

# H2Teesside Project

## Environmental Statement

Volume III – Appendices

Appendix 9B: Water Quality Modelling Report

Document Reference: 6.4.10

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

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 - Regulation 5(2)(a)



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Figure 9B-1: Proposed Development Boundary and Proposed NZT Effluent Discharge Location

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## 9B.0 APPENDIX 9B: WATER QUALITY MODELLING REPORT

### 9B.1 Introduction

#### Background

- 9B.1.1 The Proposed Development comprises the construction, operation (including maintenance where relevant) and decommissioning of an up to 1.2-Gigawatt Thermal (GWth) Lower Heating Value (LHV) Carbon Capture and Storage (CCS) enabled Hydrogen Production Facility (the 'Main Site') located in Teesside, along with the pipeline infrastructure required to supply hydrogen (H<sub>2</sub>) to offtakers (customers) and the necessary utility connections. Carbon dioxide captured on the Main Site will be transported by pipeline to the separately consented Northern Endurance Partnership infrastructure on the adjacent Net Zero Teesside site for high-pressure compression and offshore transport and underground storage. For further details on the Proposed Development refer to Chapter 4: Proposed Development (ES Volume I, EN070009/APP/6.2).
- 9B.1.2 During operations, the Main Site may discharge wastewater from on-site processes to Tees Bay via a discharge point which will be shared with the adjacent Net Zero Teesside (NZE) site (see "Development Proposals" section below for more details). In their Statutory Consultation Responses, the Environment Agency and Natural England asked for an assessment of the potential impacts of any proposed discharge on water quality in Tees Bay with specific focus on Dissolved Inorganic Nitrogen (DIN) concentrations within Tees Bay and the Tees WFD waterbody. This will aid in the assessment of the impact of the proposed development on nutrient concentrations in the Bay and how this may impact the Teesside & Cleveland Coast Special Protection Area (SPA) / Ramsar site which includes parts of Tees Bay and the Tees Estuary.
- 9B.1.3 Previous dispersion modelling and water quality impact assessments have been carried out for the wider Redcar Steelworks site and for the NZE development. Reports referred to within this current study are:
- Net Zero Teesside – Environmental Statement, Volume III – Appendices – Appendix 14E: Coastal Modelling Report, bp, April 2021 (Document Reference 6.4.31). A preliminary study of the water quality impacts of potential future discharges from the NZE site using a hydrodynamic model of Tees Bay and the River Tees Estuary. This report is included as Annex B.
  - Net Zero Teesside – Nutrient Nitrogen Briefing Paper, bp, October 2022 (Document Reference 9.36). bp used the hydrodynamic model developed for the April 2021 report to update the dispersion modelling for the NZE site. This was carried out for the new offshore discharge location only following confirmation of the location and survey of the W3 outfall which confirmed it could no longer be used – this was later confirmed by a change at the end of the NZE Examination which confirmed that only the proposal to construct a new outfall was to be taken forward. During the NZE DCO Examination, NZE committed to a nutrient neutral development secured via Requirement 37 in



the DCO. The primary option for achieving this is anticipated to be through on-site treatment plant (Net Zero Teesside, ES Vol III Appendix 25A Commitments Register Clean Oct 2022 (Document reference 6.4.49)). The modelling in this report therefore illustrates an example of the type of concentrations that could be expected from NZT following on-site treatment.

9B.1.4 The modelling focussed on chemical and thermal impacts, including modelling of mixing zones for DIN, chromium (VI) and zinc mixing zones. Thermal impacts were confirmed to be negligible.

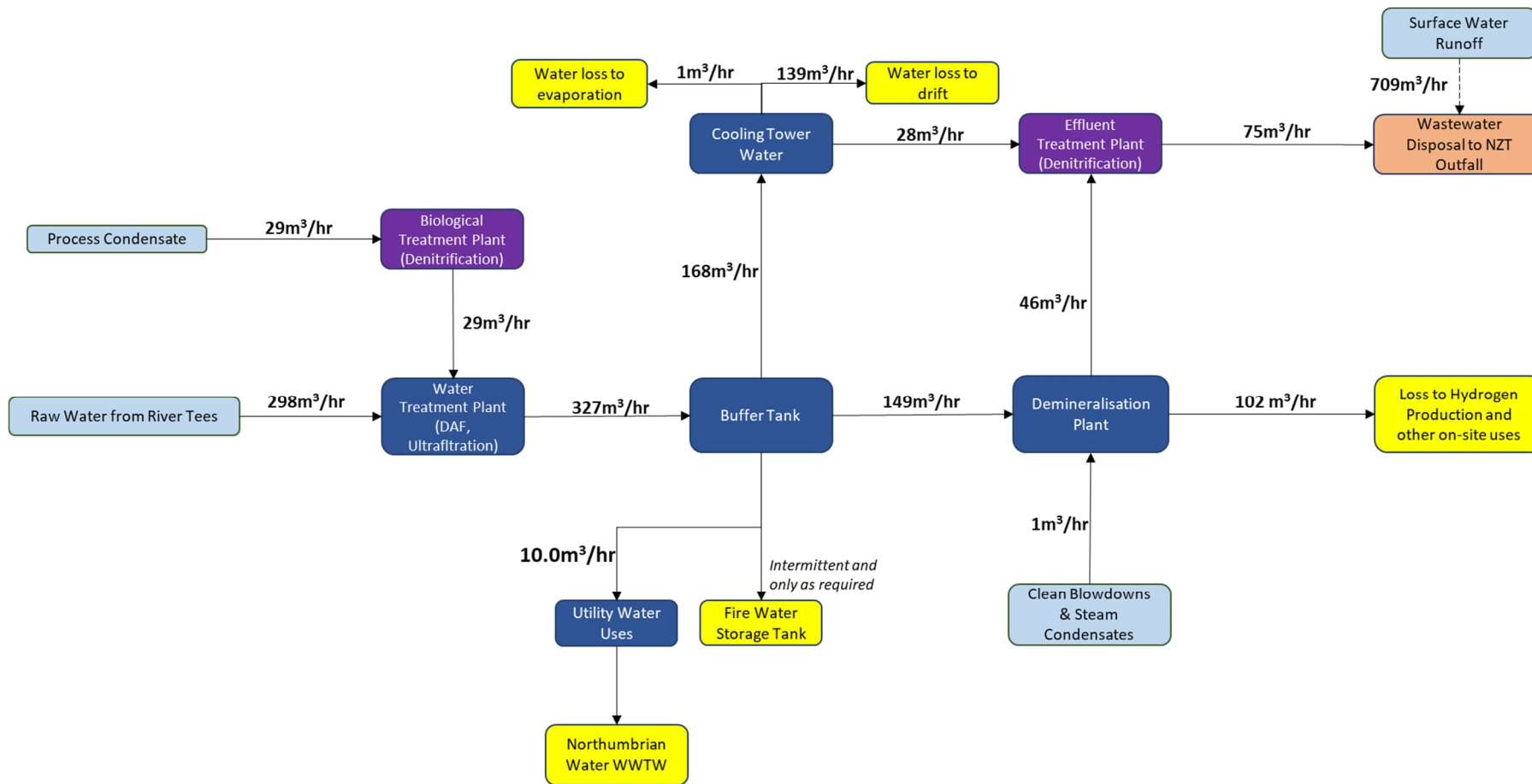
9B.1.5 This current report sets out the results of water quality modelling of discharges from the Main Site, in isolation and cumulatively with discharges from the NZT development. For the purposes of the cumulative assessment treated effluent quality has been assumed based on the primary option of an on-site treatment solution for the NZT development. . This current report assesses the combined discharges from both the Main Site and the NZT site based on the information available at the time of publication. A further assessment of both discharges may be required following finalisation of the proposals for each site.

#### Development Proposals

9B.1.6 At this stage in the design development for the Main Site, two main design scenarios are under consideration with FEED works ongoing. The two main design scenarios are:

- Minimalised Liquid Discharge (Case 1B): the Main site is supplied with water from the River Tees. This water is treated and used in the onsite processes, and process wastewater is then sent to a reverse osmosis Enhanced Treatment Plant (ETP) where pollutants, including DIN, will be removed and clean water re-circulated into the site process water supply. The pollutants will be concentrated into a brine which will be trucked offsite for disposal elsewhere. Sanitary waste generated on site will be treated via the municipal Northumbrian Water Wastewater Treatment Works (WwTW) at Bran Sands or Marske-by-the-Sea. Surface water runoff will be discharged either to the River Tees or to Tees Bay via the NZT coastal outfall.
- Discharge to the NZT Outfall (Case 2B): the Main Site is supplied with water from the River Tees. This raw water is treated to remove solids via Dissolved Air Flotation (DAF) and ultrafiltration, however this is not expected to remove dissolved contaminants such as DIN. Additional water supply to the Main Site is derived from Process Condensate which contains ammonia and will be treated by a biological denitrification plant prior to use. The two treated water supply streams will be combined and used to supply cooling towers, on-site utilities and a demineralisation plant. Blowdown from the cooling towers and reject water from the demineralisation plant will be directed to an effluent treatment plant for further treatment, including additional denitrification, and the final treated effluent will be discharged via the NZT coastal outfall. Surface water runoff will be discharged either to the River Tees or to Tees Bay via the NZT coastal outfall.

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- 9B.1.7 Case 1B does not require any discharge of process effluent from the Main Site to either the River Tees or Tees Bay (additional dispersion modelling may be required in future if this changes as the site design progresses). This Water Quality Modelling Report therefore assesses the discharges under Case 2B proposals only, with updated modelling of the NZT mixing zones. The assessment of surface water discharges to the River Tees (if this occurs) is also outside the scope of this report because this water is expected to be managed via a sustainable urban drainage system which will provide an adequate level of treatment to ensure the protection of receiving watercourses, pursuant to the Detailed Surface Water Drainage Strategy to be approved pursuant to DCO Requirement.
- 9B.1.8 The flow chart in Plate 9B-1 summarises the on-site water flows currently proposed under Case 2B at the Main Site. Water quality impacts in Tees Bay may occur because effluent may be discharged at temperatures exceeding that of Tees Bay. Further, the origin of the effluent is untreated water from the River Tees containing contaminants typical of a large lowland river, including elevated concentrations of DIN which may be further concentrated by the on-site processes. Section 2 of this report sets out the flows and pollutant loads of the final combined effluent discharges to Tees Bay.
- 9B.1.9 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 discussion of nutrient neutrality in the River Tees.
- 9B.1.10 The site location is shown in Figure 9B-1. The Environment Agency have not identified any other discharges to the Bay which may contribute significant quantities of DIN to this waterbody, and therefore modelling of cumulative impacts with other discharges has not been carried out.



**Legend**

Water Sources	On-site Water Management
On-site Water Treatment	Water Loss/Use
Wastewater Disposal	

Plate 9B-1: Current Proposed Water Balance for the Main Site (Case 2B)

## 9B.2 Discharged Effluent Quality

### Environmental Quality Standards

9B.2.1 Table 9B-1 sets out the current UK Environmental Quality Standards (EQS) relevant to the Tees Bay coastal water (reference 1, Annex E) for substances for which monitoring data exist in the River Tees. They form part of a larger list of EQS standards which includes substances for which no River Tees monitoring data are available, and substances which are monitored in the River Tees but have not been detected. The full list is presented in Annex A. EQS values are given for either annual average (mean), Maximum Allowable Concentrations (MAC) or both.

Table 9B-1: Environmental Quality Standards for Tees Bay

PARAMETER	ENVIRONMENTAL QUALITY STANDARD
Temperature	Less than 3°C increase in temperature outside the immediate mixing zone
pH	95%ile = 6-8.5
Dissolved Oxygen	Mean = 5.75 mg/l (calculated from salinity, see Section 3.7)
Un-ionised Ammonia	Mean = 21 µg/l
Flouride (dissolved)	Mean = 5 mg/l, MAC = 15 mg/l
Hydrocarbons	
Bentazone	Mean = 0.5 mg/l
Benzo(a)-pyrene	MAC = 0.027 µg/l
Benzo(b)-fluoranthene	MAC = 0.017 µg/l
Benzo(g,h,i)-perylene	MAC = 0.82 ng/l
Benzo(k)-fluoranthene	MAC = 0.017 µg/l
Flouranthene	Mean = 6.3 ng/l, MAC = 120 ng/l
Hexabromocyclo-dodecane	Mean = 8.0 ng/l, MAC = 50 ng/l
Perfluorooctane sulfonic acid and its salts (PFOS)	Mean = 0.13 ng/l, MAC = 7200 ng/l
Phenol	Mean = 7.7 µg/l, 95%ile = 46 µg/l
Polyaromatic Hydrocarbons	Mean = 0.17 ng/l
Metals	
Cadmium and its compounds (dissolved)	Mean = 0.2 µg/l
Chromium (VI)	Mean = 0.6 µg/l, 95%ile = 32 µg/l
Copper	Mean = 3.76 µg/l dissolved
Iron (dissolved)	Mean = 1 mg/l

PARAMETER	ENVIRONMENTAL QUALITY STANDARD
Lead and its compounds (dissolved)	Mean = 1.3 µg/l, MAC = 14 µg/l
Mercury and its compounds (dissolved)	MAC = 0.07 µg/l
Nickel and its compounds (dissolved)	Mean = 8.6 µg/l, MAC = 34 µg/l
Zinc	Mean = 6.8 µg/l dissolved plus ambient (1.1 µg/l) = 7.9 µg/l
Pesticides	
Atrazine	Mean = 0.6 µg/l, MAC = 2 µg/l
Chlorotoluron	Mean = 2.0 µg/l
Diazinon	Mean = 0.01 µg/l, 95%ile = 0.26 µg/l
Glyphosate	Mean = 196 µg/l, 95%ile = 398 µg/l
Propyzamide	Mean = 0.1 mg/l, MAC = 1.0 mg/l
Terbutryn	Mean = 6.5 ng/l, MAC = 34 ng/l

9B.2.2 In addition to these standards, nitrogen concentrations in coastal waters are limited with reference to DIN. The applicable EQS values for DIN are selected for each coastal waterbody based on its recorded salinity and suspended particulate matter concentration (HM Government, 2015). In this case, Environment Agency (Environment Agency, n.d.) data show an average of 8 mg/l suspended solids and normal salinity of 32.0 ppt at Tees Mouth (see Section 9B.3: Temperature and Salinity) and salinity of 33.8 ppt in Tees Bay. These values are consistent with clear water and coastal (i.e. not transitional) waters.

9B.2.3 Table 9B-2 sets out the Water Framework Directive (WFD) class boundaries for DIN concentrations for clear coastal waters. The boundaries are provided as µmol/l, which are cited in the WFD legislation (HM Government, 2017), and as the equivalent concentration in mg/l based on guidance provided by the UK Technical Advisory Group (UK Technical Advisory Group, 2008) in their method statement document in which these standards are derived.

Table 9B-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



9B.2.4 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.

9B.2.5 The dissolved oxygen EQS in Table 9B-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.

Effluent Pollutant Concentrations

River Tees Source

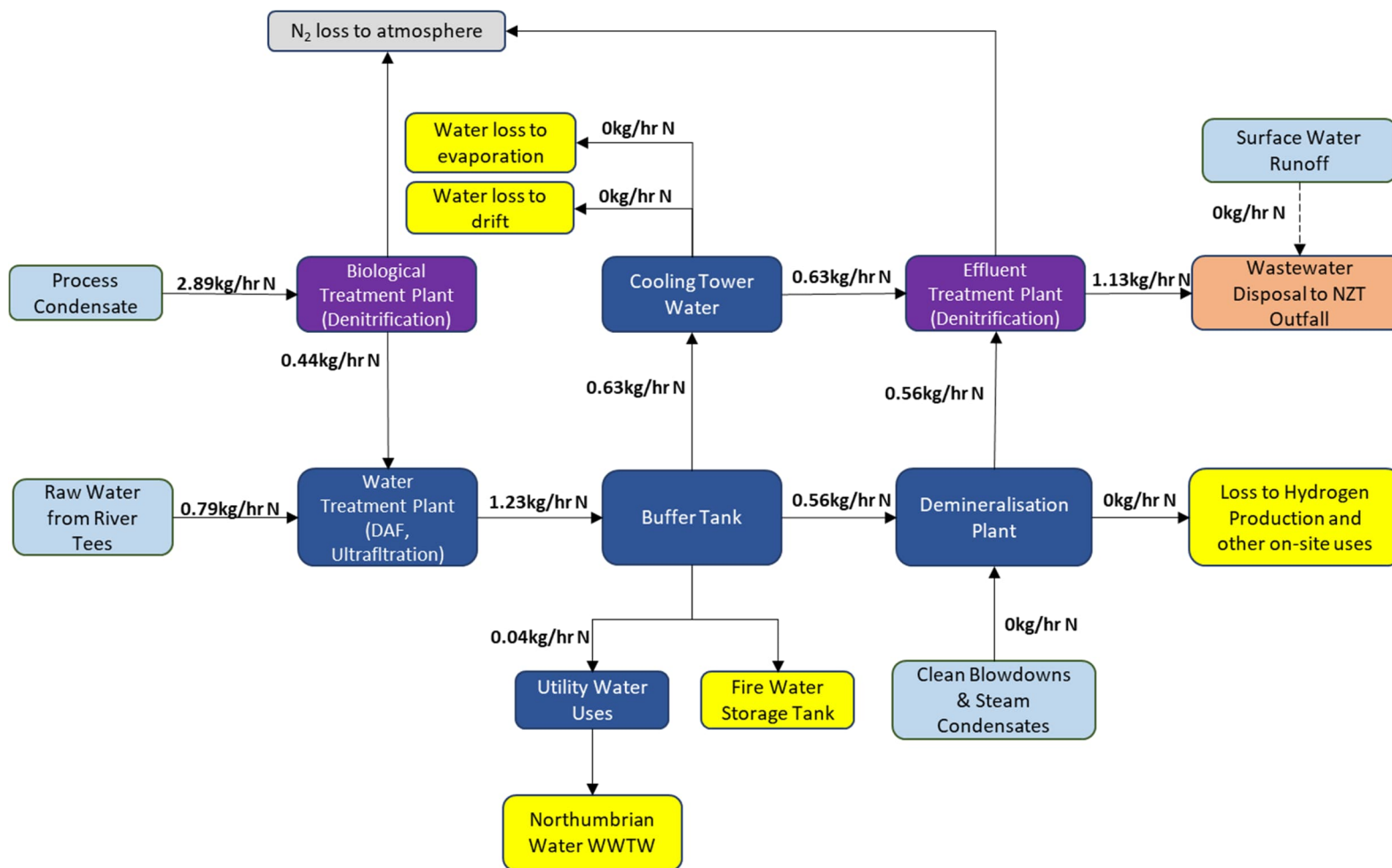
9B.2.6 The largest source of water to the Main Site will be untreated River Tees water. This water will be provided via Northumbrian Water’s system and is taken from three abstraction points on the non-tidal river – Low Worsall, Blackwell and Broken Scar. River water quality monitoring data for the non-tidal River Tees have been obtained from the Environment Agency and from Northumbrian Water. The data have been combined to provide the raw water chemistry profile for the Main Site water supply in Table 9B-3.

Table 9B-3: Pollutant Concentrations in the River Tees Main Site Water Supply 2

PARAMETER	RIVER TEES MEAN	RIVER TEES MAXIMUM
pH	8.04	8.85
Un-ionised Ammonia	0.3 µg/l	0.7 µg/l
Flouride (dissolved)	0.192 µg/l	0.86 µg/l
Dissolved Inorganic Nitrogen	2.66 mg/l	8.84 mg/l
Hydrocarbons		
Bentazone	7.1 ng/l	7.1 ng/l
Benzo(a)-pyrene	1.69 ng/l	4.50 ng/l
Benzo(b)-fluoranthene	4.77 ng/l	7.10 ng/l
Benzo(g,h,i)-perylene	2.71 ng/l	4.20 ng/l
Benzo(k)-fluoranthene	2.35 ng/l	4.70 ng/l
Flouranthene	7.5 ng/l	7.5 ng/l
Hexabromocyclo-dodecane	0.39 ng/l	0.39 ng/l
PFOS	0.75 ng/l	0.75 ng/l
Phenol	0.13 µg/l	0.13 µg/l
Polyaromatic Hydrocarbons	4.96 ng/l	15.5 ng/l

PARAMETER	RIVER TEES MEAN	RIVER TEES MAXIMUM
Metals		
Cadmium and its compounds (dissolved)	0.05 µg/l	0.24 µg/l
Chromium (VI)	1.76 µg/l	4.90 µg/l
Copper (dissolved)	1.73 µg/l	4.30 µg/l
Iron (dissolved)	0.61 mg/l	2.60 mg/l
Lead and its compounds (dissolved)	15.43 µg/l	180 µg/l
Mercury and its compounds (dissolved)	6.1 ng/l	22 ng/l
Nickel and its compounds (dissolved)	1.15 µg/l	2.50 µg/l
Zinc	9.21 µg/l	21 µg/l
Pesticides		
Atrazine	0.16 ng/l	0.16 ng/l
Chlorotoluron	1.78 ng/l	11 ng/l
Diazinon	4.91 ng/l	51 ng/l
Glyphosate	8.5 ng/l	41 ng/l
Propyzamide	6.0 ng/l	23 ng/l
Terbutryn	0.4 ng/l	0.4 ng/l

9B.2.7 Pollutants contained within the River Tees water supplied to the Main Site will be concentrated in the final treated effluent. A total inflow of 298 m<sup>3</sup>/hr is reduced to a discharged volume of 75 m<sup>3</sup>/hr (Plate 9B-1) while the pollutant mass is expected to remain the same for most dissolved contaminants. However, the denitrification stages in Plate 9B-1 will produce effluent with a final concentration of 15 mg/l N. The Main Site nitrogen balance is shown in Plate 9B-2.



**Legend**

Water Sources	On-site Water Management
On-site Water Treatment	Water Loss/Use
Wastewater Disposal	

Plate 9B-2: Main Site Nitrogen Balance

9B.2.8 The abstraction of water and dissolved pollutants, including DIN, from the non-tidal River Tees, and subsequent discharge to Tees Bay, will reduce the overall annual pollutant mass reaching the Tees Estuary. However, given the small abstraction volumes in comparison to the overall River Tees flow (estimated at 2.3% of the  $Q_{95}$  flow in the non-tidal River Tees (National River Flow Archive, n.d.)), this effect will not be significant and there will be no overall change in total annual pollutant mass reaching Tees Bay.

#### Process Condensate

9B.2.9 The only other continuous source of water to the Main Site is Process Condensate (small amounts of boiler blowdown and steam condensate are also generated on the site (Plate 9B-1) but are not expected to contain significant quantities of contaminants subject to an EQS in coastal waters). Process Condensate is expected to contain only one contaminant which is subject to an EQS in coastal waters, ammonia, which is limited through the DIN EQS. Process condensate is expected to contain only one contaminant which is subject to an EQS in coastal waters, ammonia, which is limited through the DIN EQS. The Process condensate will be treated by a denitrification plant both prior to and following use in on-site processes and the final treated effluent discharged to Tees Bay will contain 15 mg/l N at DIN. The additional ammonia will be converted to nitrogen gas for atmospheric release. The denitrification stage of effluent treatment is a process which is most efficient at a temperature of 30°C and this is therefore taken as the worst-case discharge temperature.

#### Surface Water Runoff

9B.2.10 Surface water runoff from the Main Site will be collected via a positive drainage network which will include oil interceptors and other measures for the protection of water quality. The design of the surface water drainage strategy for the site is at an early stage in development and full details of the proposals are not currently available, however final discharge rates from the site will be limited to the current average annual runoff rate of 197 l/s (709 m<sup>3</sup>/hr). It is proposed to discharge surface water runoff from the site either to local watercourses (including potentially the River Tees) or to Tees Bay via the NZT outfall.

9B.2.11 At this stage, it is expected that the design of the surface water drainage system will reduce contaminants concentrations in runoff to low levels, and therefore the addition of surface water to the Main Site wastewater will act to dilute and cool the final discharged effluent stream. Runoff will, however, only be discharged from the site following rainfall events. For the purposes of this report, the water quality impacts of the H2Teesside discharges have been modelled both with and without the addition of surface water. The scenario which includes the impacts of surface water dilution assumes zero pollutant concentrations in the runoff in addition to cooling the effluent to 15°C (summer average annual temperatures for the River Tees).

### Final Main Site Mixed Effluent Discharge Scenarios

- 9B.2.12 The final effluent discharge rate will be controlled by presence or absence of surface water runoff and the effluent treatment technology selected in the final site design. The discharge pollutant loads will depend on the treatment capability of the effluent treatment plant. The treatment plants on the site are designed to remove solids and nitrogen and, for the purpose of this assessment, no reduction in the mass of other trace contaminants from the River Tees water has been allowed for.
- 9B.2.13 Table 9B-4 gives the estimated wastewater discharge concentrations of contaminants in the final effluent from the effluent treatment plant. Final effluent concentrations exceeding the EQS are highlighted in amber in Table 9B-4 and where there is no EQS the cells in Table 9B-4 are filled in blue. Average concentrations of DIN, fluoranthene, PFOS, polyaromatic hydrocarbons, cadmium, chromium, lead, zinc, copper, iron and diazinon may be discharged at concentrations existing the average annual EQS in coastal waters in the absence of effluent dilution by surface water runoff. Similarly, maximum effluent concentrations of benzo(b)-fluoranthene, benzo(g,h,i)-perylene, benzo(k)-fluoranthene, lead and mercury may exceed the MAC in coastal waters. With the exception of DIN, the source of all substances discharged at concentrations exceeding EQS values is the River Tees – none of these substances are expected to be generated by the H2Teesside processes which only act to concentrate River Tees water.

Table 9B-4: Flows and Pollutant Loads for Modelled Main Site Discharge

PARAMETER	PROCESS EFFLUENT ONLY <sup>1</sup>		SURFACE WATER RUNOFF INCLUDED		EQS	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
Flow Rate (m <sup>3</sup> /s)	0.021	0.021	0.091	0.091		
Temperature (°C)	30	30	15	15	3°C above ambient	
pH	7.0	7.0	7.0	7.0	6.0-9.0	9.0
Un-ionised Ammonia	1.16 µg/l	3.08 µg/l	0.11 µg/l	0.11 µg/l	21 µg/l	
Dissolved Inorganic Nitrogen	15 mg/l	15 mg/l	1.435 mg/l	1.435 mg/l	0.252 mg/l	
Fluoride (dissolved)	0.74 µg/l	3.31 µg/l	0.07 µg/l	0.33 µg/l	500 µg/l	1500 µg/l

<sup>1</sup> Process Effluent contains contaminants arising from the operation of the Hydrogen Production Facility, but it should also be noted that contaminants already present in the raw water supplied to the site are further concentrated by the process.



PARAMETER	PROCESS EFFLUENT ONLY <sup>1</sup>		SURFACE WATER RUNOFF INCLUDED		EQS	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
Hydrocarbons						
Bentazone	0.027 µg/l	0.027 µg/l	0.003 µg/l	0.003 µg/l	500 µg/l	
Benzo(a)-pyrene	6.5 ng/l	17.3 ng/l	0.6 ng/l	1.7 ng/l		27 ng/l
Benzo(b)-fluoranthene	18.4 ng/l	27.4 ng/l	1.8 ng/l	2.7 ng/l		17 ng/l
Benzo(g,h,i)-perylene	10.4 ng/l	16.2 ng/l	1.0 ng/l	1.6 ng/l		0.82 ng/l
Benzo(k)-fluoranthene	9.1 ng/l	18.1 ng/l	0.9 ng/l	1.8 ng/l		17 ng/l
Flouranthene	28.9 ng/l	28.9 ng/l	2.9 ng/l	2.9 ng/l	6.3 ng/l	120 ng/l
Hexabromocyclo-dodecane	1.5 ng/l	1.5 ng/l	0.1 ng/l	0.1 ng/l	8.0 ng/l	50 ng/l
PFOS	2.9 ng/l	2.9 ng/l	0.29 ng/l	0.29 ng/l	0.13 ng/l	7200 ng/l
Phenol	0.50 µg/l	0.50 µg/l	0.05 µg/l	0.05 µg/l	7.7 µg/l	46 µg/l*
Polyaromatic Hydrocarbons	19.1 ng/l	59.7 ng/l	1.75 ng/l	5.9 ng/l	0.17 ng/l	
Metals (dissolved)						
Cadmium and its compounds	0.20 µg/l	0.92 µg/l	0.02 µg/l	0.09 µg/l	0.2 µg/l	
Chromium (VI)	6.78 µg/l	18.88 µg/l	0.67 µg/l	1.86 µg/l	0.6 µg/l	32 µg/l*
Copper	6.68 µg/l	16.57 µg/l	0.66 µg/l	1.63 µg/l	3.76 µg/l	
Iron	2.34 mg/l	10.02 mg/l	0.232 mg/l	0.988 mg/l	1 mg/l	
Lead and its compounds	59.5 µg/l	693.6 µg/l	5.86 µg/l	68.4 µg/l	1.3 µg/l	14 µg/l
Mercury and its compounds	0.024 µg/l	0.085 µg/l	0.002 µg/l	0.008 µg/l		0.07 µg/l
Nickel and its compounds	4.43 µg/l	9.63 µg/l	0.44 µg/l	0.95 µg/l	8.6 µg/l	34 µg/l

PARAMETER	PROCESS EFFLUENT ONLY <sup>1</sup>		SURFACE WATER RUNOFF INCLUDED		EQS	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
Zinc	35.49 µg/l	80.92 µg/l	3.50 µg/l	7.98 µg/l	7.9 µg/l	
Pesticides						
Atrazine	0.6 ng/l	0.6 ng/l	0.1 ng/l	0.1 ng/l	600 ng/l	2000 ng/l
Chlorotoluron	6.9 ng/l	6.9 ng/l	0.7 ng/l	4.2 ng/l	2000 ng/l	
Diazinon	18.9 ng/l	196.5 ng/l	1.9 ng/l	19.4 ng/l	10 ng/l	260 ng/l
Glyphosate	0.033 µg/l	0.158 µg/l	0.003 µg/l	0.016 µg/l	196 µg/l	398 µg/l
Propyzamide	0.023 µg/l	0.089 µg/l	0.002 µg/l	0.009 µg/l	100 µg/l	1000 µg/l
Terbutryn	1.5 ng/l	1.5 ng/l	0.2 ng/l	0.2 ng/l	6.5 ng/l	34 ng/l

\*EQS given for 95%ile concentrations

9B.2.14 Table 9B-4 shows that the addition of surface water runoff would be expected to dilute final effluent pollutant concentrations such that only average concentrations of DIN, PFOS, polyaromatic hydrocarbons, chromium (VI) and lead would exceed the EQS values in the final discharged wastewater. Similarly, only maximum concentrations of benzo(g,h,i)-perylene and lead would exceed MAC EQS values.

#### Combined Impacts with Net Zero Teesside Flows

9B.2.15 As with the Main Site, the primary supply of water to the NZT site is from the River Tees and this will have the same chemical profile as the Main Site supply (Section 9B.2: Effluent Pollutant Concentrations – River Tees Source). The River water will undergo concentration, be combined with process effluent streams and surface water runoff and undergo on-site water treatment prior to discharge of NZT final effluent to Tees Bay. This system is still at the design stage but initial estimates for the NZT processes, including water treatment methods, were used to calculate combined effluent flows and loads for both the Main Site and NZT. These will be used to model the cumulative impact of discharges from both sites on water quality in Tees Bay.

9B.2.16 The combined effluent flows and contaminant profile from both the Main Site and NZT site are given in Table 9B-5 for comparison with EQS values (where there is no EQS, the cells are filled in blue). The effluent from the NZT site provides 84% of the combined effluent flows, with the effluent from the Main Site providing a source of additional contaminants due to additional concentration of River Tees Water by the Main Site processes. The addition of surface water runoff from both sites results in a combined stream which is cooler and more dilute. The effluent profiles in Table

9B-5 show that average concentrations of DIN, fluoranthene, PFOS, polyaromatic hydrocarbons, chromium, copper, iron, lead, zinc and diazinon can exceed average annual EQS values in coastal waters when the combined process effluent is discharged from both sites (values highlighted in amber). Maximum combined process effluent concentrations of benzo(b)-fluoranthene, benzo(g,h,i)-perylene, lead and mercury can also exceed MAC EQS values. The addition of surface water from both sites dilutes the combined effluent streams such that only average concentrations of DIN, polyaromatic hydrocarbons, chromium and lead exceed average EQS limits and only maximum concentrations of benzo(g,h,i)-perylene and lead exceed MAC EQS limits.

Table 9B-5: Combined Flows and Pollutant Loads for Modelling Cumulative Impact Discharge Scenarios

PARAMETER	PROCESS EFFLUENT ONLY		SURFACE WATER RUNOFF INCLUDED		EQS	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
Flow Rate (m <sup>3</sup> /s)	0.128	0.128	0.769	0.769		
Temperature (°C)	21.6	21.6	15.0	15.0	3°C above ambient	
pH	7.0	7.0	7.0	7.0	6.0-9.0	9.0
Un-ionised Ammonia	1.04 µg/l	2.43 µg/l	0.11 µg/l	0.40 µg/l	21 µg/l	
Dissolved Inorganic Nitrogen	9.94 mg/l	27.4 mg/l	1.65 mg/l	4.55 mg/l	0.252 mg/l	
Fluoride (dissolved)	0.66 µg/l	2.98 µg/l	0.11 µg/l	0.50 µg/l	500 µg/l	1500 µg/l
Hydrocarbons						
Bentazone	0.024 µg/l	0.024 µg/l	0.004 µg/l	0.004 µg/l	500 µg/l	
Benzo(a)-pyrene	5.8 ng/l	15.6 ng/l	1.0 ng/l	2.6 ng/l		27 ng/l
Benzo(b)-fluoranthene	16.6 ng/l	27.4 ng/l	2.8 ng/l	4.1 ng/l		17 ng/l
Benzo(g,h,i)-perylene	9.4 ng/l	14.6 ng/l	1.6 ng/l	2.4 ng/l		0.82 ng/l
Benzo(k)-fluoranthene	8.2 ng/l	16.3 ng/l	1.4 ng/l	2.7 ng/l		17 ng/l
Fluoranthene	26.1 ng/l	26.1 ng/l	4.3 ng/l	4.3 ng/l	6.3 ng/l	120 ng/l
Hexabromocyclo-dodecane	1.3 ng/l	1.3 ng/l	0.2 ng/l	0.2 ng/l	8.0 ng/l	50 ng/l

PARAMETER	PROCESS EFFLUENT ONLY		SURFACE WATER RUNOFF INCLUDED		EQS	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
PFOS	2.9 ng/l	2.9 ng/l	0.4 ng/l	0.4 ng/l	0.13 ng/l	7200 ng/l
Phenol	0.50 µg/l	0.50 µg/l	0.08 µg/l	0.08 µg/l	7.7 µg/l	46 µg/l*
Polyaromatic Hydrocarbons	19.1 ng/l	59.7 ng/l	2.7 ng/l	8.9 ng/l	0.17 ng/l	
Metals						
Cadmium and its compounds	0.17 µg/l	0.83 µg/l	0.03 µg/l	0.14 µg/l	0.2 µg/l	
Chromium (VI)	6.10 µg/l	17.00 µg/l	1.02 µg/l	2.83 µg/l	0.6 µg/l	32 µg/l*
Copper	6.02 µg/l	14.92 µg/l	1.00 µg/l	2.48 µg/l	3.76 µg/l	
Iron	2.11 mg/l	9.03 mg/l	0.35 mg/l	1.50 mg/l	1 mg/l	
Lead and its compounds	53.4 µg/l	624.6 µg/l	8.90 µg/l	103.8 µg/l	1.3 µg/l	14 µg/l
Mercury and its compounds	0.021 µg/l	0.077 µg/l	0.004 µg/l	0.013 µg/l		0.07 µg/l
Nickel and its compounds	3.99 µg/l	8.69 µg/l	0.66 µg/l	1.44 µg/l	8.6 µg/l	34 µg/l
Zinc	31.95 µg/l	72.88 µg/l	5.31 µg/l	12.1 µg/l	7.9 µg/l	
Pesticides						
Atrazine	0.5 ng/l	0.5 ng/l	0.1 ng/l	0.1 ng/l	600 ng/l	2000 ng/l
Chlortoluron	6.2 ng/l	32.3 ng/l	1.3 ng/l	6.3 ng/l	2000 ng/l	
Diazinon	17.1 ng/l	176.9 ng/l	3.6 ng/l	29.4 ng/l	10 ng/l	260 ng/l
Glyphosate	0.030 µg/l	0.142 µg/l	0.006 µg/l	0.024 µg/l	196 µg/l	398 µg/l
Propyzamide	0.020 µg/l	0.080 µg/l	0.004 µg/l	0.013 µg/l	100 µg/l	1000 µg/l
Terbutryn	1.4 ng/l	1.4 ng/l	0.3 ng/l	0.2 ng/l	6.5 ng/l	34 ng/l

\*EQS given for 95%ile concentrations

## 9B.3 Receiving Environment

### Tees Estuary & Tees Bay Hydrodynamic Model

9B.3.1 Information on the physical environment of Tees Bay has been obtained for the study area from the existing calibrated hydrodynamic model configured using the Delft3D (Deltares) software. This model was developed using the available data (bp, 2021) and is provided in Annex C. The model domain covers the River Tees and extends 10 km offshore and 30 km along the Hartlepool, Redcar and Cleveland coastline, as shown in Plate 9B-3.

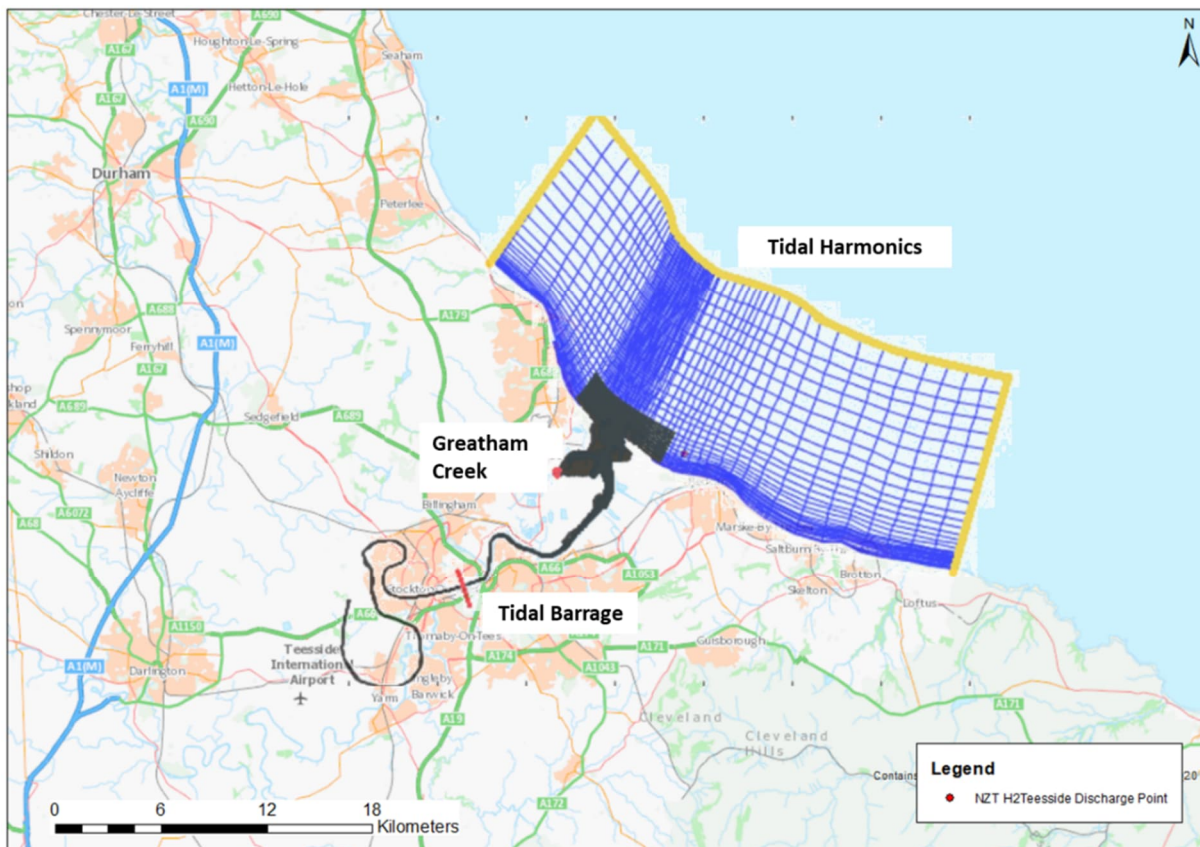


Plate 9B-3: Delft3D hydrodynamic Model Extent

9B.3.2 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 Plate 9B-3) and a coarser grid for the offshore region (blue grid lines in Plate 9B-3). The model uses a vertical layering with eight layers using a sigma coordinate system 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 outlined in Table 9B-6.



Table 9B-6: 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%

9B.3.3 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 Plate 9B-3) 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, n.d.). Peak discharge rates used in the model vary seasonally between 3 m<sup>3</sup>/s (summer) and 74 m<sup>3</sup>/s (winter).
- A continuous inflow of 1.8 m<sup>3</sup>/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.

9B.3.4 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 proposed outfall location.

#### Outfall Location

9B.3.5 Effluent from the Main Site will be discharged via a new outfall to be constructed by the NZT development. 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 red line boundary of the NZT site (see Figure 9B-1).

### Bathymetry

9B.3.6 The bathymetry data for the model has been compiled from a number of sources described in Section A2 of the hydrodynamic modelling report in Annex C. The bed profile extending from the shore towards the proposed outfall location is shown in Plate 9B-4, where zero chainage is at the high tide shoreline (mean high water). The proposed outfall location is at approximately 1,130 m chainage and at -9.4 m AOD.

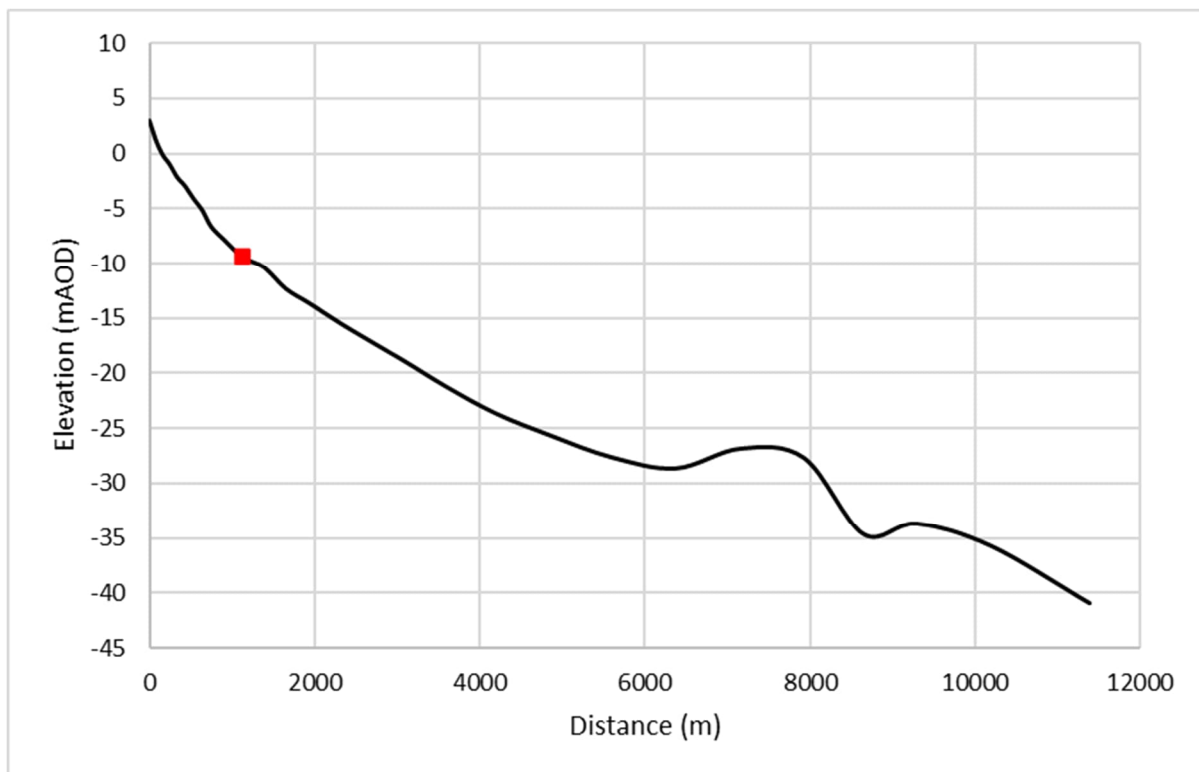


Plate 9B-4: Bed Profile Extending Offshore at Proposed Outfall Location

### Tide Levels and Currents

9B.3.7 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 Plates 9B-5 to 9B-7.

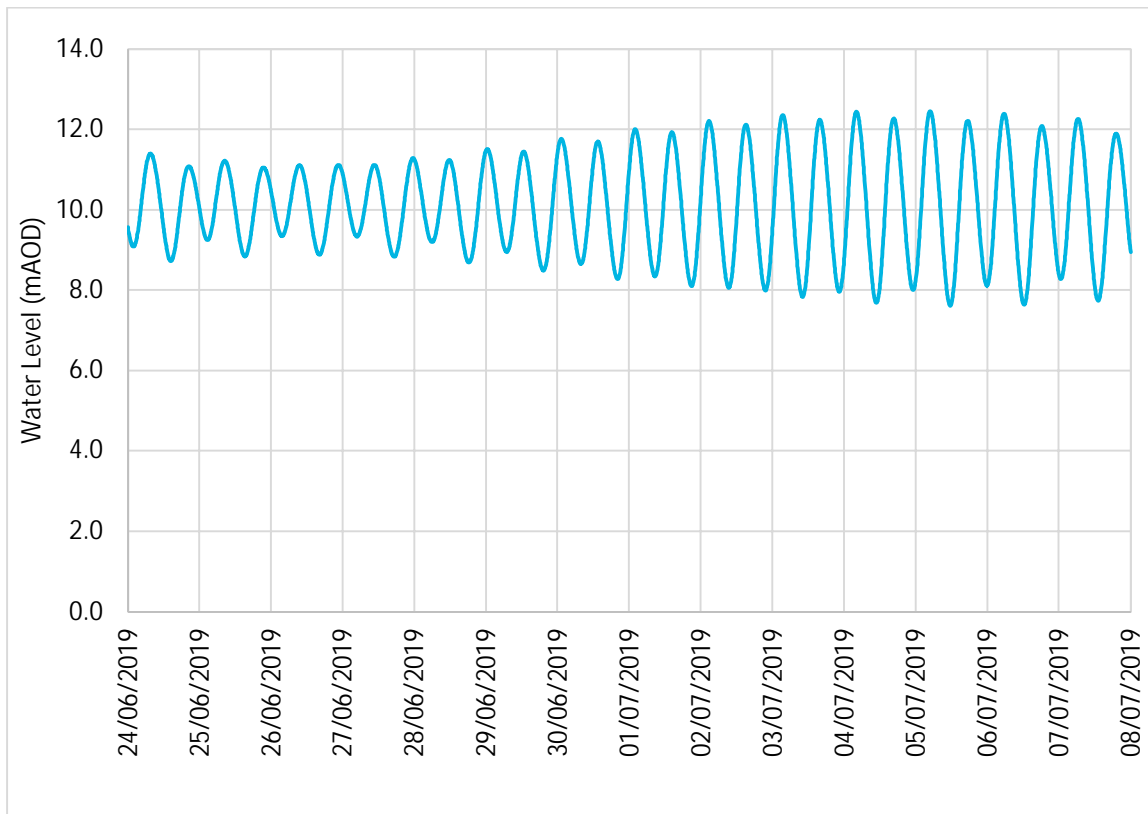


Plate 9B-5: Water Levels at Proposed New Outfall Location

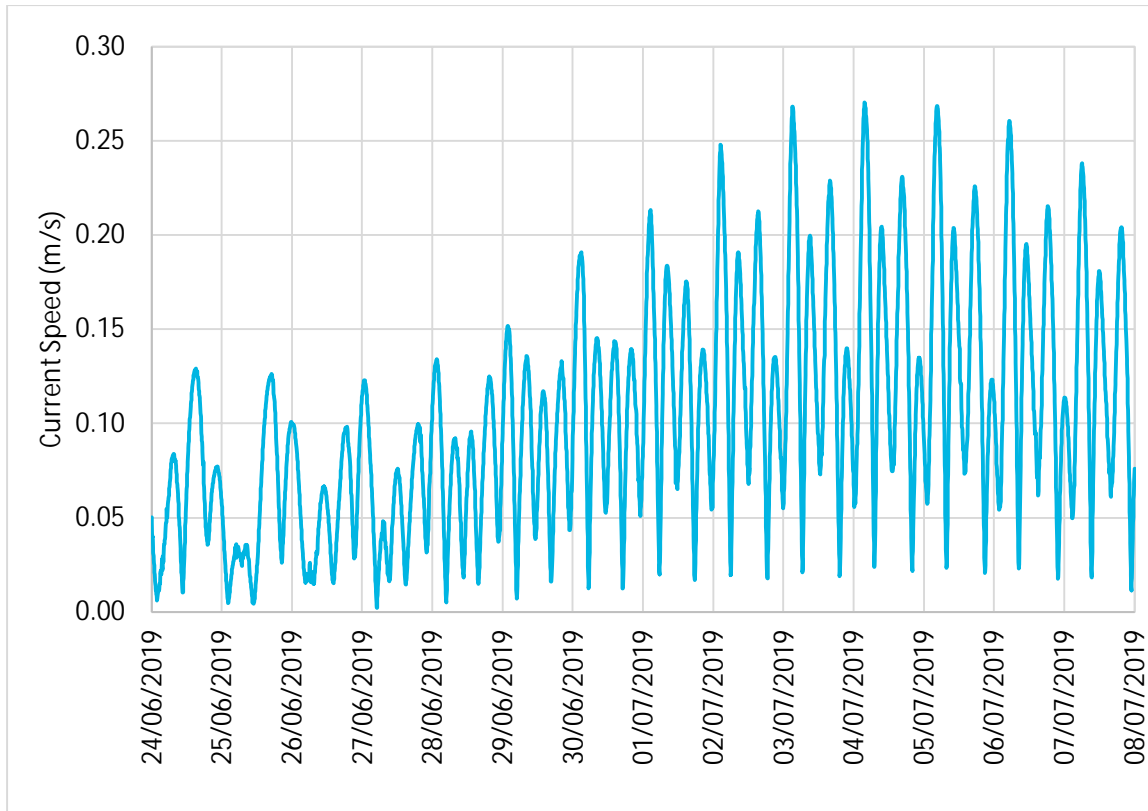


Plate 9B-6: Depth Averaged Current Speeds at the Proposed New Outfall Location

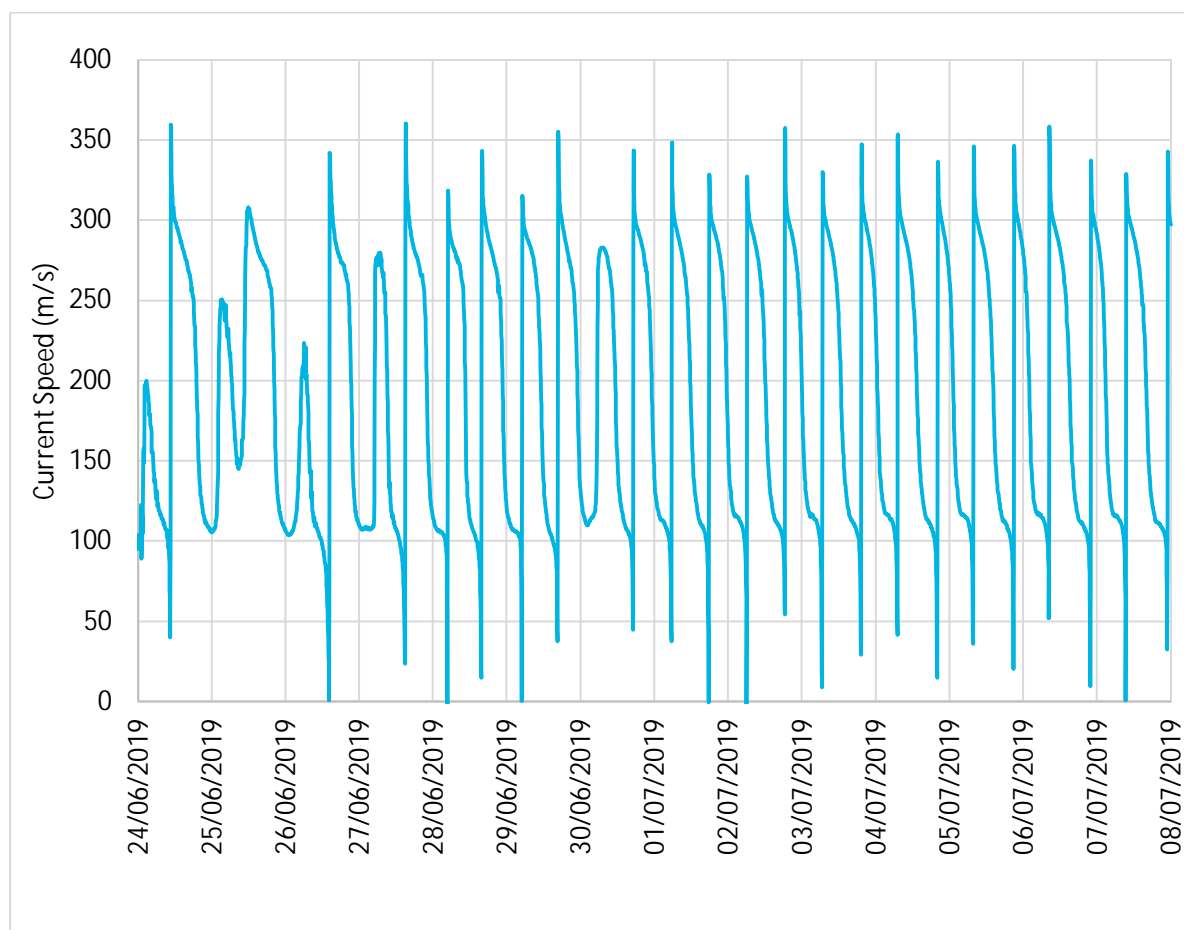


Plate 9B-7: Current Directions at the Proposed New Outfall Location

9B.3.8 Based on the above data, the values for water level, current speed and current direction, as listed in Table 9B-7, have been used in the Cornell Mixing Model software (CORMIX) near field modelling of the proposed new outfall in Section 9B.5.

