [APP-254] will also be updated to incorporate the results of the assessment and resubmitted.

2.0 LEGISLATIVE BACKGROUND TO 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). This 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.

2.1.4 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.

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

2.1.6 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).

3.1.2 The assessment of nutrient nitrogen impacts in this briefing paper is based on the assessment of total nitrogen inputs to the water environment. The effluent produced by the NZT development will contain Dissolved Inorganic Nitrogen (DIN) in the form of ammonia in the effluent. There will be no Dissolved Organic Nitrogen (DON) or particulate Nitrogen in the effluent produced by NZT. Returned effluent from Bran Sands will include an equivalent nitrogen load to that sent for treatment – which will largely be in the form of DIN, but may also include dissolved organic nitrogen or particulate nitrogen (which would otherwise have been discharged to the Estuary). Data was available for DIN at this stage and as such the modelling is based on the volume of water containing an equivalent nitrogen load in the form of DIN (see calculation in Appendix B). If further data reveals that the Bran Sands effluent contains DON and/or particulate nitrogen, a lower volume of returned effluent would be required to achieve equivalency, however, the total nitrogen load returned from Bran Sands would remain consistent.

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 for 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.

3.2.3 Based on the use of the raw water in the cooling system, nitrogen in the abstracted water will be concentrated by up to five times, as the cooling system 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 should be noted 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 abstracted from the River Tees (by NWL), used on the Site and directed into Tees Bay, albeit in a more concentrated form. This abstraction effectively reduces the quantity of nitrogen passing through the Tees Estuary by 14 kgN/h, by discharging it to Tees Bay. This concentrated discharge to Tees Bay has been assessed in the modelling outlined in Section 6.0 below.

3.3 DCC Blowdown

3.3.1 Blowdown from the Direct Contact Cooler (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) (i.e. the current Base Case as listed in paragraph 3.6.1); or
- Off-site treatment (at Bran Sands WwTW) followed by return to Site for discharge to the sea (Tees Bay) via an outfall (i.e. the current Option A as listed in paragraph 3.6.1).

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 Direct discharge to the water environment without treatment is not considered in this paper. The alternative of using on-site treatment would be designed to not cause likely significant effects on the SPA/Ramsar and is also not assessed. The following discharge scenarios are therefore considered in this paper:

- The pre-development baseline;
- The current Base Case approach to effluent management from the Proposed Development whereby effluent is treated at Bran Sands WwTW and discharged to Dabholm Gut through NWL's consented discharge point;
- 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.

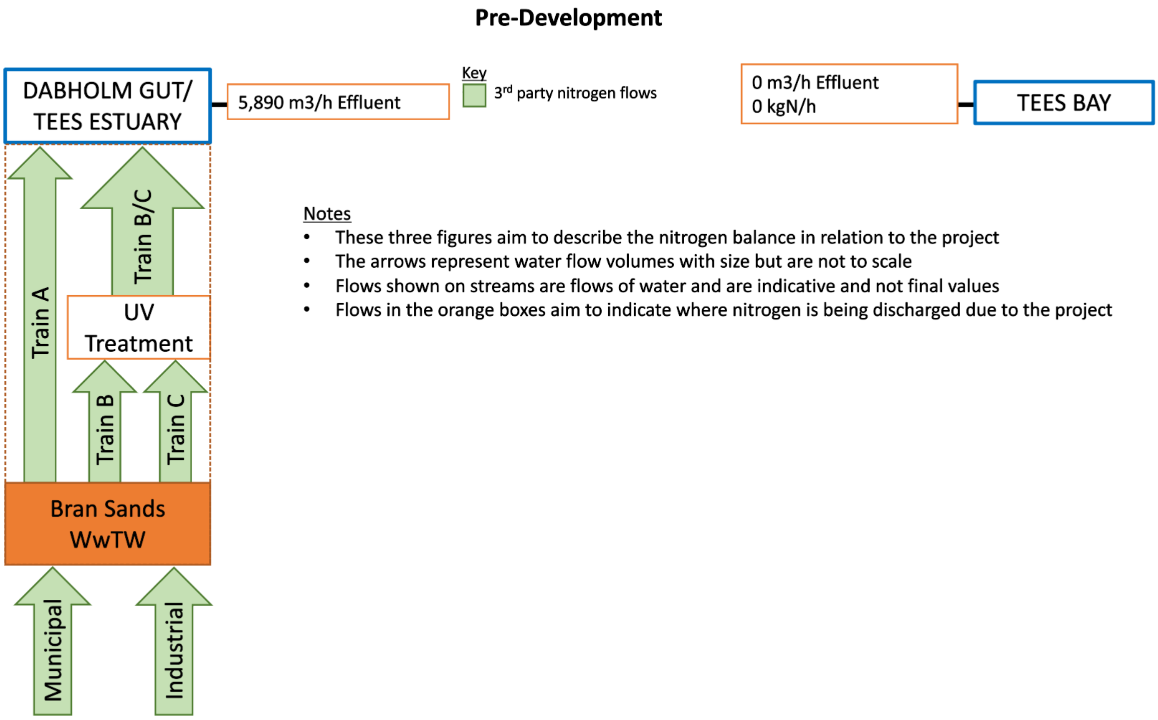
<u>Pre-Development Baseline</u>

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.

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



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.

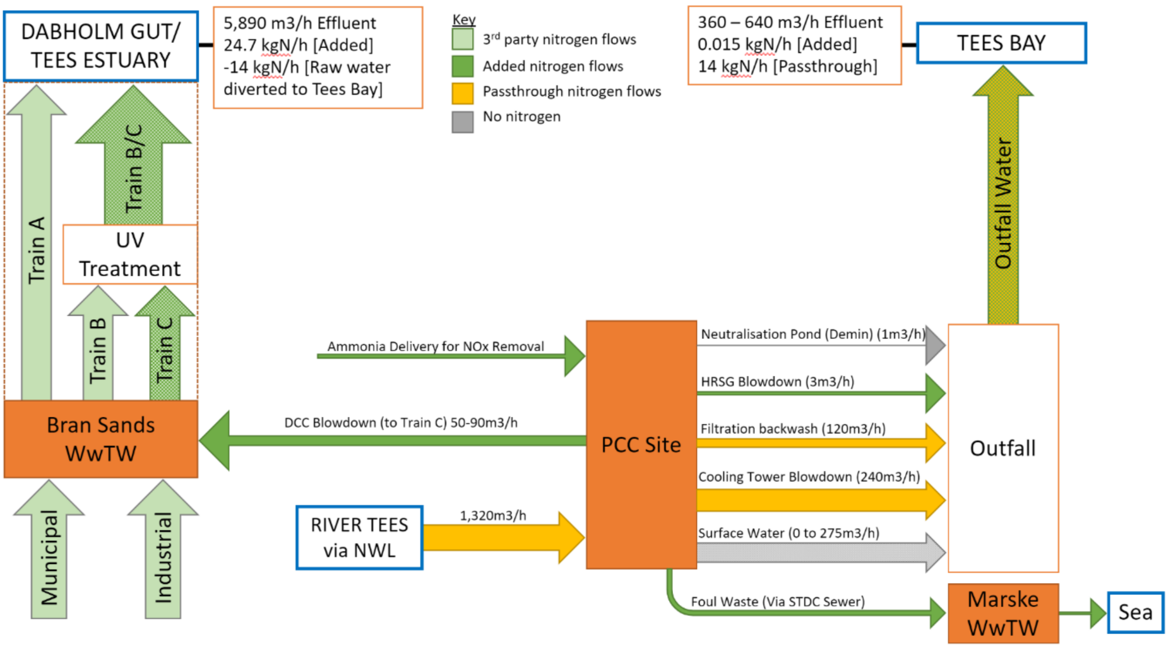
3.6.6 Outflows from the PCC Site to the Dabholm Gut (Tees Estuary) are shown as:

- 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).

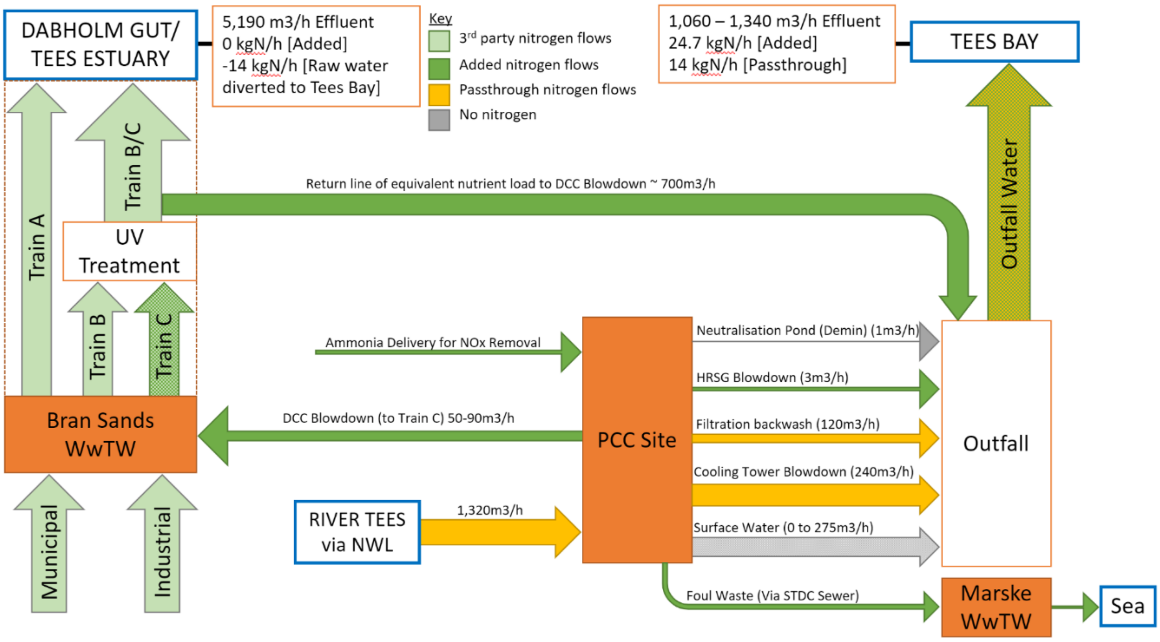
Figure 3.2: Base Case – Discharges to Dabholm Gut/Tees Estuary and Tees Bay



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 3.3: 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. The draft modelling report was submitted into Examination as Appendix A to Version 1.0 of the Nutrient Nitrogen Briefing Paper [REP8-050].

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 is used for the modelling reported in Appendix B. The approach to modelling is explained in section 6.0 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 explained 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 further meeting was held with NE on 30th September to discuss the updated discharge modelling and subsequent nutrient nitrogen assessment. A meeting will also be held with the EA in early October 2022 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.

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

5.0 THE TEESMOUTH AND CLEVELAND COAST SPECIAL PROTECTION AREA AND RAMSAR

5.1.1 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 REP6-082. 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.

5.1.2 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.

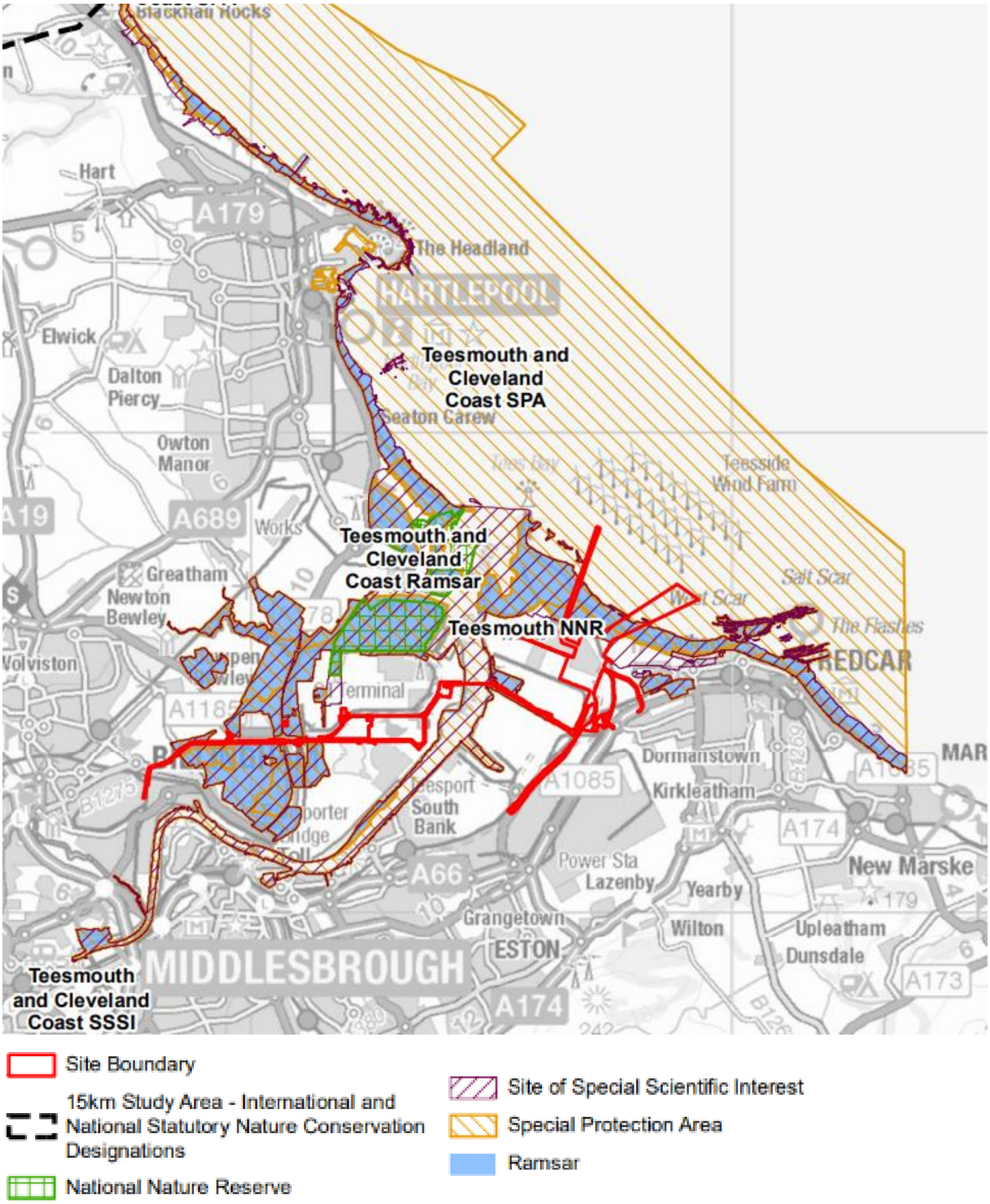
5.1.3 The Teesmouth and Cleveland Coast SPA/Ramsar was extended in 2020 to improve seabird protection within the SPA network.

5.1.4 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 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

[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.

(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).



5.1.5 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."

5.1.6 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.

5.1.7 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 website[4], 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.

5.1.8 Correspondence with NE in March 2022 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". 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.

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

6.0 DISCHARGE MODELLING

6.1.1 Modelling of discharges to Tees Bay assesses 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.

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

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).
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 has been 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

Nitrogen source	Discussion	Include in assessment?
		Dabholm Gut or to the Tees Bay via the selected outfall. Modelling of the discharge of process water has been undertaken.
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 assessment, and thus no change in leaching potential for nutrients.	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 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.

6.1.3 The modelling scenarios are summarised in Table 6.2 below:

Table 6.2: Summary of Modelling Scenarios

Scenario		Modelling
Base Case	DCC blowdown treated at Bran Sands and discharged to Dabholm Gut.	Modelled and reported on in Preliminary Discharge Modelling Report (see Appendix A)
Option A	DCC blowdown treated at Bran Sands. Returned effluent to PCC discharged to Tees Bay.	Modelling discussed in this report (see also Appendix B)

6.1.4 The impacts on the Tees Estuary have been assessed on the basis of identifying whether there is a net increase or decrease in nitrogen discharged to the Dabholm Gut/Tees Estuary directly (Base Case) or if the discharge modelling identifies the potential for effluent discharged into the Tees Bay via the outfall to disperse back into the Estuary due to tidal effects (Option A).

6.1.5 The Base Case modelling report was submitted into examination as Appendix A to Version 1.0 of the Nutrient Nitrogen Paper [REP8-050] and also forms Appendix A to this updated document. Updated discharge modelling for Option A has been undertaken for the replacement outfall (Work No. 5B), and is presented in Appendix B. Discharge modelling for the existing outfall (Work No. 5A) has not yet been completed[5].

6.1.6 The updated modelling in Appendix B has incorporated comments from NE and EA on the modelling previously undertaken (Appendix A). The modelling has included both continuous discharge and discharging on the ebb tide scenarios without surface water run-off (worst-case). No benefit from discharging on the ebb tide has been identified. The results for continuous discharge are discussed below and shown in Figures 6.1 and 6.2.

6.1.7 These show that for Option A:

- For Tees Bay, average concentrations of DIN are elevated in some locations by up to 10% above background although these are localised to the outfall location;

[5] There are outstanding technical and commercial matters with use of the existing outfall and therefore the Applicants' modelling has focused on the replacement outfall. The Applicants note that should the existing outfall be selected that additional discharge modelling will be required.

- For the Tees Estuary, average concentrations of DIN are elevated by up to 2.5% above background in some locations but these are confined to the dredged channel of the River Tees, in the bottom half of the water column;
- Average concentrations of DIN over the mudflats at Seal Sands are modelled as less than 1% above background – which is the limit of accuracy of the model.

6.1.8 Any dispersion of DIN from the outfall discharge back into the Estuary is offset by the reduction in DIN in the Tees Estuary as a result of the water abstracted for use on the PCC Site. This is discussed further in Section 7.

Figure 6.1 DIN Concentrations increase above background averaged over tidal cycle – top 5% of water column

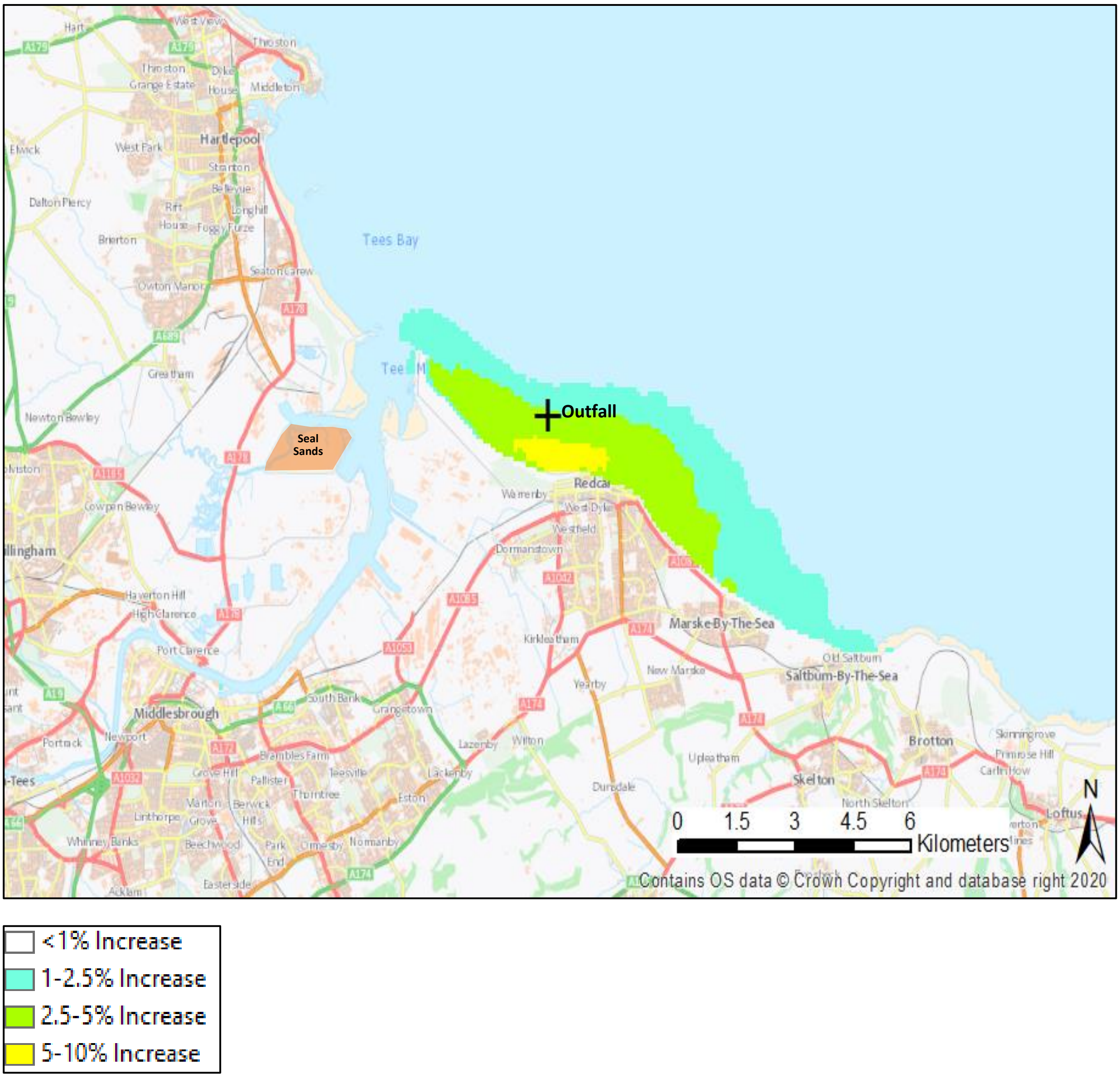
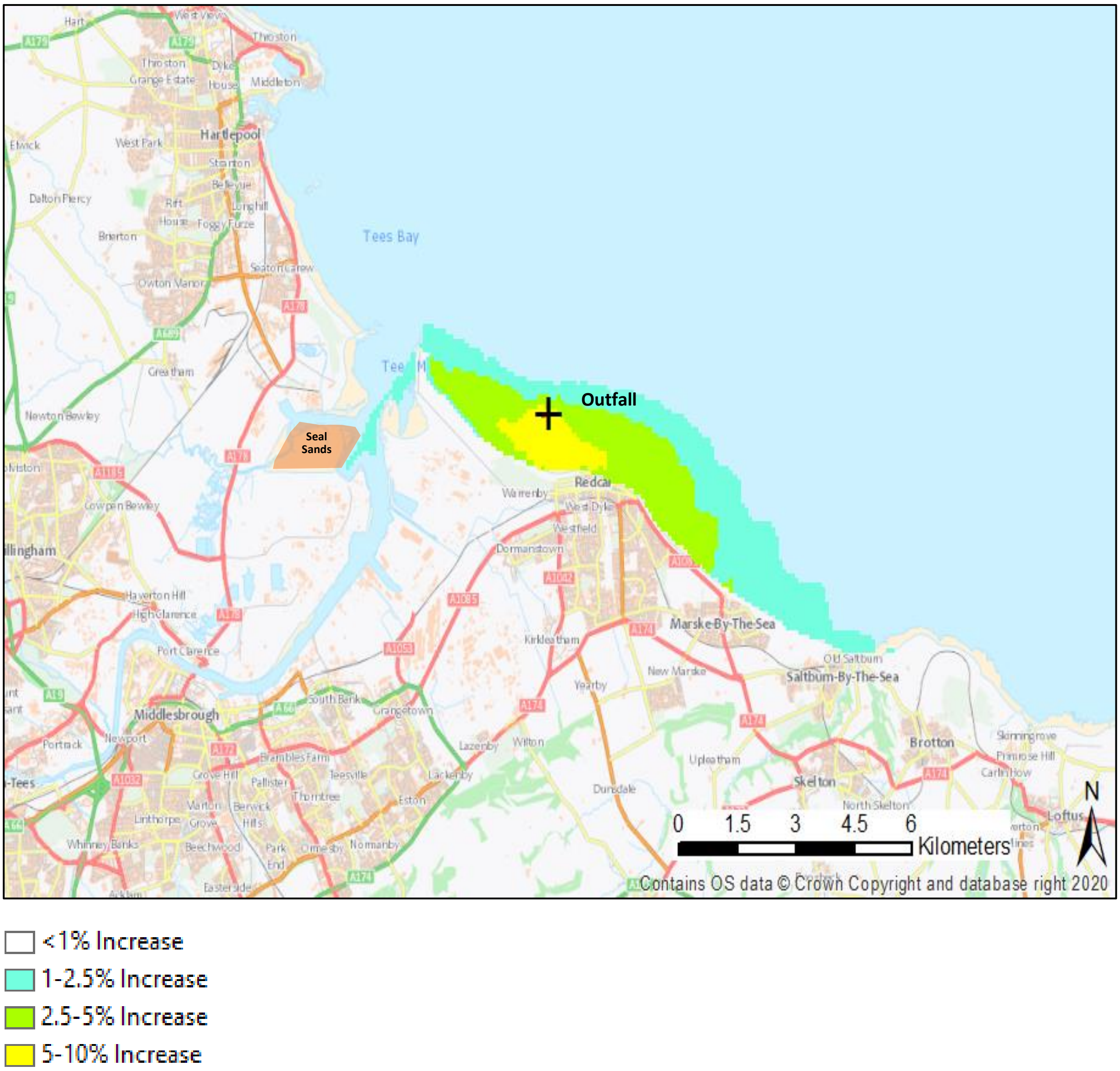


Figure 6.2 DIN Concentrations increase above background averaged over tidal cycle – bottom 10% of water column



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 The modelling shows the presence of elevated concentrations of DIN in areas of the Tees Bay (see Figures 6.1 and 6.2). 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 (Seal Sands)

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 takes 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 baseline nutrient nitrogen flux in the estuary by 14 kgN/hr.

7.2.3 Modelling of Option A has shown that even with conservative assumptions there is an increase in background DIN concentrations of less than 1% at Seal Sands mudflats arising from the discharge of treated effluent via the replacement outfall. This equates to less than 0.94 kgN/hr reaching the Seal Sands mudflats from the dispersed treated effluent. For reference, the ambient water quality shows a background DIN concentration at Tees Mouth of 0.5 mg/l (500 ug/l).

7.2.4 The amount of additional nitrogen reaching Seal Sands mudflats has been estimated as follows:

- the worst case average increase in DIN concentrations over the current 14 day model run period for the Seal Sands area –is approximately $9x10^{-6}$ kg/m^3.
- the average water depth[6] at a central location in Seal Sands over the tidal cycle is 0.7 m. Using an area of 181 ha (1,810,000 m^2) gives a volume of water of 1,267,000 m^3 ; and
- this gives an additional volume of DIN of 11.4 kg per high tide, or 0.95 kgN/hr given a duration of elevated DIN of 12 hours over a tidal cycle.

7.2.5 To assess the degree to which this is offset by the removal of nitrogen from the estuary, the reduction in the nitrogen flux due to abstraction at Low Worsall has been partitioned by the ratio between the area of the Seal Sands mudflats and the total area of the Tees Estuary. Seal Sands has an area of 181 ha and represents 16% of the

[6] using the average water depth instead of the maximum water depth takes account of the fact that there is no need to offset DIN increases during the ebb tide

Tees Estuary (as the Tees Transitional Waterbody with an area of 11.4 km^2). Based on this the effect of this removal over the area of Seal Sands is 14 x 0.16 = 2.2 kgN/hr.

7.2.6 The net additional load of nutrient nitrogen at Seal Sands from the Proposed Development is therefore less than 0.94 kgN/hr minus 2.2 kgN/hr, i.e. a net removal of potentially 1.2 kgN/hr from the Tees Estuary. As such it is considered there will be no average net increase in nutrient nitrogen deposition on the mudflats at Seal Sands arising from the Proposed Development. Consequently, it is considered that there would be no adverse effect on the integrity of the SPA/Ramsar site due to nutrient nitrogen discharges to the Tees Estuary.

7.2.7 This assessment is considered conservative because:

- The less than 0.94 kgN/hr rate of nitrogen is ultimately derived from the <1% average increase in DIN at Seal Sands predicted by the modelling. The 1% figure is the effective limit of for accuracy detecting an increase in DIN in the estuary. As the actual concentration increase will be lower than 1% then the actual rate of nitrogen increase would be lower than this.
- The calculation of the nutrient nitrogen load at Seal Sands is based on the total increased mass of nitrogen in sea water 0.7 m deep on average over the mudflats. In reality, only a fraction of this nitrogen would be available for macroalgae nutrition.

7.2.8 The Applicants' assessment demonstrates that by installing and using the return line from Bran Sands WwTW and installing a new purpose built outfall (and so not discharging treated effluent to the Dabholm Gut), nutrient nitrogen effects on the qualifying features of the SPA at Seal Sands mudflats can be avoided or even reduced as a result of the Proposed Development. The Applicants therefore propose to commit to using such measures – or alternative measures that achieve the same outcome – for the Proposed Development, through the addition of a suitably worded requirement to the draft DCO.

7.2.9 It is important to understand that Option A is only one potential means by which nutrient neutrality can be achieved. It demonstrates that this is readily achievable within the scope of the Proposed Development, but there may well be other approaches which would be at least as good if not better. It is therefore neither necessary nor desirable to constrain the scope for optimising the approach at the detailed design stage. Instead, it is proposed that the requirement will provide that the undertaker must submit details of the final design measures for approval, and that it must be demonstrated to the satisfaction of the discharging authority that these measures will ensure that there is no net increase in nutrient nitrogen loads at Seal Sands. This is considered further in Section 10.0 below.

8.0 NUTRIENT NEUTRALITY

8.1.1 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.

8.1.2 As this assessment demonstrates that Proposed Development does not have the potential to impact on water quality on the identified receptor in the Tees Estuary no nutrient nitrogen assessment is therefore required.

9.0 WATER FRAMEWORK DIRECTIVE AND EQS COMPLIANCE

9.1.1 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.

9.1.2 Following completion of the discharge modelling, an updated Water Framework Directive assessment is being prepared, considering water quality impacts from emissions to the Tees Bay and any effects on the WFD status of the Tees Coastal Water Body.

10.0 ACTION PLAN / NEXT STEPS

10.1.1 The Applicants have undertaken the following by Deadline 9.

- Update of the and Habitat Regulations Assessment Report; and
- Consultation with Natural England.

The submission at Deadline 9 of this updated nitrogen discharges briefing paper to the ExA, supported by:

- Effluent Discharge Modelling Report for Option A; and
- Updated Habitat Regulations Assessment report (DCO Document Ref. 5.13).

10.1.2 The Updated Water Framework Directive Compliance Report (Appendix 9C to the ES) and associated consultation with the EA on Water Framework Directive Compliance will be undertaken following the next meeting between the Applicants and the EA.

10.1.3 In the finalised DCO submission (scheduled for Deadline 12 on 1 November 2022) the Applicants will include a requirement that would secure the position on nutrient nitrogen in this briefing paper.

10.1.4 The replacement outfall and the return pipeline from Bran Sands are already included in the dDCO.

10.1.5 The form and wording of the proposed requirement will be discussed with Natural England, but it is likely to provide that the undertaker must submit a detailed design for approval (following consultation with Natural England) and demonstrate to the satisfaction of the discharging authority that it achieves no net increase in nutrient loads at Seal Sands. The requirement is also likely to provide that the undertaker must instigate a monitoring programme for nitrogen in the Tees Estuary to provide baseline water quality and undertake monitoring of nitrogen concentrations during site operation.

Appendix A: Discharge Modelling – Base Case

Net Zero Teesside - Water Quality Assessment

Intermediate Design Stage

BP

Project number: 60675797

14 June 2022

Quality information

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Revision History

Revision	Revision date	Details	Authorized	Name	Position
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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.

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 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.

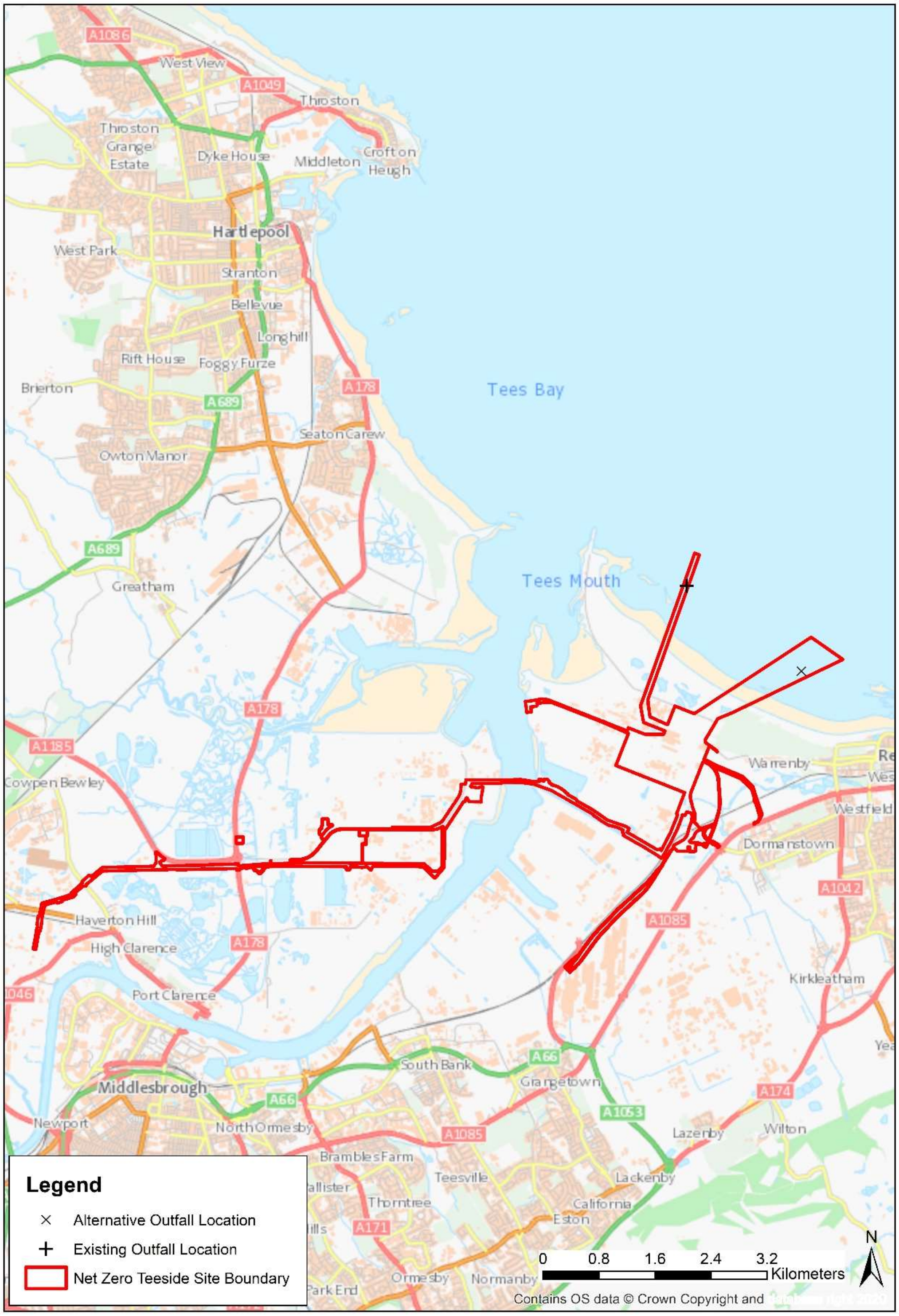


Figure 1-1: NZT Development Boundary and Potential Effluent Discharge Locations

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.

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

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]

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

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

2 [redacted], 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:

- **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.

[3] Rainfall depth information taken from Flood Estimation Handbook 2013 model, accessed at [redacted] 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

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.

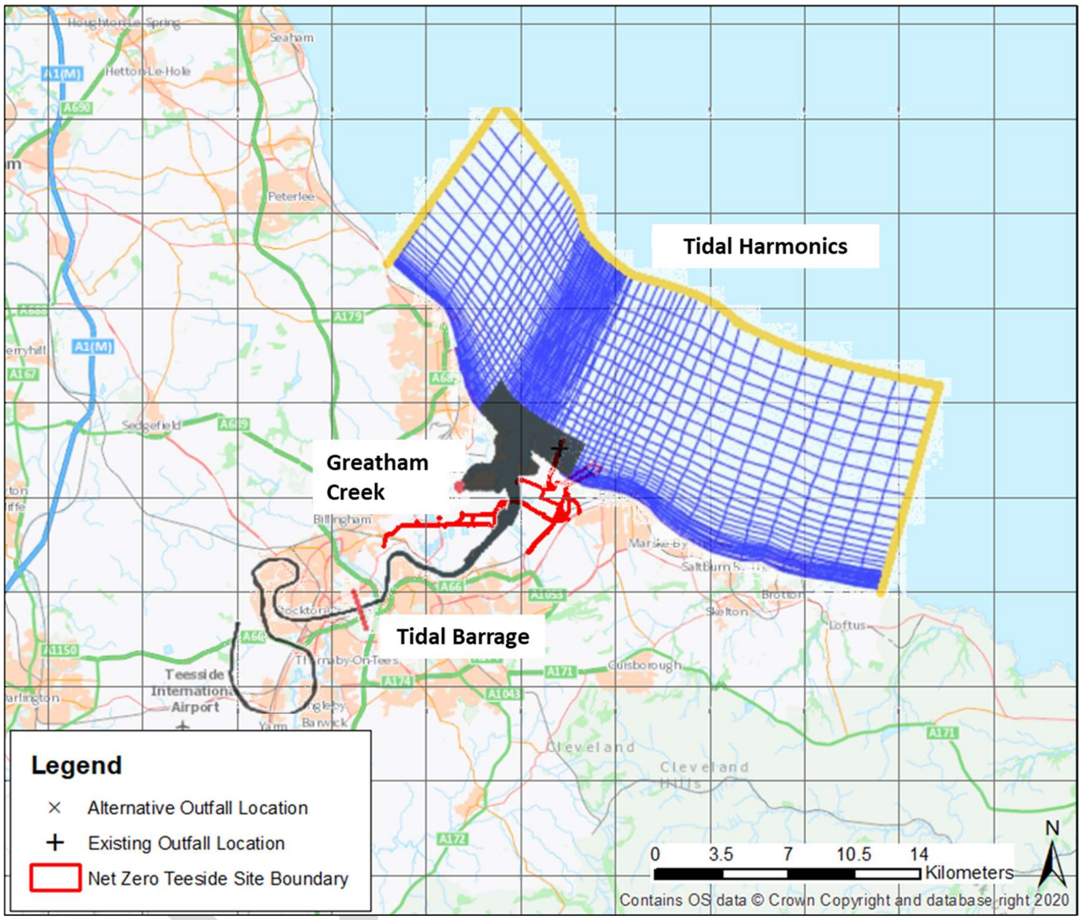


Figure 3-1: Delft3D hydrodynamic model extent

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.

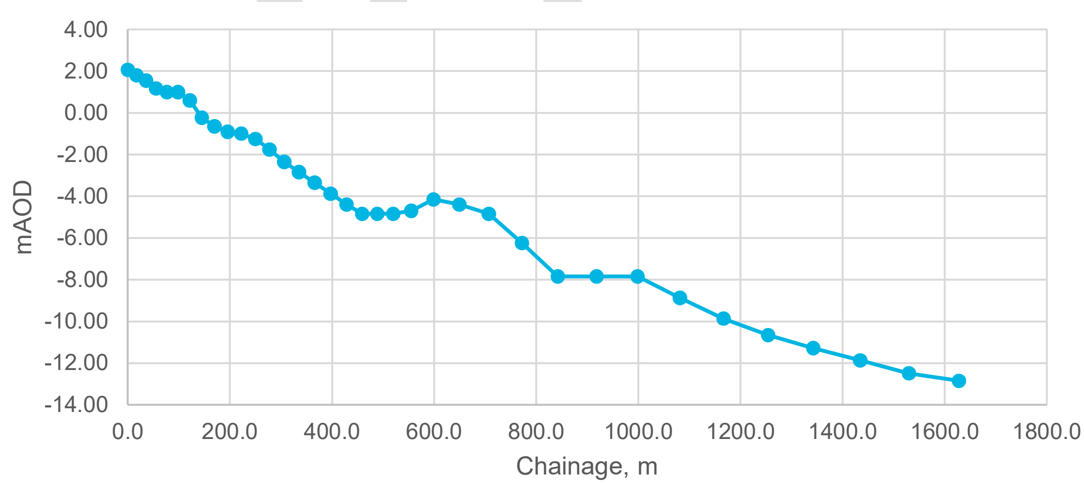


Figure 3-2: Bed Profile Extending Offshore at W3 Outfall Location

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.

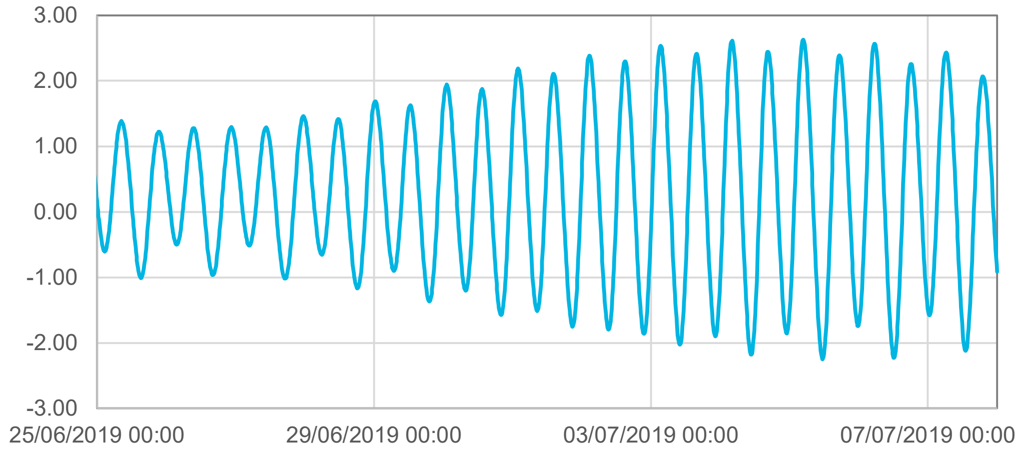


Figure 3-3: Water Levels at Existing Outfall

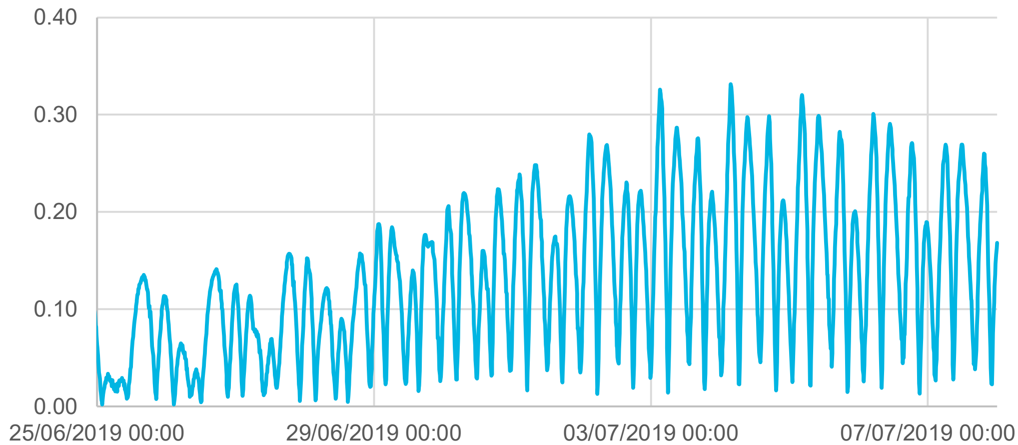


Figure 3-4: Current Speeds at the Existing Outfall Location

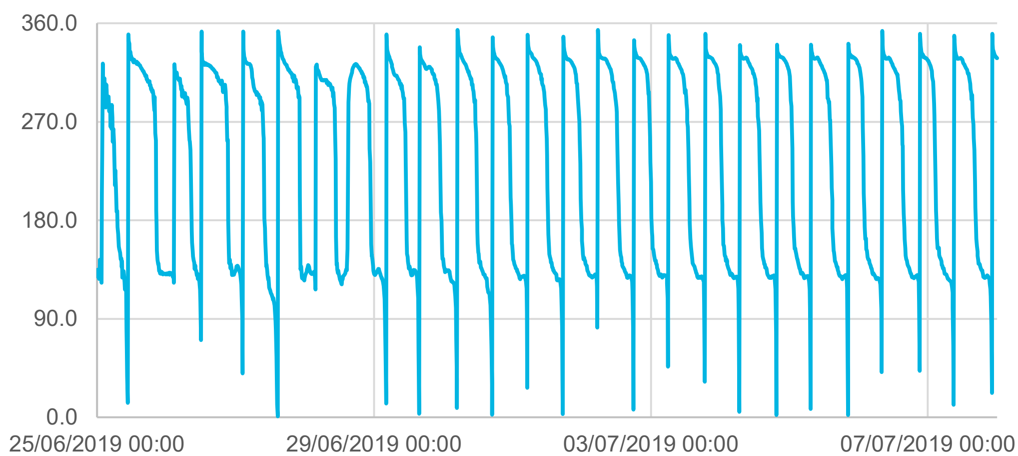


Figure 3-5: Current Directions at the Existing Outfall Location

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.

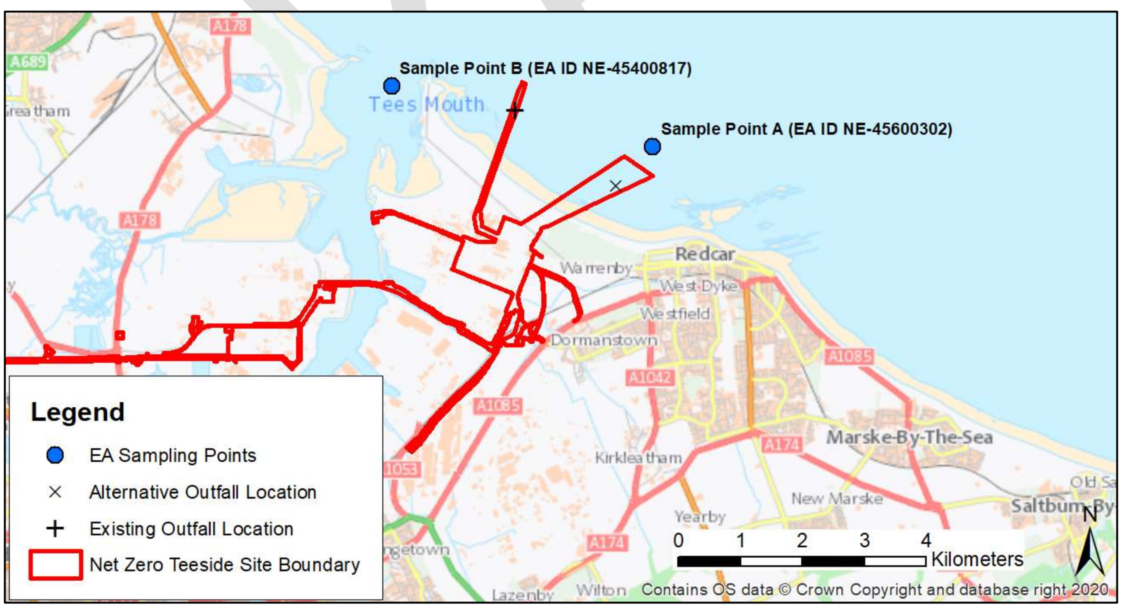


Figure 3-6: Environment Agency Ambient Water Quality Monitoring Locations

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.

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.

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.

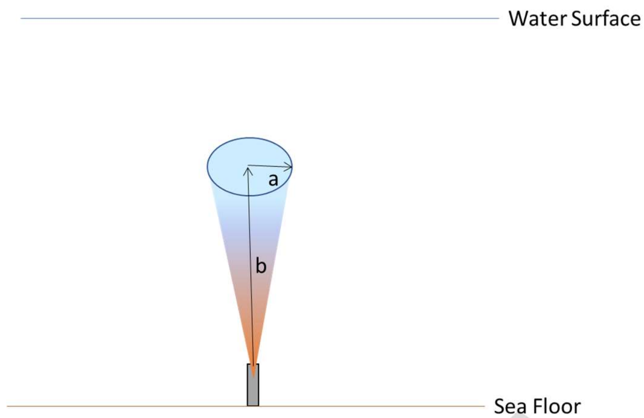


Figure 4-1: Vertical Rising Mixing Zone

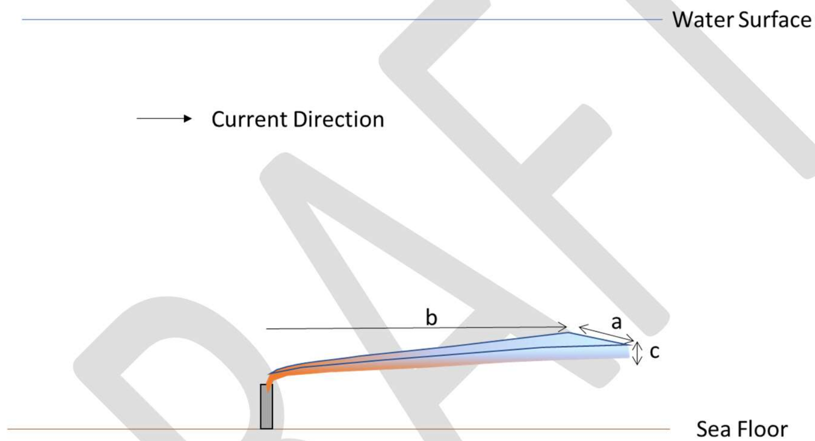


Figure 4-2: Deflected Lateral Plume Mixing Zone

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.

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
	Low Tide		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	Plume is deflected horizontally and does not reach water surface	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
1A Winter	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
	Low Tide		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	Plume is deflected horizontally and does not reach water surface	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
1A Summer	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
	Low Tide		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	Plume rises vertically and only spreads laterally at the water surface for scenarios marked *	a = 1.5 m b = 2.6 m	a = 0.3 m b = 1.6 m	a = 0.6 m b = 1.9 m
2A Winter	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

	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

			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		

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.

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

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.

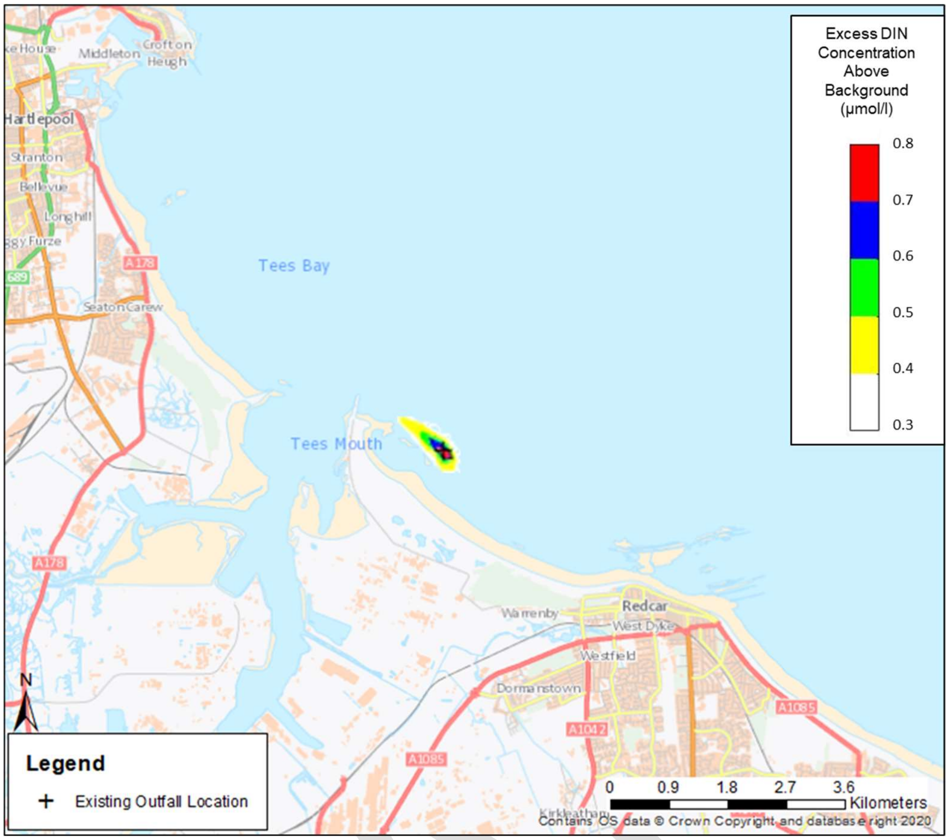


Figure 6-1: DIN Mixing Zone: Existing Outfall Option 1A, Lower 35% of Water Column

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.

