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FICHTNER CONSULTING ENGINEERS LTD.
NEAR-FIELD DISCHARGE MODELLING REPORT – MOODY LANE GRIMSBY

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Made by	**Nellie Bates**
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APPENDICES

1. INTRODUCTION

1.1 Background

On behalf of Fichtner Consulting Engineers Ltd., Ramboll UK Ltd. has been commissioned to develop a near-field surface-water dispersion model to support an Environmental Permit (EP) application for the Humber Gate Waste Treatment Facility (HG WTF) at Humber Gate, Energy Park Way, Grimsby, DN31 2TT. The Facility is a thermal waste-treatment installation with a permitted throughput of 29,500 t y^{-1} and comprises a waste reception area, designated waste storage areas, feed system, tank farm, counter-current rotary kiln, a vertical post-combustion chamber, wastewater treatment, flue gas treatment and drainage systems.

The site produces potentially contaminated surface run off from non-process, non-storage areas such as roadways or other hard standing on-site. This is treated on-site to enable its reuse. Liquid effluent sources considered in this study for discharge to the aquatic environment include:

- Wet-scrubber blow-down and associated process wastewaters generated within the flue-gas cleaning system (~3 t h^{-1} during operation).
- Roof-drainage water harvested from covered storage and process buildings.

A two-cell lagoon with a total capacity of 3,125 m^3 is present on-site for storing uncontaminated roof water and surface run off from non-process areas. One side of the lagoon (Area 1) stores potentially contaminated surface water run off from Plot I and Plot C. The other side of the lagoon (Area 2) receives uncontaminated roof water from local tanks around the site which store all roof water from the facility including canopies between buildings. The lagoon is designed in accordance with CIRIA 736 guidance and suitably lined and inspected periodically.

Water collected from site roofs or surface water drainage is treated within a separate dedicated treatment plant within Building 2 after local transfer from interceptors for surface water run off or local tanks for roof water. The run off will collect within the on-site lagoon and then be treated by DAF, filtration and activated carbon to enable its reuse as wet scrubber make-up water. The site's philosophy is to prioritise treatment of this water stream to produce wet scrubber make-up water to reduce reliance upon the local water supply. This treated water will be complemented by all roof water from on-site buildings which will be harvested and treated on-site.

All process effluents from the flue gas treatment systems are routed to a dedicated wastewater-treatment (WWT) plant located in Building 12. The WWT plant employs sequential pH-adjustment, metals precipitation (using NaOH, H_2SO_4, TMT15 and $Ca(OH)_2$), coagulation/flocculation, lamella clarification, granular-activated-carbon polishing and membrane/cloth filtration. Dewatered sludge is pressed to a filter-cake that is containerised for off-site disposal as a hazardous waste.

The treated effluent is monitored to demonstrate that it meets the necessary water quality specification prior to transfer from the effluent treatment plant within Building 12 into a dedicated tank within Building 2 pending discharge to the Humber Estuary.

From Area 1 (all surface water run off), water can be used as make-up to the wet scrubber onsite. This material is treated within a separate WWT plant within Building 12 specifically for treatment of this surface run off comprising DAF, Filtration, Coagulation, GAC and UV treatment.

The only effluents being discharged from the facility to the Humber Estuary will be treated wet scrubber effluent produced within Building 12 or, in the event of an extreme flood, uncontaminated roof water from Area 2 within the on-site lagoon.

Numerical Emission Limit Values (ELVs) for the aqueous discharge are currently being negotiated with the Environment Agency (EA); however, it is anticipated that standards will apply to parameters such as suspended solids, pH, nutrient species and metals associated with the reagents used on-site. The Humber Estuary is a tidally dominated, transitional water body with complex hydrodynamics so dilution, advection and stratification effects will strongly influence the fate of any residual contaminants.

At this stage it not possible to provide a detailed composition of the effluent as it has not been generated. Therefore, for the purposes of determining the human health impact, the BAT-AELs for direct emissions to water have been applied. For the purposes of determining the ecological impact, the emission limits within the EP (Ref: EPR/FP3935KL) for the Fawley HTI have been applied. Only those constituents which have an EQS have been considered.

As agreed in discussion with the EA, a mixing zone for both incoming and outgoing tides and an assumed continuous discharge have been defined. Subsequently, compliance with the water quality standards has been evaluated.

1.2 Scope and Objectives

To demonstrate that the Facility's effluent streams will not cause a significant adverse impact on the receiving water body, Ramboll has undertaken near-field dispersion modelling using the CORMIX system. The objectives of the modelling were to:

- Understand the impact of the outfall/diffuser configuration on near-field mixing;
- Quantify initial dilution and the spatial extent of the near-field mixing zone under representative tidal conditions; and
- Compare predicted concentrations with relevant water quality standards.

The outputs of this assessment will feed directly into Fichtner's Environmental Risk Assessment and support the overall EP application, providing robust evidence that HG WTF liquid discharges will be managed to protect the water environment of the Humber Estuary.

1.3 Modelling Approach

The specific outcomes of this hydrodynamic modelling report are as follows:

1. Describe the modelling approach and work conducted to predict the effects of discharges from the facility;
2. Describe the spatial footprint of the near-field results and dilution factors achieved within a near-field mixing zone (NMZ);
3. Describe potential movement of the discharge plume in the far-field in semi-quantitative/qualitative terms (where applicable); and
4. Describe the spatial extent of possible contact of the discharge plume with the shoreline.

CORMIX is used to predict the likely route and trajectory of wastewater discharges from a point source location (in this case, a submerged estuary outfall). CORMIX also has the unique facility of translating point source discharges into multiport diffuser arrangements in line with the existing outfall.

In the NMZ, the characteristics of the discharge govern how the discharge plume is likely to mix with receiving water. The primary forces that influence hydrodynamics and the movement of wastewater in the receiving environment beyond the NMZ are flow currents, winds and thermal/density stratification. Waves may also occasionally modify movement and influence the behaviour of the plume.

The wastewater discharge from the facility will include a combination of chemical and physical parameters. The near-field modelling work described in this report was conducted to simulate the mixing of the wastewater discharge with ambient receiving estuarine/sea water in the Humber estuary and predict the near-field dilution factor. For the purposes of the assessment, potential impacts are based on a delta increase compared with baseline conditions (using data obtained largely from the EA). The intention is to ascertain the distance from the outfall where dilution would be sufficient to ensure concentrations of each constituent of concern (CoC) are below water quality criteria.

Potential plume movements may vary with water depth. Therefore, CORMIX modelling was performed using a 3D approach to simulate the behaviour of mixing, dilution and dispersion conditions of the wastewater discharge in this particular setting.

The modelling approach included multiple runs to account for the variation of certain input parameters:

- The depth of water in the estuary and, specifically, at the outfall (varying according to tides);
- Wind conditions; and
- Ambient velocities (largely varying according to tides).

An initial set of runs were completed to establish appropriate input parameters for use in subsequent model runs to compare discharges with ELVs.

1.4 Dispersion Model

CORMIX is an industry-standard mixing zone model which is primarily used to determine detailed wastewater plume characteristics close to the outfall (<100 m). Whilst CORMIX does not include a sophisticated hydrodynamic model to directly simulate the unsteady (i.e. time-varying) movement of receiving environments, it has the functionality to model the discrete hydraulic effects associated with pipe outfalls and diffusers, typically used to aid wastewater dispersion in situations such as this. Beyond the NMZ, the accuracy of CORMIX to predict mixing characteristics is reduced. Likewise, in coastal environments, flow conditions normally vary over time in response to the rise and fall of tides. To account for this, a number of scenarios covering a range of conditions through the tidal cycle were modelled.

1.5 Tidal Model

There is very limited publicly-available tidal flow gauging data for the estuary at the spatial resolution required for this assessment, and the collection of site-specific current measurements was not considered a proportionate or reasonable requirement for this stage of the study.

A TUFLOW-FV hydrodynamic model of the Humber Estuary has been developed by Ramboll and used to extract indicative tidal velocity data at the outfall location. The full model setup, calibration and outputs are not presented within this CORMIX modelling report in the interests of brevity and proportionality.

It is recognised that, in the absence of a detailed presentation of the hydrodynamic model, regulators may place limited reliance on any single set of extracted velocity values. Accordingly, the CORMIX assessment has not been based on a single deterministic flow condition. Instead, sensitivity testing has been undertaken using a range of representative tidal velocities reflecting the principal phases of the tidal cycle (ebb, flood and slack conditions).

This approach provides a pragmatic and suitably conservative basis for assessing plume behaviour, enabling the influence of varying ambient flow conditions on dilution and plume extent to be explored within the steady-state CORMIX framework.

2. CORMIX MODEL APPROACH

2.1 CORMIX Model

Effluent discharge modelling is undertaken using the Cornell Mixing Zone Model (CORMIX) Version 12, a 3D dilution model for the definition of discharge plumes. Consistent with its intended use, the CORMIX model is used to model continuous point source discharges and predict steady-state mixing behaviour and plume geometry at the outfall location and close by.