Table 9B-7: 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	-0.42 (9.3 mAOD)	0.0023	224

Wind Conditions

9B.3.9 The wind speed data for the Delft3D model is described in Section A.3.5 in Annex C. Maximum (5.32 m/s) and minimum (4.08 m/s) average speeds are used to

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represent winter and summer conditions respectively 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 results show that the near field mixing zone is not sensitive to seasonal changes, including in wind speeds over the observed range at Durham Tees Valley Airport.

#### Ambient Water Chemistry

- 9B.3.10 Salinity data for Tees Bay are recorded in the Environment Agency water quality monitoring data and measured at the sampling points shown in Plate 9B-8 (reference 5 in Annex E). The salinity at sample point 'A' varies due to inputs from the River Tees, however salinity at the other sample points in Tees Bay is shown to be relatively constant and varies between 32 and 34 ppt (Plate 9B-9). This shows that the River Tees water becomes mixed and dispersed rapidly within Tees Bay and a single value of 34 ppt will be used in the near field modelling. Average salinity at sample points 'C' and 'D' have been used to calculate the dissolved oxygen EQS of 5.75mg/l in Table 9B-1– this is the EQS for high status as calculated in the UK Water Quality Standards (2015) (reference 2 in Annex E). It is significantly less than the average recorded dissolved oxygen at sample points 'A' to 'G' of 8.95 to 9.16 mg/l, showing that the Tees Bay complies with the requirements for high status in terms of dissolved oxygen concentrations.
- 9B.3.11 The temperature in Tees Bay is shown in Plate 9B-10 to vary between 5°C in winter and 16°C in summer at all sampling points. CORMIX model runs will be carried out to assess the seasonal variation in mixing zone extent.



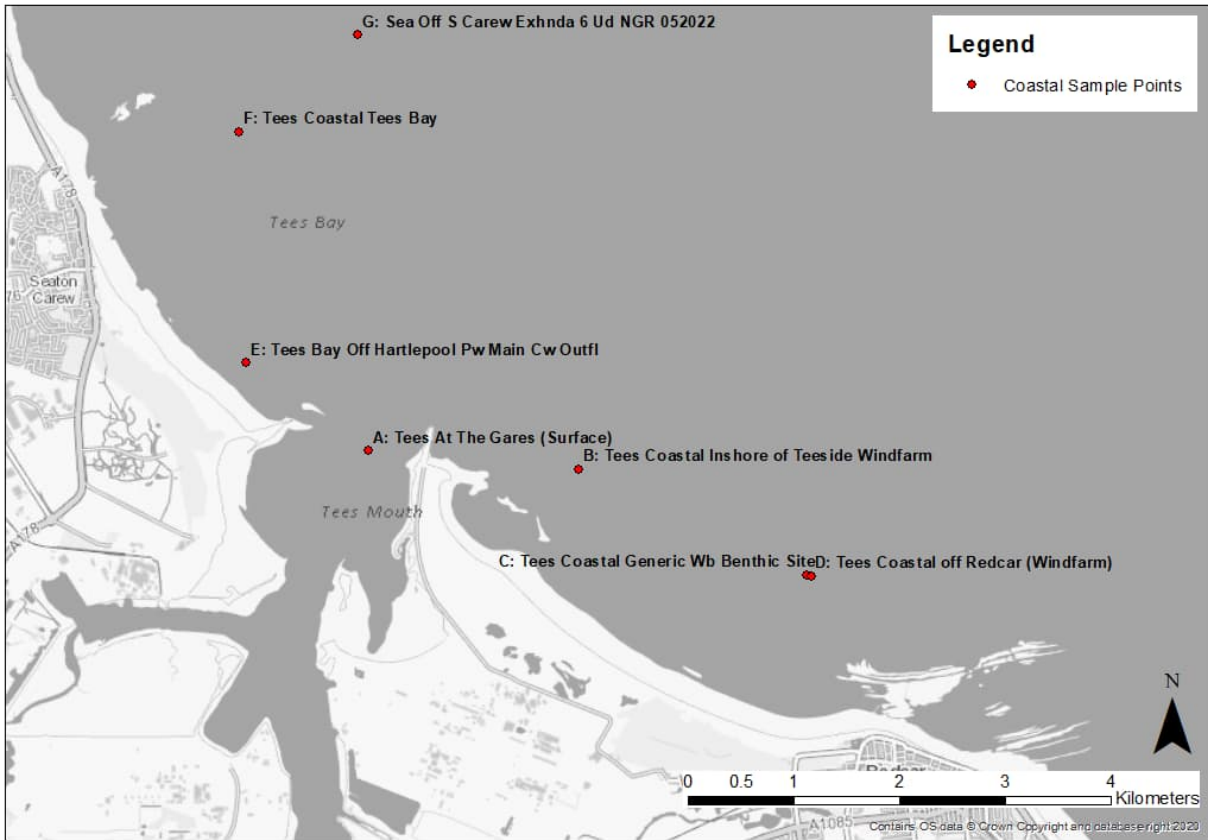


Plate 9B-8: Environment Agency Ambient Water Quality Monitoring Locations

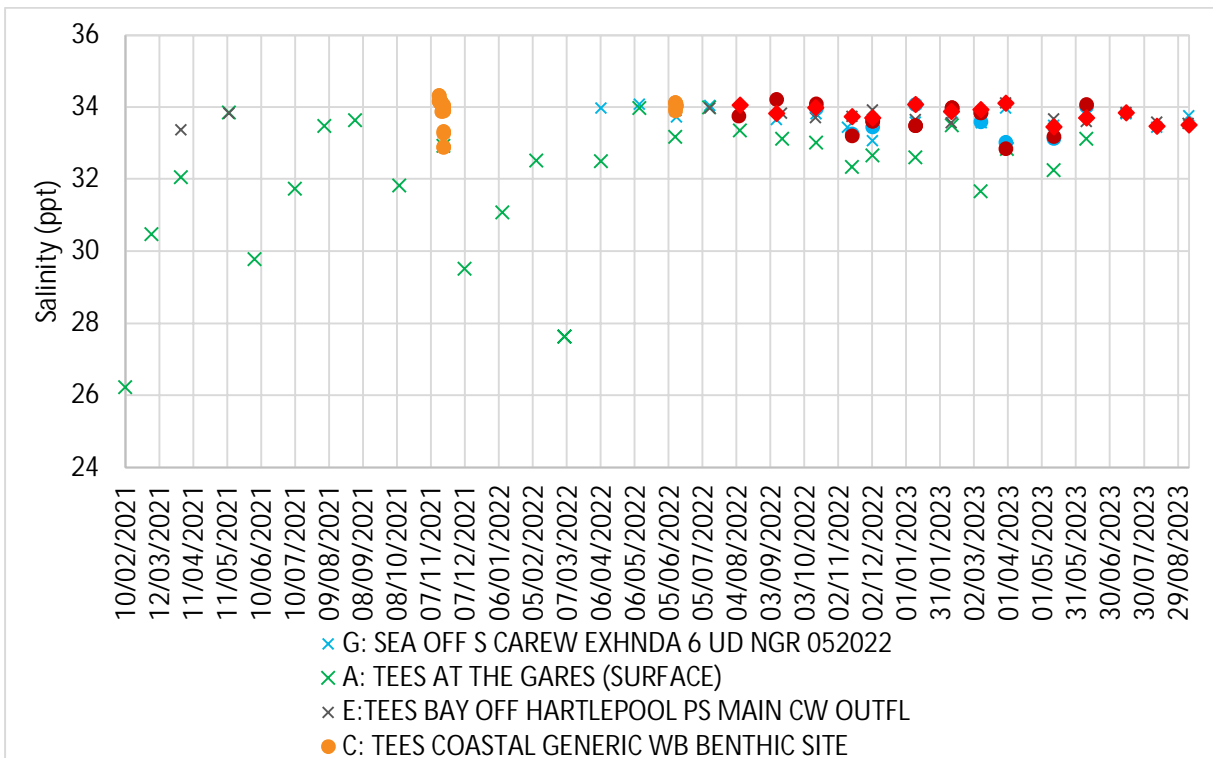


Plate 9B-9: Salinity Data for Tees Bay

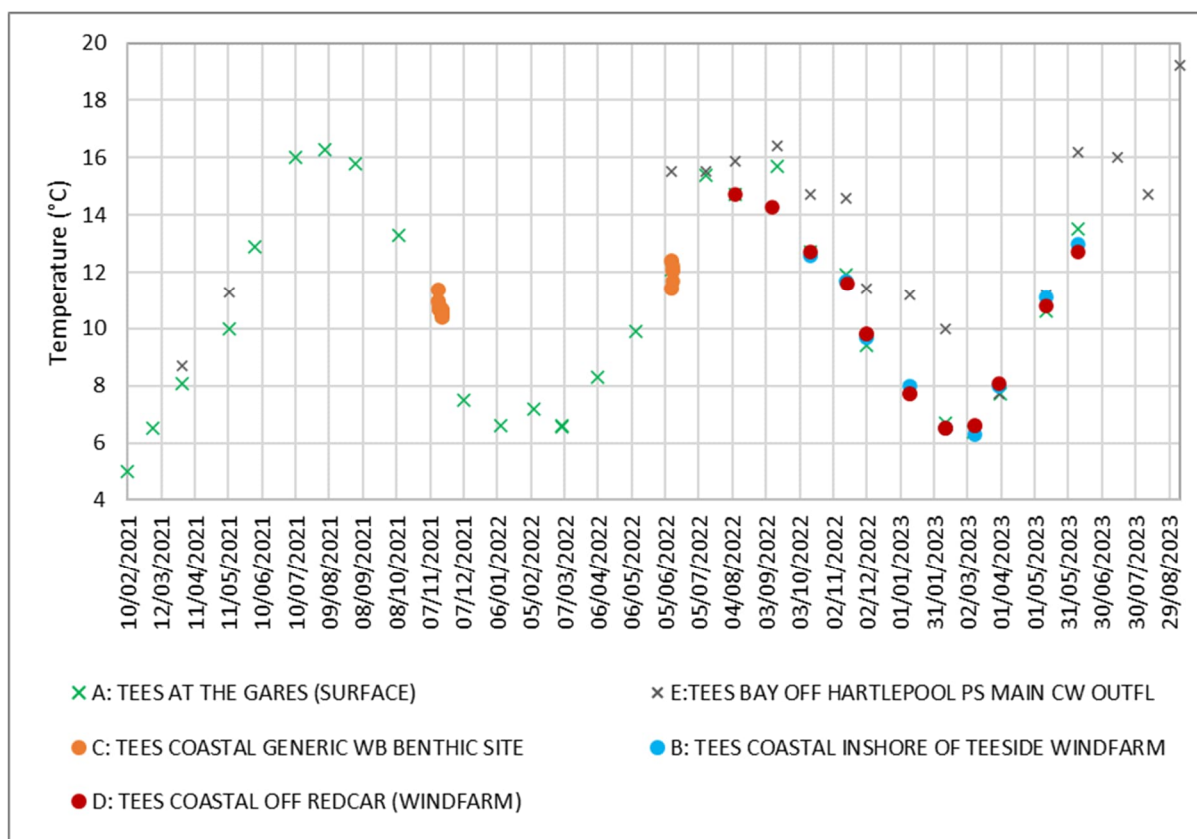


Plate 9B-10: Temperature Data for Tees Bay

9B.3.12 The Environment Agency data for the water quality sampling points shown in Plate 9B-8 have been analysed to obtain suitable ambient water quality values for near field mixing zone modelling. Monitoring for different substances is carried out at different sampling points; monitoring for DIN is only carried out at sample points 'A', 'D', 'G' and 'F' and sampling for other contaminants is mainly carried out at sample points 'A', 'B', 'C' and 'D' with occasional sampling at point 'C'. Table 9B-8 sets out ambient water quality calculated from the available data for all parameters expected to be present in the H2Teesside effluent except DIN. Unionised ammonia concentrations have been calculated from ammonia, pH and temperature data using the equation given in Annex C. No ambient monitoring data are available for Tees Bay for bentazone, phenol, polyaromatic hydrocarbons, iron or pesticides. Older data for sample point 'A' (Environment Agency, (n.d.)) show that dissolved iron (monitored until 2018) and terbutryn (monitored until 2016) were rarely present in detectable concentrations, bentazone (monitored until 2017) was not detected in any sample and phenol and atrazine (both monitored until 2017) were detected in very low concentrations well below the EQS. Ambient concentrations of these parameters are not thought to exceed the EQS at any sample location within Tees Bay. The data show that the receiving environment meets the required EQS standards for all substances and statistics except for maximum concentrations of benzo(g,h,i)-fluoranthene and mean concentrations of PFOS (highlighted in red). These substances are not used to classify the status of waterbodies under the WFD.

Table 9B-8: Ambient Water Quality for Tees Bay Coastal Water (2020-2023)

PARAMETER	EQS	A	B	C	D	E
Temperature (°C)	None	5.00-16.30	6.30-13.00	Not monitored	6.50-14.70	7.70-19.20
pH	6.00-9.00	Not monitored	Not monitored	8.12	Not monitored	Not monitored
Un-ionised Ammonia (µg/l)	Mean = 21.00	2.60	Not monitored	Not monitored	0.74	Not monitored
Dissolved Oxygen (mg/l)	Mean = 5.75	9.16	9.11	9.11	9.03	8.73
Fluoride (dissolved) (mg/l)	Mean = 0.50 MAC = 1.50	1.54	1.50	1.55	1.49	Not monitored
Hydrocarbons						
Bentazone (mg/l)	Mean = 0.50	Not monitored at any location				
Benzo(a)-pyrene (ng/l)	MAC = 27.00	1.90	2.80	0.35	1.50	Not monitored
Benzo(b)-fluoranthene (ng/l)	MAC = 17.00	1.80	2.20	0.33	1.30	Not monitored
Benzo(g,h,i)-perylene (ng/l)	MAC = 0.82	1.50	2.00	0.26	1.40	Not monitored
Benzo(k)-fluoranthene (ng/l)	MAC = 17.00	0.94	1.20	0.18	0.70	Not monitored
Fluoranthene (ng/l)	Mean = 6.30 MAC = 120.00	Mean = 5.17 MAC = 24.00	Mean = 3.29 MAC = 6.70	Mean = 0.99 MAC = 1.30	Mean = 2.50 MAC = 5.70	Not monitored
Hexabromocyclo-dodecane (ng/l)	Mean = 8.00 MAC = 50.00	Not monitored	Not monitored	None detected	Not monitored	Not monitored
PFOS (ng/l)	Mean = 0.13 MAC = 7,200.00	Mean = 0.59 MAC = 1.50	Mean = 0.31 MAC = 0.71	Mean = 0.12 MAC = 0.17	Mean = 0.25 MAC = 0.45	Not monitored
Phenol (µg/l)**	Mean = 7.70 95%ile = 46.00	Not monitored at any location				
Polyaromatic Hydrocarbons (ng/l)	MAC = 0.17ng/l	Not monitored at any location				
Metals (dissolved)						
Cadmium (µg/l) and its compounds	Mean = 0.20	None detected	None detected	None detected	0.018	Not monitored
Chromium (VI) (µg/l)	Mean = 0.60 95%ile = 32.00	None detected	Not monitored	Not monitored	Not monitored	None detected
Copper (µg/l)	Mean = 3.76	0.48	0.56	0.82	0.63	Not monitored
Iron (mg/l)	Mean = 1.00	Not monitored at any location				

PARAMETER	EQS	A	B	C	D	E
Lead (µg/l) and its compounds	Mean = 1.30 MAC = 14.00	Mean = 0.12 MAC = 0.34	Mean = 0.08 MAC = 9.23	Mean = 0.06 MAC = 0.08	Mean = 0.08 MAC = 0.11	Not monitored
Mercury (µg/l) and its compounds	MAC = 0.07	None detected	None detected	None detected	None detected	Not monitored
Nickel (µg/l) and its compounds	Mean = 8.60 MAC = 34.00	Mean = 0.40 MAC = 0.82	Mean = 0.36 MAC = 0.55	Mean = 0.24 MAC = 0.34	Mean = 0.24 MAC = 0.44	Mean = 0.28 MAC = 0.44
Zinc (µg/l)	Mean = 7.90	1.73	1.24	1.23	1.28	Not monitored
Pesticides						
Atrazine (µg/l)	Mean = 0.60 MAC = 2.00	Not monitored at any location				
Chlortoluron (µg/l)	Mean = 2.00	Not monitored at any location				
Diazinon (ng/l)	Mean = 10.00 MAC = 260.00	Not monitored at any location				
Glyphosate (µg/l)	Mean = 196.00 MAC = 398.00	Not monitored at any location				
Propyzamide (µg/l)	Mean = 100.00 MAC = 1,000.00	Not monitored at any location				
Terbutryn (ng/l)	Mean = 6.50 MAC = 34.00	Not monitored at any location				

9B.3.13 Ambient DIN concentrations are calculated in accordance with the WFD standards: (HM Government, 2015): winter (1 November to 28 February) DIN concentrations are plotted against the corresponding salinity at each sample point. 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 34 ppt. This gives an ambient winter DIN concentration at this salinity value of 0.196 mg/l at sample point D which is closest to the proposed discharge point. This is between the high and good class thresholds of 0.168 mg/l and 0.252mg/l in Table 9B-2. On this basis the current classification of Tees Bay at the proposed discharge point would be good with respect to DIN and exceeding the threshold of 0.252 mg/l would result in a class deterioration to moderate water quality. A value of 0.252 mg/l has therefore been used as an EQS limit for DIN in Tees Bay.

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## 9B.4 Initial Screening and Effective Volume Flux Calculation

### Initial EQS Screening

9B.4.1 Final discharged effluent values in Tables 9B-4 and 9B-5 have been compared with EQS values. Further assessment of the environmental impacts of discharging substances below EQS concentrations is not required because no exceedance of the EQS will occur in Tees Bay. Further assessment is only required for substances highlighted in amber in Tables 9B-4 and 9B-5, with the final list of substances requiring further assessment, the final discharge concentrations and the EQS values presented in Table 9B-9. Values highlighted in amber exceed the EQS and where there is no EQS value the cells are filled in blue. Further assessment is required for DIN, benzo(b)-fluoranthene, benzo(g,h,i)-perylene, fluoranthene, PFOS, polyaromatic hydrocarbons, chromium, copper, iron, lead, mercury, zinc and diazinon.

### Effective Volume Flux

9B.4.2 The Environment Agency guidance for assessing coastal discharge impacts (Environment Agency, 2022) sets out the procedure for calculating effective volume flux. This test is applied to substances discharged at concentrations exceeding the EQS and for discharge points which are in more than 1 m depth of water and more than 50 m offshore. If the effective volume flux is less than the allowable limit then the impacts on water quality will be minimal due to extensive dilution by ambient water and further assessment (modelling) is not required. The allowable volume flux is determined by water depth up to a depth of 3.5 m and is retained at a value of 3.5 for deeper discharge points. The proposed discharge point will be more than 3.5 m below the water surface at all stages of the tide (Section 9B.3) and therefore an allowable volume flux of 3.5 applies to this discharge.

9B.4.3 The effective volume flux is calculated as:

$$\text{Effective volume flux} = \frac{\text{discharge rate (m}^3\text{s}^{-1}) \times \text{contaminant concentration } (\mu\text{gl}^{-1})}{\text{EQS } (\mu\text{gl}^{-1}) - \text{ambient concentration } (\mu\text{gl}^{-1})}$$

9B.4.4 The effective volume flux is based on the mass of pollutant released (discharge rate x concentration). Since the pollutant mass for both sites is derived from the process effluent only and not from the surface water runoff component, the effective volume flux is the same for both the process effluent only and scenarios which include the surface water runoff contribution to effluent flows.

9B.4.5 Table 9B-10 shows the calculation of effective volume flux for contaminants discharged at concentrations above the EQS for each site and for both sites in combination. The flows and concentrations for the process effluent only scenarios have been used but the values are the same if the surface water runoff component is added to each stream. Values exceeding 3.5 are highlighted in orange and these parameters will be taken forward for further modelling. Ambient data are not available for polyaromatic hydrocarbons, iron and diazinon however, analysis of the available data in Section 9B.3: Ambient Water Quality indicates that these will not be present in Tees Bay at concentrations above the EQS. An ambient concentration

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of half the EQS value has been assumed for the purposes of this assessment. The ambient data also show that all samples from Tees Bay which were analysed for chromium and mercury returned concentrations below the limit of detection. Ambient concentrations equal to half of the LOD have been assumed for these substances.

- 9B.4.6 Table 9B-10 shows that only DIN, polyaromatic hydrocarbons and lead (for NZT and cumulative scenarios only) must be taken forward for modelling. Effective volume flux calculations cannot be carried out for benzo(g,h,i)-perylene or PFOS because the EQS values for these parameters are already exceeded in Tees Bay. Modelling will be carried out for these two additional parameters to determine the area over which the discharge may increase local concentrations by more than 5% above ambient.

Table 9B-9: Initial Screening Assessment Data: Contaminants Present in Effluent Above EQS

CONTAMINANT	H2TEESSIDE				H2TEESSIDE AND NZT				EQS	
	PROCESS EFFLUENT ONLY		SURFACE WATER RUNOFF INCLUDED		PROCESS EFFLUENT ONLY		SURFACE WATER RUNOFF INCLUDED			
	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM
Dissolved Inorganic Nitrogen (mg/l)	15.0	15.0	1.4	1.4	10.0	27.5	1.7	2.6	0.252	
Benzo(b)-fluoranthene (ng/l)	18.4	27.4	1.8	2.7	16.6	27.4	2.8	4.1		17.0
Benzo(g,h,i)-perylene (ng/l)	10.4	16.2	1.0	1.6	9.4	14.6	1.6	2.4		0.82
Benzo(k)-fluoranthene (ng/l)	9.1	18.1	0.9	1.8	8.2	16.3	1.4	2.7		17.0
Fluoranthene (ng/l)	28.9	28.9	2.9	2.9	26.1	26.1	4.3	4.3	6.3	120.0
PFOS (ng/l)	2.9	2.9	0.3	0.3	2.9	2.9	0.4	0.4	0.13	7200.0
Polyaromatic Hydrocarbons (ng/l)	19.1	59.7	1.8	5.9	19.1	59.7	2.7	8.9	0.17	
Cadmium and its compounds (dissolved) (µg/l)	0.2	0.9	0.02	0.09	0.2	0.8	0.03	0.14	0.2	
Chromium (VI) (µg/l)	6.8	18.9	0.7	1.9	6.1	17.0	1.0	2.8	0.6	32.0
Copper (dissolved) (µg/l)	6.7	16.6	0.7	1.6	6.0	14.9	1.0	2.5	3.76	
Iron (dissolved) (mg/l)	2.3	10.0	0.2	1.0	2.1	9.0	0.4	1.5	1	
Lead and its compounds (dissolved) (µg/l)	59.5	693.6	5.9	68.4	53.6	625.0	8.9	103.8	1.3	14
Mercury and its compounds (dissolved) (µg/l)	0.02	0.09	0.002	0.01	0.02	0.1	0.004	0.01		0.07
Zinc (µg/l)	35.5	80.9	3.5	8.0	32.0	72.9	5.3	12.1	7.9	
Diazinon (ng/l)	18.9	196.5	1.9	19.4	17.1	176.9	3.6	29.4	10	260



Table 9B-10: Effective Volume Flux Calculations

PARAMETER	H2TEESSIDE EFFLUENT QUALITY		COMBINED SITES EFFLUENT QUALITY		AMBIENT TEES BAY QUALITY		EQS		H2TEESSIDE EFFECTIVE VOLUME FLUX		COMBINED SITES EFFECTIVE VOLUME FLUX	
	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM
Flow Rate (m <sup>3</sup> /s)	0.021	0.021	0.128	0.128								
Dissolved Inorganic Nitrogen (mg/l)	15.0	15.0	10.0	27.5	0.196	0.249	0.252		5.6		22.7	
Benzo(b)-fluoranthene (ng/l)	18.4	27.4	16.6	27.4	0.2	1.3		17.0		0.03		0.2
Benzo(k)-fluoranthene (ng/l)	9.1	18.1	8.2	16.3	0.4	0.7		17.0		0.02		0.1
Fluoranthene (ng/l)	28.9	28.9	26.1	26.1	2.5	5.7	6.3	120.0	0.2	0.01	0.9	0.03
Polyaromatic Hydrocarbons (ng/l) <sup>1</sup>	19.1	59.7	19.1	59.7	0.09	0.09	0.17		4.5		24.0	
Cadmium and its compounds (dissolved) (µg/l)	0.2	0.9	0.2	0.8	0.02	0.04	0.20		0.002		0.01	
Chromium (VI) (µg/l) <sup>2</sup>	6.8	18.9	6.1	17.0	0.13	0.13	0.60	32.0	0.3	0.01	1.6	0.07
Copper (dissolved) (µg/l)	6.7	16.6	6.0	14.9	0.6	1.9	3.76		0.05		0.3	
Iron (dissolved) (mg/l) <sup>1</sup>	2.3	10.0	2.1	9.0	0.5	0.5	1.0		0.10		0.5	
Lead and its compounds (dissolved) (µg/l)	59.5	693.6	53.6	624.6	0.08	0.1	1.3	14.0	1.1	1.1	5.6	5.8

PARAMETER	H2TEESSIDE EFFLUENT QUALITY		COMBINED SITES EFFLUENT QUALITY		AMBIENT TEES BAY QUALITY		EQS		H2TEESSITE EFFECTIVE VOLUME FLUX		COMBINED SITES EFFECTIVE VOLUME FLUX	
	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM
Mercury and its compounds (dissolved) (µg/l) <sup>2</sup>	0.02	0.09	0.02	0.08	0.005	0.005		0.07		0.03		0.2
Zinc (µg/l)	35.5	80.9	32.0	72.9	1.3	1.8	7.9		0.1		0.6	
Diazinon (ng/l) <sup>1</sup>	18.9	196.5	17.1	176.9	5.0	130.0	10.0	260.0	0.08	0.03	0.4	0.2

<sup>1</sup>No ambient data, concentrations assumed as 50% of the EQS

<sup>2</sup>No detections in ambient data, ambient concentrations assumed as 50% of the limit of detection

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## 9B.5 Water Quality Modelling

- 9B.5.1 The Delft3D model described in Section 9B.3 has been used to provide inputs describing hydrodynamic conditions to a near field model which shows the area over which pollutants are diluted during the initial rapid phase of turbulent mixing following discharge of the buoyant effluent plume into the higher density water of Tees Bay. The CORMIX model (developed and maintained by MixZon Inc.) has been used to simulate this stage of mixing.
- 9B.5.2 The CORMIX modelling shows that the EQS concentrations for pollutants are reached within the near field for most modelled scenarios, however the model has difficulty producing reliable results for minimum ambient current conditions. The Delft3D far field model will be used to simulate mixing under these conditions and also to show the average and maximum increase in DIN above background conditions given the complex rotating tidal currents in this region. The far field model will not take account of the rapid dilution and mixing within the near field and may slightly overestimate pollutant concentrations arising from the discharge, however the results in Section 9B.6 show that the near field mixing zones are small and this limitation does not change the conclusions of this study.
- 9B.5.3 Based on the results of the effective volume flux calculations in Section 9B.4, the water quality models will be used to calculate mixing zones for temperature, DIN, polyaromatic hydrocarbons, benzo(g,h,i)-perylene and PFOS. Modelled for lead will be carried out for assessment of cumulative impacts with NZT discharges. Mixing zones will be defined based on the distance over which temperature is reduced to 3°C above ambient and over which concentrations of DIN, polyaromatic hydrocarbons and lead are diluted to below the EQS. Given elevated ambient concentration of benzo(g,h,i)-perylene and PFOS, mixing zones will be defined for these parameters based on an increase of 5% above ambient.

### CORMIX Input Data

- 9B.5.4 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.

### Outfall Representation

- 9B.5.5 The design of the new outfall will be finalised at a later point in the NZT site design process, however an initial design has been developed as described below. The initial design consists of a multiport diffuser with a total length of 30 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 as close to 90° to the prevailing current direction given the fully reversing current directions shown in Section 9B.3. The initial diffuser design is shown in Plate 9B-11.



Plate 9B-11: Initial Diffuser Design Illustration

### Ambient Geometry

9B.5.6 The following parameters must be specified in CORMIX to characterise the ambient geometry at a coastal water outfall: average depth; depth at the discharge, current velocity 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 Section 9B.3 and are set out in Table 9B-7. A Manning's  $n$  value of 0.025 has been used to represent the low resistance to flow within this area of Tees Bay.

### Ambient Density

9B.5.7 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 9B-11.

Table 9B-11: Ambient Water Density used in CORMIX

SCENARIO	TEMPERATURE (°C)	SALINITY (PPT)	DENSITY (kg/m <sup>3</sup> )
Winter	5	32	1025.3
Summer	16	32	1023.4

9B.5.8 A winter heat loss coefficient of 42 W/m<sup>2</sup>,°C has been used in the modelling while the summer heat loss coefficient is 44 W/m<sup>2</sup>,°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.

### Presentation of CORMIX Results

9B.5.9 Near field 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 second 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.

9B.5.10 Current velocities at the proposed outfall location are relatively low, however they vary by a factor of more than 100. In addition, the ports on the diffuser in Plate 9B-12 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 low current and discharge rate conditions, the model combines the mixing zone from each pair of ports and resolves the dimensions of the resulting three individual plumes (Plate 9B-12).

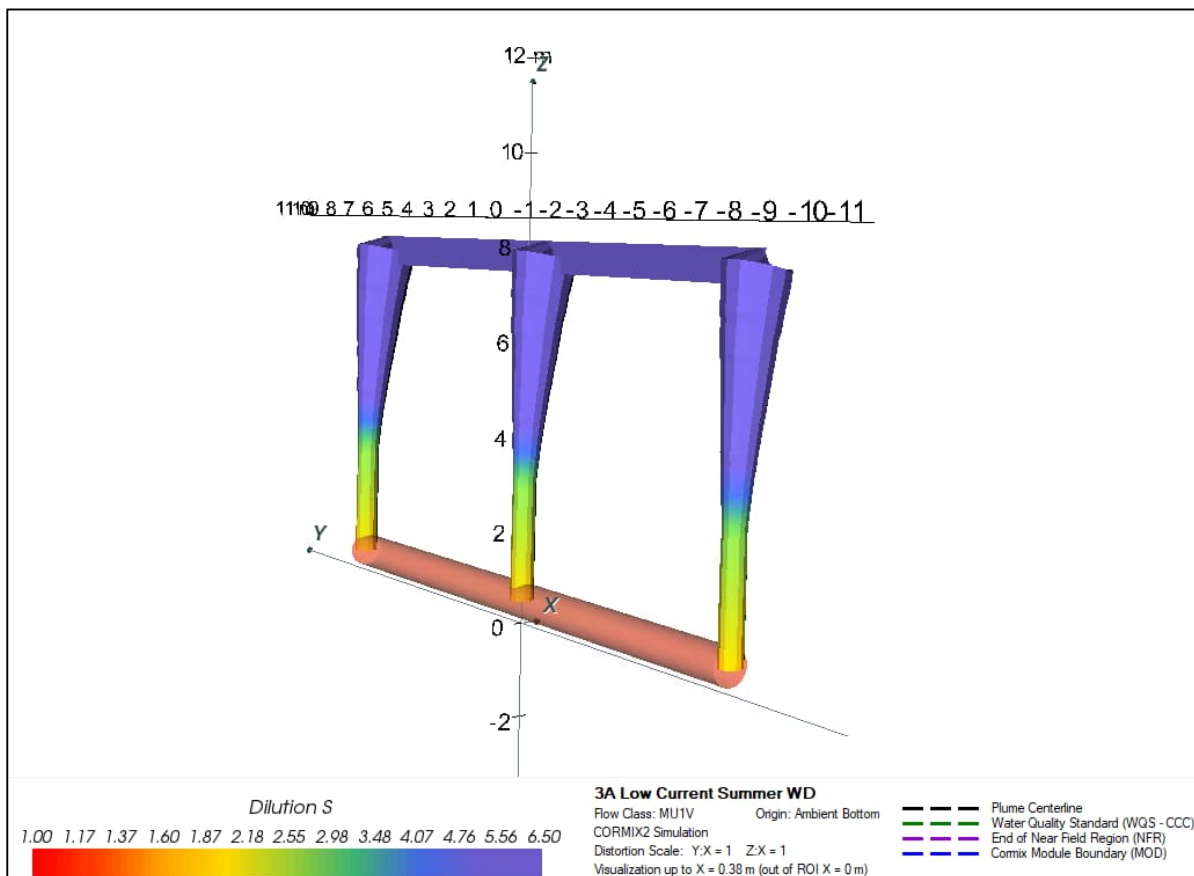


Plate 9B-12: CORMIX Vertical Mixing Stage Visualisation Output for Low Current Conditions

As ambient current speeds increase, CORMIX models how the plumes are deflected and spread through a greater vertical depth of the water column (Plate 9B-13). The plumes combine and become vertically fully mixed close to the point where the mixing zone reaches the water surface.

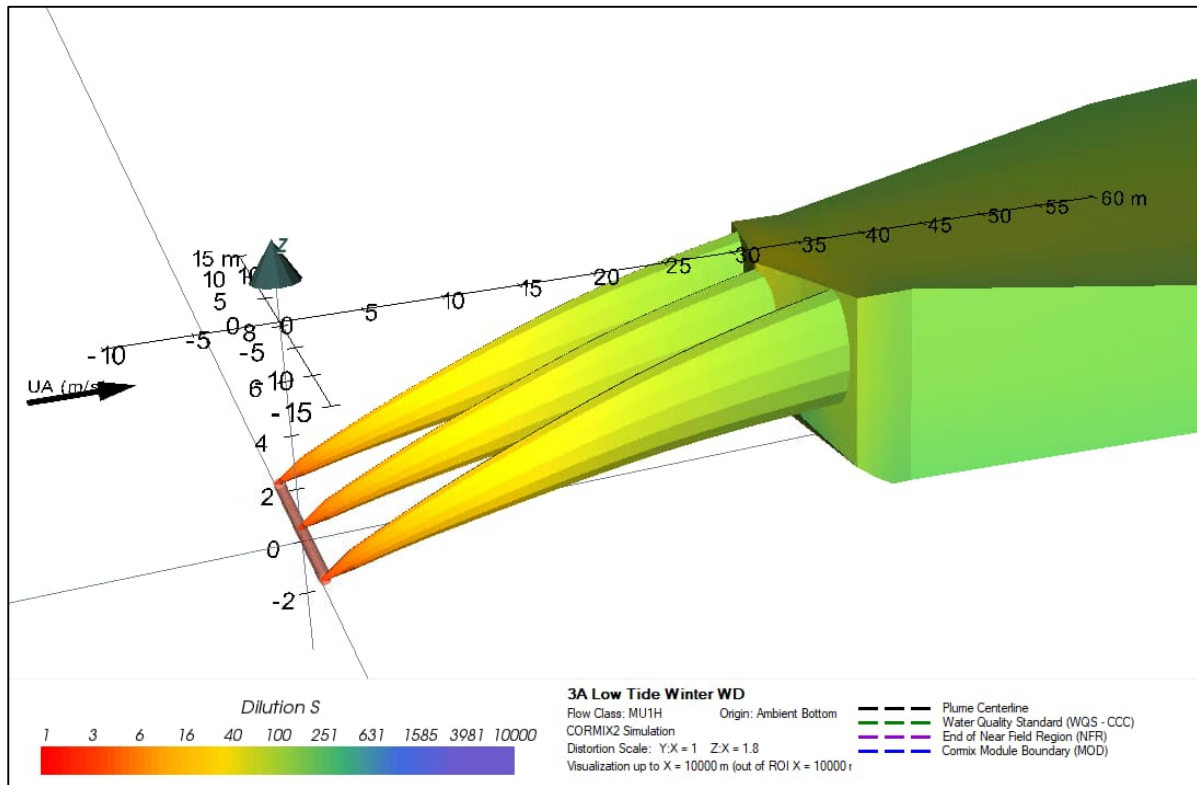


Plate 9B-13: CORMIX Visualisation Output for Low Tide Conditions

At higher current speeds and discharge volumes, the plumes undergo rapid turbulent 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 (Plate 9B-14). Given the relatively short length of the diffuser, this approximation is considered to be acceptable.

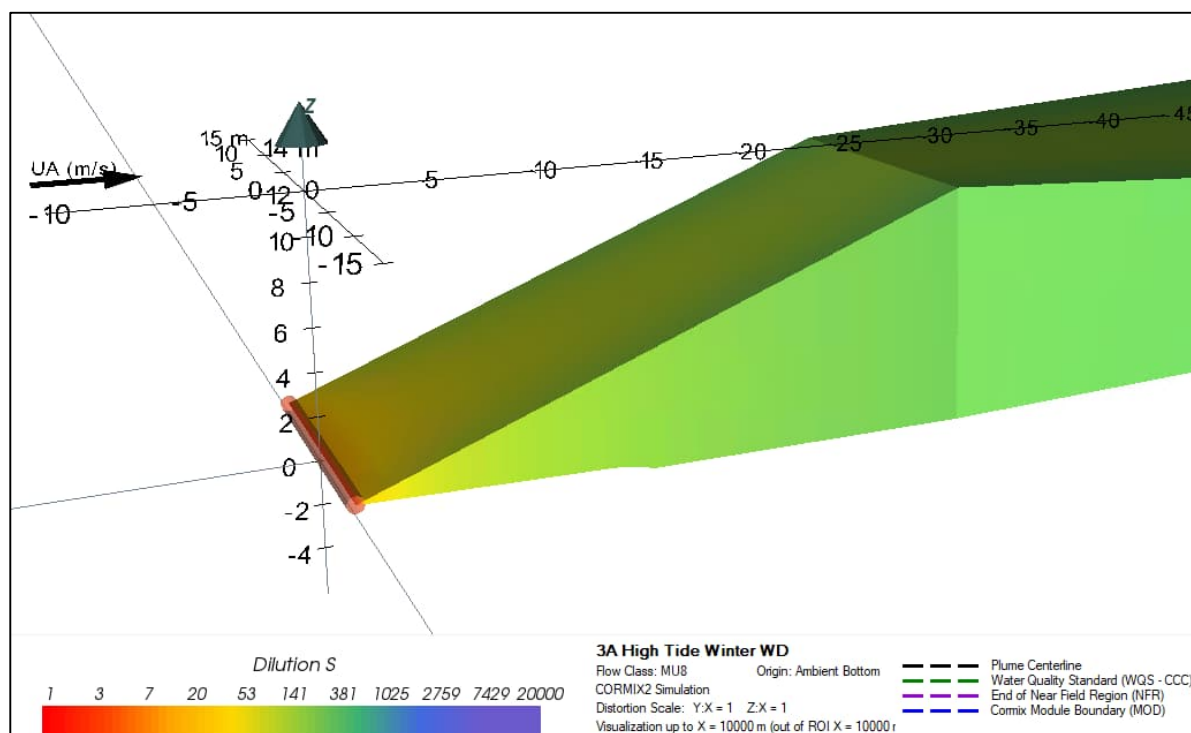


Plate 9B-14: CORMIX Visualisation Output for High Tide and High Current Conditions

9B.5.11 The CORMIX modelling results are presented in Section 9B.6 in terms of the vertical height of the top of the mixing plume above the outfall, the lateral distance travelled by the plume to the point where the EQS is reached, and the cross section width of the mixing zone plume at this location. If the EQS is met in the surface spreading stage then the cross section width is measured at the water surface.

#### Far Field Model Scenarios

9B.5.12 The CORMIX model is unable to provide a realistic representation of the surface spreading stage under minimum current conditions. The model is able to resolve the initial rising stage of mixing in the near field and this is sufficient to provide mixing zone dimensions for most substances when considering the Main Site discharges in isolation and for temperature when considering discharges from both the Main Site and NZT sites via the NZT outfall. The addition of effluent from the NZT site results in concentrations of dissolved contaminants reaching the water surface at concentrations exceeding the EQS and the CORMIX model cannot provide a realistic surface mixing zone dimension under these conditions.

9B.5.13 The Delft3D model has therefore been used to show mixed concentrations of dissolved pollutants based on far field modelling of mixing at the proposed outfall location under the absolute minimum current conditions (0.0023 m/s, with a corresponding water depth over the outfall of 9.34 m and a current direction of 224.2°, occurring on 27 June 2019 at 05.00. Full details of the far field model setup and representation of the outfalls and ambient conditions are provided in Annex B – the model was used without editing any of the model parameters or input data except for vertical layer spacing (Table 9B-6), discharge flow rate and effluent



concentration. The effluent was modelled as a conservative tracer using DIN concentrations and the model was run to identify mixing zone concentrations through the water column and laterally within Tees Bay. The results were then adjusted based on the pollutant concentration ratio to reflect dilution of polyaromatic hydrocarbons, benzo(g,h,i)-perylene, lead and PFOS, as required.

9B.5.14 In addition, the Delft3D model shows that the complex prevailing currents in the vicinity of the proposed discharge point can recirculate water and mixing effluent within the Tees Bay area and this can result in elevated concentration of pollutants developing within the shallower areas along the shoreline. The prevailing current directions and circulation patterns are shown in Plate 9B-15. The model has therefore been run over multiple tidal cycles to show if there will be any significant increase in maximum and average pollutant concentrations across Tees Bay following all tidal cycles included within the far field model. This allows an assessment of whether recirculation of pollutants will result in accumulating pollutant concentrations in excess of the EQS values.

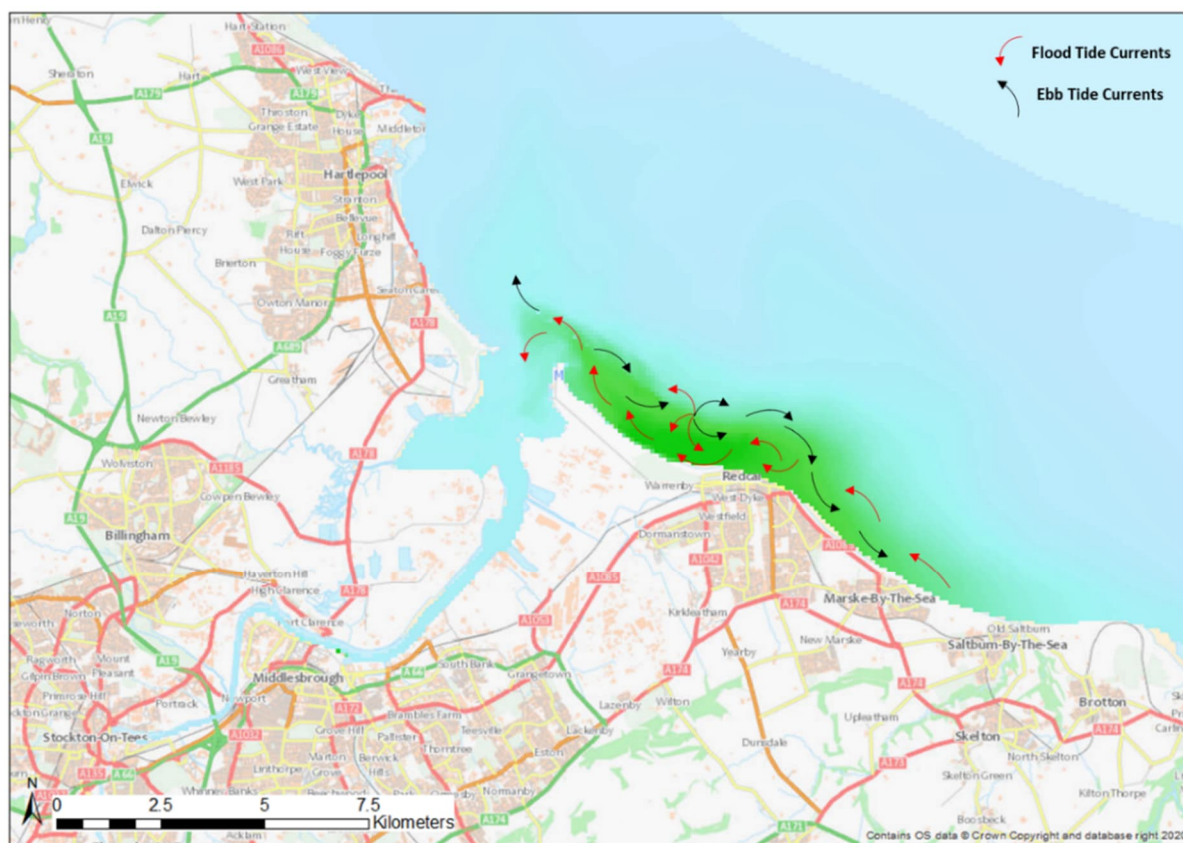


Plate 9B-15: Simplified Representation of Tees Bay Current Conditions around NZT / Main Site Coastal Outfall

9B.5.15 The Delft3D model was run for six discharge scenarios as summarised in Table 9B-12. A constant flow rate and effluent concentration (calculated as set out in Tables 9B-4, 9B-5 and 9B-6) 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.

Table 9B-12: Discharge Scenario Input Data for Delft3D Model

SCENARIO NUMBER	DESCRIPTION	FLOW (m <sup>3</sup> /s)	TEMPERATURE (°C)	EFFLUENT DIN CONCENTRATION (kg/m <sup>3</sup> )
1	H2 Teesside process effluent only, no surface water	0.021	30.0	0.0150
2	H2 Teesside process effluent with surface water	0.218	15.0	0.00007
3	H2Teesside and NZT sites process effluent only	0.128	21.6	0.0099
4	H2Teesside and NZT process effluent and surface water	0.769	15.5	0.0010

9B.5.16 The model outputs represent a worst-case scenario because the model does not 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.

## 9B.6 Water Quality Modelling Results

9B.6.1 The sub-section below, “Main Site Discharges Only” describes the size of the near and far field mixing zones for temperature and contaminant concentrations for summer and winter conditions, taking into account process discharges from the Main Site in isolation and in combination with surface water runoff from the Main Site (Scenarios 1 and 2 in Table 9B-12). The following sub-section, “Cumulative Impacts with NZT,” sets out the results of modelling the combined discharges from both the Main site and the NZT sites, with and without a contribution from surface water (Scenarios 3 and 4). The final section “Full Tidal Cycle Results” sets out the results of modelling over repeated tidal cycles to check for accumulation of pollutants within Tees Bay.

### Main Site Discharges Only

9B.6.2 Table 9B-13 sets out the results of the near field modelling with consideration of effluent streams from the Main Site processes only, excluding surface water runoff and contributions from the NZT site. The exit velocity at each port under the current diffuser design is only 0.018 m/s, which is extremely low because the outfall has been designed to manage the much larger flows from the NZT site and surface water runoff contributions. 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. The dimensions given are for each of the three mixing zones from the three pairs of ports on the diffuser pipeline. Mixing zones are based on average EQS

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values for all substances except benzo(g,h,i)-perylene for which a MAC EQS value applies.

Table 9B-13: CORMIX Near Field Modelling Results (Main Site Effluent Only)

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)	
Winter	Low Tide	Height above outfall	7.6	5.8	5.7	5.7	3.2	
		Distance from outfall	14.2	12.9	12.3	12.4	0.1	
		Plume Cross Section Width	9.0	1.4	1.4	1.4	0.3	
	High Tide	Height above outfall	4.8	4.5	4.4	4.4	0.8	
		Distance from outfall	20.8	18.3	17.5	17.5	0.6	
		Plume Cross Section Width	1.2	1.1	1.1	1.1	0.2	
	Maximum Current	Height above outfall	4.8	4.5	4.3	4.3	0.8	
		Distance from outfall	21.2	18.3	18.1	18.1	0.6	
		Plume Cross Section Width	1.2	1.1	1.1	1.1	0.2	
	Low Current	Height above outfall	See far field model results					3.2
		Distance from outfall						0.1
		Plume Cross Section Width						0.3
Summer	Low Tide	Height above outfall	7.6	5.8	5.6	5.6	1.0	
		Distance from outfall	15.0	13.3	12.8	12.8	0.5	
		Plume Cross Section Width	9.0	1.4	1.4	1.4	0.2	
	High Tide	Height above outfall	4.9	4.5	4.4	4.4	0.8	
		Distance from outfall	21.0	19.0	18.0	18	0.6	
		Plume Cross Section Width	1.2	1.1	1.1	1.1	0.2	

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)
	Maximum Current	Height above outfall	4.8	4.5	4.3	4.3	0.8
		Distance from outfall	21.0	19.4	18	18	0.6
		Plume Cross Section Width	1.2	1.1	1.1	1.1	0.1
	Low Current	Height above outfall	8.4	9.0	9.0	9.0	2.5
		Distance from outfall	40.0	32.0	30	30	0.05
		Plume Cross Section Width	2.0	1.9	1.8	1.8	0.2

9B.6.3 The results in Table 9B-13 show that the mixing zones for all substances are extremely small. EQS values for all substances are met within the near field plume rising stage for high tide and maximum current conditions and the plume only reaches the water surface at concentrations above the EQS for DIN and polyaromatic hydrocarbons under low tide and minimum current conditions. Under this scenario, the mixing zones would be seen as three extremely narrow areas of elevated contaminant concentration extending away from the outfall (the largest mixing zones are shown in Plate 9B-16). The near field mixing zones are all extremely small and would have no significant thermal or chemical environmental impact.