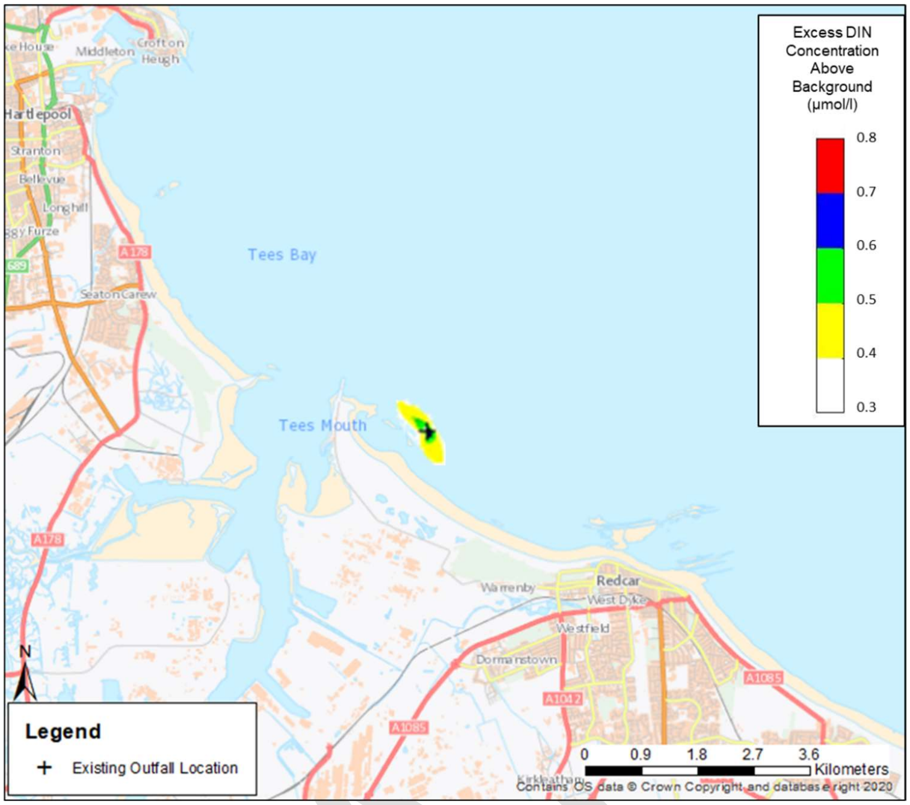


Figure 6-2: DIN Mixing Zone: Existing Outfall Option 2A, Upper 2% of Water Column

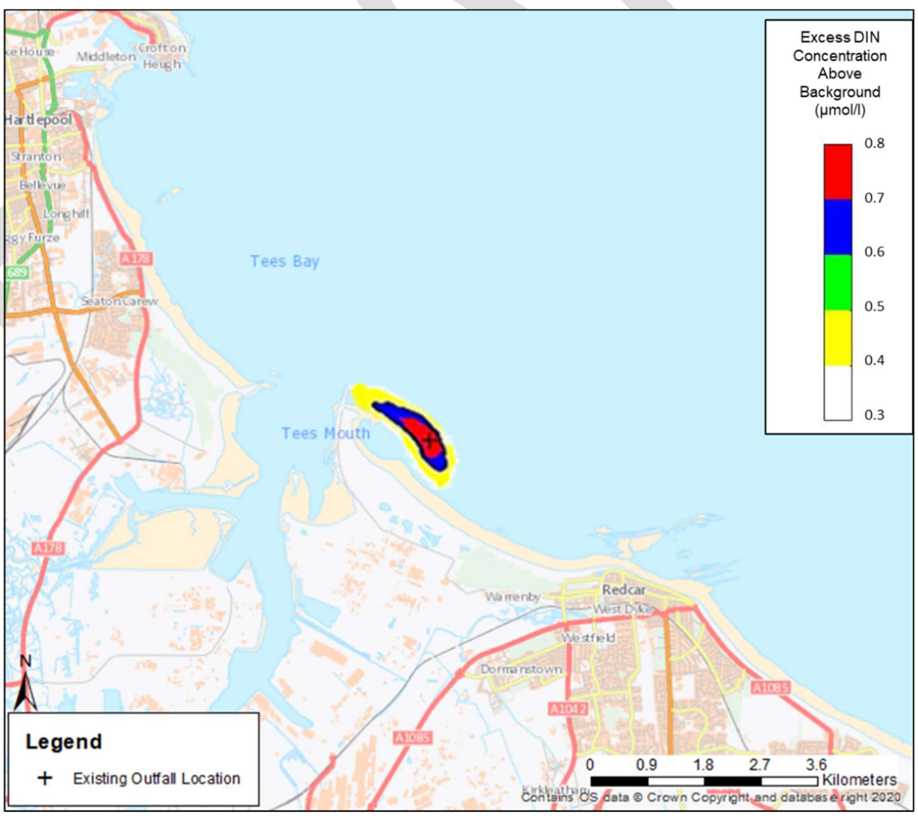


Figure 6-3: DIN Mixing Zone: Existing Outfall Option 2A, Lower 35% of Water Column

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.

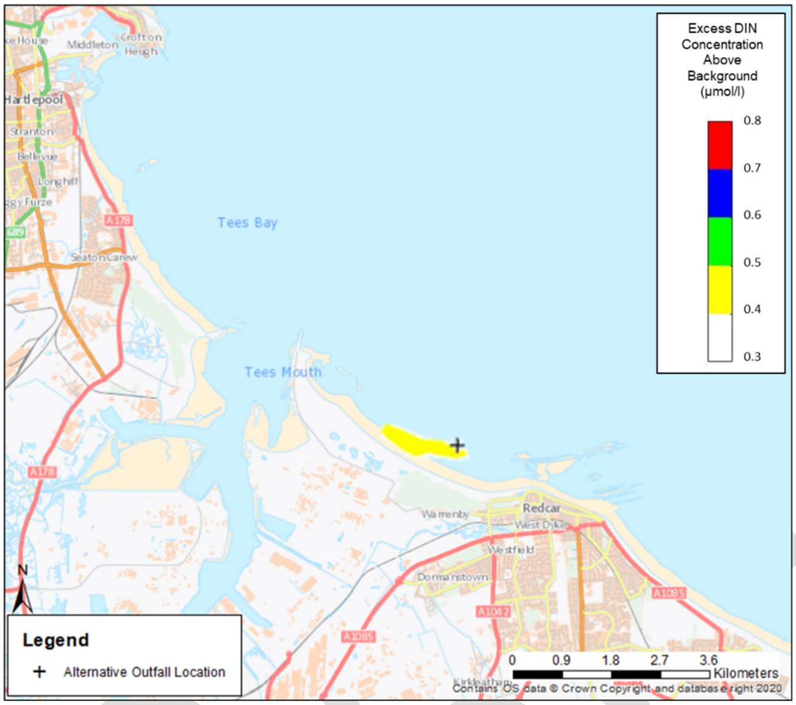


Figure 6-4: DIN Mixing Zone: Alternative Outfall Option 1A, Upper 2% of Water Column

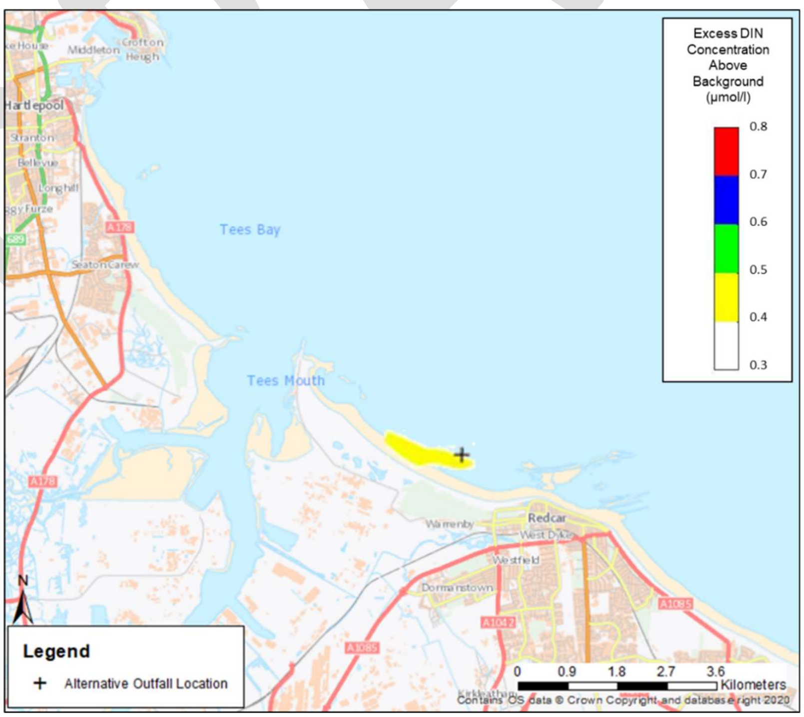


Figure 6-5: DIN Mixing Zone: Alternative Outfall Option 1A, Mid 10% of Water Column

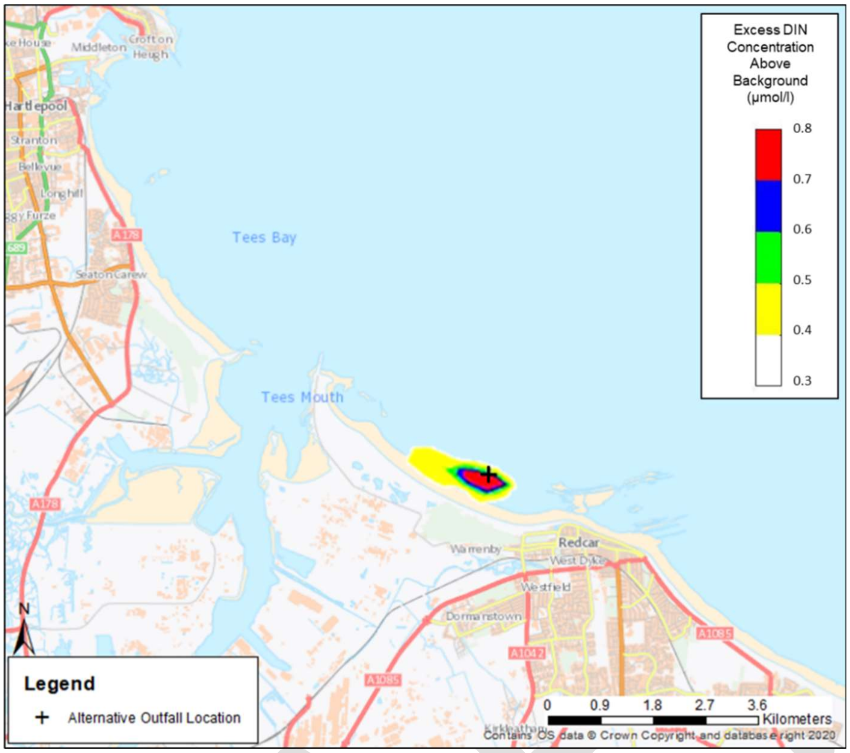


Figure 6-6: DIN Mixing Zone: Alternative Outfall Option 1A, Lower 35% of Water Column

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.

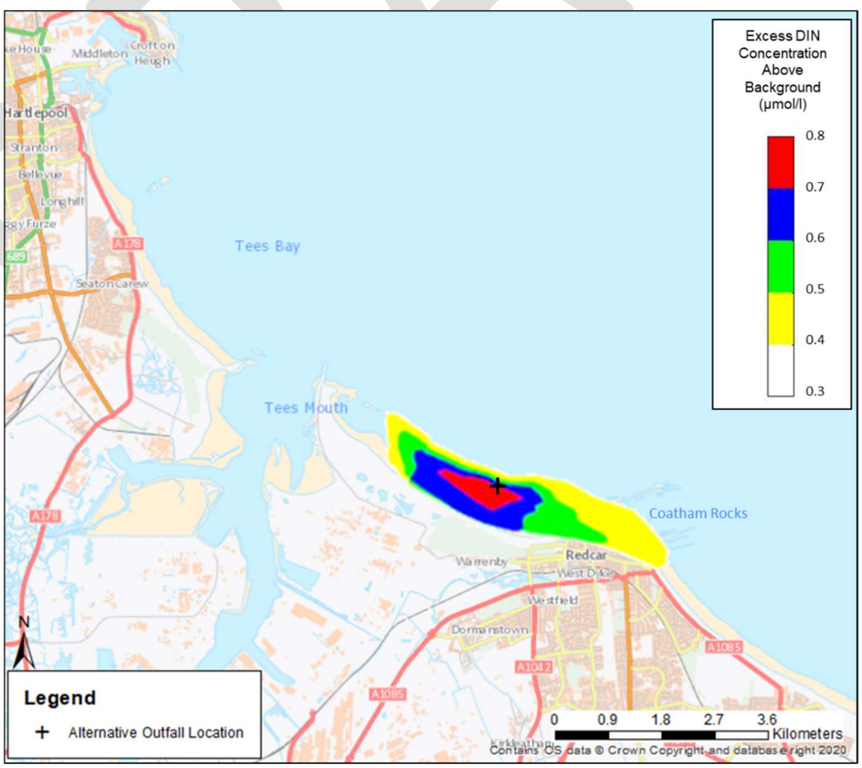


Figure 6-7: DIN Mixing Zone: Alternative Outfall Option 2A, Surface 2% of Water Column

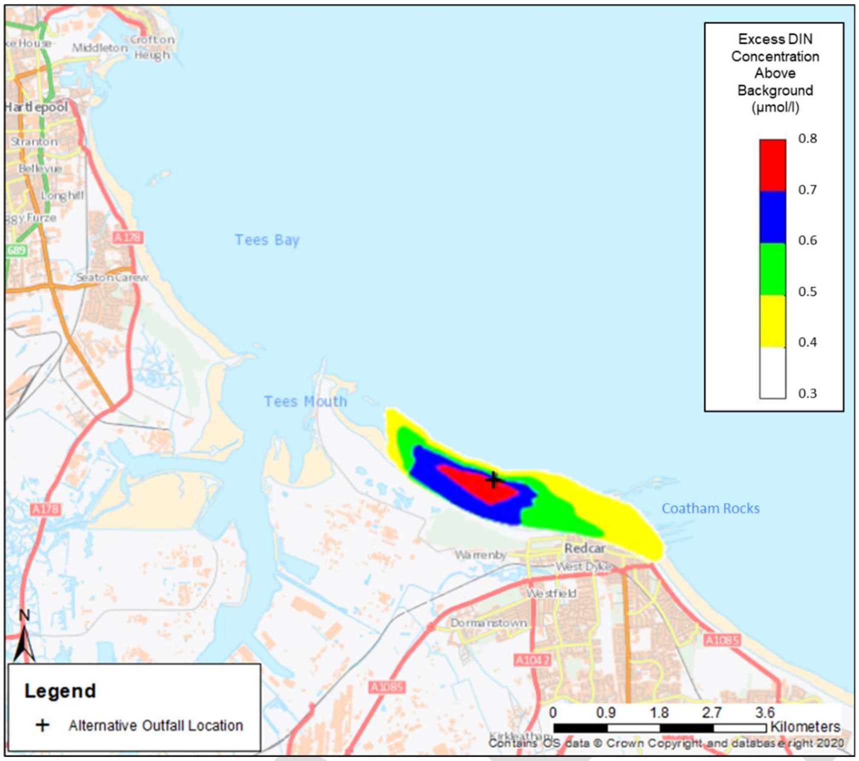


Figure 6-8: DIN Mixing Zone: Alternative Outfall Option 2A, Mid 10% of Water Column

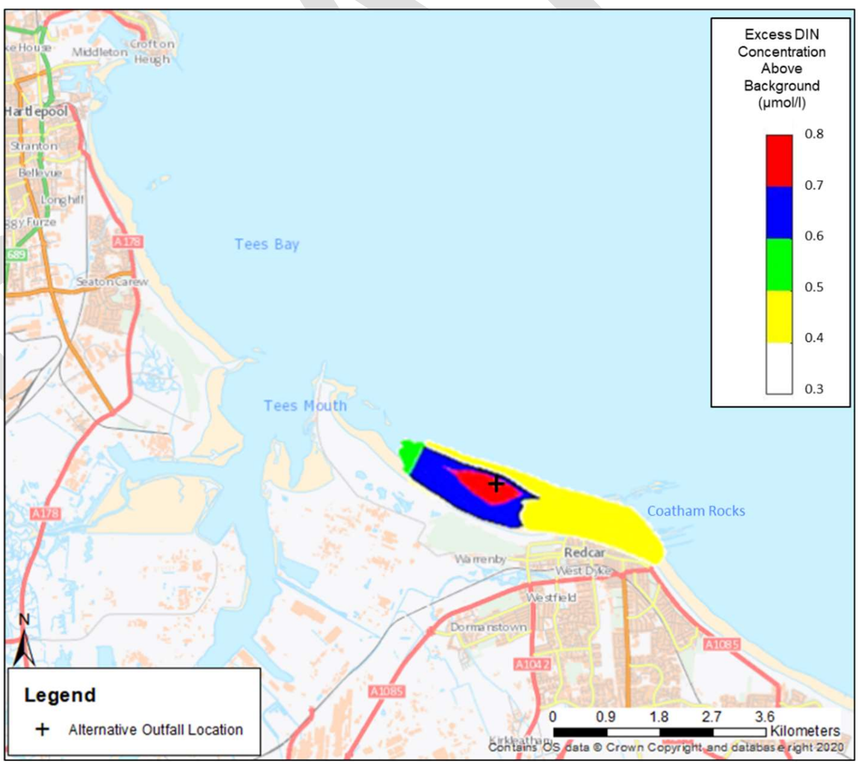


Figure 6-9: DIN Mixing Zone: Alternative Outfall Option 2A, Lower 35% of Water Column

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 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.

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 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.

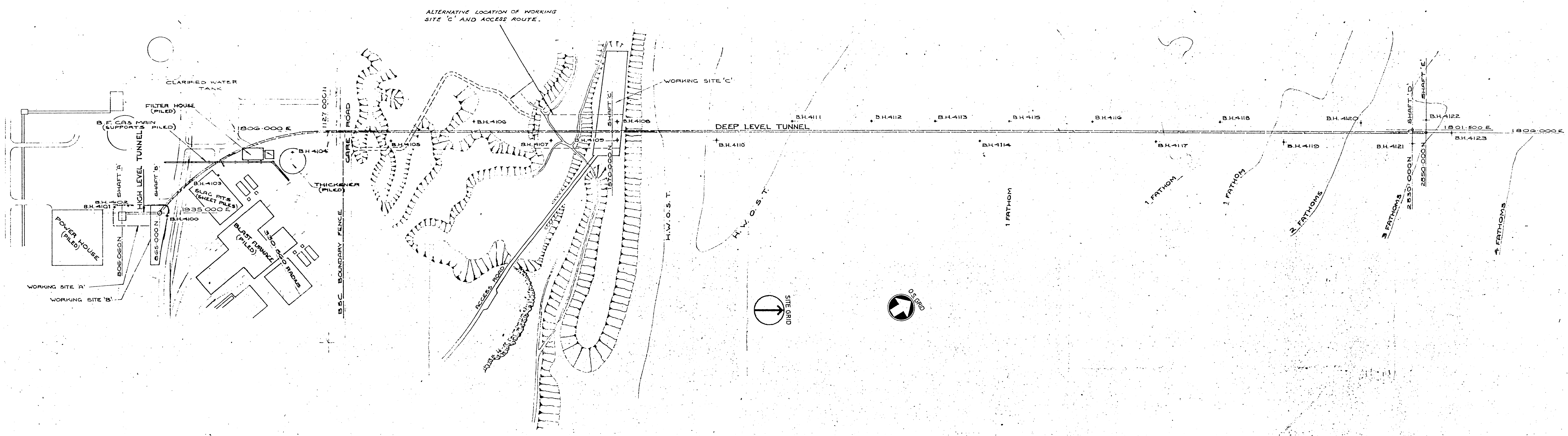
The near field modelling shows that the impacts of the discharge is small for all four assessed discharge Options at all stages of the tidal cycle. The chemical contaminants (excluding DIN) are diluted to below the EQS within a very short distance of the outfall and before the mixing plume reaches the 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 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.

Appendix A Initial Design Stage Report

Presented as a seperate attachement

Appendix B Existing Outfall Schematic



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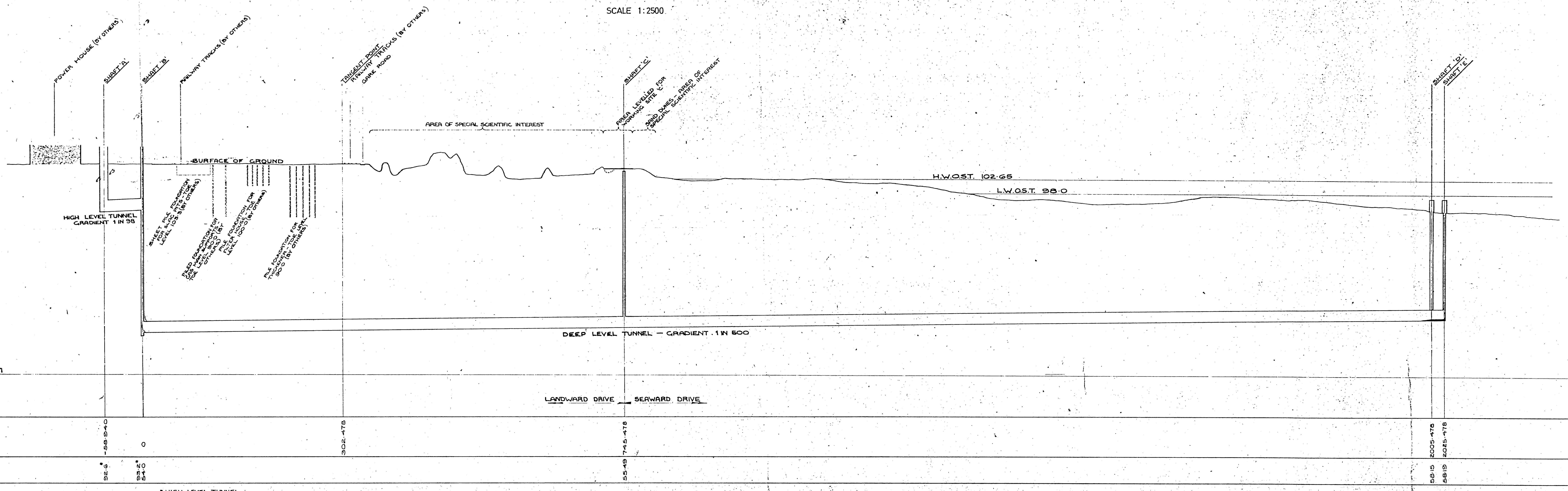

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4107		"
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4122		"
4123		"

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 '75

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CIVIL ENGINEERING WORKS — CONTRACT 'G'

British Steel Corporation
PLANNING & CAPITAL DEVELOPMENTS DIVISION
REDCAR DEVELOPMENTS

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

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	BSC 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

ABP mer

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Net Zero Teesside Project

Coastal Modelling – Final Integrated Report

April 2021

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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)

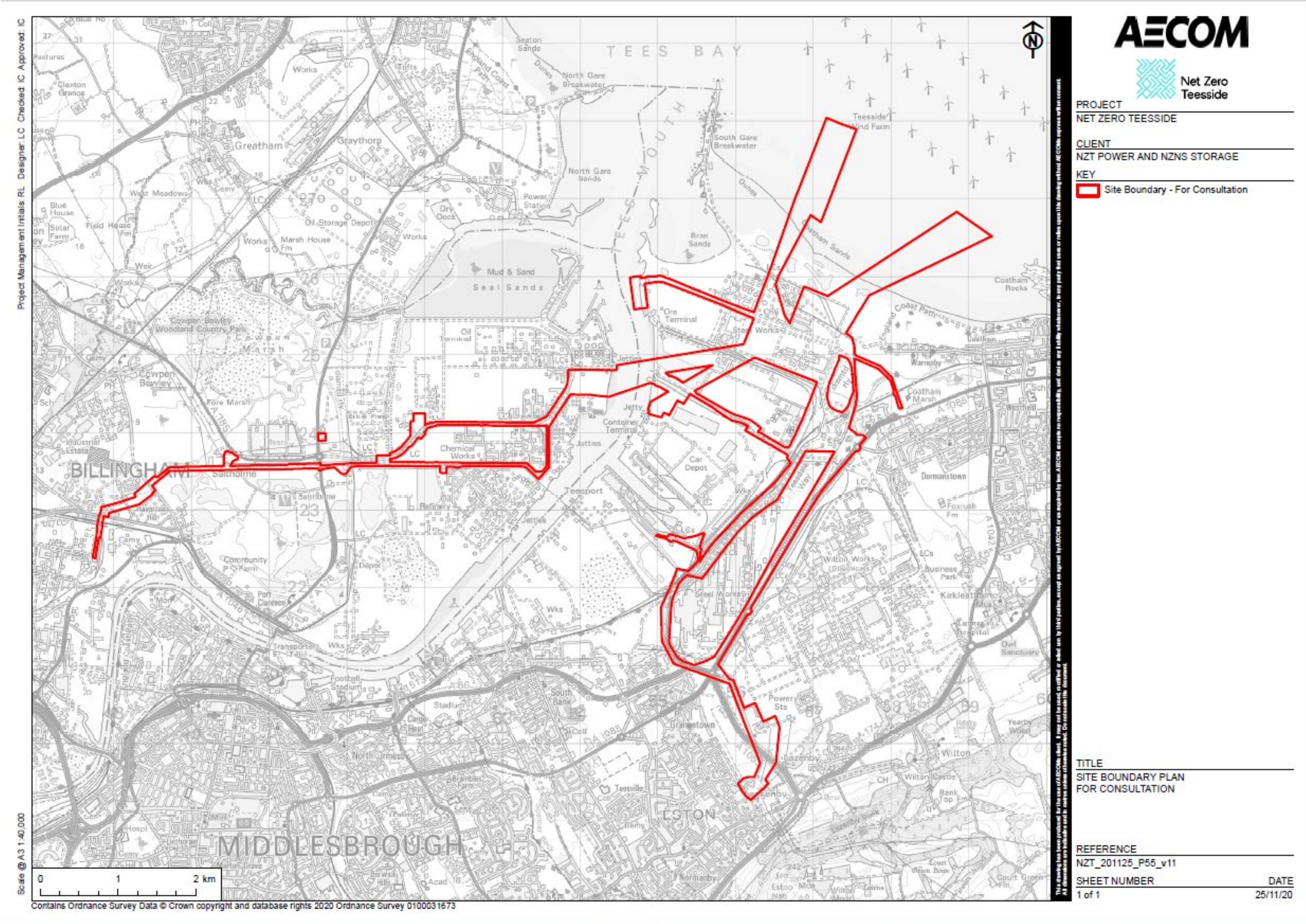


Figure 2. Net Zero Teesside – Site Boundary for Consultation

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

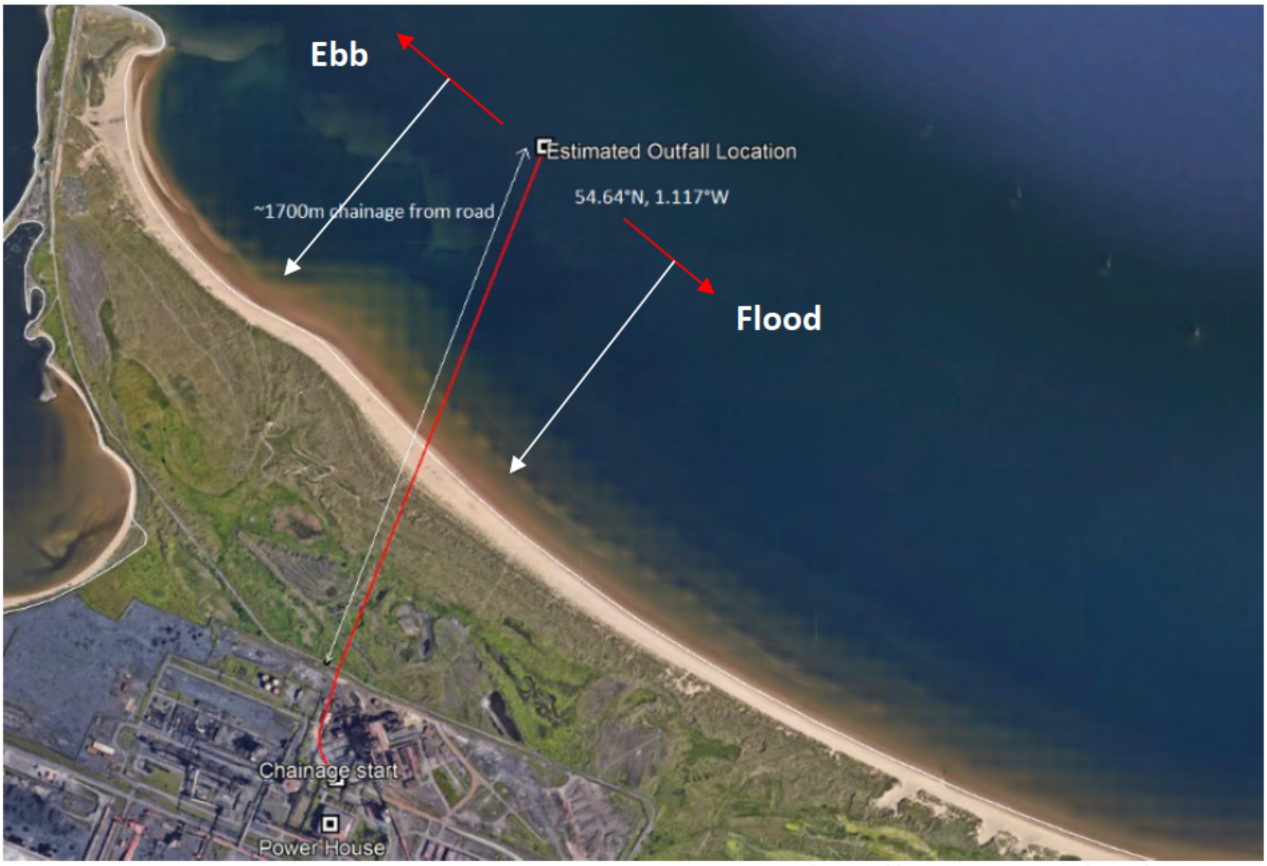
Appendix A: Delft Model Setup

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.

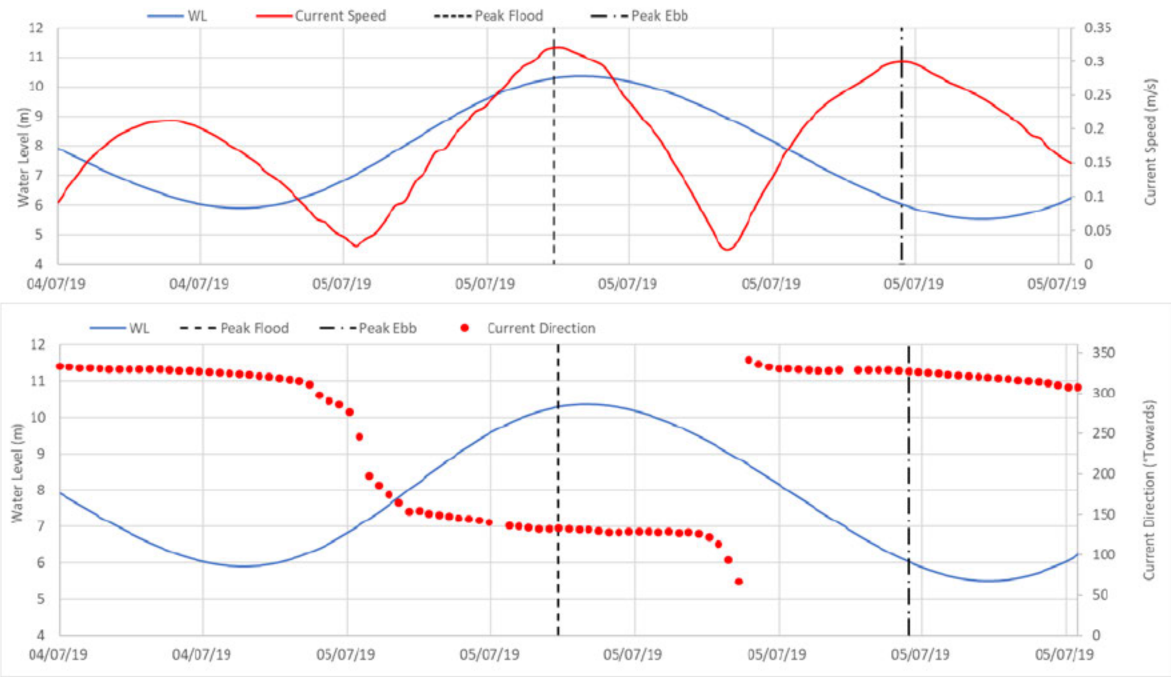


Figure 4. **Tidal characteristics during a mean spring tide**

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/m³; 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/m³) 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).

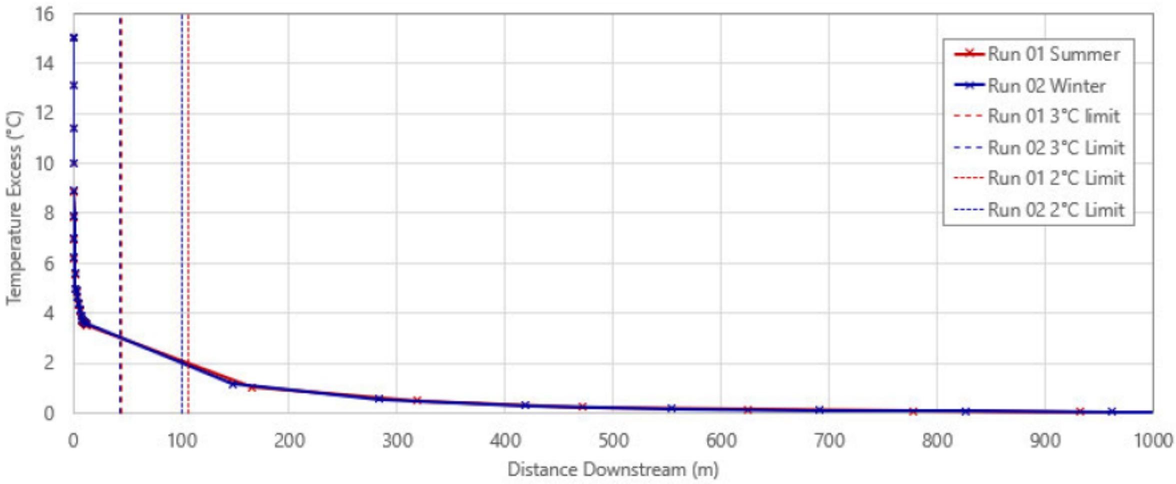


Figure 5. Spring flood seasonal variation

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.

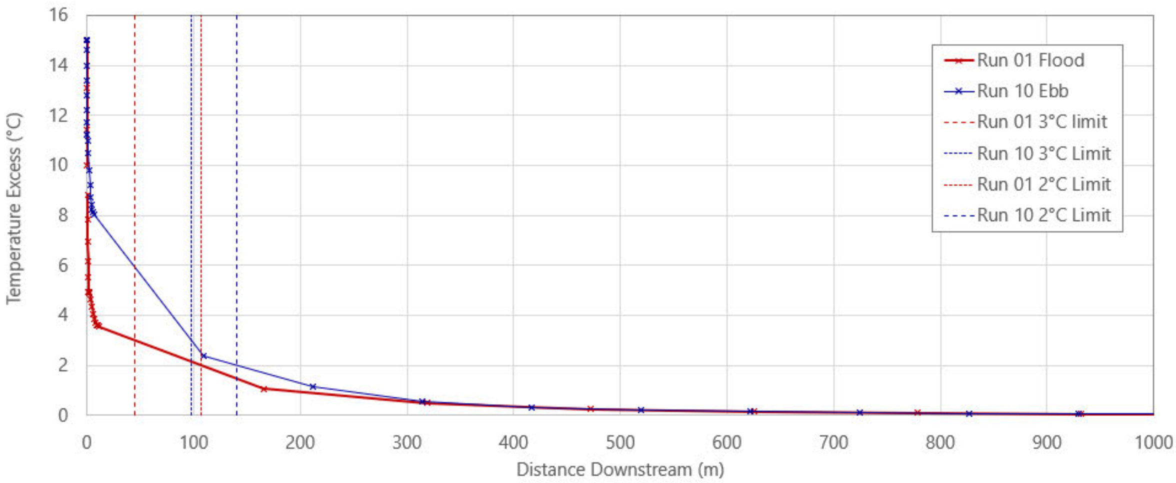


Figure 6. Summer scenario, flood and ebb sensitivity

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.

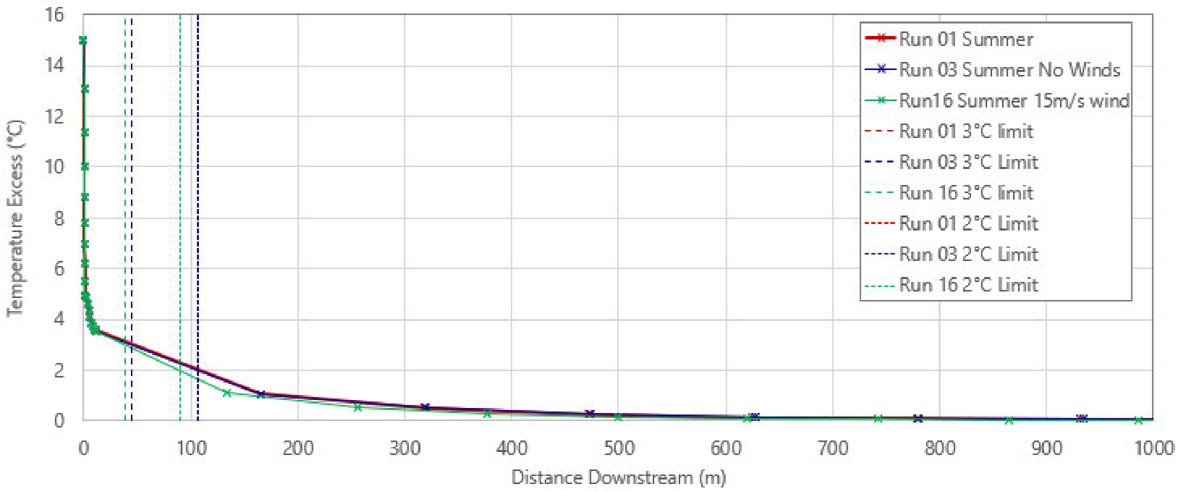


Figure 7. Spring flood wind sensitivity

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.

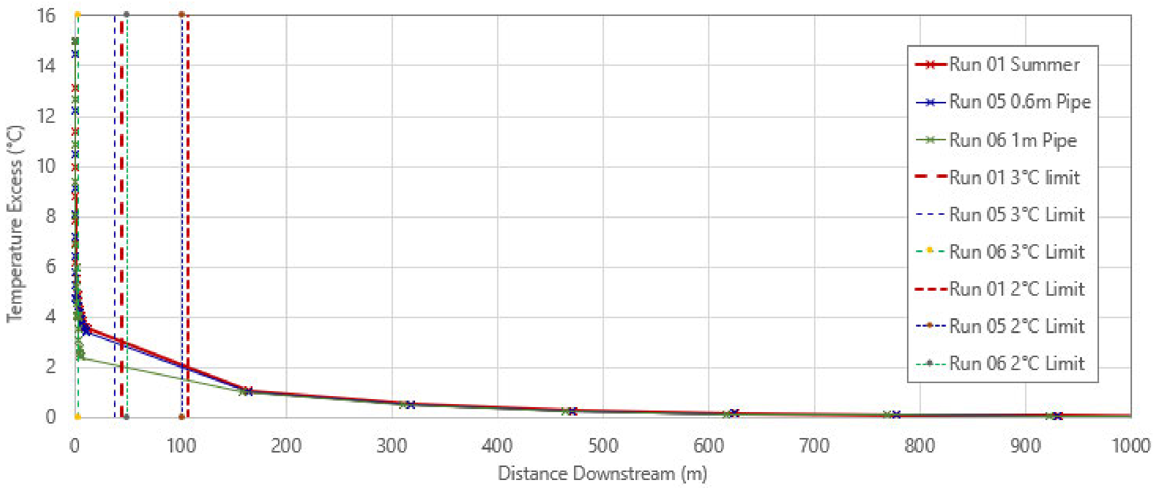


Figure 8. Spring flood, pipe diameter sensitivity

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.

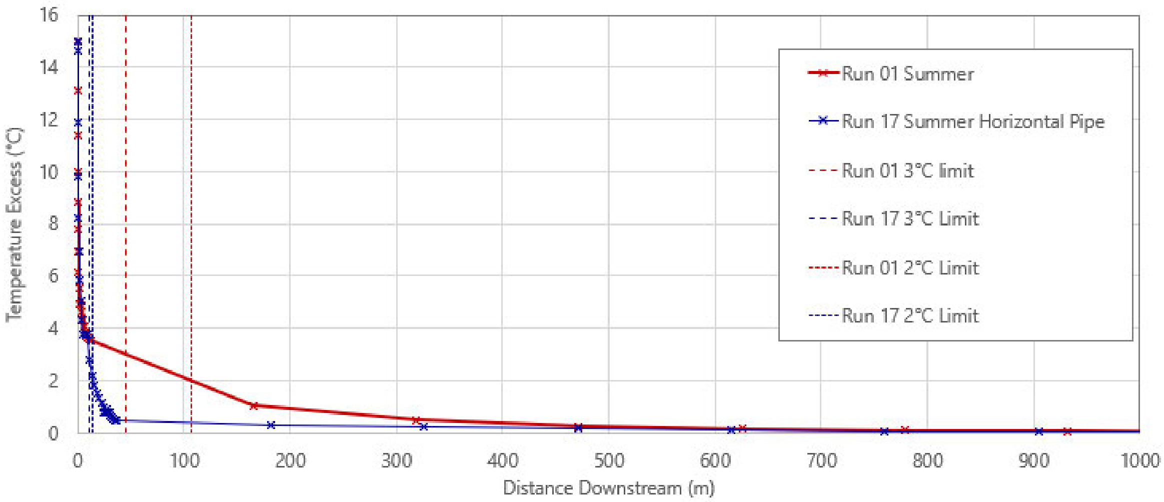


Figure 9. Spring flood, outfall projection sensitivity

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

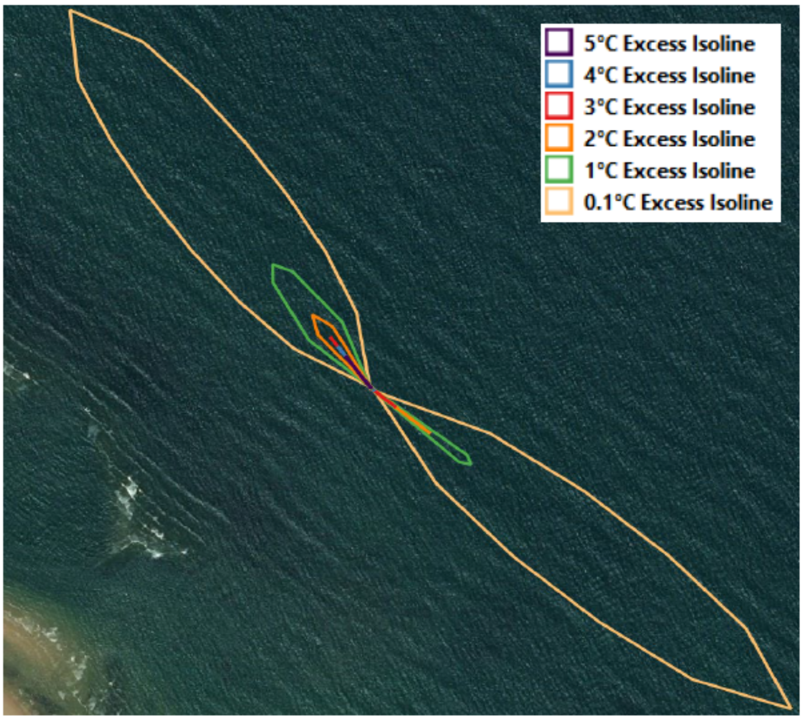


Figure 11. Zoomed extent of the CORMIX excess temperature isolines (°C) under mean spring, peak flood (SE) and ebb (NW) tidal states

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.

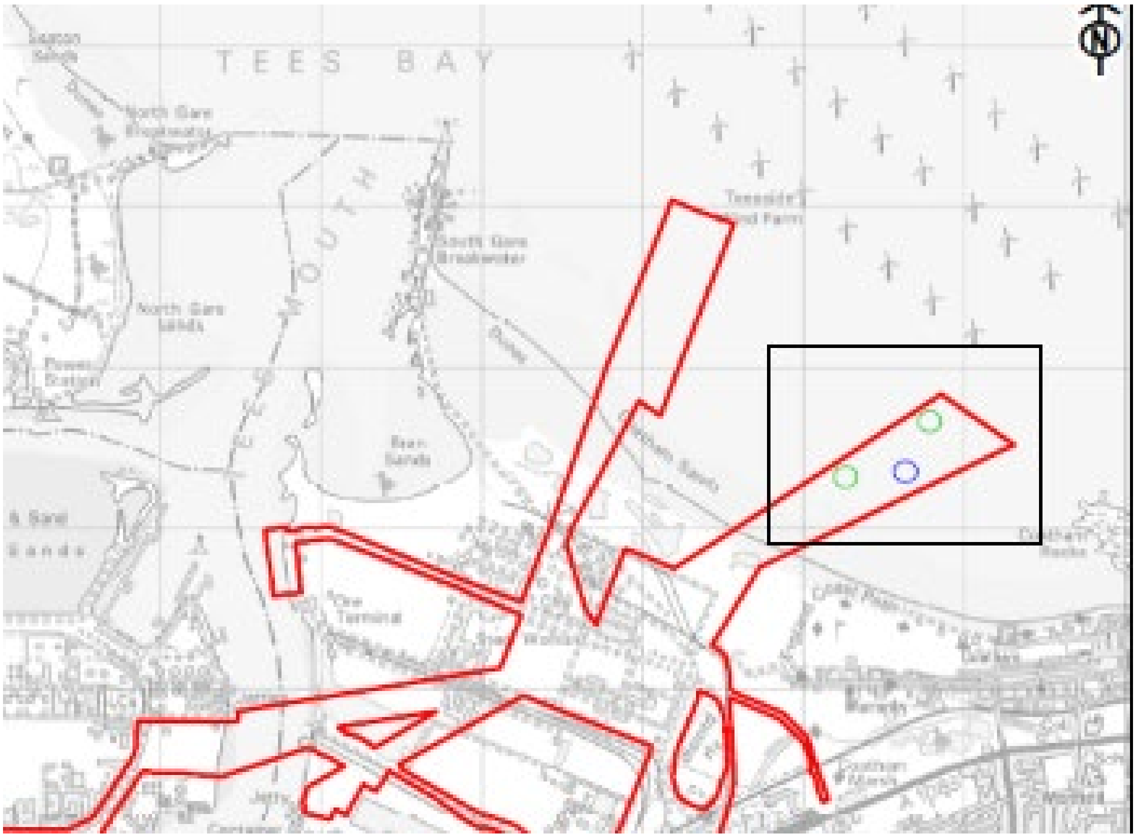


Figure 12. Outfall 2 location indicated by blue circle

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.

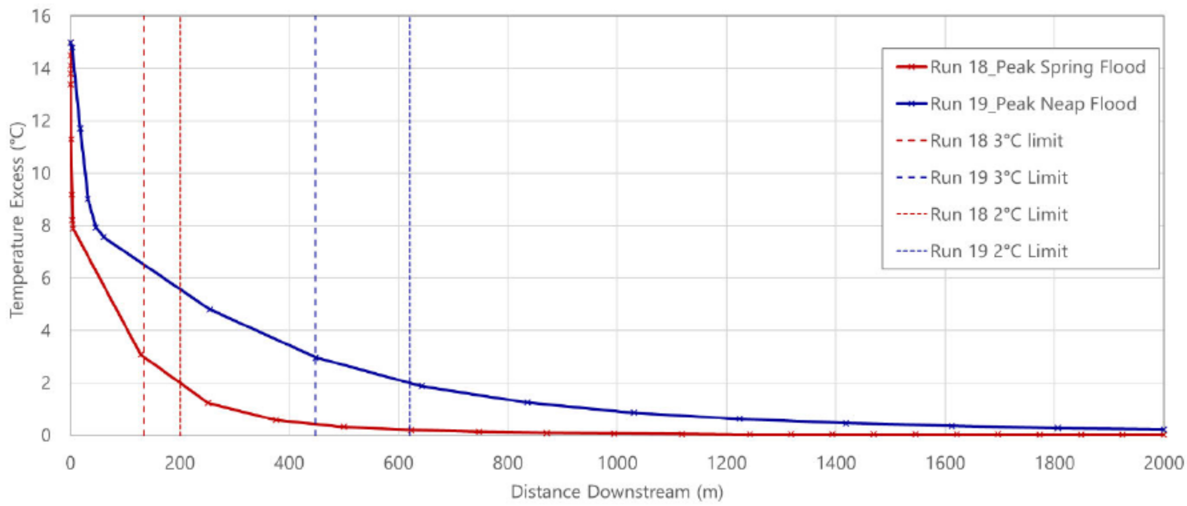


Figure 14. Spring and neap flood tide plume variations during normal discharge events.

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.

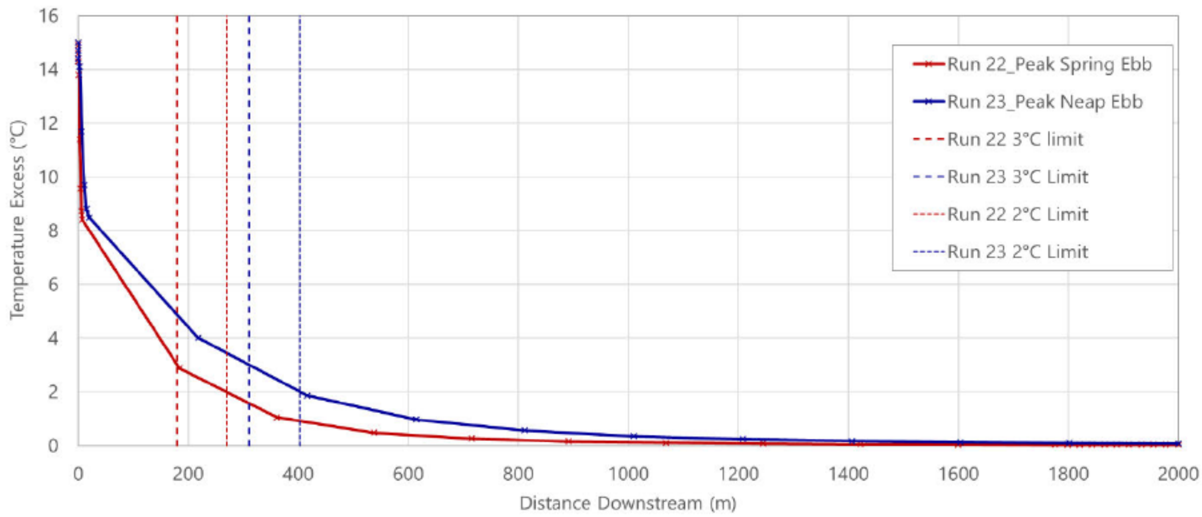


Figure 15. Spring and neap ebb tide plume variations during normal discharge events.

