Hydraulic Modelling Note – Saltend Power Station

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For: Triton Power

Site: Saltend Power Station

Date: 25/11/2025

Document Ref: 313047-REP-001

Issue-00

www.arthian.com

Quality Assurance

Issue Record

Revision	Description	Date	Author	Reviewer	Approver
00	Initial issue	25 November 2025	DH	JR	JR

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1. Introduction

1.1 Acknowledgement

1.1.1 This report has been prepared for the sole and exclusive use of Triton Power in accordance with the scope of work presented via email by Arthian (formerly Mabbett & Associates), dated 04/07/2023. This report is based on information and up-to-date data collected by Arthian following instruction to proceed. Should any of the information be incorrect, incomplete, or subject to change, Arthian may wish to revise the report accordingly.

1.1.2 Arthian has been instructed to provide hydraulic modelling to quantify the impact of raising the temperature of cooling system discharge from Saltend Power Station into the King George Dock on the local ecology in order to support an application for a permit variation.

1.2 Project Understanding

1.2.1 Saltend Power Station, Hull, currently holds a permit to discharge point source emissions from cooling systems to water at ambient temperature +8°C, up to a maximum of 28°C. Recent heatwaves have resulted in several instances where discharge has not been possible. Given the prediction that ambient temperatures are to rise and heatwaves to become more common in future years an application for a permit variation to allow discharge at temperatures up to 32°C is being prepared by Crestwood Environmental Ltd.

1.2.2 Thermal hydraulic modelling of the point source emissions into the King George Dock is necessary to quantify the potential ecological impacts within the King George Dock and the Humber Estuary as a result of increasing the temperature of the discharge and to inform the proposed permit variation. Saltend Power Station have also requested that the ecological impacts of discharge up to 40°C (if any) are evaluated in order to future-proof any permit variations.

1.2.3 The primary focus of this report is to detail the model build and testing. The Environmental Interpretations Report[1] should be consulted for in-depth analysis of the impact of any changes in discharge temperature on the local ecology. A copy of this report is provided in Appendix A.

1.3 Project Limitations

1.3.1 The wider Arthian limitations are contained within Appendix B.

[1] APEM (2024). Saltend Power Station Thermal Discharge: Environmental interpretations. APEM Report P00012515. Mabbett & Associates Ltd, November 2024, v1.0, 43 pp.