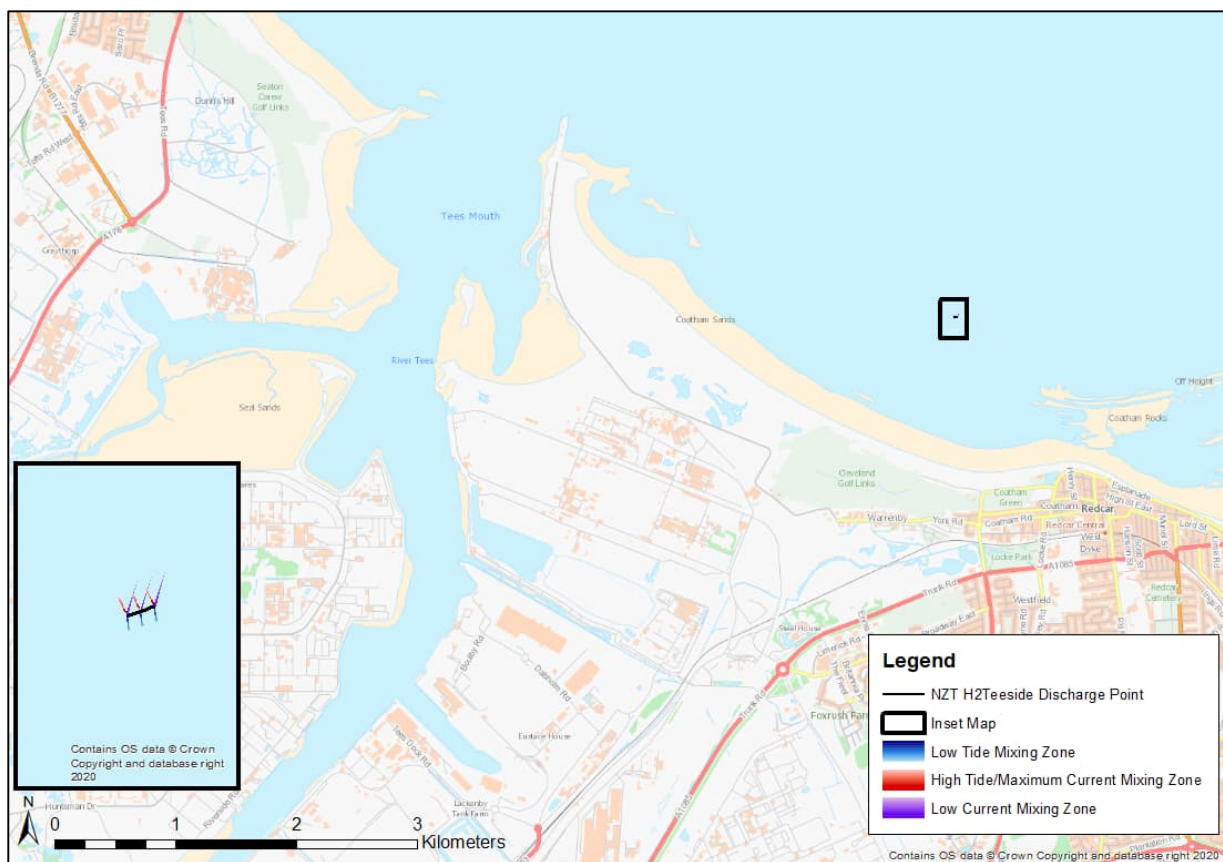


Plate 9B-16: CORMIX Near Field Mixing Zones – DIN (Main Site Process Effluent Only)

9B.6.4 Under winter discharge conditions, the elevated temperature of the Main Site's effluent in comparison to the ambient water results in a greater volume of effluent reaching the water surface prior to concentrations of DIN, polyaromatic hydrocarbons, benzo(g,h,i)-perylene and PFOS being diluted to below the EQS. Under minimum current conditions the CORMIX model then allows the buoyant effluent plume to spread over a large on the water surface without mixing with the denser ambient water. This is an unrealistic representation of mixing under this condition because vertical mixing would still occur and the plume would be shaped by the local surface currents.

9B.6.5 The far field model has therefore been used to estimate the extent of the mixing zone under minimum current conditions and the results show that the effluent is

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rapidly diluted to concentrations below the EQS by diffusion and mixing with the large volume of ambient water surrounding the discharge point. The largest elevations in pollutant concentrations occur close to the outfall and within the deeper water layers, however the maximum increase in concentration in any model cell in any layer is 0.017 mg/l for DIN and 0.022 ng/l for polyaromatic hydrocarbons, neither of which is sufficient to breach EQS values. The maximum modelled increase in benzo(g,h,i)perylene concentration is 0.018 ng/l above ambient concentrations and the maximum increase in PFOS concentration is 0.003 ng/l above ambient concentrations. Both these values are less than 5% above the ambient background.

- 9B.6.6 The far field and near field modelling therefore shows that process effluent discharges from the Main Site, in isolation, would not result in a reduction in water quality in Tees Bay at any point over a tidal cycle.
- 9B.6.7 Table 9B-14 below sets out the results of the near field modelling with consideration of effluent streams from the Main Site processes, taking account of the addition of surface water runoff from the Main Site areas only. The exit velocity at each port under the current diffuser design is 0.19 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. The dimensions given are for each of the three mixing zones from the three pairs of ports on the diffuser pipeline.



Table 9B-14: CORMIX Near Field Modelling Results (Main Site Effluent with Surface Runoff)

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)	
Winter	Low Tide	Height above outfall	7.6	7.6	EQS reached immediately on discharge			
		Distance from outfall	26	26				
		Plume Cross Section Width	0.5	0.4				
	High Tide	Height above outfall	0.6	0.6	0.5	0.5	EQS reached immediately on discharge	
		Distance from outfall	7.5	7.5	7.5	7.5		
		Plume Cross Section Width	0.3	0.3	0.1	0.1		
	Maximum Current	Height above outfall	0.6	0.6	0.5	0.5		
		Distance from outfall	7.5	7.5	7.5	7.5		
		Plume Cross Section Width	0.3	0.3	0.1	0.1		
	Low Current	Height above outfall	See far field model results			4.8	4.8	5.1
		Distance from outfall				0.2	0.2	0.2
		Plume Cross Section Width				0.4	0.4	0.4
Summer	Low Tide	Height above outfall	7.6	7.6	EQS reached immediately on discharge		Effluent discharged at less than 3°C above ambient	
		Distance from outfall	26	26				
		Plume Cross Section Width	0.5	0.4				
	High Tide	Height above outfall	0.6	0.6	0.5	0.5		
		Distance from outfall	7.5	7.5	7.5	7.5		
		Plume Cross Section Width	0.3	0.3	0.1	0.1		

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)
	Maximum Current	Height above outfall	0.6	0.6	0.5	0.5	
		Distance from outfall	7.5	7.5	7.5	7.5	
		Plume Cross Section Width	0.3	0.3	0.1	0.1	
	Low Current	Height above outfall	See far field model results	4.9	4.9		
		Distance from outfall		0.2	0.2		
		Plume Cross Section Width		0.2	0.2		

- 9B.6.8 The results in Table 9B-14 show that the pre-dilution of the effluent with surface water runoff results in smaller mixing zones for most substances compared to modelling the process effluent discharges only. EQS values for all substances are met within the near field plume rising stage for high tide and maximum current conditions higher the higher discharge velocity does result in the plume reaching the water surface at concentrations above the EQS for both DIN and polyaromatic hydrocarbons under low tide and minimum current conditions. The surface mixing zones would be smaller than those shown for DIN in Plate 9B-16. The near field mixing zones are therefore all extremely small and would have no significant thermal or chemical environmental impact.
- 9B.6.9 The higher discharge rate following addition of surface water to the Main Site process effluent results in unrealistic CORMIX representation of surface spreading under minimum current conditions. The far field model has been used to simulate mixing for this scenario and shows that the effluent is rapidly diluted such that average DIN concentrations are shown to increase by less than 0.001 mg/l within the model cell containing the discharge point and average concentrations of polyaromatic hydrocarbons are increased by less than 0.0001 ng/l. There would be no water quality impacts under this tidal condition.
- 9B.6.10 The far field and near field modelling therefore show that discharging the combined process effluent and surface water discharges from the Main Site would not result in a reduction in water quality in Tees Bay at any point over a tidal cycle.

#### Cumulative Impacts with NZT

- 9B.6.11 Table 9B-15 sets out the results of the near field modelling with consideration of combined effluent streams from the Main Site and NZT processes only, excluding a surface water runoff component from either site. Mixing zones which reach the water surface at concentrations above the relevant EQS value are highlighted in green (mean EQS values apply for DIN, polyaromatic hydrocarbons, lead and PFOS while a MAC EQS value applies for benzo(g,h,i)-perylene). The port exit velocity under this scenario is 0.11 m/s which is still low because the outfall is designed to allow for additional discharges of surface water runoff. The EQS for temperature is met during the plume rising stage for all stages of the tide and the EQS for lead is met during the rising stage for all stages except for the minimum current condition. The EQS for DIN, polyaromatic hydrocarbons, benzo(g,h,i)-perylene and PFOS are met within the initial plume rising stage at high tide and high current conditions but reach the surface for the low tide and minimum current conditions.

Table 9B-15: CORMIX Near Field Modelling Results (Combined Main Site and NZT Process Effluent Only)

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	LEAD	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)
Winter	Low Tide	Height above outfall	7.6	7.6	3.5	7.6	7.6	1.3
		Distance from outfall	54.8	94.6	23.2	61.5	59.0	4.4
		Plume Cross Section Width	12	16.5	1.4	14	14	0.5
	High Tide	Height above outfall	5.6	6.1	3.0	5.7	5.7	1.1
		Distance from outfall	12	144	34	119	115	5.3
		Plume Cross Section Width	2.5	2.8	1.2	2.5	2.5	0.4
	Maximum Current	Height above outfall	5.5	6.1	5.7	5.7	5.7	1.1
		Distance from outfall	113	147	119	123	118	5.4
		Plume Cross Section Width	2.4	2.7	2.5	2.5	2.5	0.4
	Minimum Current	Height above outfall	See Far Field Results					5.3
		Distance from outfall						0.3
		Plume Cross Section Width						0.4
Summer	Low Tide	Height above outfall	7.9	7.6	3.5	7.6	7.6	0.7
		Distance from outfall	91	91	23.2	59	78	1.0
		Plume Cross Section Width	16	16	1.4	14	16	0.3
	High Tide	Height above outfall	6.1	6.1	2.9	5.7	5.9	EOS Reached Immediately on Discharge
		Distance from outfall	138	138	33	115	130	
		Plume Cross Section Width	2.8	2.8	1.2	2.5	2.7	

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	LEAD	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)
	Maximum Current	Height above outfall	6.1	6.1	3	5.7	5.9	EQS Reached Immediately on Discharge
		Distance from outfall	141	141	35	118	133	
		Plume Cross Section Width	2.7	2.7	1.2	2.5	2.7	
	Minimum Current	Height above outfall	See Far Feld Results					3.2
		Distance from outfall						0.1
		Plume Cross Section Width						0.2

9B.6.12 The maximum mixing zone extent for the combined process effluent discharges are mapped for the low tide summer condition and maximum current condition in Plate 9B-17. These mixing zones are based on the CORMIX model outputs and are extremely small.

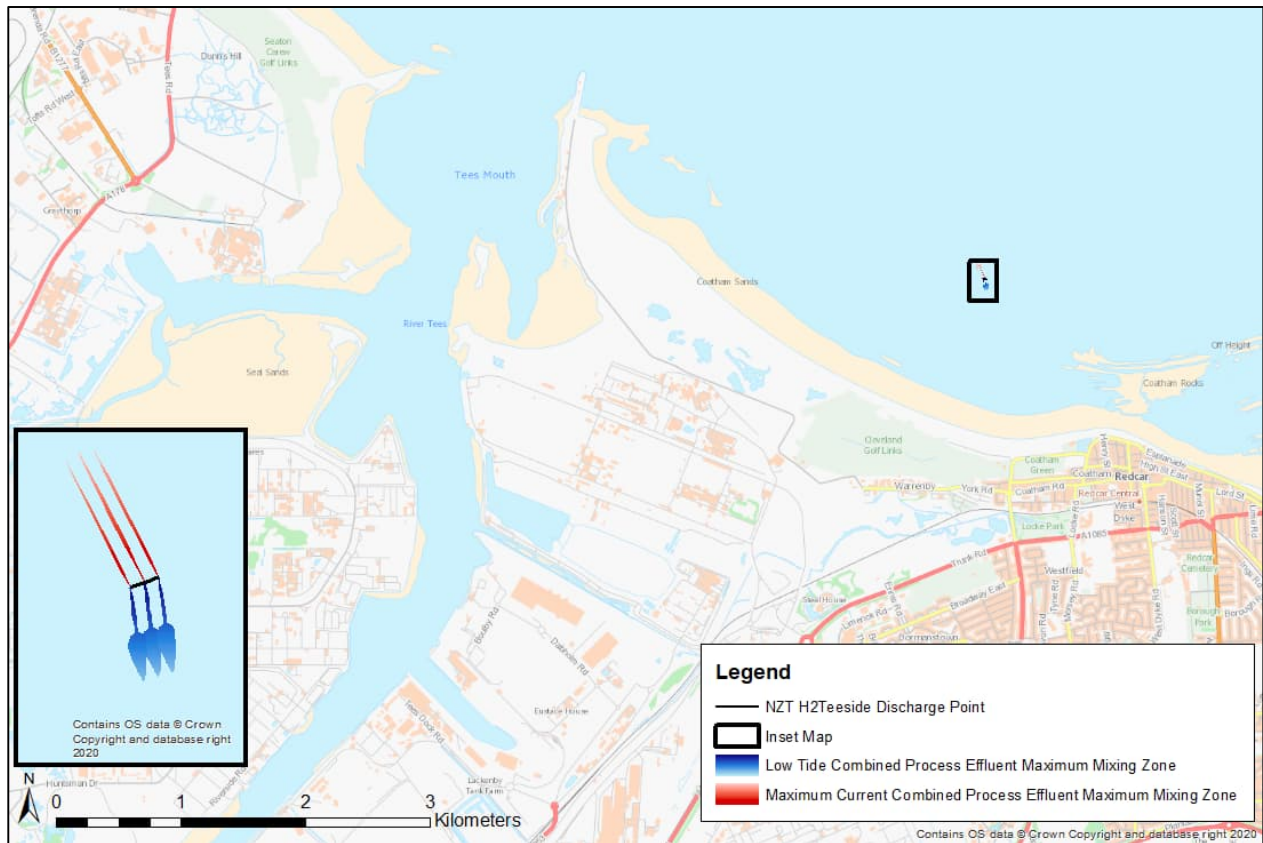


Plate 9B-17: Modelled Near Field Mixing Zones (Combined Proposed Development and NZT Process Effluent)

9B.6.13 The CORMIX model does not produce realistic mixing zone extents for the minimum ambient current condition for any parameter except temperature. The far field model has therefore been used to simulate dispersion around the outfall under the minimum current condition and the largest elevation in pollutant concentration is shown to occur close to the outfall and within the deeper water layers. Rapid dilution results in effluent concentrations falling to below the EQS over a short distance and the maximum increase in concentration in any model cell in any layer is 0.024 mg/l for DIN, 0.045 ng/l for polyaromatic hydrocarbons and 0.13 µg/l for lead, which is not sufficient to breach any EQS value. The maximum modelled increase in benzo(g,h,i)perylene concentration is 0.065 ng/l above ambient concentrations and the maximum increase in PFOS concentration is 0.007 ng/l above ambient concentrations. Both these values are less than 5% above the ambient background.

9B.6.14 The far field and near field modelling therefore show that the cumulative impacts of process effluent discharges from the Main Site and NZT sites would not result in a reduction in water quality in Tees Bay at any point over a tidal cycle.

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9B.6.15 The addition of surface water runoff from both sites to the combined process effluent greatly increases the discharge rate to Tees Bay and increases the port exit velocity to 0.65m/s. It also reduces the contaminant concentrations and the effluent temperature. Table 9B-16 sets out the dimensions of the near field mixing zones for each modelled scenario - results highlighted in green shows where mixing zones reach the water surface at concentrations exceeding the EQS (mean EQS limits apply to DIN, lead, PFOS and polyaromatic hydrocarbons while a MAC EQS value applies to benzo(g,h,i)-perylene). Thermal impacts are not modelled for the summer discharge scenario because the effluent is within 3°C of ambient temperatures. The more rapid discharge rate means that the CORMIX model represents the mixing zones based on the equivalent slot geometry option and mixing during the high tide and high current conditions is particularly vigorous, resulting in very rapid dilution and small mixing zones. The plume only reaches the surface with pollutants at concentrations above the EQS values during the low tide condition and Plate 9B-18 shows the extent of the largest mixing zone, for DIN, under these conditions.



Table 9B-16: CORMIX Near Field Modelling Results (Combined Main Site and NZT Process Effluent with Surface Water Runoff)

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	LEAD	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)	
Winter	Low Tide	Height above outfall	7.6	7.6	4.1	5.5	5.2	3.0	
		Distance from outfall	29	53	9.6	18	15	4.3	
		Plume Cross Section Width	12	16	1.1	1.7	1.6	0.7	
	High Tide	Height above outfall	1.3	1.6	0.6	0.7	0.6	EQS Reached Immediately on Discharge	
		Distance from outfall	4.1	5.9	0.3	1.1	0.8		
		Plume Cross Section Width	7.6	7.6	7.5	7.5	7.5		
	Maximum Current	Height above outfall	1.2	1.5	0.6	0.7	0.6		
		Distance from outfall	4.0	5.6	0.3	1.1	2.8		
		Plume Cross Section Width	7.6	7.6	7.5	7.5	7.5		
	Minimum Current	Height above outfall	See Far Field Results						7.2
		Distance from outfall							0.1
		Plume Cross Section Width							0.7

SEASON	TIDE CONDITION	MIXING ZONE MEASUREMENT (m)	DIN	POLYAROMATIC HYDROCARBONS	LEAD	BENZO(G,H,I)-PERYLENE	PFOS	TEMPERATURE (+3°C)	
Summer	Low Tide	Height above outfall	7.6	7.6	7.6	7.6	7.6	Effluent discharged at less than 3°C above ambient	
		Distance from outfall	28	29	22	26	26		
		Plume Cross Section Width	4.3	7.3	1.0	2.3	1.9		
	High Tide	Height above outfall	1.3	1.6	0.5	0.7	0.7		
		Distance from outfall	7.6	7.6	7.5	7.5	7.5		
		Plume Cross Section Width	4.1	5.9	0.3	0.9	0.9		
	Maximum Current	Height above outfall	1.2	1.5	0.7	0.7	0.6		
		Distance from outfall	7.6	7.6	7.5	7.5	7.5		
		Plume Cross Section Width	4.0	5.6	1.3	1.1	0.8		
	Minimum Current	Height above outfall	See Far Field Results						
		Distance from outfall							
		Plume Cross Section Width							

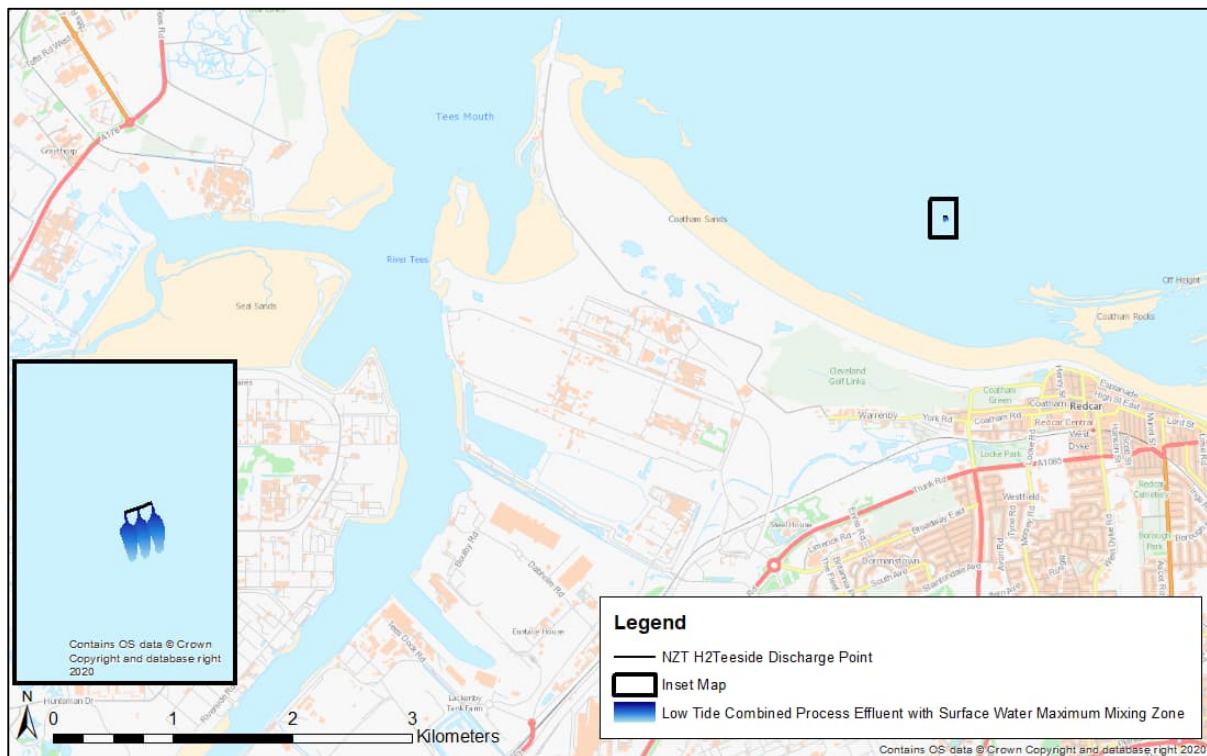


Plate 9B-18: Near Field Mixing Zone for PAH (Low Tide Condition, Combined Effluent from Main Site and NZT, with Surface Water Runoff)

9B.6.16 The CORMIX model does not produce a realistic representation of mixing under the minimum current condition for any parameter except temperature. The far field model has therefore been used to simulate dispersion around the outfall under this tidal condition. Rapid dilution results in effluent concentrations falling to below the EQS over a short distance the largest elevations in pollutant concentrations occur close to the outfall and within the deeper water layers. The maximum increase in concentration in any model cell in any layer is 0.011 mg/l for DIN, 0.010 ng/l for polyaromatic hydrocarbons and 0.03 µg/l for lead, which is not sufficient to breach any EQS value. The maximum modelled increase in benzo(g,h,i)perylene concentration is 0.009 ng/l above ambient concentrations and the maximum increase in PFOS concentration is 0.002 ng/l above ambient concentrations. Both these values are less than 5% above the ambient background.

9B.6.17 The far field and near field modelling therefore show that the cumulative impacts of process effluent combined with surface water discharges from the Main Site and NZT sites would not result in a reduction in water quality in Tees Bay at any point over a tidal cycle.

#### Full Tide Cycle Results

9B.6.18 Table 9B-17 shows the maximum increase in average pollutant concentrations across Tees Bay shown in the far field model for Scenarios 1, 2, 5 and 6. Table 9B-18 provides a similar comparison for substances limited using EQS applied to maximum concentrations.

9B.6.19 The far field model results show that the effluent is diluted and well mixed within Tees Bay and there is no accumulation of pollutants sufficient to risk breaching EQS limits. The increase in average or maximum pollutant concentrations in Tees Bay is not sufficient to result in breach of the relevant EQS limits under any modelled scenario.

Table 9B-17: Far Field Model Change in Average Pollutant Concentrations in Tees Bay

POLLUTANT	EQS (MEAN)	AMBIENT MEAN	INCREASE REQUIRED TO BREACH EQS	MAXIMUM MODELLED INCREASE IN TEES BAY			
				1: H2TEESSIDE PROCESS EFFLUENT ONLY	2: H2TEESSIDE PROCESS EFFLUENT WITH SURFACE WATER RUNOFF	5: H2TEESSIDE & NZT PROCESS EFFLUENT	6: H2TEESSIDE & NZT PROCESS EFFLUENT WITH NZT RUNOFF
DIN (mg/l)	0.252	0.196	0.056	0.005	0.0009	0.012	0.005
PFOS (ng/l)	0.13	0.25	0.013 <sup>1</sup>	0.001	0.00003	0.004	0.0008
Polyaromatic Hydrocarbons (ng/l)	0.17	0.085 <sup>2</sup>	0.085	0.007	0.0002	0.023	0.012
Lead (µg/l)	1.3	0.08	1.22	0.021	0.0006	0.066	0.015

<sup>1</sup>EQS values exceeded in ambient waters, an EQS proxy of 5% above ambient has been used to assess the significance of the discharge

<sup>2</sup>No ambient data available, ambient concentrations assumed to be 50% of the EQS

Table 9B-18: Far Field Model Change in Maximum Pollutant Concentrations in Tees Bay

POLLUTANT	EQS (MAC)	AMBIENT MAXIMUM	INCREASE REQUIRED TO BREACH EQS	MAXIMUM MODELLED INCREASE IN TEES BAY			
				1: H2TEESSIDE PROCESS EFFLUENT ONLY	2: H2TEESSIDE PROCESS EFFLUENT WITH SURFACE WATER RUNOFF	5: H2TEESSIDE & NZT PROCESS EFFLUENT	6: H2TEESSIDE & NZT PROCESS EFFLUENT WITH SURFACE WATER RUNOFF
Benzo(g,h,i)-perylene (ng/l)	0.82	1.40	0.070 <sup>1</sup>	0.030	0.0057	0.139	0.002
Lead (µg/l)	14.0	0.11	13.89	1.30	0.03	3.17	0.42

<sup>1</sup>EQS values exceeded in ambient waters, an EQS proxy of 5% above ambient has been used to assess the significance of the discharge

The maximum concentration of benzo(g,h,i)-perylene is only increased by more than 5% above ambient under Scenario 5 (process discharges for both sites) within the two deepest water layers (lower 35% of the water column) and within the immediate area the discharge point (Plate 9B-21). This would not affect the wider area of Tees Bay. The water quality modelling results therefore show that the water quality impacts of the Main Site discharge, in isolation or as a cumulative impact with discharges from the NZT site, will not have significant impact on water quality in Tees Bay.

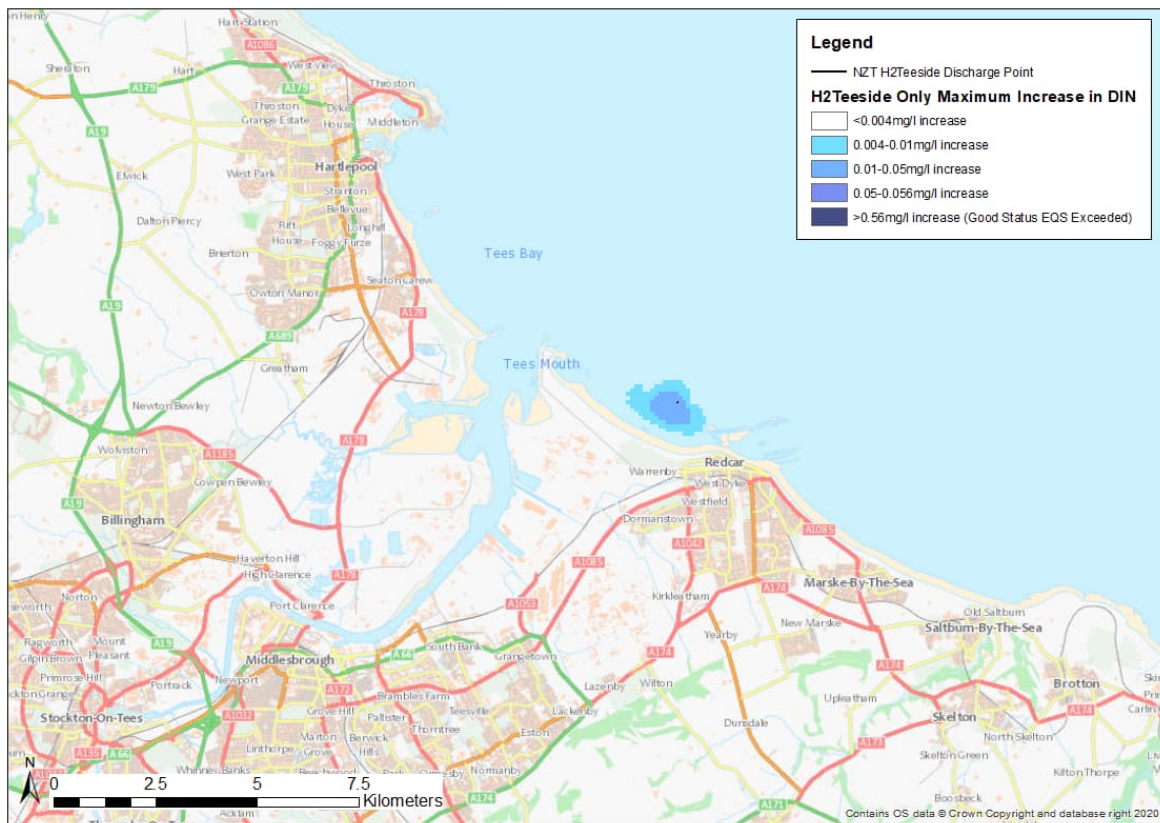


Plate 9B-19: Increase in Average DIN Concentrations in Tees Bay After Multiple Tidal Cycles (Deepest 10% of Water Column, Main Site Process Effluent Only)



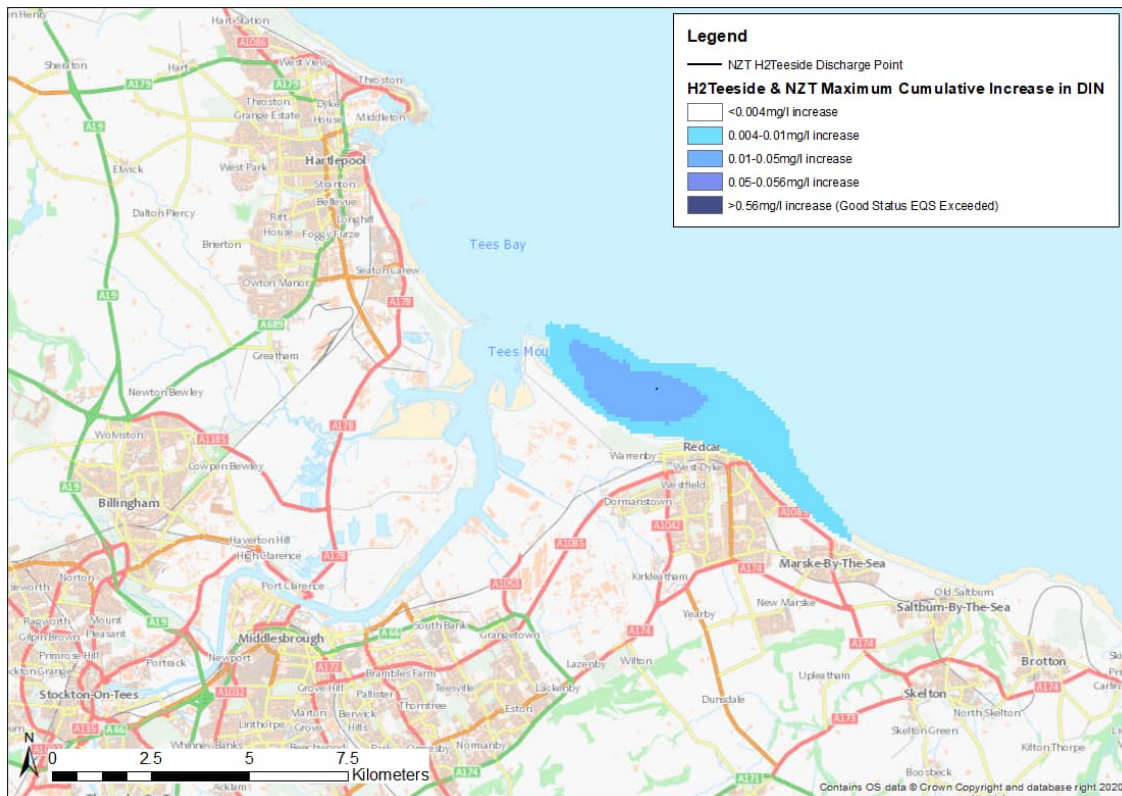


Plate 9B-20: Increase in Average DIN Concentrations in Tees Bay After Multiple Tidal Cycles (Deepest 10% of Water Column, Main Site & NZT Process Effluent)

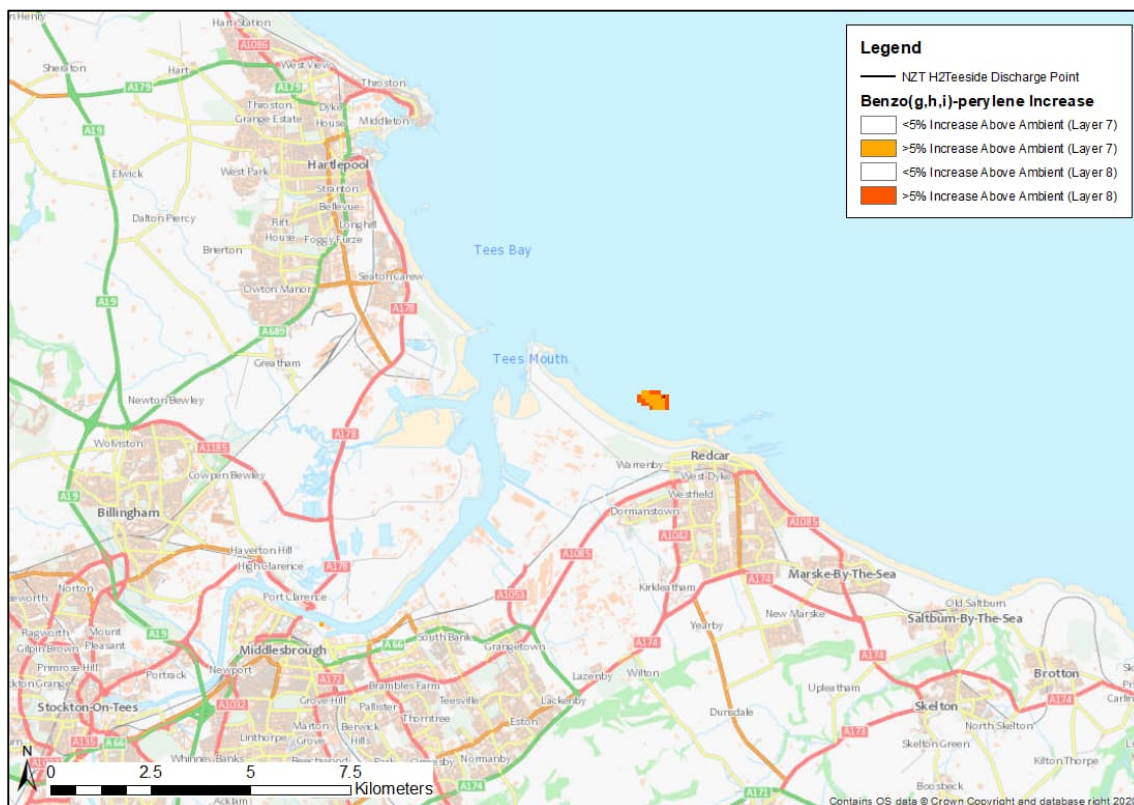


Plate 9B-21: Increase in Maximum Benzo(g,h,i)-perylene Concentrations in Tees Bay After Multiple Tidal Cycles (Main Site & NZT Process Effluent)

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## 9B.7 Summary and Conclusions

- 9B.7.1 Near field and far field water quality modelling has been carried out to support the design of the Main Site in respect of process effluent and surface water management. This early design stage report utilises information available at the time of publication and draws on hydrodynamic water quality modelling carried out for the adjacent NZT site. The design proposals for the Main Site and adjacent NZT site remain under development, and it is anticipated that a further stage of water quality modelling will be carried out following finalisation of the proposals, including water treatment methods. This will be required as part of the Environmental Permit application for operation of the Main Site. This report includes water quality modelling for discharge of the Main Site effluent, in isolation and in combination with effluent from the NZT site.
- 9B.7.2 This report does not contain detailed modelling for other discharges of DIN into Tees Bay as no additional sites that required consideration were identified through consultation with the Environment Agency. This report includes an implicit allowance for these sites by using current observed DIN concentrations in Tees Bay in the ambient background (section 9B.3).
- 9B.7.3 The discharged effluent at the Main Site will be comprised of treated process water which is ultimately sourced from the non-tidal River Tees and will contain river water contaminants. These will be concentrated within the process effluent, however the effluent from the Main Site will be treated via a denitrification plant prior to discharge which will reduce DIN concentrations to 15 mg/l N. Discharges from the NZT site will likewise comprise concentrated River Tees water with additional flows generated on-site and treated. Water quality data for the River Tees has been provided by Northumbrian Water and combined with information from the Environment Agency and initial plans for water treatment technology on both sites to characterise discharged effluent flows and pollutant loads. The calculations have been carried out for effluent streams which include or exclude a surface water runoff component from the two sites.
- 9B.7.4 Pollutant concentrations within the effluent have been compared with EQS standards for Tees Bay under the WFD. The available information shows that effluent concentrations of DIN, benzo(b)-fluoranthene, benzo(g,h,i)-perylene, fluoranthene, PFOS, polyaromatic hydrocarbons, chromium, copper, iron, lead, mercury, zinc and diazinon may exceed EQS values. Effective volume flux calculations have been carried out and show that only DIN and polyaromatic hydrocarbons will be discharged from the Main Site above the allowable volume flux value, although lead is also discharged above the allowable volume flux value when taking account of NZT discharges. Effective volume flux calculations cannot be carried out for benzo(g,h,i)-perylene or PFOS because ambient concentrations of these substances already exceed EQS values due to other point source and diffuse pollution sources to Tees Bay and the River Tees.
- 9B.7.5 The final list of substances taken forward for detailed water quality modelling is DIN, polyaromatic hydrocarbons, lead, benzo(g,h,i)-perylene and PFOS. Mixing zones for DIN, polyaromatic hydrocarbons and lead have been defined based on EQS limits
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and mixing zones for benzo(g,h,i)-perylene and PFOS have been defined using an EQS proxy of 5% above ambient. Thermal impacts were modelled based on an increase in temperature of 3°C above ambient.

- 9B.7.6 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 Annex B of this report. The current proposal is to discharge the effluent via a new outfall constructed for the NZT site which will consist of a multiport diffuser located offshore in an area with an average water depth of approximately 9 m.
- 9B.7.7 The near field and far field modelling show that the impact of the Main Site process effluent discharge is small for all polluting substances at all stages of the tidal cycle. The chemical contaminants 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. Discharging process effluent and surface water discharges from the Main Site to Tees Bay via the NZT outfall will not have significant impact on receiving water quality.
- 9B.7.8 The cumulative impact of discharges from the Main Site and NZT sites is larger, with mixing zones more likely to reach the water surface. However, the thermal mixing zones remain extremely small and pollutants are diluted to below the EQS value (or EQS proxy) within a very short distance of the discharge point. Concentrations of DIN are slightly elevated above background concentrations over a wider area but the overall increase in average and maximum pollutant concentrations do not approach EQS values, taking into account the complex tidal currents in this region which can result in pollutants accumulating in shallow water. The near field and far field modelling results show that there is no significant impact on water quality in Tees Bay due to the cumulative impact of discharges from both sites.



9B.8 ANNEX A: Substances with EQS in Coastal Waters

SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)	SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)
1,1,1-trichloroethane	100		Endosulphan	0.0005	0.004
1,1,2-trichloroethane	300		Fenclorphos	0.03	0.1
1,2-dichloro-ethane	10		Fenitrothion	0.01	
2,4-dichlorophenol	0.42	6 (95th percentile)	Fluocofuron		1 (95th percentile)
2,4-dichlorophenoxyacetic acid (2,4-D)	0.3	1.3 (95th percentile)	Fluoranthene	0.0063	0.12
2-chlorophenol	50		Fluoride - dissolved	5,000	15,000
3,4-dichloroaniline	0.2	5.4 (95th percentile)	Glyphosate	196	398 (95th percentile)
3-chlorophenol 4-chlorophenol - total or individual monochlorophenols	50	250	Heptachlor & heptachlor epoxide	1E-08	0.00003
4-chloro-3-methylphenol	40		Hexabromocyclo-dodecane (HBCDD)	0.0008	0.05
Abamectin	0.003	0.01	Hexachloro-benzene		0.05
Aclonifen	0.012	0.012	Hexachloro-butadiene		0.6
Alachlor	0.3	0.7	Hexachloro-cyclohexane	0.002	0.02
Ammonia - un-ionised	21		Hydrogen sulphide		10
Anthracene	0.1	0.1	loxynil	10	100
Arsenic	25		Iron - dissolved	1,000	
Atrazine	0.6	2	Isoproturon	0.3	1
Azinphos methyl - dissolved	0.01		Ivermectin	0.001	0.01
Bentazone	500		Lead and its compounds (dissolved)	1.3	14

SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)	SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)
Benzene	8	50	Linuron	0.5	0.9 (95th percentile)
Benzo(a)-pyrene (BaP)		0.027	Malachite green	0.5	100
Benzo(b)-fluor-anthene		0.017	Malathion	0.02	
Benzo(g,h,i)-perylene		0.00082	Mancozeb	2	20
Benzo(k)-fluor-anthene		0.017	Maneb	3	30
Benzyl butyl phthalate	0.75	10 (95th percentile)	MCPA	80	800
Bifenox (Methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate)	0.0012	0.004	Mecoprop	18	187 (95th percentile)
Biphenyl	25		Mercury and its compounds (dissolved)		0.07
Boron	7,000		Naphthalene	2	130
Brominated diphenylether		0.014	Nickel and its compounds (dissolved)	8.6	34
Bromine -total residual oxidant		10	Nitrilotriacetic acid (NTA)	3,000	30,000
Bromoxynil	100	1,000	Nonylphenol (4-nonylphenol)	0.3	2
C10-13 chloroalkanes	0.4	1.4	Octylphenol (4-(1,1',3,3'-tetramethyl-butyl)-phenol)	0.01	
Cadmium and its compounds (dissolved)	0.2		Para-para-DDT	0.01	
Carbon tetrachloride	12		PCSDs		0.05 (95th percentile)
Chlorfenvinphos	0.1	0.3	Pentachloro-benzene	0.0007	
Chlorine		10	Pentachloro-phenol	0.4	1

SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)	SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)
Chloronitrotoluenes	10		Perfluorooctane sulfonic acid and its salts (PFOS)	0.00013	7.2
Chlortoluron	2		Permethrin	0.0002	0.001 (95th percentile)
Chlorpropham	10	40	pH		6-8.5 (95th percentile)
Chlorpyrifos (chlorpyrifos-ethyl)	0.03	0.1	Phenol	7.7	46 (95th percentile)
Chromium (VI) - dissolved	0.6	32 (95th percentile)	Pirimicarb	1	5
Cobalt - dissolved	3	100	Pirimiphos-methyl	0.015	0.05
Copper - dissolved	3.76		Polyaromatic hydrocarbons (PAH)	0.00017	
Copper - dissolved	3.76 + (2.677 x ((DOC/2) - 0.5)) µg/l		Prochloraz	4	40
Coumaphos	0.03	0.1	Propetamphos	0.03	0.1
Cyanide	1	5 (95th percentile)	Propyzamide	100	1,000
Cybutryne	0.0025	0.016	Quinoxifen	0.015	0.54
Cyclodiene pesticides (total aldrin, dieldrin, endrin and isodrin)	0.005		Silver - dissolved	0.5	1
Cyfluthrin		0.001 (95th percentile)	Simazine	1	4
Cypermethrin	8 x 10 <sup>-6</sup>	6 x 10 <sup>-5</sup>	Styrene	50	500
Cypermethrin	0.0001	0.0004 (95th percentile)	Sulcofuron		25 (95th percentile)
DDT (total)	0.025		Tecnazene - total	1	10

SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)	SUBSTANCE	ANNUAL AVERAGE (µg/l)	MAC (µg/l)
Demetons	0.5		Terbutryn	0.0065	0.034
Di(2-ethylhexyl)-phthalate (DEHP)	1.3		Tetrachloro-ethylene	10	
Diazinon (sheep dip)	0.01	0.26 (95th percentile)	Thiabendazole	5	50
Dibutyl phthalate	8	40	Tin (inorganic) - dissolved	10	
Dichlorobenzene - total dichlorobenzene isomers	20	200	Toluene	74	370 (95th percentile)
Dichloro-methane	20		Triallate	0.25	5
Dichlorvos	0.04	0.6	Triazaphos	0.005	
Dichlorvos	6 x 10 <sup>-5</sup>	7 x 10 <sup>-5</sup>	Tributyl phosphate	50	500
Dicofol	3.2 x 10 <sup>-5</sup>		Tributyltin compounds (tributyltin-cation)	0.0002	0.0015
Diethyl phthalate	200	1,000	Trichloro-benzenes	0.4	
Diflubenzuron	0.005	0.1	Trichloro-ethylene	10	
Dimethoate	0.48	4 (95th percentile)	Trichloro-methane (chloroform)	2.5	
Dimethyl phthalate	800	4,000	Triclosan	0.1	0.28 (95th percentile)
Diocetyl phthalate	20	40	Trifluralin	0.03	
Dissolved Inorganic Nitrogen as N	252		Triphenyltin and its derivatives		0.008
Diuron	0.2	1.8	Vanadium	100	
Doramectin	0.001	0.1	Xylene	30	
EDTA	400	4,000	Zinc	6.8 (7.9)	

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9B.9 ANNEX B: Far Field Model Build Report



# 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)



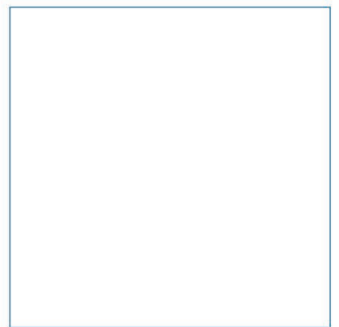
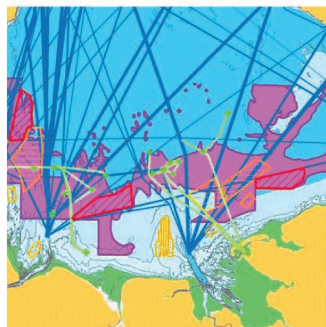
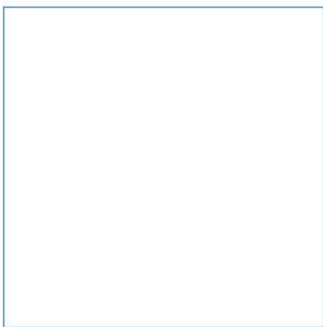
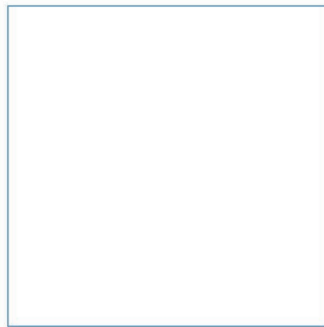
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# Net Zero Teesside Project

Coastal Modelling – Final Integrated Report

April 2021



Innovative Thinking - Sustainable Solutions



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# Net Zero Teesside Project

Coastal Modelling – Final Integrated Report

April 2021



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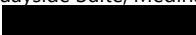
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# Executive Summary

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 CO<sub>2</sub> 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.

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# 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)

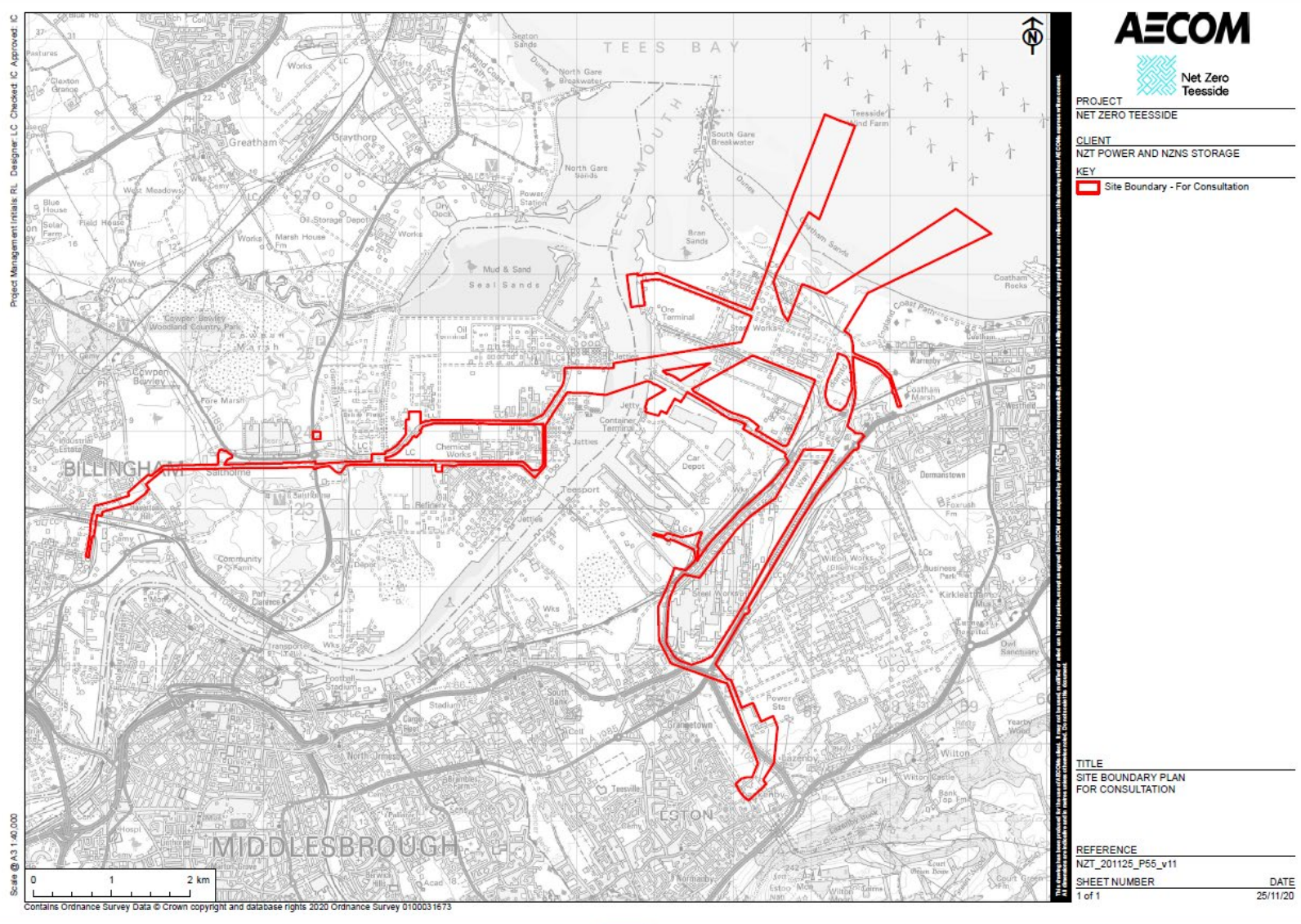


Figure 2. Net Zero Teesside – Site Boundary for Consultation

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:

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



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 characteristics 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<sup>3</sup>/s; and
- Density: 1,018/ 1,020 kg/m<sup>3</sup> (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.