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

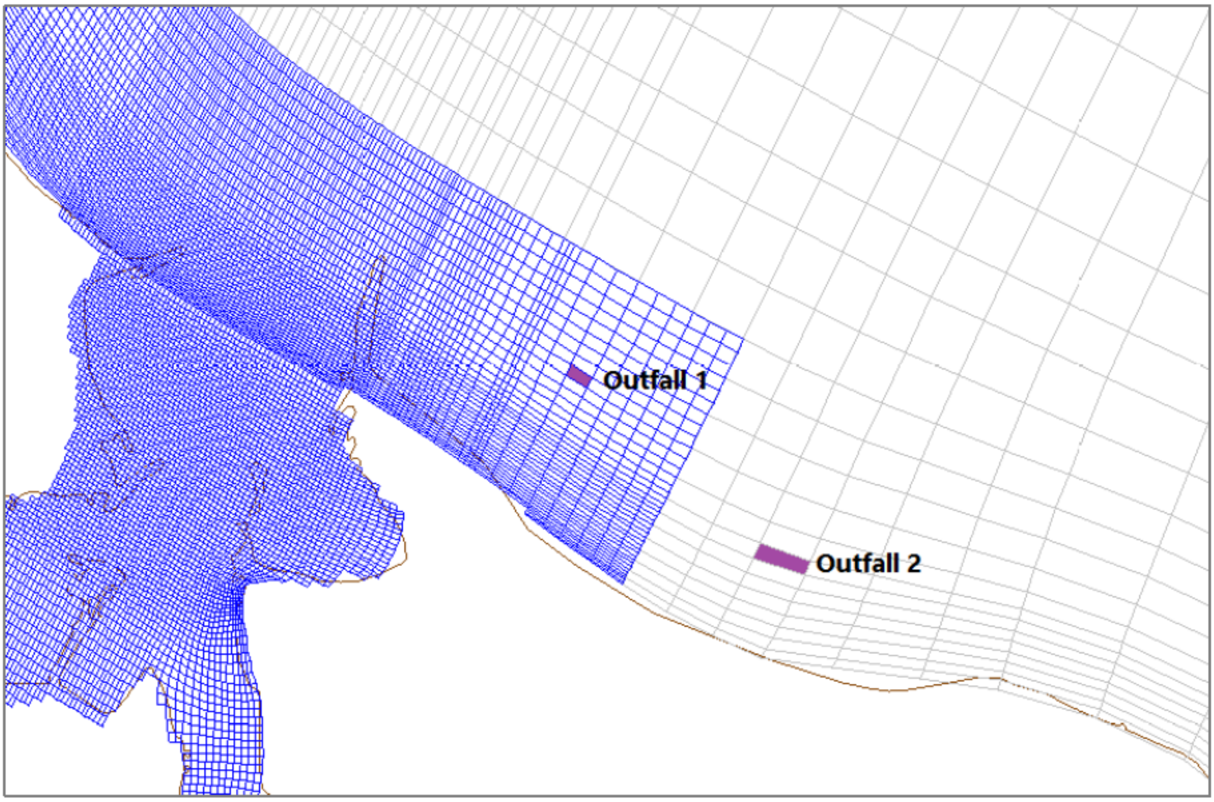


Figure 17. **Location of Outfalls in far-field (Delft3D) model grid**

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

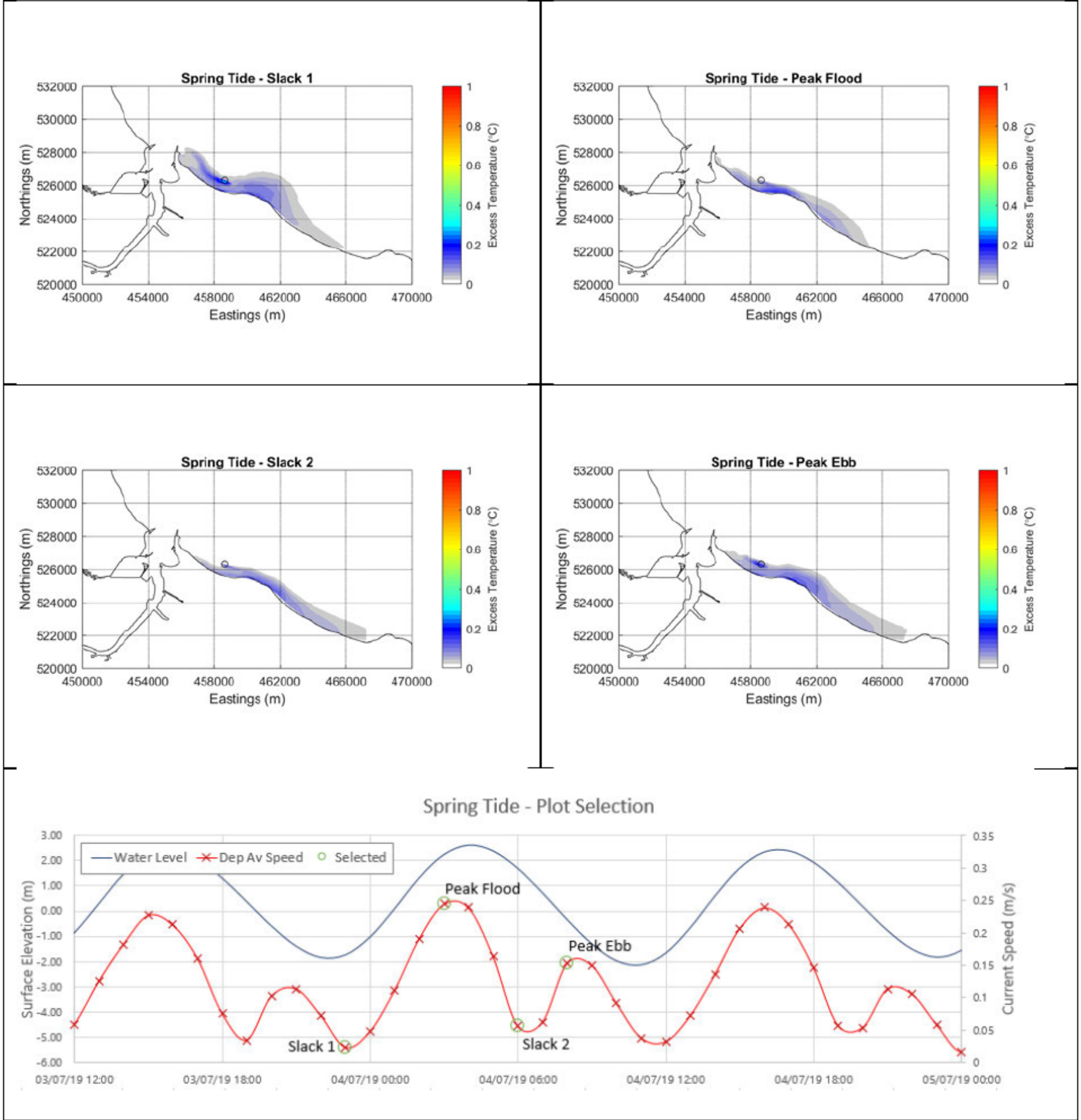


Figure 18. **Temperature excess contour plots: Summer spring tide – Outfall 2 location**

Summer Conditions: Neap Tide – Outfall 2 Location

15 °C excess temperature (14 °C ambient)

4.08 m/s wind speed from 230°

1.37 m^3/s discharge rate

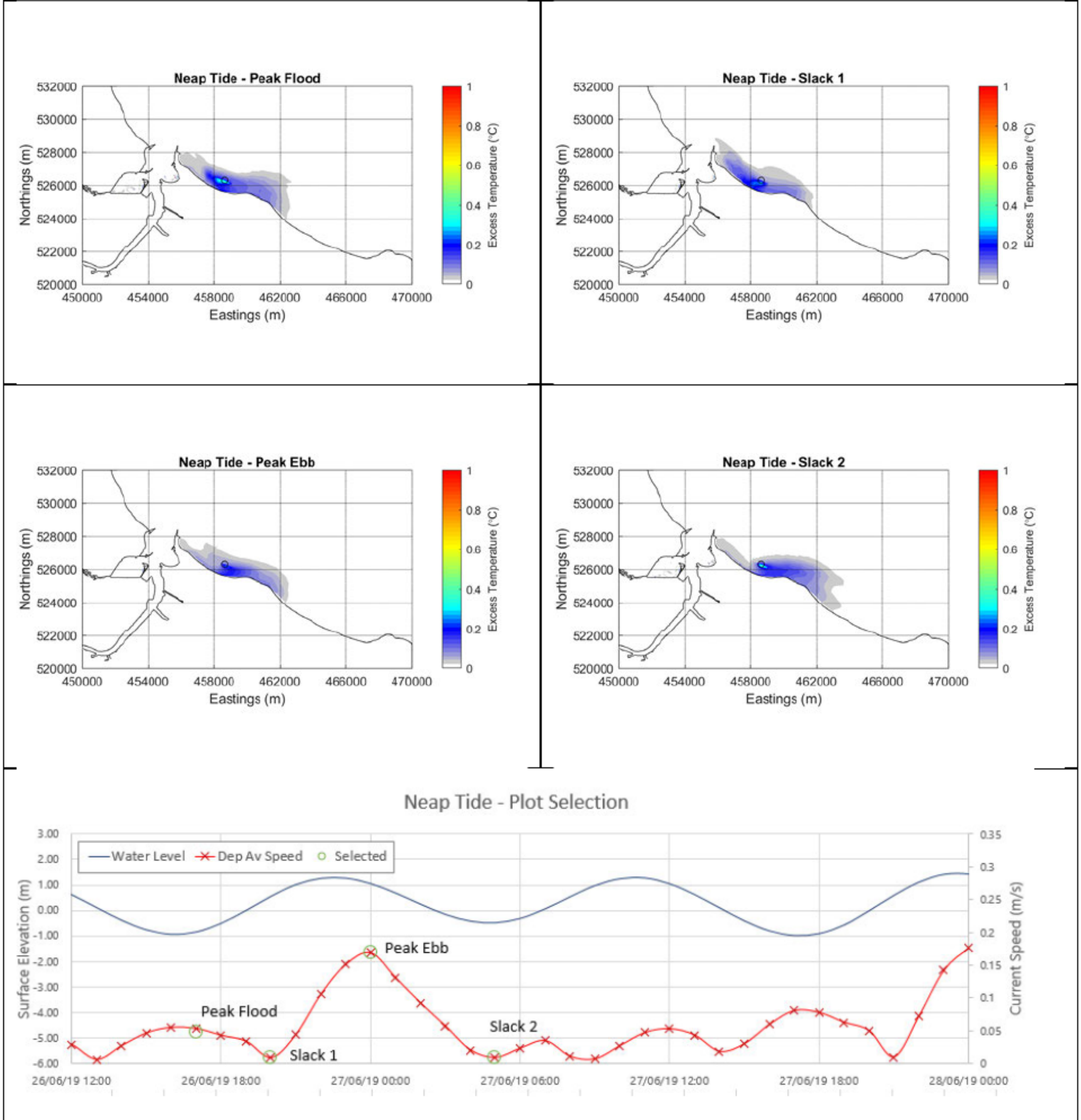


Figure 19. **Temperature excess contour plots: Summer neap tide – Outfall 2 location**

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

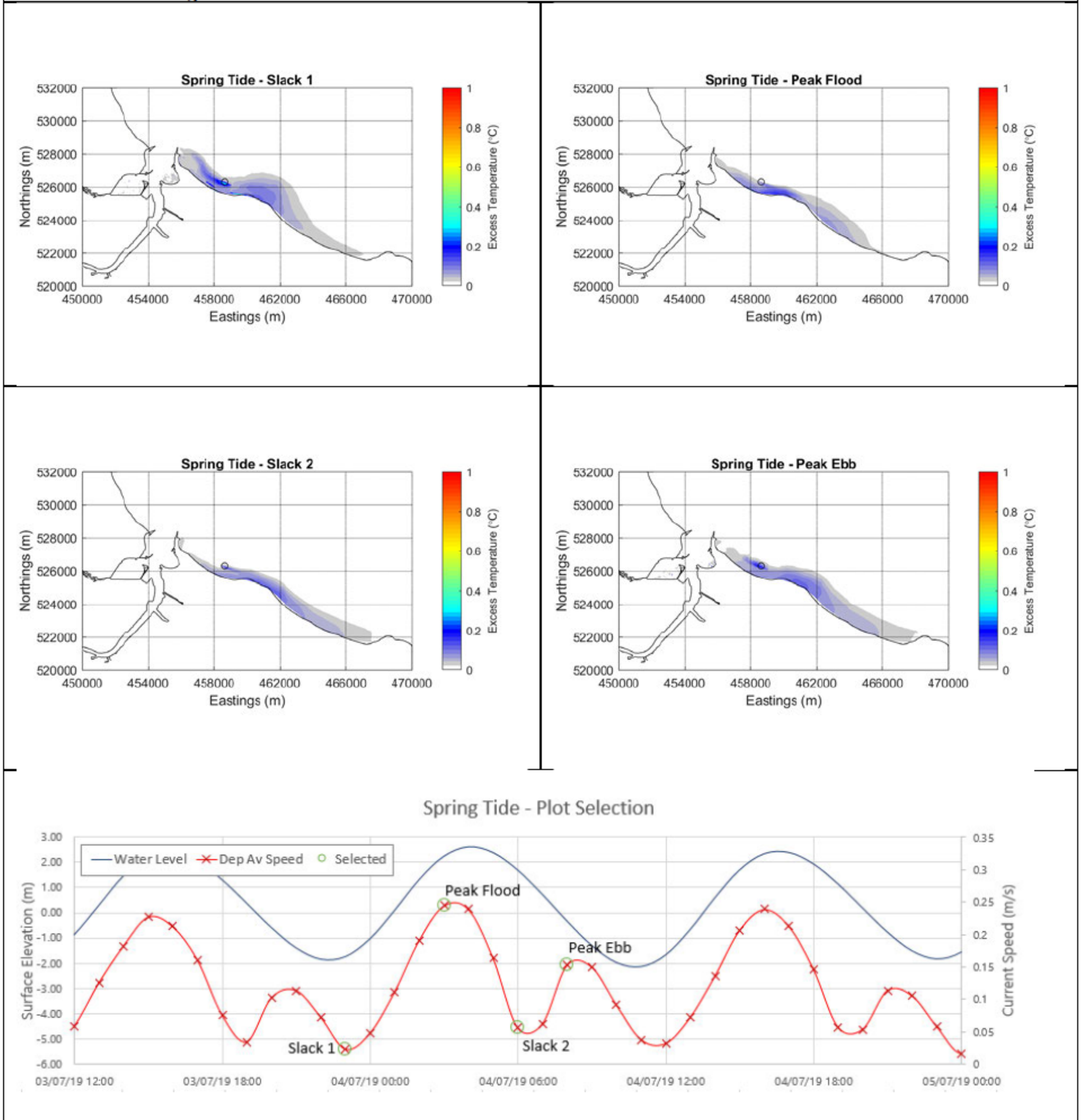


Figure 20. Temperature excess contour plots: Winter spring tide – Outfall 2 location

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

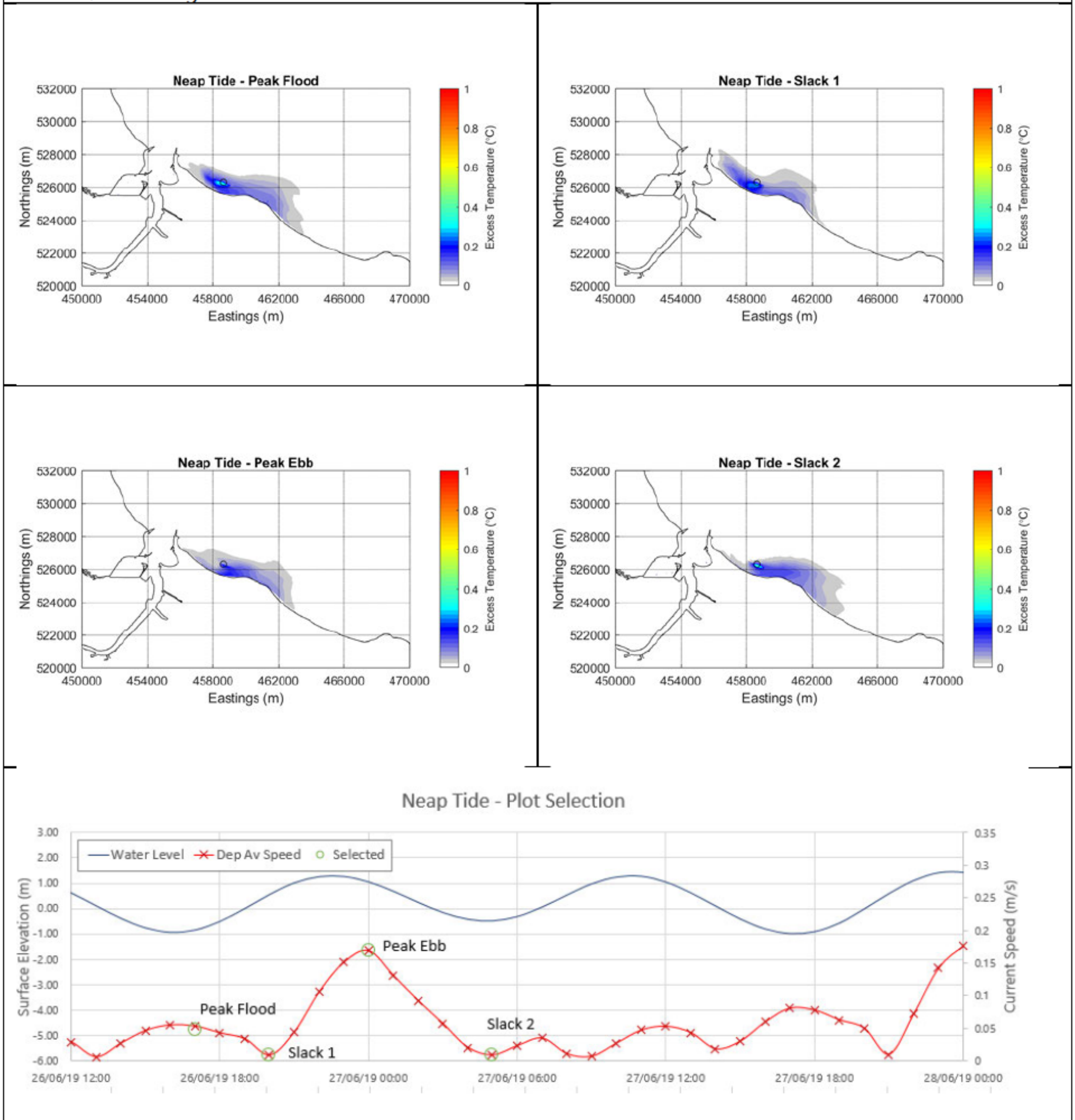


Figure 21. Temperature excess contour plots: Winter neap tide – Outfall 2 location

4.3.2 Runs 3 and 4: Sensitivity to Wind conditions

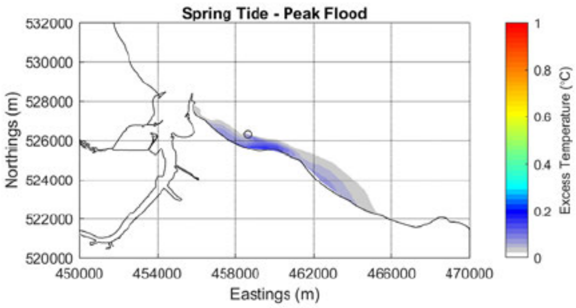
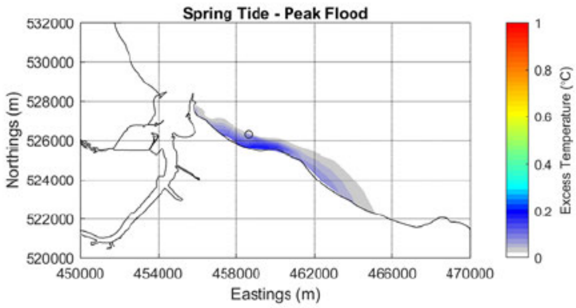
The Run 1 and 2 simulations applied the average seasonal wind conditions (derived during model calibration (Appendix A)), of 4.08 m/s for the summer and 5.32 m/s in the winter, both applied with a continuous direction of 230° from.

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.

<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 m³/s discharge rate</td></tr>
<tr><th>South westerly wind</th><th>Onshore wind</th></tr>
<tr><td>4.08 m/s wind speed from 230°</td><td>4.08 m/s wind speed from 30°</td></tr>
<tr><td>
</td><td>
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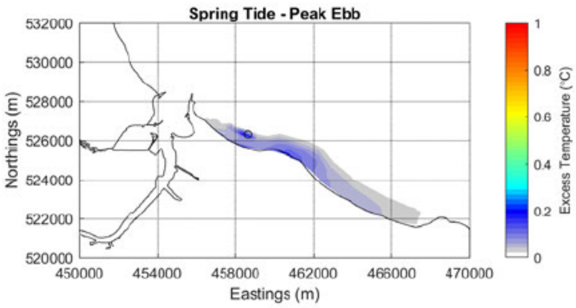
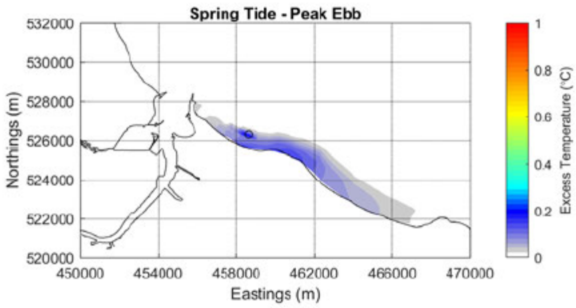
<tr><td>
</td><td>
</td></tr>
</table>

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

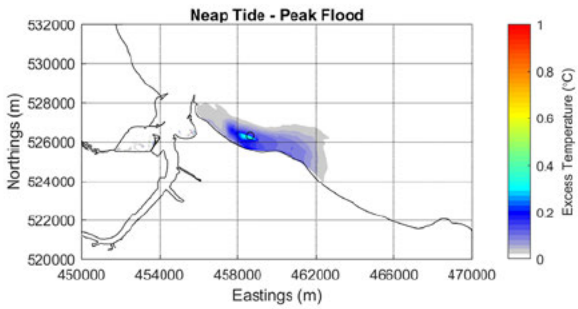
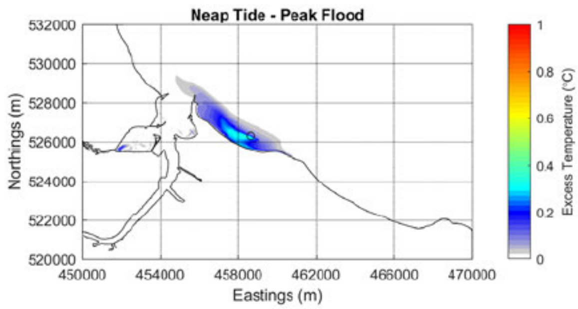
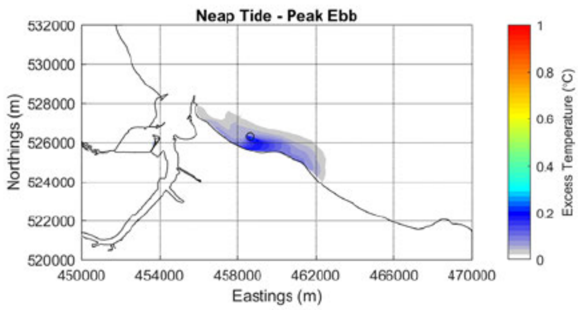
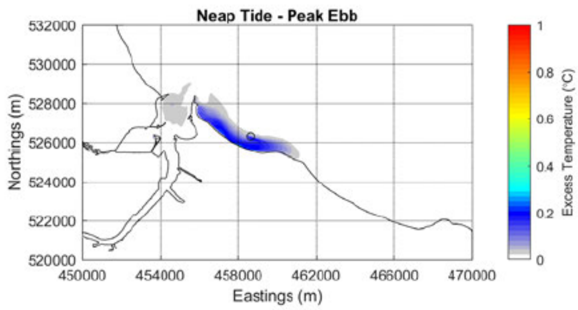
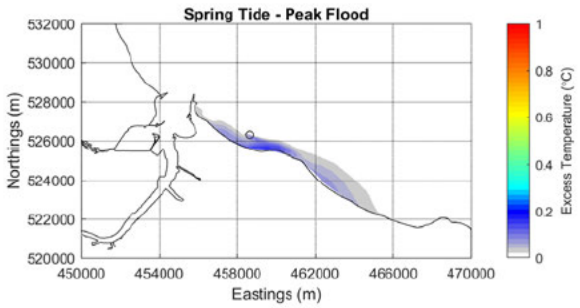
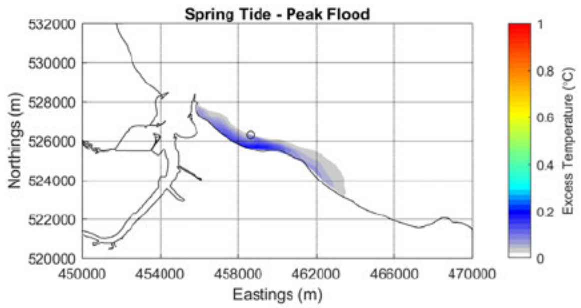
Comparison of wind direction sensitivity: Summer Neap Tide – Outfall 2 Location	
15 °C excess temperature (14 °C ambient) 1.37 m^3/s discharge rate	
South westerly wind	**Onshore wind**
4.08 m/s wind speed from 230°	4.08 m/s wind speed from 30°
	
	

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 m³/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>
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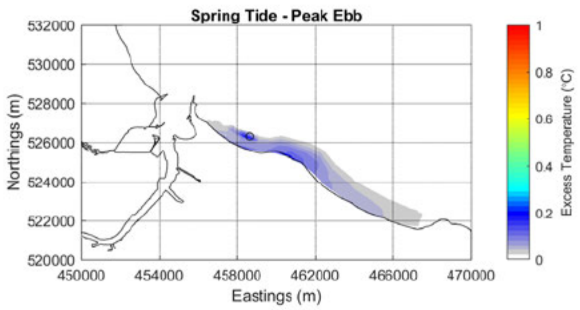
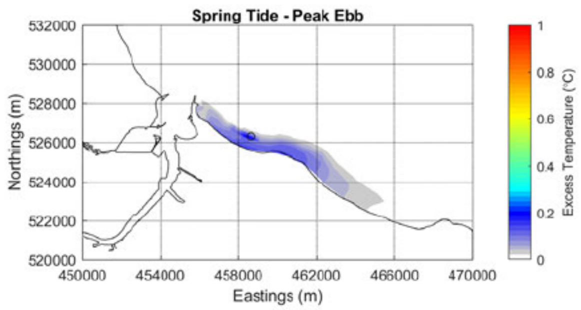
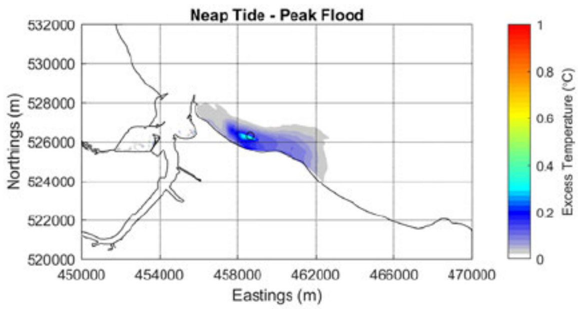
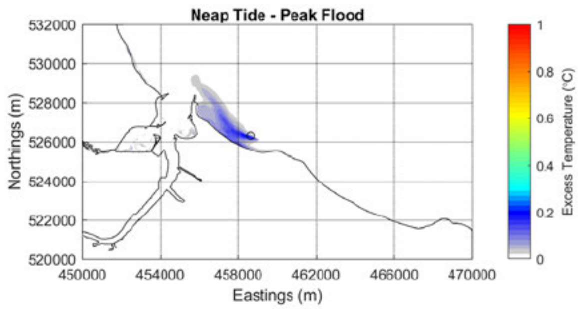
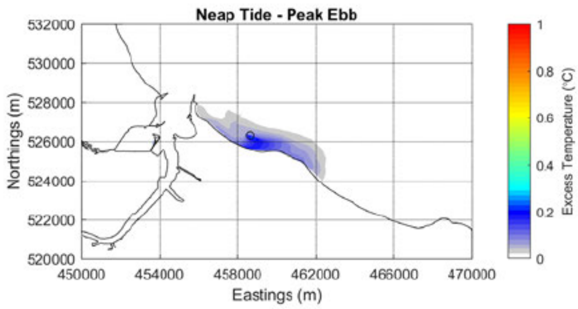
<tr><td>
</td><td>
</td></tr>
</table>

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

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	**South easterly wind**
4.08 m/s wind speed from 230°	4.08 m/s wind speed from 120°







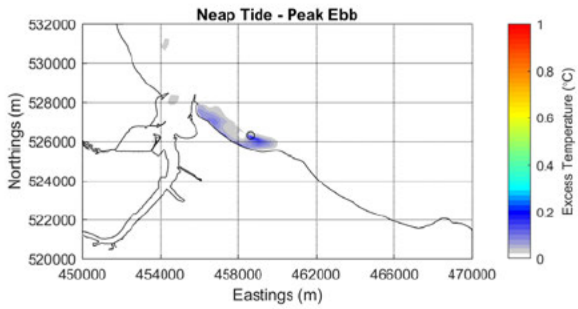


Figure 25. Temperature excess contour plots: Comparison of neap summer conditions with a 230° wind direction (left) vs 120° wind direction (right)

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.

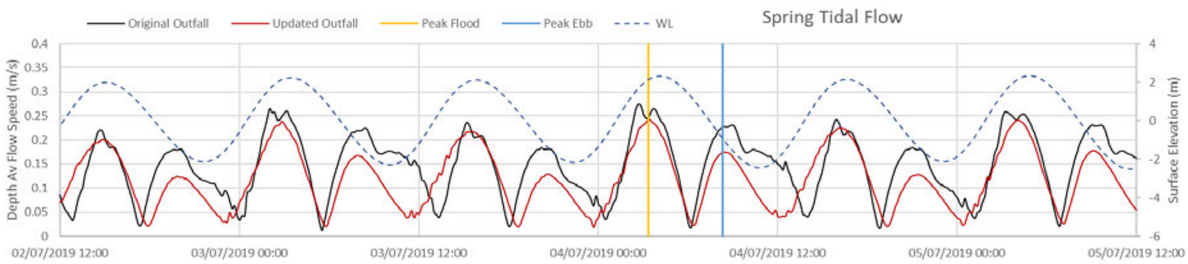


Figure 26. Flow speeds over a spring tide at Outfall 1 and Outfall 2 positions

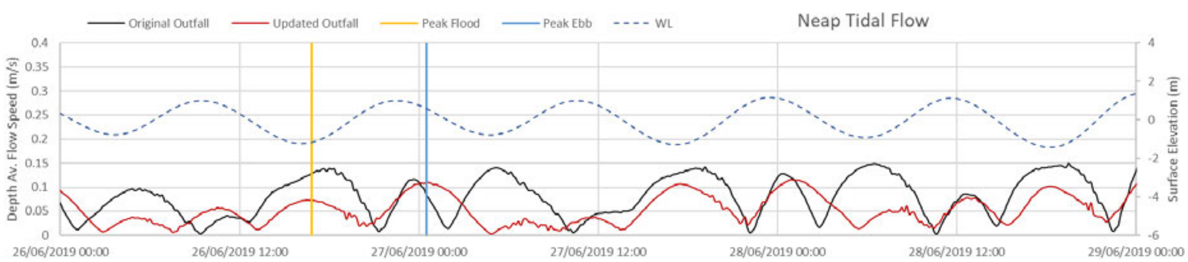


Figure 27. Flow speeds over a neap tide at Outfall 1 and Outfall 2 positions

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.

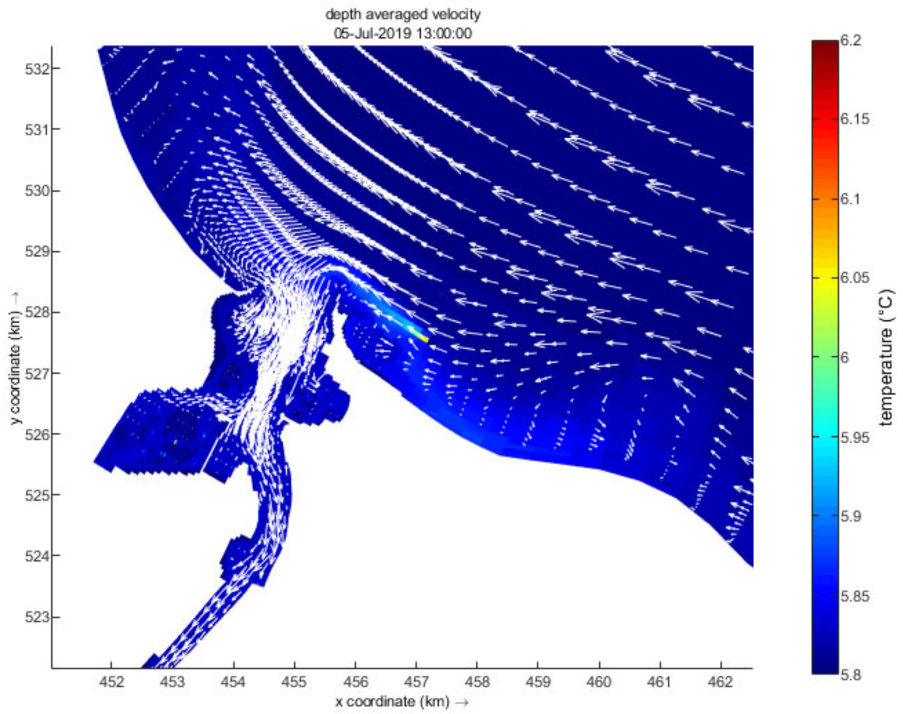


Figure 28. **Temperature contours and Flow Speed Vectors from Run 6: Winter – Outfall 1**

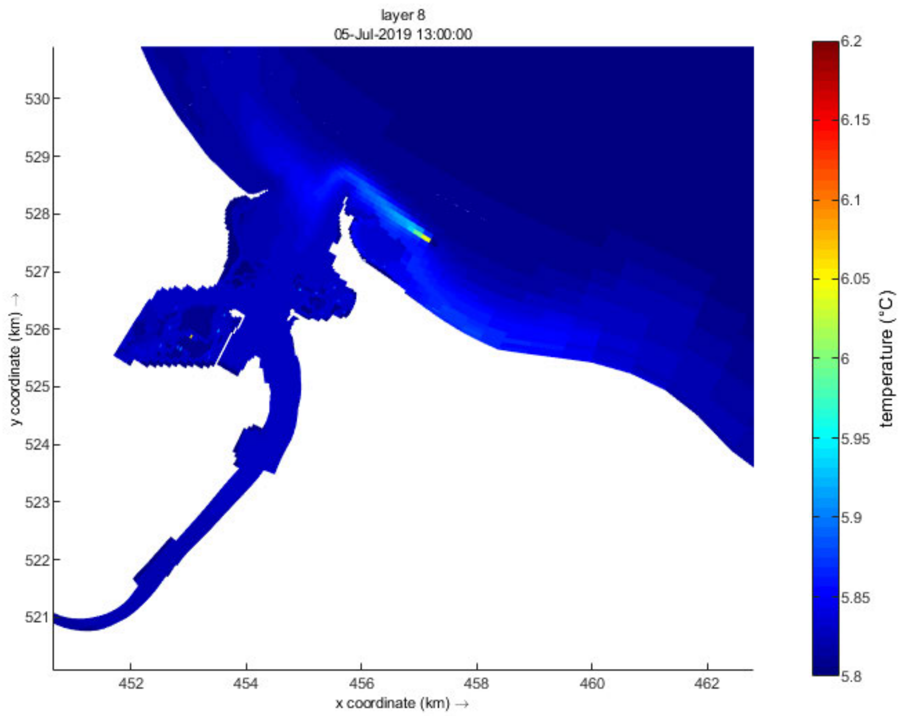


Figure 29. **Temperature Contours from Run 6: Winter – Outfall 1**

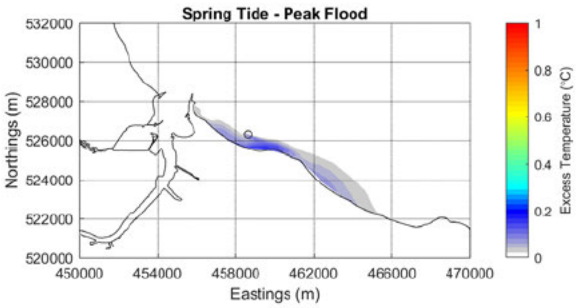
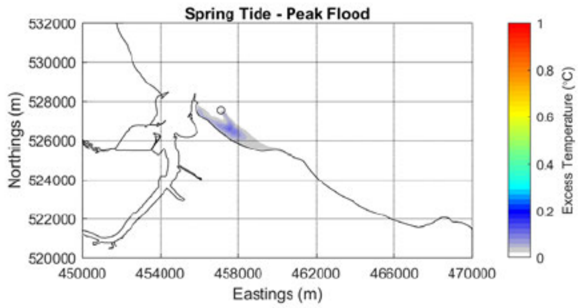
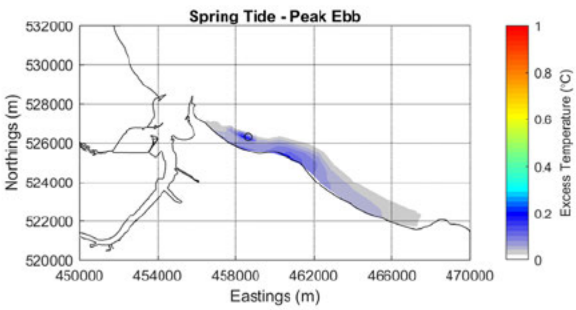
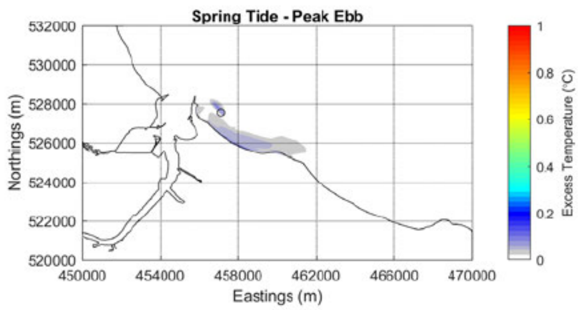
Comparison of outfall location: Summer Spring Tide	
15 °C excess temperature (14 °C ambient) 4.08 m/s wind speed from 230° 1.37 m^3/s discharge rate	
Outfall 2 location	**Outfall 1 location**
	
	

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 m^3/s discharge rate	
Outfall 2 location	**Outfall 1 location**

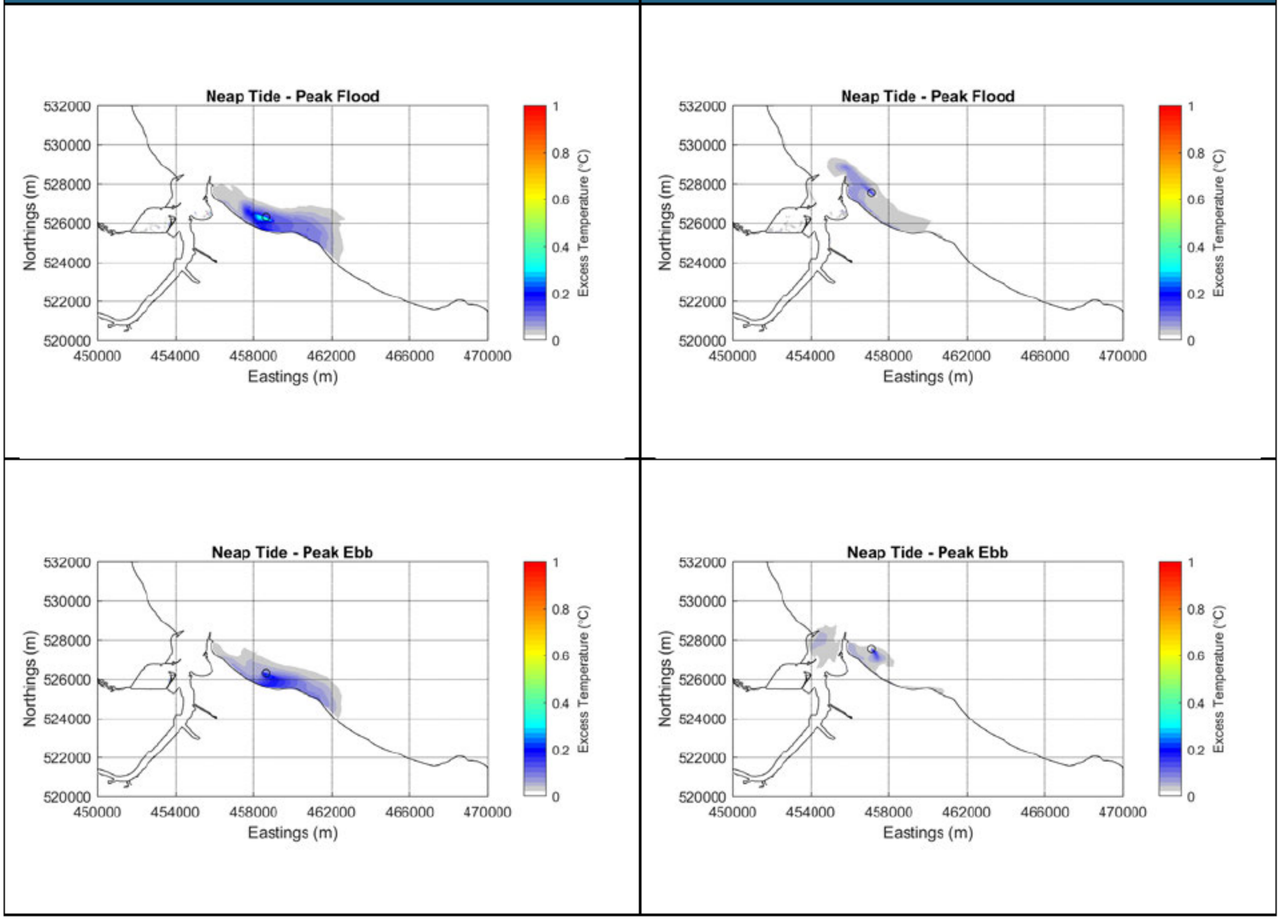


Figure 31. **Temperature excess contour plots: Comparison of neap summer conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)**

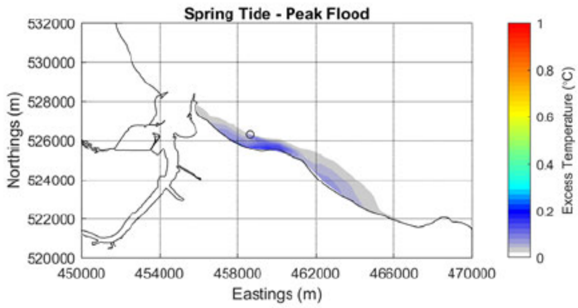
Comparison of outfall location: Winter Spring Tide

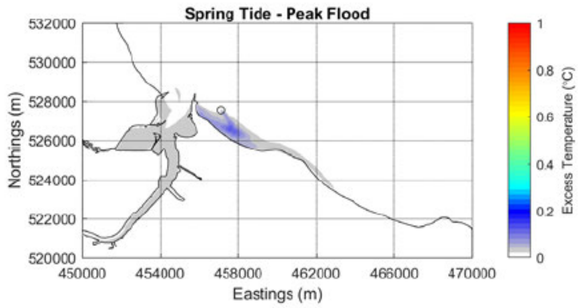
15 °C excess temperature (5.8 °C ambient)

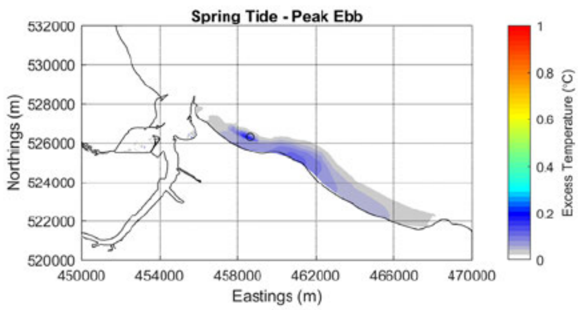
5.32 m/s wind speed from 230°

1.37 m^3/s discharge rate

Outfall 2 location	**Outfall 1 location**







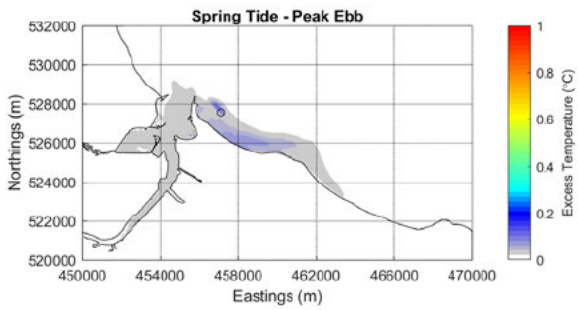


Figure 32. Temperature excess contour plots: Comparison of spring winter conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

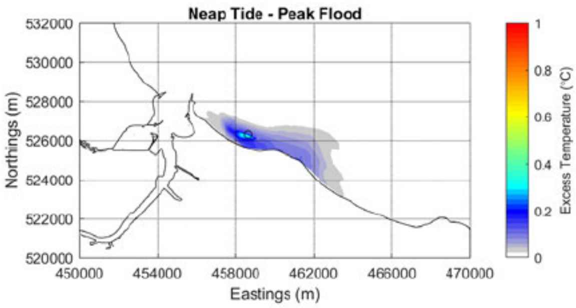
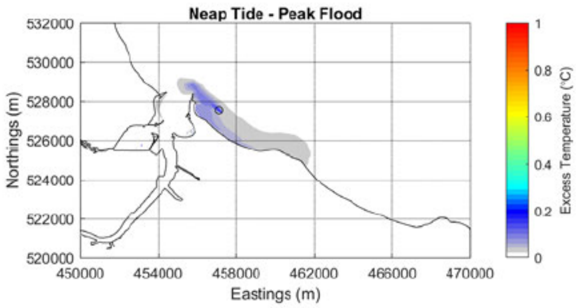
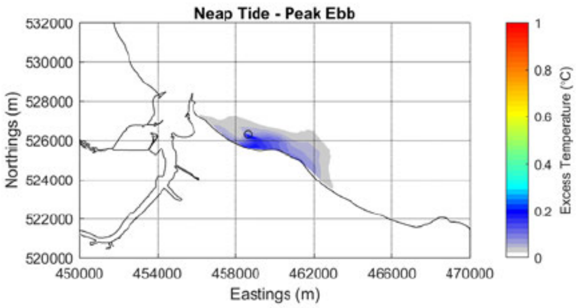
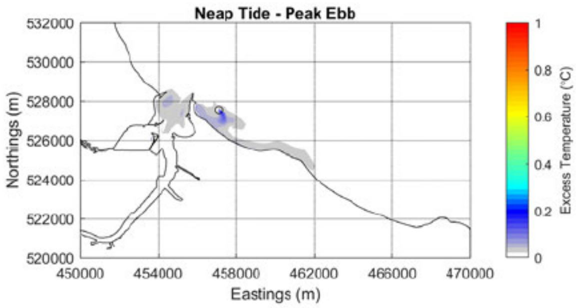
Comparison of outfall location: Winter neap Tide	
15 °C excess temperature (5.8 °C ambient) 5.32 m/s wind speed from 230° 1.37 m^3/s discharge rate	
Outfall 2 location	**Outfall 1 location**
	
	

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

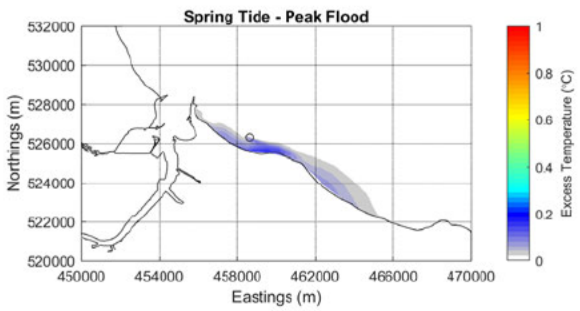
4.3.4 Run 7: Comparison of high flow scenario

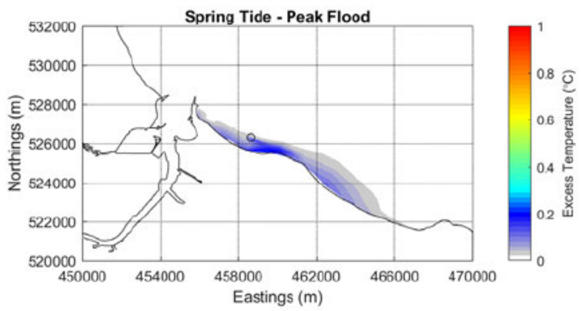
The nearfield thermal plume modelling considered an extreme 1 in 30-year flow rate discharge through the pipe, with a specified rate of 5.75 m³/s. This discharge would consist of a portion of heated water combined with land run-off water at ambient temperature. Information provided by AECOM anticipates 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.

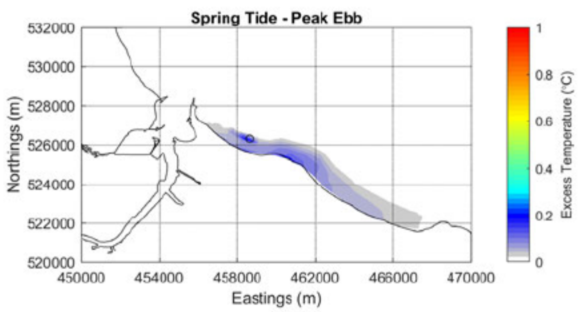
This 1 in 30-year high flow event has been simulated in the Deflt3D far field model and compared over summer spring and neap conditions in this section.

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.

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







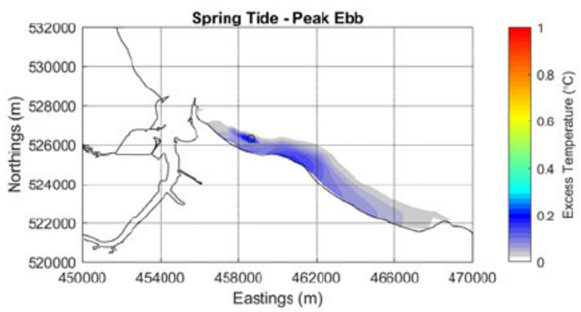
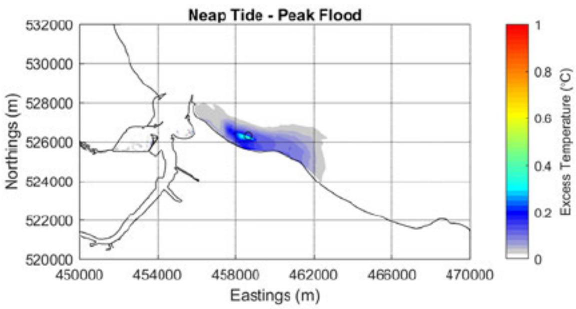
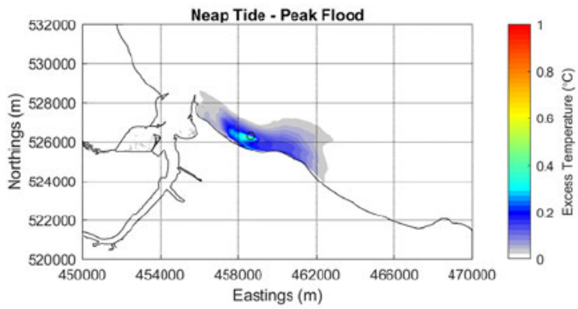
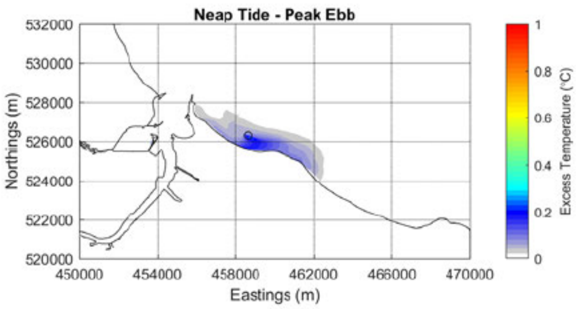


Figure 34. Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates

Comparison of normal and extreme flow scenario: Summer Neap Tide – Outfall 2 Location	
4.08 m/s wind speed from 230°	
Normal flow rate	**Extreme flow rate**
1.37 m^3/s discharge rate 15°C excess temperature (14°C ambient)	5.75 m^3/s discharge rate 5°C excess temperature (14°C ambient)







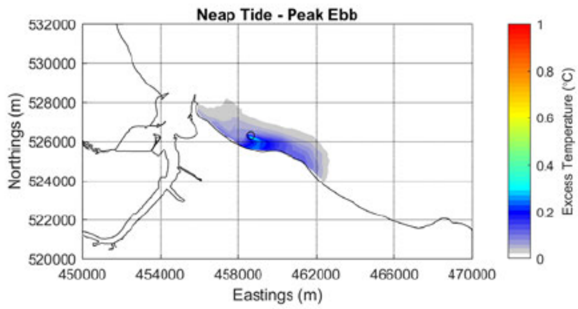


Figure 35. Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates

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]

UKHO (2020) Admiralty Tide Tables, United Kingdom and Ireland, NP201B, Volume 1B. UK Hydrographic Office 2020.