Data on the proposed discharge via the existing outfall and receiving environment were obtained from several sources (indicated below in brackets []). Where unavailable, engineering judgment has been used to make appropriate assumptions to allow the model to be run. The discharge is based on known outfall design information provided to Ramboll by Fichtner. Hydrodynamics, concentrations of selected constituent parameters, recirculation and dispersion have largely been evaluated using the following conditions:

- Outfall location = NGR - 524423, 413458 [Fichtner];
- Pipe distance from shore = approximately 500 m [Fichtner];
- Diffuser alignment = perpendicular to shore [information unavailable – assumed];
- Number of ports = 1 (with 3 nozzle diffuser) [Fichtner];
- Port diameter = 60 mm [information unavailable - assumed];
- Port angle = 10° (upward and outward from the horizontal) [information unavailable – assumed];
- Port height off bottom = 0.5 m [information unavailable – assumed];
- Average depth of Humber in vicinity of outfall = 2.5 - 6 m [UK Hydrographic Office];
- Depth at discharge = 2.5 -6 m [UK Hydrographic Office];
- Average width of Humber = 5.3 km [calculated using GIS from Google Earth];
- Tidal period = 12.35 hr [British Oceanographic Data Centre];
- Range of tidal velocities = 0 - 0.379 m/s [Ramboll Modelling];
- Range of wind speeds = 3.8 – 5.4 m/s [Met Office];
- Humber density = 1,018 kg/m^3 [calculated from average temperature and salinity];
- Effluent density = 1,001 kg/m^3 [estimated based on mass of known constituents (Table 3.1) added to fresh water]; and
- Manning's roughness (n) = 0.015 [Humber Reporting – see Section 3].

Further information on all input data is provided in Section 3 of this report. For the purposes of near-field modelling, ambient flow currents were modelled as uni-directional for the duration of each tidal scenario (see Section 5). The configuration and orientation of the diffuser is applicable for determining the mixing and dilution potential of the effluent discharge in the near-field.

3. INPUT DATA

3.1 Effluent Concentrations

The theoretical composition of the effluent is as follows (Fichtner provided):

Table 3.1: Effluent Water Quality:

Parameter	Unit	Concentration
Ammonia CaCO3 >50mg/l (90%ile)	µg/l	2,400
Antimony	µg/l	1,010
Arsenic	µg/l	50
Atrazine	µg/l	0.06
Cadmium and its compounds	µg/l	30
Carbon tetrachloride	µg/l	12
Chloroform	µg/l	12
Chromium III (95%ile) (dissolved)	µg/l	50
Chromium VI (95%ile) (dissolved)	µg/l	50
Copper	µg/l	150
Cyanide	µg/l	30
DDT (All isomers)	µg/l	0.025
1,2-Dichloroethane	µg/l	5
Endosulfan	µg/l	0.03
Endrin	µg/l	0.005
Fluoride	µg/l	25
Hexachlorobenzene	µg/l	0.03
Hexachlorobutadiene	µg/l	0.06
Hexachlorocyclohexane (All isomers)	µg/l	0.02
Iron (dissolved)	µg/l	1500
Isodrin	µg/l	0.005
Lead and its compounds	µg/l	60
Malathion	µg/l	0.08
Mercury and its compounds	µg/l	10
Nickel and its compounds	µg/l	150
Pentachlorophenol	µg/l	0.7
Phenol	µg/l	10
Simazine	µg/l	0.06
Sulphate	µg/l	1,000,000
Tetrachloroethylene	µg/l	10
Thallium	µg/l	30
1, 1, 1 Trichloroethane	µg/l	10
Trichloroethylene	µg/l	40
Trichlorobenzene	µg/l	0.2
Zinc	µg/l	500

The total volume of effluent discharged is understood to have a mean flow rate of 85.65m^3/s and a max flow rate of 209.43m^3/s as stated by Fichtner – noting that the volume of effluent discharged from the HG WTF is only approximately 3 t h^{-1} during operation. The allowable discharge rate is 15,000 m^3/day. The discharge is not continuous but, for the purpose of the modelling and in order to be conservative, a continuous discharge has been assumed in steady state model runs.

3.2 Compliance Points and Mixing Zones

The EA PPC Permit for the Moody Lane installation (VP3335LK) specifies two on-site compliance locations for liquid discharges: W1 (surface-water drains) and W2 (site process-effluent system). All concentration-based emission limits, e.g. 1 µg l^{-1} for mercury, 1 µg l^{-1} for cadmium, 200 µg l^{-1} for lead and 500 µg l^{-1} for total chromium, copper and nickel, are to be met at these points before any mixing occurs with the receiving waters of the Humber Estuary. Fichtner has advised that ELVs should be based on the World Health Organisation (WHO) Water Quality Upper Limits for Drinking Water for certain parameters and Environmental Quality Standards (EQS) for others. Further information on this is provided in Section 6.

The permit conditions are believed to anticipate that initial dilution in the estuary will rapidly reduce concentrations so that compliance with ELVs is achieved within a short distance of the outfall. To demonstrate that this assumption is valid, near-field dispersion modelling of the plume in the Humber Estuary has been completed.

This evidence-based approach aligns with EA guidance for assessing discharges to coastal and transitional waters and will provide confidence that, despite potentially elevated on-site ELVs, the installation will not compromise water quality objectives beyond the immediate vicinity of the diffuser.

3.3 Diffuser Arrangement

Available information on the outfall indicates that the discharge is conveyed through a 600 mm diameter pipeline extending approximately 500 m from the shoreline to the point of release into the estuary. The consented maximum discharge volume is 15,000 m^3 per day (equivalent to 0.174 m^3/s). It is understood that the outfall terminates in three nozzle-type diffusers; however, no as-built design drawings or detailed specifications of the diffuser manifolds or port configuration are available.

For the purpose of the CORMIX near-field mixing assessment, it has been assumed that each diffuser comprises a short manifold (approximately 8 m in length) fitted with equally-spaced circular ports of 60 mm diameter, located approximately 0.5 m above the seabed and aligned 10° upward and outward from the horizontal. These parameters are typical of engineered diffusers designed to promote effective initial dilution without excessive seabed impingement and are consistent with common practice for coastal and estuarine outfalls of this scale.

3.4 Effluent Flows

The discharge is capped in the existing PPC Permit for the Moody Lane installation at 15,000 m^3/day, equivalent to about 174 l/s at the on-site compliance point W2. Typical (mean) discharge rate is approximately 85.65 l/s rising to a short-term maximum of around 209.43 l/s, noting that the volume of effluent discharged from the HG WTF is only ~3 t h^{-1} during operation.

For dispersion modelling the calculation of exit velocities and near-field plume behaviour is based on the representative mean discharge of 85.65 l/s. The substantial dilution available in the Humber, coupled with the high momentum of the combined discharge, is expected to reduce concentrations to below ELVs within a short distance of the diffuser.

For the purposes of the modelling, given the relatively low contribution of flows attributable to the site, the approach taken is as follows:

1. The emission concentrations of other flows entering the same discharge pipe are not known.
2. It cannot be assumed that those concentrations are lower (and would therefore provide dilution of the site-derived effluent), nor can we assume they are higher, as it would not be the site’s responsibility to dilute other operators’ discharges.
3. The plume will behave in the receiving environment according to the overall discharge volume and rate — it is not possible to meaningfully assess the site’s contribution in isolation.
4. It has therefore been assumed that the entire plume has the same emission concentrations as site-derived discharge, on the basis that this represents a conservative “no worse” scenario.

If a plume based on the total discharge volume and rate, with these assumed emission concentrations, can be shown not to have a detrimental impact on the receiving environment, then this justifies effluent emissions at these concentrations. If other contributors are in fact diluting the discharge, the environmental impact would be lower and the modelling results are conservative. If other contributors are increasing concentrations, that is outside the control and responsibility of the site.

3.5 Bathymetry

Bathymetry data for the Humber estuary was downloaded from the DEFRA[1] data services platform. The data comprises the SurfZone Digital Elevation Model (DEM) - 2m produced in 2019. The datasets combine LIDAR and near-shore multibeam SONAR Bathymetry elevation data and comprises the best currently available DEM covering the inter-tidal zone produced by the EA. This data is freely available to use under the Open Government Licence (© EA copyright and/or database right 2019).

The EA notes that *“the SurfZone DEM was produced by using a bespoke feathering technique to smooth the overlaps between LIDAR and Bathymetric surveys to produce a merged surface. Where small gaps existed between the LIDAR and Bathymetric surveys these were interpolated using a bilinear interpolation technique.”*

The Humber Estuary relevant to the site is covered by 23 SurfZone raster tiles which have been combined as a mosaic dataset. Raster tile information is as follows:

Table 3.2: Surfzone Raster Tiles

Dataset Name	Dataset Tile
Surfzone_DEM_2019_2_TA11	NE
Surfzone_DEM_2019_2_TA12	NE, NW, SE, SW
Surfzone_DEM_2019_2_TA20	NE
Surfzone_DEM_2019_2_TA21	NE, NW, SE, SW
Surfzone_DEM_2019_2_TA22	SW
Surfzone_DEM_2019_2_TA30	NE, NW, SE, SW
Surfzone_DEM_2019_2_TA31	NE, NW, SE, SW
Surfzone_DEM_2019_2_TA40	NW, SW
Surfzone_DEM_2019_2_TA41	NW, SW

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[1] https://environment.data.gov.uk/dataset/77e6f743-d708-4909-a80f-9510b7dbaa16

The below figure shows the coverage of the bathymetric dataset over the Humber Estuary.