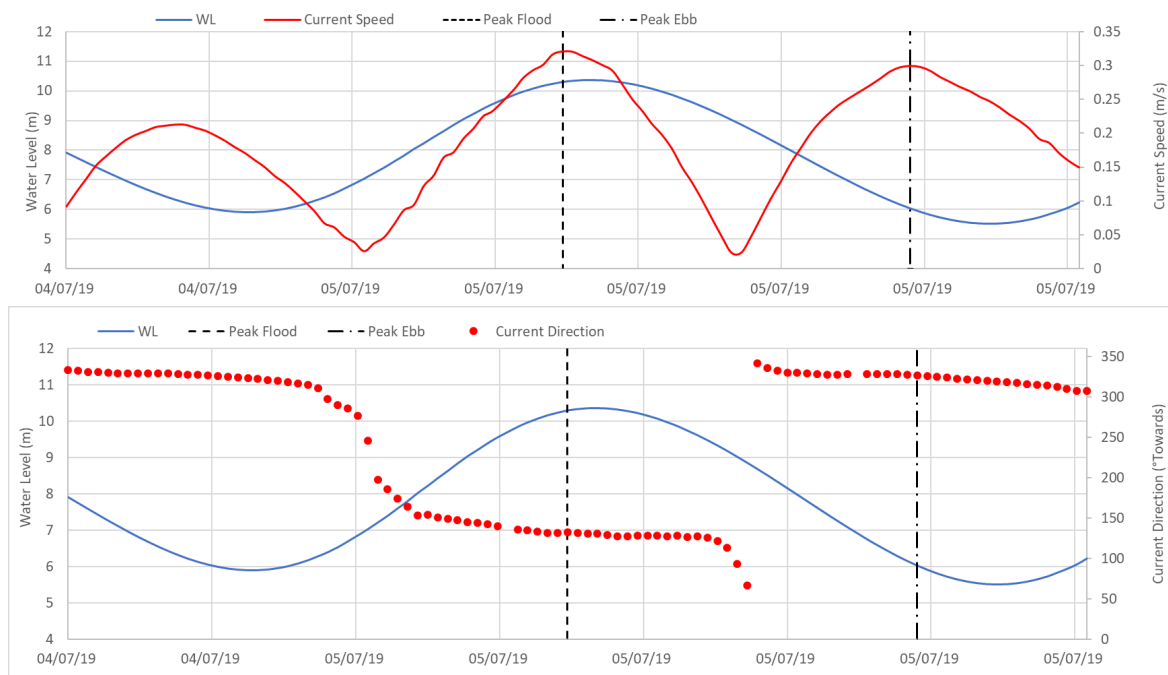


Figure 4. Tidal characteristics during a mean spring tide

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<sup>3</sup>) and bed roughness (default of 0.04) parameters were also applied. Furthermore, the enabling of the model environment to be classified as 'Unbounded' is possible, which indicates that there is only one 'bank' in the model (consistent with outfalls into the open sea). This is opposed to a riverine environment, which would be classed as 'Bounded', in which the distance between banks would be required.

### 2.2.3 Discharge

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

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

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

## 2.3 CORMIX Outfall 1 results

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

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

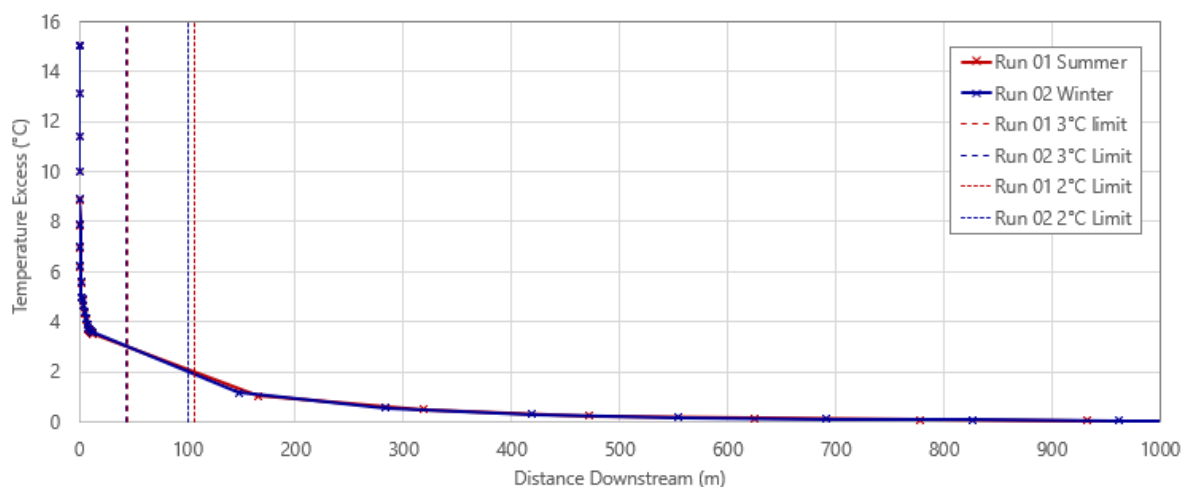
This model setup has been used as a ‘baseline’ scenario to use as a comparison for a range of sensitivity tests. The tests completed to reach this conclusion are outlined below. A summary of the sensitivity tests presented in this report section are provided in Table 2.

**Table 2. CORMIX Run Summary**

Run no	Description
01	Spring flood tide (summer season) baseline case, this includes: <ul style="list-style-type: none"> <li>▪ Seasonal wind speeds</li> <li>▪ 0.8 m pipe diameter</li> <li>▪ Pipe orientation vertical</li> </ul>
02	Spring flood tide (winter season)
03	Spring flood tide (summer season) no winds applied
04	Spring flood tide (winter season) no winds applied
05	Spring flood tide (summer season) 0.6 m pipe diameter
06	Spring flood tide (summer season) 1 m pipe diameter
10	Spring ebb tide (summer season)
16	Spring flood tide (summer season) 15 m/s wind speed
17	Spring flood tide (summer season) horizontal pipe orientation, directed offshore

### 2.3.1 Spring flood - Seasonal variation

Shown in Figure 5 is the spring flood tide, demonstrating the seasonal variation (summer/ winter). The winter variation is distinguished by applying different wind speeds (4.08 and 5.23 m/s) and effluent densities (1,018 and 1,020 kg/m<sup>3</sup>) 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.

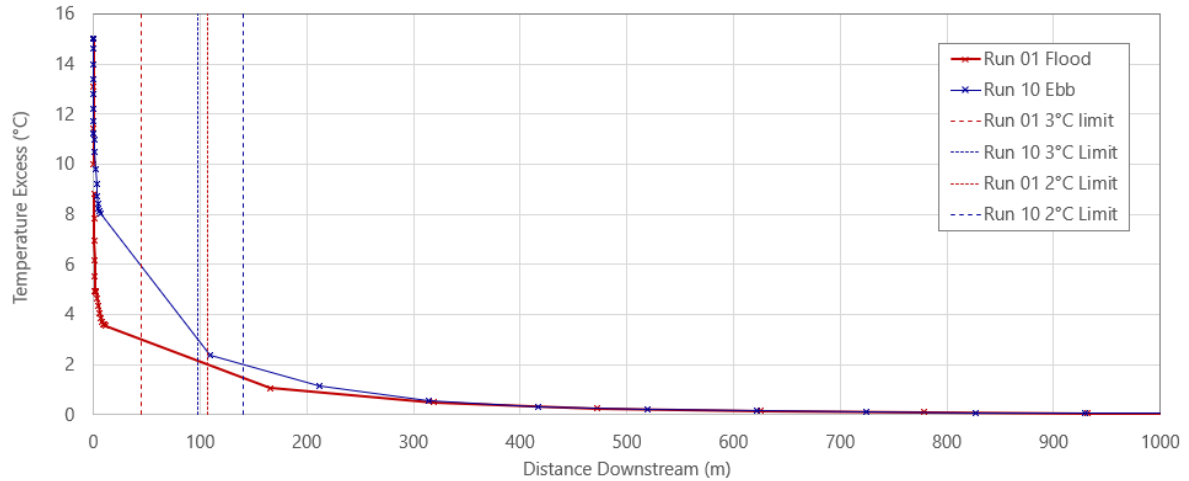


Figure 6. Summer scenario, flood and ebb sensitivity

### 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.

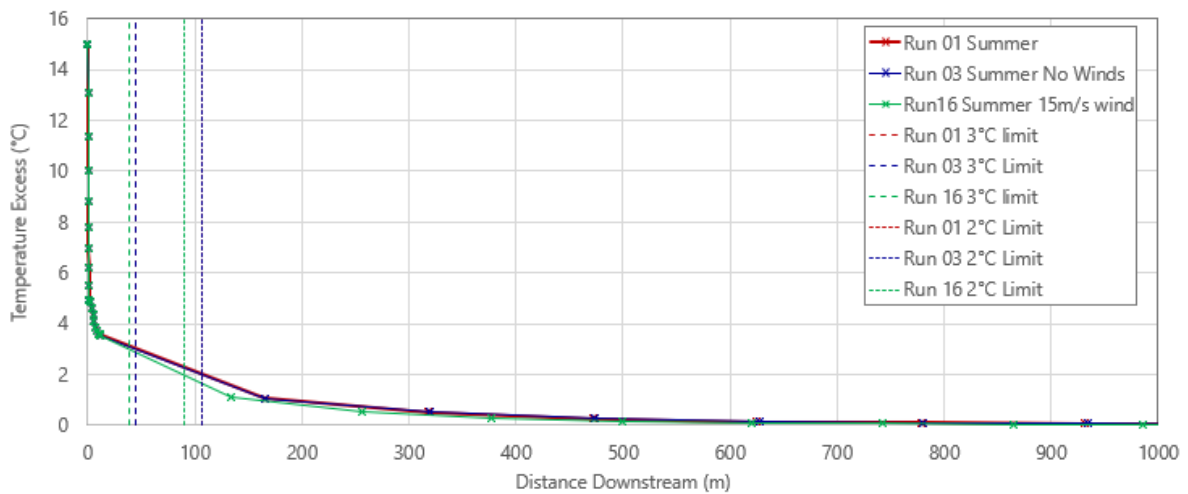


Figure 7. Spring flood wind sensitivity



### 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  $\pm 0.2$  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.

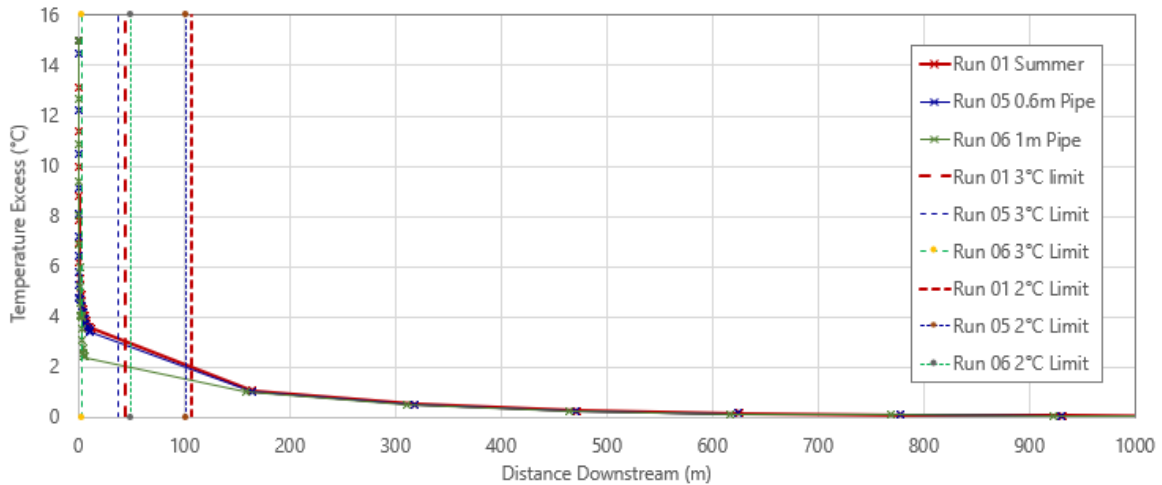


Figure 8. Spring flood, pipe diameter sensitivity

### 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 exceeded at around 15 m, compared to approximately 105 m for the vertical projection in Run 01.

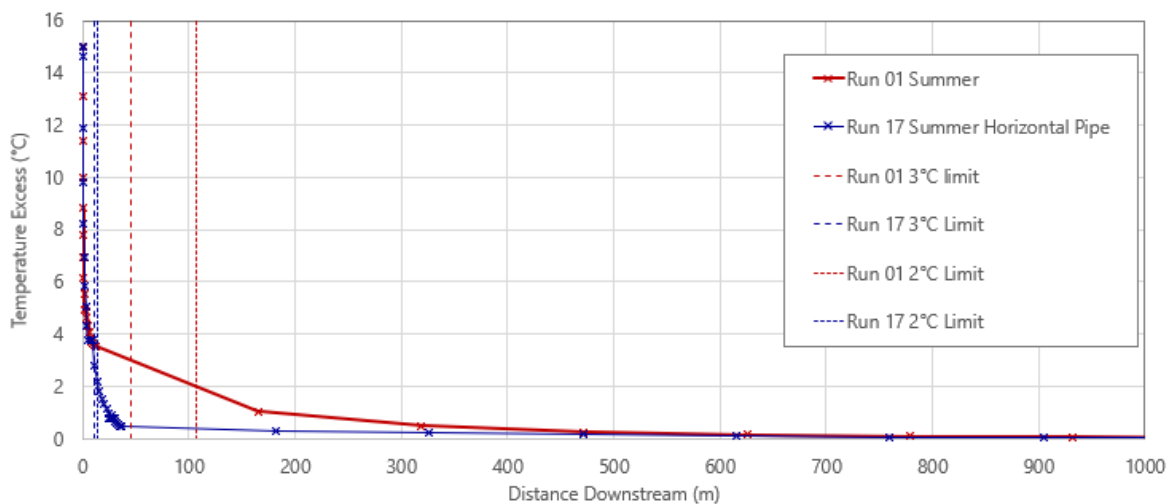


Figure 9. Spring flood, outfall projection sensitivity

### 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

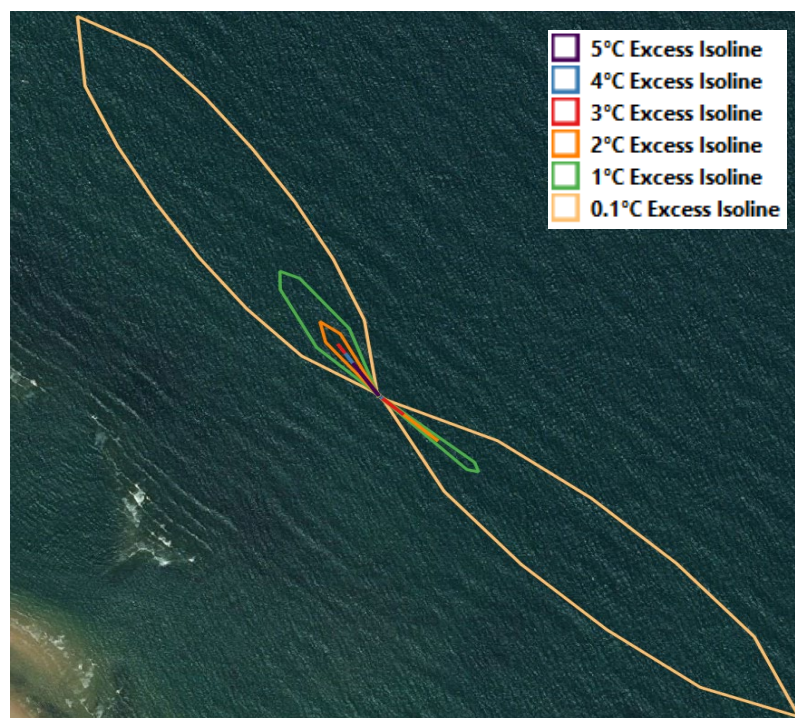


Figure 11. Zoomed extent of the CORMIX excess temperature isolines (°C) under mean spring, peak flood (SE) and ebb (NW) tidal states

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 <sup>2</sup> )	Isoline Extent from Outfall (m)	Area of Excess Temperature (m <sup>2</sup> )
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.

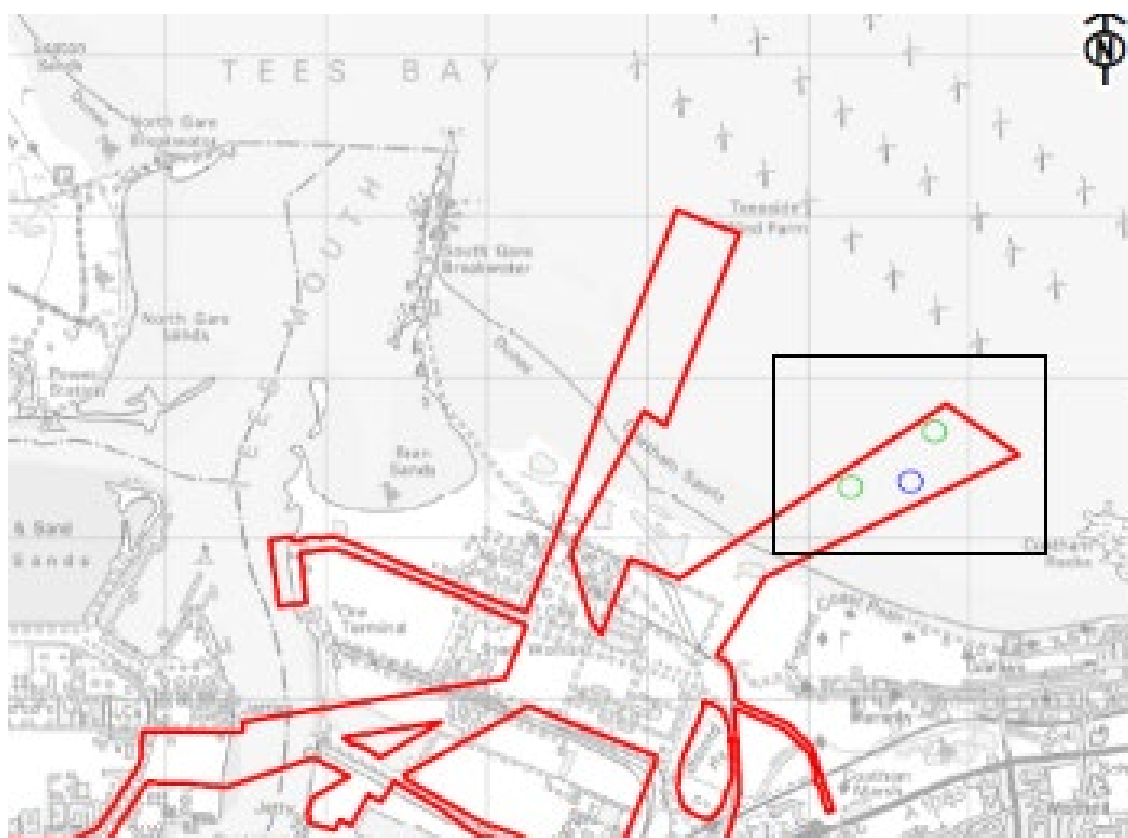


Figure 12. Outfall 2 location indicated by blue circle

**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<sup>3</sup>) 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) *

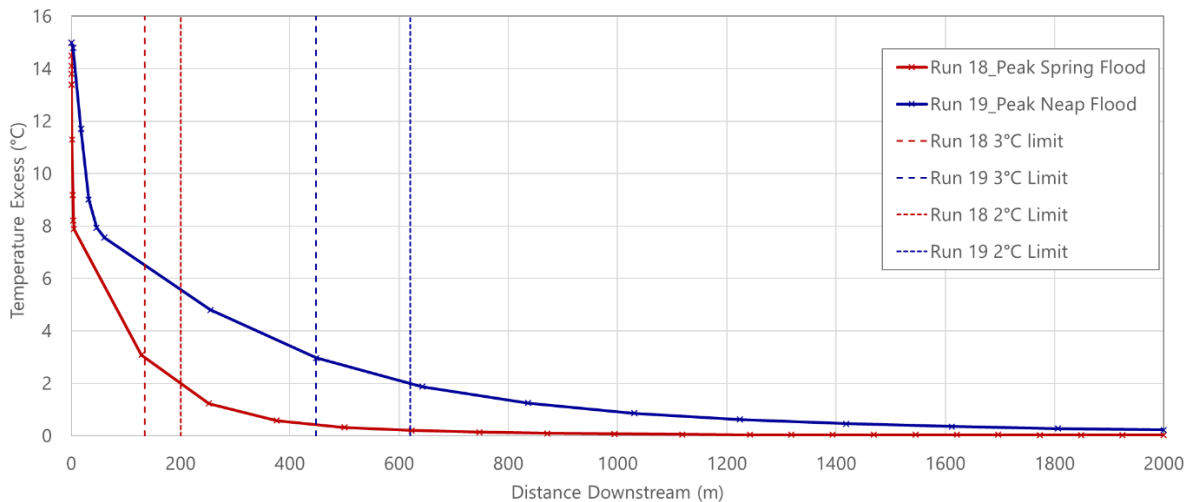
\*results presented in Appendix A.

### 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.

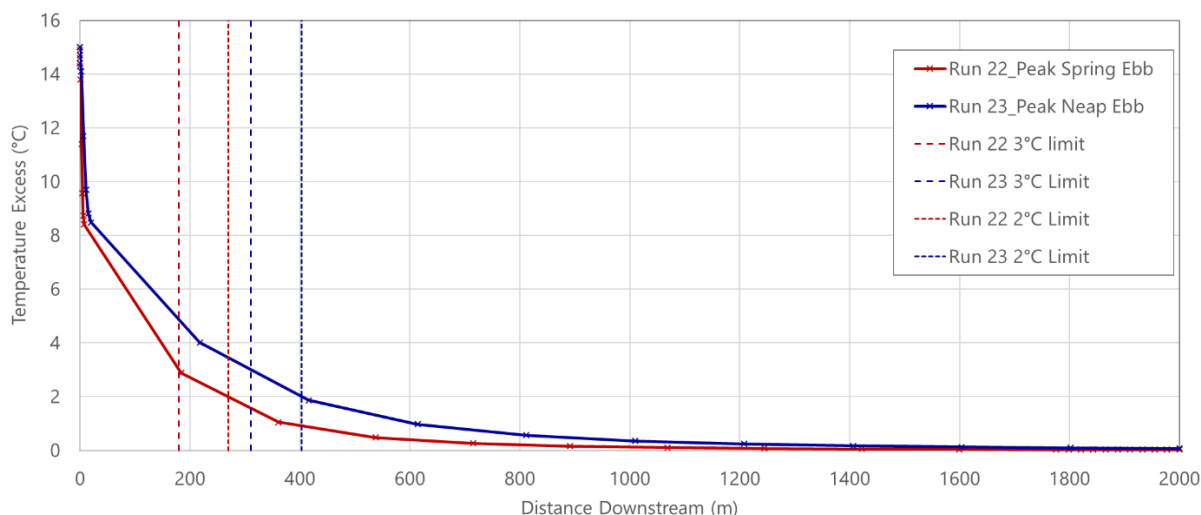


Figure 15. Spring and neap ebb tide plume variations during normal discharge events.

### 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

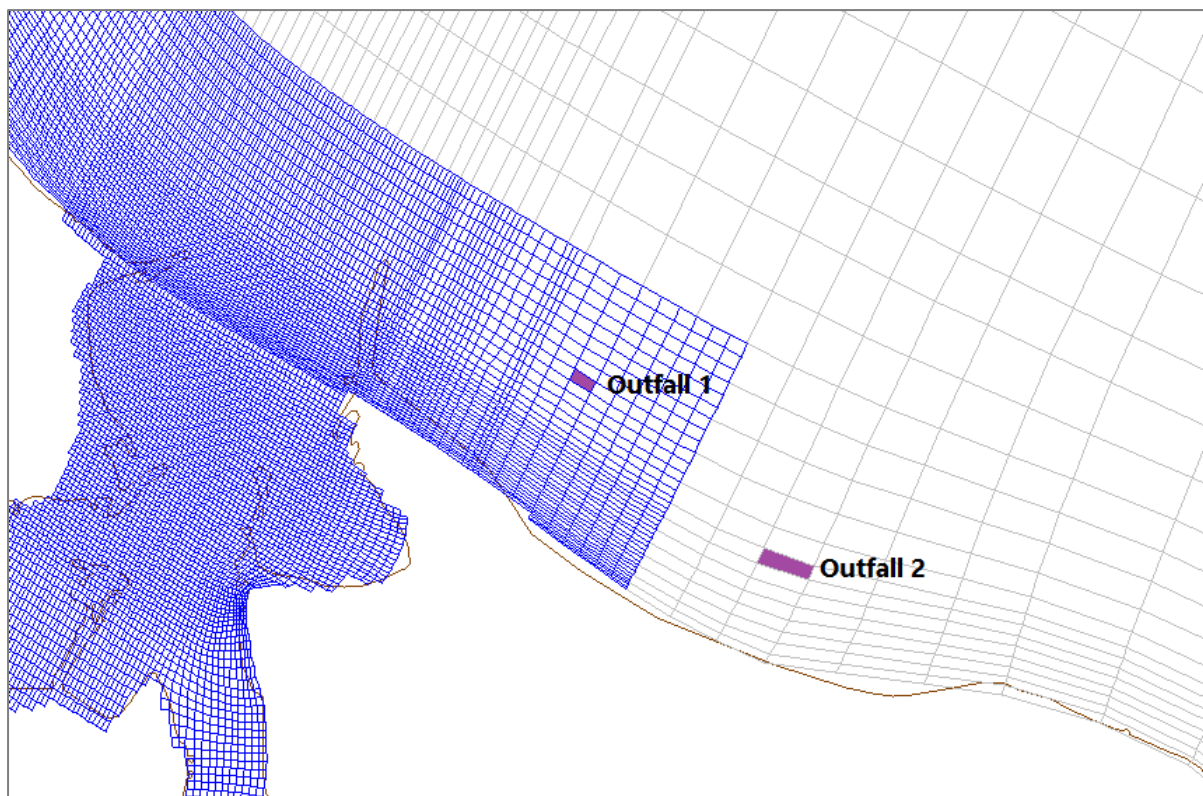


Figure 17. Location of Outfalls in far-field (Delft3D) model grid

### 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<sup>3</sup>/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.

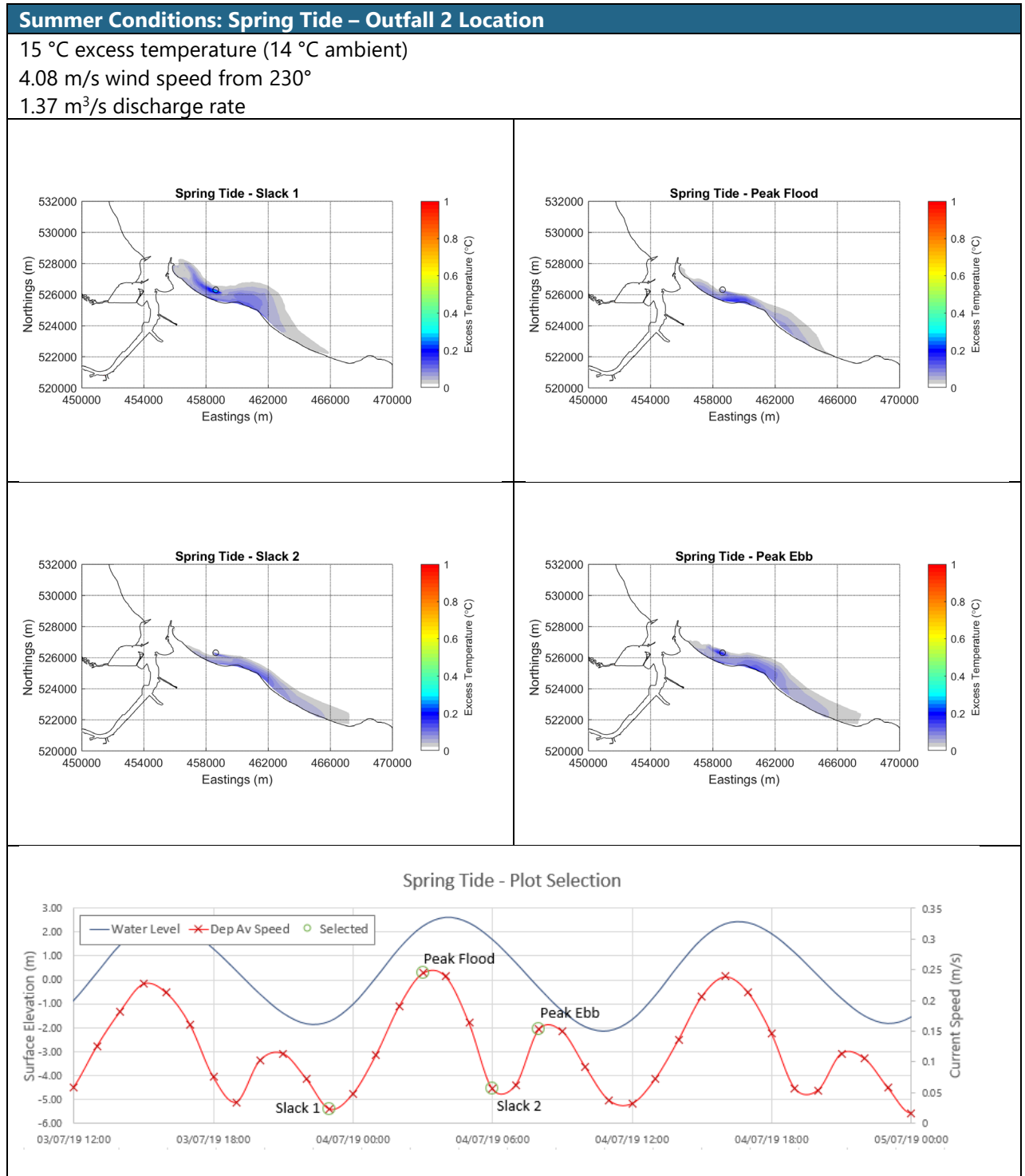


Figure 18. Temperature excess contour plots: Summer spring tide – Outfall 2 location

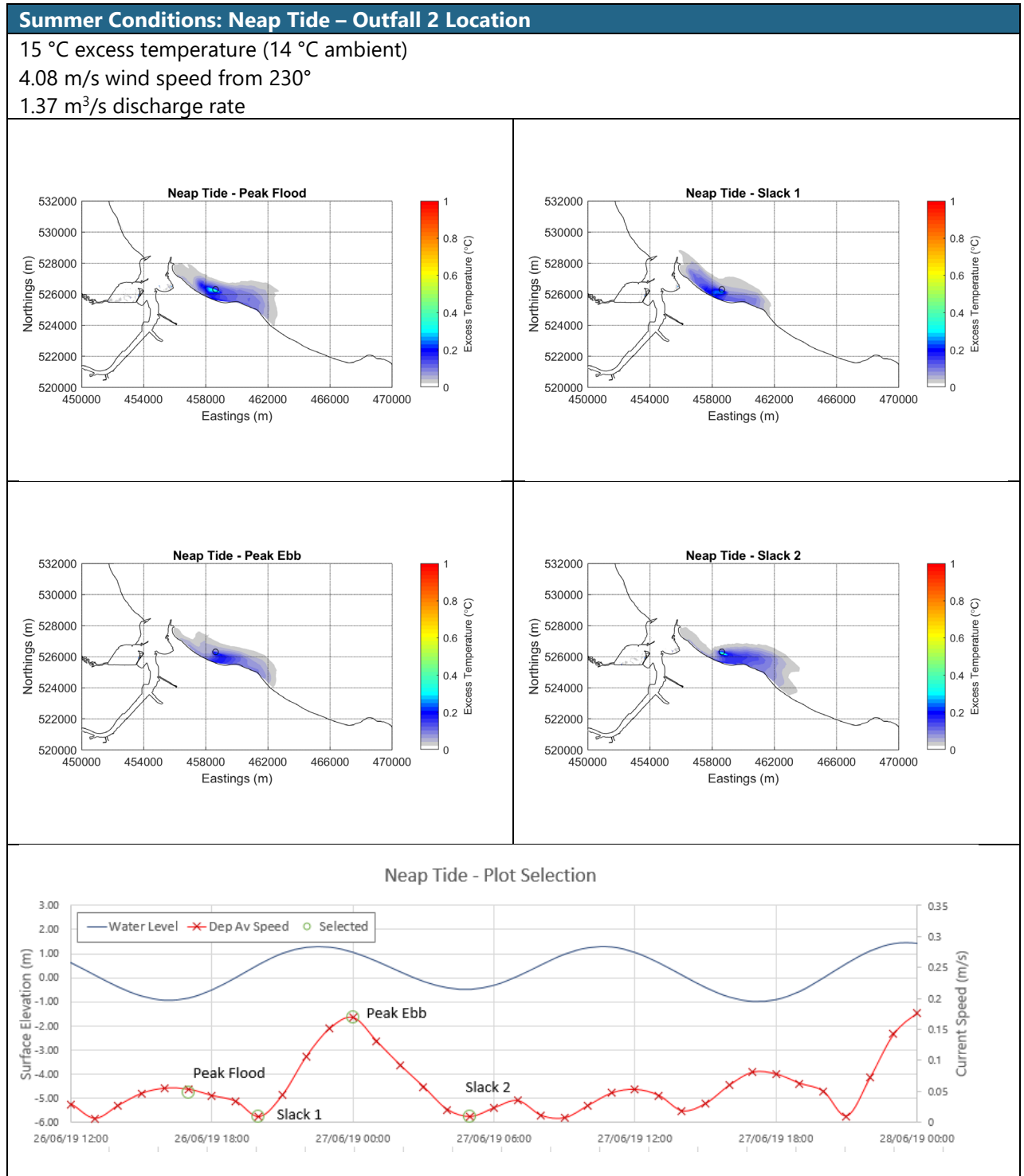


Figure 19. Temperature excess contour plots: Summer neap tide – Outfall 2 location

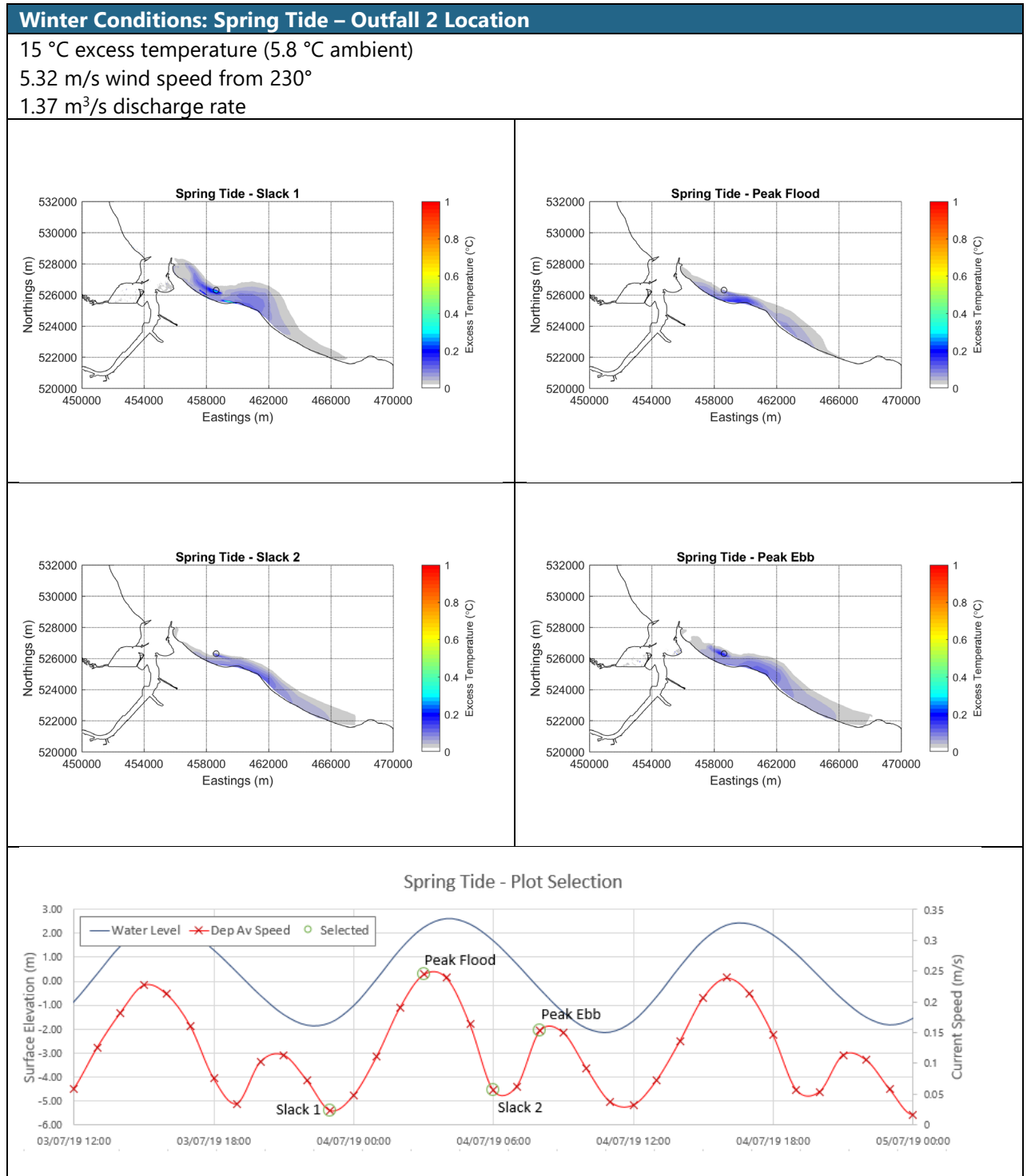


Figure 20. Temperature excess contour plots: Winter spring tide – Outfall 2 location



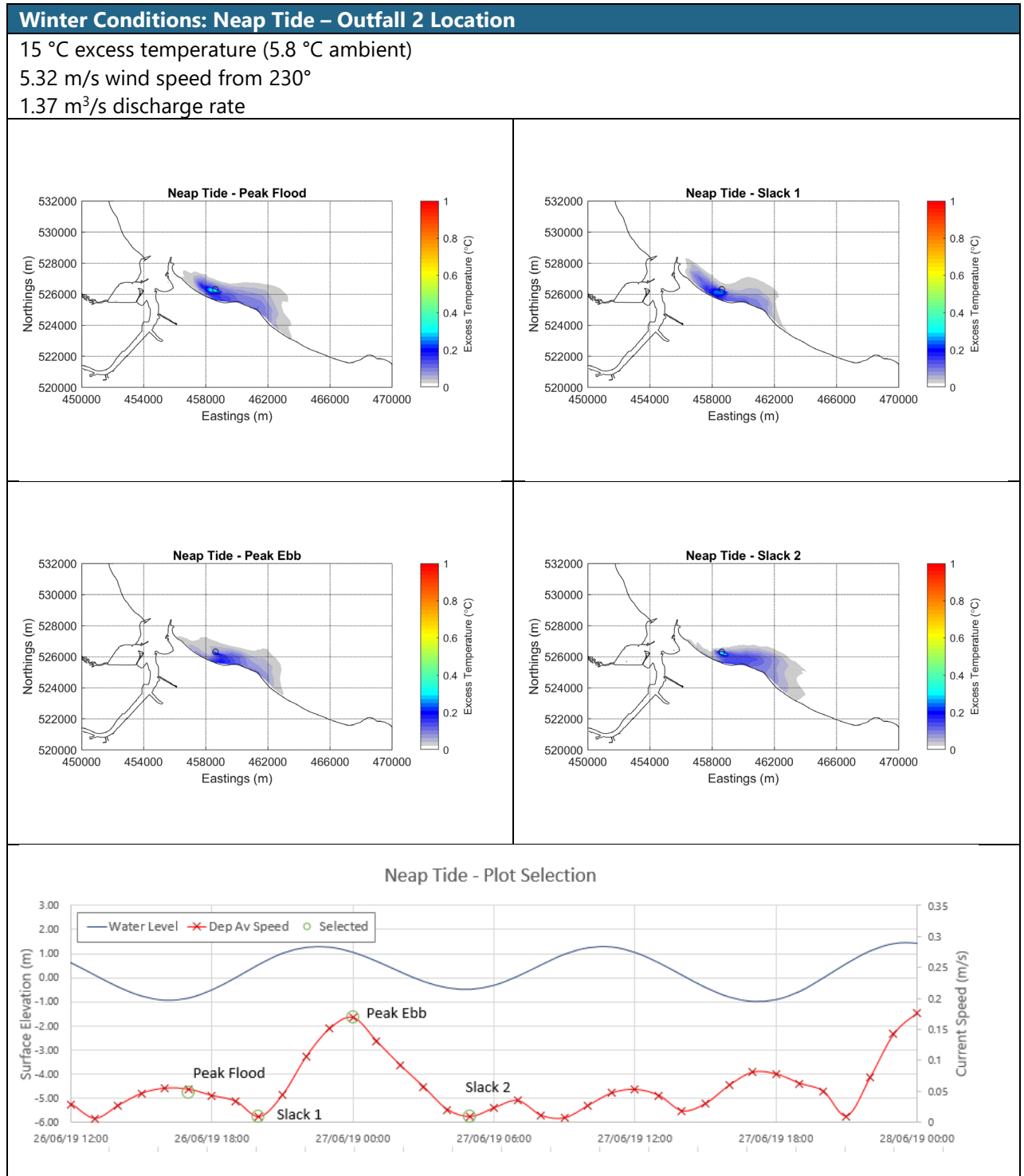


Figure 21. Temperature excess contour plots: Winter neap tide – Outfall 2 location

### 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.

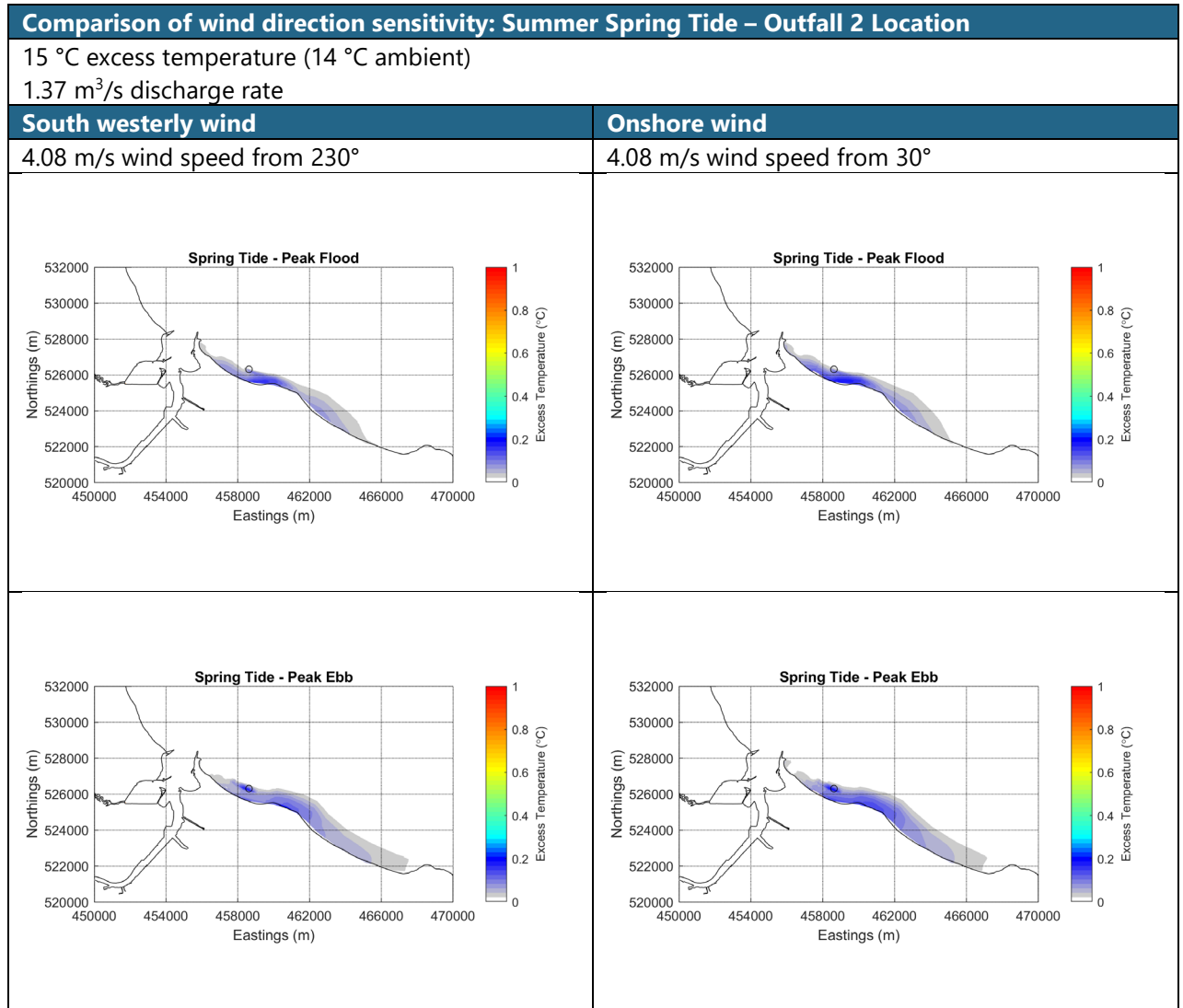


Figure 22. Temperature excess contour plots: Comparison of spring summer conditions with a 230° wind direction (left) vs onshore wind (right)

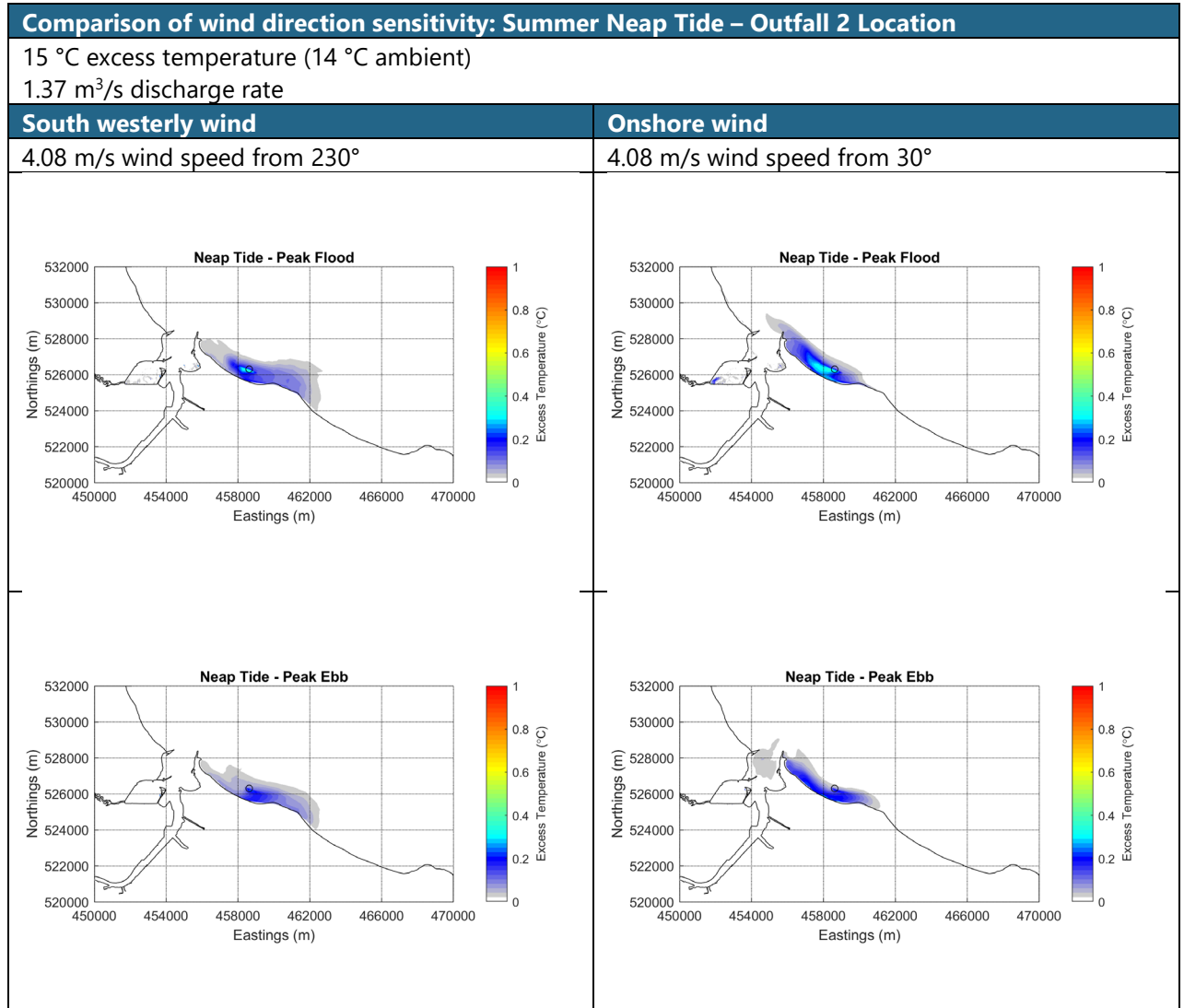


Figure 23. Temperature excess contour plots: Comparison of neap summer conditions with a 230° wind direction (left) vs onshore wind (right)