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

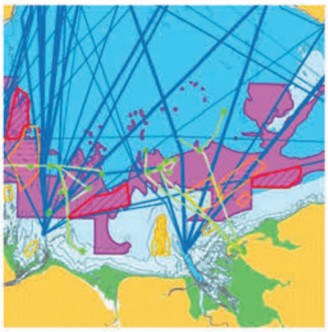
2D	Two Dimension(al)
3D	Three Dimension(al)
ADCP	Acoustic Doppler Current Profiler
AECOM	AECOM Ltd
CCGT	Combined Cycle Gas Turbines
CCUS	Carbon Capture, Utilisation and Storage
CD	Chart Datum
CFSR	Climate Forecast System Reanalysis
CTD	Conductivity-Temperature-Depth
CurDir	Current Direction
CurSpd	Current 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

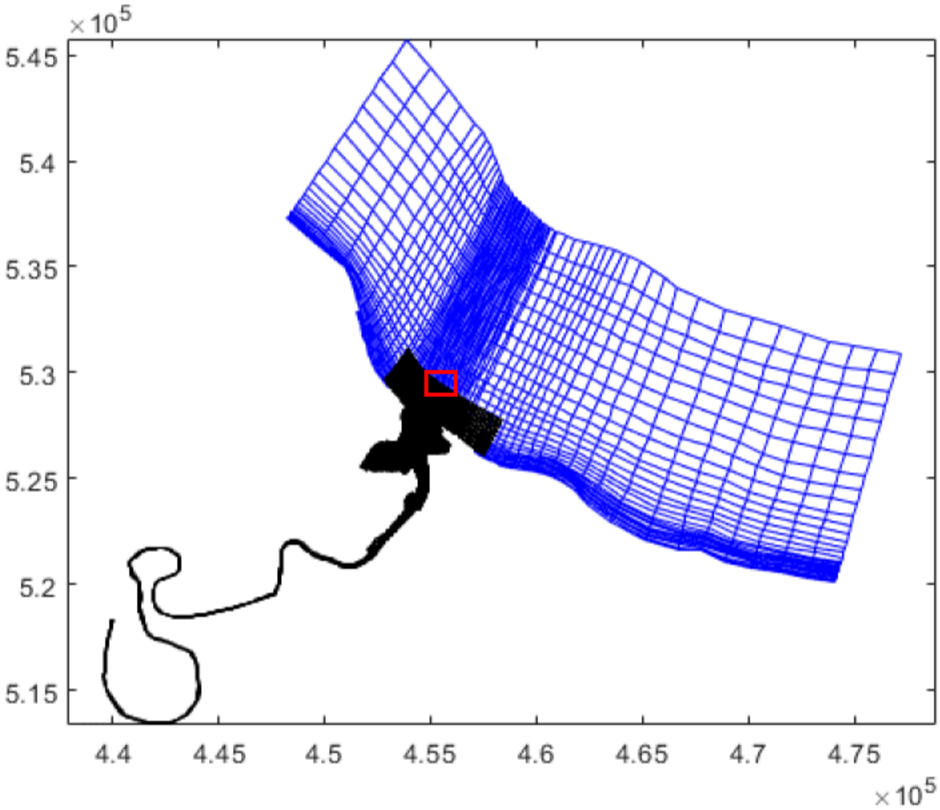
The Delft3D model uses a curvilinear computational grid, which allows a grid composed of various sizes to be used throughout a model domain. In addition to this, the original hydrodynamic model has been further refined using a 'domain decomposition' (dd) approach. This approach allows the creation of 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

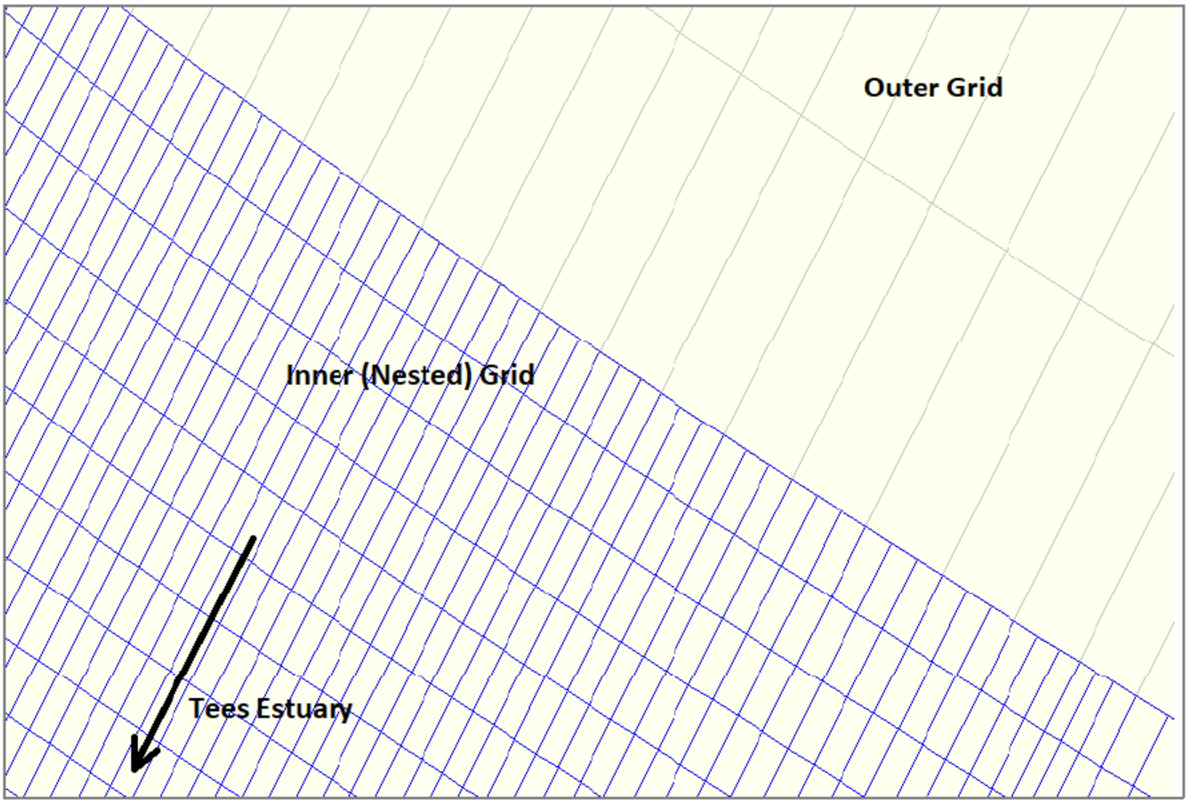


Figure 37. Delft3D hydrodynamic model grid – Refinement of nested grid

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.

1 https://environment.data.gov.uk/DefraDataDownload/?Mode=survey
2 Admiralty Chart 2566 Tees and Hartlepool Bays

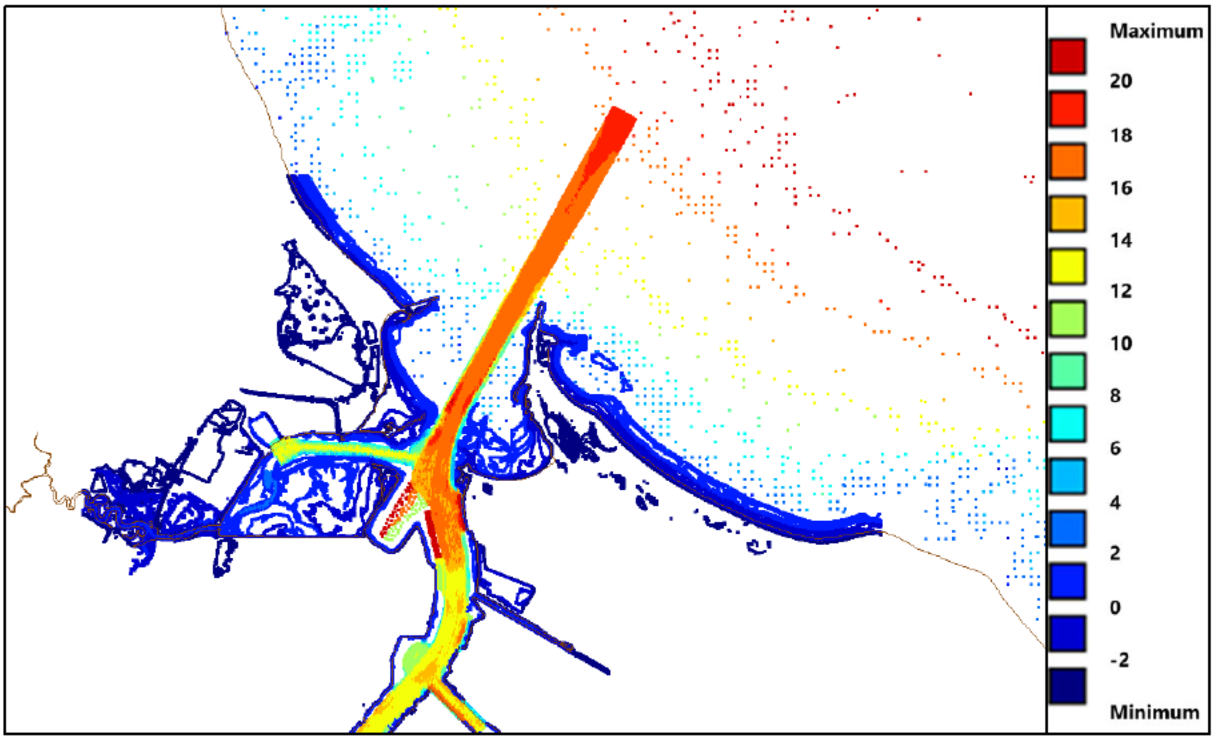


Figure 38. **Scatter plot showing available bathymetry data resolution and coverage. All values are depth positive and referenced to meters below ODN.**

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.

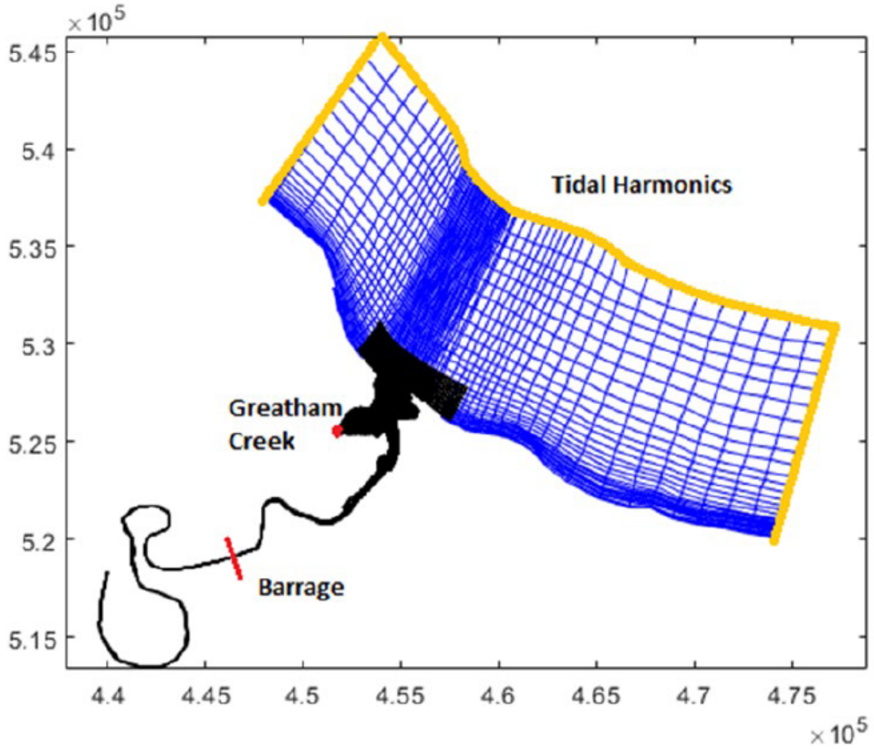


Figure 39. HD model domain and boundary positions (shown by yellow lines)

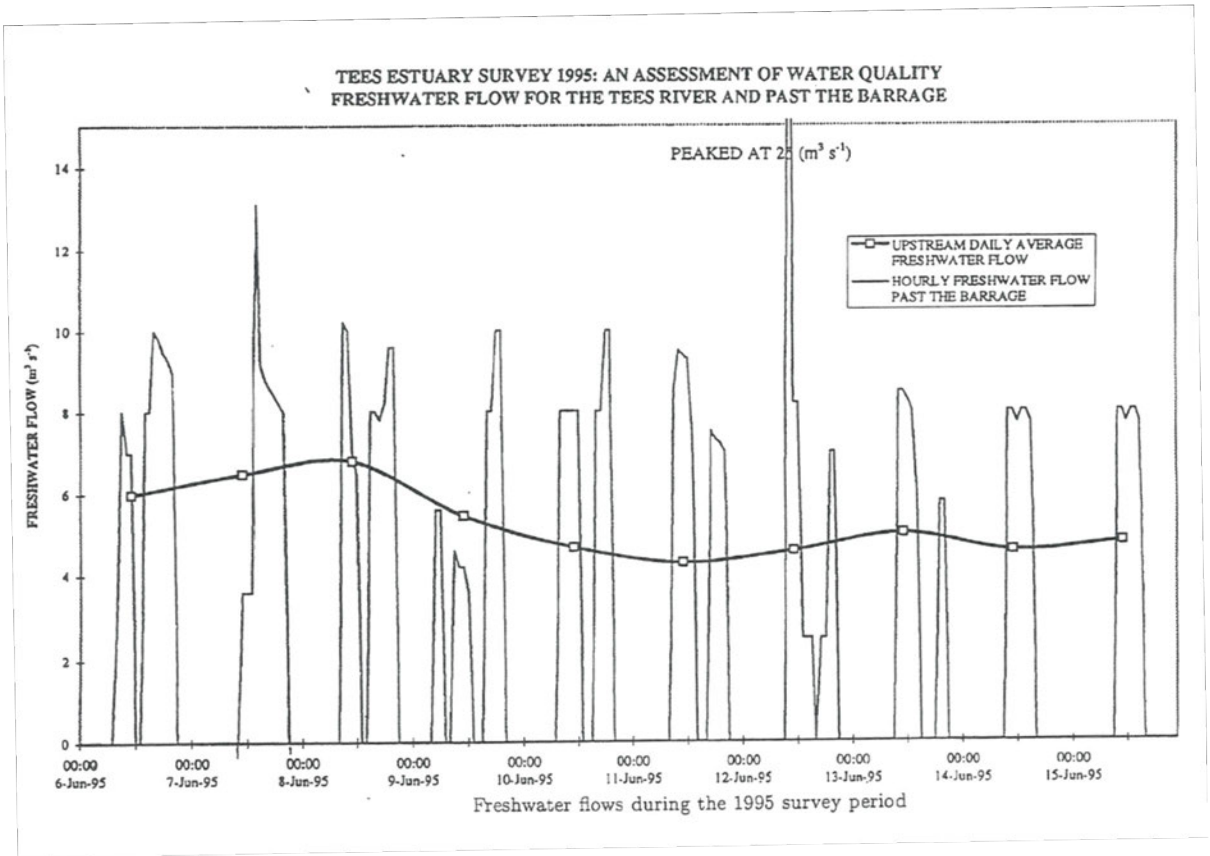
The harmonic constituents defined at these boundaries have been extracted from a wider area model (ABPmer 2003) previously constructed by ABPmer which has previously been calibrated and verified against three data sets. This data has been derived from TIDECALC (a programme for generating tidal predictions 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.

3 [redacted]

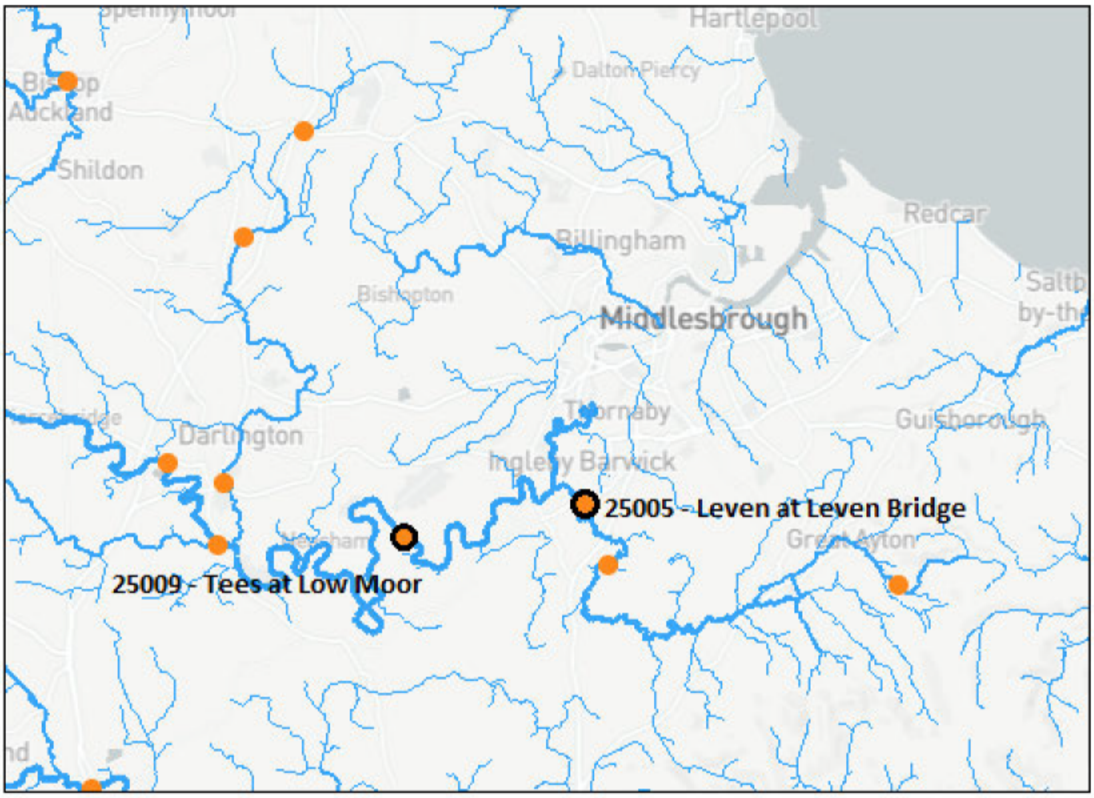


Figure 41. **Flow data stations assessed for Tees Barrage discharge calculations**

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.

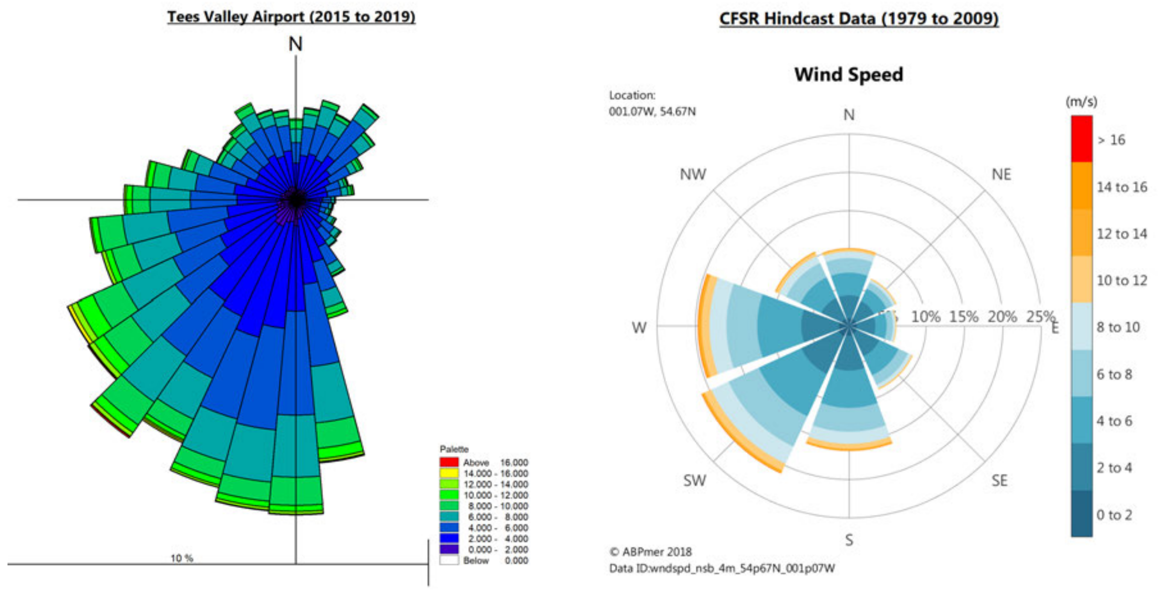


Figure 42. Wind rose of Tees Valley Airport wind data (left) and CFSR Hindcast data (right).

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).

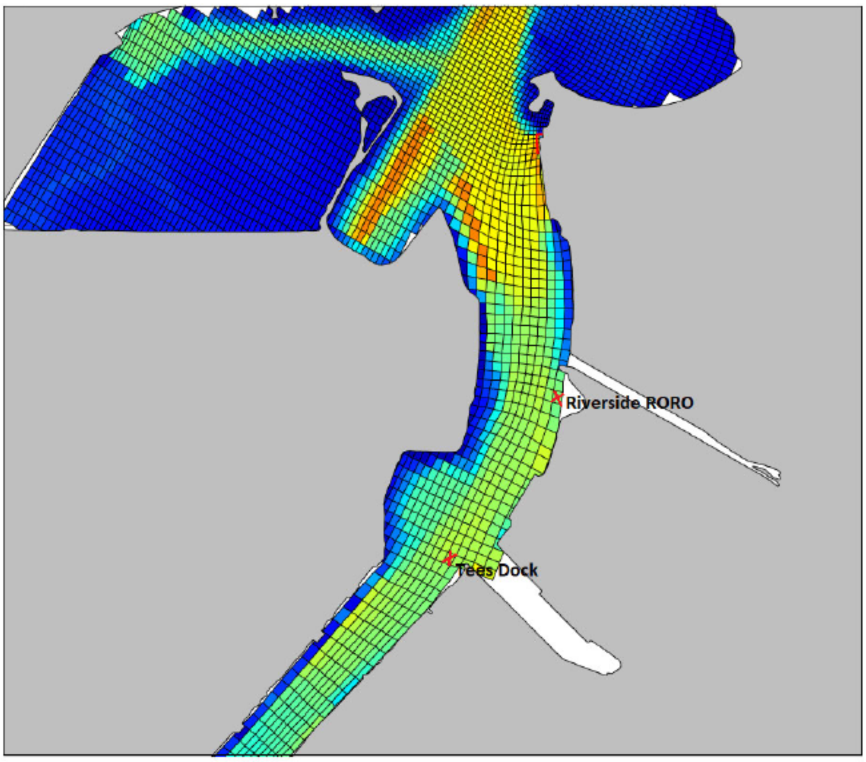


Figure 43. Location of model extraction points for tide gauge calibration overlaid onto model grid and underlying bathymetry.

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.

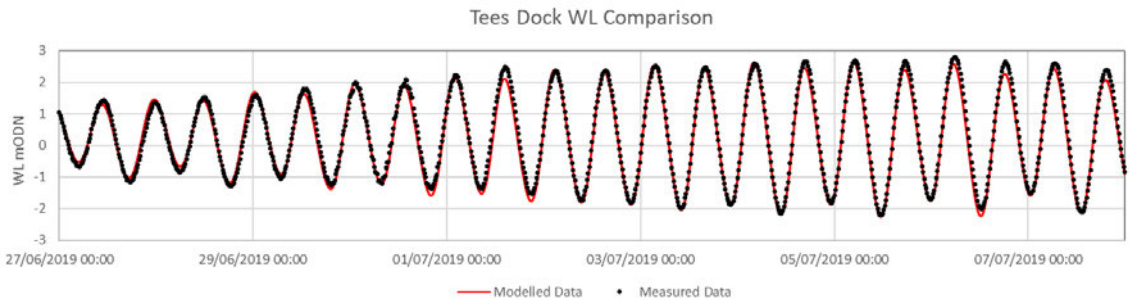


Figure 44. Water level comparison: Model vs measured data (Tees Dock)

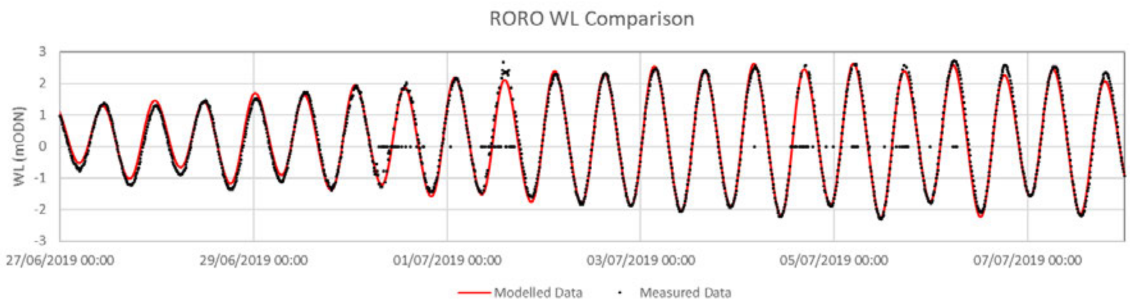


Figure 45. Water level comparison: Model vs measured data (Riverside RORO)

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.

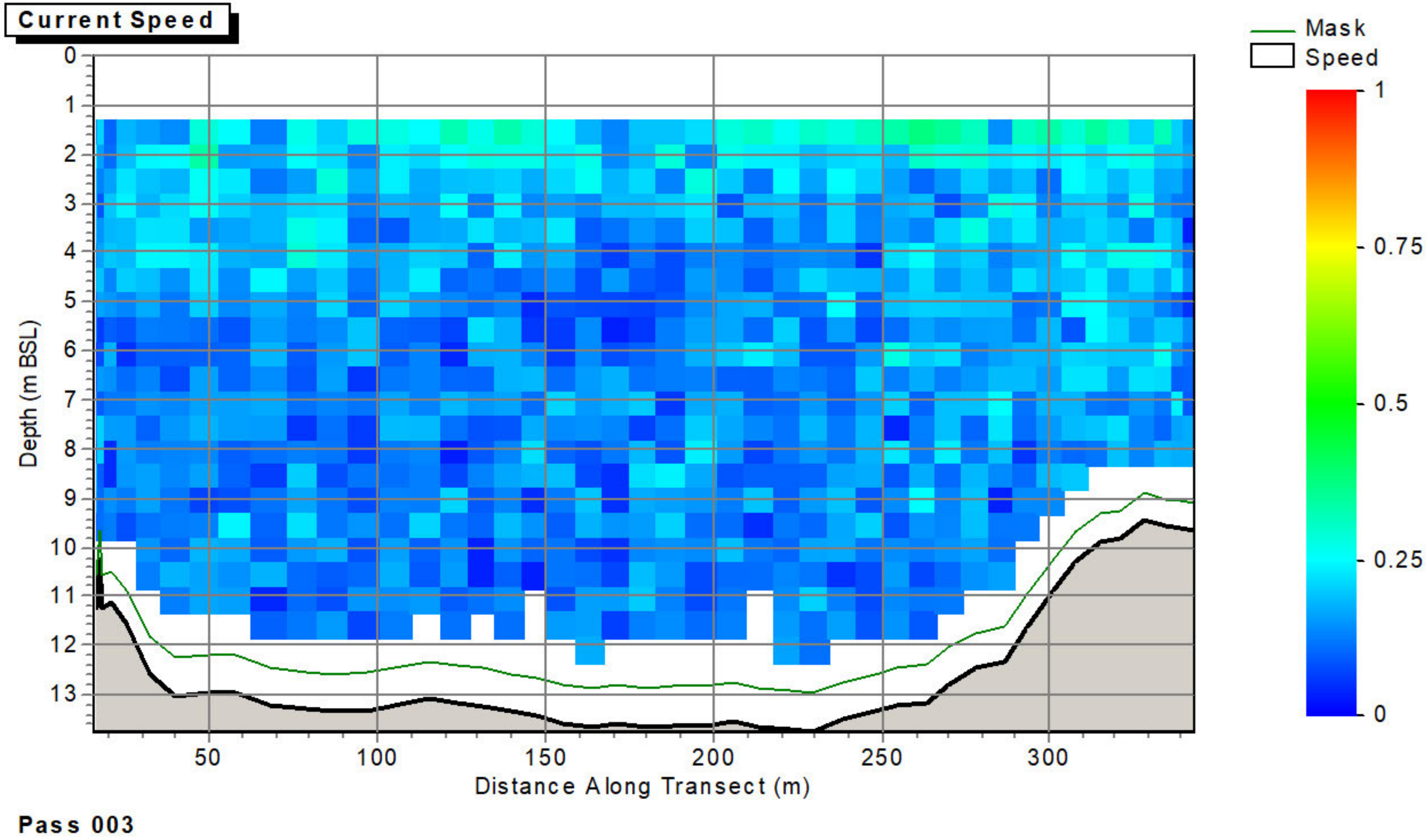


Figure provided by PD Teesport

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

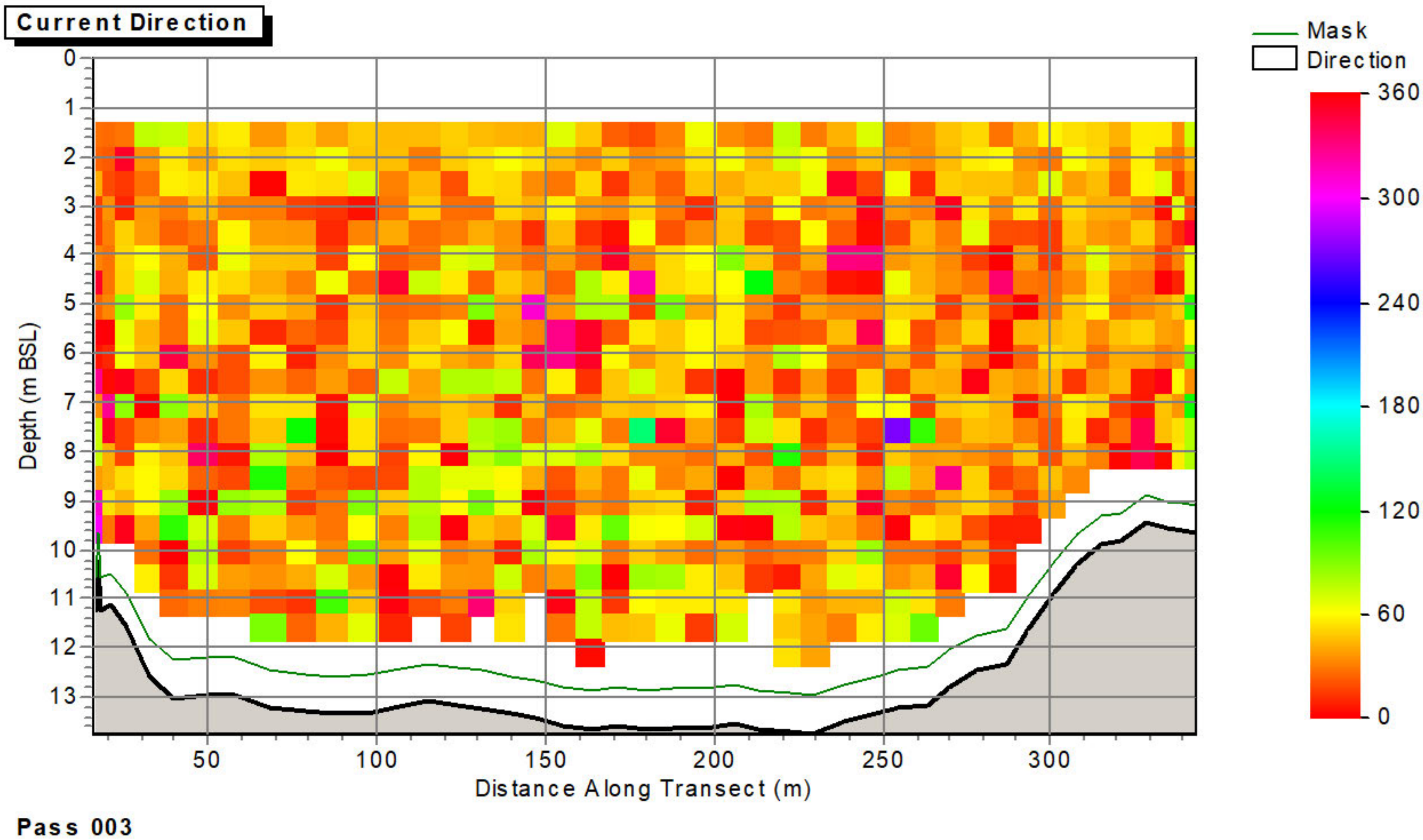


Figure provided by PD Teesport

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

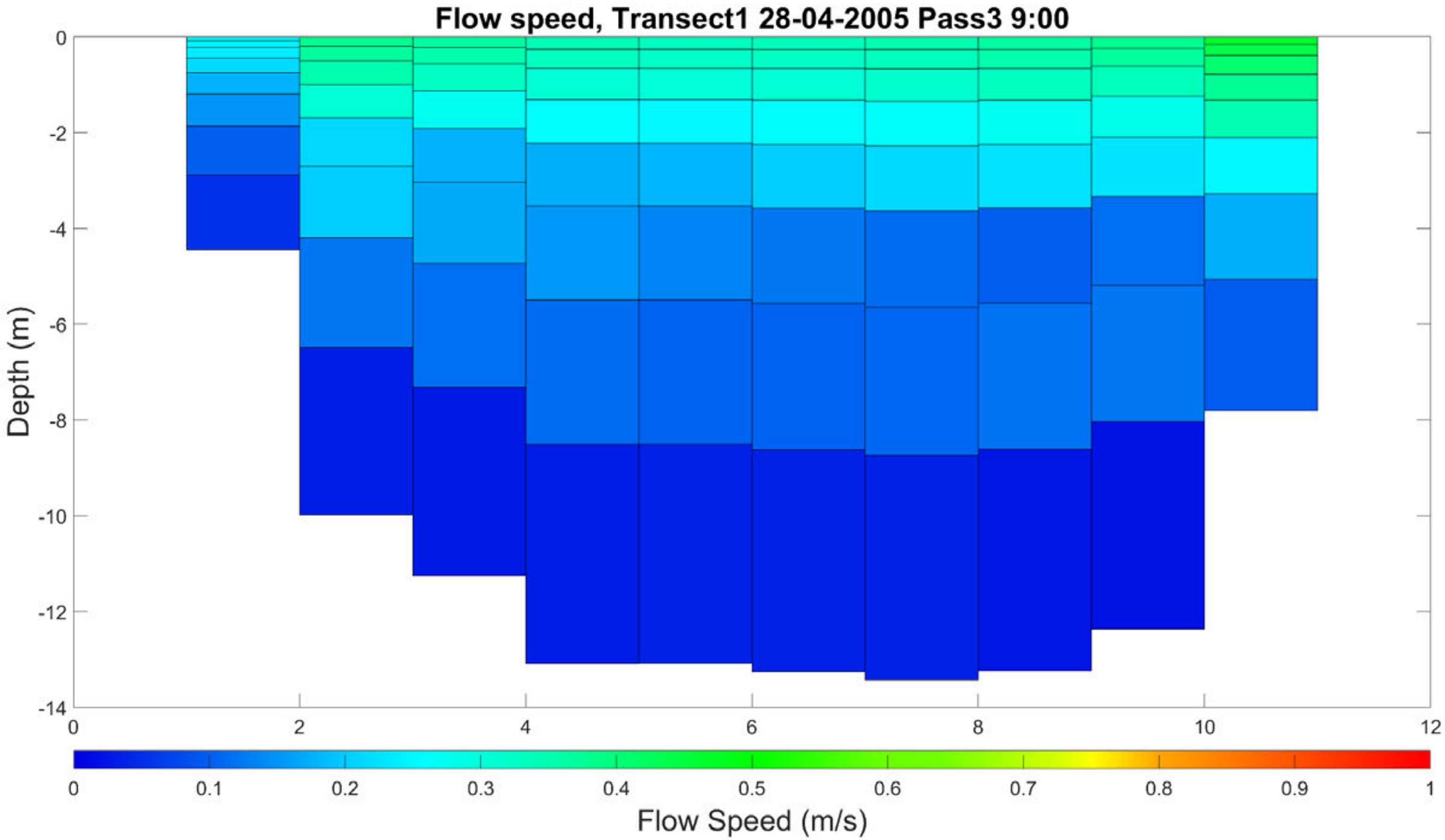


Figure 48. Modelled flow speed, Transect 1: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

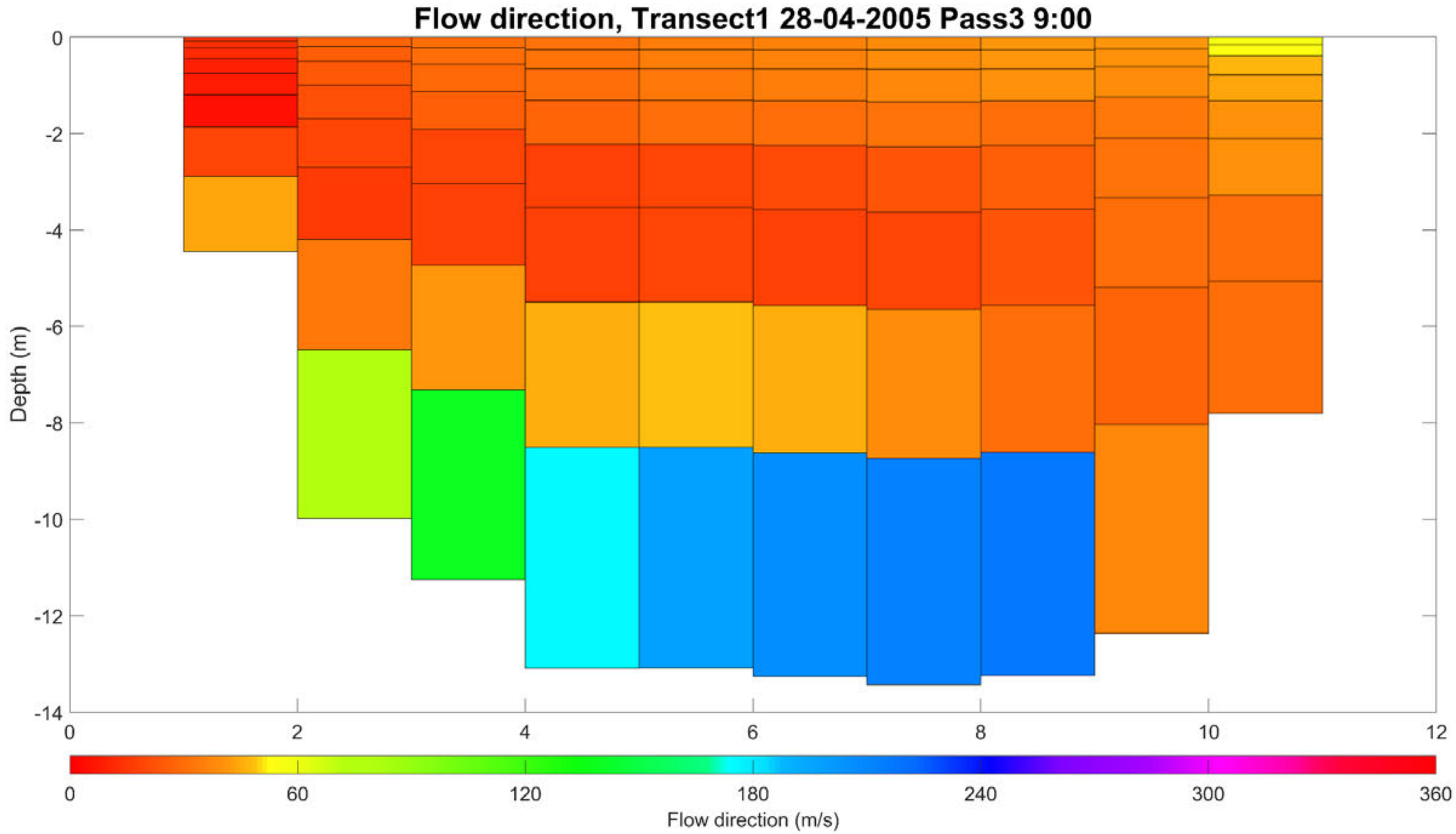


Figure 49. **Modelled flow direction, Transect 1: Ebb tide, cross section of direction with depth shown from west (left) to east (right)**

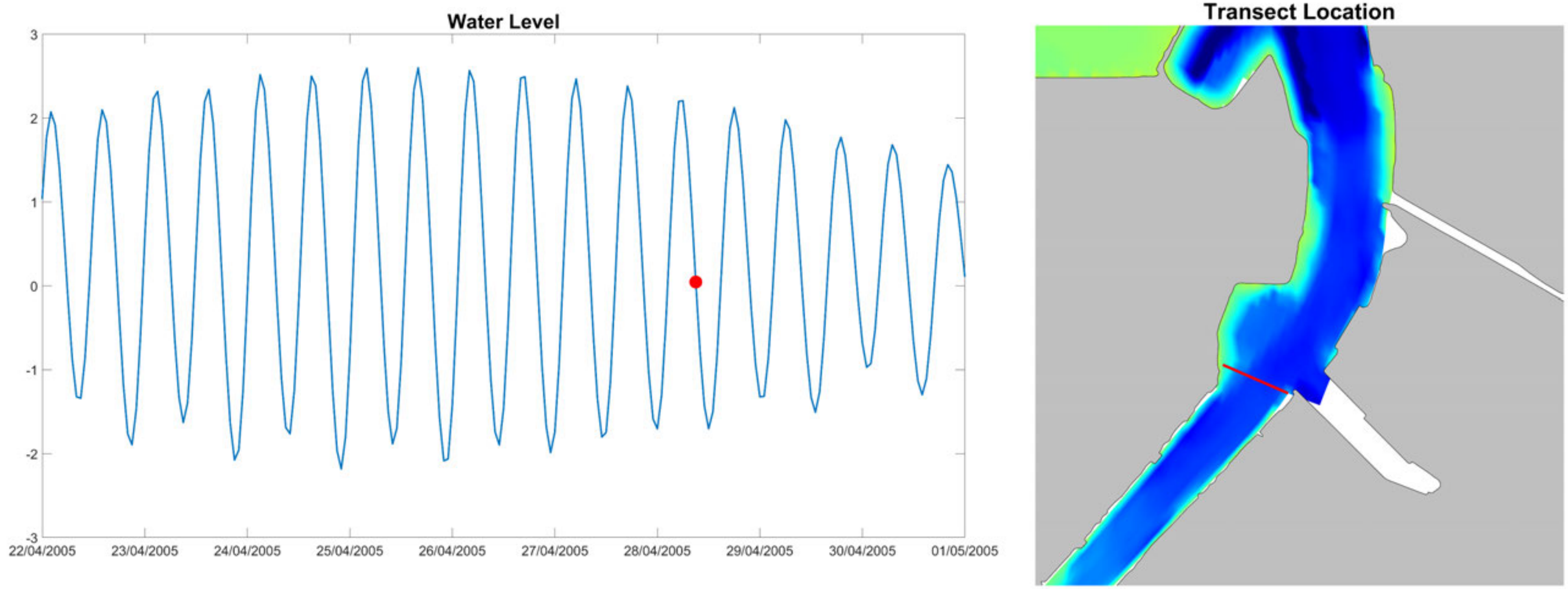


Figure 50. Tidal state and transect location extracted from the model for Transect 1 Pass 03: 28/04/2005

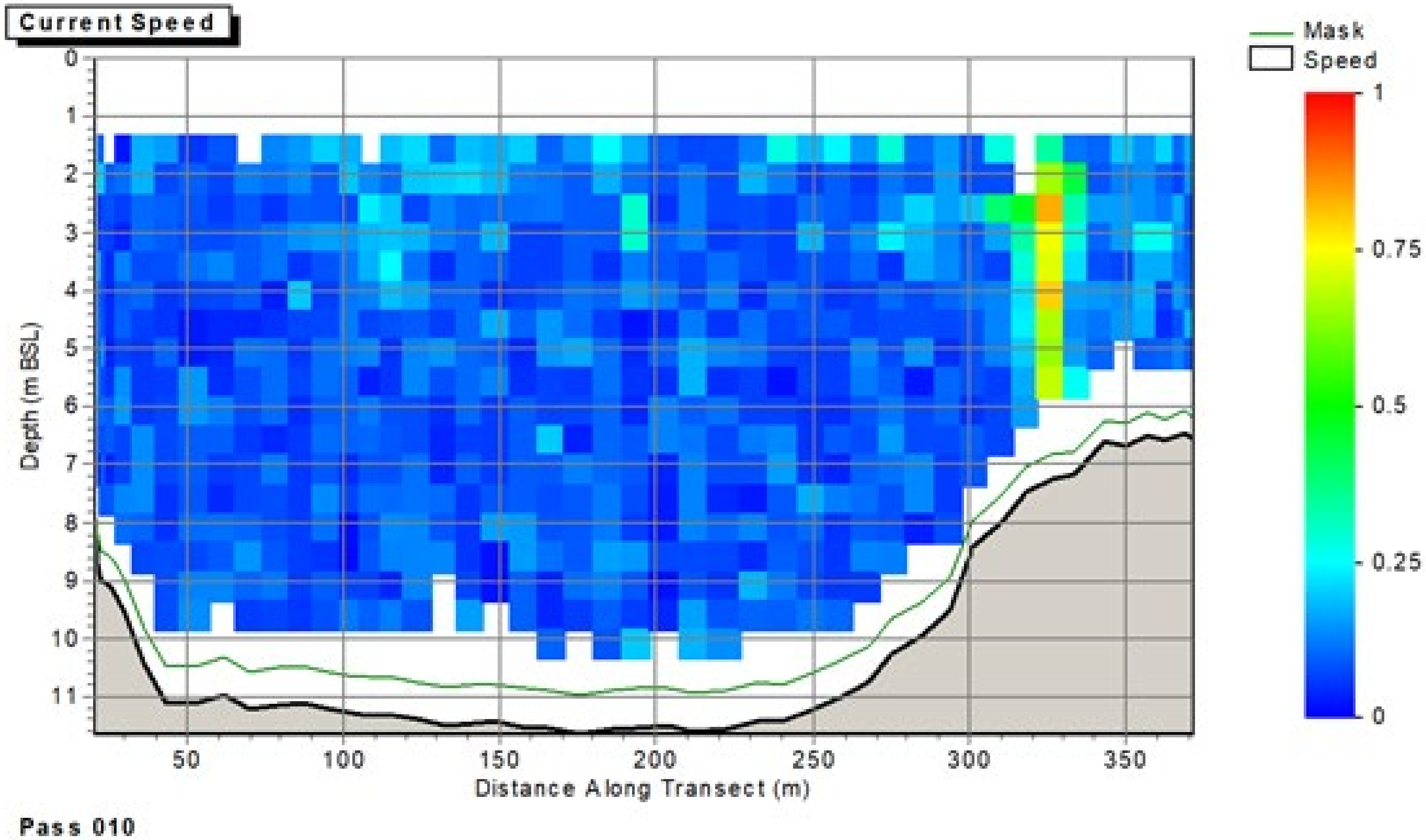


Figure provided by PD Teesport

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

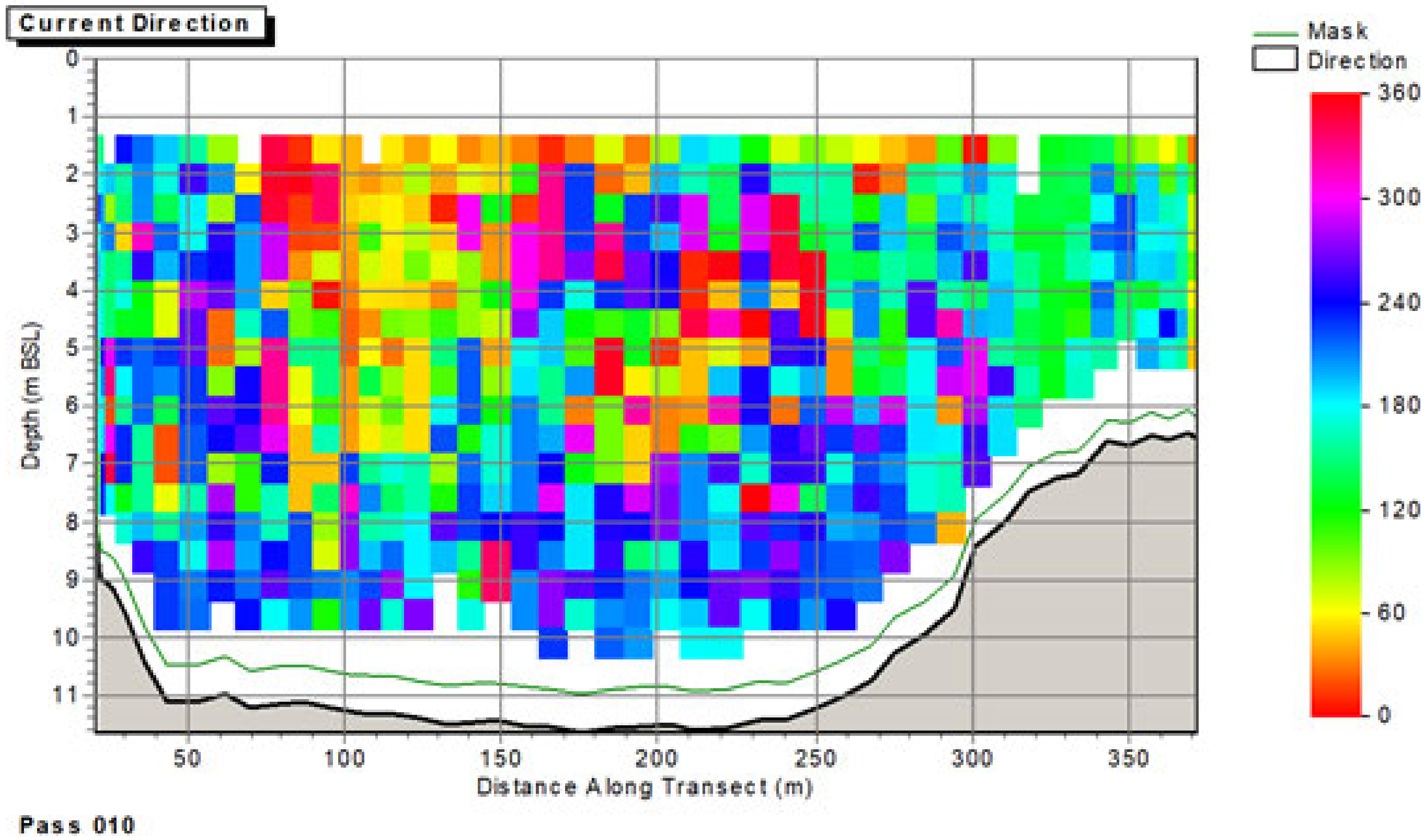


Figure provided by PD Teesport

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

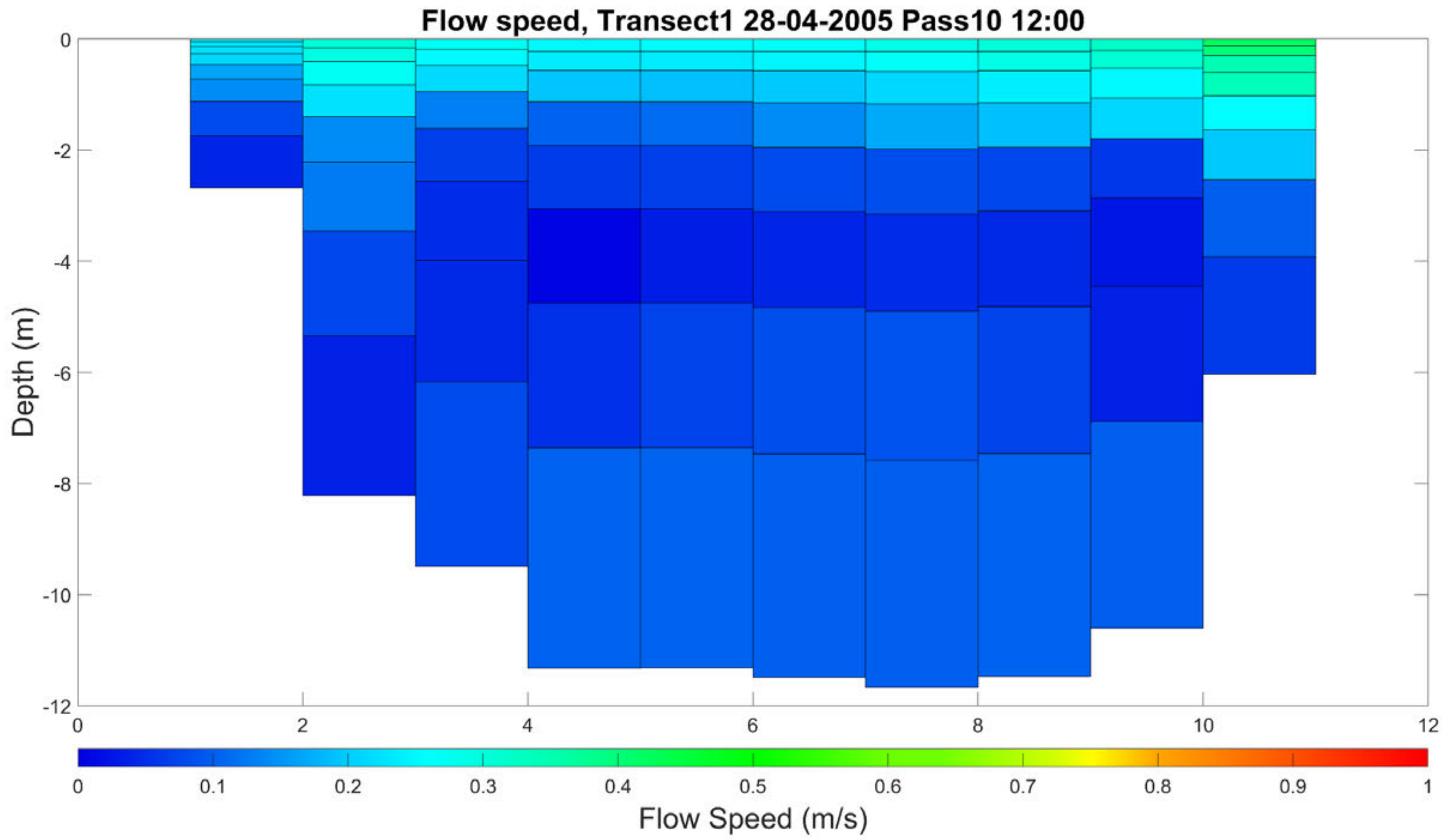


Figure 53. Modelled flow speed, Transect 1: Low tide, cross section of speed with depth shown from west (left) to east (right)