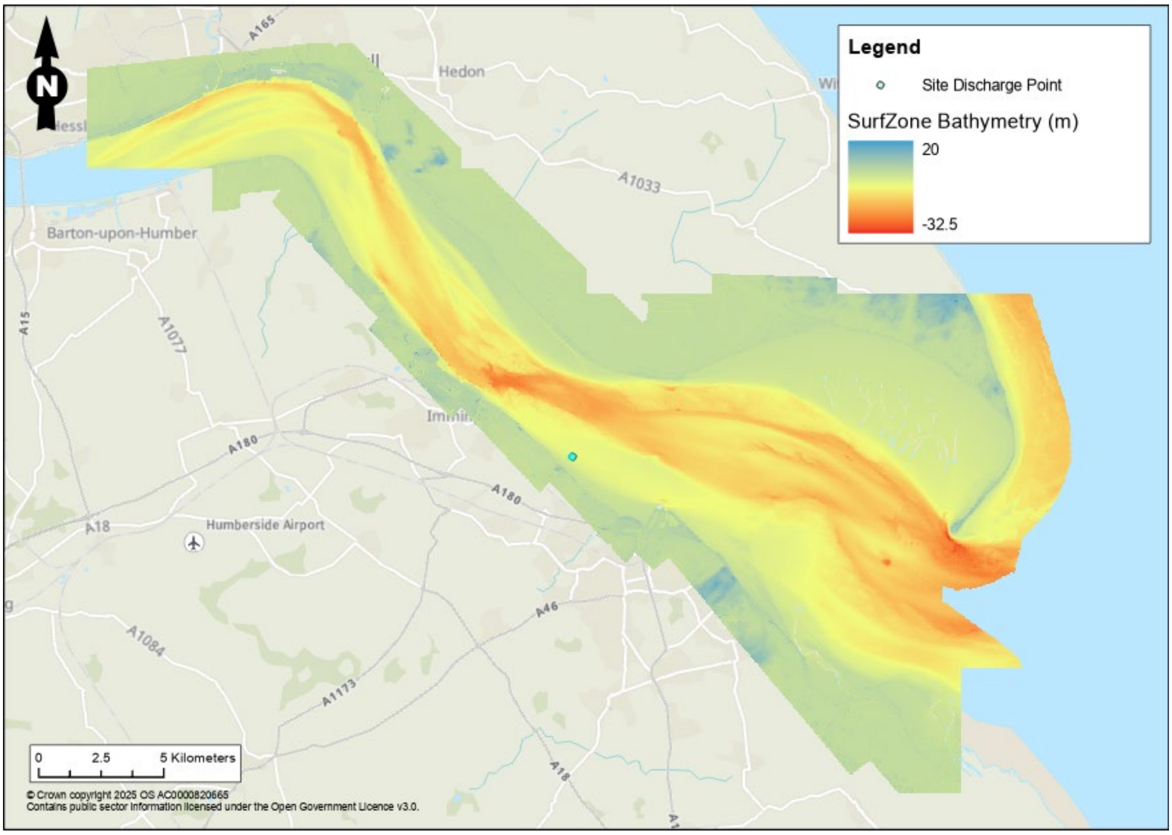

Figure 3.1: Coverage of the Bathymetric Dataset for Humber Estuary

A total of 7,844 sampling points within 100 m radius of the diffuser location have been used to extract bathymetric statistics, minimum, maximum and average depth. Figure 1-2 presents the locations of the sampling points and Table 3.3 shows the extracted bathymetric statistics noting that these depths are for a representative ebbing tide (not the full range of a typical tidal cycle).

Table 3.3: Bathymetric statistics points within 100m radius of the diffuser location

Bathymetric Dataset	**Depth (m)**		
	Min	**Max**	**Average**
SurfZone Mosaic DEM 2019 - 2m	-3.39	-4.97	-4.10

3.5

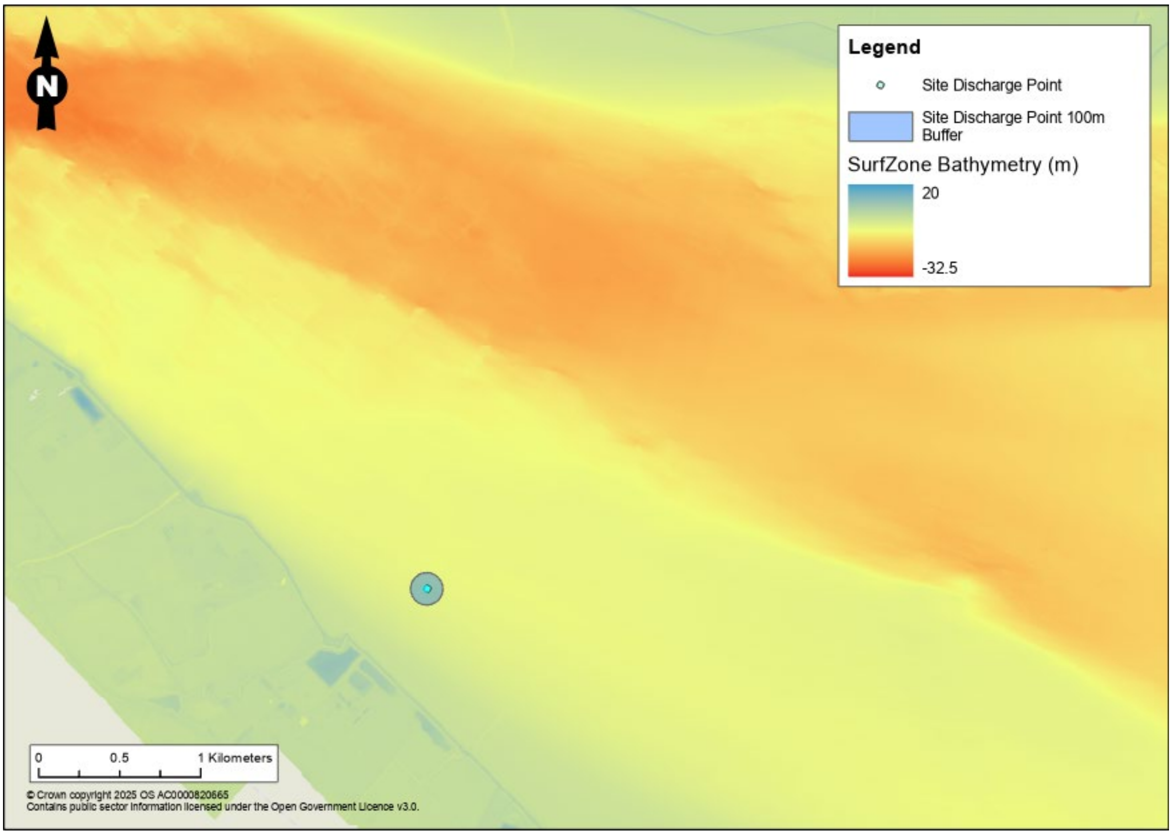

Figure 3.2: Bathymetric Statistics Sampling Points within 100m Radius of the Diffuser Location

3.6 Wind Speed

Wind Speed Data relevant to the site has been acquired from online Met Office Climate Research[2]. Whilst the Cleethorpes, Haverstoe Park Station (approximately 8.8 km to the south-east) is the nearest data measuring station to the site, average wind speed data is not available at this location. Therefore, mean wind speed data (between 1991-2000) has been taken from the second closest station; Manby Station which is located approximately 30 km south-east of the site and is presented in Table 3.4.

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[2] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcvqdmufu

Table 3.4: Met Office Mean Monthly Wind Speed Data for the Manby Climate Station

Month	Monthly mean wind speed at 10 m	
	Knots	m/s
January	10.42	5.4
February	10.59	5.4
March	9.90	5.1
April	9.32	4.8
May	7.96	4.1
June	9.33	4.8
July	7.80	4.0
August	7.47	3.8
September	7.84	4.0
October	8.79	4.5
November	8.08	4.2
December	8.22	4.2
Annual	**8.80**	4.5

Mean wind speed data (dated between 1991-2000) for the East and North-East of England District has also been summarised below as taken from the Met Office data.

Table 3.5: Met Office Mean Monthly Wind Speed Data for the E&NE England District

Month	Monthly mean wind speed at 10 m	
	Knots	m/s
January	10.39	5.3
February	10.39	5.3
March	9.98	5.1
April	9.01	4.6
May	8.68	4.5
June	7.87	4.0
July	7.58	3.9
August	7.67	3.9
September	8.18	4.2
October	8.88	4.6
November	9.32	4.8
December	9.64	5.0
Annual	**8.96**	4.6

3.7 Tidal Data

Data from the National Tidal and Sea Level Facility[3] provided for the Immingham tide gauge site (TA 1995 1640) are as presented in **Table 3.6**.