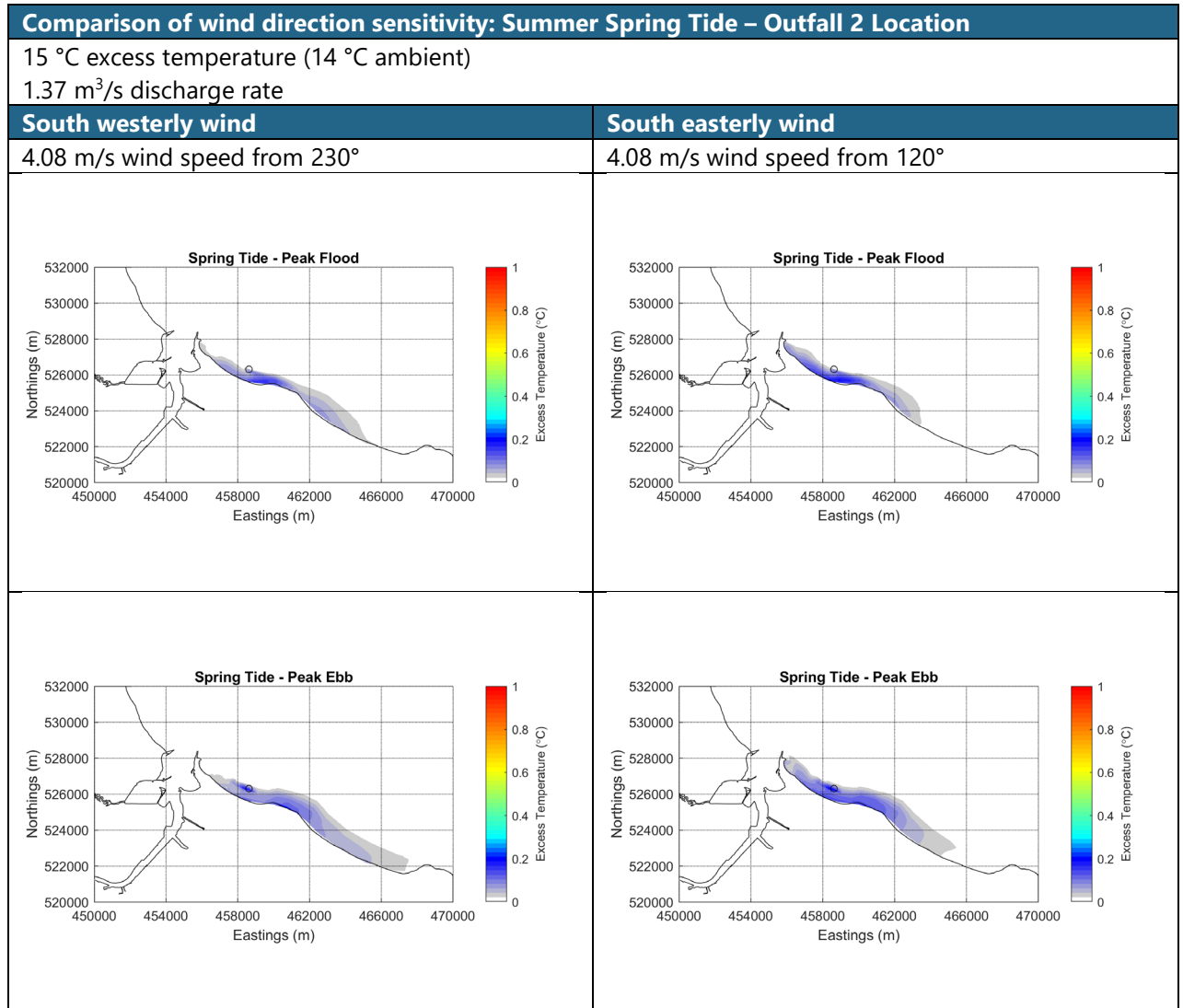


Figure 24. Temperature excess contour plots: Comparison of spring summer conditions with a 230° wind direction (left) vs 120° wind direction (right)

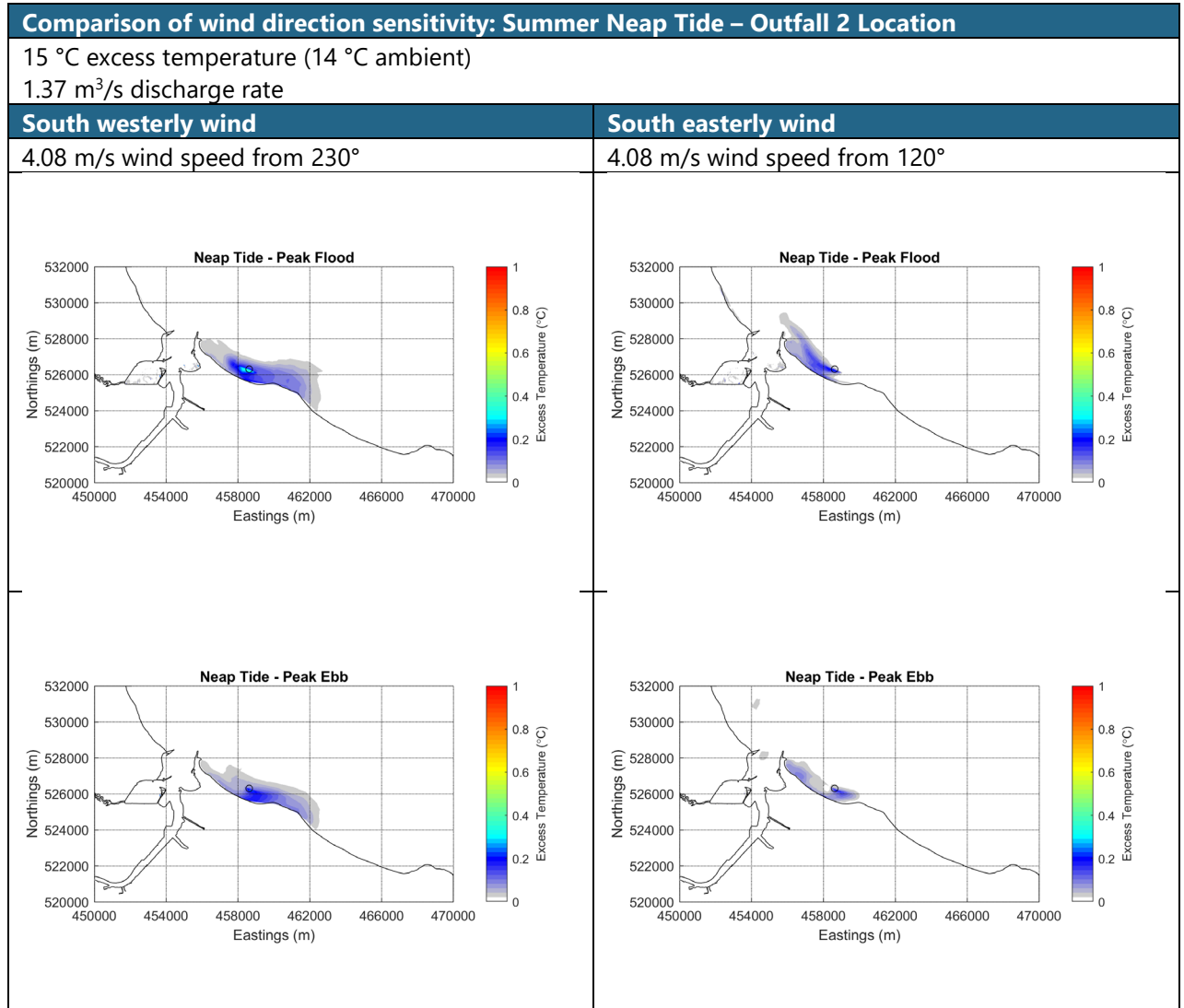


Figure 25. Temperature excess contour plots: Comparison of neap summer conditions with a 230° wind direction (left) vs 120° wind direction (right)

### 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.

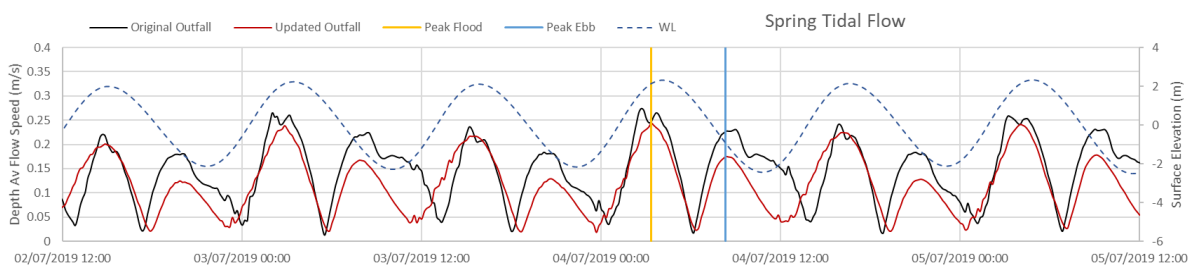


Figure 26. Flow speeds over a spring tide at Outfall 1 and Outfall 2 positions

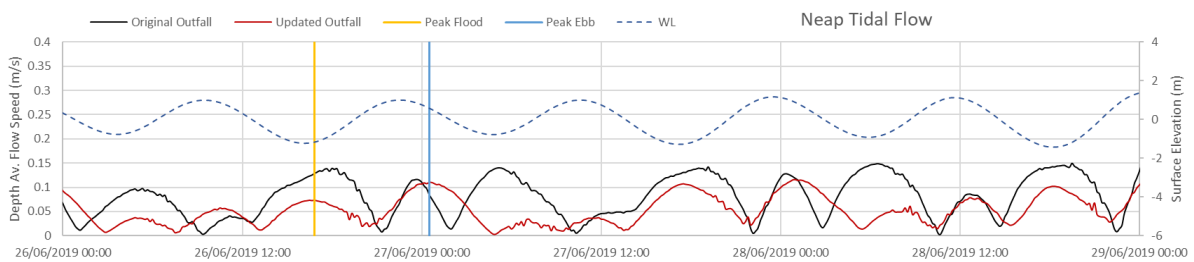


Figure 27. Flow speeds over a neap tide at Outfall 1 and Outfall 2 positions

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.



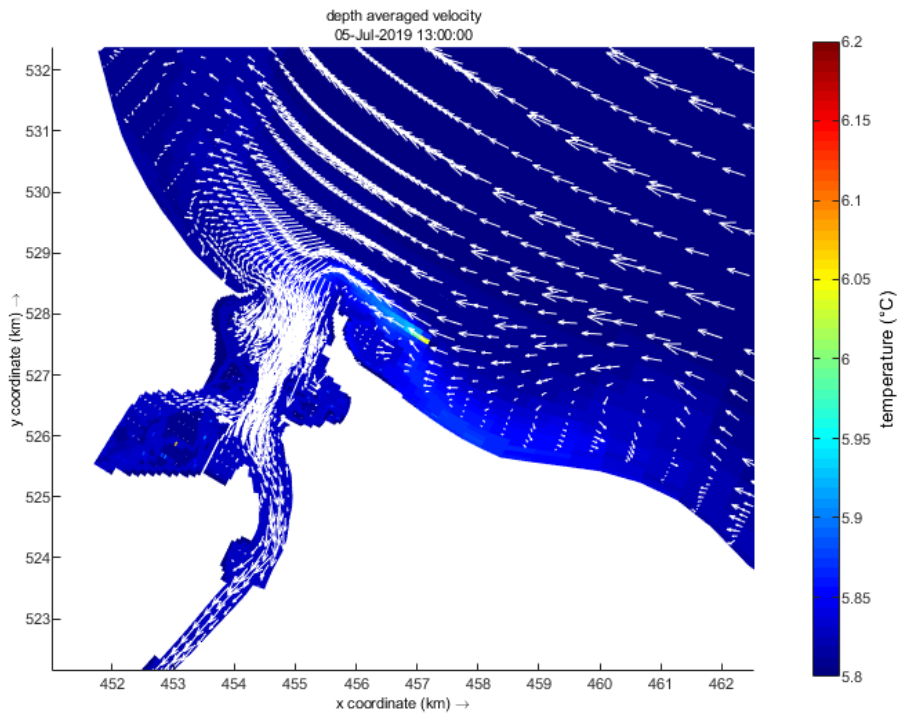


Figure 28. Temperature contours and Flow Speed Vectors from Run 6: Winter – Outfall 1

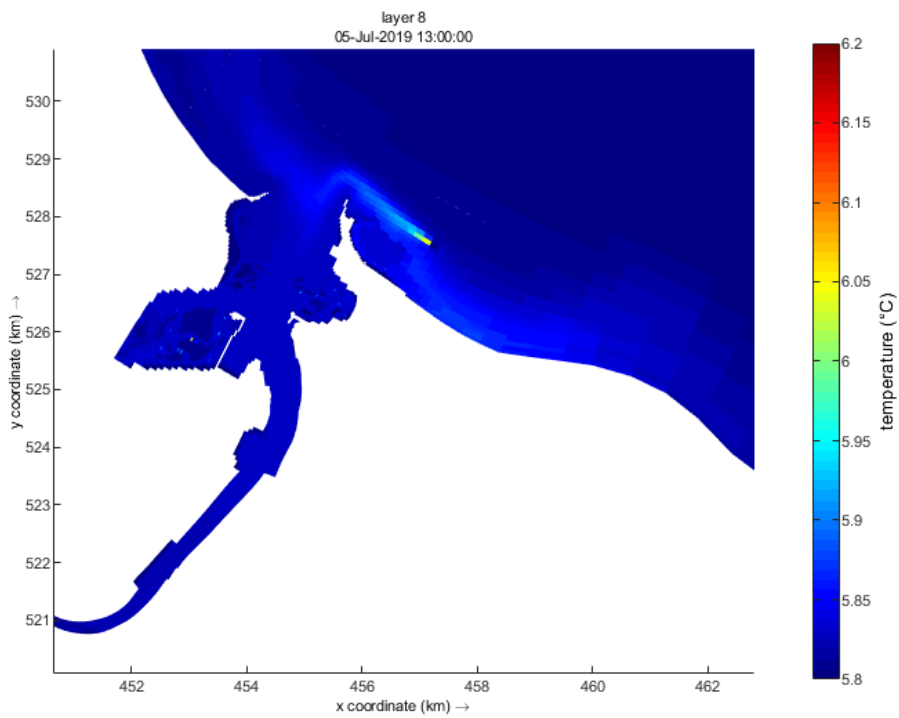


Figure 29. Temperature Contours from Run 6: Winter – Outfall 1

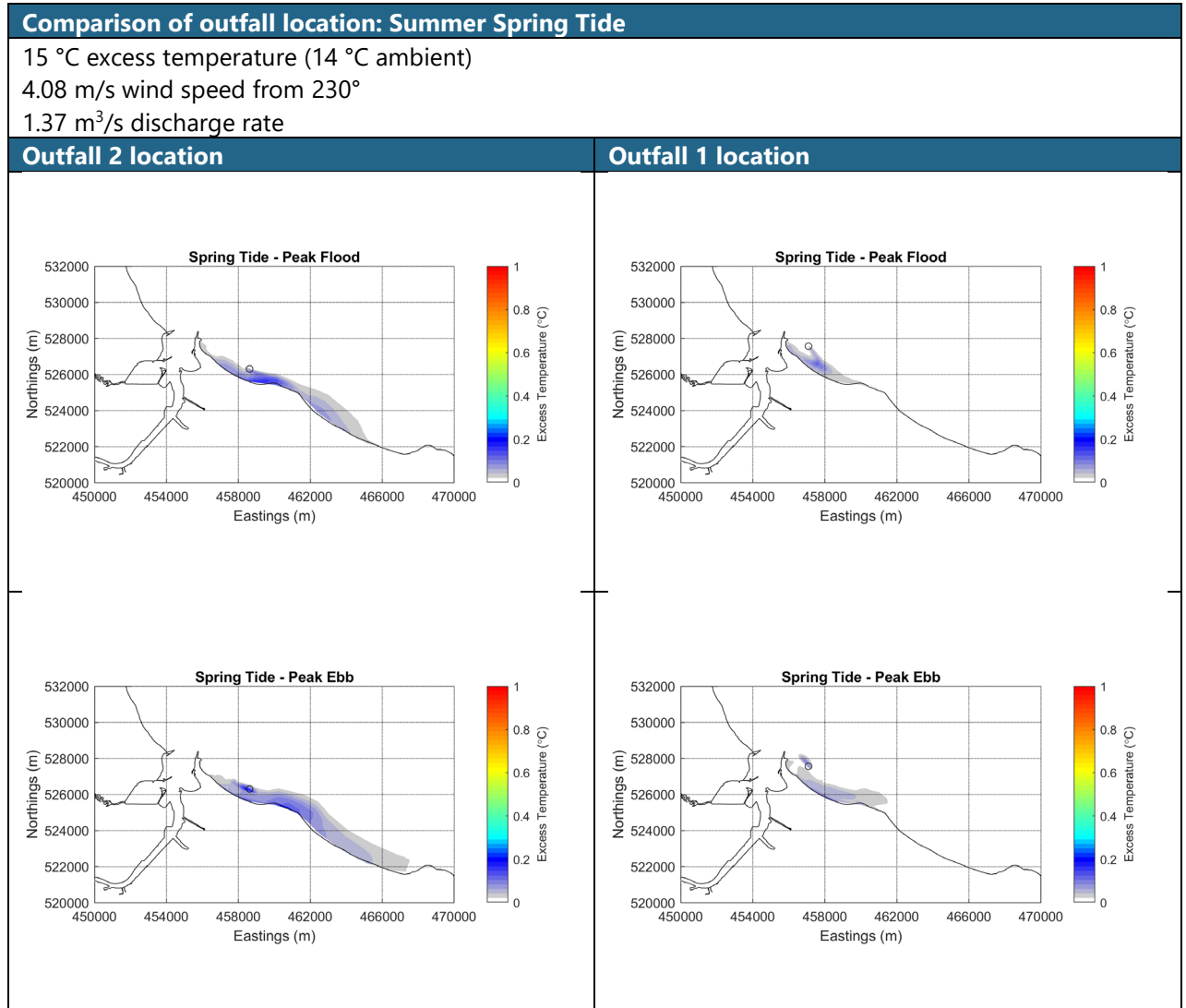


Figure 30. Temperature excess contour plots: Comparison of spring summer conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

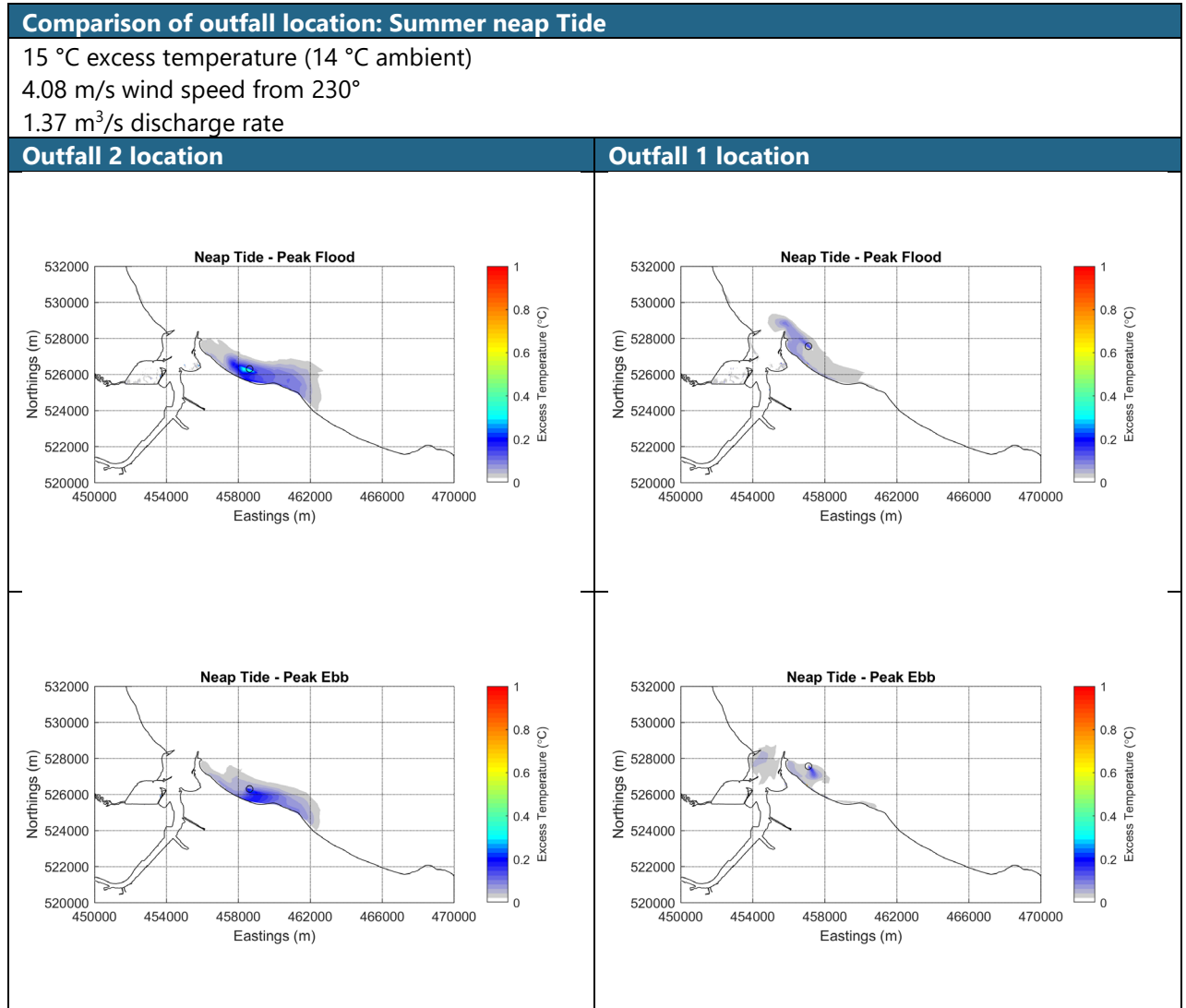


Figure 31. Temperature excess contour plots: Comparison of neap summer conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

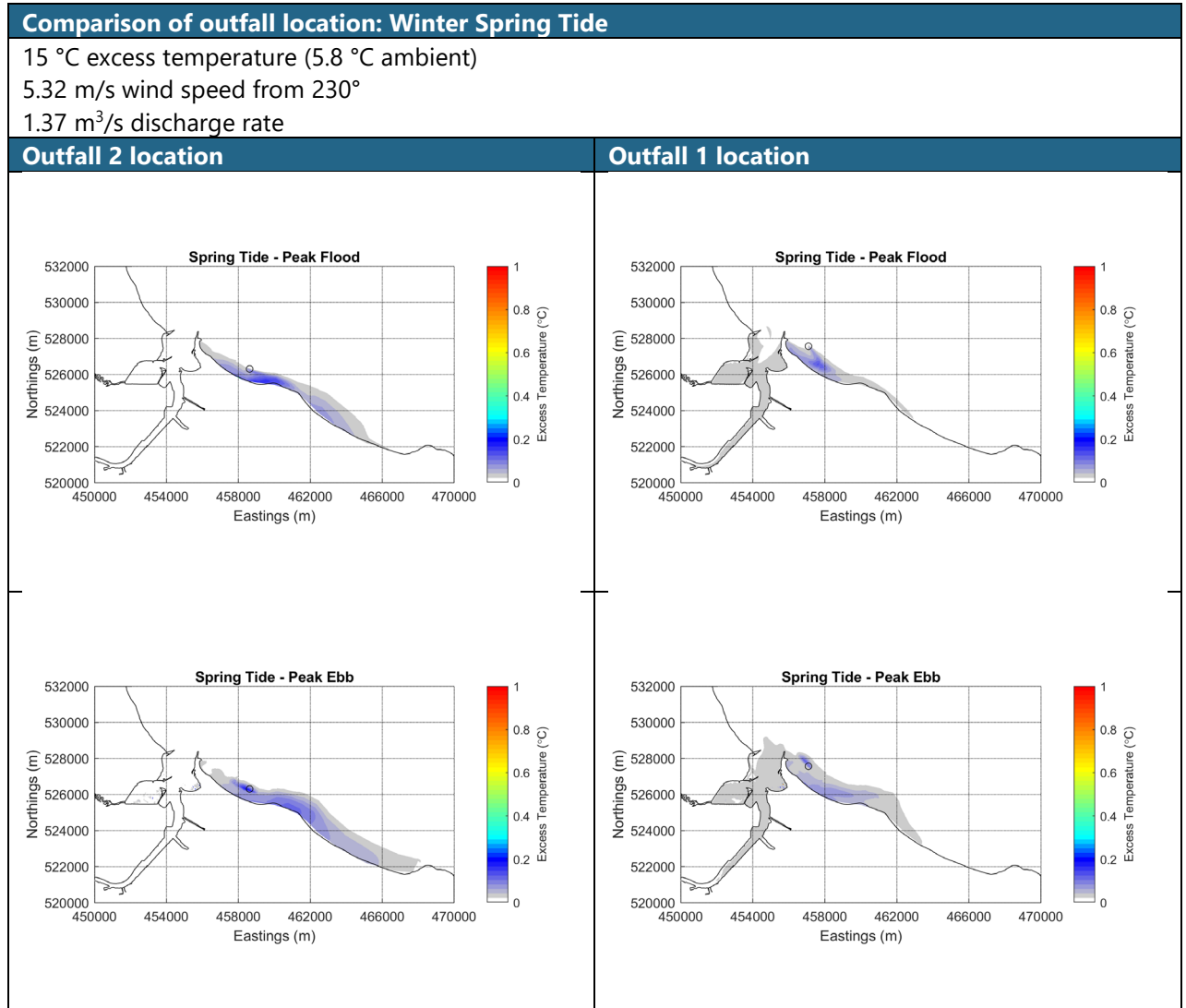


Figure 32. Temperature excess contour plots: Comparison of spring winter conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

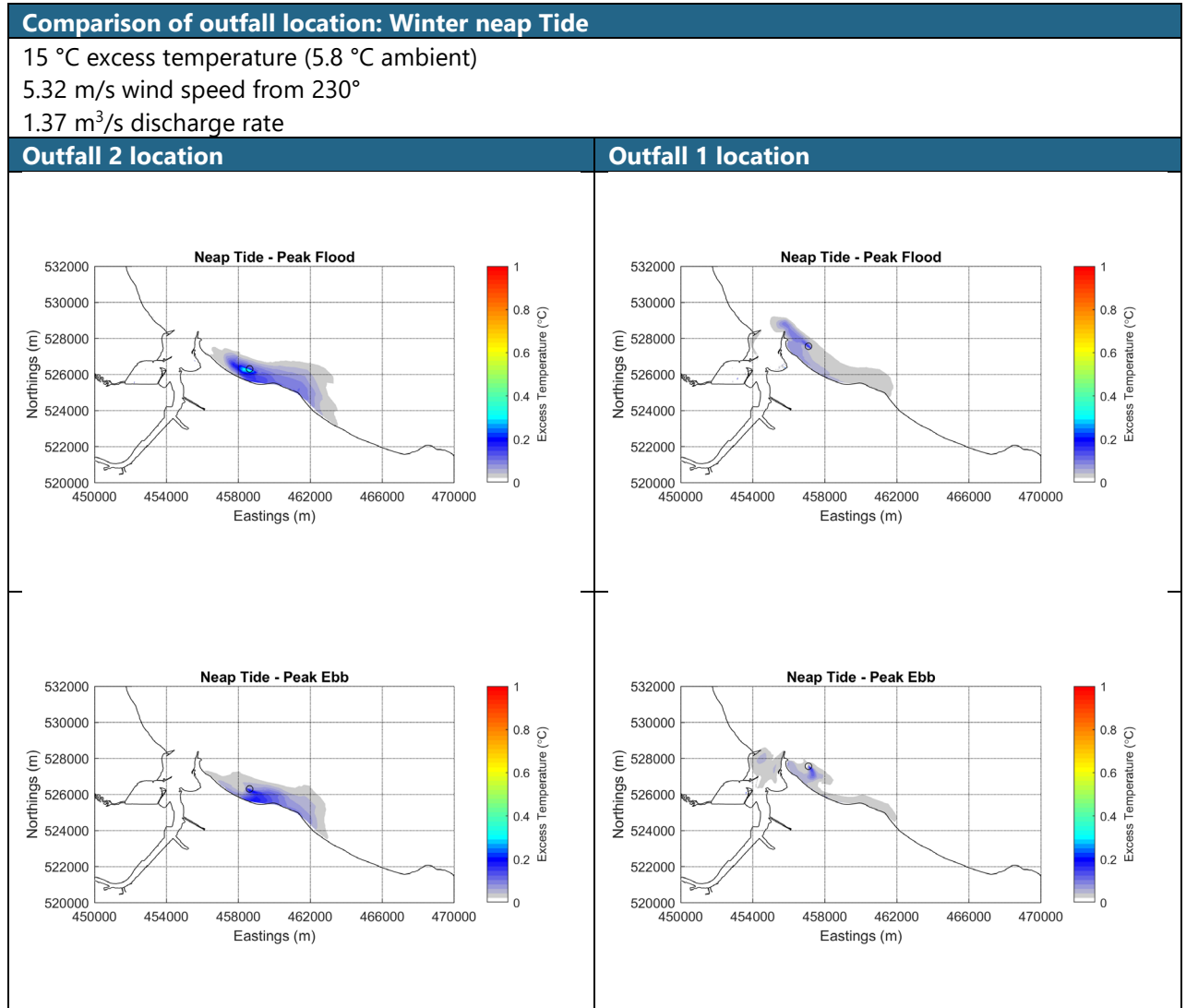


Figure 33. Temperature excess contour plots: Comparison of neap winter conditions with a discharge specified at Outfall 2 (left) vs Outfall 1 (right)

### 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 m<sup>3</sup>/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.

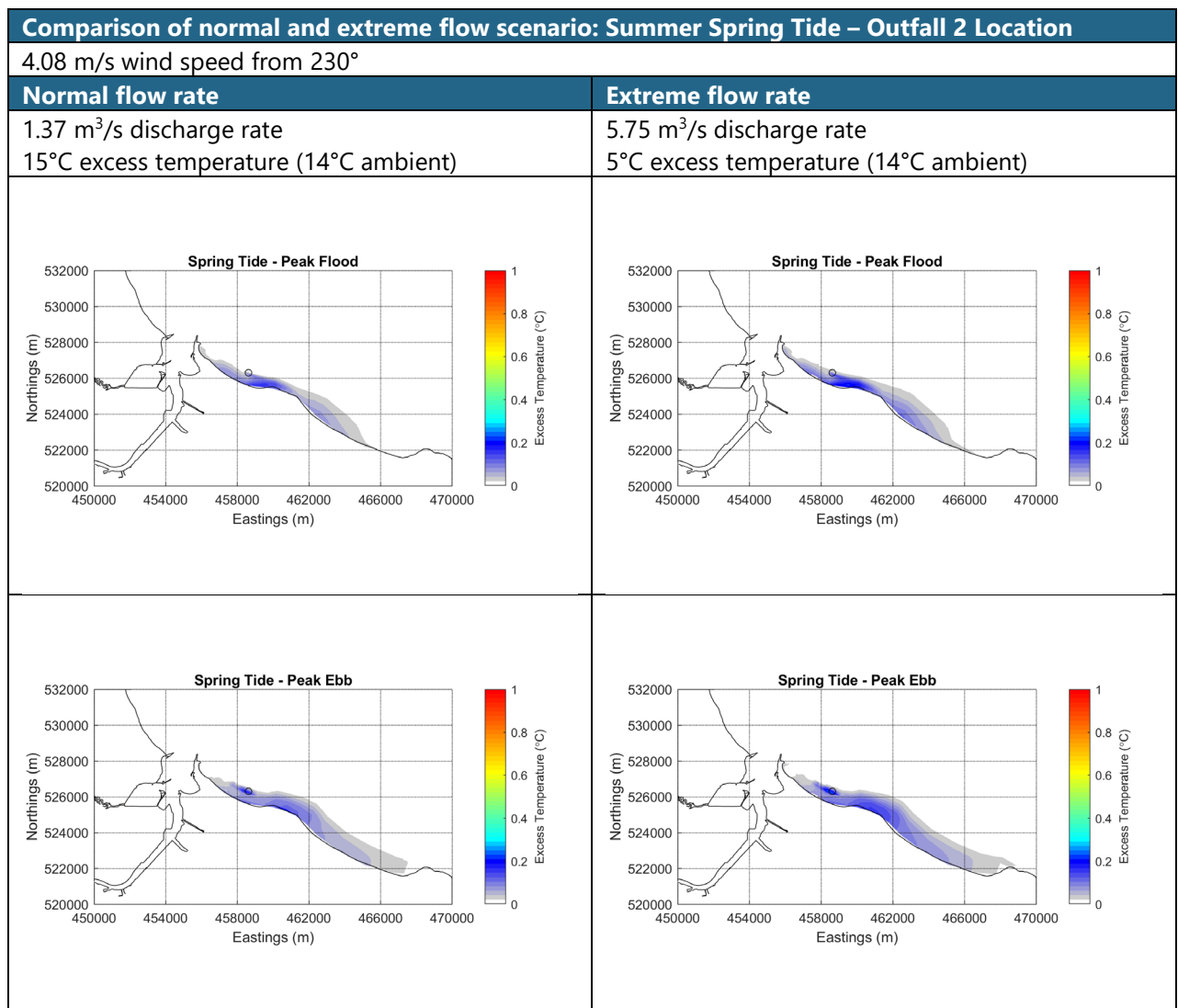


Figure 34. Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates

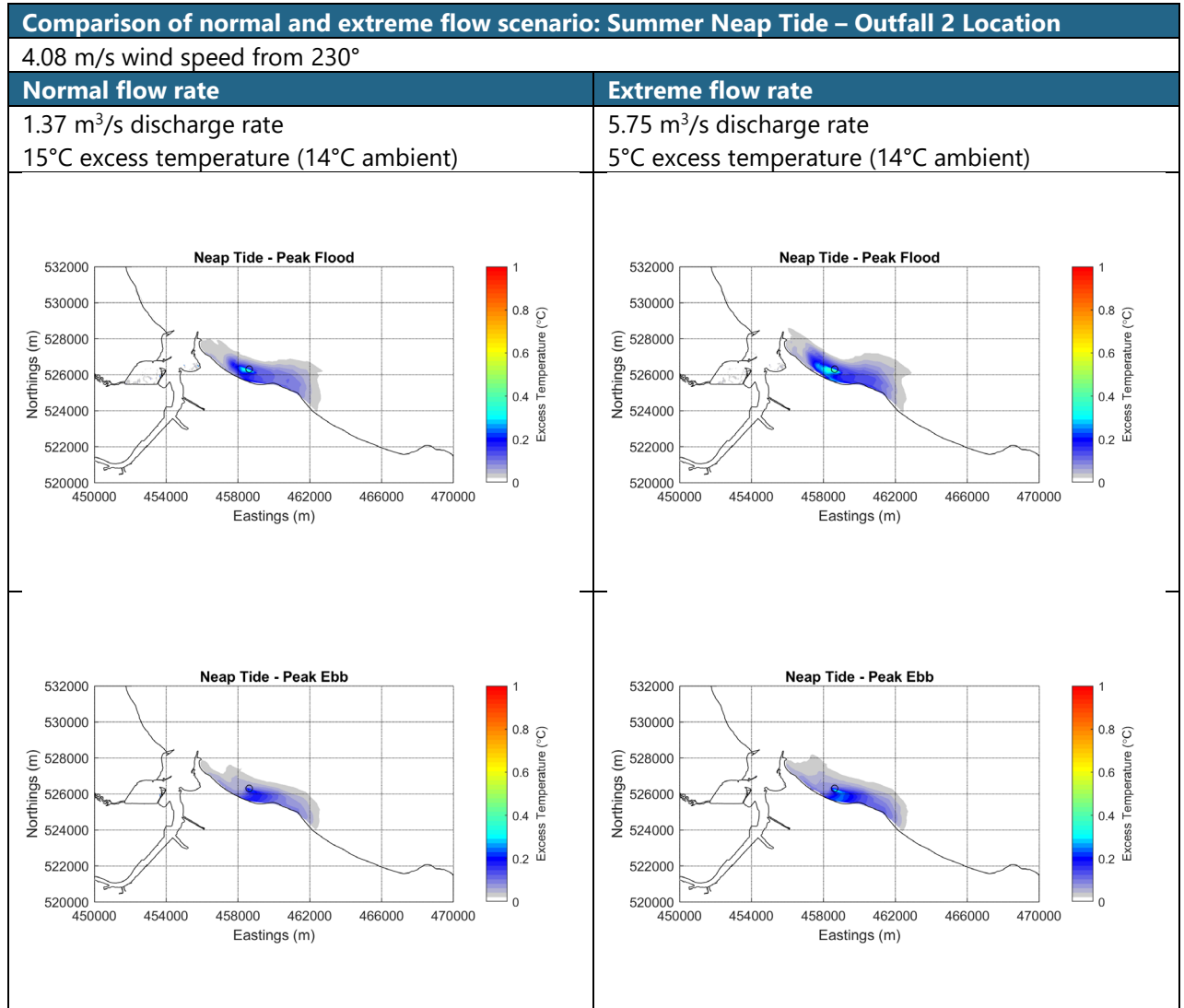


Figure 35. Temperature excess contour plots: Comparison of spring summer conditions with normal and extreme flow rates



## 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  $3^{\circ}\text{C}$  temperature excess only extends approximately 45 m from the discharge point on the flood and 98 m on the ebb. Considering a  $2^{\circ}\text{C}$  temperature excess the ebb extent of the plume increases to 140 m, and then 235 m to the  $1^{\circ}\text{C}$  excess temperature contour, which still represents a very limited excursion from the original discharge point.

To examine the wider plume dispersion a  $0.1^{\circ}\text{C}$  temperature excess contour was exported from CORMIX. This shows that a  $0.1^{\circ}\text{C}$  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  $>0.02^{\circ}\text{C}$  are predicted up to  $\sim 9$  km of the Outfall 2 site, however greater temperature excesses of up to  $0.3^{\circ}$  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).

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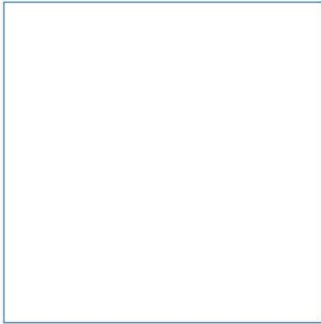
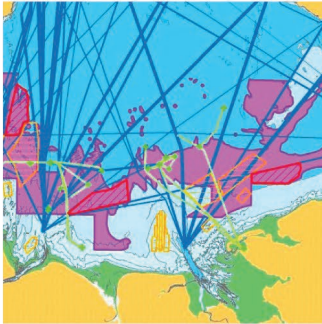
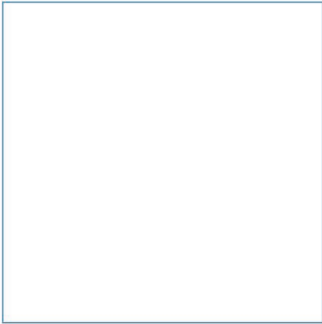
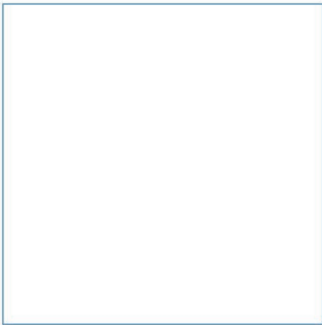
## 7 Acronyms/Abbreviations

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

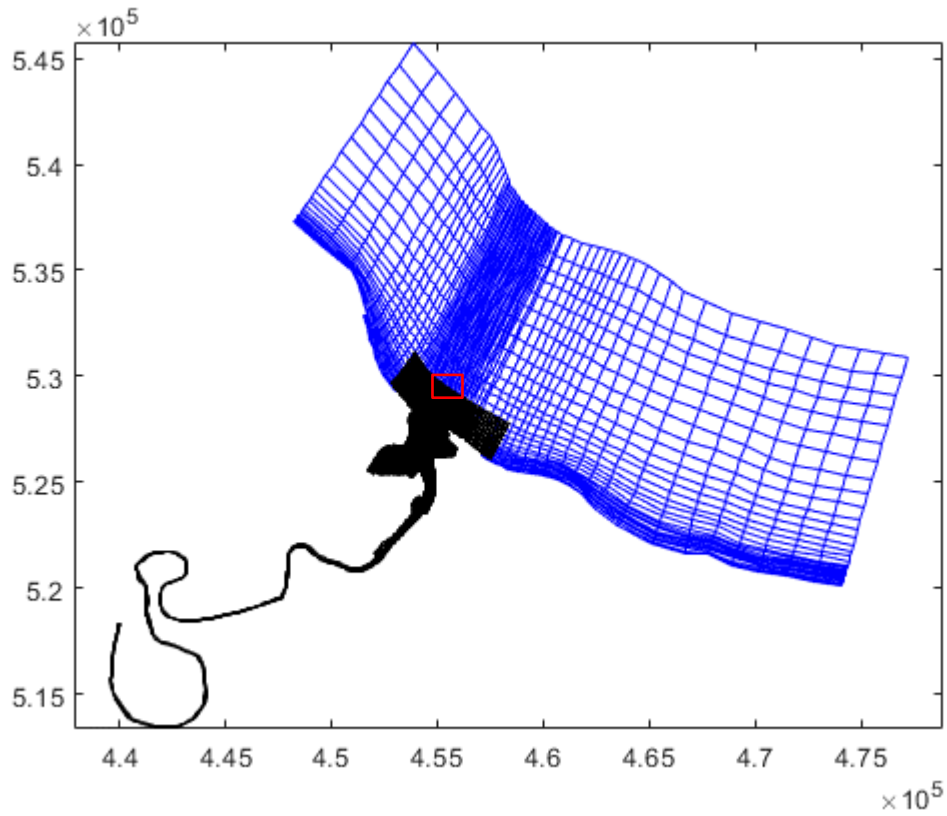
The Delft3D model uses a curvilinear computational grid, which allows a grid composed of various sizes to be used throughout a model domain. In addition to this, the original hydrodynamic model has been further refined using a 'domain decomposition' (dd) approach. This approach allows the creation of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

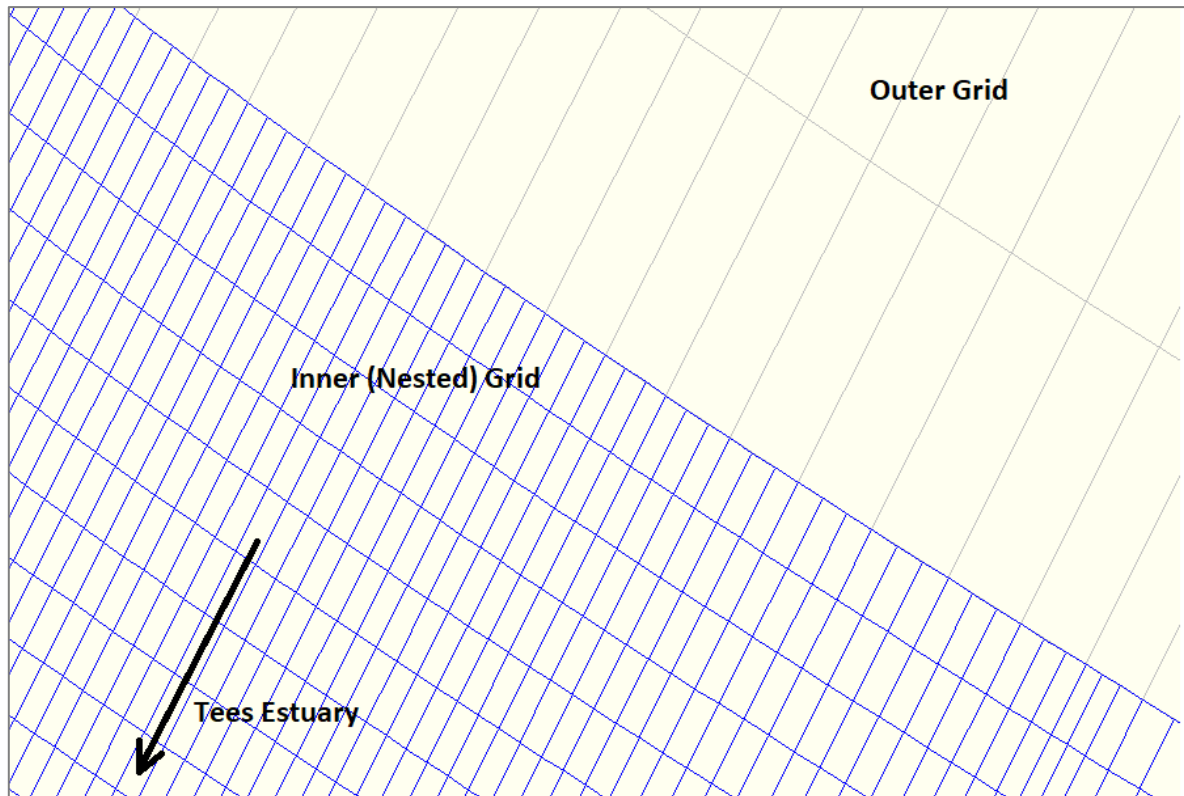


Figure 37. Delft3D hydrodynamic model grid – Refinement of nested grid



## 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<sup>1</sup>, 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<sup>2</sup> have been used to inform the water depth in areas where alternative data were sparse. Chart depths were manually digitised for the areas of interest which included the Philips Inset Dock and dredged areas of the Tees river channel.

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

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<sup>1</sup> <https://environment.data.gov.uk/DefraDataDownload/?Mode=survey>

<sup>2</sup> Admiralty Chart 2566 Tees and Hartlepool Bays

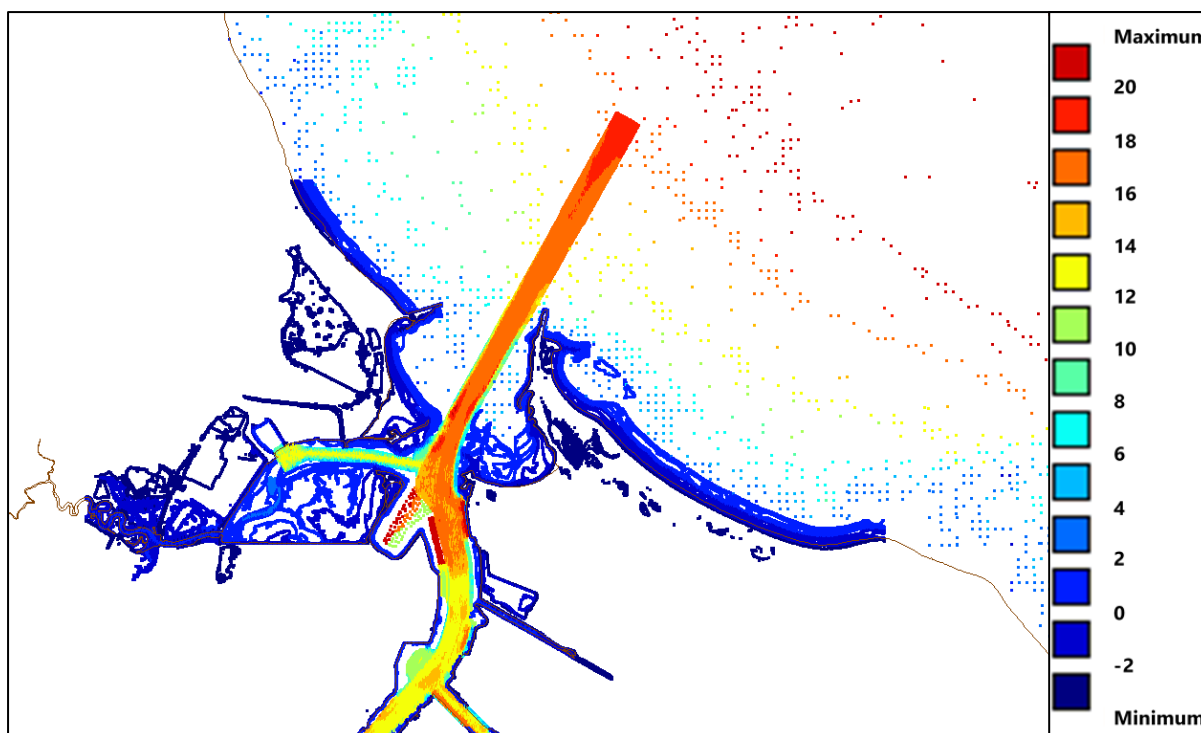


Figure 38. Scatter plot showing available bathymetry data resolution and coverage. All values are depth positive and referenced to meters below ODN.

## 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:  $ODN = CD + 2.85 \text{ m}$ . 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:

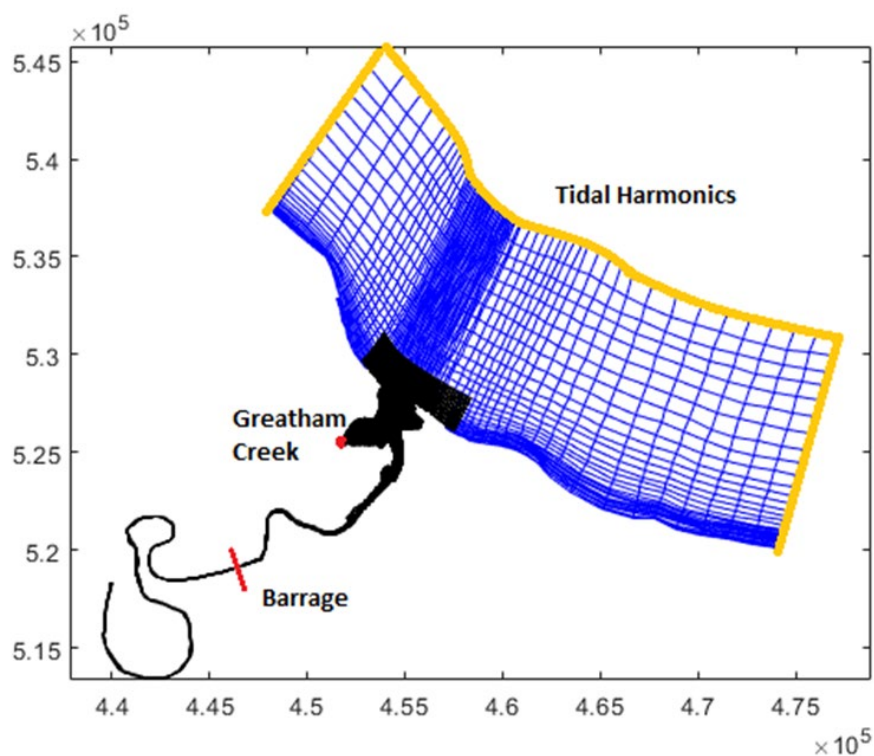
- PD Teesport Survey;
- LiDAR Contours;
- CMap;
- Admiralty Chart; and
- Previous model depths in the upper section for rivers.