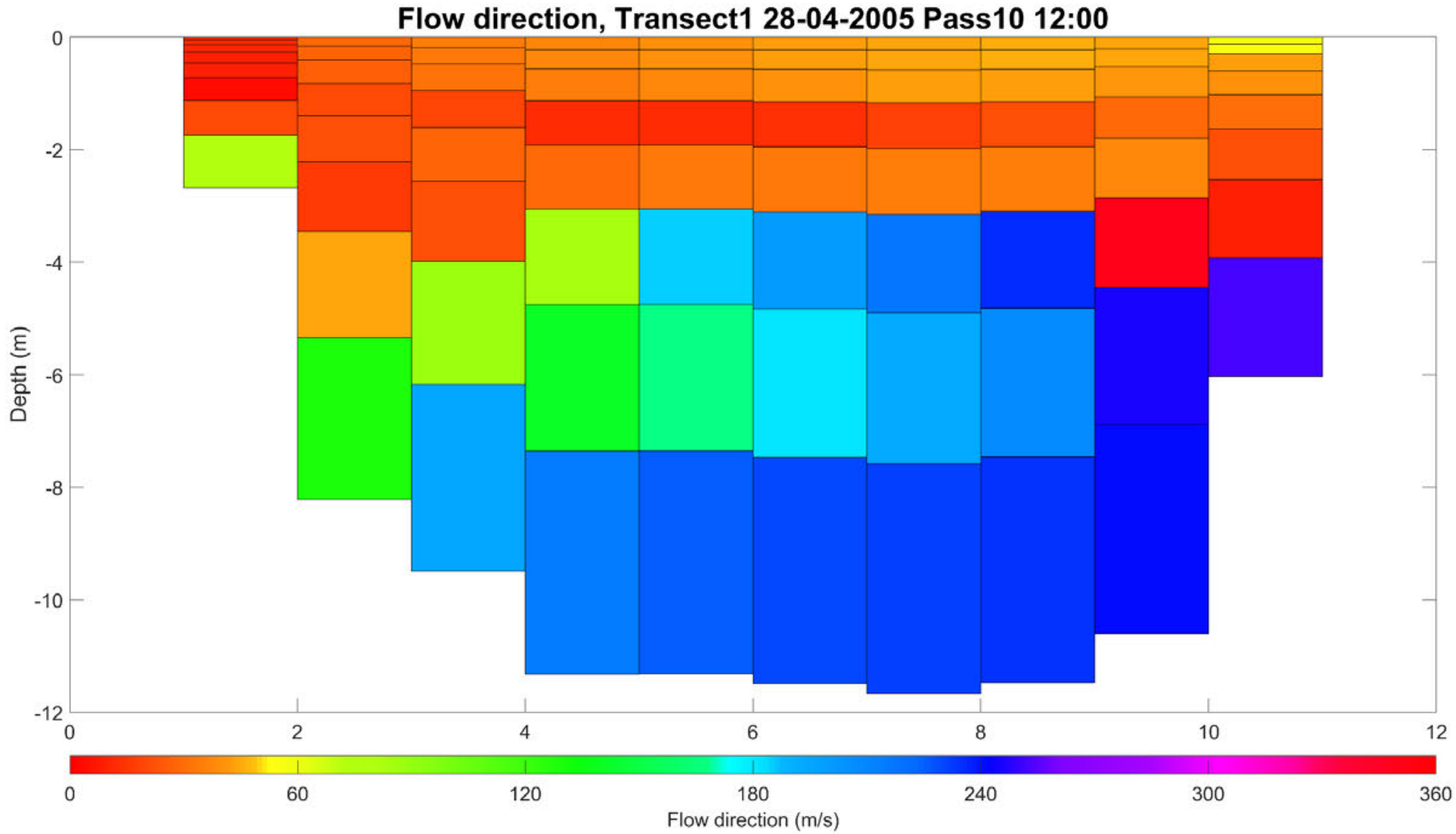


Figure 54. Modelled flow direction, Transect 1: Low tide, cross section of direction with depth shown from west (left) to east (right)

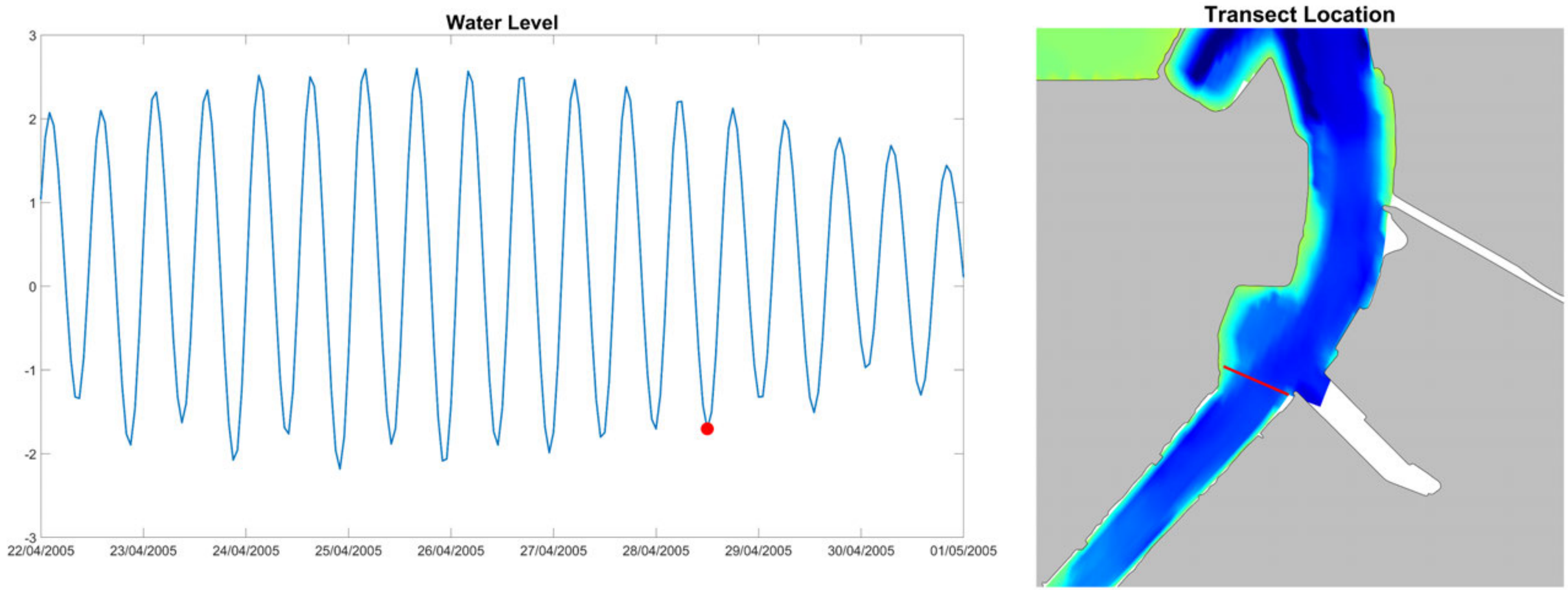


Figure 55. Tidal state and transect location extracted from the model for Transect 1 Pass 01: 28/04/2005

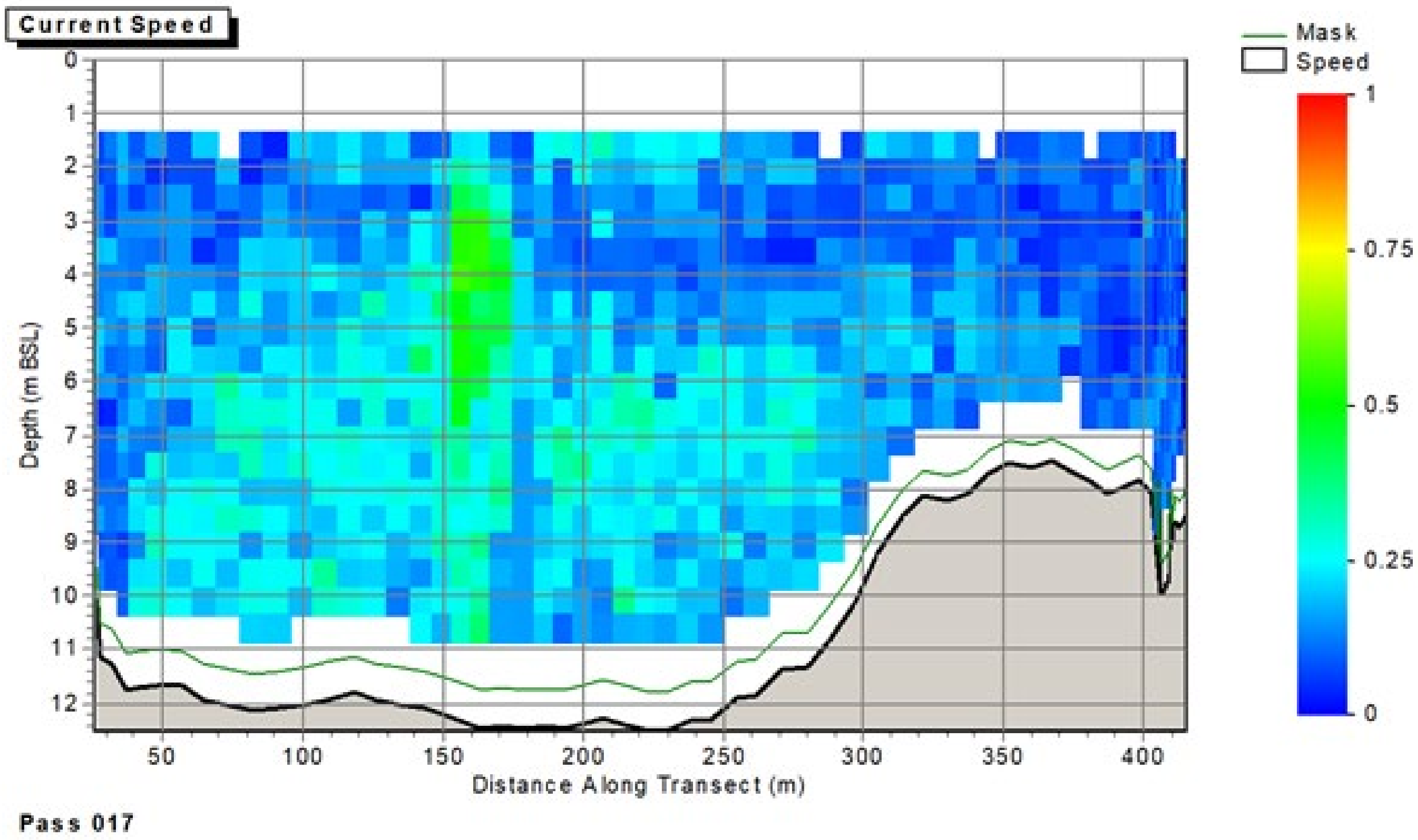


Figure provided by PD Teesport

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

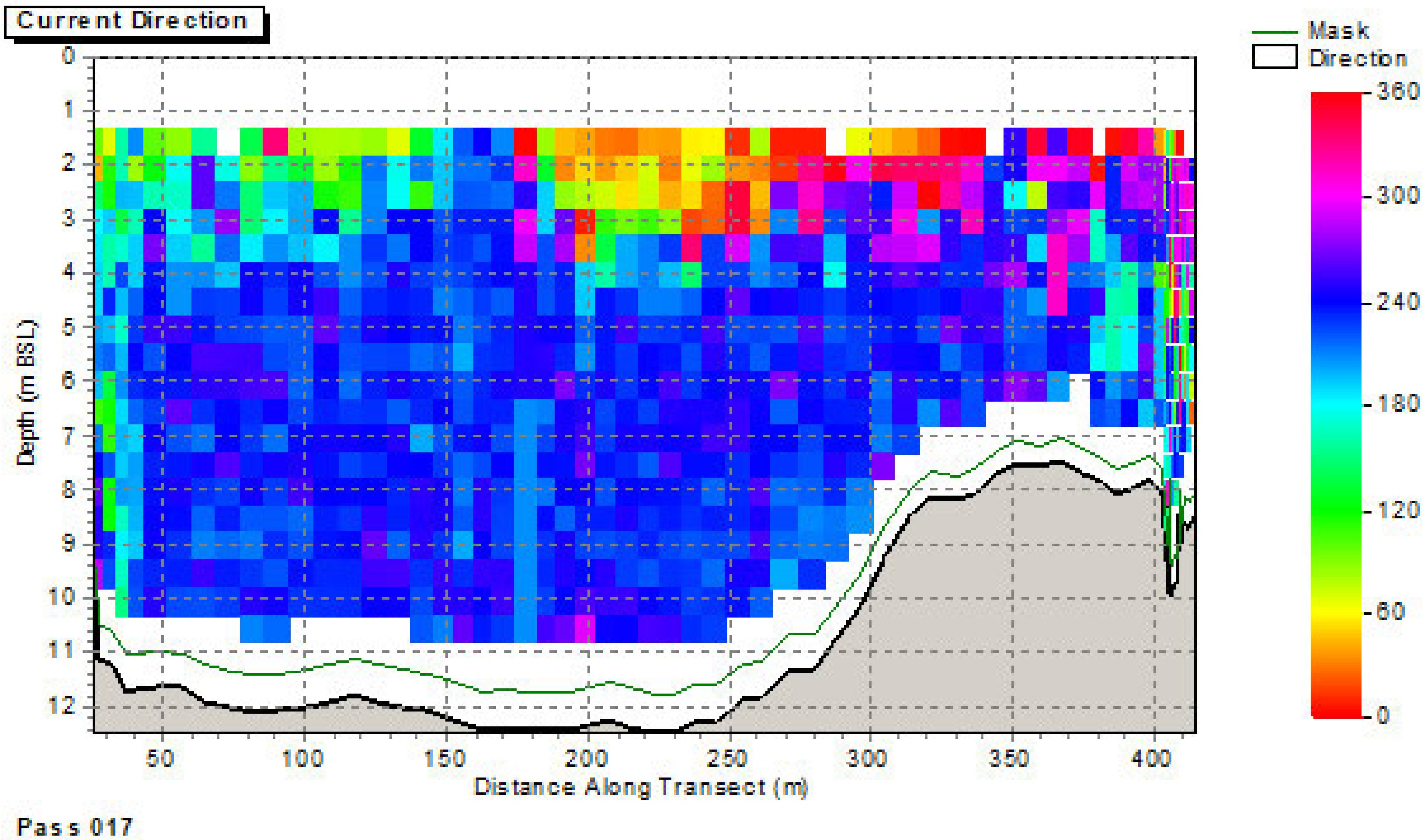


Figure provided by PD Teesport

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

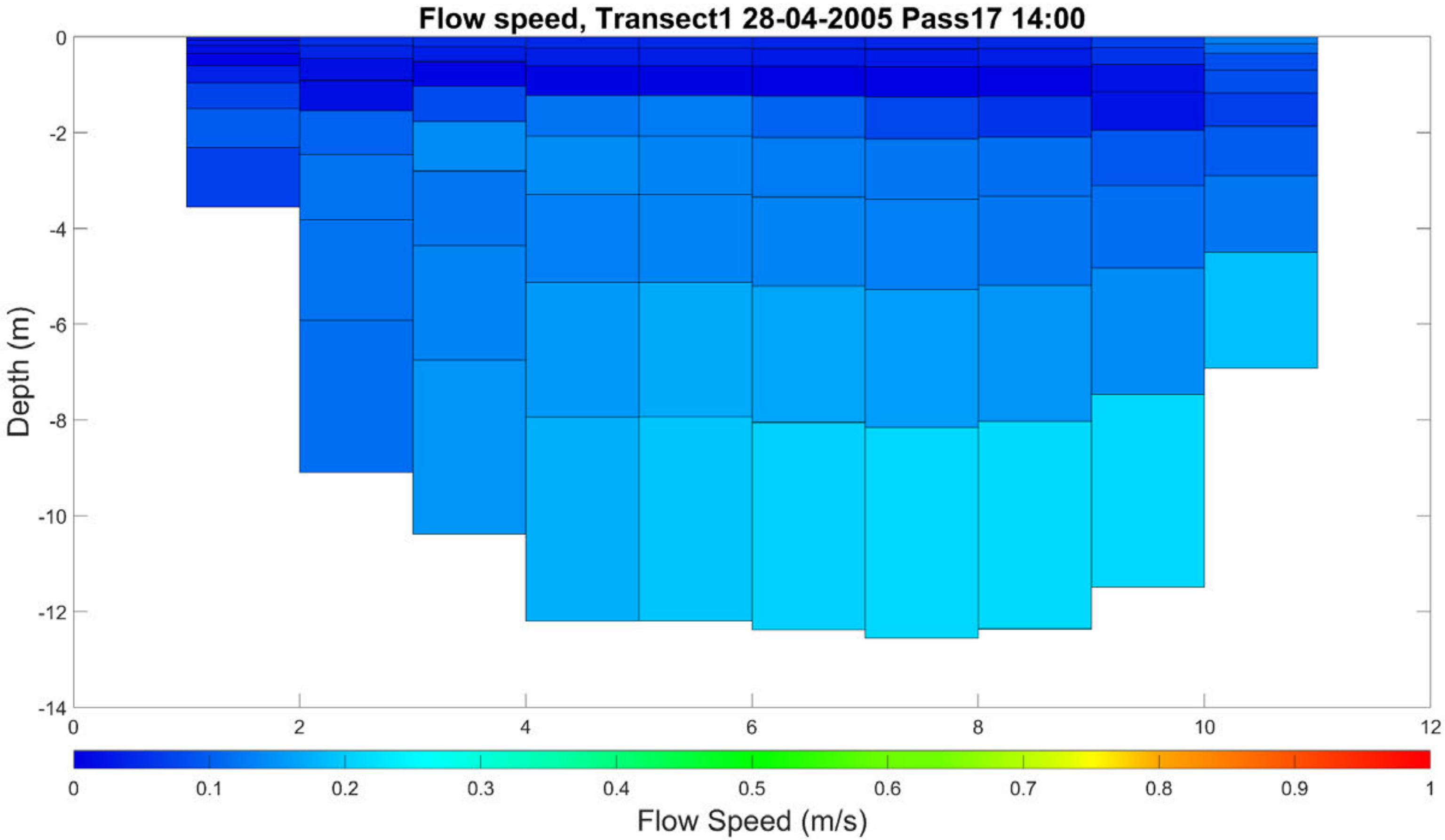


Figure 58. Modelled flow speed, Transect 1: Flood tide, cross section of speed with depth shown from west (left) to east (right)

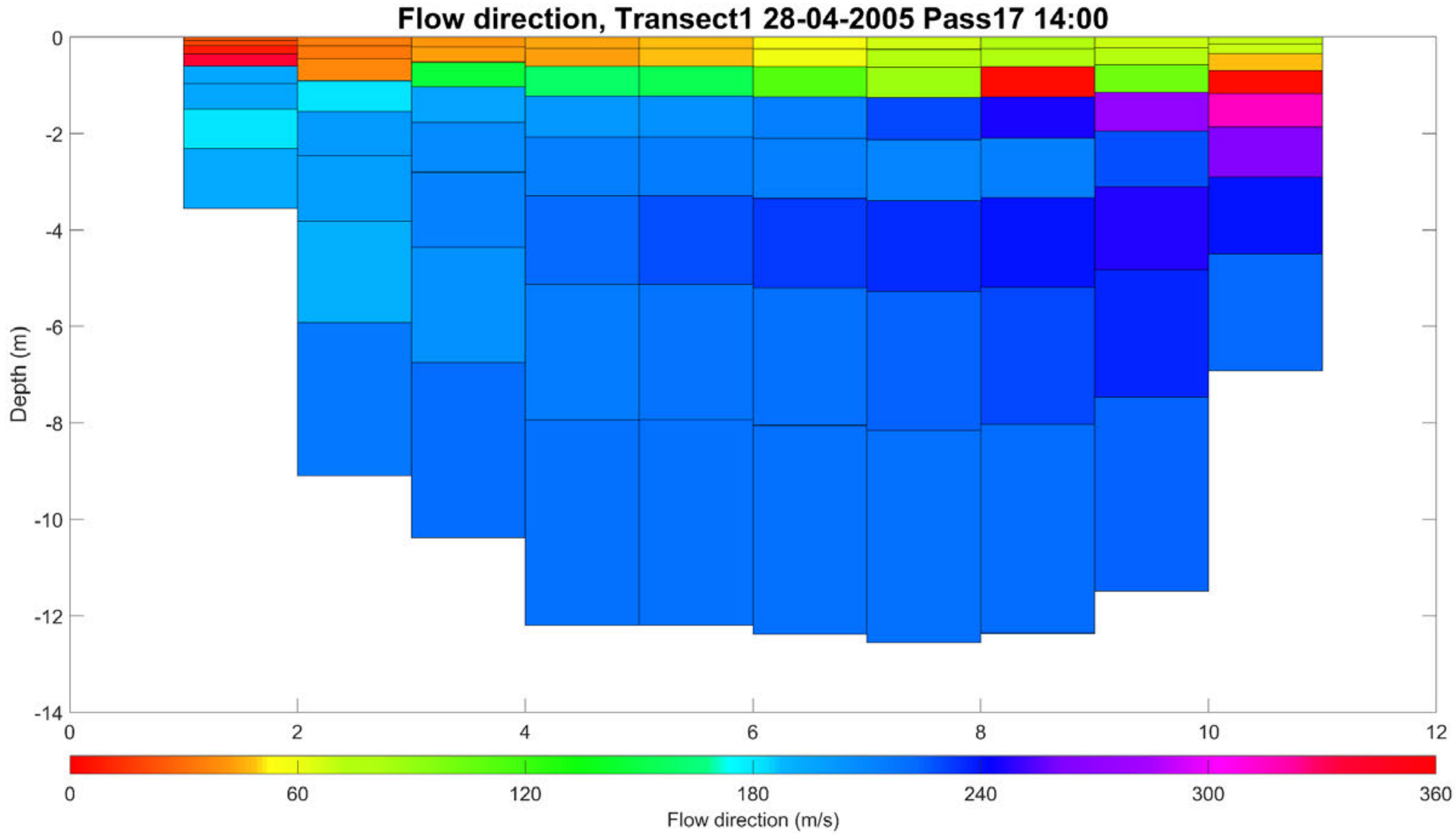


Figure 59. Modelled flow direction, Transect 1: Flood tide, cross section of direction with depth shown from west (left) to east (right)

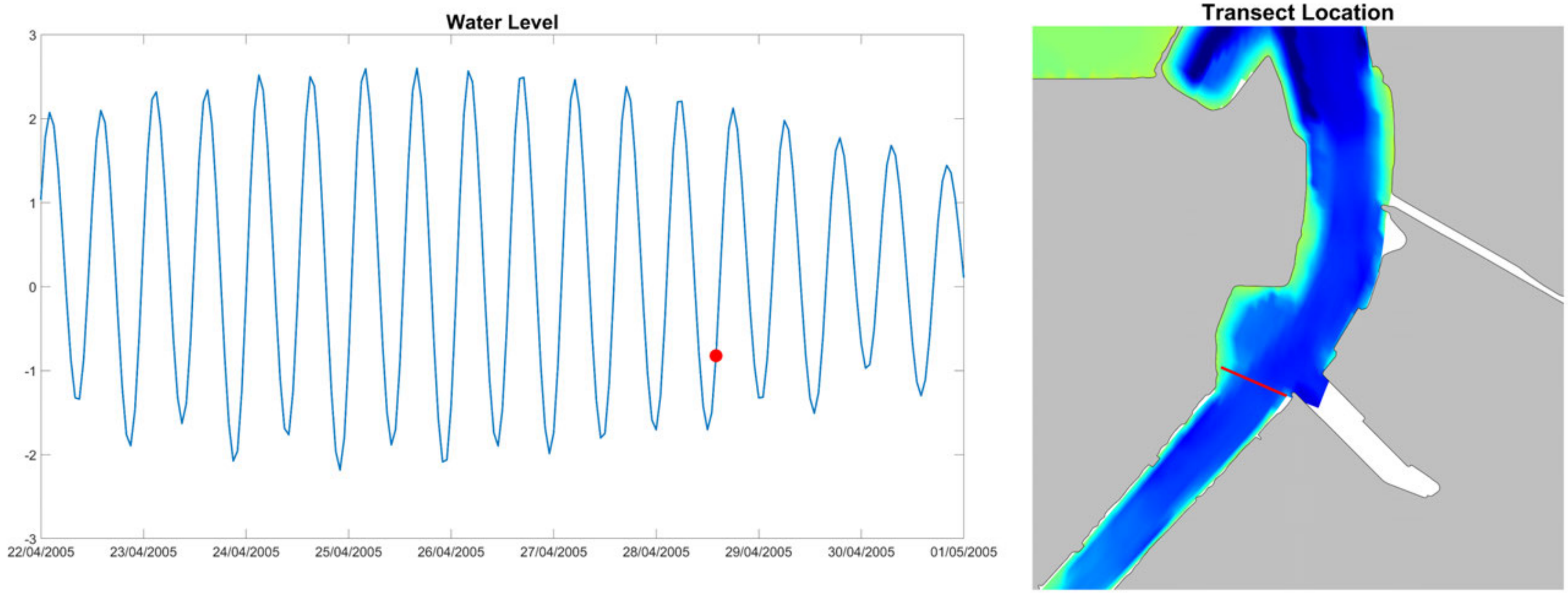


Figure 60. Tidal state and transect location extracted from the model for Transect 1 Pass 17: 28/04/2005

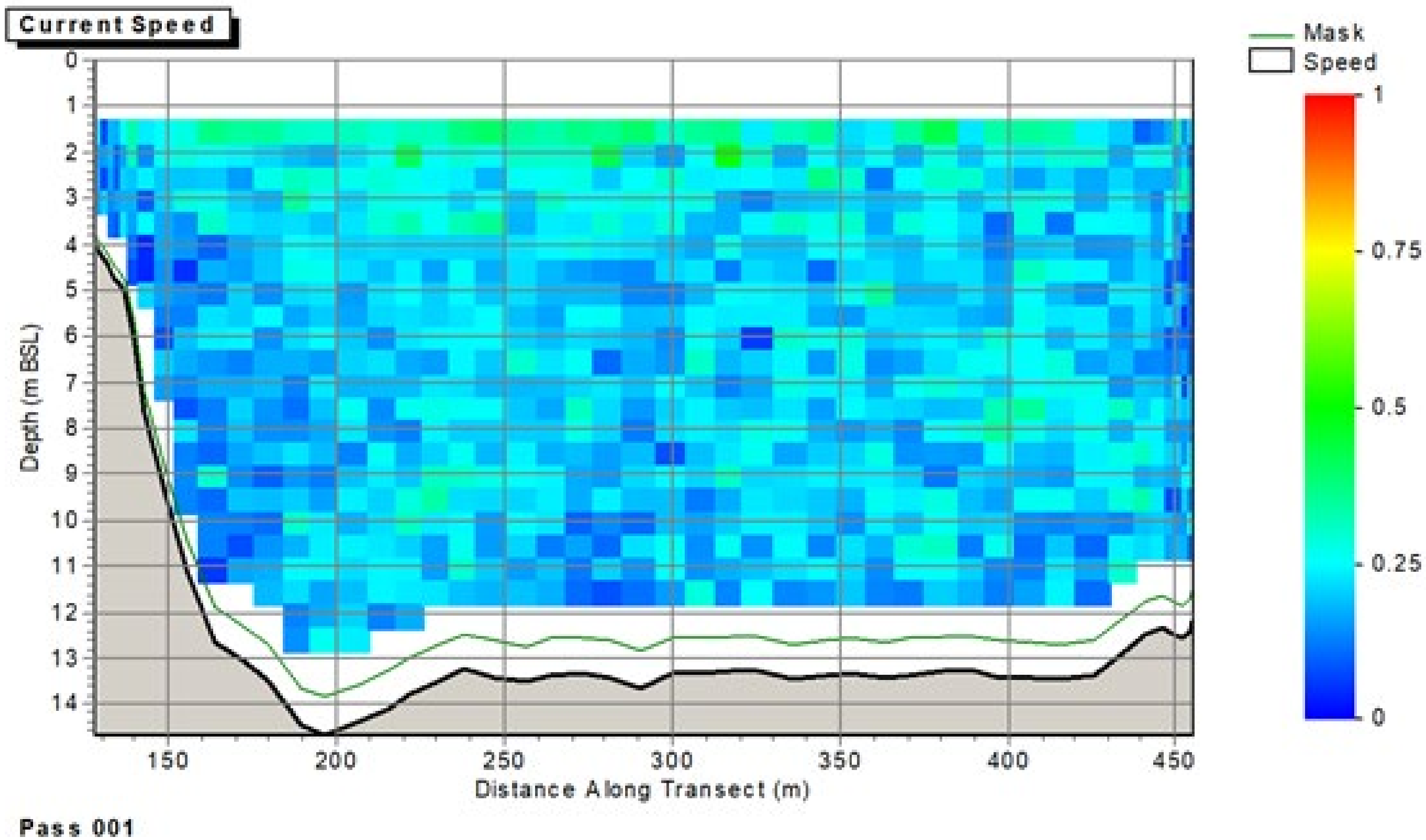


Figure provided by PD Teesport

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

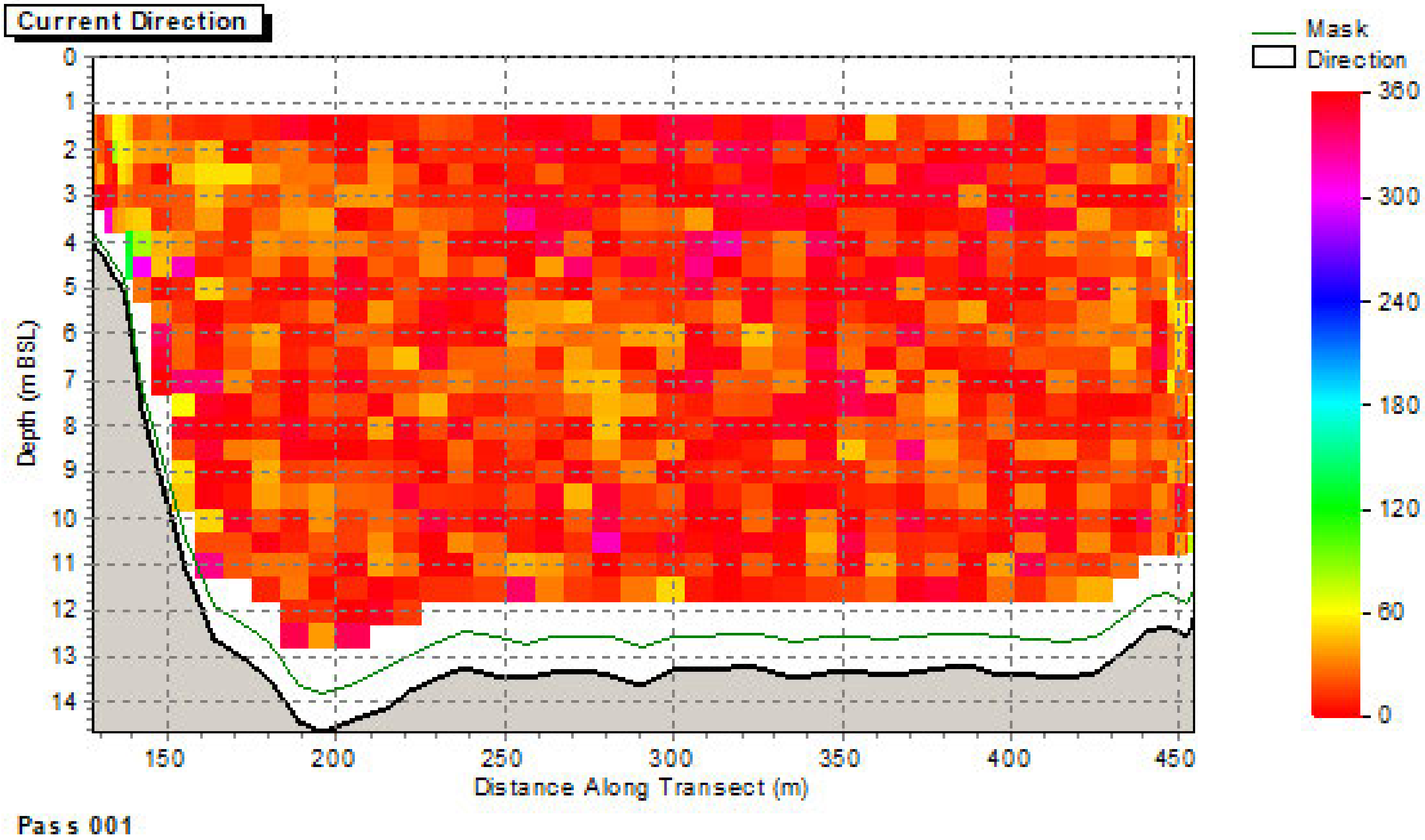


Figure provided by PD Teesport

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

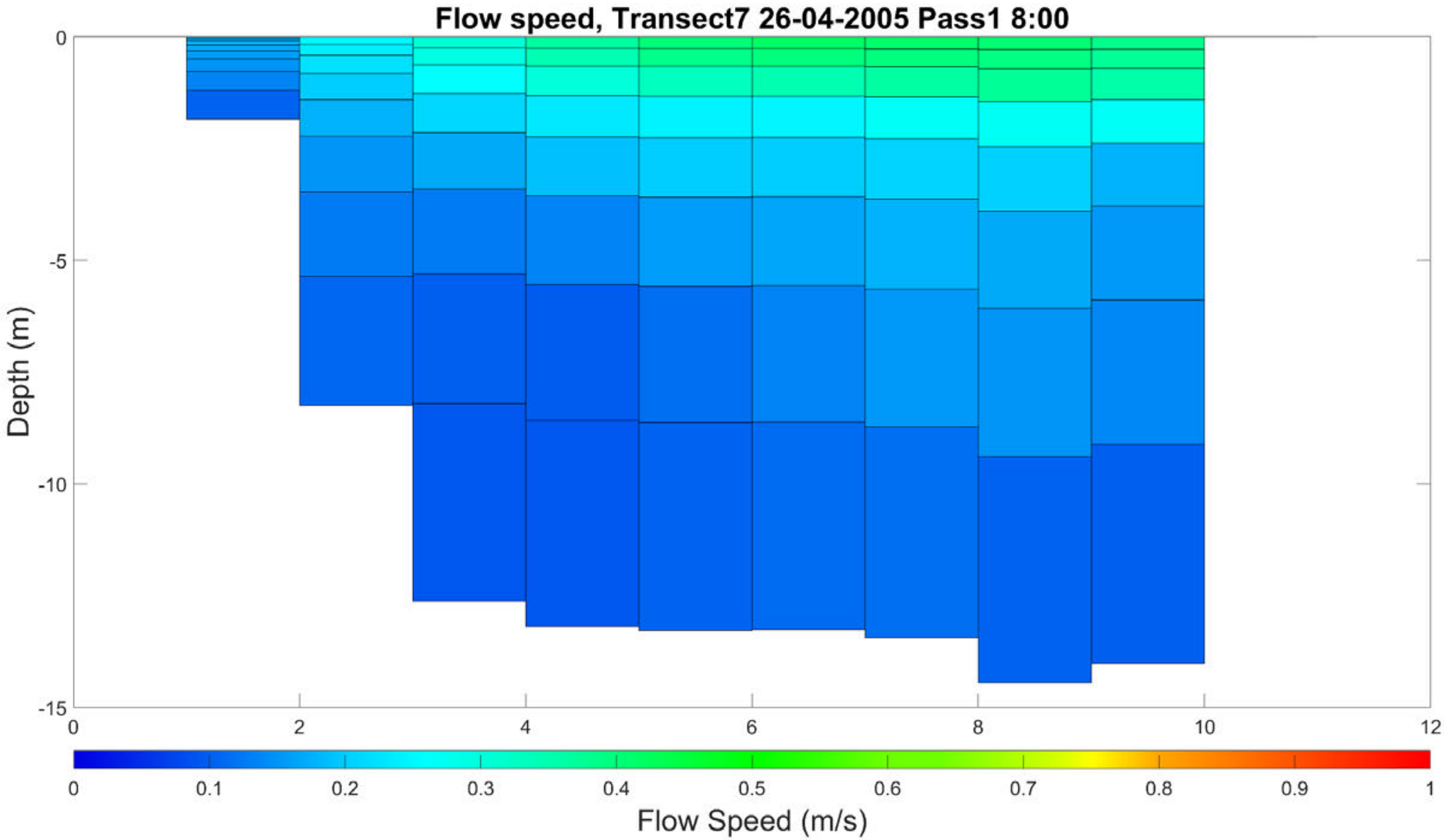


Figure 63. Modelled flow speed, Transect 7: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

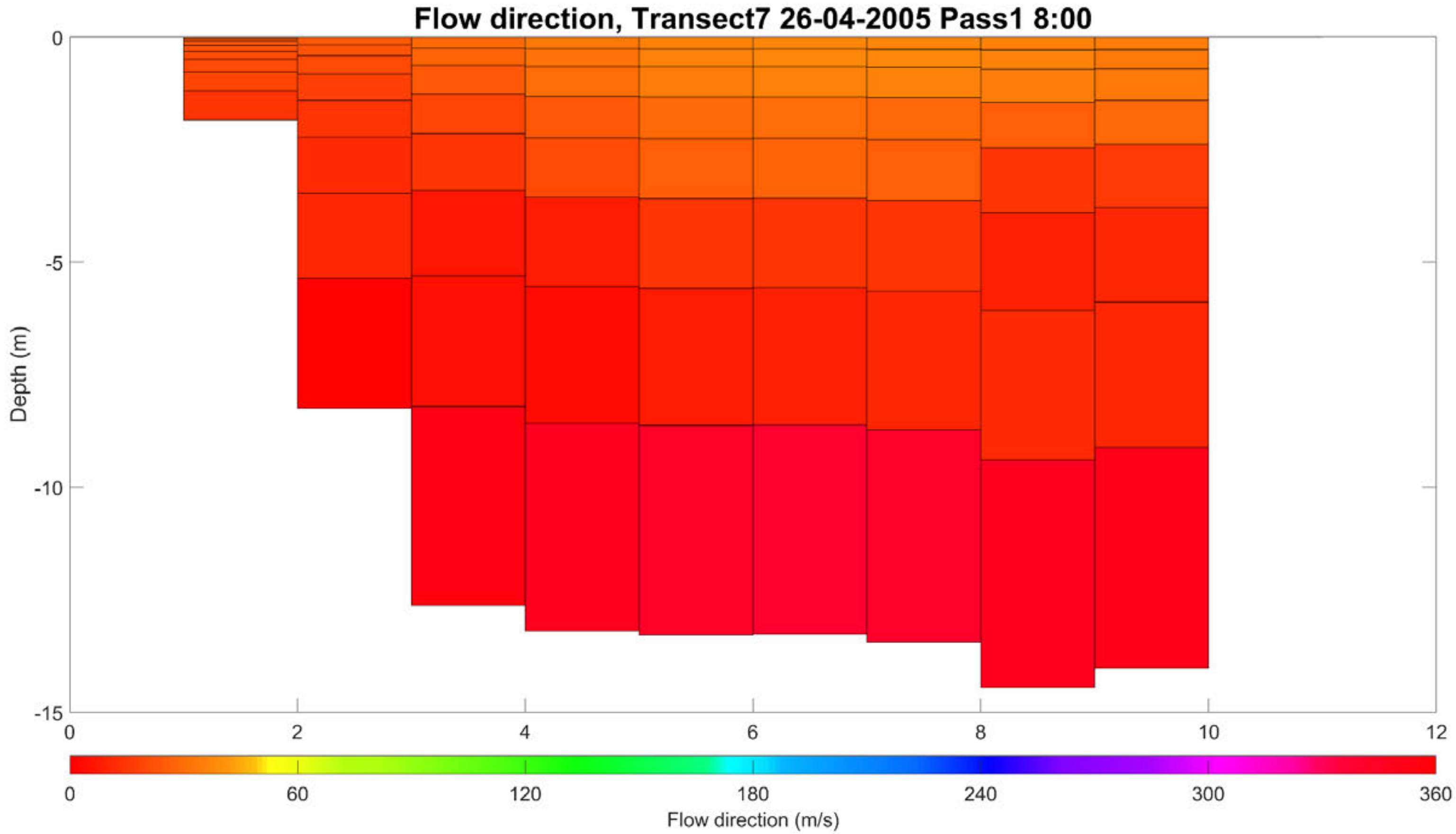


Figure 64. Modelled flow direction, Transect 7: Ebb tide, cross section of direction with depth shown from west (left) to east (right)

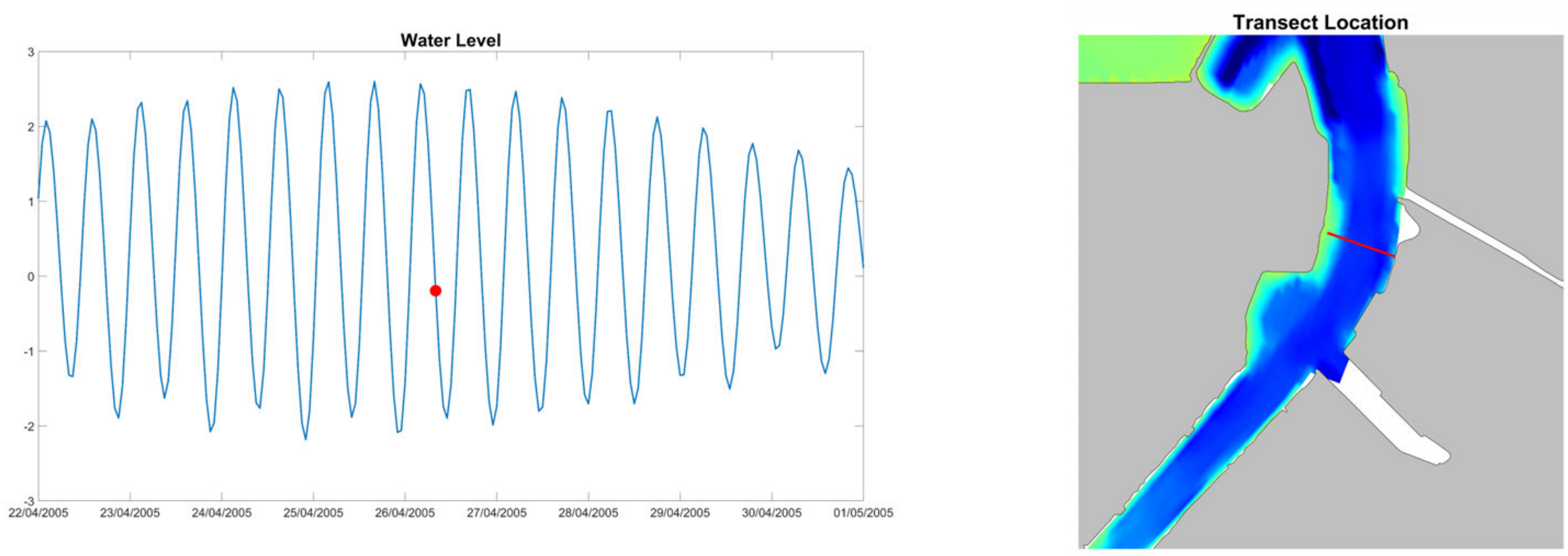


Figure 65. Tidal state and transect location extracted from the model for Transect 7 Pass 1: 26/04/2005

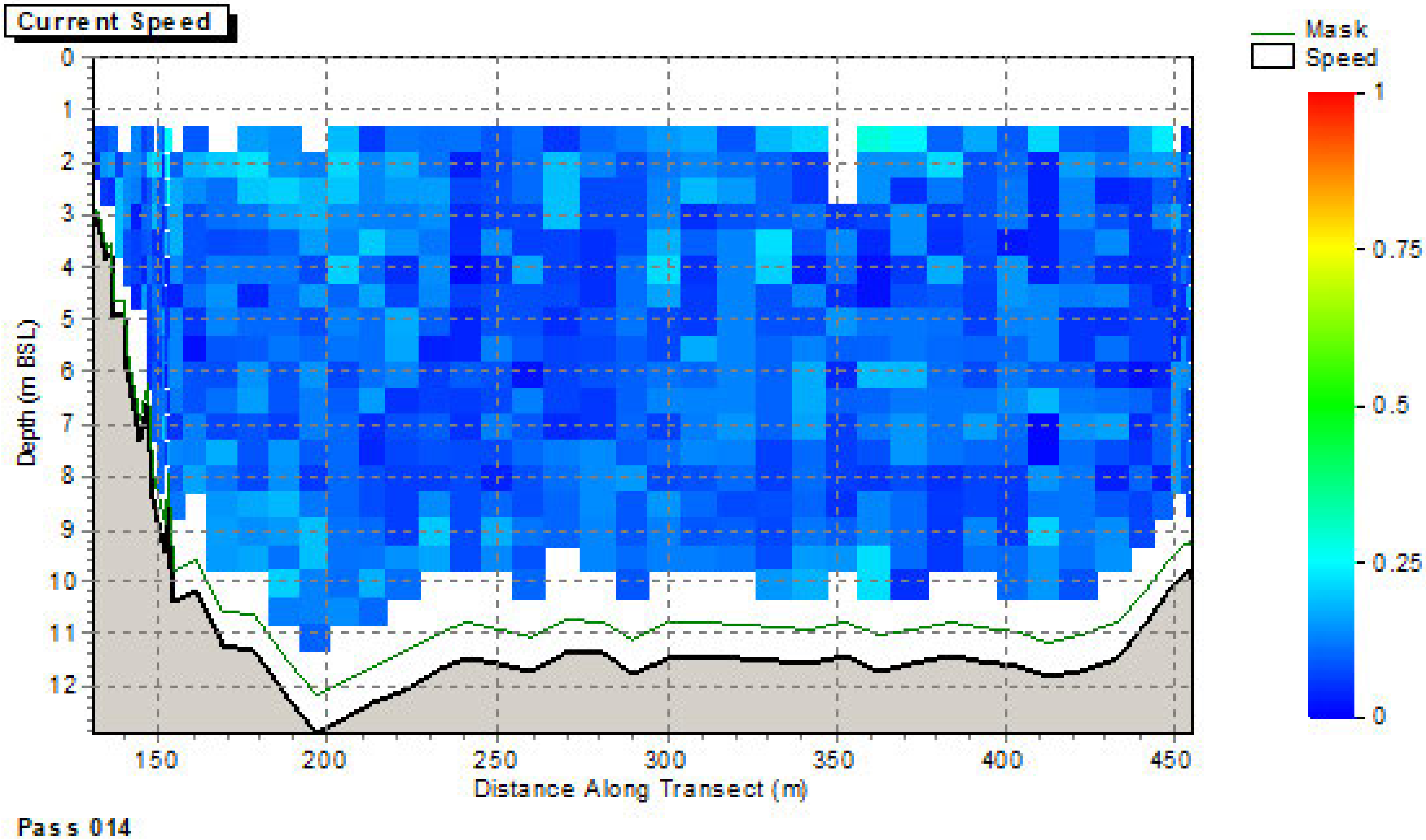


Figure provided by PD Teesport

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

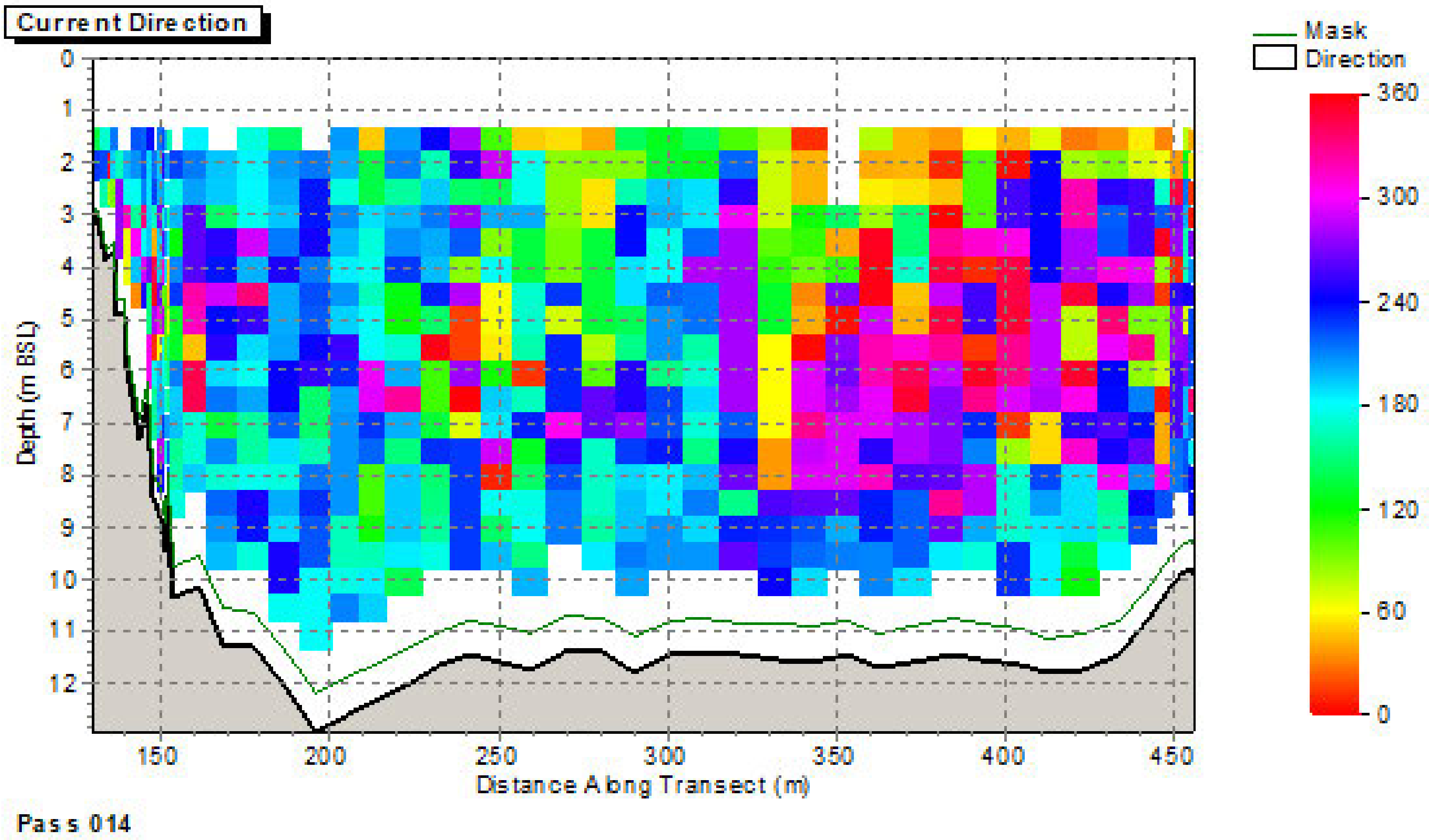


Figure provided by PD Teesport

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

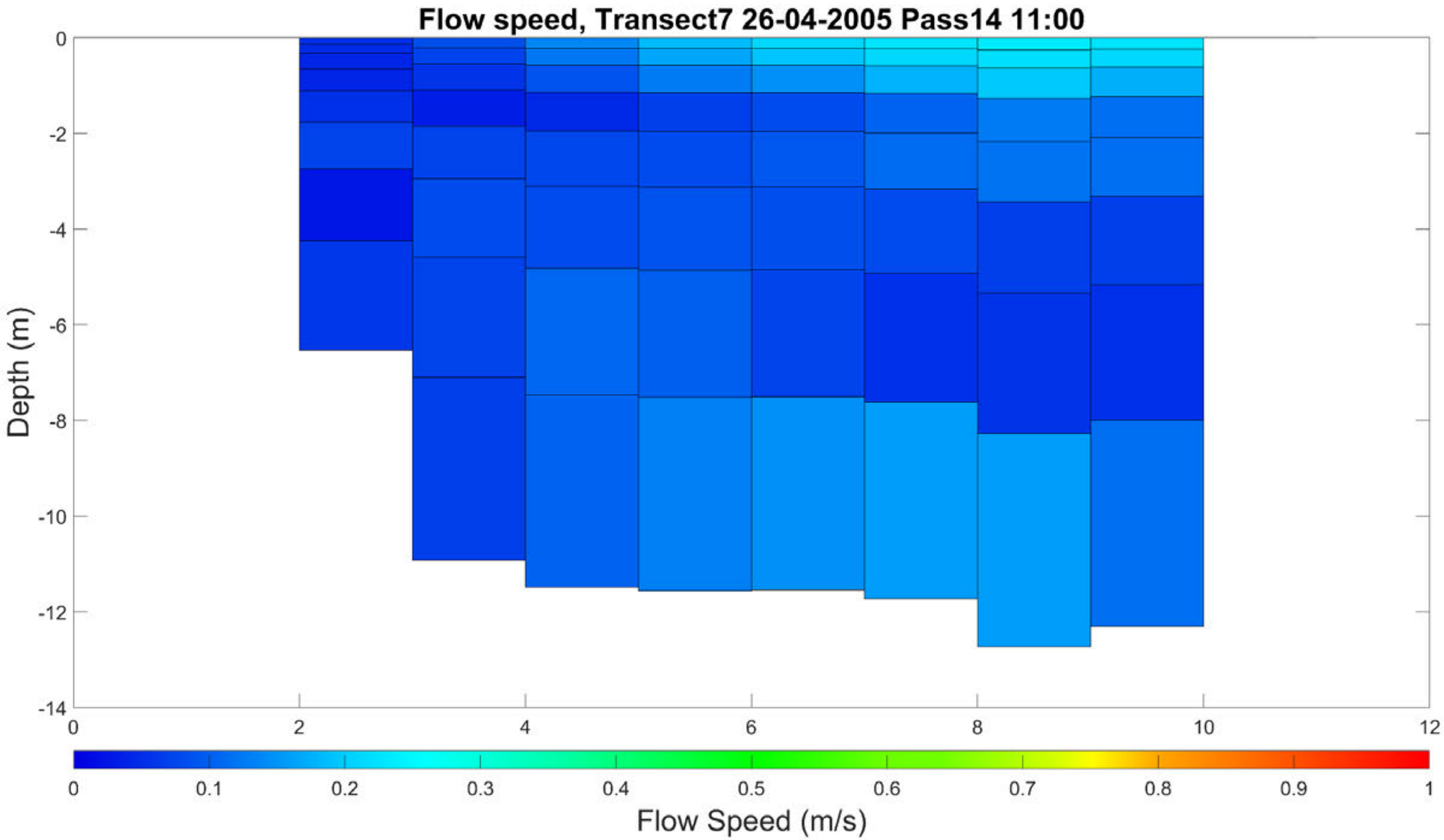


Figure 68. Modelled flow speed, Transect 7: Low water, cross section of speed with depth shown from west (left) to east (right)