Table 3.6: Immingham Tide Gauge Data Summary

Parameter	Abbreviation	Value
Highest Astronomical Tide	HAT	7.98m
Lowest Astronomical Tide	LAT	0.17m
Mean High Water Springs	MHWS	7.2m
Mean High Water Neaps	MHWN	5.7m
Mean Low Water Neaps	MLWN	2.7m
Mean Low Water Springs	MLWS	1.2m
Highest for year	H for 2025	7.83m
Lowest for year	L for 2025	0.37m
Highest for year	H for 2026	7.62m
Lowest for year	L for 2026	0.51m
Mean Spring Range	MSR	6m
Mean Neap Range	MNR	3m

3.8 Tidal Period

The UK Tide Gauge Network, available from the National Oceanography Centre British Oceanographic Data Centre (BODC)[4], has been used to derive the tidal period for the Humber Estuary. Data from the tide gauge at Immingham, which has data from 1953-2023 onwards. The tide curve data was analysed for 2023, and the wave period ranged from 11:50 hrs to 13:00 hrs, with the general tide period sitting at 12:35hrs. These values were calculated by filtering out tidal periods greater than 13 hours, to remove inconsistencies within the data set that had been queried by BODC.

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[3] Tide gauge site information | National Tidal and Sea Level Facility

[4] https://www.bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/

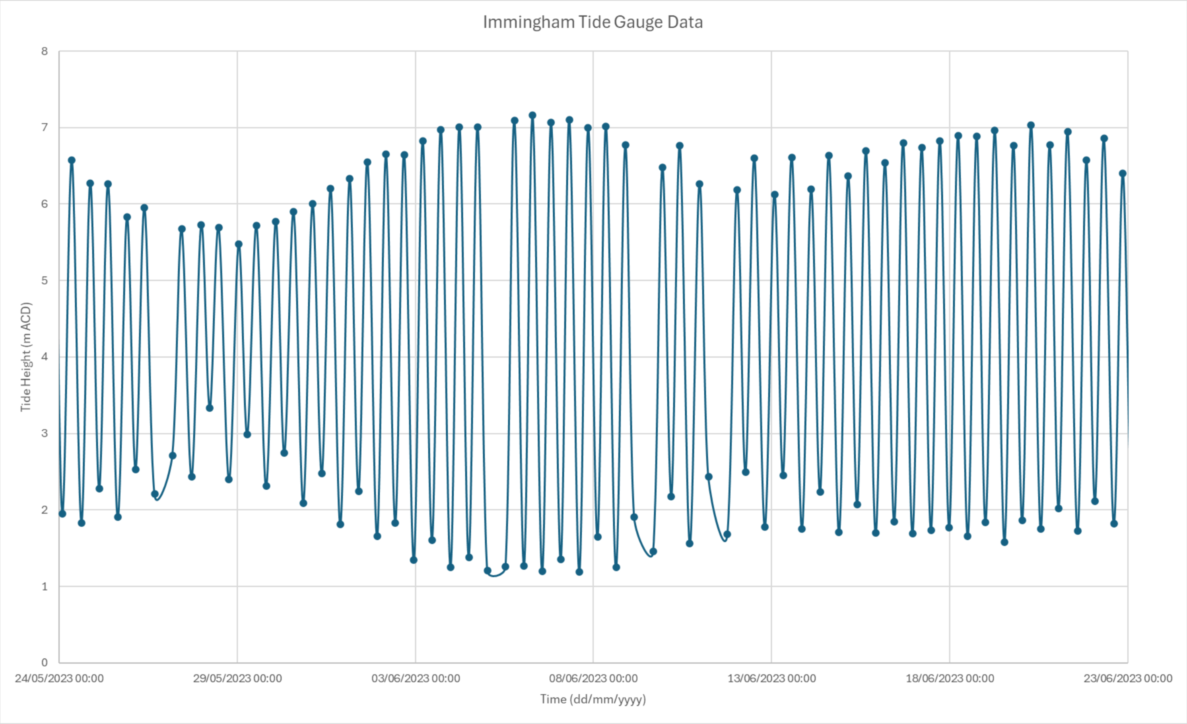

Figure 3.3: BODC Tide Level Data for the Tide Gauge at Immingham

3.9 Tidal Velocity

A tide gauge for the Harbour Estuary is located at Immingham Docks[5] (National Tidal and Sea Level Facility). The tide gauge is located on the East side of the entrance to Immingham Docks with the measuring system mounted on a leg of the lead-in-jetty. The aim of this study was to assess the worst-case effluent discharge plume distance and therefore, a low energy Mean High Water Neap (MHWN) tide (5.7mCD, 1.8mAOD) was used to provide a minimal mixing effect, with the average neap tide range measuring 3m. A MHWN tide was identified in the 15 minutes water level timeseries for Immingham sourced from the British Oceanographic Data Centre (BODC)[6] processed data.

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[5] https://ntslf.org/tides/uk-network/portinfo?port=Immingham

[6] https://www.bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/processed/

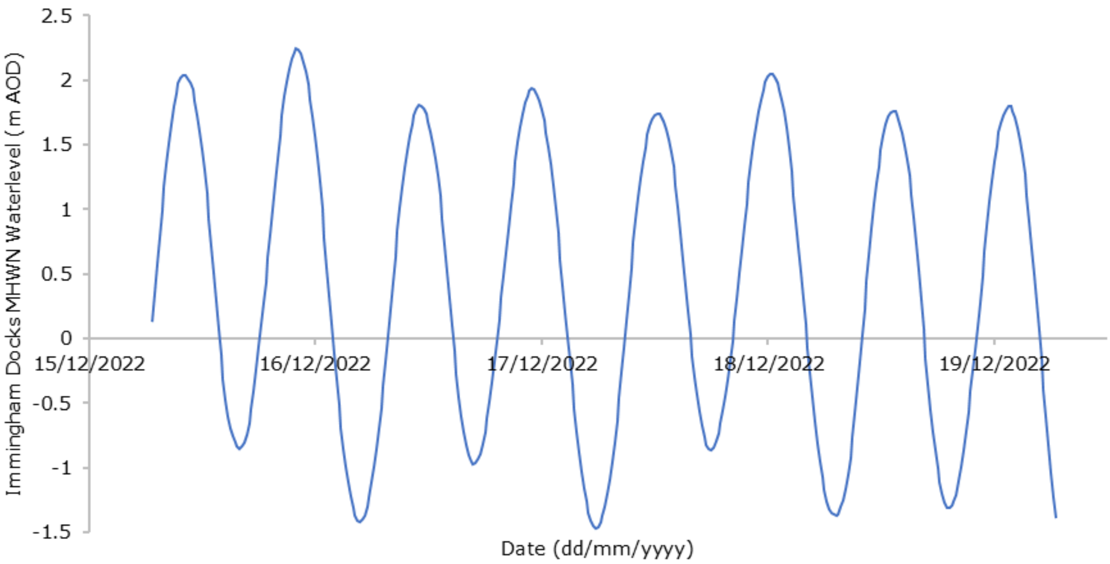

Figure 3.4: MHWN (1.8mAOD) tidal cycle at Immingham Dock (National Tidal and Sea Level Facility)

The tide data was run through a 3D TUFLOW-FV Hydraulic Model of the Humber Estuary to derive velocities and directions during the tidal cycle at the outfall location. Using extracted data from the TUFLOW-FV Hydraulic Model which was run over a 91 hour timeframe, average velocities and depths have been derived in the below table. For the purposes of this assessment, the following tide type definitions are used.

- **Ebbing Tide** – the phase during which the sea level falls and the tidal current flows seaward; taken from the model to calculate average flow velocity from 30 minutes before it reaches its peak to 30 minutes after.
- **Low-Tide Slack** - the short period, from 30 minutes before to 30 minutes after low tide, when tidal currents stop moving or are at their weakest.
- **Flooding Tide** – the phase during water level rises, moving from low tide towards high tide; taken from the model to calculate average flow velocity from 30 minutes before it reaches its peak to 30 minutes after.
- **High-Tide Slack -** the short period, from 30 minutes before to 30 minutes after high tide, when tidal currents stop moving or are at their weakest.

Table 3.7: Tidal Cycle Flow Velocities and Depths

	Ebbing Tide	Low-Tide Slack	Flooding Tide	High-Tide Slack
Flow Direction	South-East	North-West	North-West	South-East
Average Velocity (m/s)	0.161	0.064	0.145	0.078
Average Depth (m)	4.04	2.50	4.09	5.63
Range of Velocities (m/s)	0.116 – 0.202	0.052 - 0.080	0.123 – 0.162	0.046 – 0.137
Range of Depths (m)	3.82 - 4.24	2.22 – 2.84	3.82 – 4.49	5.44 – 5.95

3.10 Manning’s ‘n’

The Humber is an estuarine environment, characterised by mudflats and sandbanks. Online reporting suggests a 0.015 manning’s ‘n’ roughness value (lower 0.010, upper 0.019).

3.11 Physical Environment Summary

Table 3.8 summarises the data values for the input parameters required for the CORMIX water quality modelling of the Humber Estuary.