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)**

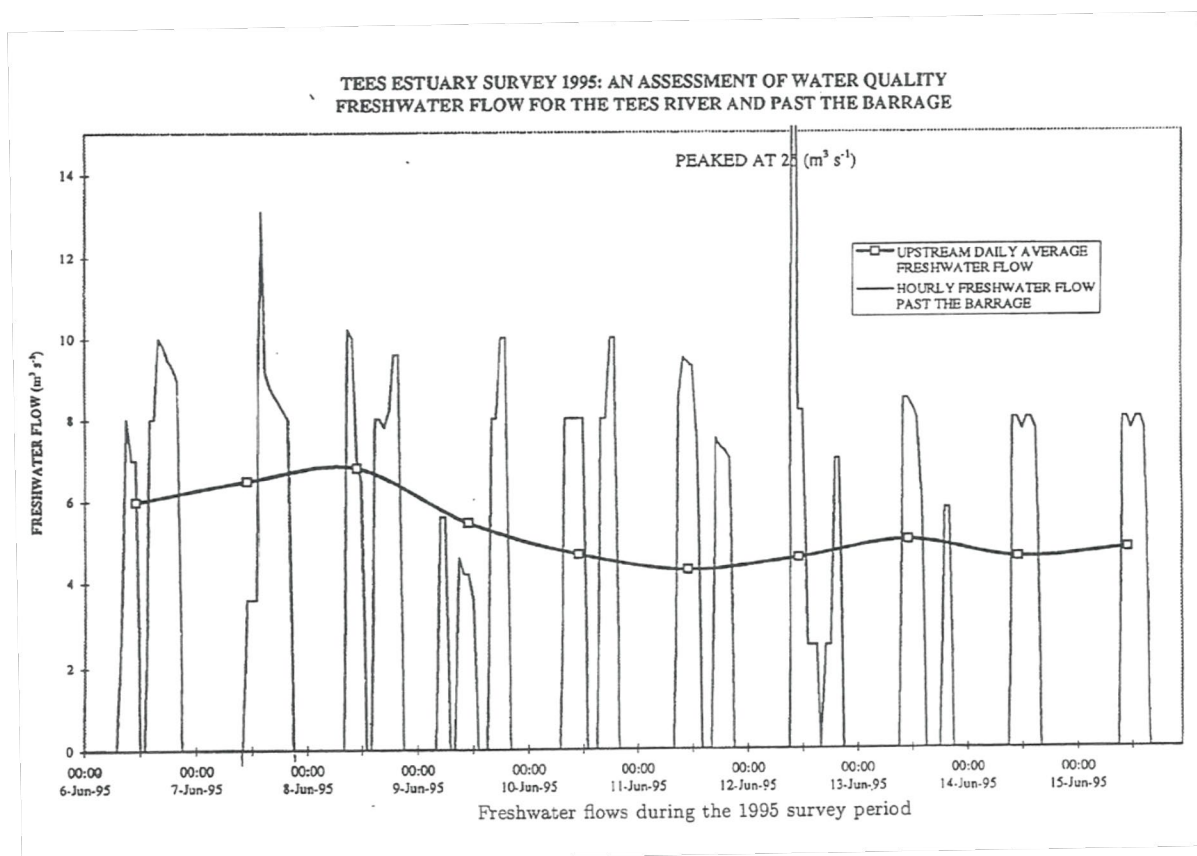
The harmonic constituents defined at these boundaries have been extracted from a wider area model (ABPmer 2003) previously constructed by ABPmer which has previously been calibrated and verified against three data sets. This data has been derived from TIDECALC (a programme for generating tidal predictions 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)<sup>3</sup>. 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.

<sup>3</sup> <https://nrfa.ceh.ac.uk/data/search>

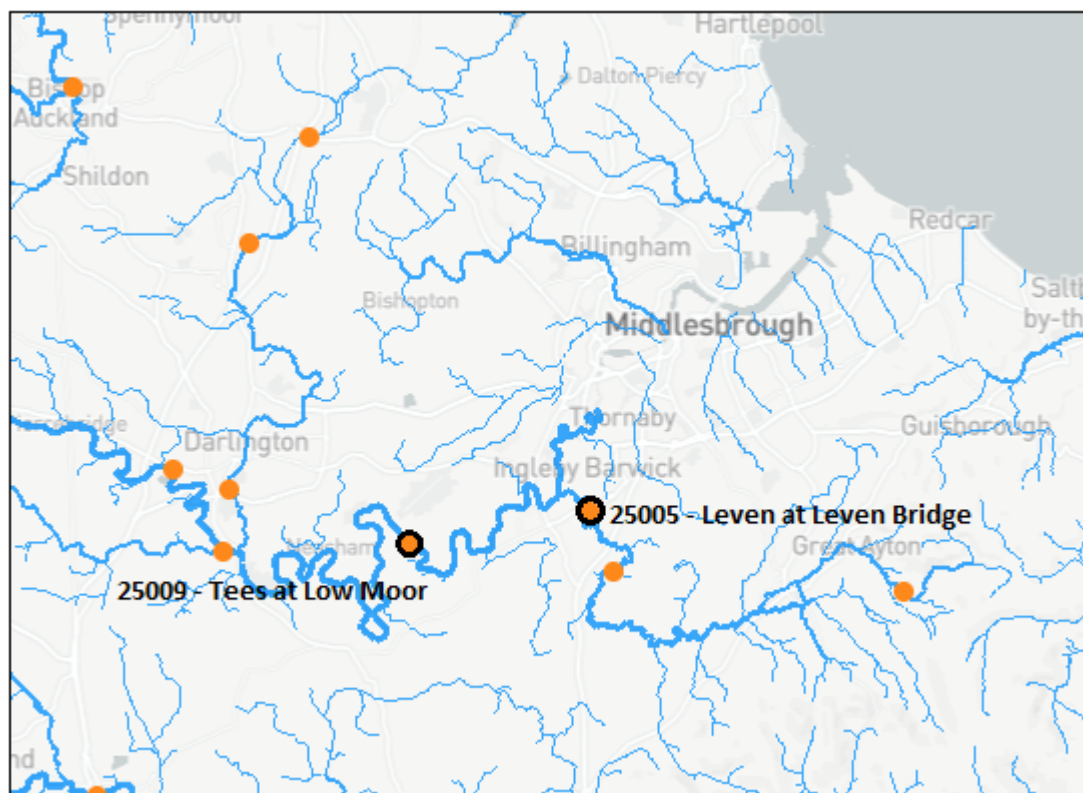


Figure 41. Flow data stations assessed for Tees Barrage discharge calculations

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
<b>Mean Flow:</b>	<b>1.892 m<sup>3</sup>/s</b>	<b>20.528 m<sup>3</sup>/s</b>
<b>95% Exceedance (Q95):</b>	<b>0.249 m<sup>3</sup>/s</b>	<b>3.07 m<sup>3</sup>/s</b>
70% Exceedance (Q70):	0.517 m <sup>3</sup> /s	6.15 m <sup>3</sup> /s
50% Exceedance (Q50):	0.873 m <sup>3</sup> /s	10.9 m <sup>3</sup> /s
10% Exceedance (Q10):	4.248 m <sup>3</sup> /s	46.5 m <sup>3</sup> /s
<b>5% Exceedance (Q5):</b>	<b>6.78 m<sup>3</sup>/s</b>	<b>67.7 m<sup>3</sup>/s</b>

Source: National River Flow Archive, March 2020

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

Parameter	Flow rate (m <sup>3</sup> /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<sup>3</sup>/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.

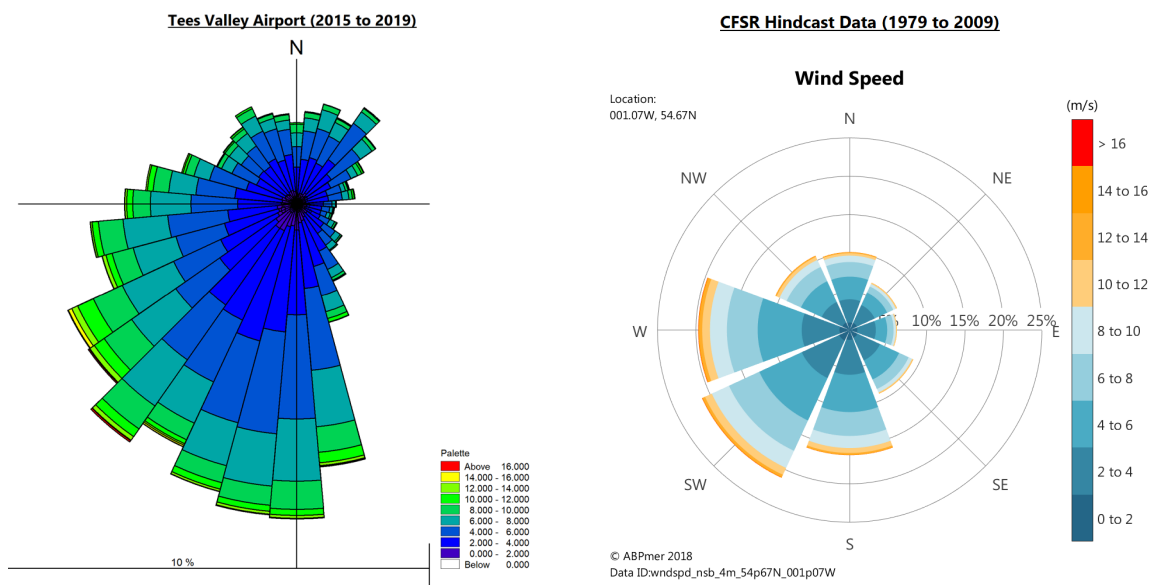


Figure 42. Wind rose of Tees Valley Airport wind data (left) and CFSR Hindcast data (right).

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).

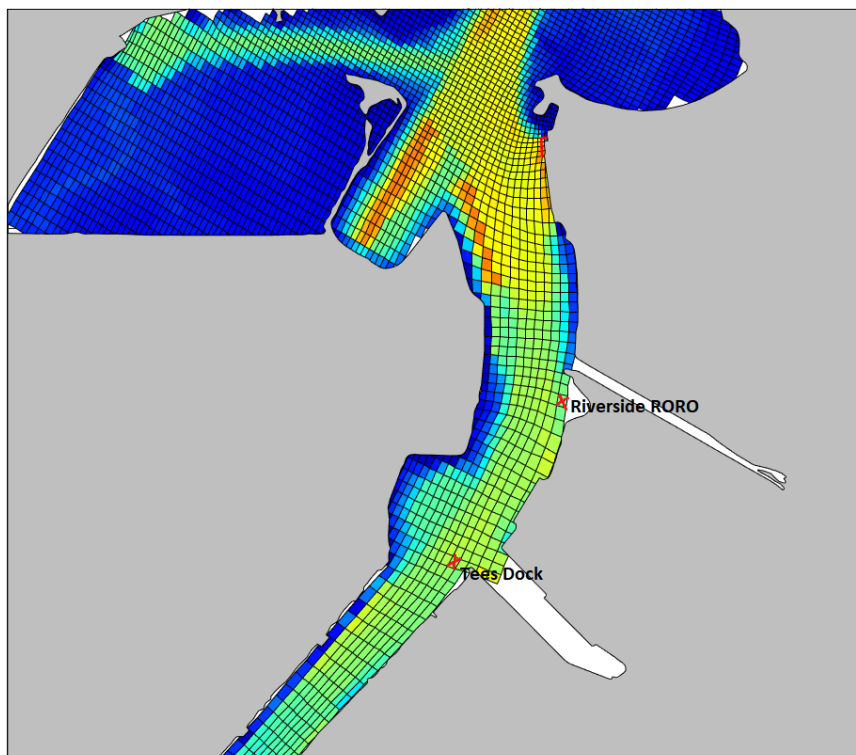
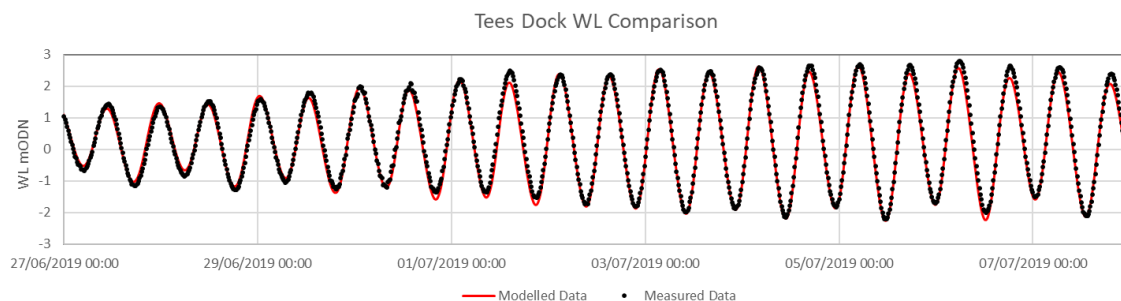


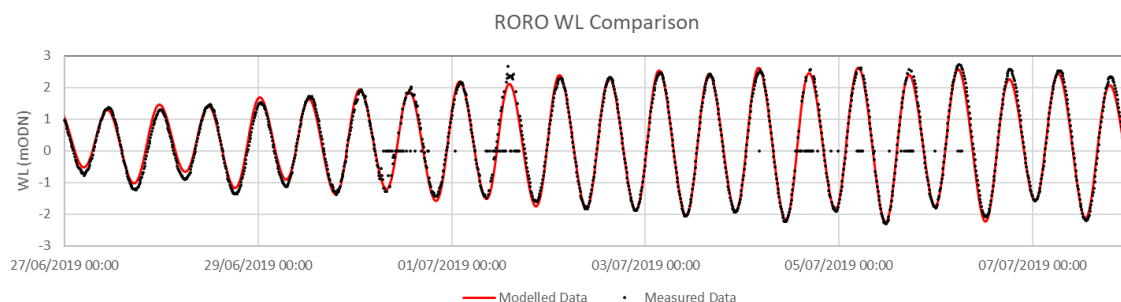
Figure 43. Location of model extraction points for tide gauge calibration overlaid onto model grid and underlying bathymetry.

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.

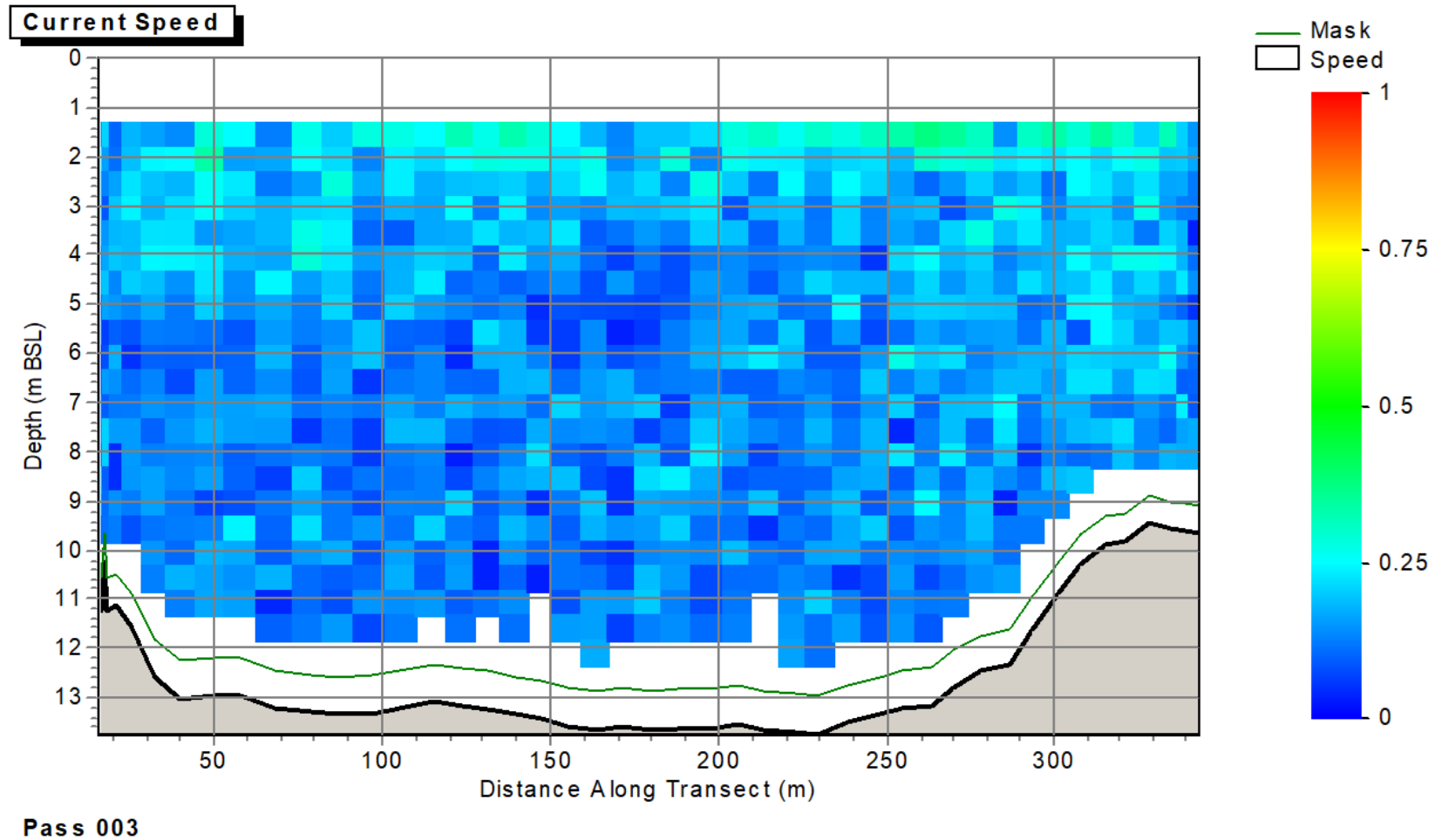


Figure provided by PD Teesport

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

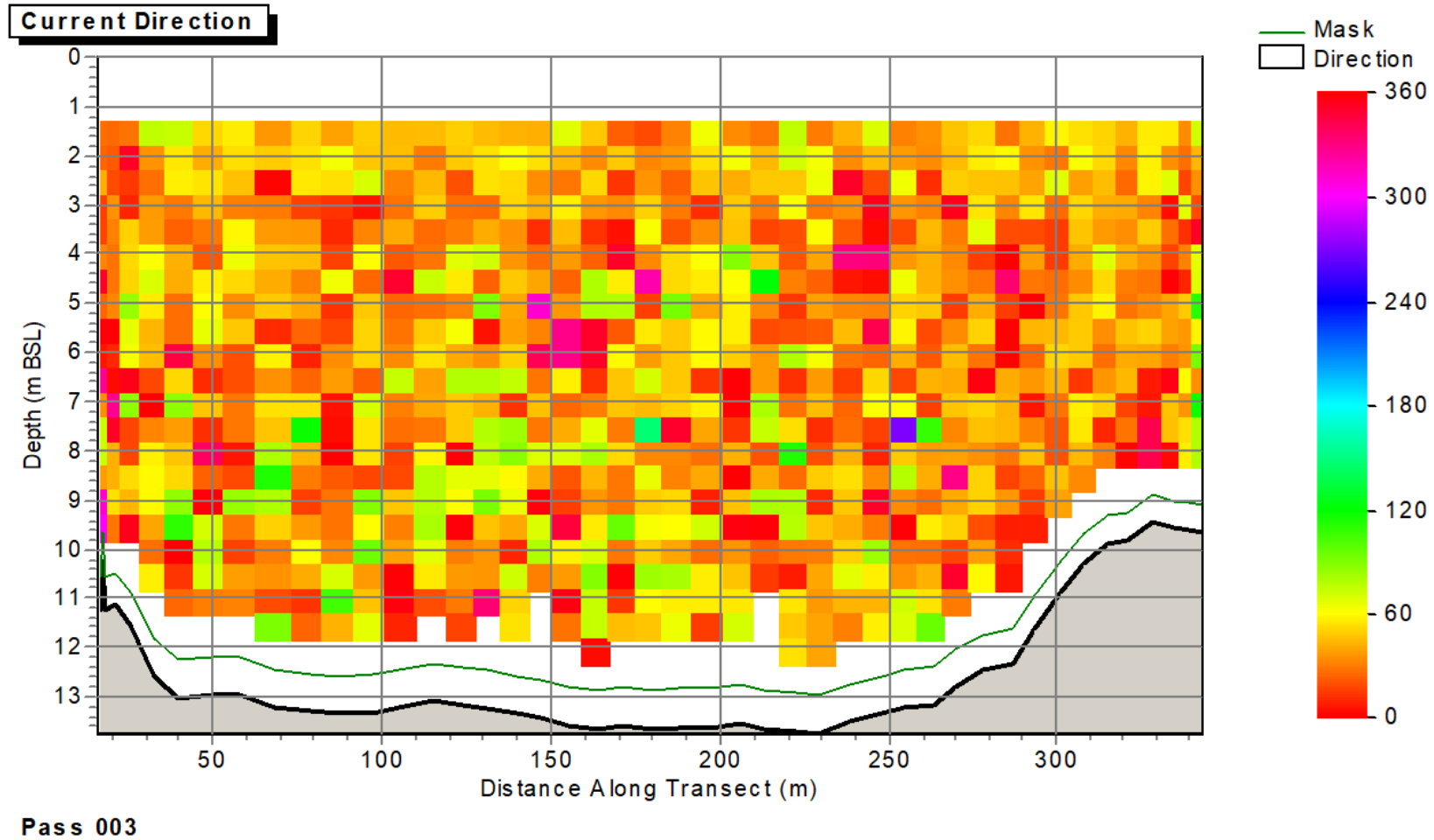


Figure provided by PD Teesport

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

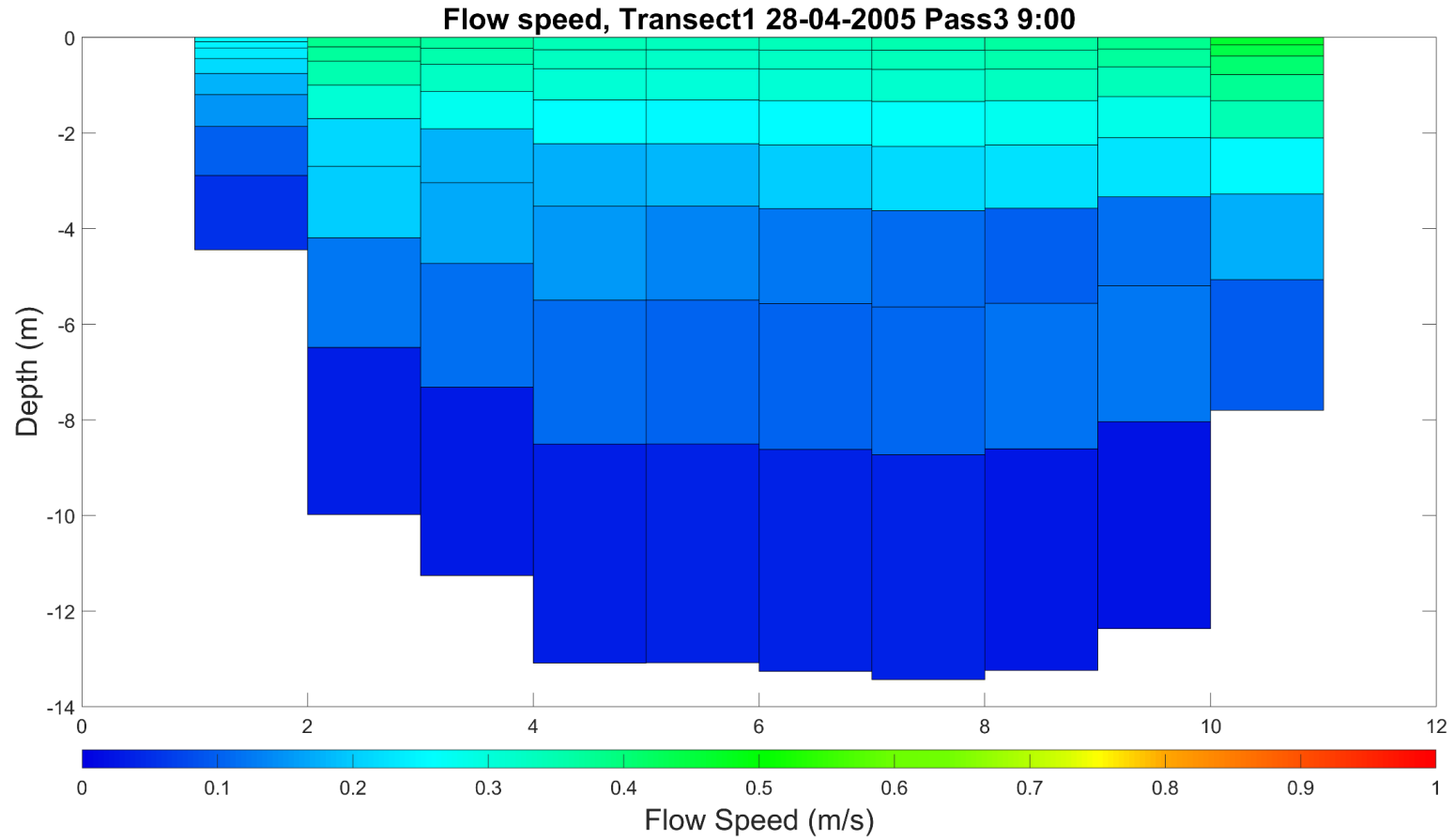


Figure 48. Modelled flow speed, Transect 1: Ebb tide, cross section of speed with depth shown from west (left) to east (right)

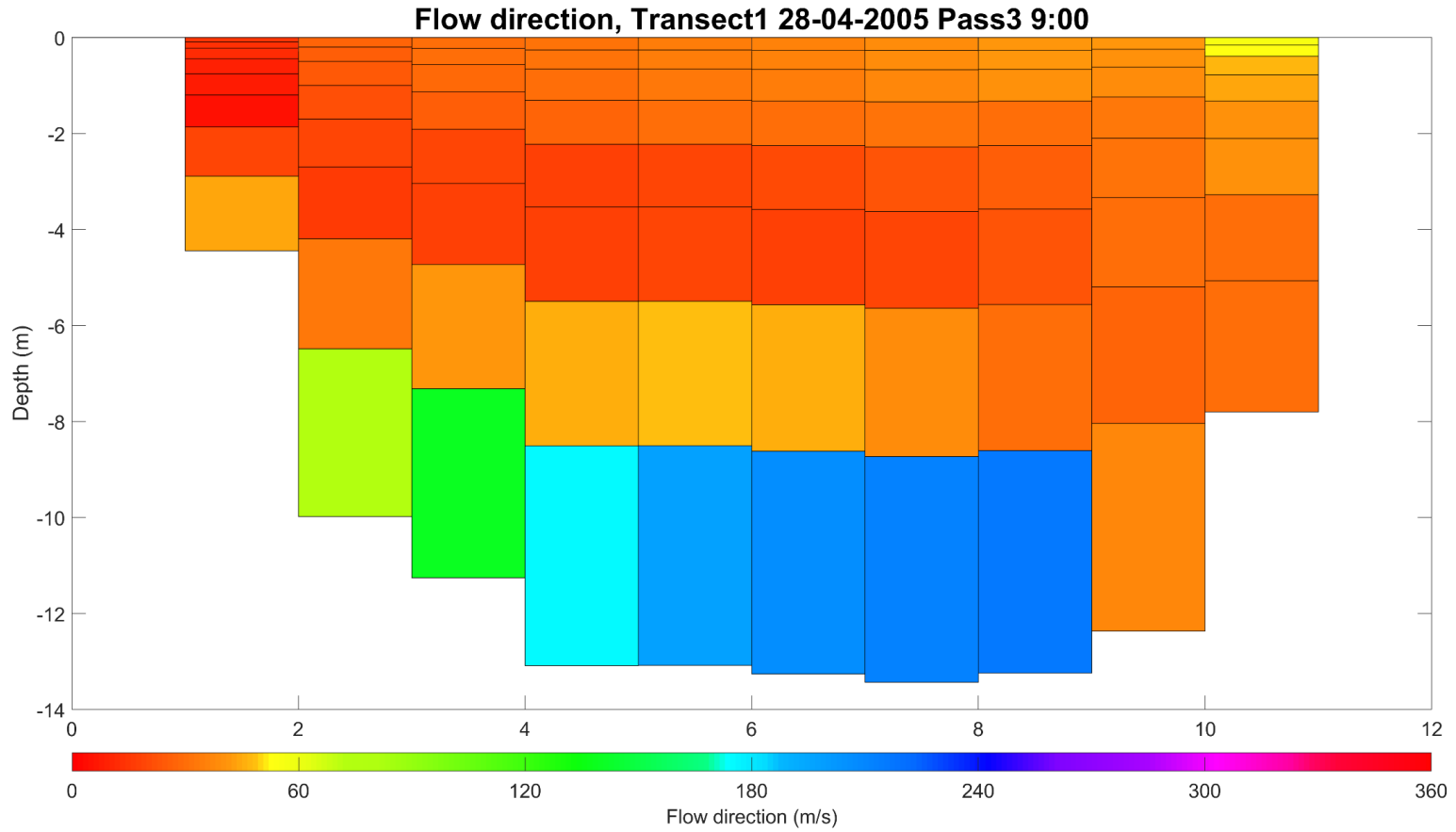


Figure 49. Modelled flow direction, Transect 1: Ebb tide, cross section of direction with depth shown from west (left) to east (right)



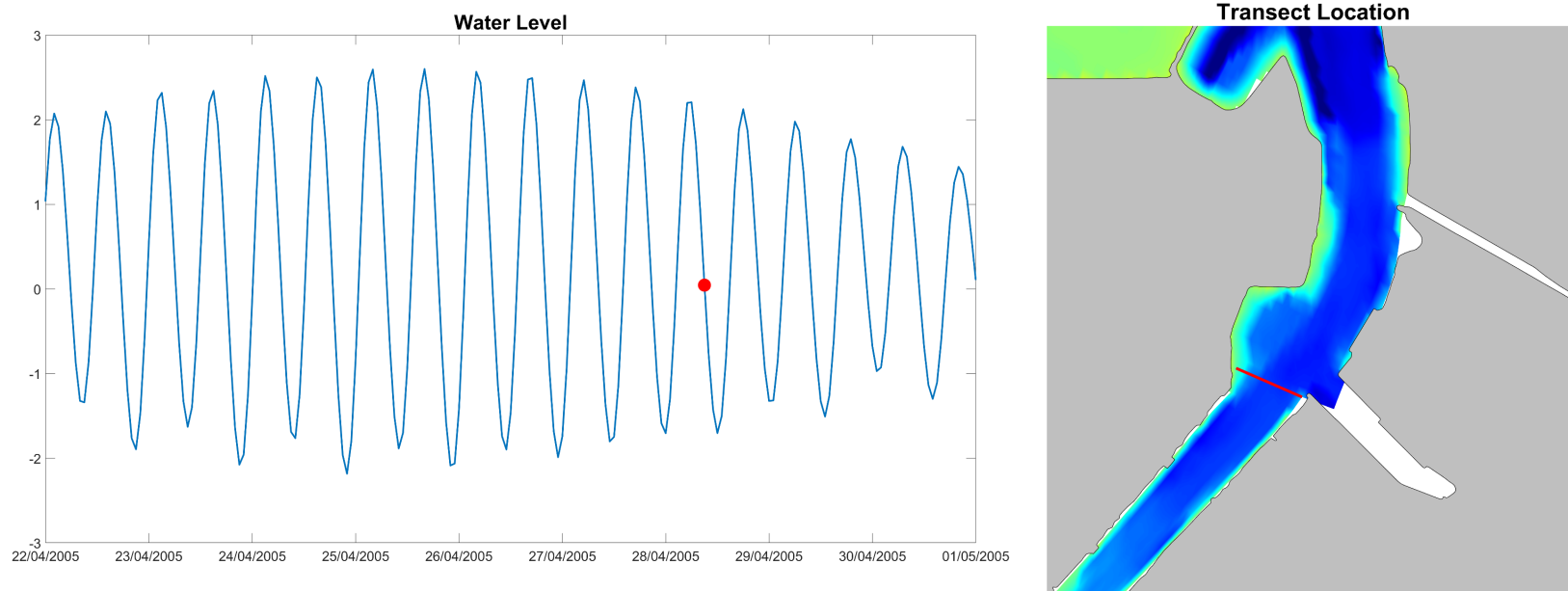


Figure 50. Tidal state and transect location extracted from the model for Transect 1 Pass 03: 28/04/2005

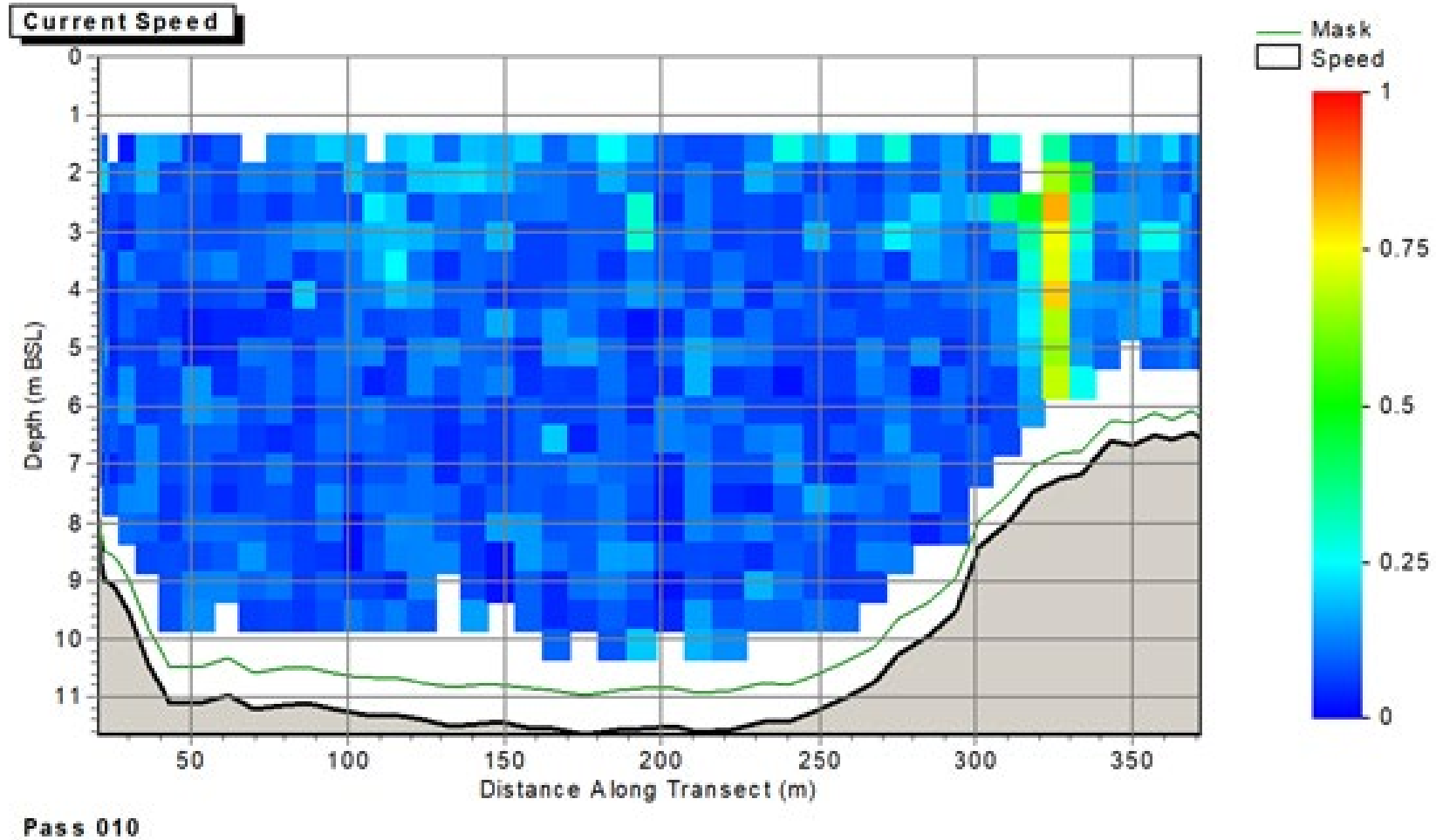


Figure provided by PD Teesport

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

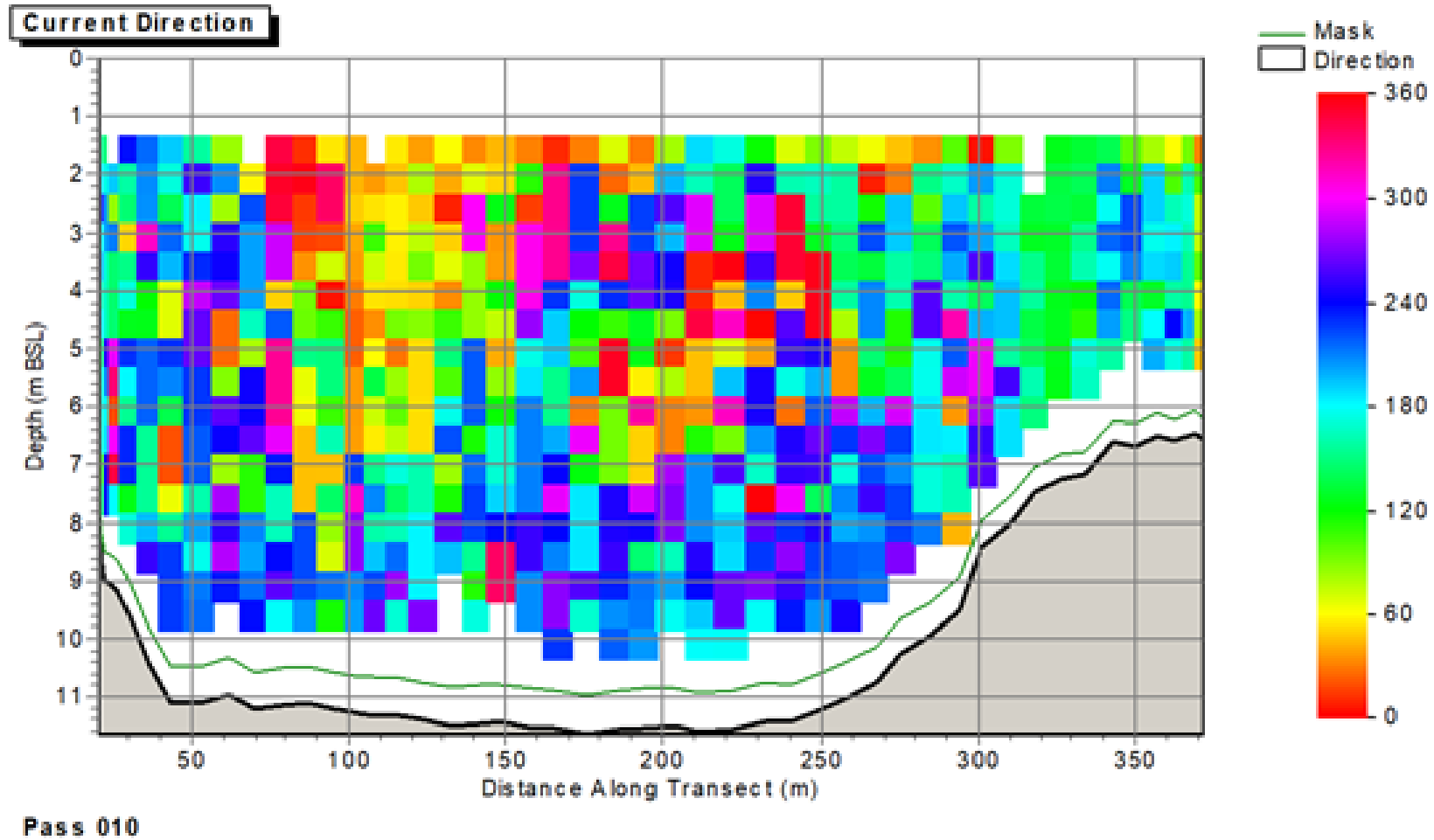


Figure provided by PD Teesport

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

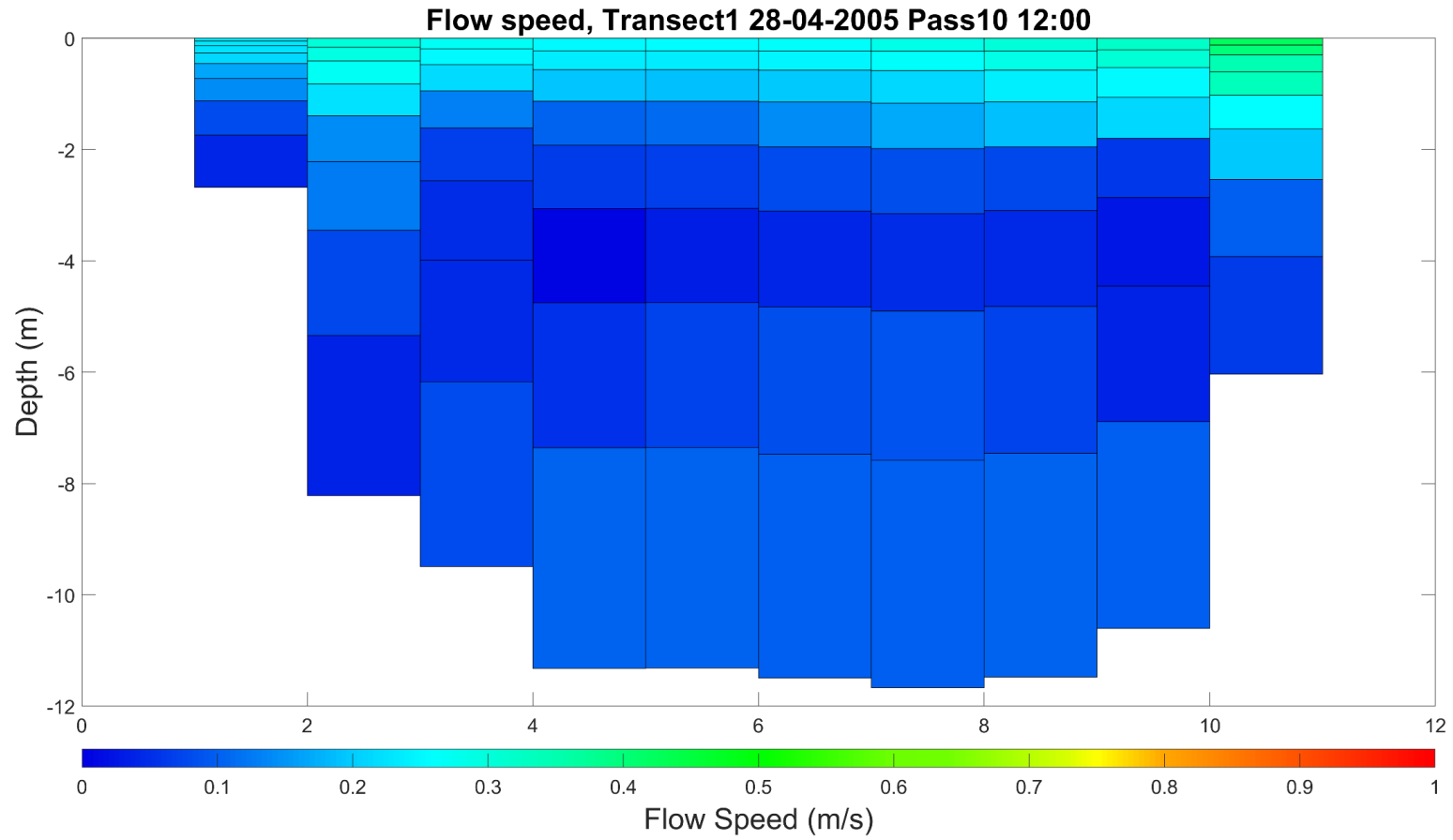


Figure 53. Modelled flow speed, Transect 1: Low tide, cross section of speed with depth shown from west (left) to east (right)

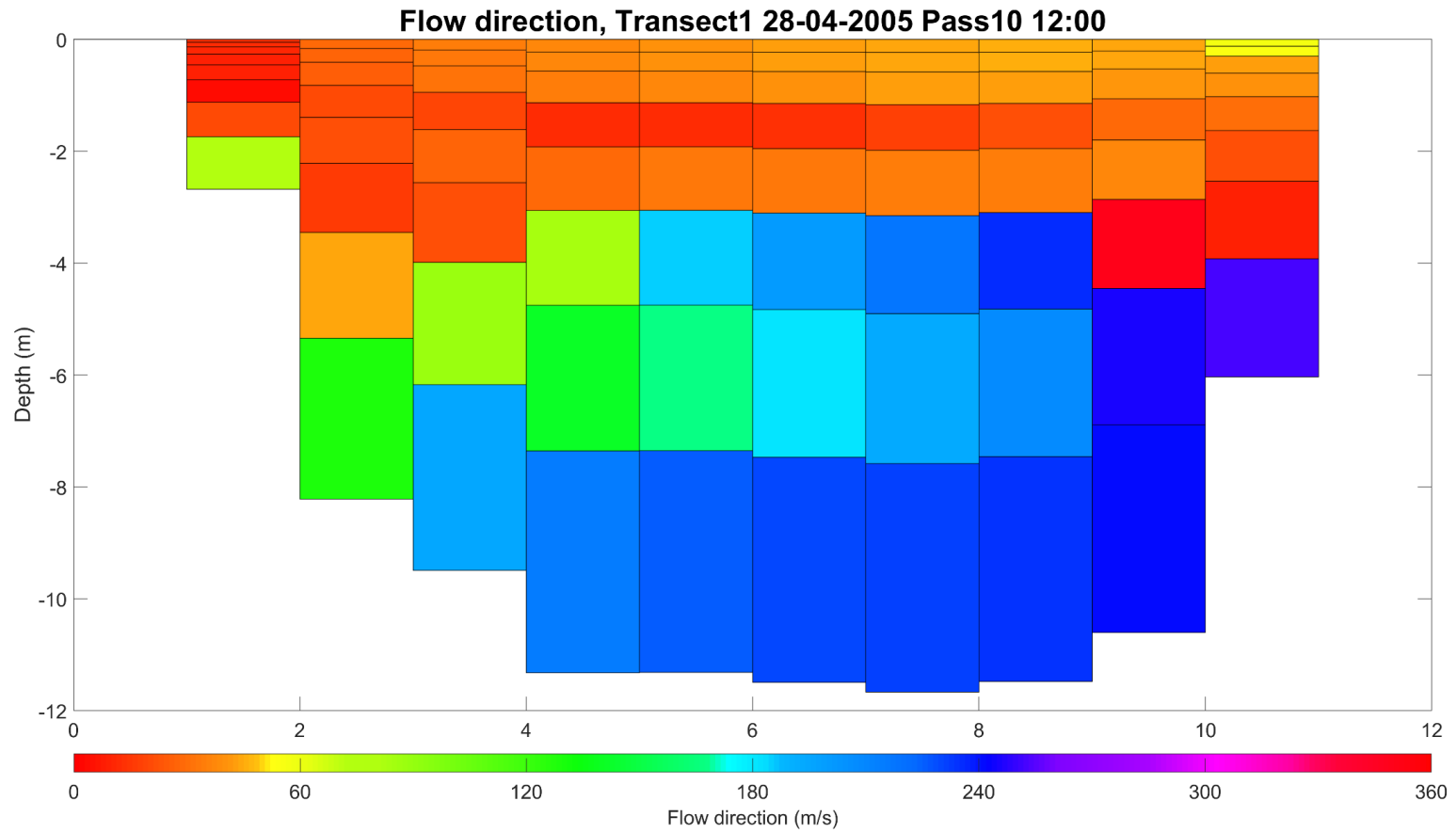


Figure 54. Modelled flow direction, Transect 1: Low tide, cross section of direction with depth shown from west (left) to east (right)

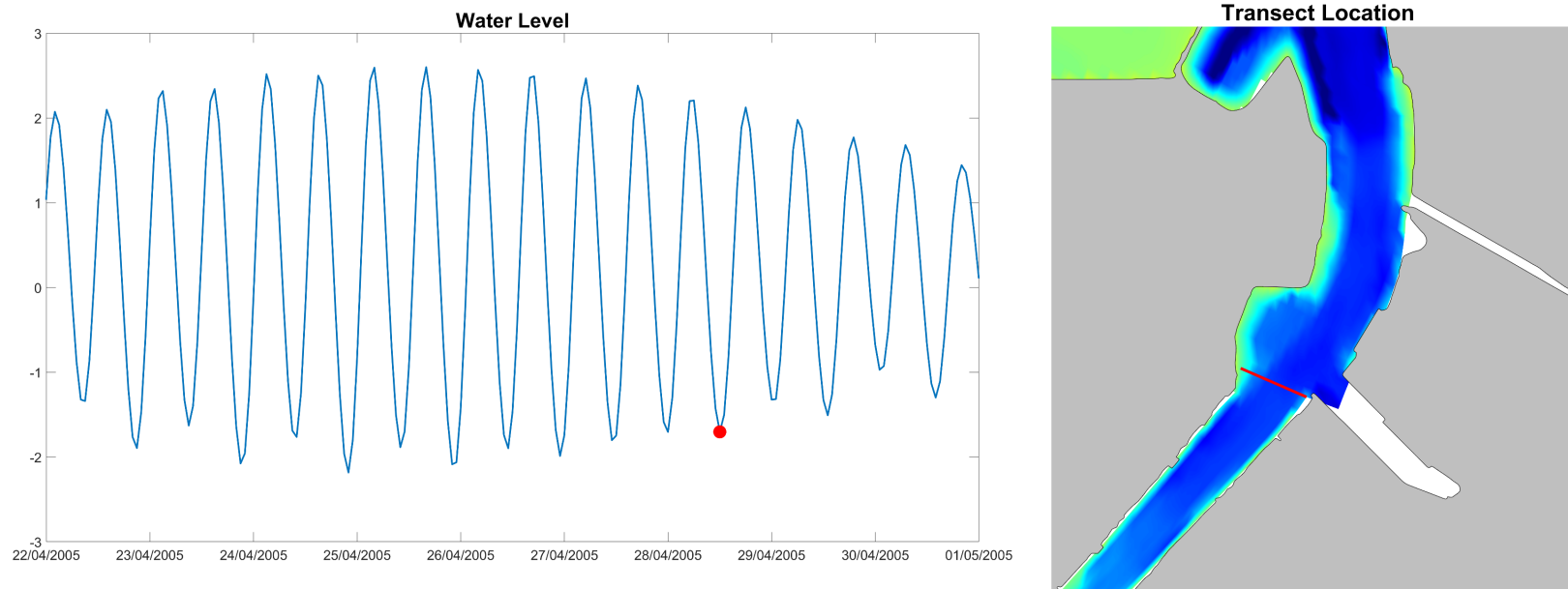


Figure 55. Tidal state and transect location extracted from the model for Transect 1 Pass 01: 28/04/2005