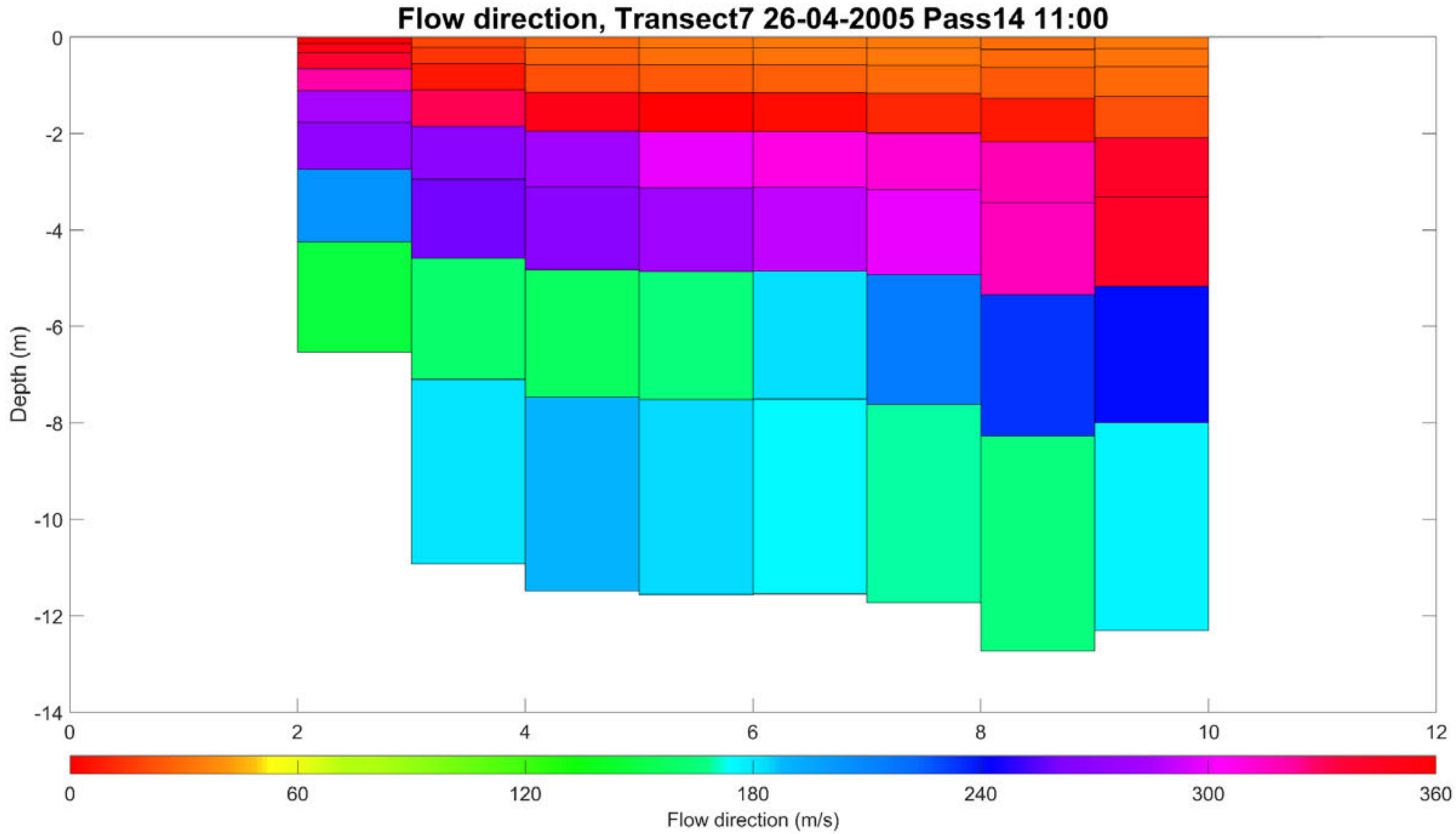


Figure 69. Modelled flow direction, Transect 7: Low water, cross section of direction with depth shown from west (left) to east (right)

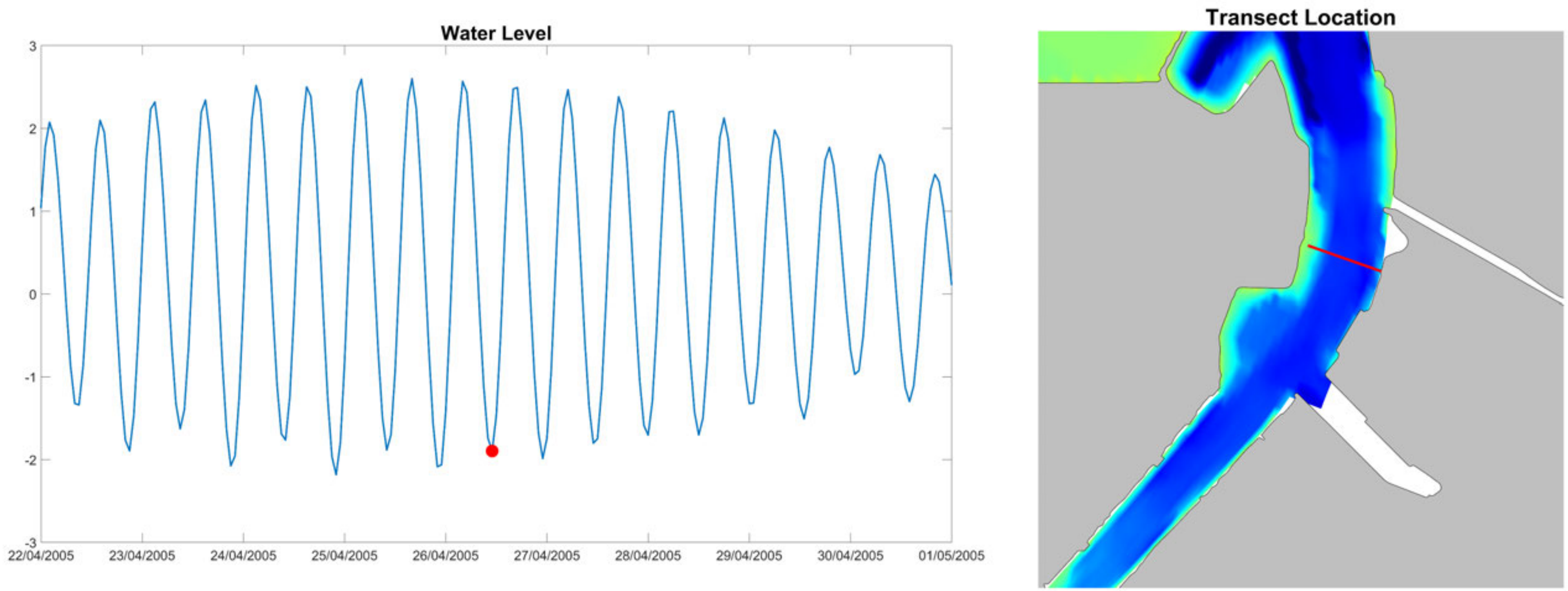


Figure 70. Tidal state and transect location extracted from the model for Transect 7 Pass 14: 26/04/2005

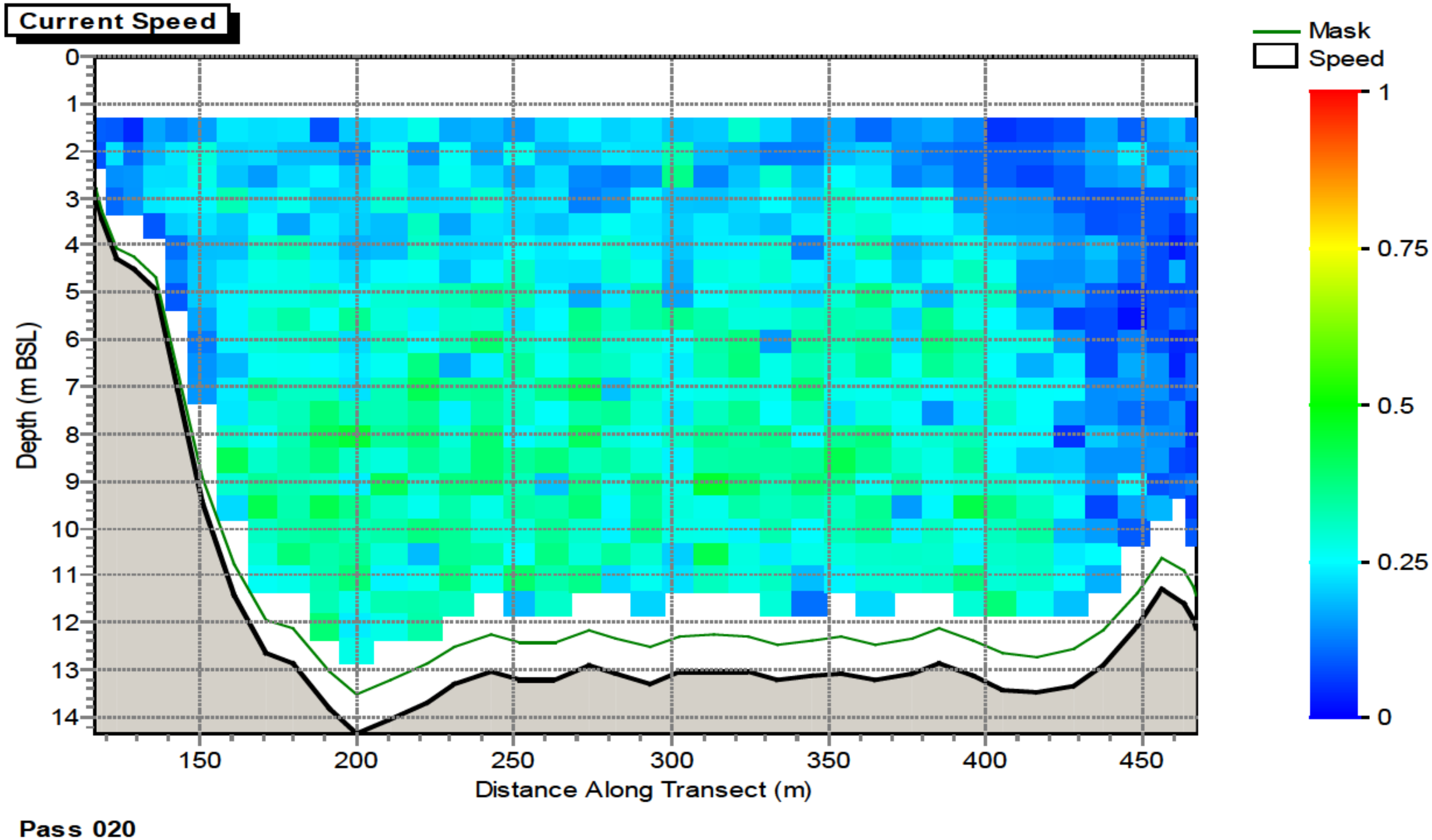


Figure provided by PD Teesport

Figure 71. Measured flow speed, Transect 7, Pass 20: Flood tide, cross section of speed with depth shown from west (left) to east (right)

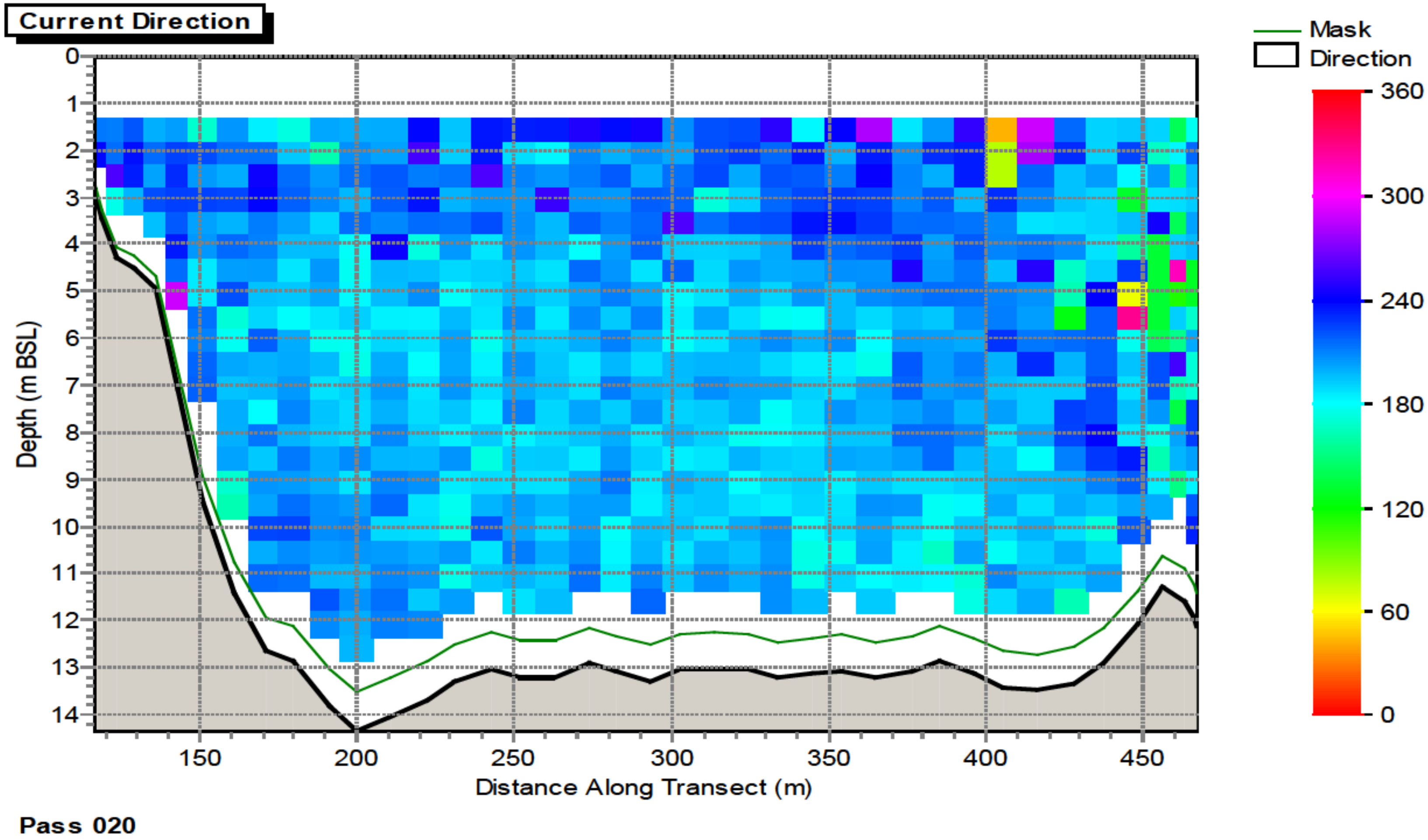


Figure provided by PD Teesport

Figure 72. Measured flow direction, Transect 7, Pass 20: Flood tide, cross section of direction with depth shown from west (left) to east (right)

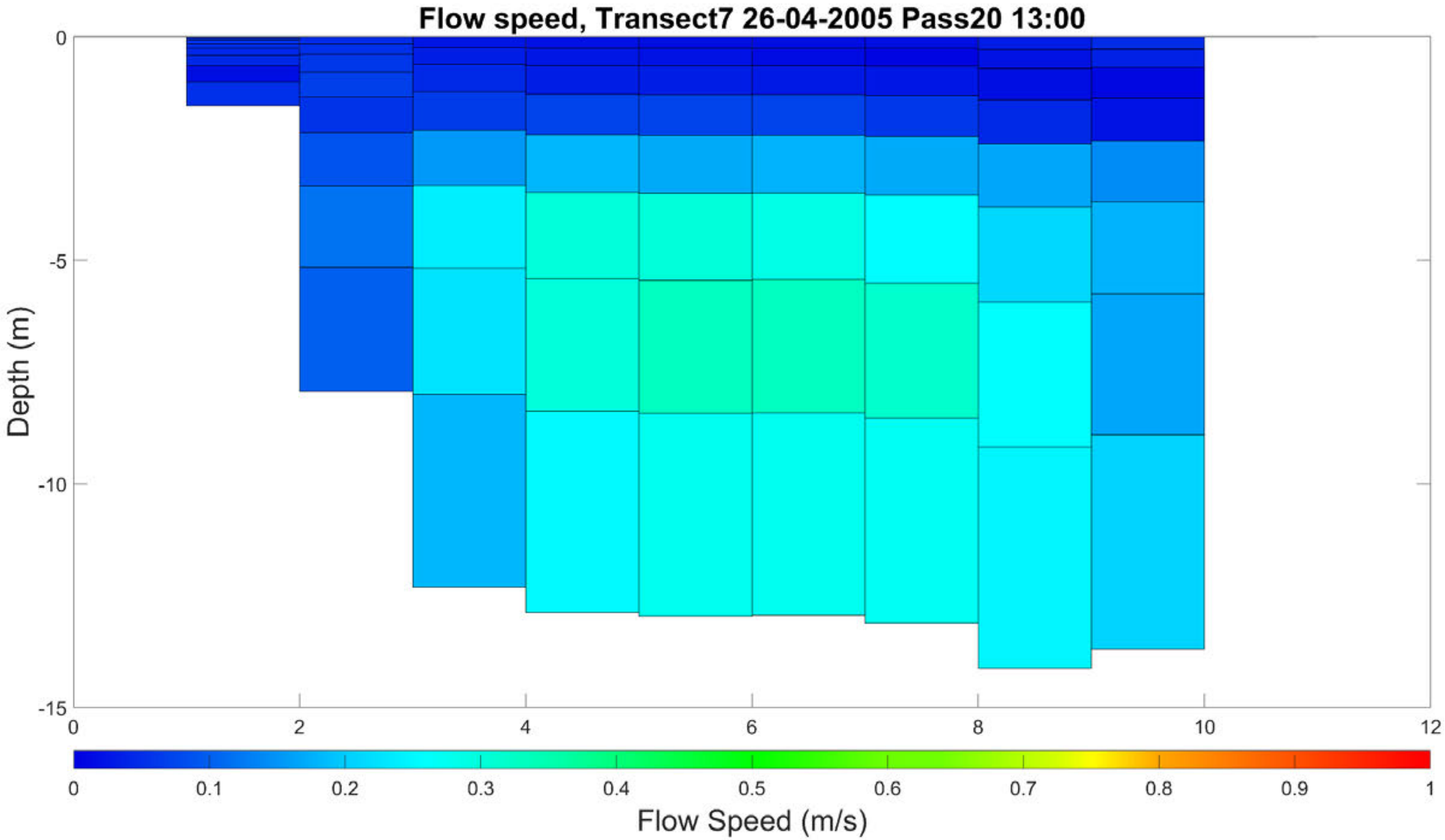


Figure 73. Modelled flow speed, Transect 7: Flood tide, cross section of speed with depth shown from west (left) to east (right)

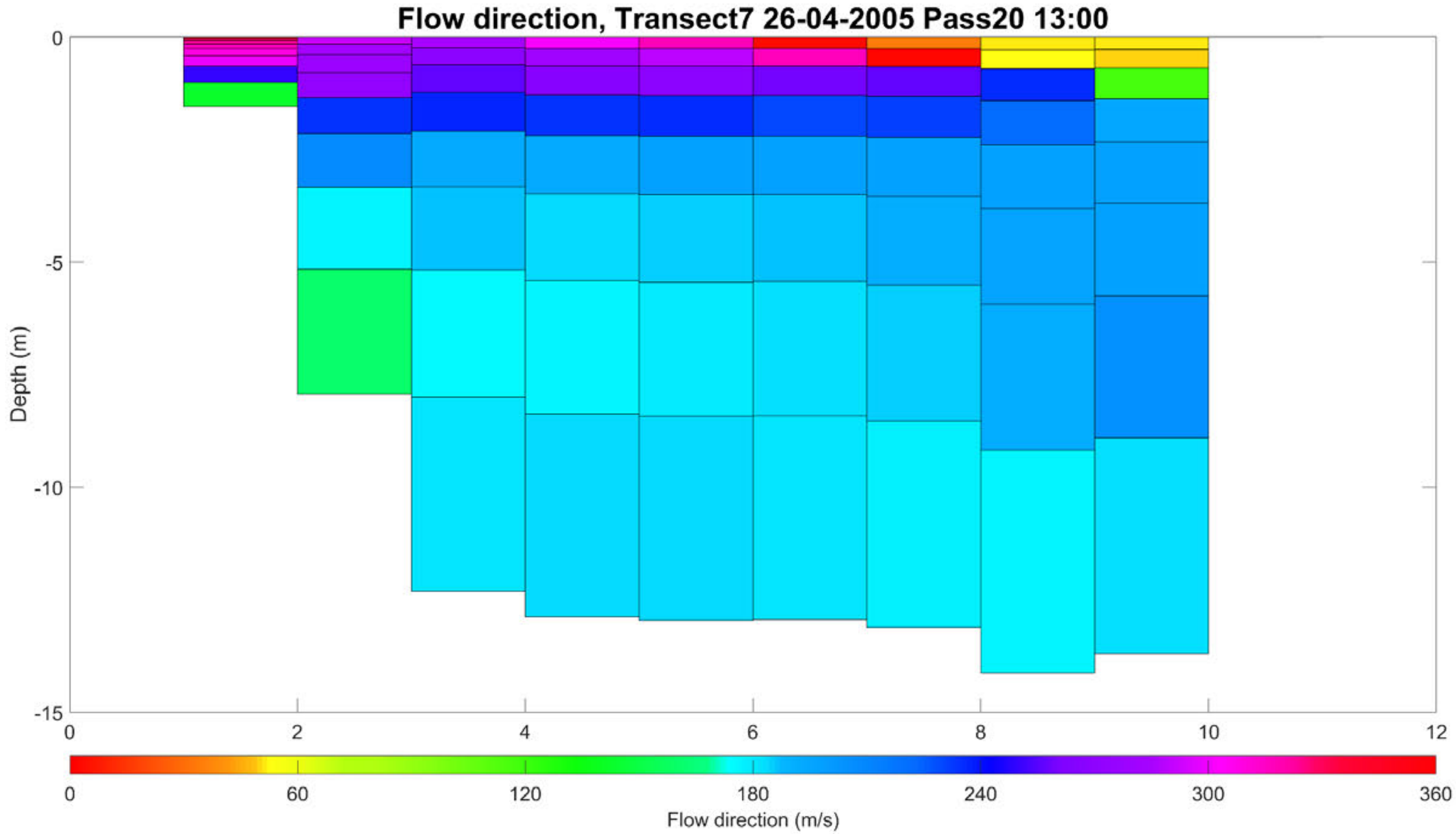


Figure 74. **Modelled flow direction, Transect 7: Flood tide, cross section of direction with depth shown from west (left) to east (right)**

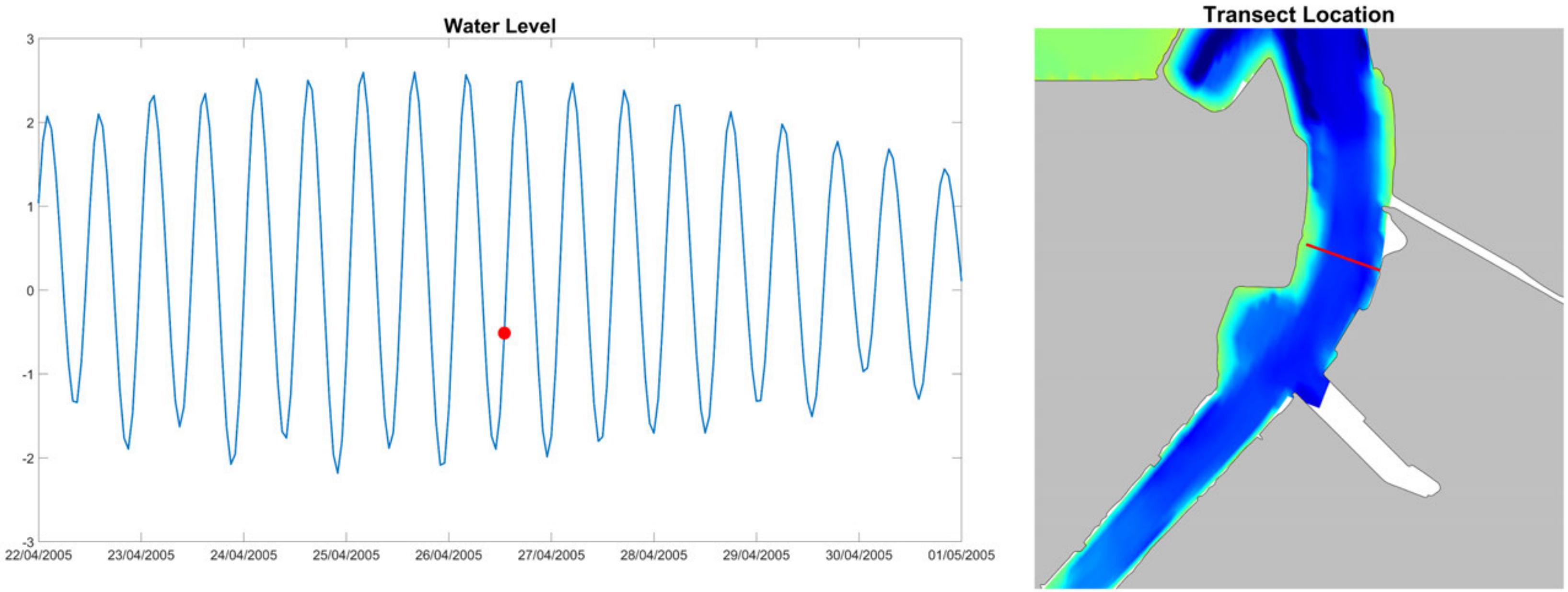


Figure 75. Tidal state and transect location extracted from the model for Transect 7 Pass 20: 26/04/2005

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.

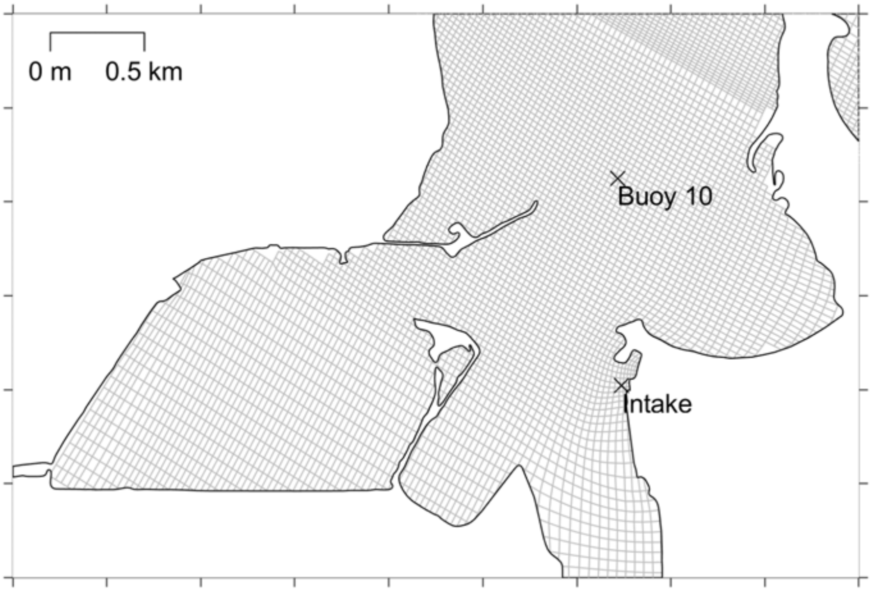


Figure 76. Fixed current meter location: Buoy 10

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.

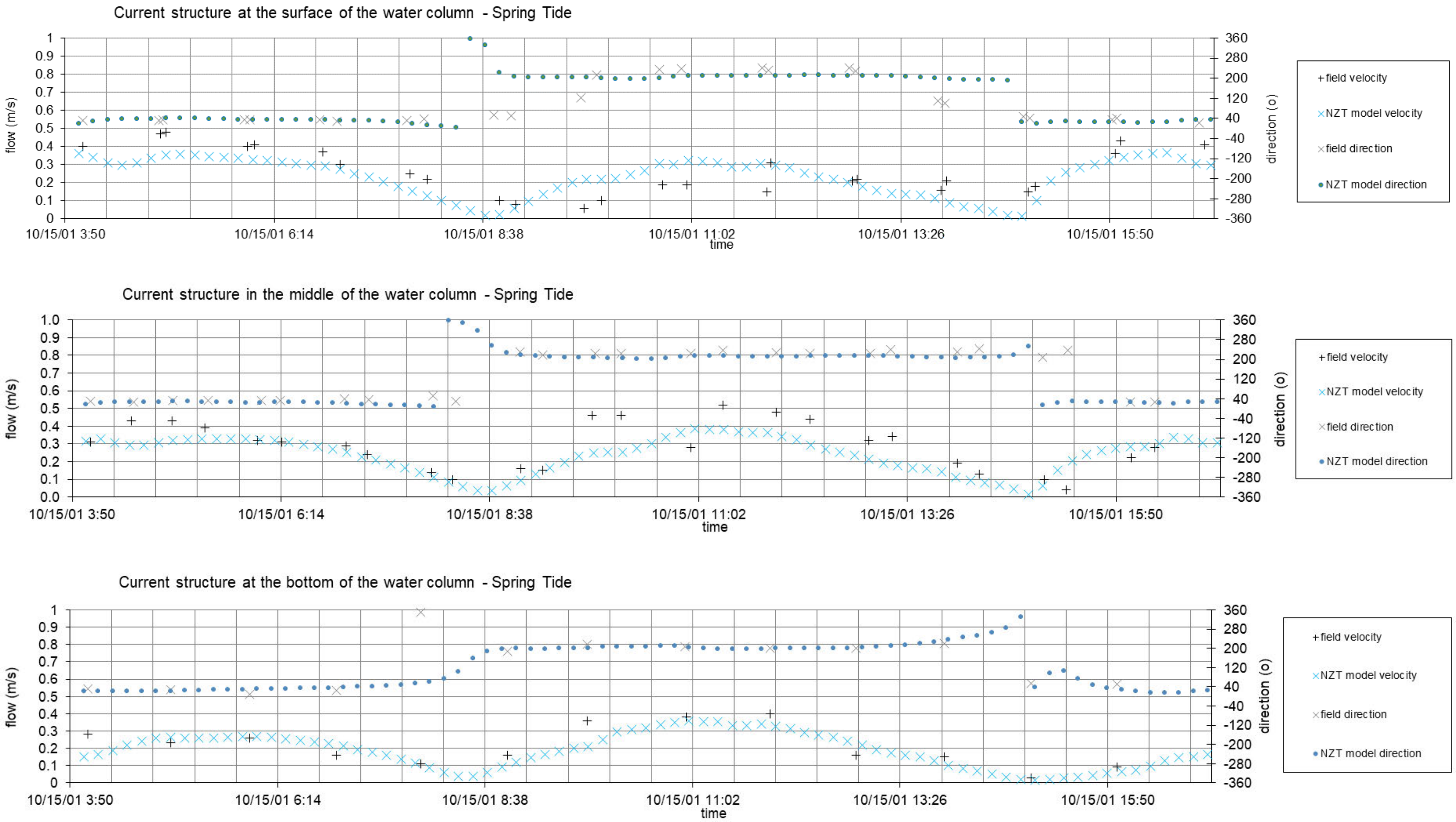


Figure 77. Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Spring tide

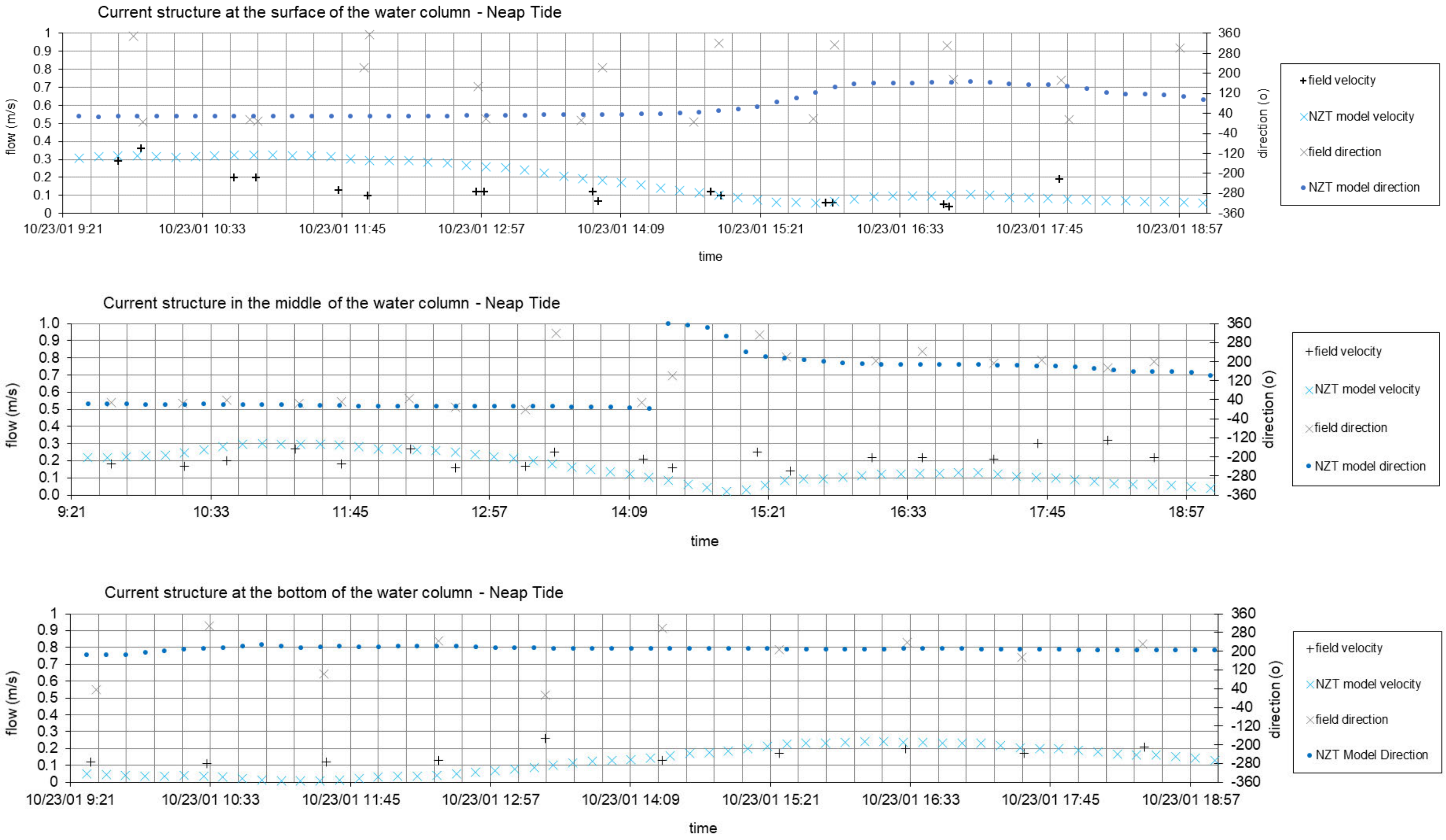


Figure 78. Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Neap tide

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'.

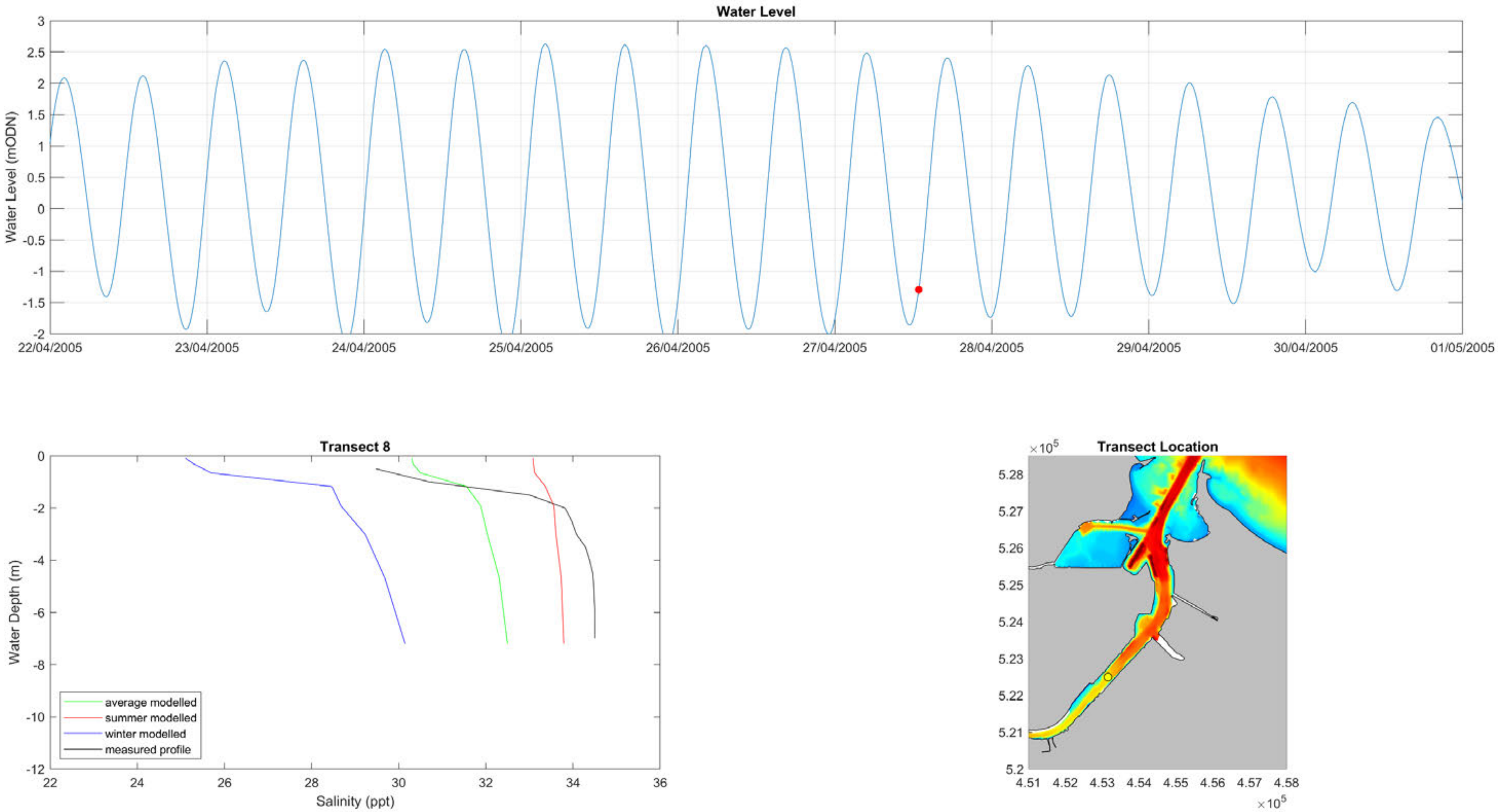


Figure 79. Comparison of measured and modelled salinity with depth: Transect 8 (red dot on top water level plot indicates point of the tide).

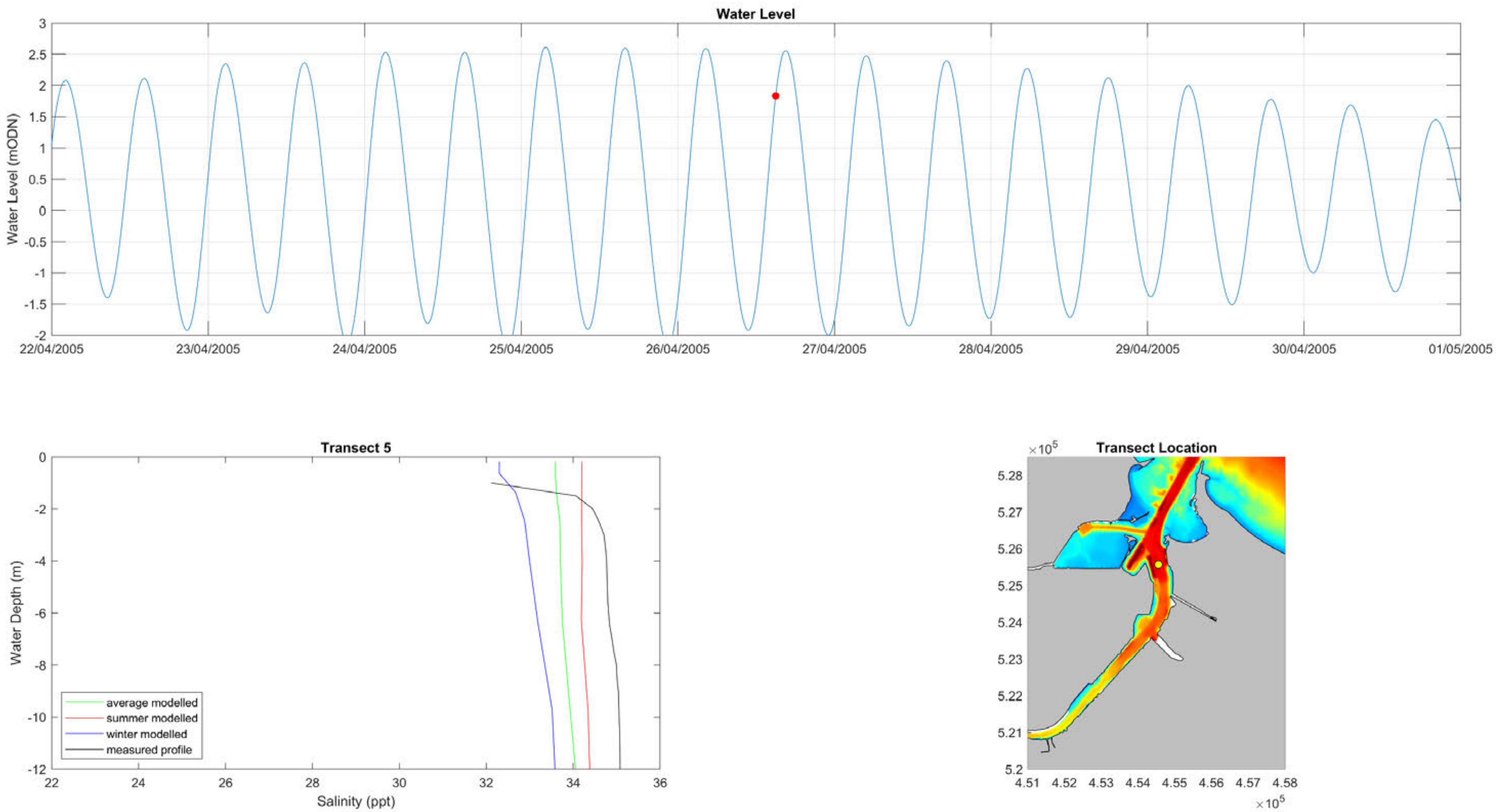


Figure 80. Comparison of measured and modelled salinity with depth: Transect 5, closest transect location to the cofferdam (red dot on top water level plot indicates point of the tide).

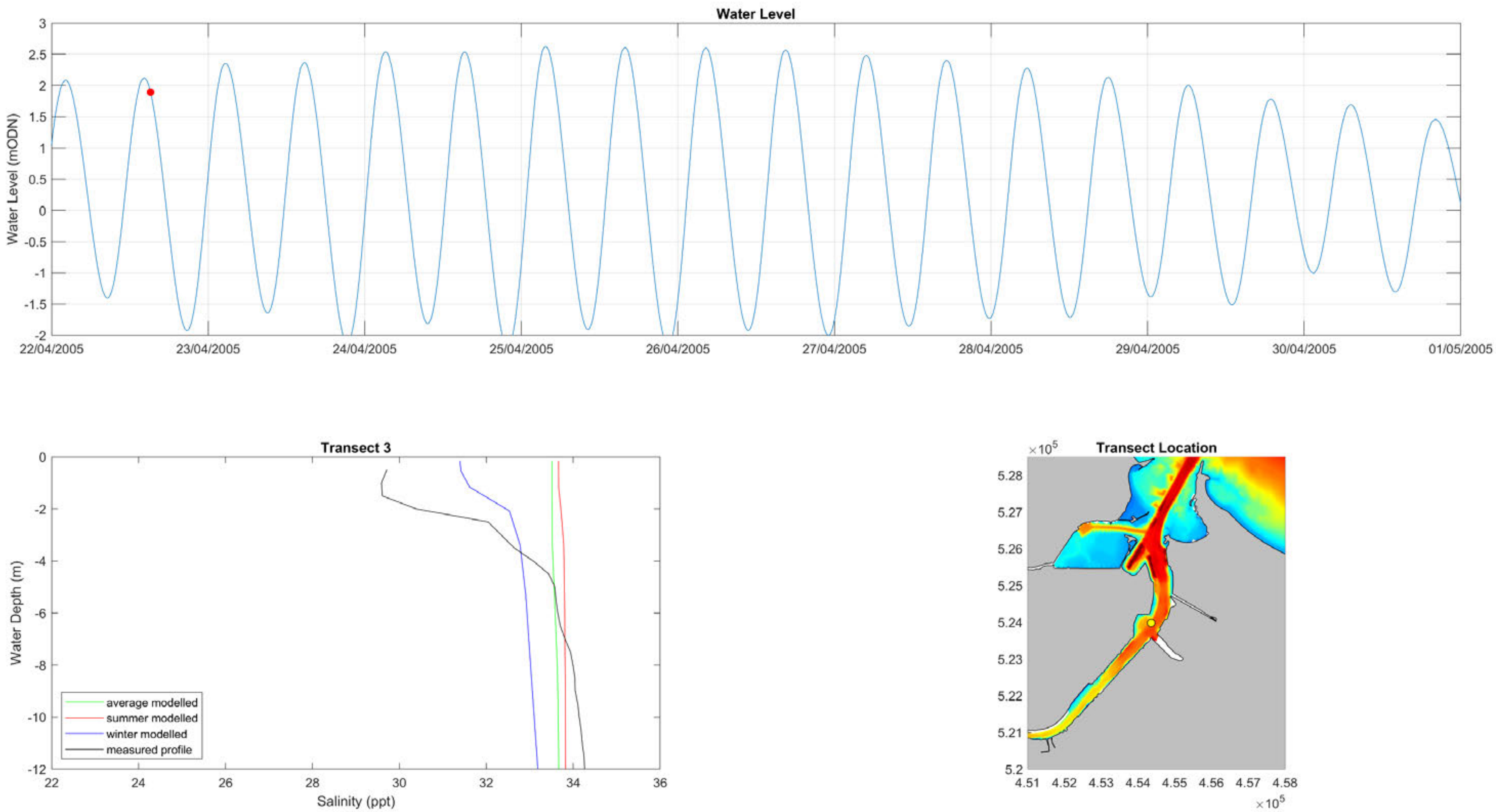


Figure 81. Comparison of measured and modelled salinity with depth: Transect 3 (red dot on top water level plot indicates point of the tide

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.

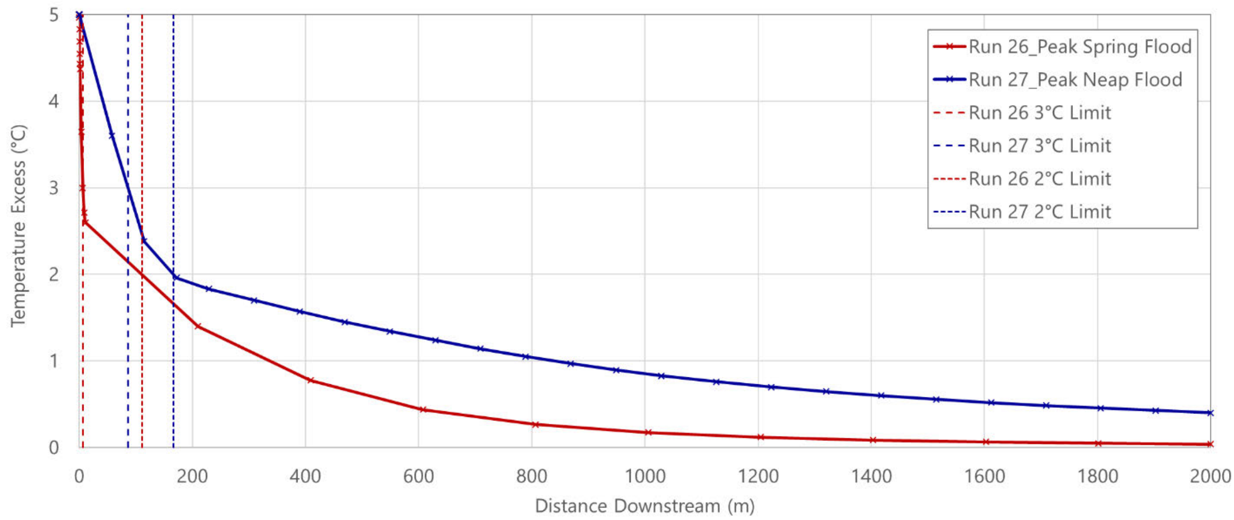


Figure 82. Spring and neap flood tide plume variations during extreme discharge events.