Table 3.8: Summary of Receiving Environment Data for CORMIX Modelling

Data	Unit	Average	Minimum	Maximum
Humber Estuary Average Depth (Mid Tide)	m	4.10	3.39	6.0
Humber Estuary Depth at Discharge (High Tide)	m	5.63	5.44	5.95
Humber Estuary Depth at Discharge (Low Tide)	m	2.5	2.22	2.84
Humber Estuary Depth at Discharge (Mid Tide)	m	4.07	3.82	4.49
Wind Speed	m/sec	4.6	3.8	5.3
Tidal Period	hr	12:35	11:50	13:00
Manning 'n' Silt	N	0.015	0.010	0.019
Humber Estuary at Discharge Density	kg/m^3	1018.2	1009	1021.5
Tidal Velocities (Ebbing Tide)	m/sec	0.161	0.116	0.202
Tidal Velocities (Low Tide Slack)	m/sec	0.064	0.052	0.08
Tidal Velocities (Flooding Tide)	m/sec	0.145	0.123	0.162
Tidal Velocities (High Tide Slack)	m/sec	0.078	0.046	0.137

3.12 Water Temperature

A dataset of water temperatures was obtained from the EA Centre Water Quality Archive[7]. Estuary temperature records were taken from the EA Archive and averaged from 5 different sampling points: AN-CEGE4D25, AN-CTDE2D25, AN-SCME5D25, AN-TIOMON2 and AN-DOVE1D10 (as presented below in Figure 3.5) to represent the discharge area.

Figure 3.5: EA Data Archive Sampling Points within Discharge Vicinity

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[7] https://environment.data.gov.uk/water-quality/view/download

The ambient water temperatures are summarized as follows:

Table 3.9: Water Temperatures

	Unit	Average	Minimum	Maximum
January	ºC	6.37	5.1	6.9
February	ºC	5.92	5	6.9
March	ºC	6.91	5.6	8.1
April	ºC	10.43	10	10.9
May	ºC	12.50	11.4	13.4
June	ºC	15.15	14.1	16.6
July	ºC	18.03	16.2	19.4
August	ºC	18.62	16.6	20
September	ºC	17.56	14.6	19.5
October	ºC	14.23	13.4	15.3
November	ºC	11.08	10.5	11.4
December	ºC	6.88	5.9	7.8

Ambient water quality data for selected parameters calculated from five sampling points and obtained from the EA are presented as below:

Table 3.10: Ambient Water Quality of Available CoCs

Pollutants	Average	Min	Max
Temperature of Water (°C)	11.82	5	20
Salinity : In Situ (ppt)	24.17	11.62	30.71
Carbon, Organic, Dissolved as C:- {DOC} (mg/l)	2.18	1.7	2.9
Zinc, Dissolved (µg/l)	3.11	2.3	6.2
Nickel, Dissolved (µg/l)	1.63	0.86	9.3
Copper, Dissolved (µg/l)	1.38	1.1	1.8
Lead, Dissolved (µg/l)	0.06	0.04	0.24
Mercury, Dissolved (µg/l)	0.01	0.01	0.01
Arsenic, Dissolved (µg/l)	1.70	1.7	1.7
Chromium Hexavalent, Dissolved :- {Cr VI} (µg/l)	0.3	0.3	0.3
Chromium, Dissolved (µg/l)	0.5	0.5	0.5

4. SENSITIVITY TESTING

4.1 Overview

The modelling approach included multiple runs to account for the variation of certain input parameters:

- The depth of water in the Humber Estuary, specifically, at the outfall (varying according to tides);
- Wind conditions; and
- Ambient velocities in the Humber Estuary (largely varying according to tides).

For sensitivity testing, a discharge concentration of 1 mg/L was used with the water quality standard set at 0.1 mg/L for indicative purposes. Input parameters as listed in Section 2.1 and Section 3 were used for all other parameters.

4.2 Ambient Depth

Table 4.1 presents the results of modelling variations in depth in terms of the distance to achieve compliance with the theoretical water quality standard. Flow velocity was set at 0.01 m/s, wind speed at 3.8 ms.

Table 4.1: Average Depth Sensitivity Test Results

Average Depth (m)	Depth at Discharge (m)	Maximum Distance to Achieve Compliance (m)
4.4	3.4	0.39
5	4	0.38
3.4	2.4	0.39

Due to the diffusers, the distance to achieve 10x dilution is relatively short (<5 m). This is the same for each of the tests done on the depth of water in the vicinity of the outfall. There is very little impact on the distance to achieve compliance showing that the model is not sensitive to these parameters within the range of possible depths. On the basis that there is insufficient reason to override the recommendations of the CORMIX manual in respect of modelling tidal currents, all model runs use depths representative of a range of tidal conditions as described in Section 5.2.

4.3 Wind Conditions

Table 4.2 presents the results of modelling variations in wind speed in terms of the distance to achieve compliance with the theoretical water quality standard. Flow velocity was set at 0.01 m/s, depth at -4.10 m.

Table 4.2: Wind Speed Sensitivity Test Results

Wind Speed (m/s)	Maximum Distance to Achieve Compliance (m)
0.2	0.39
3.8	0.39
5.3	0.39

Sensitivity tests of different wind speeds suggest the model is not sensitive to these parameters. This is most probably because mixing occurs largely underwater and, by the time there is surface interaction, the concentrations of CoCs are very low which means winds are not significant in providing further dilution. On this basis, all model results described in Section 5 use a wind speed of 3.8 m/s.

4.4 Ambient Current Velocities

Table 4.3 presents the results of modelling variations in ambient velocities in terms of the distance to achieve compliance with the theoretical water quality standard. Depth was set at -4.10 m, wind speed at 3.8 ms.

Table 4.3: Ambient Velocities Sensitivity Test Results

Current (m/s)	Maximum Distance to Achieve Compliance (m)
0.01	0.39
0.25	0.37
0.75	0.36

Sensitivity tests of different current velocities suggest the model is not sensitive to these parameters. Again, this is most probably because mixing occurs largely within the first 4 m at which point the influence of diffuser exit velocities is more important to mixing than ambient conditions. On the basis that there is insufficient reason to override the recommendations of the CORMIX manual in respect of modelling tidal currents, all model runs use current velocities representative of a range of tidal conditions as described in Section 5.2.

5. MODEL SCENARIOS

5.1 Overview

The receiving environment is a tidally-influenced estuary. On this basis, a single steady-state simulation is not necessarily representative of the range of conditions experienced over a tidal cycle. Accordingly, a set of four scenarios has been modelled to bound the range of plume behaviour.

The scenarios comprise: ebbing tide, low tide slack, flooding tide and high tide slack. These conditions capture the principal phases of the tidal cycle, including periods of strongest advection (ebb and flood) and periods of minimal current velocity (slack water). The ebbing and flooding tide scenarios represent conditions under which the plume is advected in opposing directions with relatively high velocities, typically resulting in greater dilution and elongation of the plume. In contrast, the slack water scenarios represent conditions of minimal advection, under which dilution is reduced and the potential for localised accumulation is greatest. Consideration of both low tide and high tide slack also accounts for variations in water depth and ambient dilution conditions across the tidal range.

For each scenario, input parameters including depth-averaged current velocity, flow direction and water depth were derived from outputs of the previously-mentioned TUFLOW-FV model at the outfall location. These inputs were used to define representative, physically realistic conditions for each phase of the tidal cycle.

The results of the four simulations have been used collectively to characterise the range of potential plume extents and associated water quality outcomes. This approach provides a pragmatic and proportionate means of assessing the discharge within a tidally varying environment, capturing both worst-case and more dispersive conditions, without the need to undertake fully unsteady combined hydrodynamic and water quality modelling.

Flow conditions within the estuary are governed by the semi-diurnal tidal cycle, resulting in periodic reversals in current direction between flood and ebb phases. Notwithstanding this reversal, the dominant flow vectors are strongly constrained by the geometry of the estuary and are aligned broadly along the main channel axis, which in this reach has an overall north-west to south-east orientation.

During the flooding tide, currents are directed north-west along the channel towards land, whilst during the ebbing tide they flow seaward (towards the south-east). At slack water, current velocities reduce (though the dynamic flux of the estuary means they never truly reach zero) and flow direction becomes less well defined, with limited advection and increased potential for localised dispersion. Although short-term variability in flow direction can occur due to local bathymetry and secondary circulation effects, the principal transport pathway remains along the estuary axis.

This predominantly along-channel behaviour means that plume development is expected to be characterised by elongation parallel to the estuary rather than significant cross-channel transport. While minor lateral components of flow may occur, particularly under slack or transitional conditions, these are expected to be small relative to the dominant along-channel velocities. As a result, the likelihood of sustained transport of the plume in a south-westerly direction towards the shoreline is considered to be very low. This is significant in the consideration of whether plumes would interact with the shoreline.

The use of representative ebb, flood and slack scenarios therefore provides an appropriate basis for capturing the range of plume orientations and extents likely to arise over a tidal cycle.

5.2 CORMIX Parameters

The CORMIX simulations have been undertaken using a consistent set of discharge and ambient parameters across all scenarios, with variation only in those parameters that are governed by the tidal state. This approach ensures that differences in predicted plume behaviour are attributable to changes in hydrodynamic conditions rather than inconsistencies in model setup.