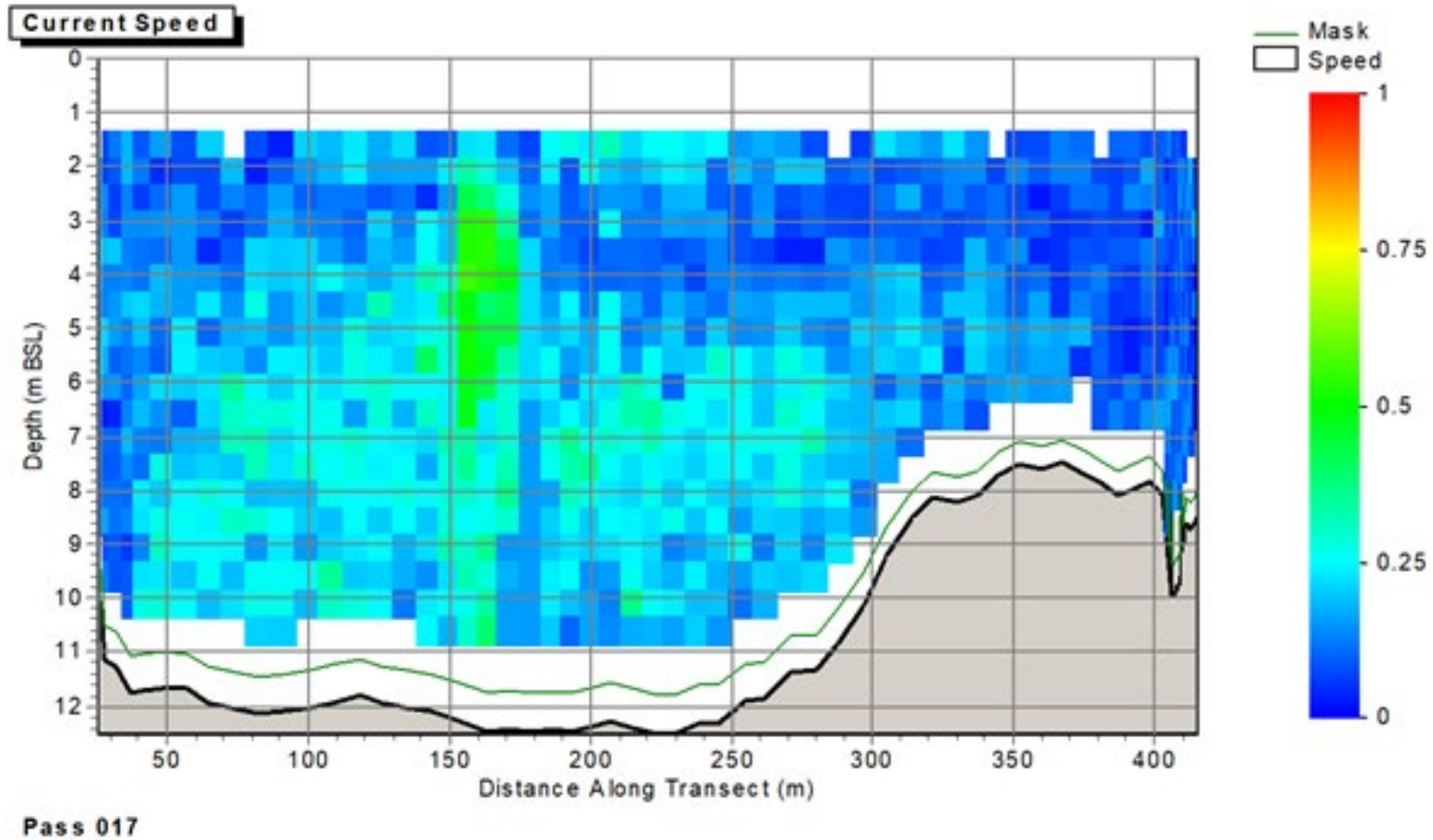


Figure provided by PD Teesport

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



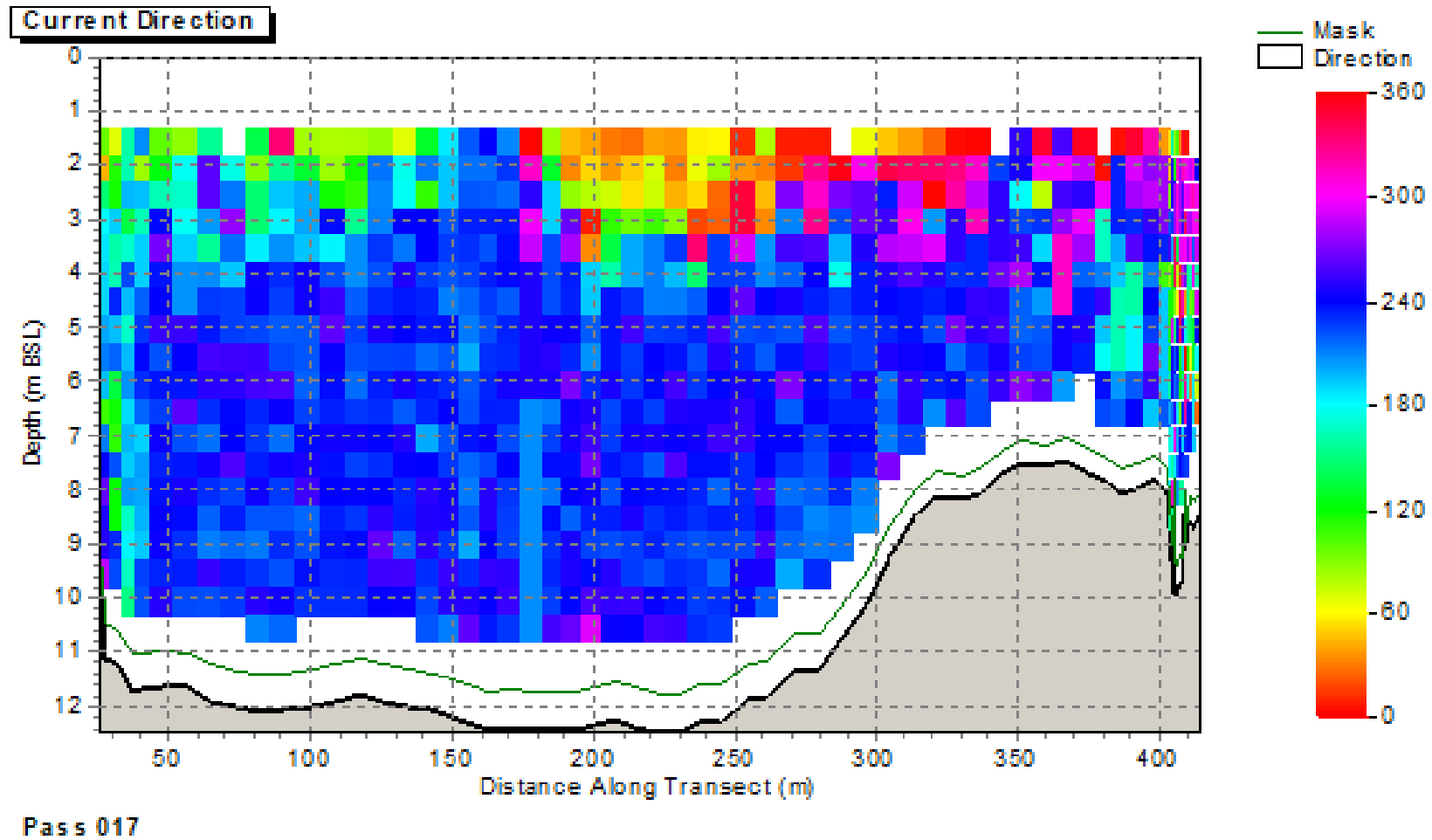


Figure provided by PD Teesport

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

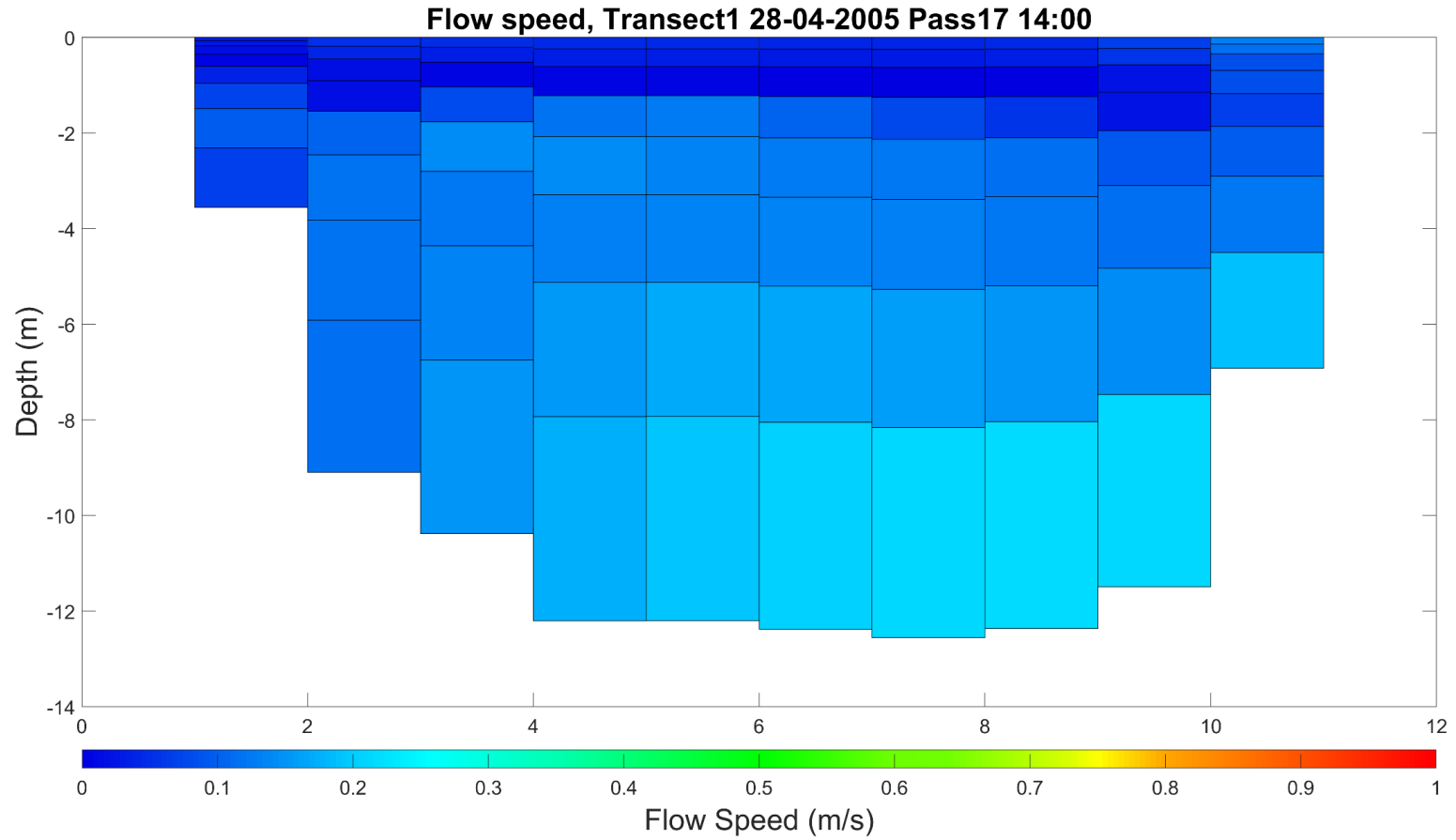


Figure 58. Modelled flow speed, Transect 1: Flood tide, cross section of speed with depth shown from west (left) to east (right)

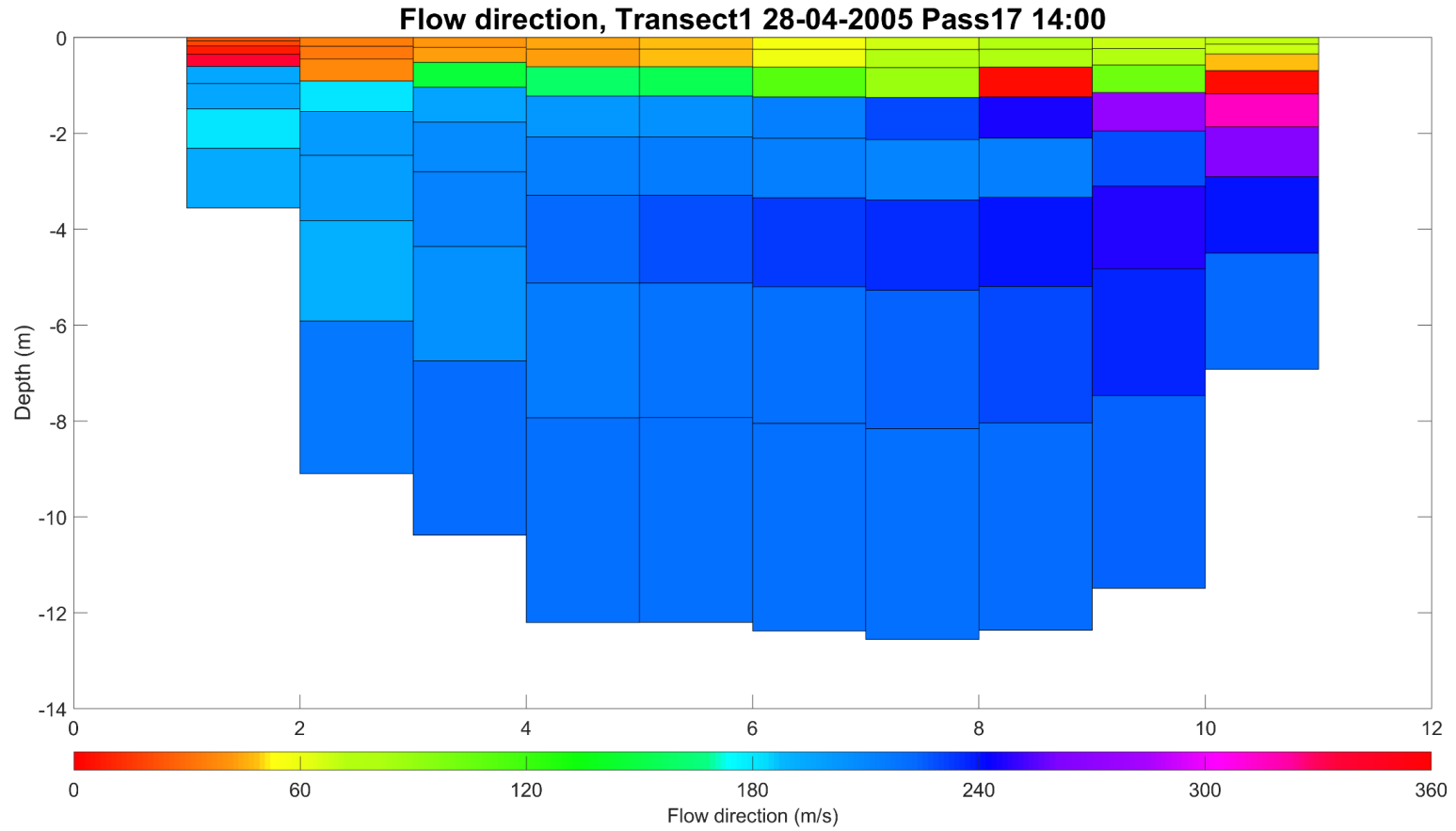


Figure 59. Modelled flow direction, Transect 1: Flood tide, cross section of direction with depth shown from west (left) to east (right)

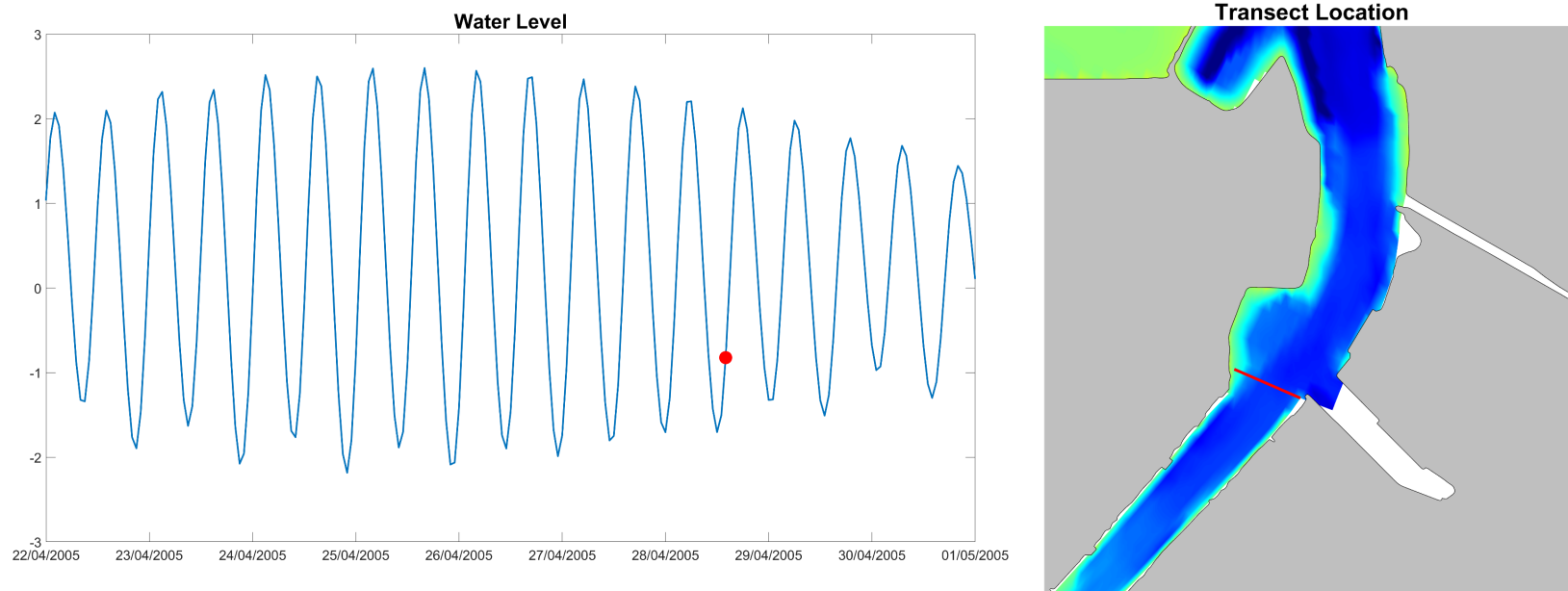


Figure 60. Tidal state and transect location extracted from the model for Transect 1 Pass 17: 28/04/2005

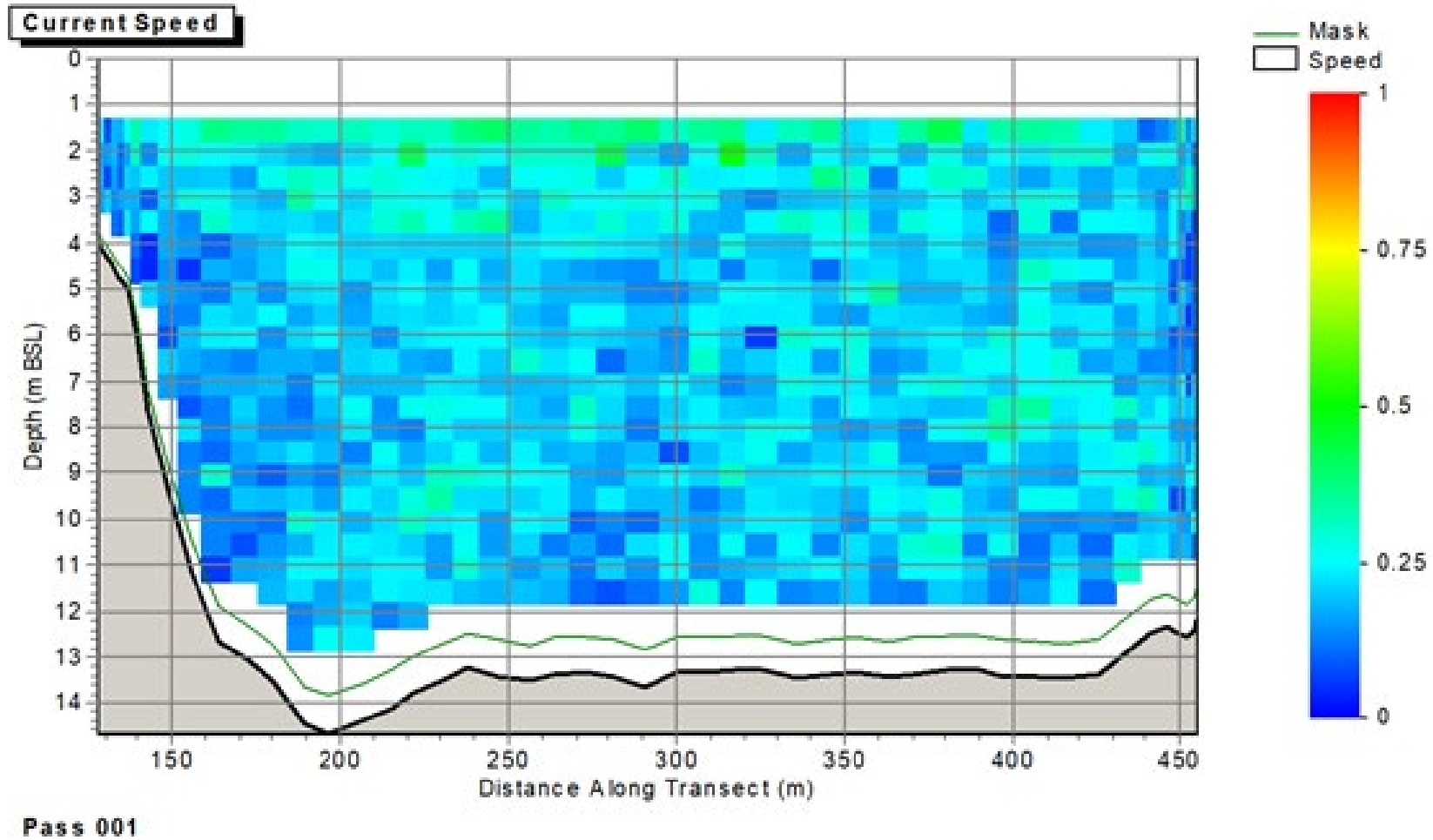


Figure provided by PD Teesport

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

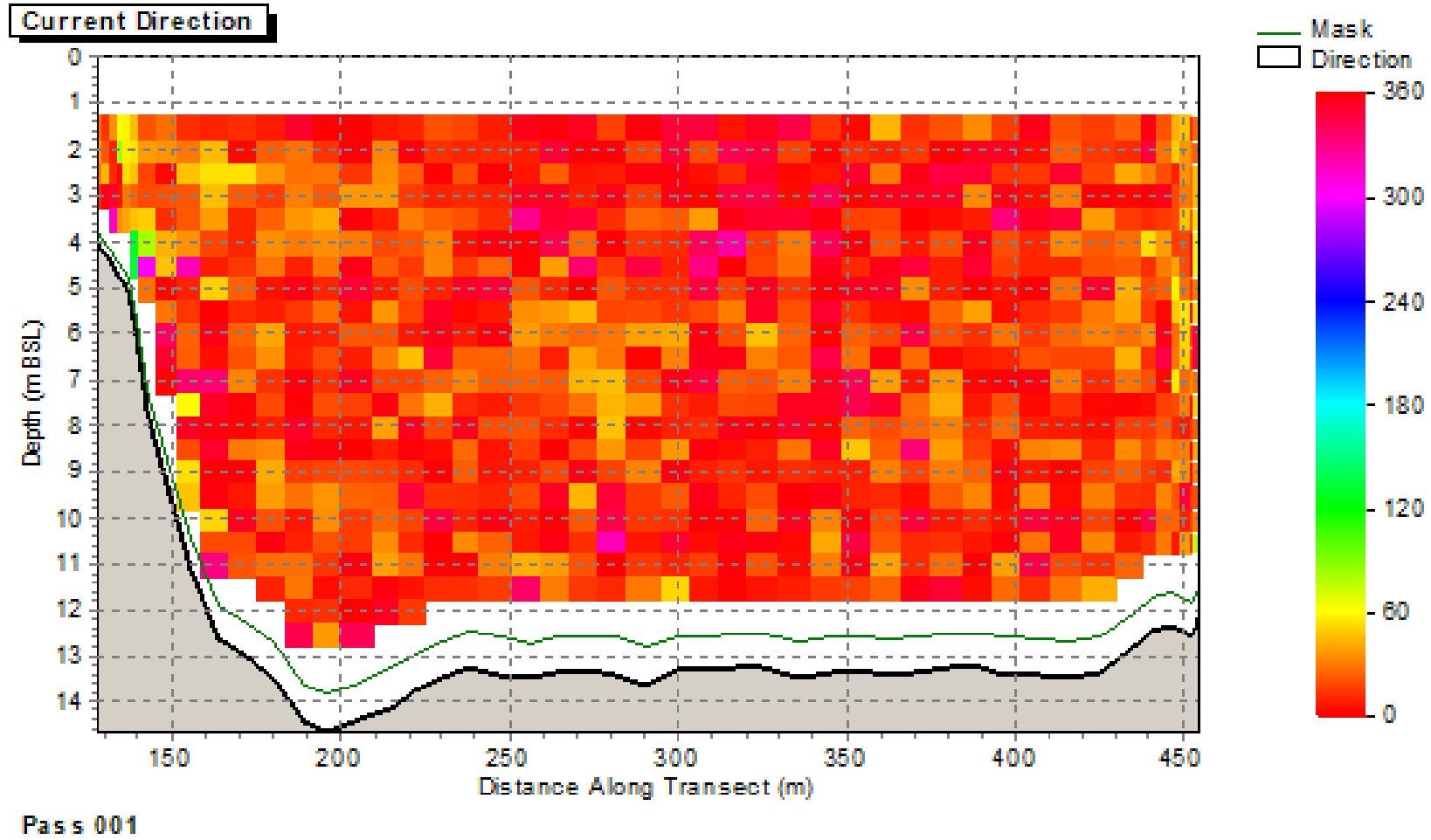


Figure provided by PD Teesport

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

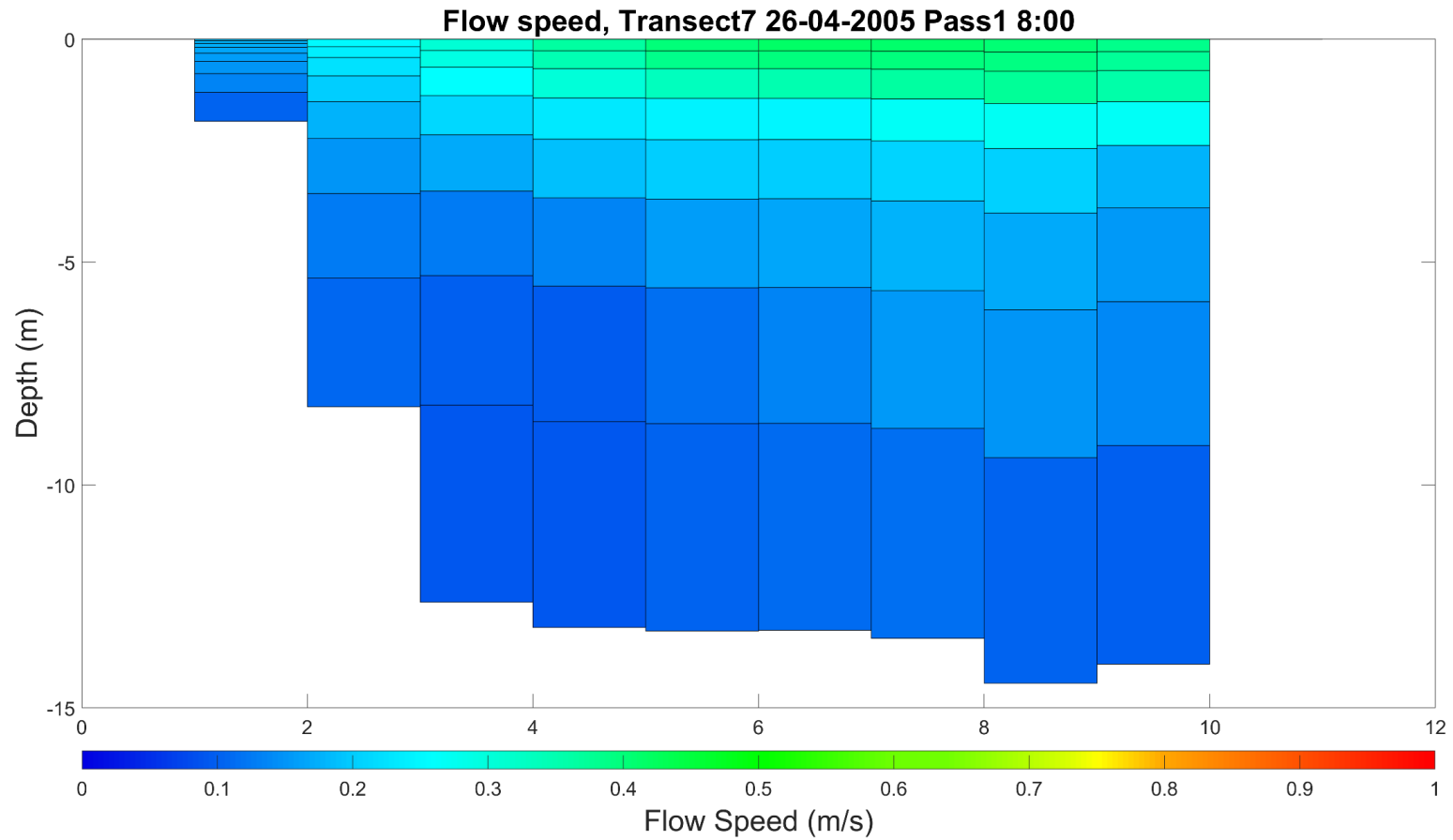


Figure 63. Modelled flow speed, Transect 7: Ebb tide, cross section of speed with depth shown from west (left) to east (right)



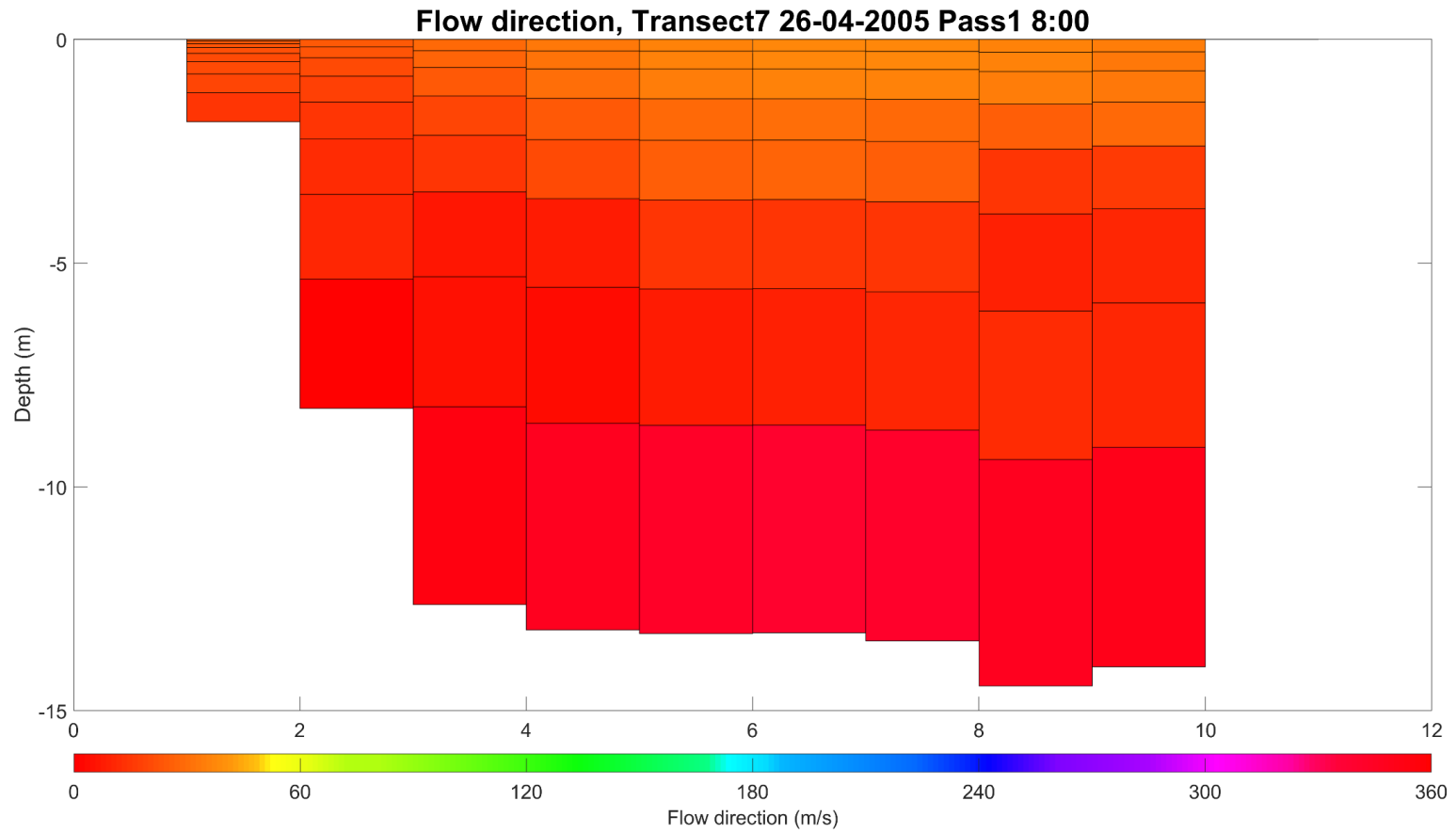


Figure 64. Modelled flow direction, Transect 7: Ebb tide, cross section of direction with depth shown from west (left) to east (right)

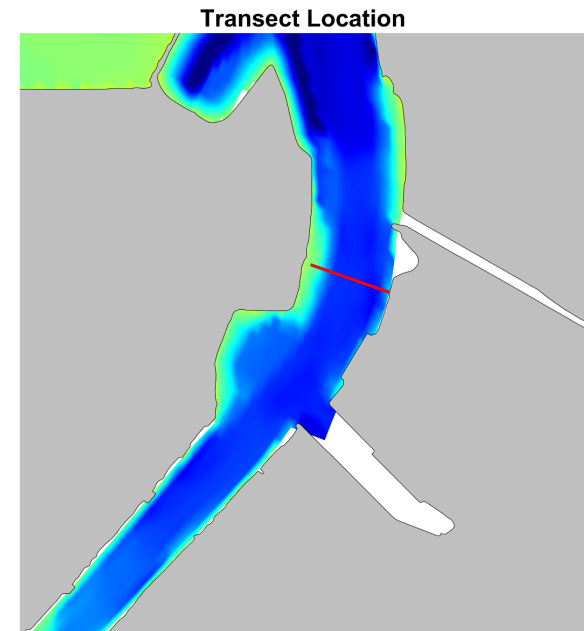
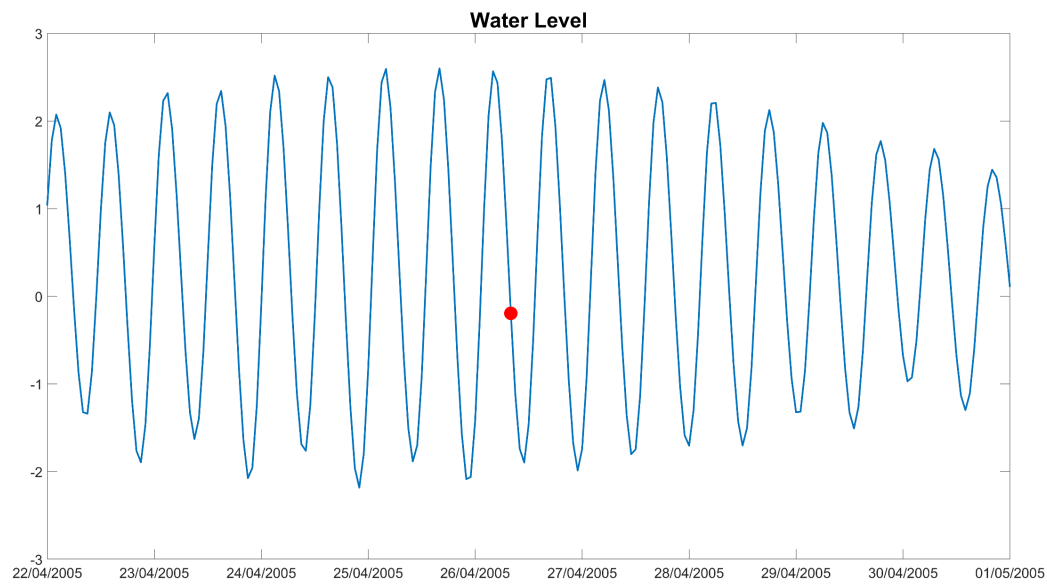


Figure 65. Tidal state and transect location extracted from the model for Transect 7 Pass 1: 26/04/2005

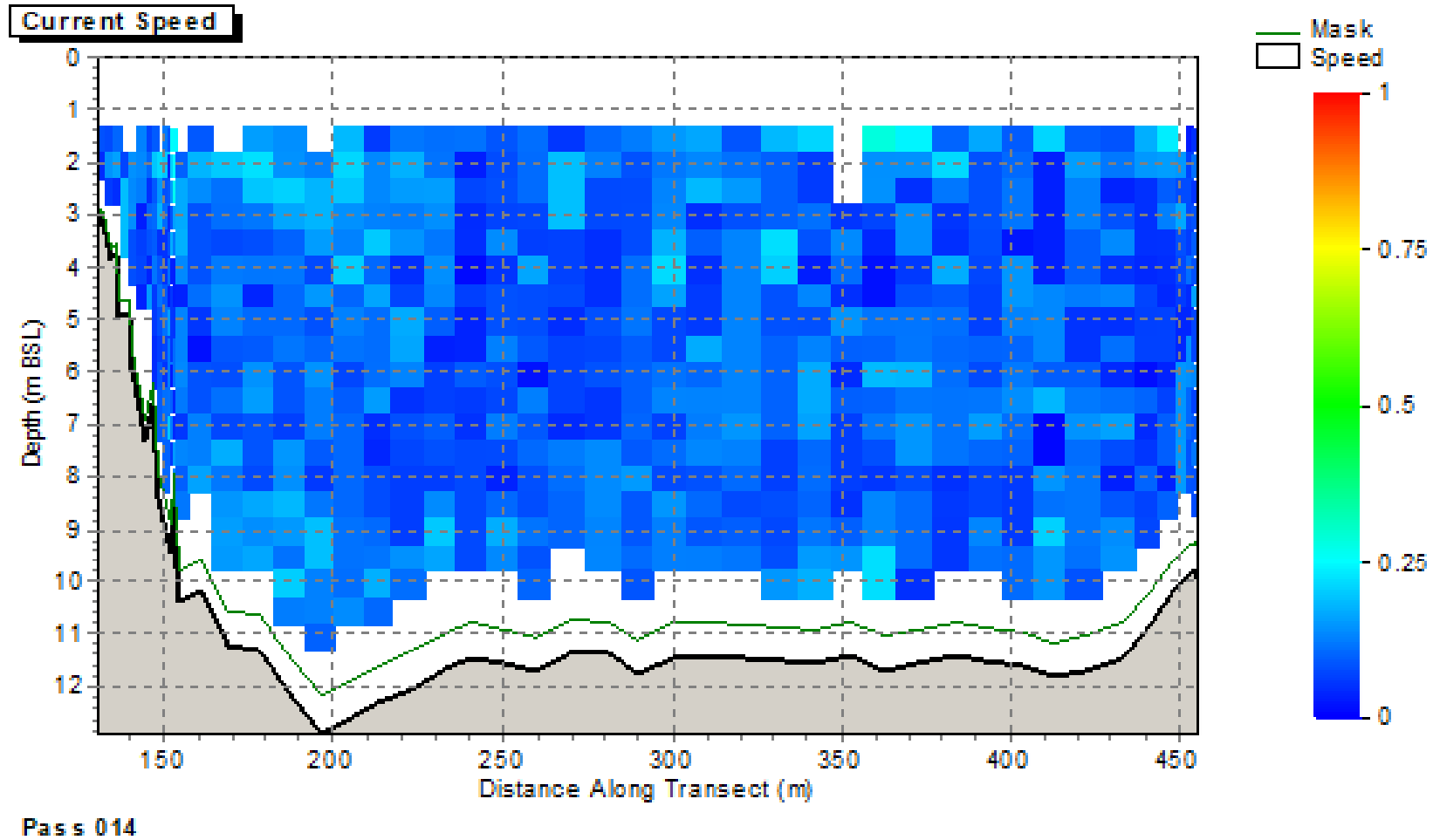


Figure provided by PD Teesport

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

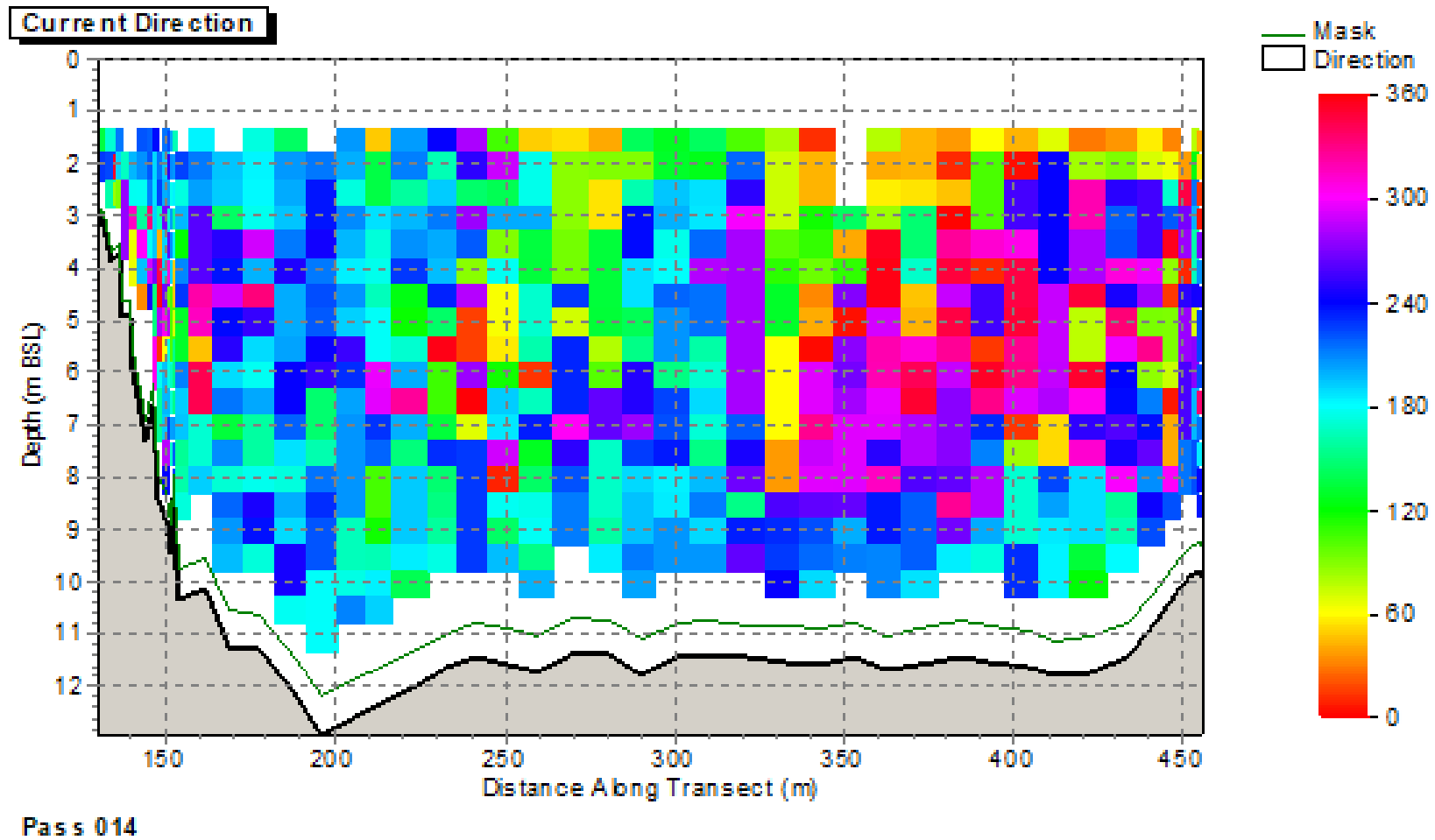


Figure provided by PD Teesport

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

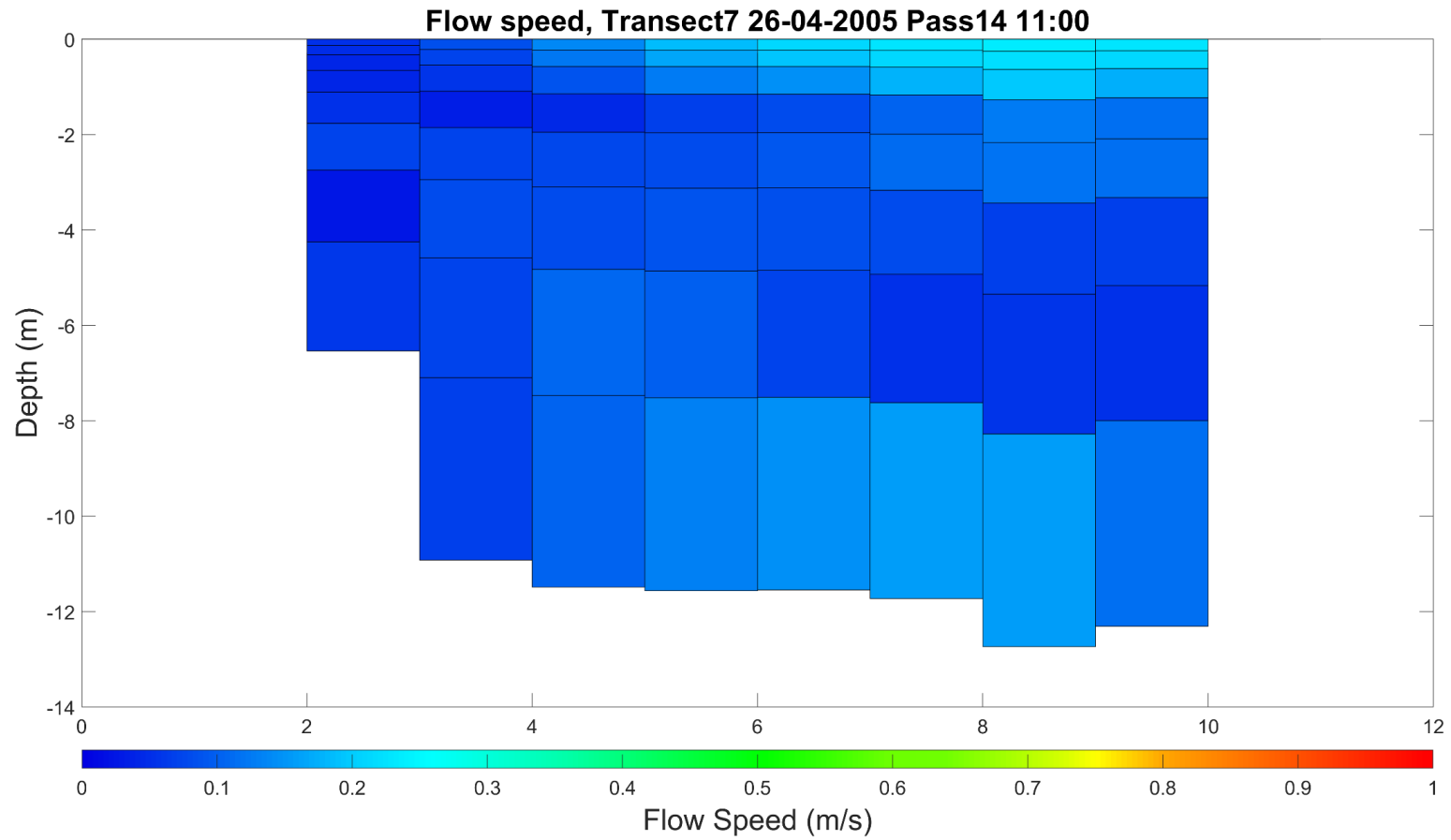


Figure 68. Modelled flow speed, Transect 7: Low water, cross section of speed with depth shown from west (left) to east (right)

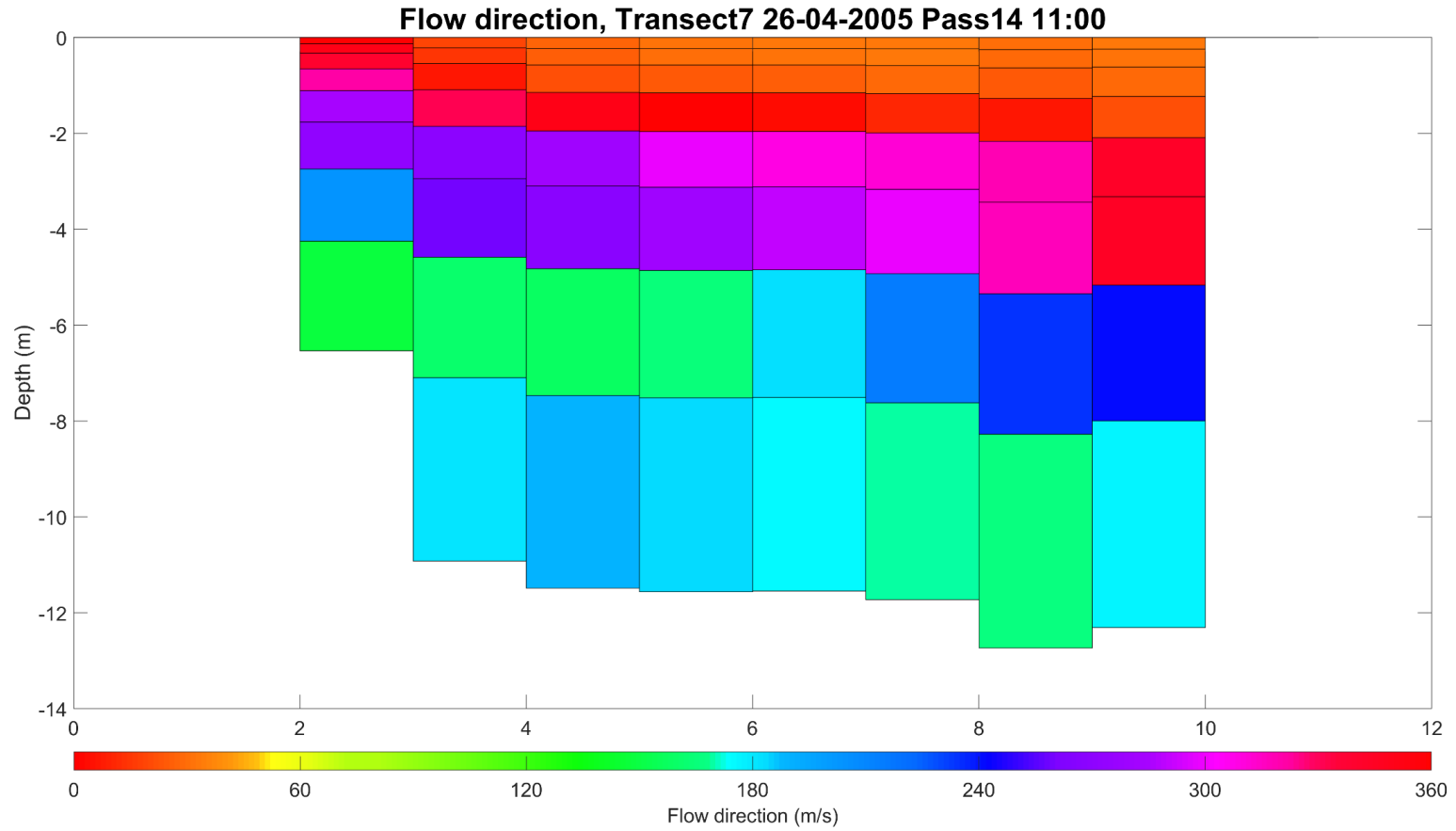


Figure 69. Modelled flow direction, Transect 7: Low water, cross section of direction with depth shown from west (left) to east (right)