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.

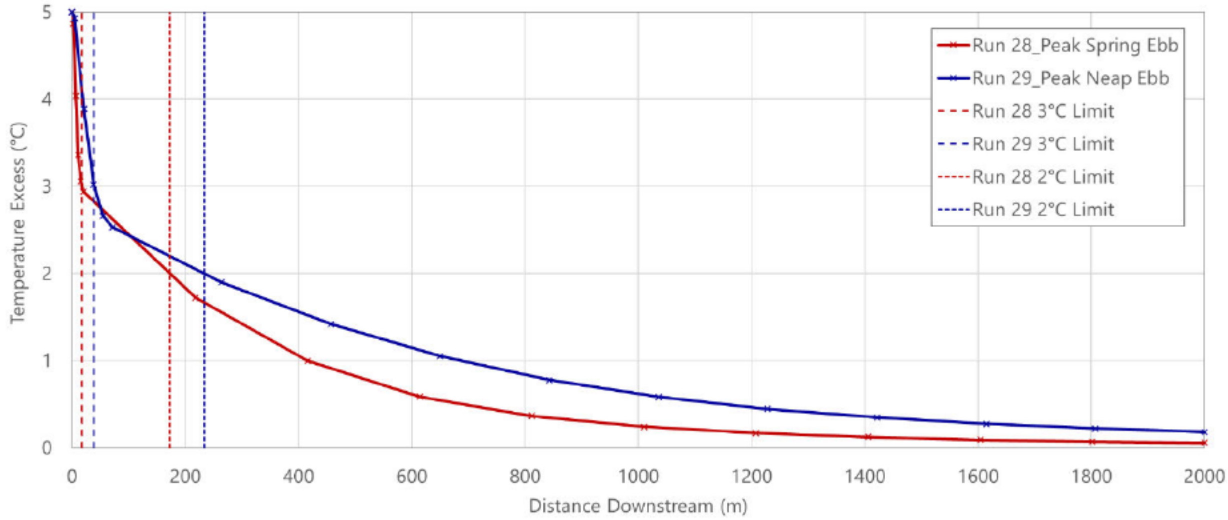


Figure 83. Spring and neap ebb tide plume variations during normal discharge events.

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

Figure 84. Excess temperature isolines during a neap tide under 1-in-30-year discharge conditions.

The same trend as in the normal discharge conditions is also mirrored by the 1-in-30-year extreme discharge event. Since the tidal characteristics remain the same it follows that the same tidal states that produce the larger plumes under normal discharge events also produce the largest plumes during extreme discharge events. This is highlighted by the neap flood (run 27), with the flood tide plumes dominating in extent over the ebb phase.

Although the CORMIX output portrays the plume (neap flood – run 27) to potentially make landfall (using the low-water background image as guidance in Figure 84), it is again to be noted that the CORMIX model assumes full plume development under the given conditions and that the ambient flows (defined as constant in the model) will not persist long enough for a fully developed plume to form. In reality, the flows will reduce either side of the modelled peak conditions and turn with the tidal phase, further dissipating the excess thermal plume before it can fully develop to the state portrayed by the CORMIX outputs. Therefore, the CORMIX model results are to be only used to provide an insight to the relative differences between fully developed plumes under the range of constant ambient conditions modelled and that the far-field plume modelling using the Delft software is to be used as a more detailed insight into the influence of the varying tidal states on the excess temperature discharges.

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Appendix B: Discharge Modelling – Option A

Net Zero Teesside - Water Quality Assessment

Intermediate Design Stage - Alternative Discharge Option

Net Zero Teesside

Project number: 60675797

October 2022

Quality information

Prepared by	Checked by	Verified by	Approved by
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Revision History

Revision	Revision date	Details	Authorized	Name	Position
Rev 1.0	05/10/2022	Option A Modelling			

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1. Introduction

1.1 Background

The Power Capture and Compression (PCC) site of the Net Zero Teesside (NZT) Proposed Development is located on part of the former Redcar Steel Works. 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. A CO_2 Gathering Network will also be constructed in the Teesside area which will facilitate decarbonisation of industry in the area.

During operation of the PCC site, it is proposed to discharge surface water run-off and slightly contaminated wastewater from on-site processes including condensed water from the Heat Recovery Steam Generator (HRSG) to Tees Bay via an outfall. Contaminated effluent will be pumped to Northumbrian Water Ltd.'s (NWL's) Bran Sands Waste Water Treatment Works (WwTW). The 'base case' assumption for the Proposed Development has been that the treated effluent from Bran Sands WwTW will be discharged through the existing NWL consented discharge to the Dabholm Gut which in turn discharges into the Tees Estuary.

In their Relevant Representations, the Environment Agency and Natural England have asked for an assessment of the potential impacts of the proposed discharges on water quality in the Tees Estuary and Tees Bay with specific focus on localised temperature impacts and wider impacts on nitrogen concentrations within Tees Bay and the 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.

The impacts of the discharge of surface water and slightly contaminated wastewater to Tees Bay were assessed in the Base Case Water Quality Assessment (Appendix A to the Nutrient Nitrogen Briefing Paper 9, DCO Document Ref. 5.36).

Natural England have expressed their concerns about the discharge of treated NZT effluent from Bran Sands WwTW to the Tees Estuary (via Dabholm Gut) due to the increased loading of nitrogen entering the waterbody. Following consultation with NWL, the Applicants have looked at an alternative discharge option involving returning treated effluent from NWL to the PCC site by pipeline. This effluent will contain an equivalent nitrogen loading to the effluent sent from NZT to Bran Sands WwTW for treatment. This document sets out an updated assessment to assess this alternative option.

Two alternative proposals were under consideration for the location of the Tees Bay outfall during the Initial Design Stage Assessment. The first option was to re-use the existing former steelworks outfall. The second was to construct a new outfall at a location south-east of the existing outfall, with the precise location and outfall pipeline/diffuser design still to be determined. As there are technical and commercial challenges to reusing the existing outfall this report only assesses the use of a newly constructed outfall to Tees Bay from the PCC site. If the challenges to re-using the existing outfall can be managed, the discharge from the existing outfall would also need to be modelled.

This assessment sets out details of the near and far field water quality modelling carried out on the basis of the information now available. This includes consideration of chemical constituents using data which were not available to inform the Initial Design Stage Assessment. The assessment aims to represent worst case thermal and nitrogen 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 post consent when a Final Design Stage Assessment is carried out. The purpose of this assessment is to establish the worst-case possible impacts on Tees Bay and the Tees Estuary using the discharge of returned effluent from Bran Sands via the alternative outfall option.

This 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. 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. The scope of each design stage assessment is summarised in Table 1-1.

Table 1-1: Design Stage Water Quality Assessment Scopes

Design Stage	Scope
Initial Assessment	Assesses thermal impacts of heated discharges on Tees Bay only Assesses mixing zone extents at the location of an existing discharge point and a potential future discharge point (outfall locations generally known but not precise) One single discharge rate from the site of 1.37 m^3/s (combination of all wastewater streams and surface water runoff) Assumes entire discharge is heated to 30°C (theoretical maximum based on general power station operations, separate heated and cold water stream components of final discharge not known) Focussed on developing 3D hydrodynamic model of Tees Bay, the River Tees and Tees Estuary to allow mixing and dispersion modelling Includes near and far field mixing zone modelling for thermal impacts Shows smaller mixing zones in the region of the existing discharge point and larger mixing zones in the region of the potential future discharge point
This Assessment	Presents sources and flows of wastewater streams for the current design philosophy for the site Calculates resulting chemistry and temperature of the combined wastewater discharge to Tees Bay Redefines thermal impacts on Tees Bay from Initial Assessment modelling given known future heated water flows Following comments from the Environment Agency and Natural England, models DIN mixing and dispersion in Tees Bay Provides initial calculations for impacts in terms of microcontaminant loads (dissolved metals, hydrocarbons and pesticides) with some assumptions to account for data availability Uses the 3D hydrodynamic model developed for the Initial Design Stage report to inform near field mixing zone modelling and carry out far field mixing zone modelling for the future discharge location which is more precisely defined
Final Assessment (to be undertaken post consent)	Confirm the final sources and flows of wastewater streams given finalised site design Recalculate the resulting chemistry and temperature of the combined wastewater discharge to Tees Bay using known chemistry and temperature data. Use the 3D hydrodynamic model developed for the Initial Design Stage report to check the extent of the thermal and chemical mixing zones for the final selected discharge location Update the model representation of the outfall to reflect the final design of the outfall, including multiport diffuser if required

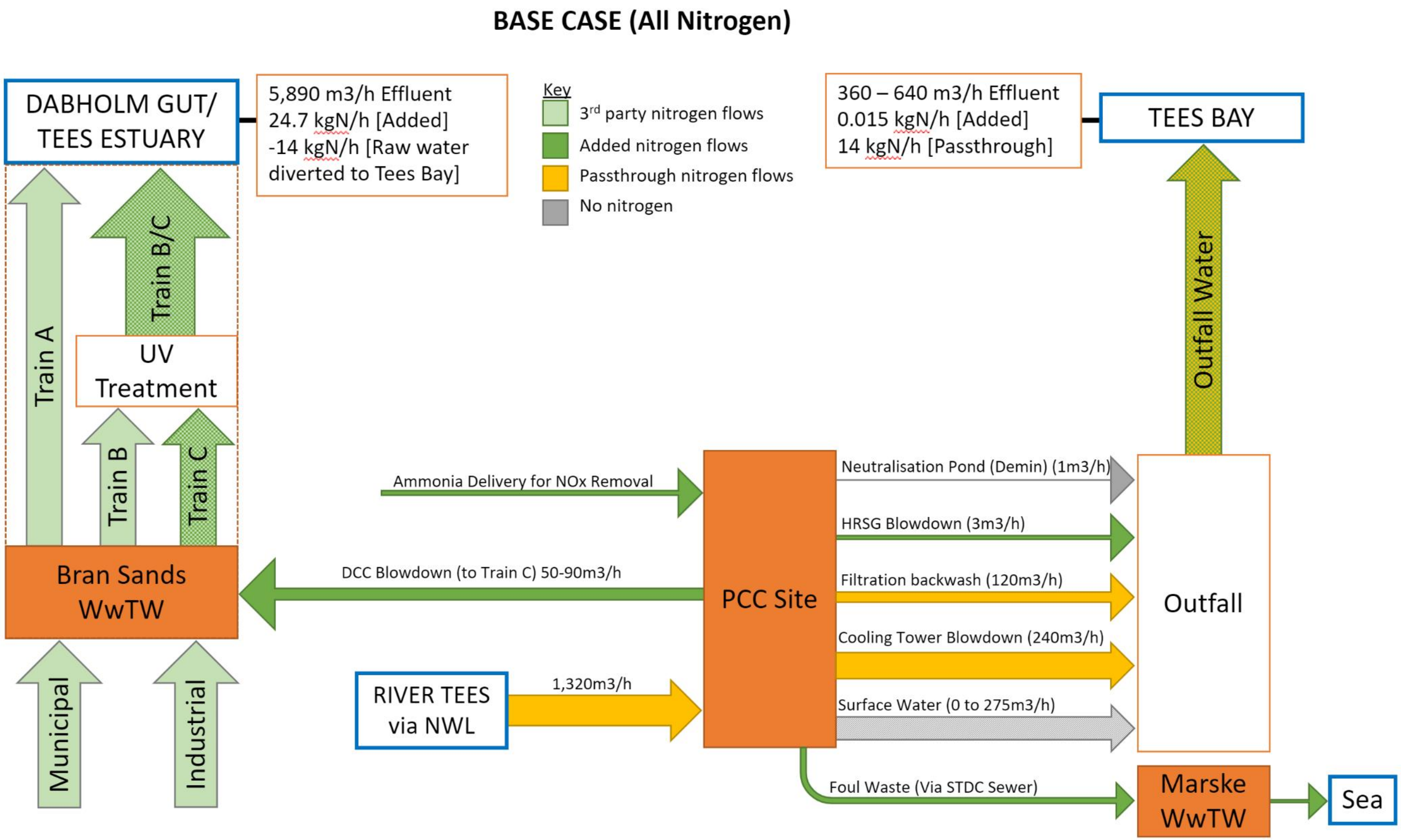
Design Stage	Scope
	Ensure that the impacts of the final design on Tees Bay water quality are acceptable and support application for discharge licencing

1.2 Development Proposals

At this stage the Proposed Development design remains under development, with FEED works ongoing. Based on the available information, for the alternative design option the effluent from the PCC site will consist of:

- **Cooling Tower Blowdown Water**: a supply of untreated raw water abstracted upstream of the tidal limit on the River Tees by Northumbrian Water Limited (NWL) will be supplied to the site via NWL's network. This supply will be used as cooling water in the power station, after which a portion of the used cooling water is discharged as blowdown. The blowdown will be discharged as effluent to Tees Bay.
- **Filter Reject Water**: prior to use in the cooling system, the untreated raw water from the River Tees will be filtered on site. An allowance of 10% water loss at this stage has been allowed for, with the rejected water directed to the Tees Bay outfall.
- **Process Water**: CO_2 compression and dehydration produces a small amount of water which will be diluted and neutralised prior to discharge.
- **Condensed Water**: A small amount of additional effluent will be generated on site as steam condensate ("Condensed Water") and will also be discharged to Tees Bay.
- **Return Flows**: Some wastewater produced on site within the Carbon Capture and Storage plant (Direct Contact Cooler (DCC) Blowdown) will contain significant concentrations of ammonia and will be routed to Bran Sands WwTW for treatment. Bran Sands WwTW discharges to Dabholm Gut; in order to preserve nutrient neutrality within the Gut (and the River Tees downstream) water will be returned to the NZT site from Bran Sands WwTW at an agreed rate ("Return Flows") for discharge to Tees Bay.
- **Surface Water Runoff**: surface water runoff from the NZT site will be collected and discharged to Tees Bay via on-site attenuation storage facilities. Where there is the potential for hydrocarbon contamination, surface water from the redeveloped site will be routed through oil interceptors.

The flow chart in Figure 1-1 summarises the different flows at the proposed NZT site in the base case and alternative design options. Water quality impacts in Tees Bay may occur from the Cooling Tower Blowdown Water and Condensed Water. Further, the origin of the Cooling Tower 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. These contaminants can be concentrated by up to five times by re-use within the cooling system. The Condensed Water flows are significantly smaller than the Cooling Tower Blowdown Water flows but this water may contain concentrations of ammonia up to 5 mg/l. The Return Flows from Bran Sands WwTW will also comprise treated wastewater and will have pollutant profiles typical of a large WwTW final treated effluent, including elevated nitrate concentrations. This may include dissolved organic nitrogen or particulate nitrogen but the return of this effluent from Bran Sands and discharge to Tees Bay will merely divert this effluent from the estuary (as at present) to the bay. Section 2 of this report sets out the flows and pollutant loads of the different streams and the final combined effluent discharged to Tees Bay.


BASE CASE (All Nitrogen)
DABHOLM GUT/ TEES ESTUARY
5,890 m3/h Effluent
24.7 kgN/h [Added]
-14 kgN/h [Raw water diverted to Tees Bay]
Key
3rd party nitrogen flows
Added nitrogen flows
Passthrough nitrogen flows
No nitrogen
360 – 640 m3/h Effluent
0.015 kgN/h [Added]
14 kgN/h [Passthrough]
TEES BAY
Train A
Train B/C
UV Treatment
Train B
Train C
Outfall Water
Ammonia Delivery for NOx Removal
Neutralisation Pond (Demin) (1m3/h)
HRSG Blowdown (3m3/h)
Filtration backwash (120m3/h)
Cooling Tower Blowdown (240m3/h)
Surface Water (0 to 275m3/h)
PCC Site
Outfall
Bran Sands WwTW
DCC Blowdown (to Train C) 50-90m3/h
RIVER TEES via NWL
1,320m3/h
Municipal
Industrial
Foul Waste (Via STDC Sewer)
Marske WwTW
Sea

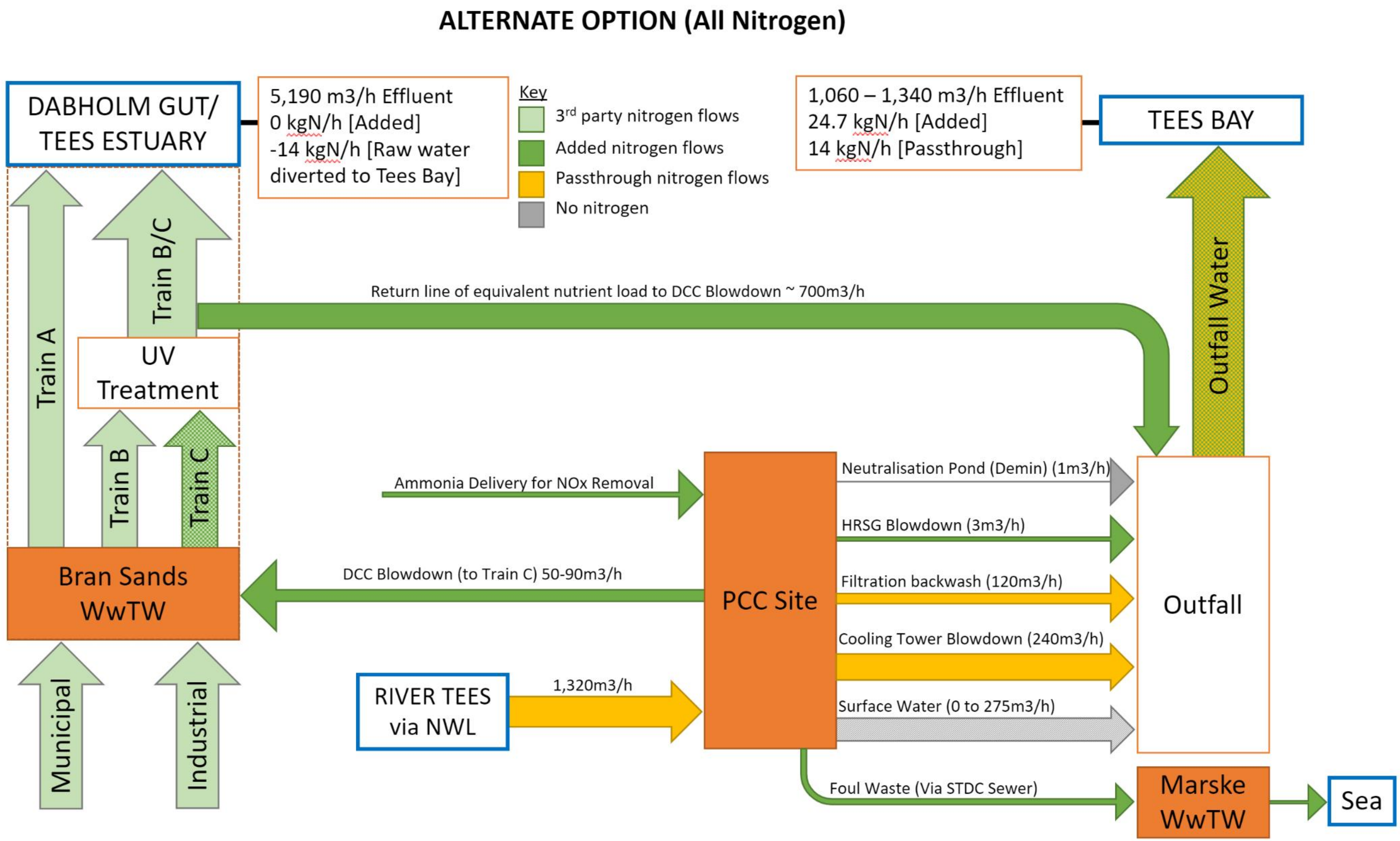


Figure 1-1: Proposed Wastewater Streams from NZT Site in Base Case and Alternate Option

The main purpose of the modelling in this report is to assess the water quality impacts of discharging to Tees Bay. However, Natural England have also requested consideration of nutrient neutrality in the Tees Estuary which forms part of the Teesside and Cleveland Coast Special Protection Area and Ramsar Site. Abstracting and discharging the Blowdown Water will slightly reduce the mass of nitrogen reaching the tidal Tees Estuary as the water (and dissolved nitrogen compounds) abstracted from the non-tidal Tees upstream will be diverted to Tees Bay and bypass the Estuary. This effective reduction in DIN in the Tees Estuary needs to be balanced by DIN that disperses back into the Estuary from the discharges of DIN to the Tees Bay. For further details of the Nutrient Nitrogen Assessment, please see the Nutrient Nitrogen Briefing Paper (Document Ref. 9.36) and the Habitat Regulations Assessment (Document Ref. 5.13).

This report assesses the impacts of discharges to Tees Bay based on discharges from the NZT site only. The site location is shown in Figure 1-2. The Environment Agency have confirmed that currently the NZT Proposed Development will be the only existing or potential permitted discharge to the Bay which has the potential to contribute nitrogen to this waterbody and therefore modelling of cumulative impacts with other discharges into Tees Bay or the Tees Estuary is not required.

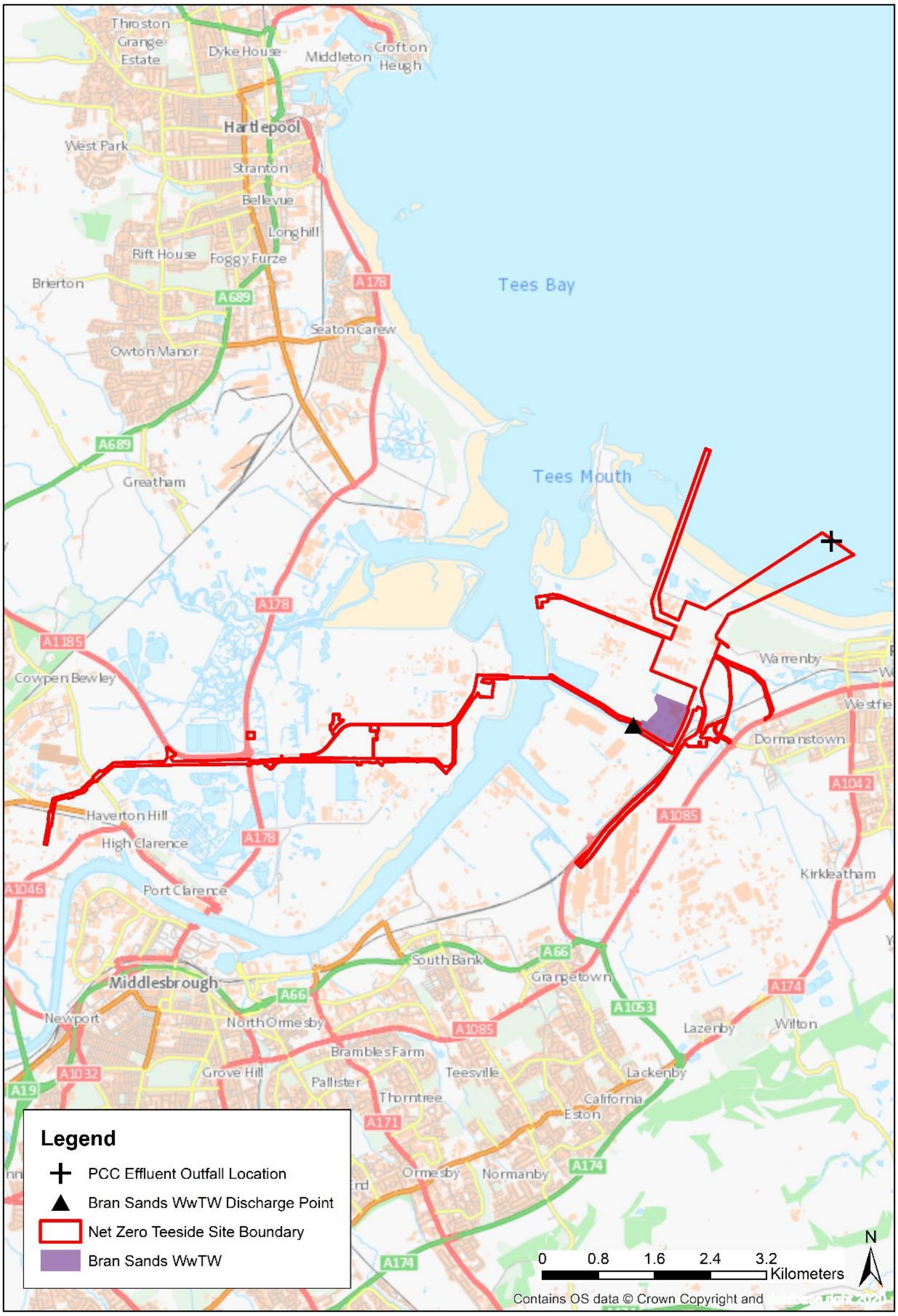


Figure 1-2: NZT Development Boundary and Potential Effluent Discharge Locations

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 have been 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 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 µg/l, 95%ile = 0.370 µg/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 mg/l
Zinc	Mean = 6.8 µg/l dissolved plus ambient (1.1 µg/l) = 7.9 µg/l
Pesticides	
Cypermethrin	Mean = 0.1 ng/l, 95%ile = 0.4 ng/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

In addition to these standards, nitrogen concentrations in coastal waters are limited with reference to Dissolved Inorganic Nitrogen (DIN). The applicable EQS values for DIN are selected for each coastal waterbodies based on its recorded salinity and suspended particulate matter concentration[1]. In this case, Environment Agency data show an average of 8 mg/l suspended solids and normal salinity of 30 ppt at Tees Mouth (see Section 3.6) and salinity of 32-35 ppt in Tees Bay. These values are consistent with clear water and coastal (i.e. not transitional) waters.

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

Table 2-2 sets out the WFD class boundaries for DIN concentrations for clear coastal waters. The boundaries are provided as µmol/l, which are citied in the WFD legislation, and as the equivalent concentration in mg/l based on guidance provided by the UK Technical Advisory Group[2] in their method statement document in which these standards are derived.

Table 2-2: WFD Class Boundary EQS Values for DIN

Unit Expression	WFD Class Boundary			
	High	Good	Moderate	Poor
Dissolved Inorganic Nitrogen (µmol/l)	12	18	27	40.5
Dissolved Inorganic Nitrogen (mg/l)	0.168	0.252	0.378	0.567

Nitrogen data available for this analysis are presented using varying units between different forms and sources of nitrogen. For consistency, the DIN standards expressed as mg/l N will be used in this report, with the appropriate conversions applied to the raw data where required.

The dissolved oxygen EQS in Table 2-1 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.

2.2 Effluent Pollutant Concentrations

2.2.1 Filtration Reject Water and Cooling Tower Blowdown Water Quality

The source of the Cooling Tower Blowdown Water is untreated River Tees water from one of 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. Additional water quality data have been sourced from the Environment Agency monitoring at Low Worsall. 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 2-3.

Table 2-3: Mean Pollutant Concentrations at River Tees Abstraction Points (2016-2022)[2]

Parameter	Broken Scar	Blackwell	Low Worsall
Temperature (°C)[3]	11.2	10.8	10.9
Dissolved Inorganic Nitrogen (mg/l)	0.81	0.83	2.49
Un-ionised Ammonia (µg/l)	0.12	0.51	1.34
Arsenic (µg/l)	No data	No data	0.54
Chlorine (µg/l)	No data	No data	No data
Cyanide (µg/l)	No data	No data	Not detected
Hydrocarbons			
Benzyl butyl phthalate (µg/l)	No data	No data	No data
2,4-dichorophenol (µg/l)	No data	No data	Not detected
3,4-dichloroaniline (µg/l)	No data	No data	No data
Phenol (µg/l)	No data	No data	No data
Toluene (µg/l)	No data	No data	Not detected

[redacted] page 40, accessed 23 August 2022

[3] Data provided by Northumbrian Water for Low Worsall abstraction

Parameter	Broken Scar	Blackwell	Low Worsall
Triclosan (µg/l)	No data	No data	Not detected
Metals			
Chromium (VI) (µg/l)	Mean = 0.48, 95%ile = 1.40	No data	Mean = 0.73, 95%ile = 1.85
Copper (µg/l)	No data	1.0	1.6
Iron (mg/l)	0.6	0.5	0.6
Zinc (µg/l)	No data	No data	17.6
Pesticides			
Cypermethrin (ng/l)	Not detected	No data	Mean = 0.03, 95%ile = 0.1
Diazinon (µg/l)	Mean = 0.003, 95%ile = 0.005	No data	Mean = 0.001, 95%ile = 0.002
2,4-D (µg/l)	Mean = 0.002, 95%ile = 0.006	No data	Mean = 0.035, 95%ile = 0.070
Dimethoate (µg/l)	No data	No data	Not detected
Glyphosate (µg/l)	Mean = 0.012, 95%ile = 0.042	No data	Mean = 0.094, 95%ile = 0.260
Linuron (µg/l)	No data	No data	Not detected
Mecoprop (µg/l)	Mean = 0.002 95%ile = 0.007	No data	Mean = 0.062, 95%ile = 0.269
Permethrin (µg/l)	No data	No data	Not detected

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, including in response to development of the PCC site. It is therefore assumed that the PCC site will receive the majority of its raw water supply from Low Worsall. Based on the current site design information (see Figure 1-1), the raw water from the River Tees will be filtered, with approximately 10% directed straight to the Tees Bay as Filter Reject Water. The remaining 90% will be used in the cooling towers where potential contaminant will be concentrated by up to five times as the raw water is condensed and recycled as Cooling Tower Blowdown Water.

The pollutant loads in the Filter Reject Water and Cooling Tower Blowdown Water have been calculated in this report based on the assumption that all raw 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. The Low Worsall data show that the raw water will not contain significant quantities of cyanide, 2,4-dichlorophenol, toluene, triclosan, dimethoate, linuron or permethrin. There are no data for chlorine, benzyl butyl phthalate, 3,4-dichloroaniline or phenol. The impact of mixing and concentration on final effluent quality is discussed in Section 2.2.6.

The abstraction of water and dissolved pollutants, including dissolved nitrogen, from the non-tidal River Tees, and subsequent discharge to Tees Bay, will effectively reduce the overall annual pollutant mass reaching the Tees Estuary. There will be no overall change in total annual pollutant mass reaching Tees Bay through the Filter Reject Water or Cooling Tower Blowdown Water creation process because the ultimate source of pollutants in these effluent streams is the River Tees – use of this water changes the pathway of pollutants reaching Tees Bay but does not represent a new source of pollutants.

2.2.2 Direct Contact Cooler Water and Return Flows

The carbon capture and storage facility proposed at the NZT site will generate Direct Contact Cooler Water which will contain high concentrations of ammonia. This water will be sent to Bran Sands WwTW. In order to maintain nutrient neutrality in the Dabholm Gut and Estuary, it is proposed to return an appropriate volume of treated effluent from Bran Sands to the NZT site. The volume of Return Flow treated effluent required to offset the additional supply of dissolved nitrogen to Dabholm Gut is calculated below.

STEP 1: DIRECT CONTACT COOLER WATER N MASS	
Flow rate to Bran Sands WwTW	50-90 m^3/hr *(assume 90 m^3/hr as worst case scenario)*
Ammonia load to Bran Sands WwTW	10-30 kg/hr *(assume 30 kg/hr as worst case scenario)*
N load as ammonia to Bran Sands WwTW	$\frac{30}{1.1259} = \mathbf{24.67\ kg/hr}$
STEP 2: DIRECT CONTACT COOLER WATER TREATMENT AT BRAN SANDS WWTW	
At Bran Sands, an average of 97% of ammonia is converted to nitrate with 3% remaining as ammonia	
Treated Water N load as nitrate	$24.67 \times 97\% = 23.90\ kg\ N/hr$
Treated Water N load as ammonia	$24.67 \times 3\% = 0.74\ kg\ N/hr$
STEP 3: TREATED WATER IS MIXED WITH BRAN SANDS TREATED EFFLUENT	
Average existing Bran Sands Effluent discharge rate	5774 m^3/hr
Current (2015 onwards) Dissolved Inorganic Nitrogen concentration breakdown in Bran Sands treated effluent (based on Environment Agency regulatory monitoring data)	Average N as ammonia = 5.53 mg/l Average N as nitrate = 24.58 mg/l Average N as nitrite = 0.99 mg/l Total Current N load = 31.10 mg N/l
Current Dissolved Inorganic Nitrogen load breakdown in Bran Sands treated effluent	Average N load as ammonia = 31.95 kg/hr Average N load as nitrate = 141.1 kg/hr Average N load as nitrite = 5.69 kg/hr
Dissolved Inorganic Nitrogen Load Breakdown in Bran Sands Treated Effluent, including additional load from NZT	Average N as ammonia = 32.69 kg/hr Average N as nitrate = 165.06 kg/hr Average N as nitrite = 0.99 kg/hr
Predicted Dissolved Inorganic Nitrogen concentration breakdown, including additional flows from NZT Total flow rate = 5774+ 90 = 5864 m^3/hr	Average N as ammonia = 5.57 mg/l Average N as nitrate = 28.15 mg/l Average N as nitrite = 0.97 mg/l Total N, including NZT contribution = 34.69 mg N/l
STEP 4: NUTRIENT NEUTRALITY CALCULATION	
Required nitrogen mass to be returned to NZT	24.67 kg N/hr
N concentration in return flow	34.69 mg N/l (3.469 x10^{-5} kg N/l)
Return flow rate required	$\frac{24.67}{3.469 \times 10^{-5}} = 7.11 \times 10^5 l/hr = \mathbf{711 m^3/hr}$

The above calculation shows that a return flow rate of 711 m^3/hr from Bran Sands will be required to preserve nutrient neutrality in the Dabholm Gut and River Tees estuary. A return flow rate of 750 m^3/s will be assumed at this stage in the design to allow for future refinement of the NZT site operations.

The current concentrations of pollutants in Bran Sands effluent is set out in Table 2-4. Un-ionised Ammonia concentrations have been calculated from observed ammonia concentrations from 2015 onwards using the formula in Equation 2-1.

Equation 2-1: Approximation for Calculating Un-ionised Ammonia Fraction from Total Ammonia[4]

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

[4] [redacted] accessed 10 May 2022

Table 2-4: Mean Pollutant Concentrations in Bran Sands Effluent

Parameter	Current
Temperature (°C)	16.3
Dissolved Inorganic Nitrogen (µg/l)	2,478 (including contribution from NZT)
Un-ionised Ammonia (µg/l)	28
Arsenic (µg/l)	4.51
Chlorine (µg/l)	Not detected
Cyanide (µg/l)	No data
Hydrocarbons	
Benzyl butyl phthalate (µg/l)	No data
2,4-dichorophenol (µg/l)	No data
3,4-dichloroaniline (µg/l)	No data
Phenol (µg/l)	No data
Toluene (µg/l)	Mean = 0.003, 95%ile = 0.015
Triclosan (µg/l)	No data
Metals	
Chromium (VI) (µg/l)	Mean = 7.81, 95%ile = 21.5
Copper (µg/l)	12.9
Iron (mg/l)	0.34
Zinc (µg/l)	54.0
Pesticides	
Cypermethrin (µg/l)	No data
Diazinon (µg/l)	No data
2,4-D (µg/l)	No data
Dimethoate (µg/l)	No data
Glyphosate (µg/l)	No data
Linuron (µg/l)	No data
Mecoprop (µg/l)	No data
Permethrin (µg/l)	No data

2.2.3 Condensed Water Quality

The Cooling Tower Blowdown Water and Return Flows will make up the majority of the effluent produced by the PCC site. However, as noted previously a small additional flow of Condensed Water from the HRSG 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, 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 2.2.5.

2.2.4 Process Water and Surface Water Runoff

Process water from CO_2 compression and dehydration is a very small contribution to effluent discharges from the PCC site. This water is not expected to contain pollutants limited through EQS standards for coastal waters.

Surface water runoff is also not expected to be a significant source of contaminants or nitrogen 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, plus testing of any surface water prior to discharge, in accordance with Environmental Permitting requirements. 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 2.2.5).

2.2.5 Final Mixed Effluent Discharge Scenarios

As discussed in Section 1.2, the final effluent discharged to Tees Bay will comprise a mixture of concentrated Cooling Tower Blowdown Water, Filter Reject Water, Return Flows, Process Water and Condensed Water, with or without surface water addition. The pollutant flows, effluent loads and temperatures in scenarios which include or exclude the addition of surface water are set out in Table 2-5. Worst case scenario conditions are assumed where required, e.g. it is assumed that all Filter Reject Water and Cooling Tower Blowdown Water are sourced from Low Worsall as this is the worst case for DIN. When considering the impact of surface water runoff, the runoff volume has been estimated by allowing for 9 mm rainfall depth[5] (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.

Effluent quality has been calculated using the quality data summarised in Tables 2-3 and 2-4 for Filter Water, Cooling Tower Blowdown Water and Return Flows. Note that data are not available for pesticide concentrations and concentrations of most hydrocarbons in the Return Flows. An allowance has been made for some contribution of Return Flows to pollutant loads for these substances by assuming that concentrations in the final treated effluent from Bran Sands WwTW is similar to those in the non-tidal River Tees at Low Worsall. Condensed Water is assumed to contain only ammonia as a pollutant, while surface water runoff and Process Water are not expected to significantly contribute to the concentrations of pollutants.

For each scenario, each chemical substance present in the effluent at concentrations greater than the EQS in Table 2-1 is highlighted in yellow. The combined effluent is not expected to contain concentrations of any restricted hydrocarbon above the EQS and does not contain chlorine, cyanide, 2,4-dichorophenol or triclosan. The effluent may contain traces of arsenic and iron originating from the non-Tidal River Tees and Bran Sands WwTW, however average concentrations are not expected to exceed the EQS and there will be no net change in the pollutant load reaching Tees Bay because these pollutants currently reach the Bay via the River Tees or Bran Sands discharge currently. Mixed effluent concentrations of DIN, unionised ammonia chromium (VI), copper and zinc are expected to exceed the EQS. There are no data available for benzyl butyl phthalate, 3,4-dichloroaniline or phenol.

The temperature of the discharged effluent will depend on the final development design because the current site designs include balancing ponds where Cooling Tower Blowdown Water, Condensed Water and surface water run-off will be mixed prior to discharge, giving opportunity for cooling. Significant additional cooling will occur through addition of the Filter Reject Water and Return Flows, which are not heated and make up the majority if the discharged effluent in the absence of surface water runoff. The current site design is expected to result in a worst-case summer scenario discharged effluent temperature of approximately 19°C, reducing to 15°C when the effects of runoff are included.

The current design for the site includes pumping of the combined effluent streams to the Tees Bay outfall. This means that the rate of discharge will be limited by the pump capacity. The current site

[5] Rainfall depth information taken from Flood Estimation Handbook 2013 model, accessed at [redacted] on 10 May 2022

design shown in Figure 1-1 shows a final pumped discharge rate of 341 m^3/hr, or 0.094 m^3/s, however this does not account for Return Flows or surface water runoff addition. The Return Flows are continuous and will increase discharge rates by 750 m^3/hr to 0.30 m^3/s. The further addition of surface water runoff will require an increase in pumping rate – a rate of 0.4 m^3/s (30% increase) has been allowed for in the modelling to represent this.

The discharge has been modelled to represent two options:

- Continuous discharge – the flow rate is taken as 0.3 m^3/s or 0.4 m^3/s with surface runoff and is discharged at all stages of the tidal cycle.
- Intermittent discharge – effluent is discharged only during high tide conditions when the current direction carries effluent away from the River Tees estuary. This is in order to provide additional protection to sensitive environmental receptors within the Tees Bay and Tees Estuary the 3D hydrodynamic model described in Section 3 has been used to identify pumping times. The model shows that effluent can be pumped for 50% of the tidal cycle, therefore pumping rates of 0.6 m^3/s and 0.8 m^3/s are assumed.

Table 2-5: Flows and Pollutant Loads for Modelled Discharge Scenarios

Parameter	Without Surface Water Runoff	Surface Water Runoff Included	EQS
Temperature (°C)	19	15	3°C above ambient
Dissolved Inorganic Nitrogen (mg/l)[1]	26.34	12.21	0.567
Un-ionised Ammonia (µg/l)	36	16	21
Arsenic (µg/l)	3.68	1.73	25
Chlorine (µg/l)	None	None	95%ile = 10 µg/l
Cyanide (µg/l)	None	None	Mean = 1 µg/l, 95%ile = 5 µg/l
Hydrocarbons			
Benzyl butyl phthalate (µg/l)	No Data	No Data	Mean = 0.75 µg/l 95%ile = 10 µg/l
2,4-dichorophenol (µg/l)	None	None	Mean = 0.42 µg/l, 95%ile = 6 µg/l
3,4-dichloroaniline (µg/l)	No Data	No Data	Mean = 0.2 µg/l, 95%ile = 5.4 µg/l
Phenol (µg/l)	No Data	No Data	Mean = 7.7 µg/l, 95%ile = 46 µg/l
Toluene (µg/l)	0.002	0.001	Mean = 0.074 µg/l, 95%ile = 0.370 µg/l
Triclosan (µg/l)	None	None	Mean = 0.1 µg/l, 95%ile = 0.28 µg/l
Metals			
Chromium (VI) (µg/l)	6.13	2.86	Mean = 0.6 µg/l, 95%ile = 32 µg/l
Copper (µg/l)[2]	10.6	4.98	Mean = 3.76 µg/l dissolved
Iron (mg/l)[2]	0.94	0.50	Mean = 1 mg/l
Zinc (µg/l)	57.2	28.1	Mean = 6.8 µg/l dissolved plus ambient (1.1 µg/l) = 7.9 µg/l
Pesticides			
Cypermethrin (ng/l)	0.14	0.07	Mean = 0.1 ng/l, 95%ile = 0.4 ng/l
Diazinon (µg/l)	0.005	0.002	Mean = 0.01 µg/l, 95%ile = 0.26 µg/l
2,4-D (µg/l)	0.19	0.08	Mean = 0.3 µg/l, 95%ile = 1.3 µg/l
Dimethoate (µg/l)	None	None	Mean = 0.48 µg/l, 95%ile = 4 µg/l
Glyphosate (µg/l)	0.43	0.21	Mean = 196 µg/l, 95%ile = 398 µg/l
Linuron (µg/l)	None	None	Mean = 0.5 µg/l, 95%ile = 0.9 µg/l
Mecoprop (µg/l)	0.28	0.14	Mean = 18 µg/l, 95%ile = 187 µg/l
Permethrin (µg/l)	None	None	Mean = 0.2 ng/l, 95%ile = 1 ng/l

[1] Represents worst case scenario operating conditions when condensate collected on site is being discharged to Tees Bay. Discharge of condensate occurs for 1 hour per month.

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.

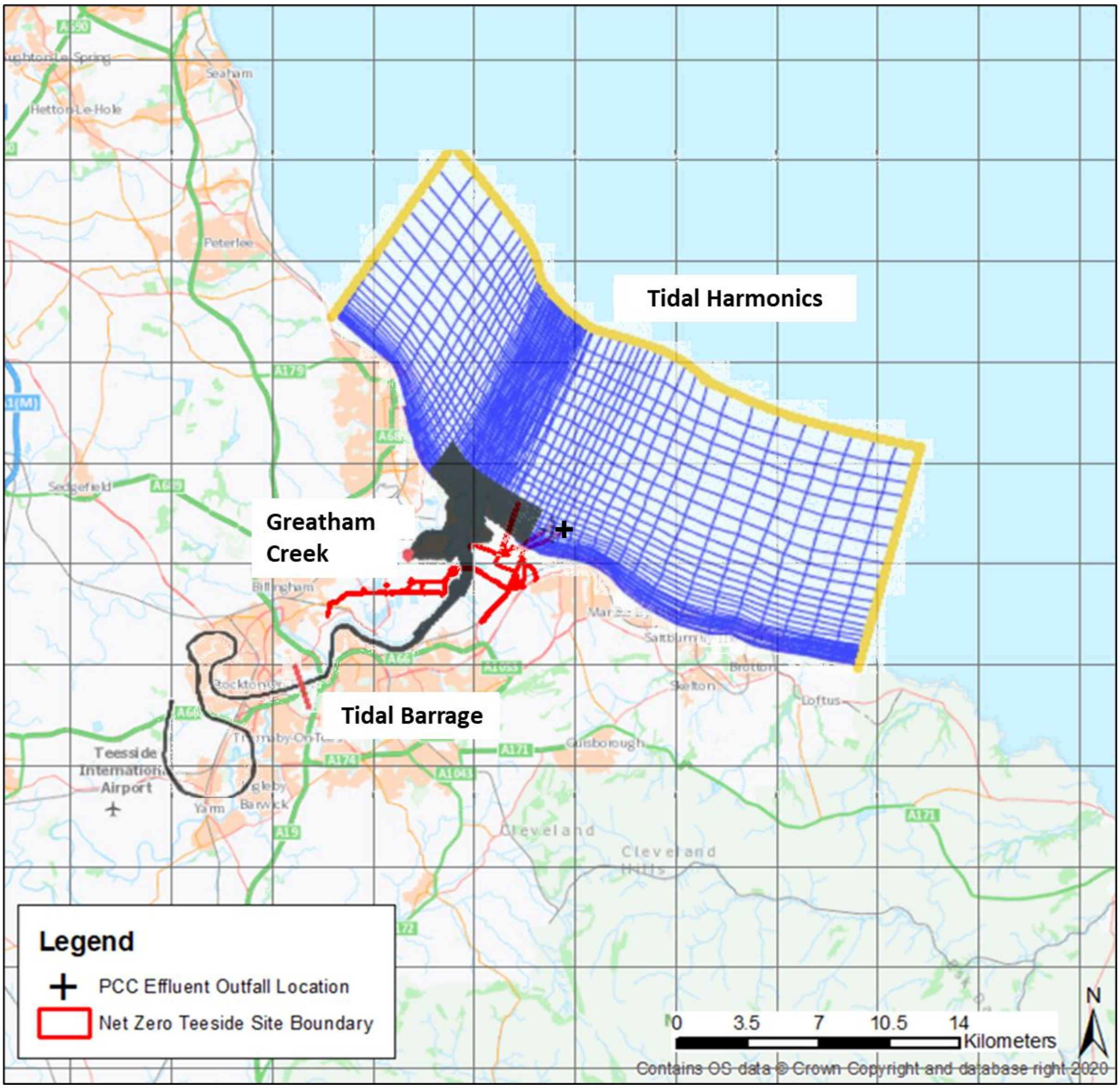


Figure 3-1: Delft3D hydrodynamic model extent

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 coarser grid for the offshore region (blue grid lines in Figure 3-1). The model uses a vertical layering with eight layers using a sigma value setup such that the layers compress or stretch with changes in the vertical water depth while retaining a given percentage of the total water depth in each layer. The vertical layering structure is as follows:

Table 3-1: Vertical Layering Details for the River Tees and Tees Bay Hydrodynamic Model

Layer	Layer Percentage	Percentage of Water Column Depth
1	5%	95%-100%
2	5%	90-95%
3	7%	82-90%
4	10%	72-82%
5	15%	58-72%
6	23%	35-58%
7	25%	10-35%
8	10%	Bed to 10%

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 (an infinitely thin barrier which prevents flow passing between two model cells without affecting the total volume of the channel) to prevent 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 Location

Effluent from the PCC site is modelled as being discharged via a newly constructed outfall. The current proposed location of the new outfall is at OS NGR 458983N 526734E. This location has been selected to allow construction of the new outfall within the deepest water present within the proposed DCO boundary (Figure 1-2).

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 proposed outfall location is shown in Figure 3-2, where zero chainage is at the high tide shoreline (mean high water). The proposed outfall location is at approximately 1130 m chainage and at -9.4 mAOD.

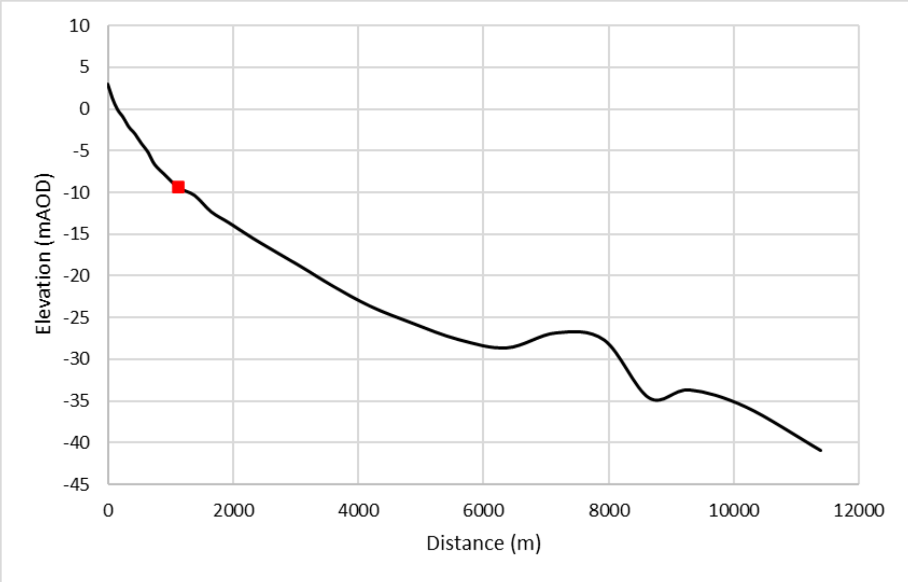


Figure 3-2: Bed Profile Extending Offshore at W3 Outfall Location

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 proposed new outfall and are shown in Figures 3-3 to 3-5.