The following parameters have been applied uniformly in all scenarios:

- Effluent flow rate: 0.08565 m^3/s
- Effluent density: 1001 kg/m^3
- Ambient density: 1018 kg/m^3
- Wind speed: 3.8 m/s
- Channel width: 5,300 m
- Manning's n: 0.015
- Outfall configuration: multiport diffuser located approximately 500 m offshore

These parameters reflect the physical characteristics of the discharge and receiving environment and are not expected to vary significantly over the tidal cycle.

Scenario-specific inputs have been derived to represent the four tidal conditions assessed, namely ebbing tide, low tide slack, flooding tide and high tide slack. The parameters varied between scenarios are water depth (at the discharge location and as an average across the channel) and ambient current velocity, as these are the principal controls on dilution and plume transport.

For the ebbing tide scenario, a depth at the discharge of 4.07 m and an average channel depth of 5.07 m have been adopted, with an ambient velocity of 0.161 m/s.

For the low tide slack scenario, a reduced depth at the discharge of 2.5 m and an average depth of 3.5 m have been used, together with a low ambient velocity of 0.064 m/s to represent near-slack conditions.

For the flooding tide scenario, the depth conditions are consistent with the ebb case (4.07 m at the discharge and 5.07 m average depth), with an ambient velocity of 0.145 m/s applied in the opposite flow direction.

For the high tide slack scenario, increased depths have been applied, with 5.63 m at the discharge and an average depth of 6 m, and a low ambient velocity of 0.078 m/s representing slack conditions at high water.

These inputs have been used within CORMIX to simulate plume behaviour under each tidal condition, providing a range of dilution and dispersion outcomes reflecting both relative high-energy (ebb and flood) and low-energy (slack) states of the estuary.

6. MODEL RESULTS

6.1 Mixing Zone Criteria

The specific model outputs to meet the objectives of this study are to find the distance from the outfall where plume concentrations meet ELVs. For those plumes which were found to not meet ELVs within close proximity of the outfall (<5 m), further assessment including an estimate of the plume dimensions and shape was considered.

6.2 Near-field

Water quality screening has been undertaken to identify those parameters requiring further assessment. For the heavy metals (antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc), ELVs have been defined as WHO drinking water guideline values. For all other parameters, ELVs use the relevant EQSs provided to Ramboll by Fichtner. Findings from the near-field modelling are presented in Table 6.1 and present distances to compliance with these ELVs.

The purpose of this screening step is to establish whether the potential quality of the discharge could exceed applicable standards following dilution within the receiving environment. Where the concentration of a given parameter in the discharge is already below the relevant water quality standard, no further assessment is considered necessary, as mixing and dilution within the estuary will not result in a deterioration relative to that standard.

Accordingly, the table below reports only those parameters for which the predicted concentration in the discharge exceeds the relevant screening criterion. These parameters have been taken forward for further consideration within the mixing and dispersion assessment.

For a number of parameters, two EQS criteria were provided: Annual Average and Maximum Allowable Concentration (MAC). These represent different compliance measures, with the former intended to protect against long-term exposure and the MAC standard addressing short-term peak concentrations.

In order to ensure a conservative and precautionary assessment, a single screening value has initially been adopted for each parameter by selecting the lower (i.e. more stringent) of the available criteria where both standards exist. Where only one EQS value is defined, that value has been used directly. Only where this lower criterion results in a potential exceedance greater than 5 m from the outfall has the higher value also been modelled.

In practice, this approach generally results in the adoption of the Annual Average standard, as these are typically lower than the corresponding MAC values. This ensures that the assessment is based on the most protective threshold and avoids underestimating the potential for exceedance.

Full CORMIX outputs are available upon request (example output is presented in Appendix A).

Table 6.1: Distance to Compliance with Water Quality Standards (Ebbing Tide)

Parameter	Concentration (µg/l)	Annual Average EQS (µg/l)	Maximum Allowable Concentration EQS (µg/l)	Tide Scenario	Distance to Compliance (m)
Chloroform	12	2.5	-	Ebbing Tide	0.33
Cyanide	30	1	5	Ebbing Tide	0.41
Endosulfan	0.03	0.0005	0.004	Ebbing Tide	1.69
Iron (dissolved)	1500	1000	-	Ebbing Tide	0.14
Malathion	0.08	0.02	-	Ebbing Tide	0.31
Pentachlorophenol	0.7	0.4	1	Ebbing Tide	0.18
Phenol	10	7.7	46	Ebbing Tide	0.1
Antimony	1010	20	-	Ebbing Tide	1.18
Arsenic	50	10	-	Ebbing Tide	0.33
Cadmium	30	3	-	Ebbing Tide	0.37
Chromium	100	50	-	Ebbing Tide	0.21
Lead	60	10	-	Ebbing Tide	0.34
Mercury	10	6	-	Ebbing Tide	0.17
Nickel	150	70	-	Ebbing Tide	0.22

Table 6.2: Distance to Compliance with Water Quality Standards (Low Tide Slack)

Parameter	Concentration (µg/l)	Annual Average EQS (µg/l)	Maximum Allowable Concentration EQS (µg/l)	Tide Scenario	Distance to Compliance (m)
Chloroform	12	2.5	-	Low Tide Slack	0.34
Cyanide	30	1	5	Low Tide Slack	1.62
Endosulfan	0.03	0.0005	0.004	Low Tide Slack	25.25
Iron (dissolved)	1500	1000	-	Low Tide Slack	0.14
Malathion	0.08	0.02	-	Low Tide Slack	0.32
Pentachlorophenol	0.7	0.4	1	Low Tide Slack	0.18
Phenol	10	7.7	46	Low Tide Slack	0.1
Antimony	1010	20	-	Low Tide Slack	11.36
Arsenic	50	10	-	Low Tide Slack	0.34
Cadmium	30	3	-	Low Tide Slack	0.39
Chromium	100	50	-	Low Tide Slack	0.21
Lead	60	10	-	Low Tide Slack	0.36
Mercury	10	6	-	Low Tide Slack	0.17
Nickel	150	70	-	Low Tide Slack	0.23

Table 6.3: Distance to Compliance with Water Quality Standards (Flooding Tide)

Parameter	Concentration (µg/l)	Annual Average EQS (µg/l)	Maximum Allowable Concentration EQS (µg/l)	Tide Scenario	Distance to Compliance (m)
Chloroform	12	2.5	-	Flooding Tide	0.33
Cyanide	30	1	5	Flooding Tide	0.49
Endosulfan	0.03	0.0005	0.004	Flooding Tide	1.9
Iron (dissolved)	1500	1000	-	Flooding Tide	0.14
Malathion	0.08	0.02	-	Flooding Tide	0.31
Pentachlorophenol	0.7	0.4	1	Flooding Tide	0.18
Phenol	10	7.7	46	Flooding Tide	0.1
Antimony	1010	20	-	Flooding Tide	1.35
Arsenic	50	10	-	Flooding Tide	0.33
Cadmium	30	3	-	Flooding Tide	0.37
Chromium	100	50	-	Flooding Tide	0.21
Lead	60	10	-	Flooding Tide	0.35
Mercury	10	6	-	Flooding Tide	0.17
Nickel	150	70	-	Flooding Tide	0.22

Table 6.4: Distance to Compliance with Water Quality Standards (High Tide Slack)

Parameter	Concentration (µg/l)	Annual Average EQS (µg/l)	Maximum Allowable Concentration EQS (µg/l)	Tide Scenario	Distance to Compliance (m)
Chloroform	12	2.5	-	High Tide Slack	0.33
Cyanide	30	1	5	High Tide Slack	0.54
Endosulfan	0.03	0.0005	0.004	High Tide Slack	2.07
Iron (dissolved)	1500	1000	-	High Tide Slack	0.14
Malathion	0.08	0.02	-	High Tide Slack	0.31
Pentachlorophenol	0.7	0.4	1	High Tide Slack	0.18
Phenol	10	7.7	46	High Tide Slack	0.1
Antimony	1010	20	-	High Tide Slack	1.47
Arsenic	50	10	-	High Tide Slack	0.33
Cadmium	30	3	-	High Tide Slack	0.37
Chromium	100	50	-	High Tide Slack	0.52
Lead	60	10	-	High Tide Slack	0.35
Mercury	10	6	-	High Tide Slack	0.17
Nickel	150	70	-	High Tide Slack	0.22

The results indicate that, for the majority of parameters, concentrations reduce rapidly with distance from the discharge. Compliance is generally achieved within a very short distance (<5m).