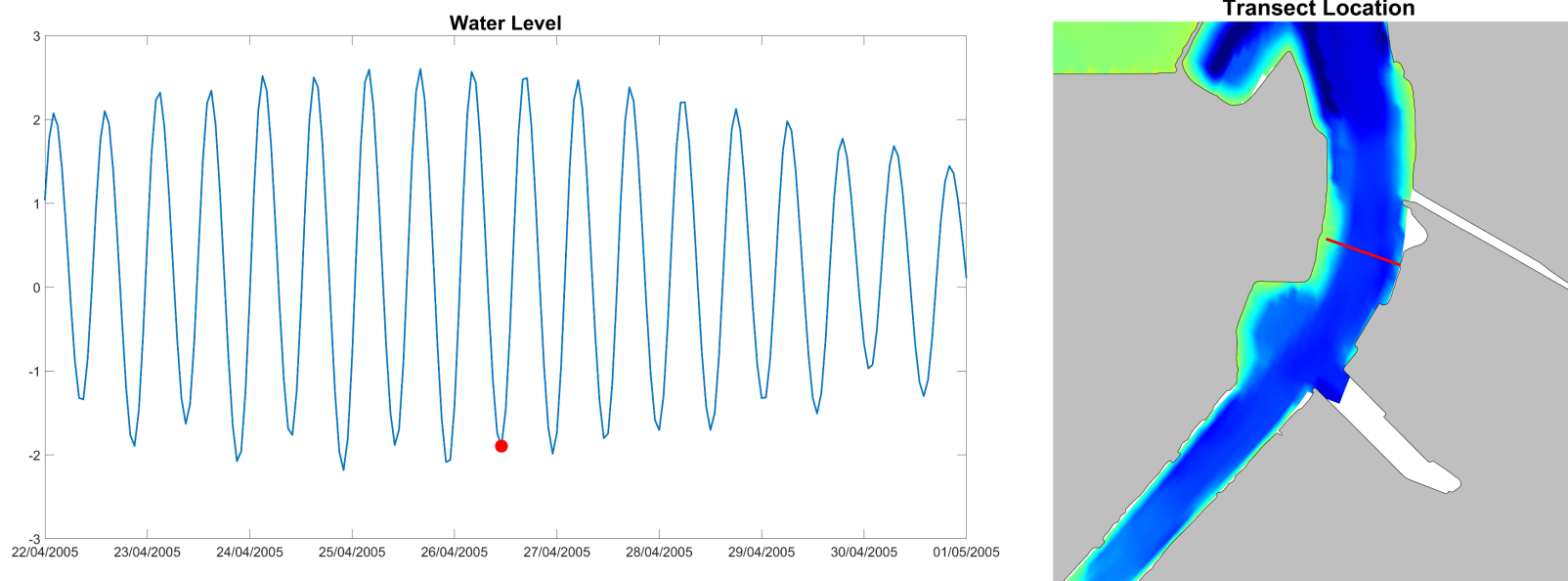


Figure 70. Tidal state and transect location extracted from the model for Transect 7 Pass 14: 26/04/2005

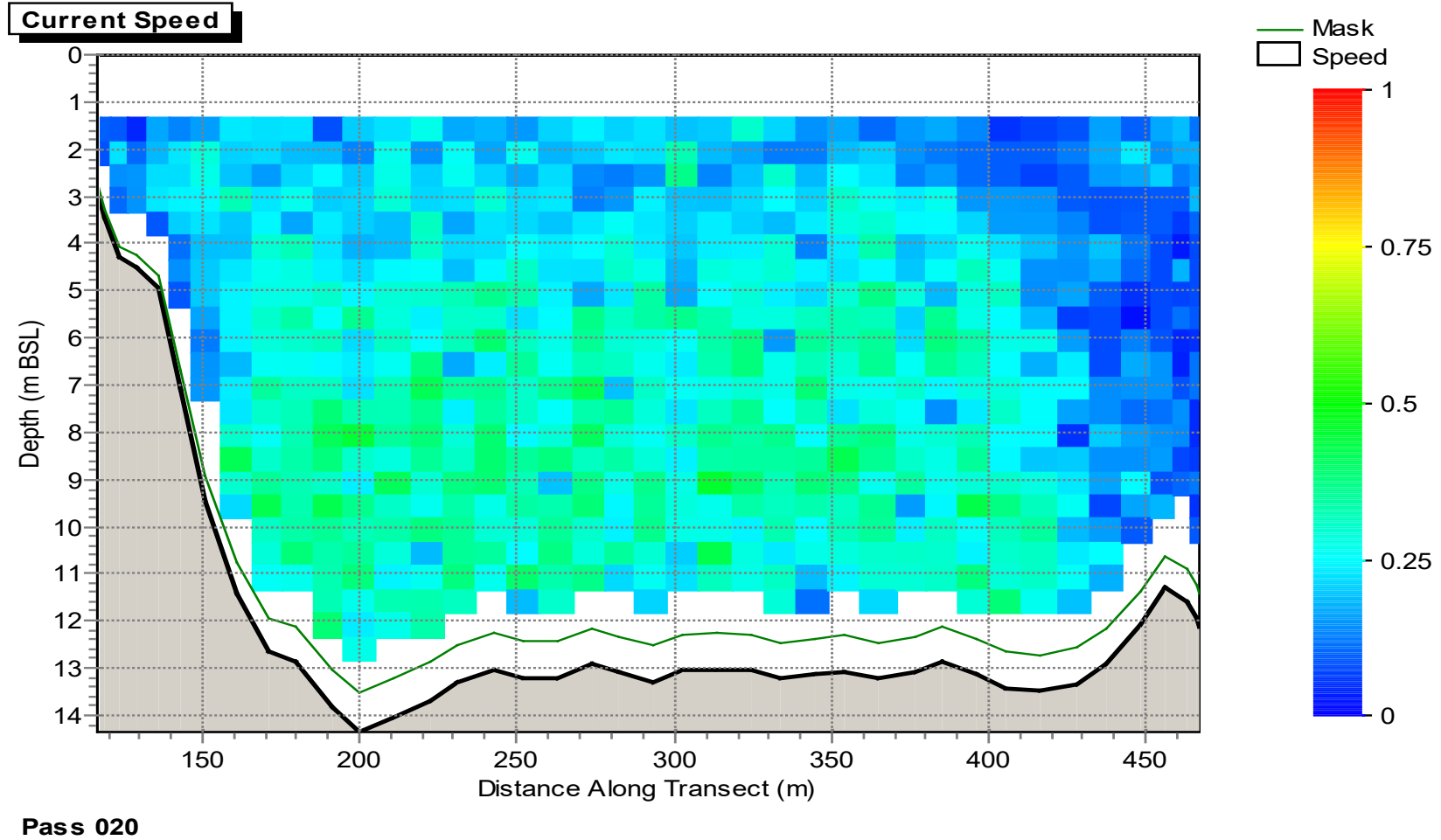


Figure 71. Measured flow speed, Transect 7, Pass 20: Flood tide, cross section of speed with depth shown from west (left) to east (right)

Figure provided by PD Teesport



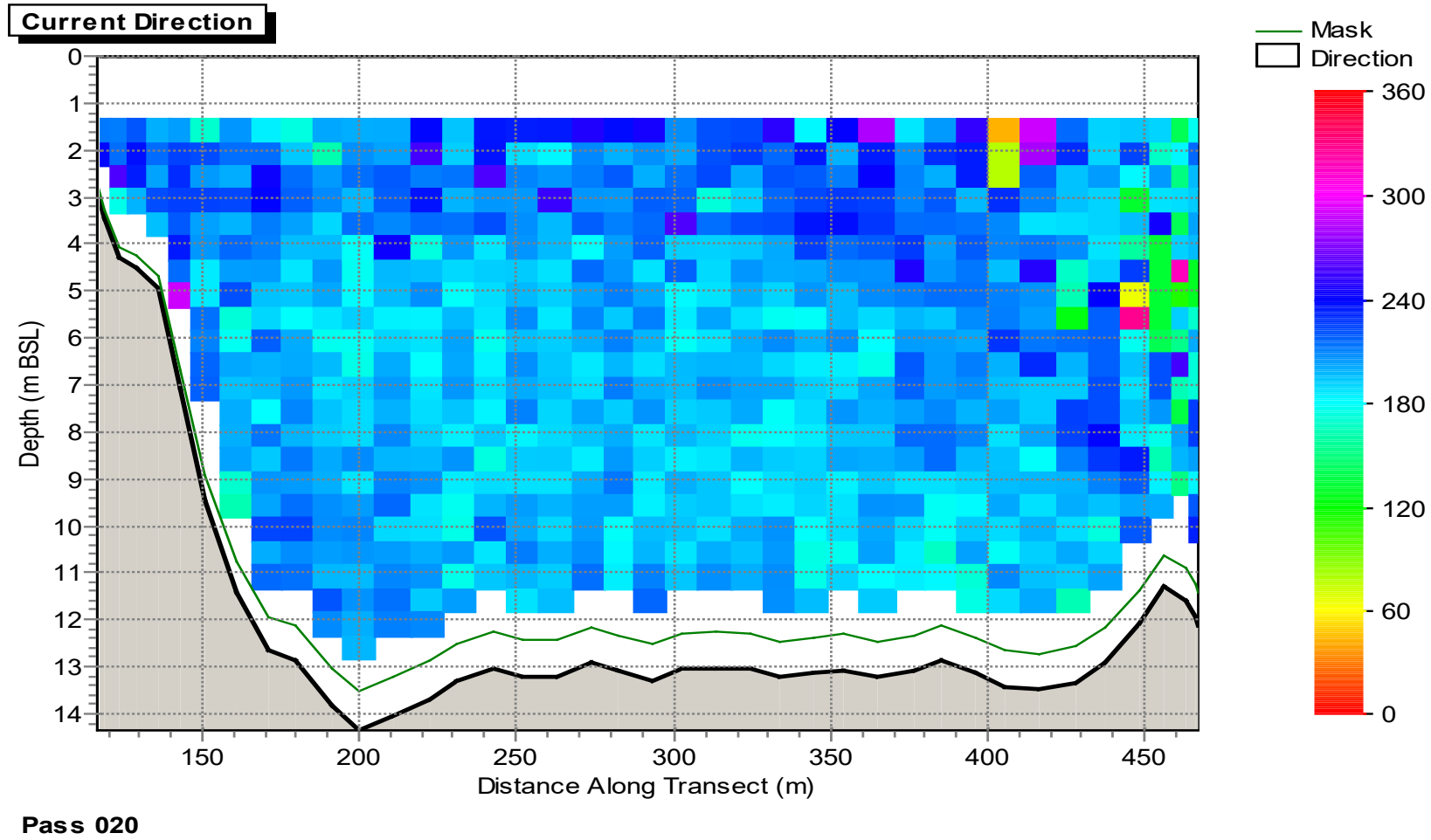


Figure provided by PD Teesport

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

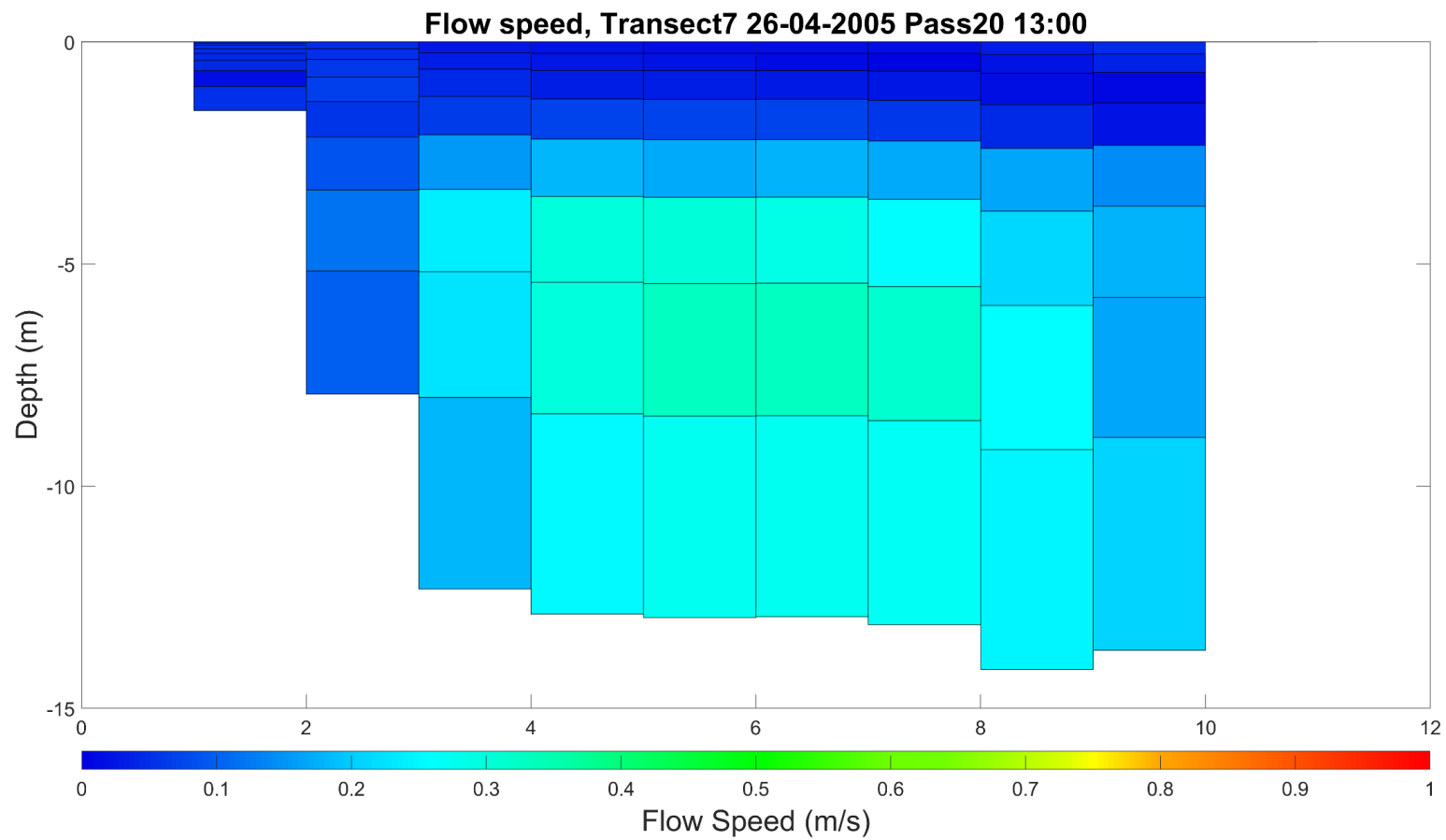


Figure 73. Modelled flow speed, Transect 7: Flood tide, cross section of speed with depth shown from west (left) to east (right)

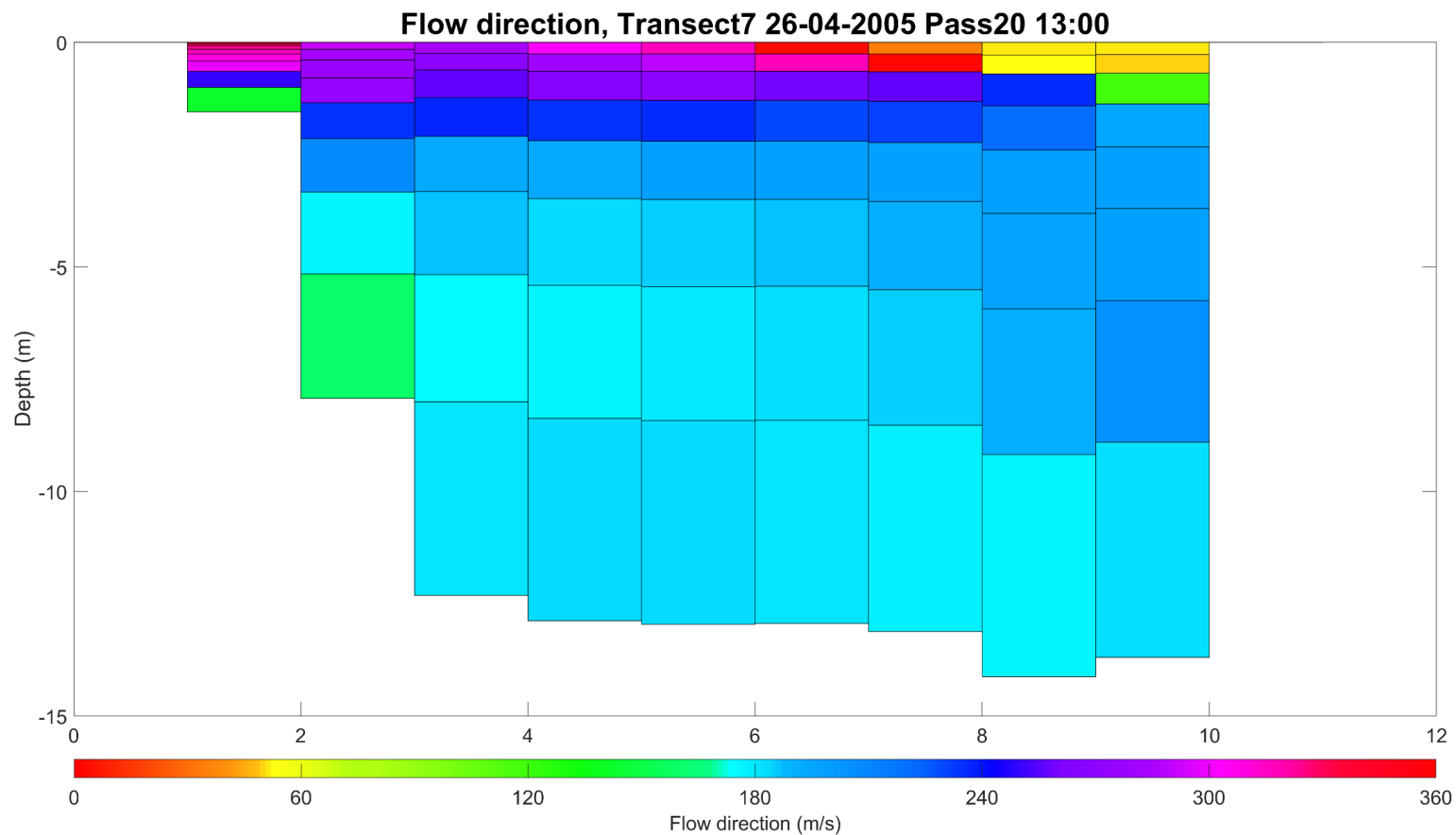


Figure 74. Modelled flow direction, Transect 7: Flood tide, cross section of direction with depth shown from west (left) to east (right)

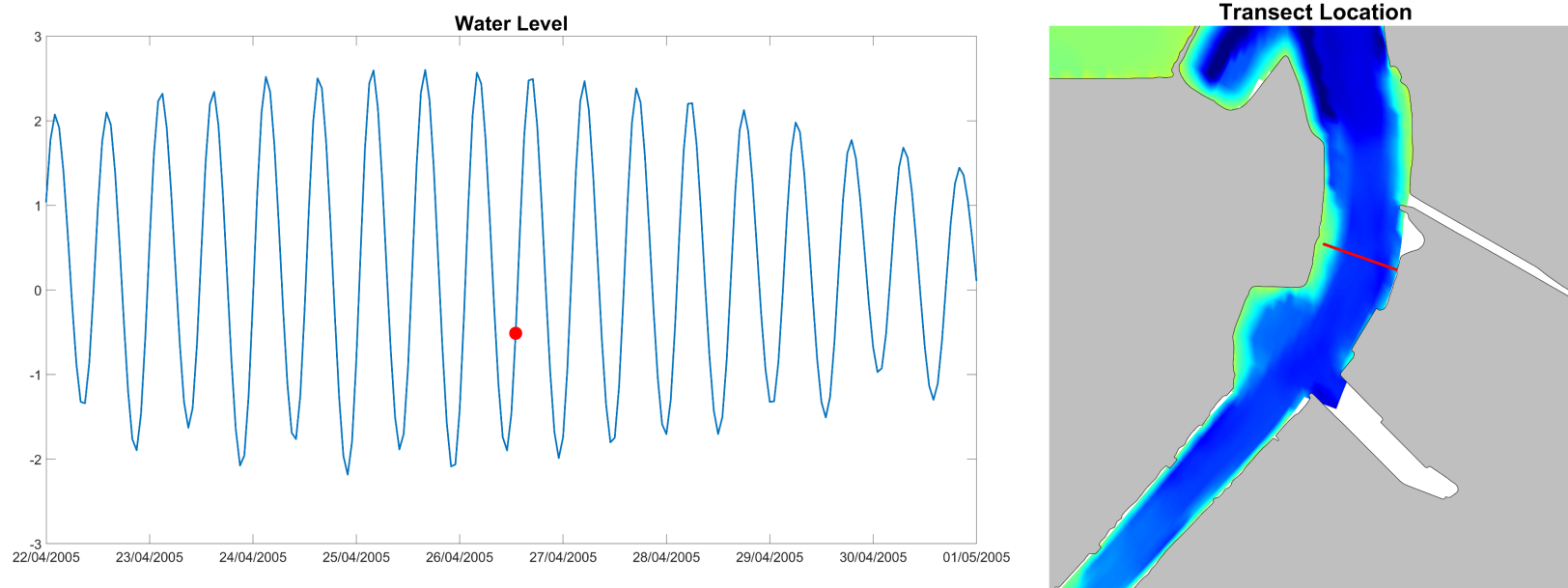


Figure 75. Tidal state and transect location extracted from the model for Transect 7 Pass 20: 26/04/2005

## 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.

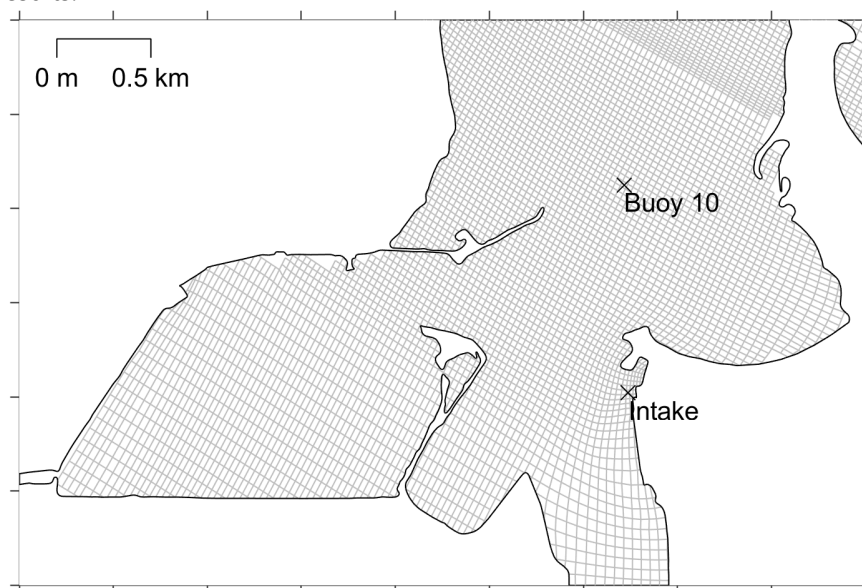


Figure 76. Fixed current meter location: Buoy 10

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.

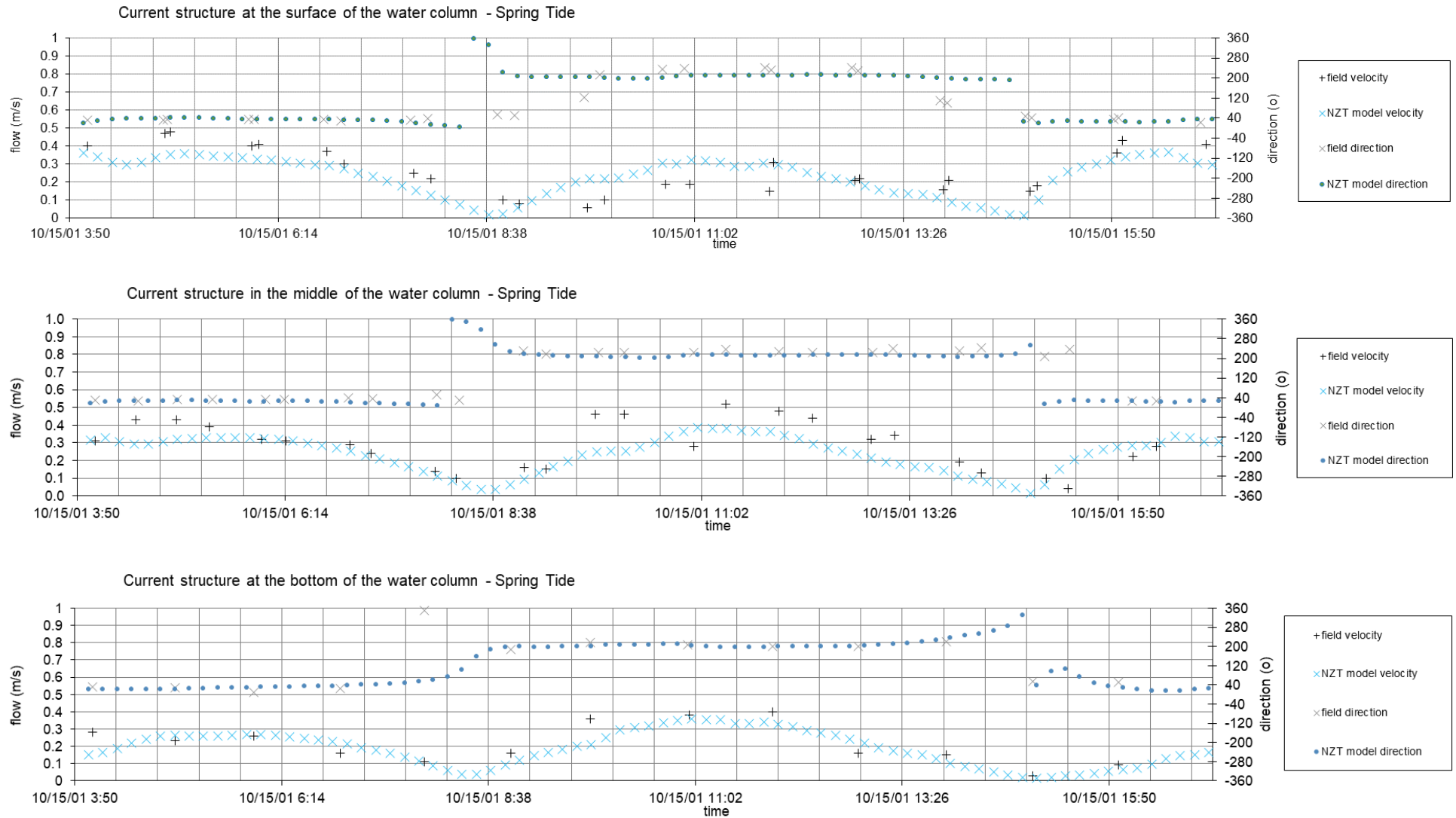


Figure 77. Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Spring tide

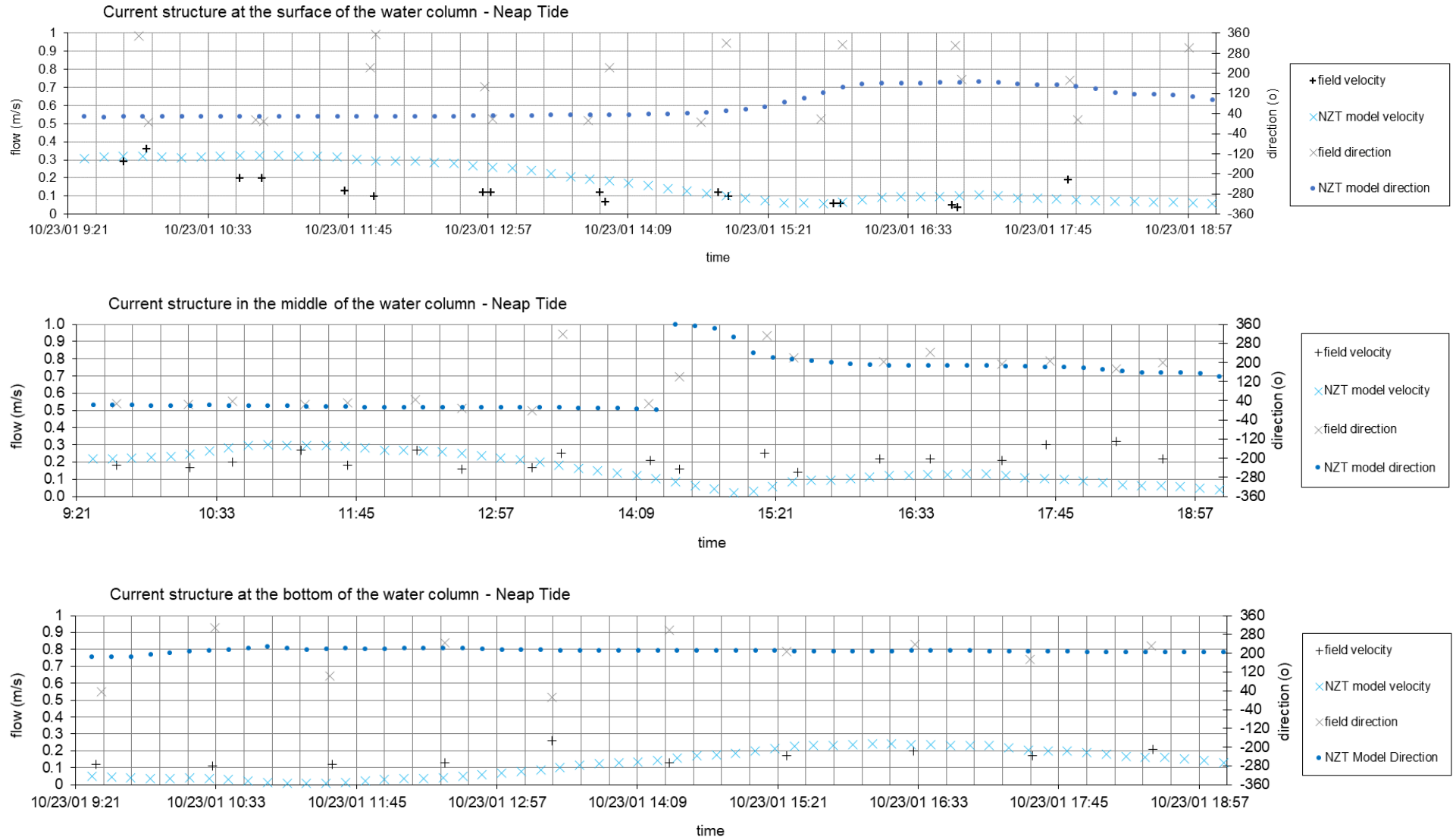


Figure 78. Measured and modelled flow speed and direction comparison at the top, middle and bottom of the water column. Buoy 10 – Neap tide

## 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).



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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'.

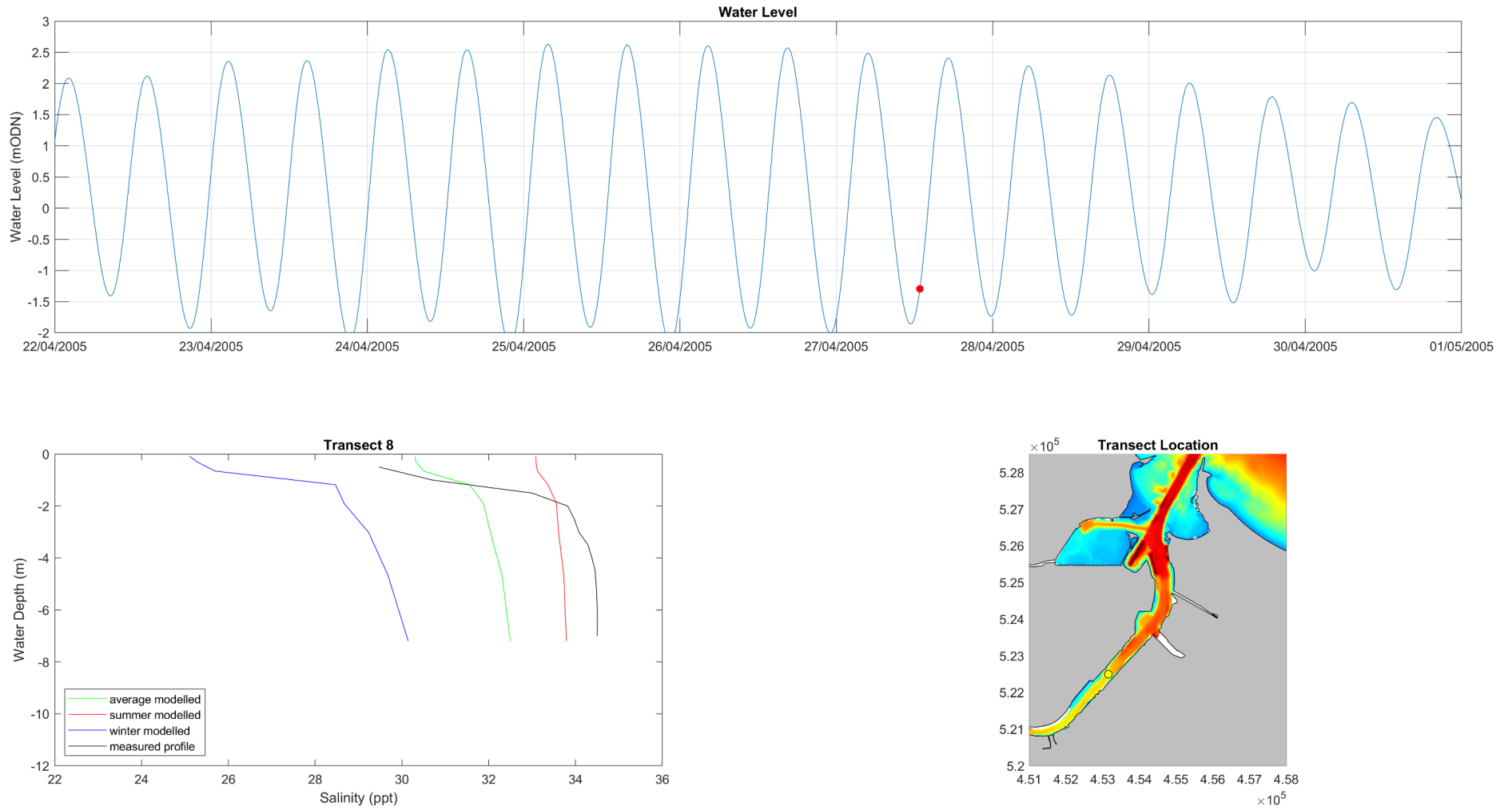


Figure 79. Comparison of measured and modelled salinity with depth: Transect 8 (red dot on top water level plot indicates point of the tide).

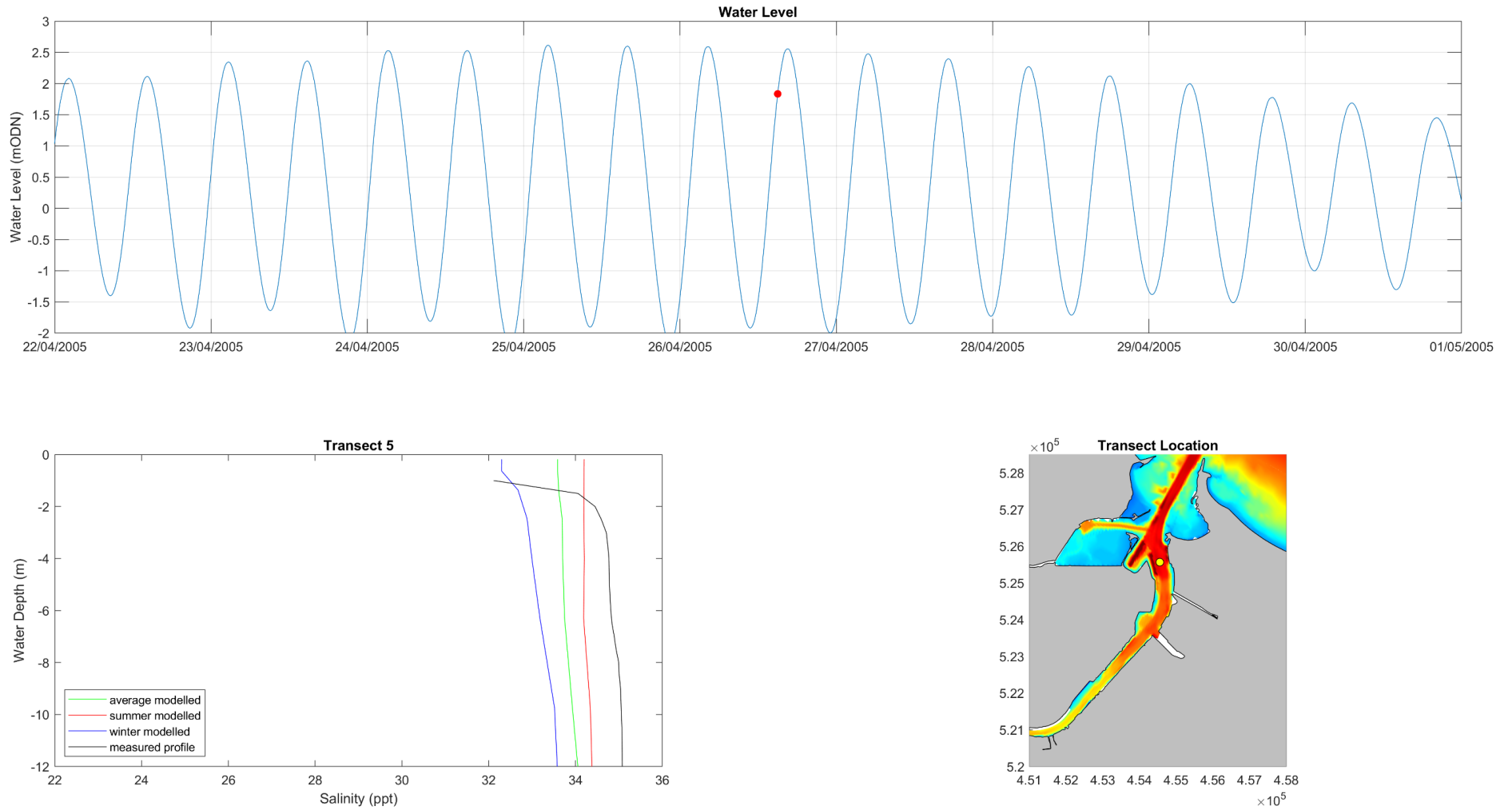


Figure 80. Comparison of measured and modelled salinity with depth: Transect 5, closest transect location to the cofferdam (red dot on top water level plot indicates point of the tide).

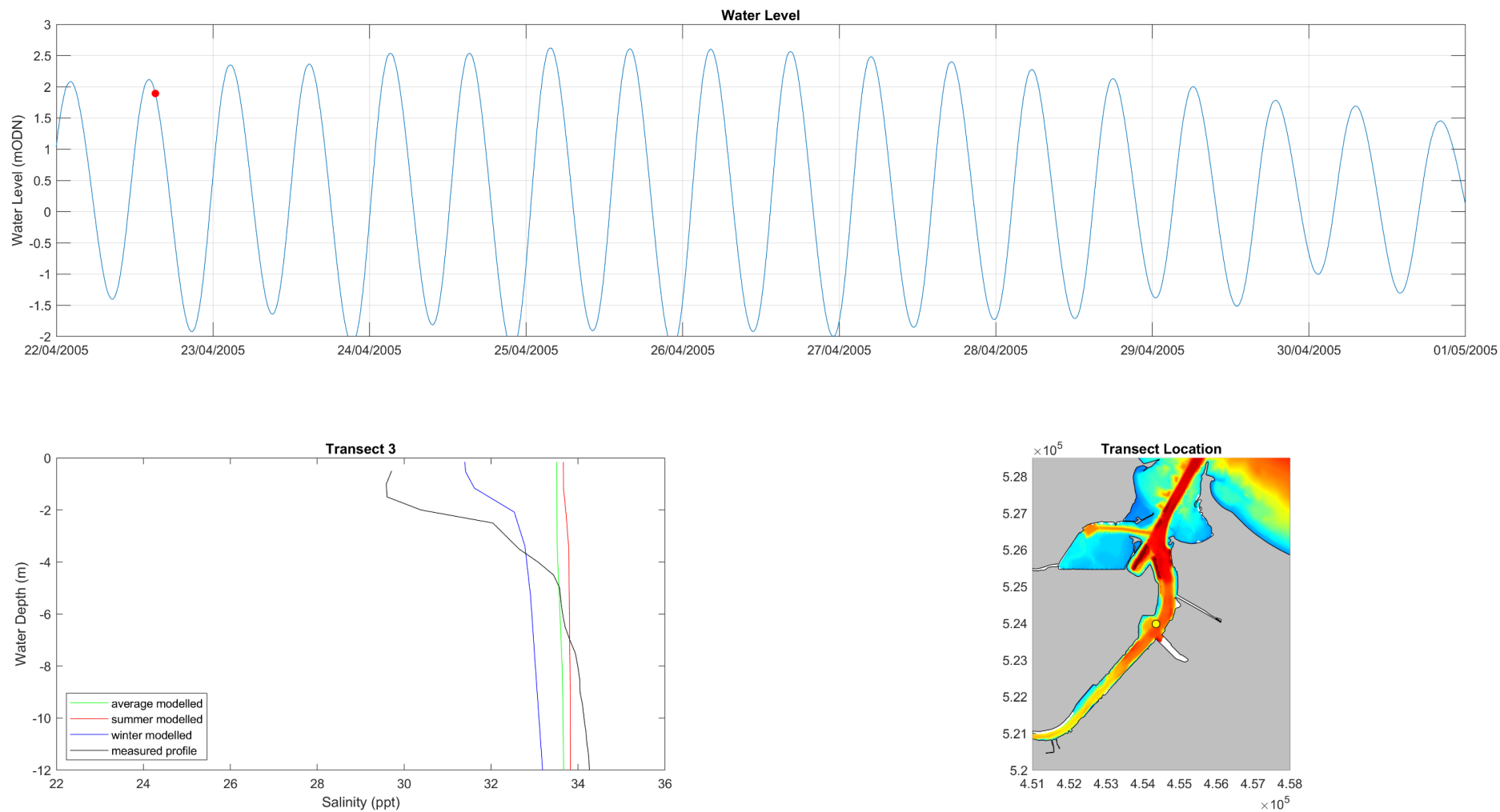


Figure 81. Comparison of measured and modelled salinity with depth: Transect 3 (red dot on top water level plot indicates point of the tide)

# 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<sup>3</sup>/s. However, only a portion of the discharge (1.81 m<sup>3</sup>/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.

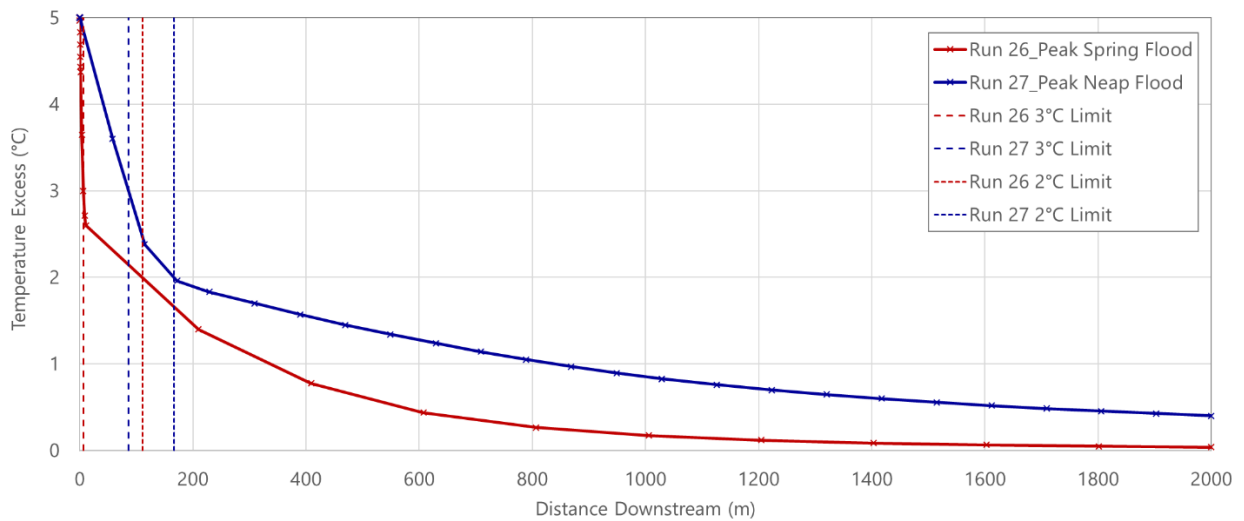


Figure 82. Spring and neap flood tide plume variations during extreme discharge events.

## 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.

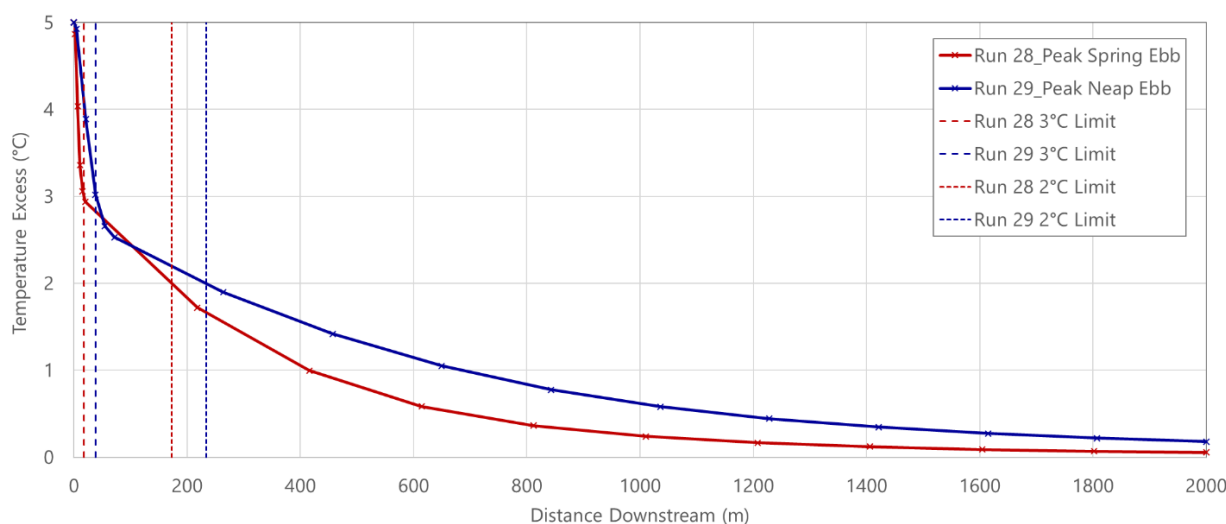


Figure 83. Spring and neap ebb tide plume variations during normal discharge events.

## 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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9B.10 ANNEX C: Approximation for Unionised Ammonia

Equation 9C-1: Approximation for Calculating Unionised Ammonia Fraction from Total Ammonia

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

Equation based on Calculation of un-ionised ammonia in fresh water (Florida Department of Environmental Protection, 2001).

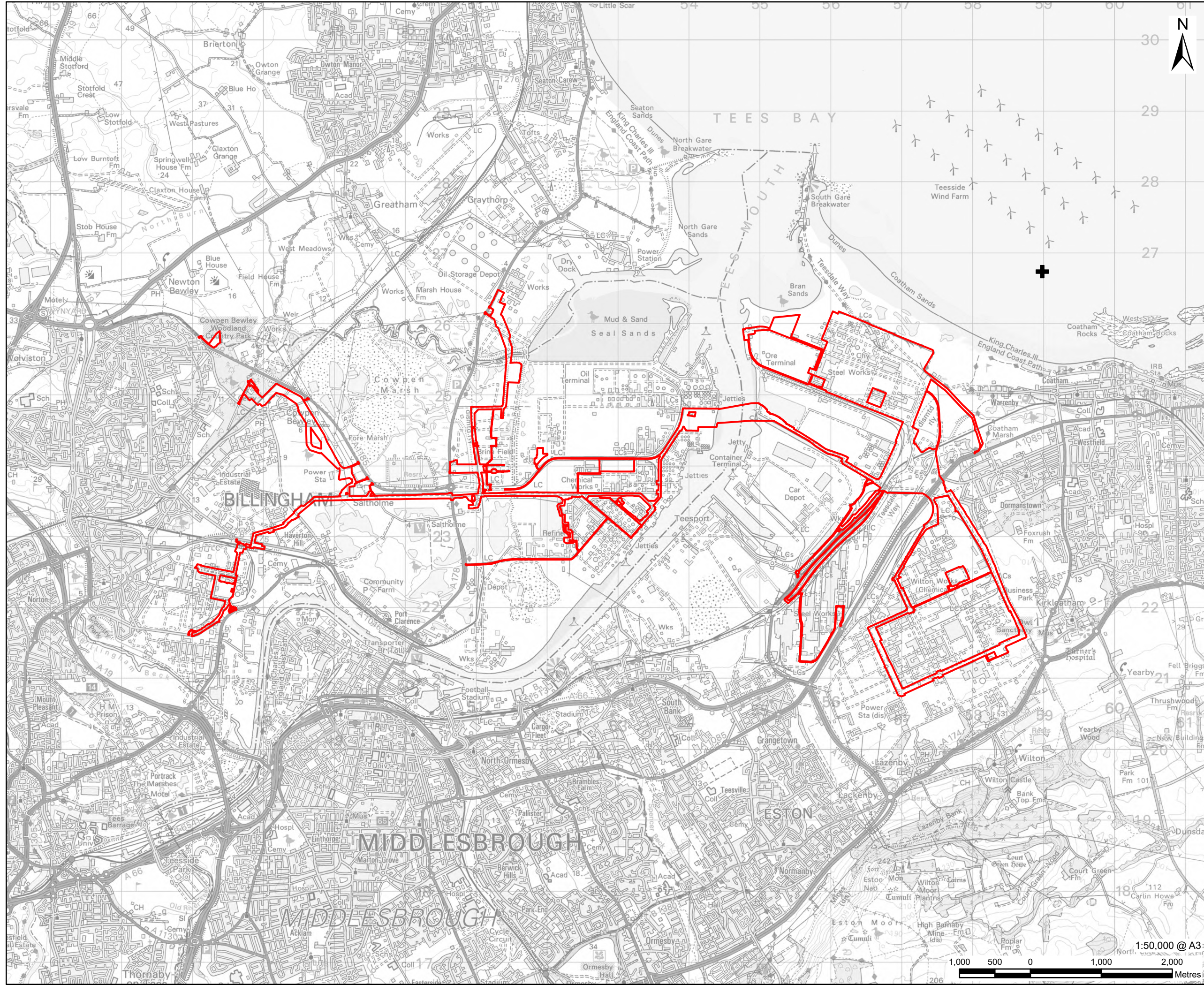
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9B.11 ANNEX D: References

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- Net Zero Teesside (2022). *ES Vol III Appendix 25A Commitments Register, bp, October 2022 (Document Reference 6.4.49).*
- UK Technical Advisory Group (2008). *UK Environmental Standards and Conditions (Phase 2).*

## 9B.12 ANNEX E: Figures





# AECOM

**PROJECT**  
H2Teesside

**APPLICANT**  
H2 Teesside Limited

**CONSULTANT**  
AECOM Limited  
100 Embankment,  
Cathedral Approach,  
Manchester, M3 7FB  
www.aecom.com

**LEGEND**  
 Proposed Development Site  
+ Discharge Location

**NOTES**  
1: Reproduced from Ordnance Survey digital map data © Crown copyright 2024. All rights reserved. Licence number 0100031673.

**ISSUE PURPOSE**  
Environmental Statement

**PROJECT NUMBER**  
60689030

**FIGURE TITLE**  
Proposed Development Boundary and  
Proposed Net Zero Teesside Effluent  
Discharge Location

**FIGURE NUMBER**  
Figure 9B-1



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