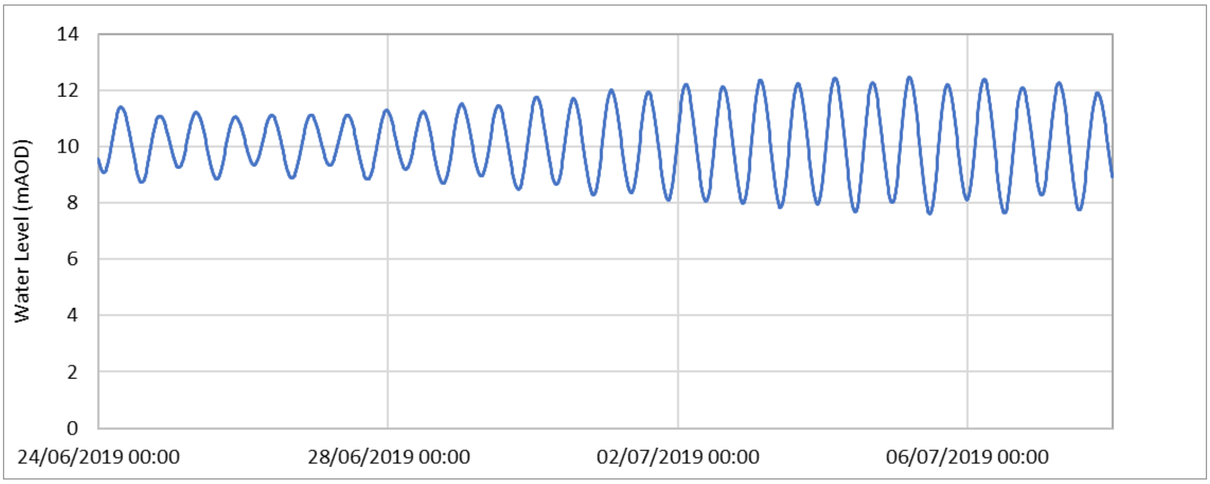


Figure 3-3: Water Levels at Proposed New Outfall Location

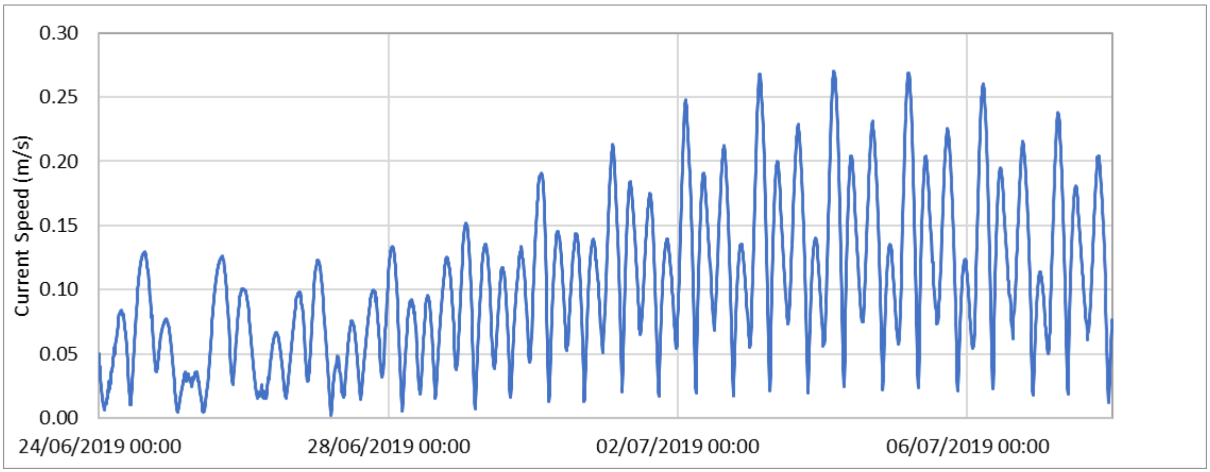


Figure 3-4: Depth Averaged Current Speeds at the Proposed New Outfall Location

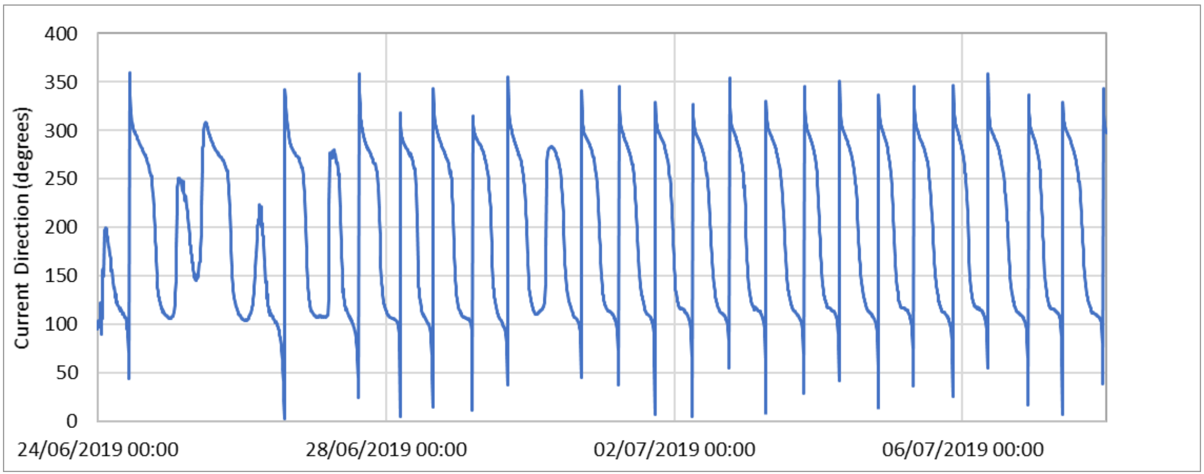


Figure 3-5: Current Directions at the Proposed New Outfall Location

Based on the above data, the values for water level, current speed and current direction, as listed in Table 3-2, have been used in the CORMIX modelling of the proposed new outfall. Note that the minimum current condition corresponds to the 99th percentile condition rather than the absolute modelled minimum current. This condition was used in place of a minimum current condition due to CORMIX results becoming unreliable during extreme low current conditions.

Table 3-2: Water Level and Current Conditions at Proposed New Outfall Location

Tidal Stage	Water Level (mAOD)	Current Speed (m/s)	Current Direction (°)
Minimum Tide Level	-2.23 (7.6 mAOD)	0.163	278
Maximum Tide Level	2.61 (12.5 mAOD)	0.264	116
Maximum Current Condition	2.54 (12.4 mAOD)	0.271	117
Minimum Current Condition	-0.41 (9.4 mAOD)	0.010	73

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.

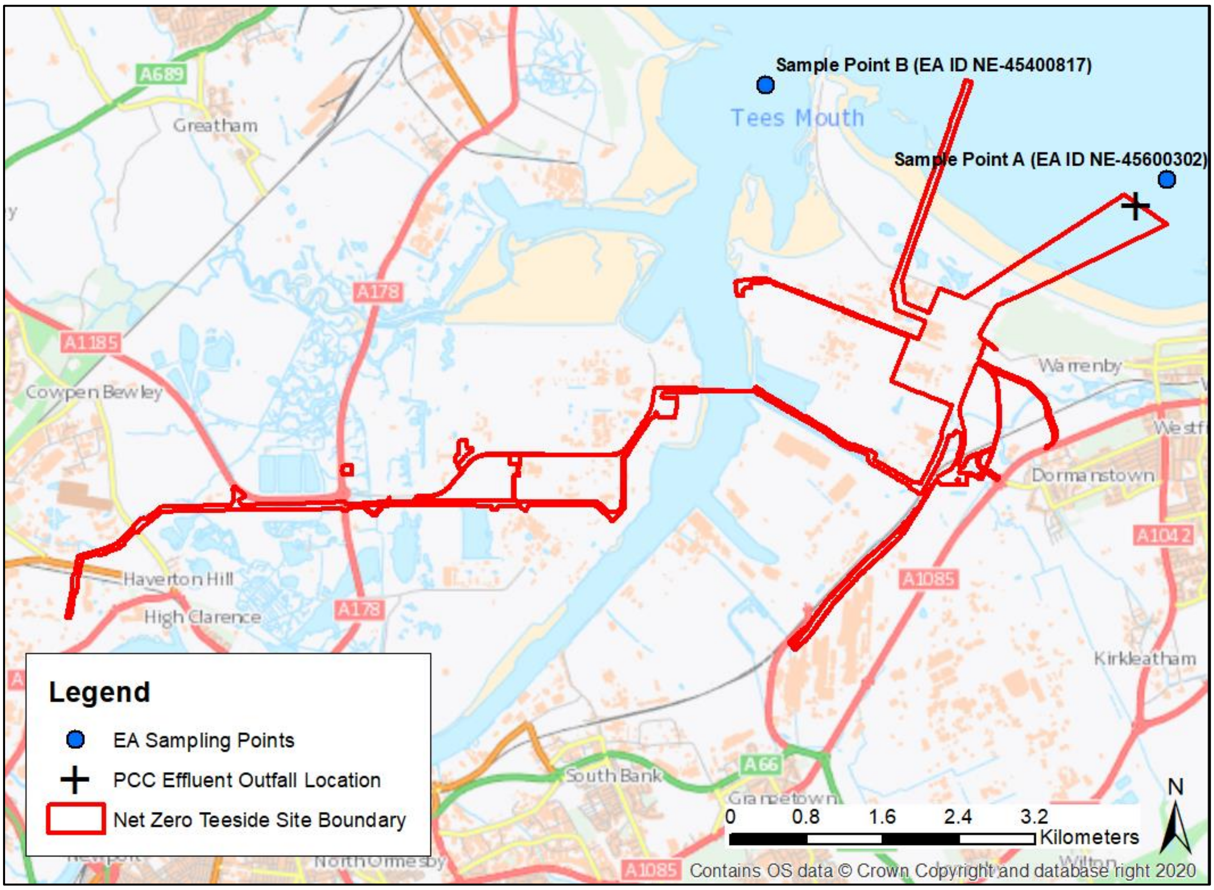


Figure 3-6: Environment Agency Ambient Water Quality Monitoring Locations

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, however this sample point mainly records concentrations of metals, hydrocarbons and particulates, with physical parameters such as temperature and salinity. Parameters such as DIN are monitored at Sample Point B which has a longer record, from 2007 onwards, and is considered to be the best available data for water quality in Tees Bay. The location of Sample Point B does mean that water quality at this location may be more influenced by flows from the River Tees and use of the Sample Point B data will therefore allow for the effects of discharges into the River Tees to be taken into account in the modelling. Sample point B gives an average suspended solids concentration of 8.5 mg/l.

Table 3-2 sets out ambient water quality values used in the near field CORMIX modelling and the sample point(s) used to provide the data. DIN concentrations are calculated in accordance with the WFD standards – winter (1 November to 28 February) DIN concentrations at Sample Point B have been plotted against the corresponding salinity at Sample Point A. A linear line of best fit is plotted through the data and the equation of this line is solved for DIN at a salinity of 32 ppt. This gives an ambient winter DIN concentration at this salinity value of 0.50 mg/l, which is between the moderate and poor class thresholds of 0.378 mg/l and 0.567 mg/l in Table 2-2. The current classification of Tees Bay would be poor with respect to DIN and exceeding the threshold of 0.567 mg/l would result in a class deterioration to bad water quality.

Calculated average ambient chromium (VI) concentrations are above the mean EQS value, however of 14 samples taken at Sample Point B between 2008 and 2022, only 5 contained measurable chromium VI and a further 14 contained concentrations below a limit of detection of 30 µg/l. The minimum recorded chromium (VI) concentration recorded at Sample Point B was 1.58 µg/l which still exceeds the EQS value for mean chromium (VI) concentrations. Given these high ambient concentrations, the effluent from the NZT site will not be diluted to below the EQS. The extent of any mixing zone for chromium (VI) will therefore be taken as the distance over which there is no longer a measurable increase in ambient concentrations. For the purposes of this analysis, this is taken as 0.1 µg/l above ambient concentrations, or 2.6 µg/l.

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

Table 3-3: Ambient Pollutant Concentrations in Tees Bay

Substance	Ambient Concentration	EQS	Sample Point
DIN[1]	0.500 mg N/l	0.567 mgN/l	A & B
Un-ionised Ammonia	3.9 µg/l	21 µg/l	A & B
Chromium (VI)	Mean =2.5 µg/l[2] 95%ile = 3.32 µg/l	Mean = 0.6 µg/l 95%ile = 32 µg/l	B
Copper	0.81 µg/l[3]	3.76 µg/l	B
Zinc	2.83 µg/l[3]	7.90	B

[1]EQS value based on average suspended solids concentration of 8.5 mg/l recorded at Sample Point B and average salinity of 32 PSU at Sample Point A. This is the WFD class boundary for Poor water quality.
[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 and zinc quoted as per UK water quality standards

4. Near Field Mixing Zone Modelling

4.1 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 the proposed new outfall. 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. 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, unionised ammonia, copper, chromium (VI) and zinc.

The CORMIX modelling shows that the EQS concentration for DIN is not exceeded 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. The mixing zones for DIN will therefore 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.

4.2.1 Outfall Representation

The design of the new outfall for the PCC will be finalised at a later point in the design process, however an initial design has been carried out[6] to inform costings for options assessments. The initial design consists of a multiport diffuser with a total length of 10 m and a main pipe diameter of 500 mm. The diffuser has three pairs of 500 mm diameter parallel ports orientated at 45° to the horizontal and will be orientated approximately east-west to be at close to 90° to the prevailing current direction given the fully reversing current directions shown in Section 3.3. The initial diffuser design is shown in Figure 4-1.

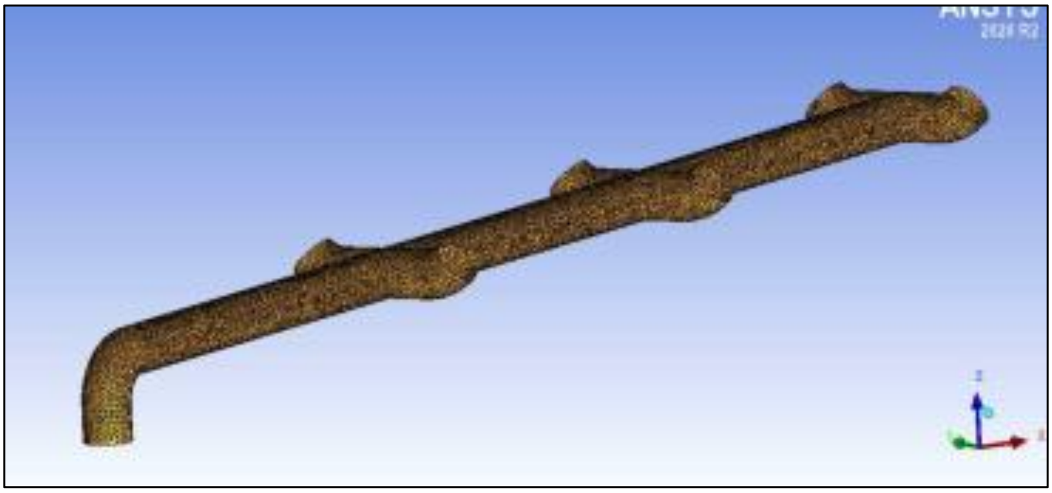


Figure 4-1: Initial Diffuser Design Illustration

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.

[6] PCC Outfall Study (Net Zero Teesside (NZT) / Northern Endurance Partnership (NEP) Carbon Capture & Storage Project) carried out by Wood on behalf of bp Exploration Operating Company Ltd, 19 August 2022

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 4-1.

Table 4-1: 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 5.32 m/s in winter and 4.08 m/s in summer.

4.3 Presentation of Results

The CORMIX results are presented in terms of the distance from the outfall over which the temperature in the mixing zone falls to less than 3°C above ambient temperatures and when contaminant concentrations are diluted to below the EQS. Mixing zone plumes in CORMIX are modelled over different stages; the stages relevant for this outfall are an initial period of mixing as effluent rises vertically and is deflected laterally by momentum and ambient currents (the rising stage) and the later period of mixing when the plume reaches the water surface and spreads laterally (the surface spreading stage). Dilution occurs during the rising stage due to turbulent mixing and entrainment of ambient water, while dilution during the surface spreading stage is more dominated by diffusion of the plume into the large ambient water volume.

Current velocities at the proposed outfall location are relatively low, however they vary by a factor of more than 20. In addition, the ports on the diffuser in Figure 4-1 are relatively close in terms of spacing and relatively large in terms of diameter and flow rate. This means that the software models the mixing zone plumes in different ways depending on the current conditions specified:

- For minimum current conditions (0.01 m/s), the model combines the mixing zone from each pair of ports and resolve the dimensions of the resulting three individual plumes (Figure 4-2). However, the model cannot solve the equations for the surface spreading stage unless a slightly higher current speed of 0.013 m/s is specified.

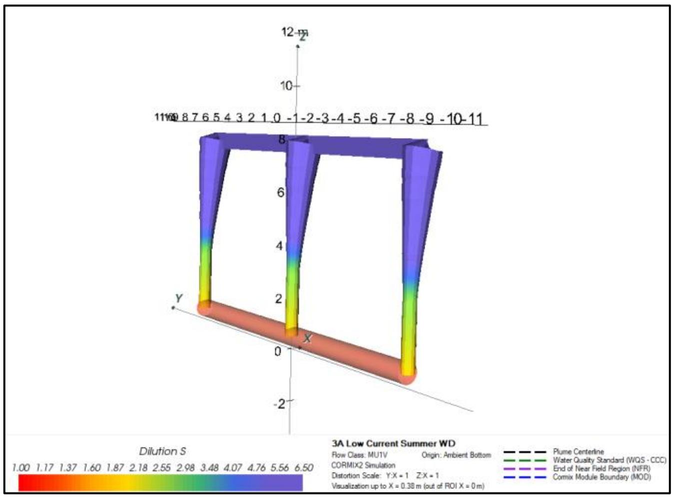


Figure 4-2: CORMIX Vertical Mixing Stage Visualisation Output for Minimum Current Conditions

- The current speed during the low tide condition (0.163 m/s) is low enough for CORMIX to resolve individual mixing plumes for each pair of outfalls, although the plumes are significantly deflected by the current (Figure 4-3). The model produces results for both the initial rising stage of each plume and for the surface spreading stage. The plumes combine and become vertically fully mixed close to the point where the mixing zone reaches the water surface.

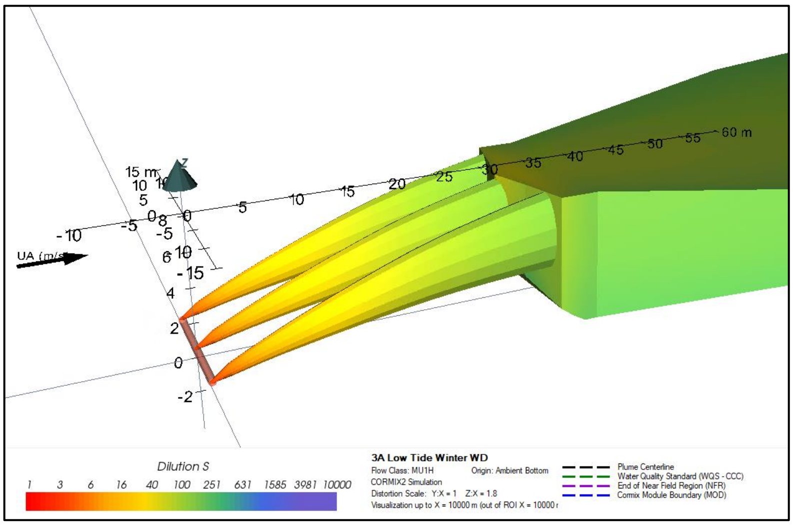


Figure 4-3: CORMIX Visualisation Output for Low Tide Conditions

- At higher current speeds (high tide and maximum current, with current speeds of 0.264 m/s and 0.271 m/s respectively) the plumes undergo rapid lateral mixing at the point of discharge. CORMIX represents this by combining the plumes into a single mixing zone for both the vertical and lateral spreading stage (Figure 4-4). Given the short length of the diffuser (10 m) and the relatively large port diameter (0.5 m), this approximation is considered to be acceptable.

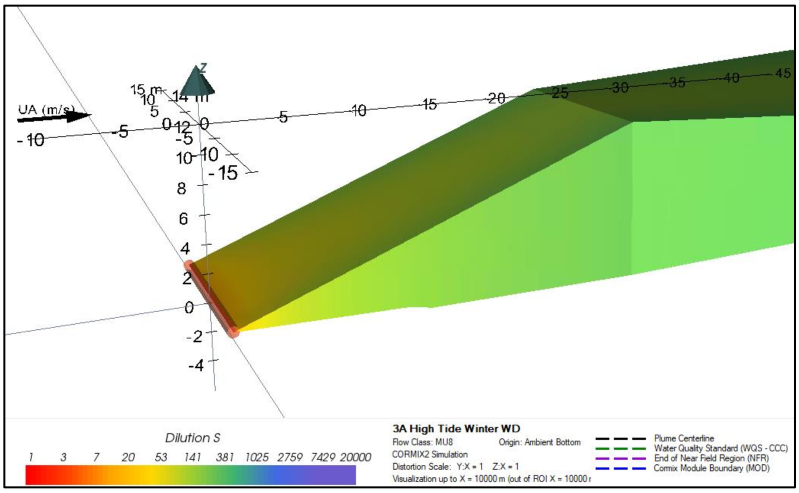


Figure 4-4: CORMIX Visualisation Output for High Tide and High Current Conditions

The CORMIX modelling results are presented below in terms of the vertical height of the top of the mixing plume above the outfall, the lateral distance travelled by the plume and the cross section width of the mixing zone plume at the point when the EQS is reached. If the EQS is met in the surface spreading stage then the cross section width is measured at the water surface.

4.4 Near Field Modelling Results

Sections 4.4.1 and 4.4.2 below describe the size of the near field mixing zones for temperature and contaminant concentrations for summer and winter conditions, with and without the addition of surface water runoff in the final discharged effluent. The addition of surface water results in an effluent temperature which is similar to summer seawater temperatures, therefore thermal impacts are only assessed for winter conditions for this model scenario. Further, concentrations of unionised ammonia in the effluent are diluted to below the EQS by the addition of runoff (see Table 2-5) so the mixing zone for this substance is not assessed for the surface water runoff scenario.

4.4.1 PCC Effluent Only

Table 4-2 below sets out the results of the near field modelling with consideration of effluent streams from the PCC and returned treated effluent from Bran Sands, excluding surface water runoff. The exit velocity at each port under the current diffuser design is 0.26 m/s. Entries highlighted in green show where the EQS is met in the surface spreading stage; for all other entries the EQS is met during the plume rising stage.

Table 4-2: CORMIX Near Field Modelling Results (Excluding Surface Runoff) – distances from discharge to where parameters drop below the EQS (m)

Season	Tide Condition	Mixing Zone Measurement	Chromium (VI)	Copper	Zinc	Unionised Ammonia	Temperature (+3°C)
Winter	Low Tide	Height above outfall	4.7	1.3	2.6	1.0	1.6
		Distance from outfall	26.1	3.0	10.4	1.6	4.7
		Plume Cross Section Width	1.9	0.5	1.0	0.6	0.9
	High Tide	Height above outfall	0.8	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall	1.5				
		Plume Cross Section Width	15				
	Maximum Current	Height above outfall	0.8	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall	1.5				
		Plume Cross Section Width	15				
	Minimum Current	Height above outfall	8.5	5.2	8.5	4.2	6.5
		Distance from outfall	124	0.2	19	0.2	0.4
		Plume Cross Section Width	1.8	0.4	0.5	0.3	0.5
Summer	Low Tide	Height above outfall	4.7	1.3	2.6	1.0	0.8
		Distance from outfall	26.4	3.0	10.4	1.6	0.6
		Plume Cross Section Width	1.9	0.5	1.0	0.4	0.3
	High Tide	Height above outfall	0.8	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall	1.5				
		Plume Cross Section Width	15				
	Maximum Current	Height above outfall	0.8	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall	1.5				
		Plume Cross Section Width	15				
	Minimum Current	Height above outfall	8.5	5.2	8.5	4.2	3.4
		Distance from outfall	125	0.2	19	0.1	0.1
		Plume Cross Section Width	1.8	0.4	0.8	0.3	0.3

The results in Table 4-3 show that EQS values for all substances are met within the plume rising stage for low tide, high tide and maximum current conditions. EQS values for all substances except chromium (VI) are met immediately after discharge during the high tide and maximum current conditions and are met extremely close to the outfall for chromium (VI). EQS values for copper, unionised ammonia and temperature are met within the vertical rising stage during minimum current conditions and EQS values for chromium (VI) and zinc are met during the lateral spreading stage. This would be seen as three extremely narrow areas of elevated concentration extending away from the outfall (Figure 4-5). The near field mixing zone for temperature, unionised ammonia and metals are all extremely small and would have no significant environmental impact.

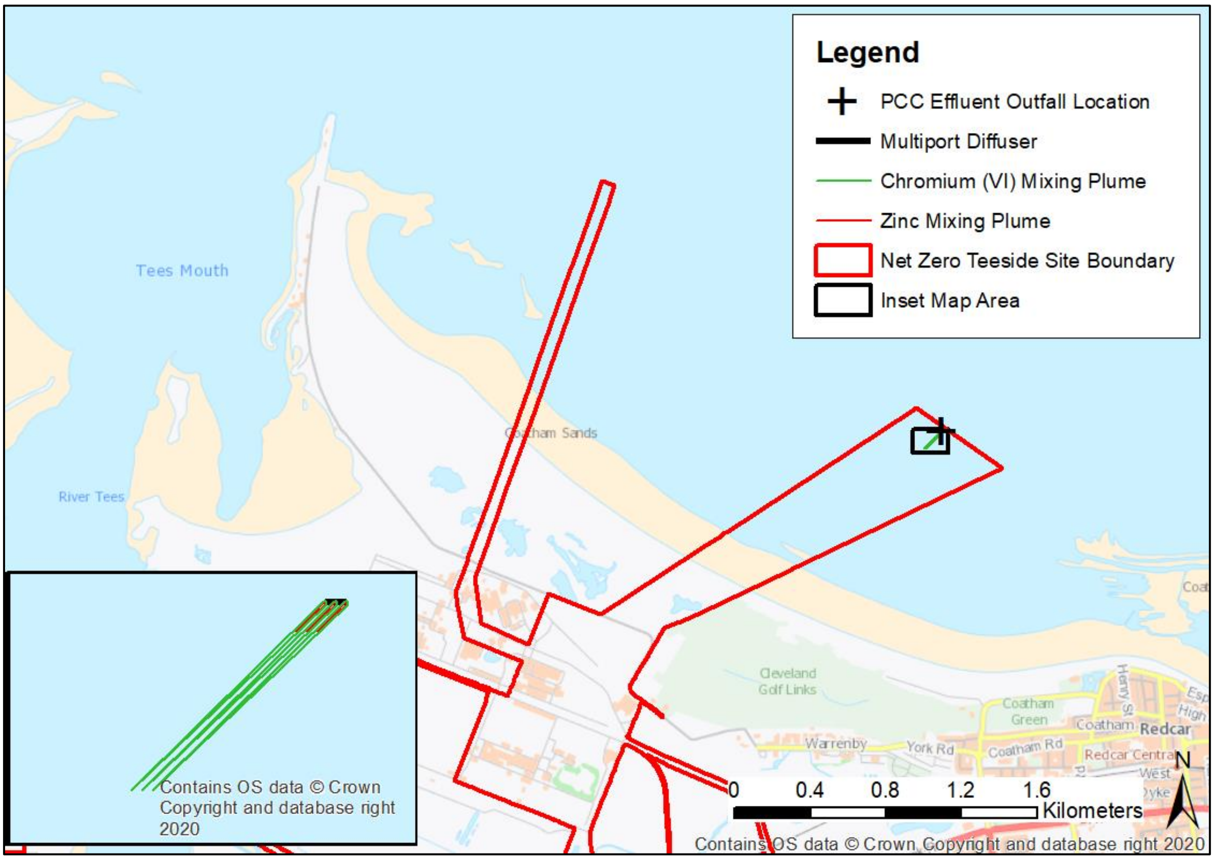


Figure 4-5: Surface Spreading Zones for Chromium (VI) and Zinc (Low Current Condition)

4.4.2 PCC Effluent with Surface Water Runoff

Table 4-3 below sets out the results of the far field modelling with consideration of effluent streams from the PCC processes when including a surface water runoff component. The port exit velocity under this scenario is 0.34 m/s and the EQS for all substances are met during the plume rising stage. Results are not presented for unionised ammonia because the effluent concentrations are already below the EQS (Table 2-5) and results for temperature are not presented for the summer scenario because the effluent temperature and ambient seawater temperature are expected to be similar. The results show that adding surface runoff to the discharged effluent dilutes contaminants and mixing zone sizes become small.

Table 4-3: CORMIX Near Field Modelling Results (Including Surface Runoff) – distances from discharge to where parameters drop below the EQS (m)

Season	Tide Condition	Mixing Zone Measurement	Chromium (VI)	Copper	Zinc	Temperature (+3°C)
Winter	Low Tide	Height above outfall	2.0	immediately on discharge	2.2	2.0
		Distance from outfall	4.4		5.6	4.4
		Plume Cross Section Width	0.6		0.7	0.6
	High Tide	Height above outfall	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall				
		Plume Cross Section Width				
	Maximum Current	Height above outfall	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall				
		Plume Cross Section Width				
	Minimum Current	Height above outfall	6.5	immediately on discharge	7.3	6.5
		Distance from outfall	0.3		0.4	0.3
		Plume Cross Section Width	0.6		0.7	0.6
Summer	Low Tide	Height above outfall	2.0	immediately on discharge	2.2	
		Distance from outfall	4.4		5.6	
		Plume Cross Section Width	0.6		0.7	
	High Tide	Height above outfall	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall				
		Plume Cross Section Width				
	Maximum Current	Height above outfall	Vigorous lateral mixing means that the EQS values for this parameter are met immediately on discharge			
		Distance from outfall				
		Plume Cross Section Width				
	Minimum Current	Height above outfall	6.6	immediately on discharge	7.3	
		Distance from outfall	0.3		0.4	
		Plume Cross Section Width	0.6		0.7	

5. Far Field Modelling Results

5.1 Far Field Model Scenarios

The Delft3D model has been used to carry out far field modelling of DIN mixing from the proposed outfall location. 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 4). 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 vertical layer spacing (Section 3.1), 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 two discharge scenarios as summarised in Table 5-1. A constant flow rate and DIN concentration (calculated as set out in Section 2.2) is assumed in each scenario. 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 not expected to provide significant dilution of DIN in comparison to the far field.

Table 5-1: Discharge Scenario Input Data for Delft3D Model

Parameter	Without Surface Water Addition	With Surface Water Addition
Flow Rate (m^3/s)	0.31	0.40
DIN (mg/l)	26.34	12.21

The model outputs represent a worst case scenario because the model does not currently take account of wave action. This is likely to be important for mixing because the proposed outfall location is 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. The omission of wave action allows for worst case scenario impact prediction based on the currently available information.

5.2 Far Field Model Results

The far field model results are presented below based on the average percentage change in DIN concentration in the receiving waters and the duration of increases of over 1% above background in hours per day as this represents the long-term effect of any discharge. The maps use the consistent contour intervals shown in Figure 5-1. The 1% lower limit in the assessment reflects concentrations below which, in practice, changes in concentration would not be detectable and which are at the limit of accuracy of the model.

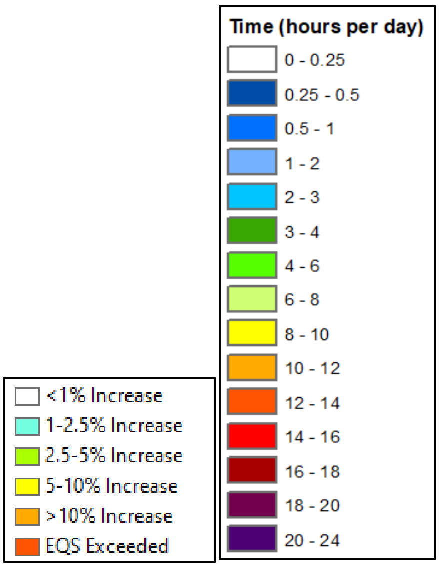


Figure 5-1: Legends for Far Field DIN Mixing Zone Mapping (left = percent change in DIN, right = duration of increase above 1%)

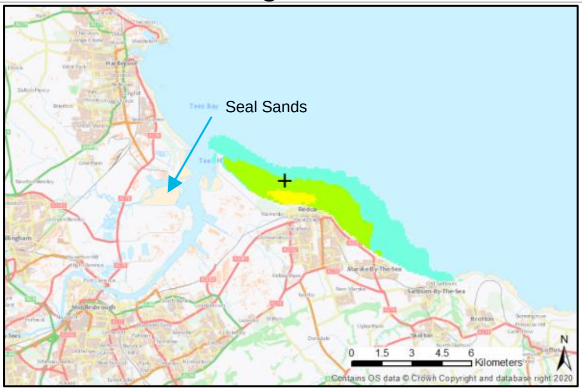
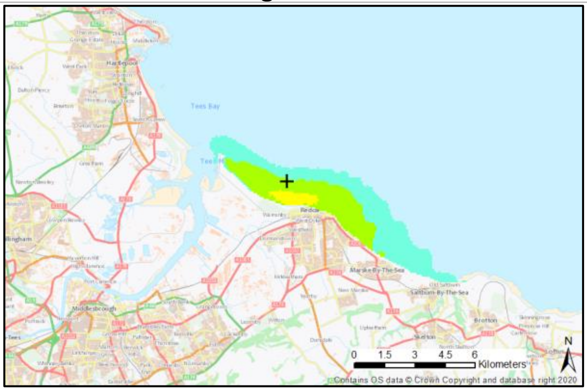
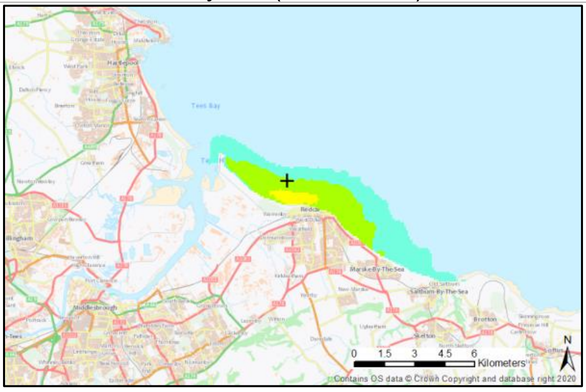
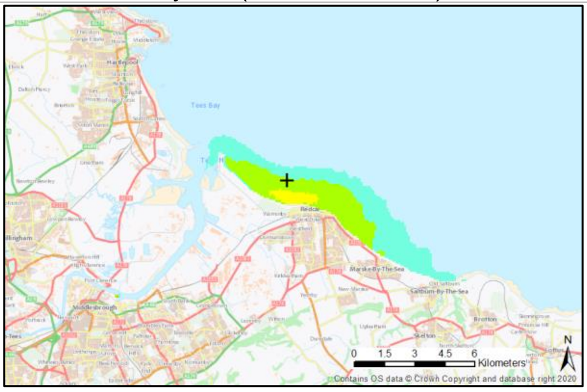
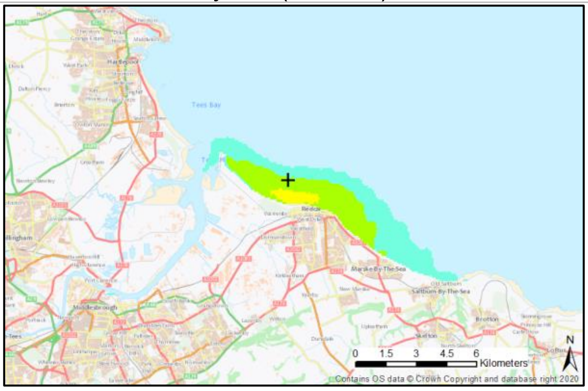
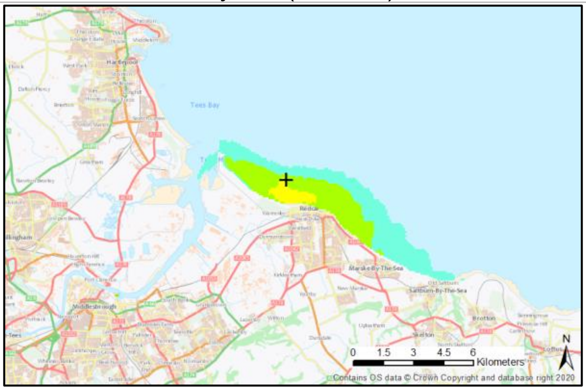
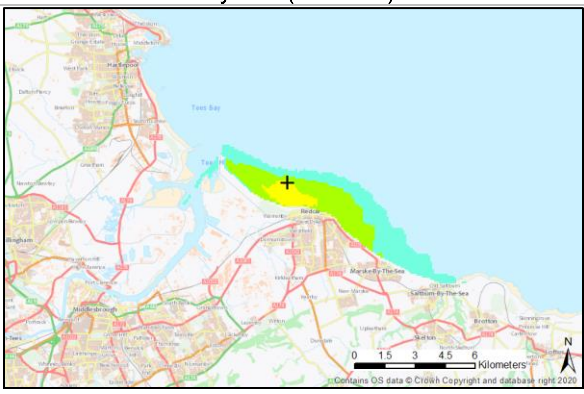
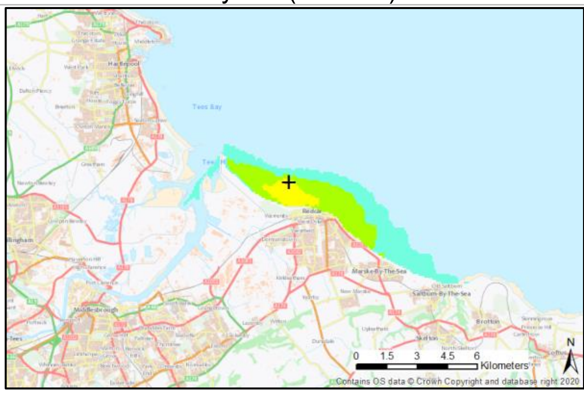
Average Increase	Average Increase
	
Layer 1 (surface 5%)	Layer 2 (surface 90-95%)
	
Layer 3 (82-90%)	Layer 4 (72-82%)
	
Layer 5 (58-72%)	Layer 6 (35-58%)
	
Layer 7 (10-35%)	Layer 8 (bed to 10%)

Figure 5- 2 Average Percentage Increase in DIN Concentrations over a tidal cycle (Surfacewater Runoff Excluded from Effluent)

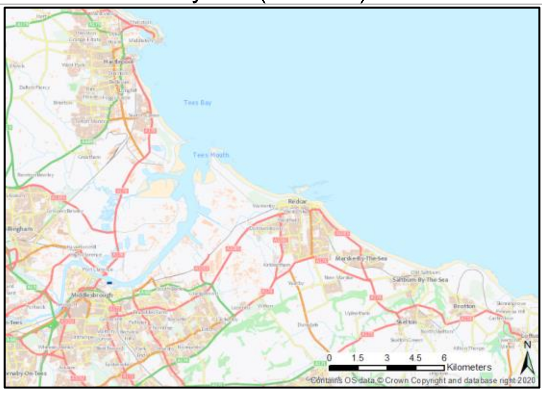
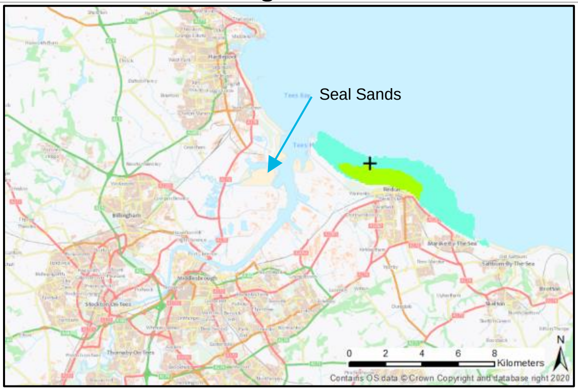
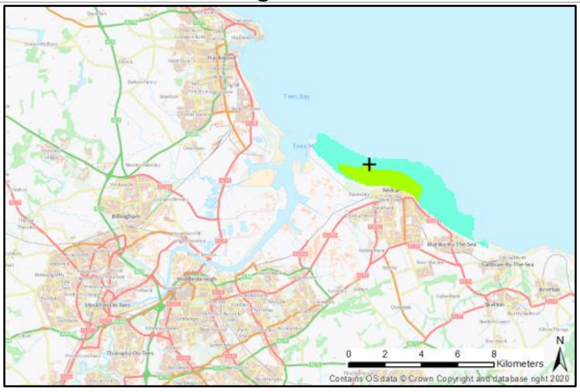
Duration of EQS Exceedance	Duration of EQS Exceedance
	
Layer 1 (surface 5%)	Layer 2 (surface 90-95%)
	
Layer 3 (82-90%)	Layer 3 (72-92%)
	
Layer 5 (58-72%)	Layer 6 (35-58%)
	
Layer 7 (10-35%)	Layer 8 (bed to 10%)

Figure 5-2: Duration of EQS Exceedance (Surfacewater Runoff Excluded from Effluent)

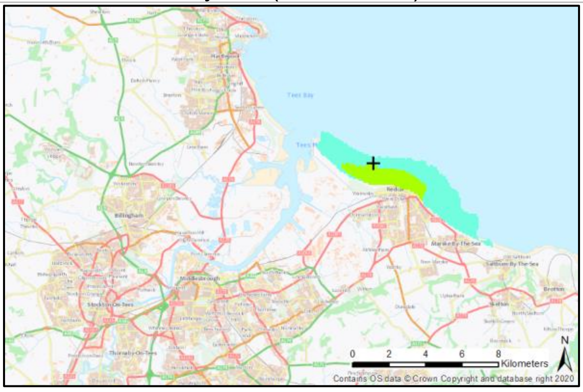
Average Increase	Average Increase



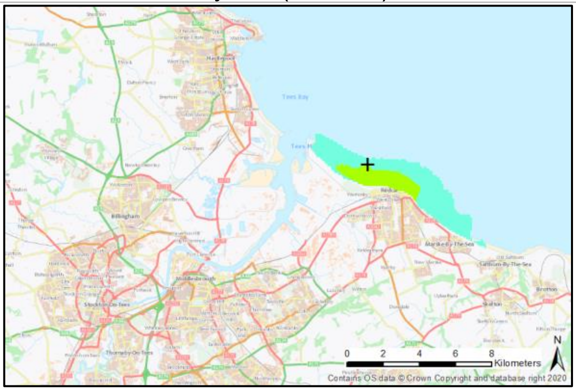
Layer 1 (surface 5%)



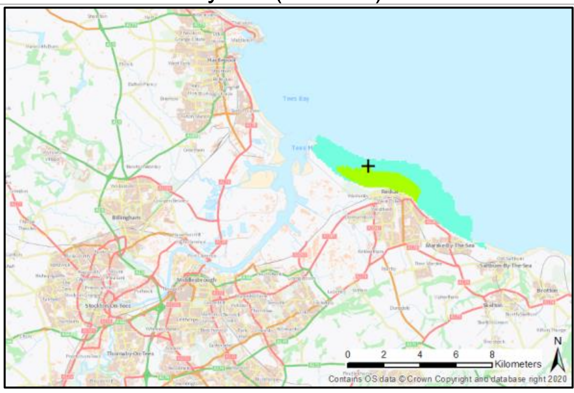
Layer 2 (90-95%)



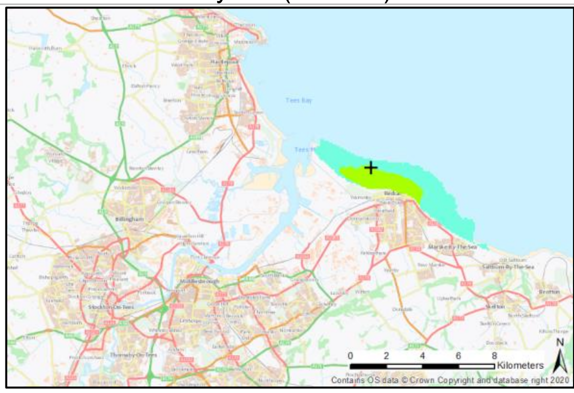
Layer 3 (82-90%)



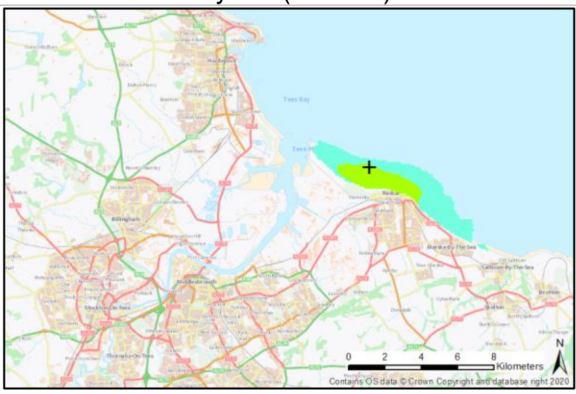
Layer 4 (72-82%)



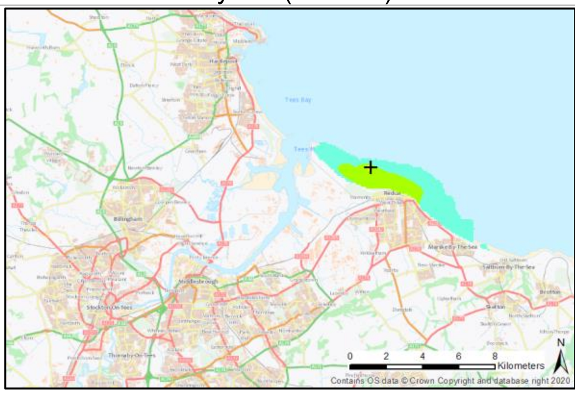
Layer 5 (58-72%)



Layer 6 (35-58%)



Layer 7 (10-35%)



Layer 8 (bed to 10%)

Figure 5-3: Average Percentage Increase in DIN Concentrations over a tidal cycle (With Surfacewater Runoff in Effluent)

Duration of EQS Exceedance	Duration of EQS Exceedance

Layer 1 (surface 5%)

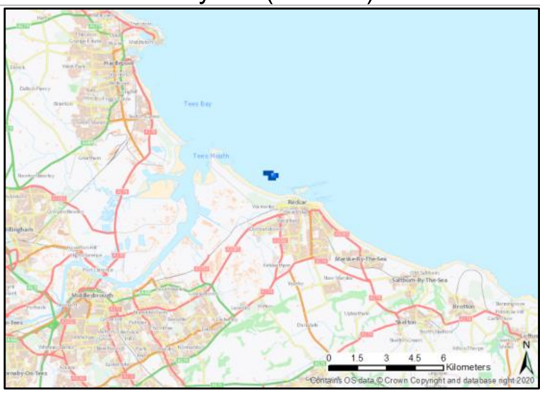
Layer 2 (90-95%)

Layer 3 (82-90%)

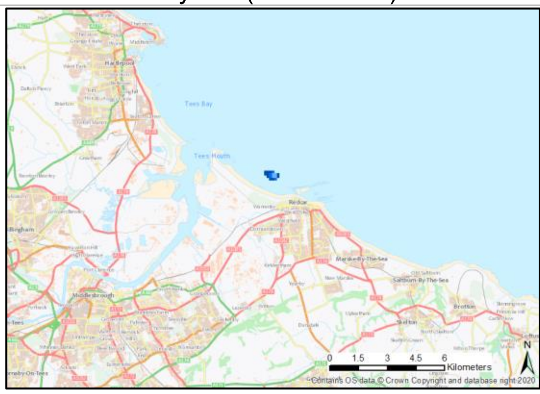
Layer 4 (72-82%)

Layer 5 (58-72%)

Layer 8 (bed to 10%)



Layer 7 (10-35%)



Layer 8 (bed to 10%)

Figure 5-4: Duration of EQS Exceedance (Surfacewater Runoff Included in Effluent)

Figure 5-2 and 5-3 show the following for modelling of effluent discharges without surface water present in the effluent:

- The average impact of the effluent discharge over the tidal cycle is to increase DIN concentrations in a small part of the Tees Bay by up to 10% around the outfall and by 1-5% in the wider area. There are no areas of significant size which show exceedances of the EQS as an average condition over the tidal cycle. There are small areas within the Tees Estuary at Tees Mouth specifically in the dredged channel of the Tees where average DIN concentrations increase but this is limited mainly to less than 1%, and to less than 2.5% at any location. Also this effect is concentrated in the lower half of the water column of the dredged channel of the Tees and not at the location of the Seal Sands mudflats where average DIN concentrations show a less than 1% increase above background.

- For the maximum increase over the tidal cycle the EQS around the outfall in Tees Bay is predicted to be exceeded, however, the duration of EQS exceedance at any given location around the outfall is short due to the rotating and reversing current directions over the tidal cycle. The duration is limited to 0.25 to 2 hours per day.

- The duration over which concentrations of DIN are increased by more than 1% have been calculated and show that DIN concentrations within the Tees Estuary are increased over approximately half of the tidal cycle, on the flood tide only. These results also show that areas away from the immediate coastline of Tees Bay experience an increase in DIN concentration of more than 1% for less than 10 hours per day, with areas north of Tees Mouth showing this increase for less than 2 hours per day

Figure 5-4 and 5-5 show the following for modelling of effluent discharges when a surface water runoff component is present in the effluent:

- The average impact of effluent discharge over the tidal cycle within Tees Bay is limited to less than 5% except in extremely localised areas at the outfall. DIN concentrations in Tees Bay still increase by 1-2.5% over a wider area. There are no increases in average DIN concentration within the Tees Estuary including the mudflats at Seal Sands.

- The assessment of maximum impact across the tidal cycle shows that the DIN EQS concentration is only exceeded close to the outfall and that the duration of EQS exceedance at any given location around the outfall is up to 1 hour per day.

- DIN concentrations along the coastline in Tees Bay are increased by more than 1% throughout the tidal cycle but this reduces to less than half the tidal cycle for more distant locations. Concentration in the Tees Estuary at Tees Mouth are increased by 1% for less than 6 hours per day on the maximum flood tide.

The extent of EQS breaches is extremely limited in terms of extent and duration. Some increase in average DIN concentrations is expected throughout the water column over a wider area and this will include impacts on the deeper parts of the Tees channel at Tees Mouth but does not include the mudflats at Seal Sands. This report aims to quantify the impact of the proposed discharges on water quality in Tees Bay and the River Tees estuary only; the resulting impacts on ecological receptors will be discussed in the WFD assessment.

6. 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, location, 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 size and surface water drainage rates are still to be finalised. It is therefore envisaged that the water quality assessment will be revisited post consent to verify the predicted 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.

The discharged effluent at the PCC site will comprise cooling water blowdown from the proposed gas fired power station, filtration reject water, condensed and process water from a carbon capture facility, return treated effluent flows from Bran Sands Wastewater Treatment Works and surface water runoff. The blowdown water and filtration reject water will be sourced from the non-tidal River Tees and will contain background river water contaminants. These will be concentrated by up to 5 times within the blowdown water component. The condensed water is a much smaller stream but can contain up to 5 mg/l of ammonia, however the process water is expected to consist of highly purified water only. Return flows from Bran Sands will comprise treated wastewater and is included as part of arrangements to treat effluent with very high concentrations of ammonia which are generated on the PCC site at Bran Sands WwTW while preserving nutrient neutrality within Dabholm Gut and the River Tees Estuary. The surface water runoff component of the effluent will be routed through oil interceptors to remove contamination and combined with the runoff with the other wastewater streams and discharging the final combined effluent to Tees Bay.

Water quality data for the River Tees has been provided by Northumbrian Water and combined with information on PCC condensed and process water quality and Bran Sands effluent quality to characterise final discharge effluent flows and loads. The calculations have been carried out for effluent streams which include or exclude the surface water runoff component.

Pollutant concentrations within the effluent have been compared with EQS standards for Tees Bay under the WFD (note there are some gaps in the data, e.g. lack of hydrocarbon concentration information for the River Tees Water). The available information does show that concentrations of chromium (VI), copper, zinc, un-ionised ammonia and DIN in the effluent may exceed EQS concentrations locally, especially if excluding the surface water runoff component of the effluent. The effluent from the PCC site may also be discharged at temperatures exceeding ambient temperatures in Tees Bay. On the basis of the available information, the near field mixing zone modelling has been carried out to assess the water quality impacts for copper, chromium (VI), zinc, unionised ammonia and temperature using the flow rates and effluent temperatures and pollutant loads summarised in Table 6-1. 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 6-1: Flows and Pollutant Loads for Modelled Discharge Scenarios

Parameter	Without Surface Water Runoff	Surface Water Runoff Included	EQS
Temperature (°C)	19	15	3°C above ambient

Dissolved Inorganic Nitrogen (mg/l)[1]	26.34	12.21	0.567
Un-ionised Ammonia (µg/l)	36	16	21
Copper (µg/l)[2]	10.6	4.98	Mean = 3.76 µg/l dissolved
Zinc (µg/l)	57.2	28.1	Mean = 6.8 µg/l dissolved plus ambient (1.1 µg/l) = 7.9 µg/l

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. The current proposal is to discharge the effluent via a new outfall with multiport diffuser located in an area with an average water depth of approximately 9 m.

The near field modelling shows that the impact of the discharge is not significant for metals, temperature and unionised ammonia 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 generally 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 conditions within a very short distance. Surface temperatures are not increased by more than 3°C for any combination of effluent discharge option and tidal stage.

The far field modelling for DIN shows that:

- Average increases in the concentrations of DIN at the mudflats in Seal Sands do not exceed 1% above background. Average Tees Estuary DIN concentrations are increased in the Tees Mouth area by up to 2.5% within the dredged channel of the river in the bottom half of the water column. The duration of impact is less than 10 hours per day, falling to less than 6 hours per day if surface water is present in the effluent.
- Average DIN concentrations in Tees Bay do not exceed the EQS for either scenario over any significant area. The maximum DIN concentration in Tees Bay exceeds the EQS in the lower 58% of the water column over an area of approximately 2.7 km^2 around the discharge point when surface water is excluded from the effluent. The average duration of this exceedance at a given location is short, at 0.25-2 hours per day. If surface water is included in the effluent then the EQS is breached only in the lower 35% of the water column, over a smaller area and the duration of the exceedance is shorter.
- Average DIN concentrations along the coastline in Tees Bay increase up to 5% under both discharge scenarios, with increases of up to 10% closer to the outfall and in deeper water and increases of 1-2.5% over a wider area closer to the water surface. The area affected is reduced by the inclusion of surface water runoff in the effluent. Due to the rotating and reversing current direction, DIN concentrations at most locations are increased for less than half the tidal cycle although concentrations along the coastline are shown to be elevated at all tidal stages.

The extent of EQS breaches is extremely limited in terms of extent and duration. Whilst some average increase in DIN concentrations is expected throughout the water column over a wider area average increases in the concentrations of DIN at the mudflats in Seal Sands are minimal, not exceeding 1% above background.