During the low tide slack, Endosulfan and antimony also exceed screening criteria beyond 5 m of the outfall (approximately 25 m and 11 m respectively). An indicative extent of the plume for Endosulfan in the context of the Humber Estuary is presented below:

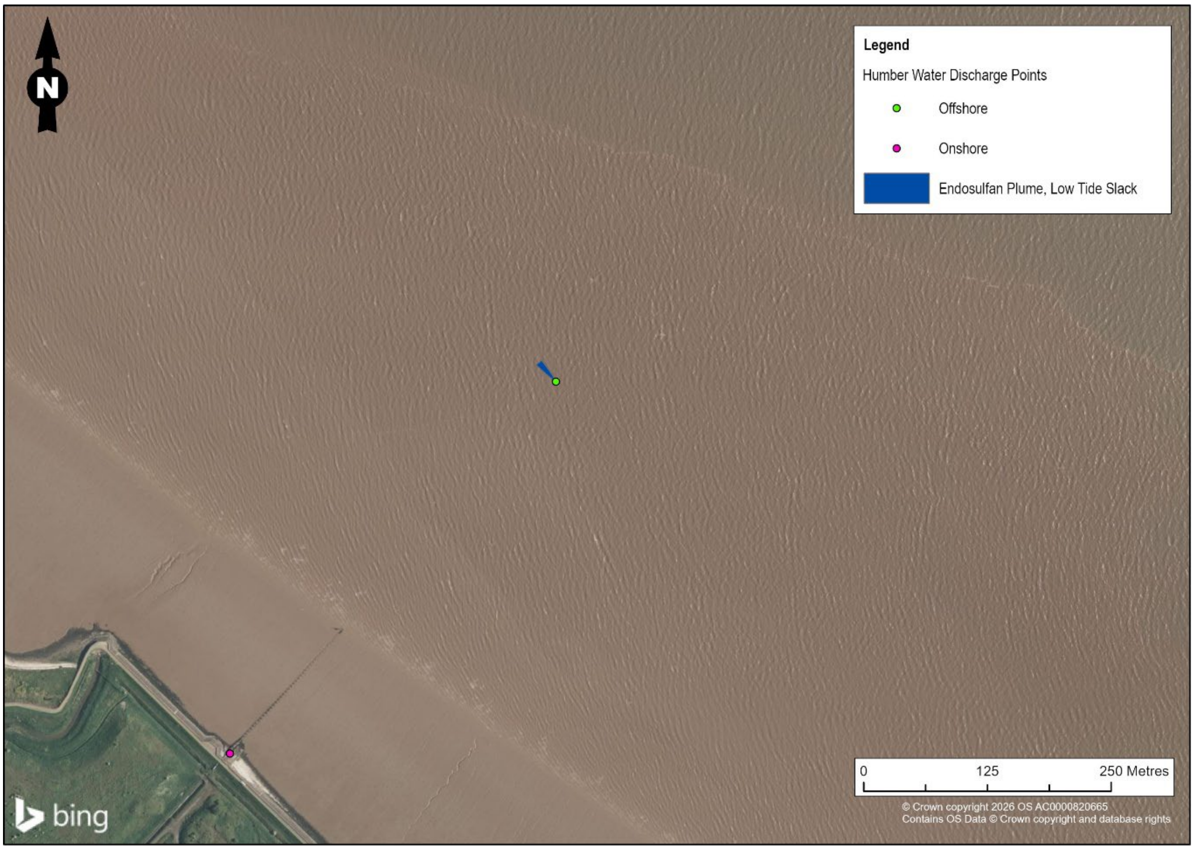

Figure 6.1: Indicative Plume Extent – Endosulfan Low Tide Slack

When the MAC screening criterion is used for Endosulfan in the Low Tide Slack scenario, the ELV is reached within 0.37 m of the outfall.

6.3 Far-field

Based on the results of near-field modelling, mixing of the plume within the NMZ is generally considered to be significant and would result in water quality concentrations well in compliance with screening criteria in the far field. The outfall is a considerable distance from the shoreline and the Humber estuary is very wide. This means that there would always remain a significant distance between the edge of the NMZ and the shoreline whereby additional dissipation and dilution would occur. Therefore, potential far-field impacts are considered to be minimal.

7. SUMMARY

The near-field surface-water dispersion modelling conducted for the Humber Gate Waste Treatment Facility (HG WTF) has effectively demonstrated that the effluent streams from the facility are very unlikely to cause significant adverse impacts on the receiving waters of the Humber Estuary. Using the CORMIX system, Ramboll performed extensive modelling to:

- Understand the impact of the outfall/diffuser configuration on near-field mixing;
- Quantify initial dilution and spatial extent of the near-field mixing zone under representative tidal conditions; and
- Compare predicted concentrations with relevant environmental quality standards.

The modelling results presented in Tables 6.1 to 6.4 showed that, whilst several parameters exceed screening criteria at the point of discharge, subsequent dilution and attenuation modelling indicated these concentrations reduce rapidly a short distance from the discharge. Compliance is generally achieved within less than 5 m of the outfall throughout the tidal cycle.

Far-field impacts are considered minimal for all parameters due to significant dilution and dissipation as the plume mixes within the estuary. The outfall's distance from the shoreline and the width of the Humber Estuary will ensure further attenuation and dilution, resulting in water quality concentrations well within screening criteria.

Overall, the results confirm that HG WTF's liquid discharges would be managed to protect the water environment of the Humber Estuary. The rapid attainment of compliance indicates effective dilution and attenuation, ensuring that the Facility's operation will not compromise water-quality objectives beyond the immediate vicinity of the diffuser.

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CORMIX2 PREDICTION FILE:
22222222222222222222222222222222222222222222222222222222222222222222222222222222222
222222222222
                       CORMIX MIXING ZONE EXPERT SYSTEM
               Subsystem CORMIX2: Multiport Diffuser Discharges
                             CORMIX Version 12.0G
                     HYDRO2 Version 12.0.1.0 August 2021
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CASE DESCRIPTION
 Site name/label:   Moody Lane Grimsby
 Design case:       Ebbing Tides
 FILE NAME:         C:\...rimsby\Low Tide Slack\GRI_Pb_Low Tide Slack_A.prd
 Time stamp:        04/23/2026--13:18:13

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =   5300.00  AS    =  18550.00  QA    =   1187.20  ICHREG= 1
 HA    =      3.50  HD    =      2.50
 UA    =      0.064 F     =      0.012 USTAR =0.2440E-02
 UW    =      3.800 UWSTAR=0.4358E-02
 Uniform density environment
 STRCND=  U         RHOAM = 1018.0000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:     DITYPE= unidirectional_perpendicular
 BANK  =  LEFT      DISTB =    504.00  YB1   =    500.00  YB2   =    508.00
 LD    =      8.00  NOPEN =    3       NRISER=    3       SPAC  =      4.00
NPPERR =    1
 D0    =      0.060 A0    =      0.003 H0    =      0.50  SUB0  =      2.00
 D0INP =      0.060 CR0   =      1.000 B0    =0.7069E-03
 Nozzle/port arrangement:   unidirectional_with_fanning
 GAMMA =     90.00  THETA =     10.00  SIGMA =      0.00  BETA  =     90.00
 U0    =     10.097 Q0    =      0.086 Q0A   =0.8565E-01
 RHO0  = 1001.0000  DRHO0 =0.1700E+02  GP0   =0.1638E+00
 C0    =0.6000E+02  CUNITS=  ppb
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0    =0.1071E-01         SIGNJ0=      1.0
 m0 =U0^2*B0 =0.7207E-01   j0 =U0*GP0*B0 =0.1169E-02   (based on slot width B0)
 m0 =U0*q0   =0.1081E+00   j0 =q0*GP0    =0.1753E-02   (based on volume flux q0)
 Associated 2-d length scales (meters)
 lQ=B  =      0.001 lM    =      6.48  lm    =     26.39
 lmp   =  99999.00  lbp   =  99999.00  la    =  99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0    =0.8565E-01  M0    =0.5766E+00  J0    =0.9351E-02
```

```
 Associated 3-d length scales (meters)
 LQ    =      0.05  LM    =      6.84  Lm    =     14.53  Lb    =     53.51
                                       Lmp   =  99999.00  Lbp   =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =    938.51  FRD0  =    101.87  R     =    157.77  PL    =   44.29
 (slot)             (port/nozzle)

RECOMPUTED SOURCE CONDITIONS FOR RISER GROUPS:
 Properties of riser group with  1 ports/nozzles each:
 U0    =     10.097 D0    =      0.060 A0    =      0.003 THETA =     10.00
 FR0   =    938.51  FRD0  =    101.87  R     =    157.77
 (slot)             (riser group)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)      =    MU2          2
 2  Applicable layer depth HS =     2.50        2
 2  Limiting Dilution S=QA/Q0 + 1= 13862.06     2
 222222222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    =0.6000E+02  CUNITS=  ppb
 NTOX  =  0
 NSTD  =  1         CSTD  =0.1000E+02
 REGMZ =  1
 REGSPC=  1         XREG  =      5.00  WREG  =      0.00  AREG  =      0.00
 XINT  =  53000.00  XMAX  =  53000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
       504.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  10 display intervals per module
------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------
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BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Due to complex near-field motions:  EQUIVALENT SLOT DIFFUSER (2-D) GEOMETRY

 Profile definitions:
   BV = Gaussian 1/e (37%) width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)
   Uc = Local centerline excess velocity (above ambient)
   TT = Cumulative travel time
```

```
       X        Y       Z        S       C       BV       BH       Uc        TT
      0.00     0.00    0.50     1.0 0.600E+02   0.00     4.00    10.034
.00000E+00

END OF MOD201: DIFFUSER DISCHARGE MODULE
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BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

 Because of the FANNED-OUT HORIZONTAL ORIENTATION of the diffuser jets,
   the near-field dilution is slightly improved.

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =    2.50m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
   TT = Cumulative travel time

       X        Y       Z        S       C       BV       BH         TT
      0.00     0.00    0.50     1.0 0.600E+02   0.00     4.00 .00000E+00
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of 0.100E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      0.40     0.00    0.52    15.4 0.389E+01   0.25     3.60 .55637E+00
      0.80     0.00    0.55    21.4 0.281E+01   0.50     3.30 .14923E+01
      1.20     0.00    0.57    26.0 0.231E+01   0.75     3.07 .26502E+01
      1.60     0.00    0.60    29.8 0.201E+01   1.00     2.89 .39756E+01
      2.00     0.00    0.62    33.2 0.181E+01   1.25     2.74 .54378E+01
      2.40     0.00    0.64    36.3 0.165E+01   1.50     2.63 .70164E+01
      2.80     0.00    0.67    39.1 0.153E+01   1.75     2.55 .86969E+01
      3.20     0.00    0.69    41.8 0.144E+01   2.00     2.50 .10468E+02
      3.60     0.00    0.72    44.3 0.136E+01   2.25     2.47 .12321E+02
      4.00     0.00    0.74    46.6 0.129E+01   2.50     2.46 .14249E+02
 Cumulative travel time =          14.2488 sec  (    0.00 hrs)
   Plume centerline may exhibit slight discontinuities in transition
     to subsequent far-field module.

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER
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BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

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 Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = Gaussian 1/e (37%) half-width in horizontal plane normal to trajectory
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)
   TT = Cumulative travel time

       X        Y       Z        S       C        BV       BH         TT
      4.00     0.00    2.50    46.6 0.129E+01   2.50     2.78 .14249E+02
 ** REGULATORY MIXING ZONE BOUNDARY is within the Near-Field Region **
 In this prediction interval the plume DOWNSTREAM distance meets or exceeds
 the regulatory value =     5.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
     26.17     0.00    2.50    60.8 0.988E+00   0.88    12.66 .45660E+03
     48.34     0.00    2.50    72.2 0.831E+00   0.73    20.60 .10026E+04
     70.52     0.00    2.50    82.0 0.731E+00   0.66    28.43 .16354E+04
     92.69     0.00    2.50    90.8 0.660E+00   0.61    36.30 .23443E+04
    114.86     0.00    2.50    98.9 0.607E+00   0.58    44.23 .31220E+04
    137.03     0.00    2.50   106.3 0.565E+00   0.55    52.24 .39628E+04
    159.20     0.00    2.50   113.2 0.530E+00   0.53    60.32 .48622E+04
    181.38     0.00    2.50   119.7 0.501E+00   0.51    68.48 .58168E+04
    203.55     0.00    2.50   125.9 0.477E+00   0.49    76.71 .68234E+04
    225.72     0.00    2.50   131.8 0.455E+00   0.48    85.02 .78795E+04
 Cumulative travel time =        7879.4526 sec  (    2.19 hrs)

END OF MOD251: DIFFUSER PLUME IN CO-FLOW
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** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  1.47 to conserve the mass flux in the far-field!
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BEGIN MOD241: BUOYANT AMBIENT SPREADING

 Profile definitions:
   BV = top-hat thickness, measured vertically
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   BH = top-hat half-width, measured horizontally in y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
   TT = Cumulative travel time

 Plume Stage 1 (not bank attached):
       X        Y       Z        S       C       BV      BH      ZU      ZL
TT
    225.72     0.00    2.50   131.8 0.455E+00   0.71   124.98    2.50    1.79
.78795E+04
    424.81     0.00    2.50   168.4 0.356E+00   0.63   179.87    2.50    1.87
.10990E+05
    623.91     0.00    2.50   219.6 0.273E+00   0.65   226.27    2.50    1.85
.14101E+05
    823.00     0.00    2.50   289.2 0.207E+00   0.72   267.85    2.50    1.78
.17211E+05
   1022.09     0.00    2.50   379.6 0.158E+00   0.83   306.33    2.50    1.67
.20322E+05
   1221.18     0.00    2.50   492.7 0.122E+00   0.96   342.60    2.50    1.54
.23432E+05
   1420.28     0.00    2.50   630.3 0.952E-01   1.12   377.19    2.50    1.38
.26543E+05
   1619.37     0.00    2.50   793.8 0.756E-01   1.29   410.43    2.50    1.21
.29654E+05
   1818.46     0.00    2.50   984.5 0.609E-01   1.49   442.56    2.50    1.01
.32764E+05
   2017.56     0.00    2.50  1203.8 0.498E-01   1.70   473.71    2.50    0.80
.35875E+05
   2216.65     0.00    2.50  1452.8 0.413E-01   1.93   504.03    2.50    0.57
.38986E+05
 Cumulative travel time =       38985.5078 sec  (   10.83 hrs)

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 Plume is ATTACHED to LEFT  bank/shore.
   Plume width is now determined from LEFT  bank/shore.

 Plume Stage 2 (bank attached):
       X        Y       Z        S       C       BV      BH      ZU      ZL
TT
   2216.65   504.00    2.50  1452.8 0.413E-01   1.93  1008.00    2.50    0.57
.38986E+05
   2256.40   504.00    2.50  1503.5 0.399E-01   1.98  1013.58    2.50    0.52
.39606E+05
   2296.14   504.00    2.50  1554.8 0.386E-01   2.04  1019.15    2.50    0.46
.40227E+05
   2335.89   504.00    2.50  1606.7 0.373E-01   2.10  1024.73    2.50    0.40
.40848E+05
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   2375.63   504.00    2.50  1659.2 0.362E-01   2.15  1030.31    2.50    0.35
.41469E+05
   2415.38   504.00    2.50  1712.3 0.350E-01   2.21  1035.88    2.50    0.29
.42090E+05
   2455.12   504.00    2.50  1766.0 0.340E-01   2.27  1041.46    2.50    0.23
.42711E+05
   2494.87   504.00    2.50  1820.3 0.330E-01   2.33  1047.03    2.50    0.17
.43332E+05
   2534.61   504.00    2.50  1875.3 0.320E-01   2.38  1052.60    2.50    0.12
.43953E+05
   2574.36   504.00    2.50  1930.8 0.311E-01   2.44  1058.17    2.50    0.06
.44574E+05
   2614.10   504.00    2.50  1987.0 0.302E-01   2.50  1063.73    2.50    0.00
.45195E+05
 Cumulative travel time =       45195.2812 sec  (   12.55 hrs)

END OF MOD241: BUOYANT AMBIENT SPREADING
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 Bottom coordinate for FAR-FIELD is determined by average depth, ZFB = -1.00m
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BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   = 0.230E-02 m^2/s
  Horizontal diffusivity (initial value) = 0.288E-02 m^2/s

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)
   TT = Cumulative travel time

 Plume Stage 2 (bank attached):
       X        Y       Z        S       C       BV       BH      ZU      ZL
TT
   2614.10   504.00    2.50  1987.0 0.302E-01   2.50  1063.73    2.50    0.00
.45195E+05
   7652.69   504.00    2.50  2783.2 0.216E-01   3.50  1064.07    2.50    0.00
.12392E+06
  12691.28   504.00    2.50  2784.1 0.216E-01   3.50  1064.40    2.50    0.00
.20264E+06
  17729.87   504.00    2.50  2785.0 0.215E-01   3.50  1064.73    2.50    0.00
.28136E+06
  22768.46   504.00    2.50  2785.8 0.215E-01   3.50  1065.07    2.50    0.00
```

```
.36008E+06
  27807.05   504.00    2.50  2786.7 0.215E-01   3.50  1065.40    2.50    0.00
.43881E+06
  32845.64   504.00    2.50  2787.6 0.215E-01   3.50  1065.74    2.50    0.00
.51753E+06
  37884.23   504.00    2.50  2788.5 0.215E-01   3.50  1066.07    2.50    0.00
.59625E+06
  42922.82   504.00    2.50  2789.3 0.215E-01   3.50  1066.40    2.50    0.00
.67497E+06
  47961.41   504.00    2.50  2790.2 0.215E-01   3.50  1066.74    2.50    0.00
.75370E+06
  53000.00   504.00    2.50  2791.1 0.215E-01   3.50  1067.07    2.50    0.00
.83242E+06
 Cumulative travel time =      832418.0000 sec  (  231.23 hrs)

Note:
CORMIX is a steady state model and assumes discharge and ambient conditions do not
vary
 over time. The predicted plume cumulative travel time exceeds 48 hours at this
trajectory
 distance. Keep in mind that ambient and discharge conditions are likely to vary
over
 large space and time scales. Predictions at such large space and time scales may
be
 inconsistent with CORMIX modeling assumptions.

Please carefully evaluate your simulation results and limit model interpretation to
space
 and time scales consistent with steady state assumptions and ambient
schematization.

 Simulation limit based on maximum specified distance =  53000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
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CORMIX2: Multiport Diffuser Discharges       End of Prediction File
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