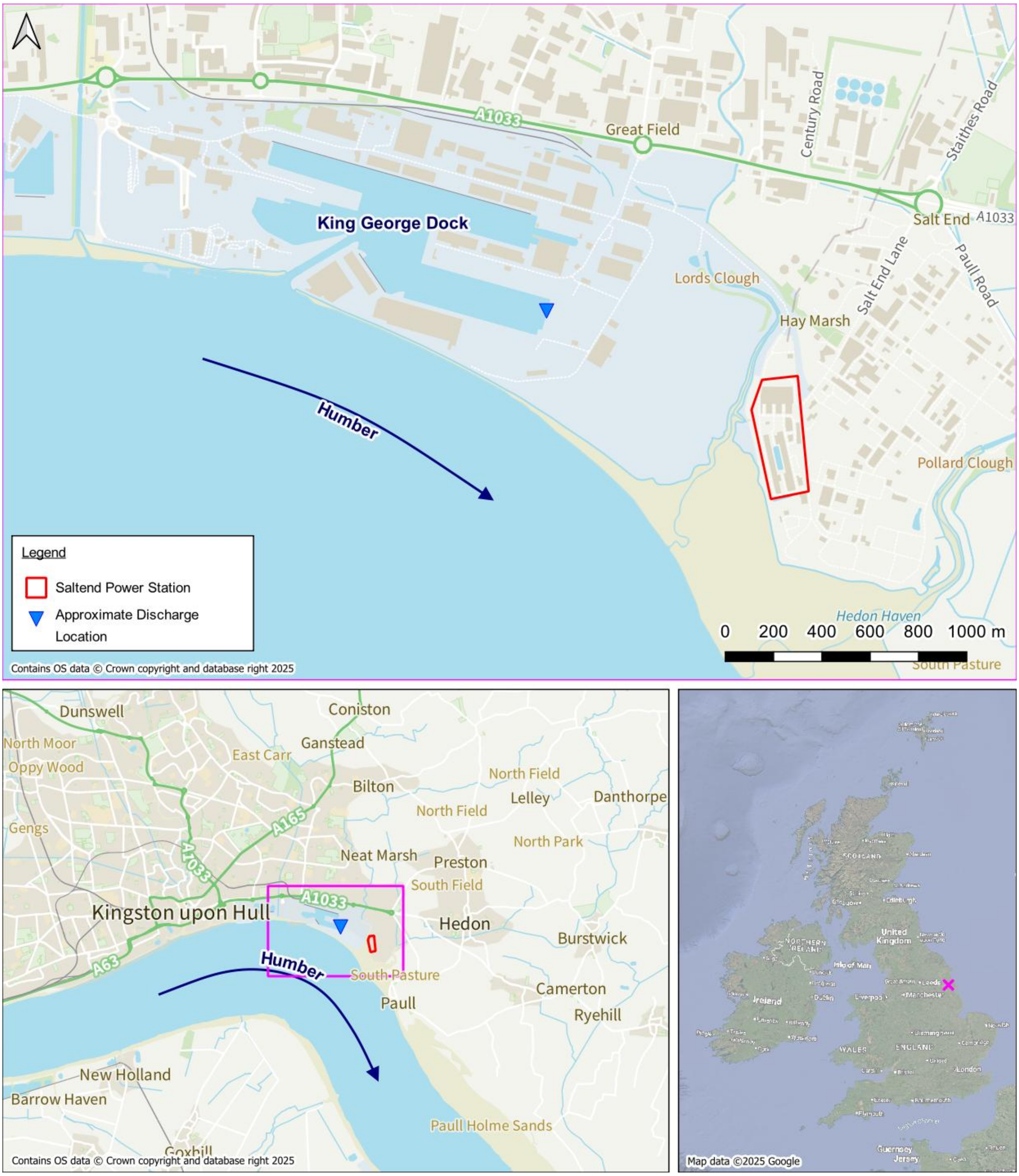


Figure 1: Site location

2. Model Build

2.1 Model Setup and Updates

Table 1: Model details, methodology, and parameters

Arthian Model Reference and Version:	313047_SPS_v10
Simulation Type:	Thermal discharge
Model Type:	3D Salinity, temperature, and heat modules enabled Spatial Order == 1,2 *(horizontal, vertical)*
Software Builds:	TUFLOW FV 2023.1.1 *(latest build available at the time of simulation)*
Model Extent:	The extent of the model is shown in Figure 2.
DTM Data Sources:	EA LiDAR data dated between September 2007 and November 2021 has been used as a base for the model, primarily to form the riverbanks and mostly overwritten with more appropriate in-channel levels. EA coastal bathymetry dated 2019 is used to inform in-channel bed levels where available. A bathymetric survey of King George Dock was undertaken by APEM in December 2023.
Mesh Development and Setup:	A mesh was developed using GIS Mesher 2023.01, with a default mesh size of $50m^2$, and breaklines used to adjust cell sizes to between $225m^2$ (15 x 15m) through the dock and lock gates and $10{,}000m^2$ (100 x 100m) across the Humber Estuary as required. The DTM sources were stamped on top of each other, with the 2023 bathymetric survey of King George Dock taking precedence, followed by the 2019 EA coastal bathymetry data, and finally 2022 EA National LiDAR Programme DTM data (1m resolution). Uniform roughness was applied throughout given the aims of the model did not involve simulation of overland flows – Manning's 'n' set to $0.03s/m^{1/3}$. **Key Mesh Parameters** Vertical Mesh Type == Z Surface Sigma Layers == 8 Cell 3D Depth == 1.0 Min Bottom Layer Thickness == 1

Boundary Conditions:	Tidal boundary conditions were applied at the upstream and downstream extents of the model using nodestrings. To avoid the need to model an unnecessary length of the Humber Estuary, a simplified boundary approach was adopted. This approach represents the dominant tidal dynamics while keeping the computational domain focused on the area of interest. At the downstream boundary, an astronomical tide curve was generated using softwarr “POLTIPS 3” for the standard port, Hull, for the year 2023 (year at the start of the model build). Storm surge effects were not considered, as suitable concurrent storm-tide datasets are not available for the required period and as the primary purpose of the boundary is to reproduce the principal tidal oscillation and associated bidirectional flows, which is sufficient for assessing thermal behaviour under representative tidal conditions. Ambient temperature data for 2023 was extracted from the Copernicus ERA5 Ocean Reanalysis (ERA5-Ocean) Dataset dataset using TUFLOW’s “get_atmos” utility. A separate preliminary model was developed to quantify a representative relationship between atmospheric and water temperatures. This enabled the spatially-variable water temperatures to be applied consistently to the tidal boundary conditions throughout the year. For the upstream tidal boundary, the same tide curve was applied but time-shifted to reflect the average travel time of the tidal wave between the two boundary locations. This approach captures the phase difference in the tidal signal without the need for a full hydrodynamic characterisation of the entire Humber Estuary, which is considered commensurate for the scope and scale of the modelling exercise. The resulting boundary conditions reproduce realistic ebb and flood patterns while keeping the modelling framework appropriately targeted on King George Dock and the immediate estuary system.
Structures:	Operational data on lock-gate opening times at King George Dock were requested from the port operators, but none were available. Because gate operation influences local circulation, a representative opening schedule was introduced to reflect typical vessel-driven activity. In the absence of formal records, a synthetic regime was created by applying a 15-minute opening at randomly selected times within two-hour intervals between 05:00 and 19:00 each day. This provides a reasonable approximation of normal daytime, intermittent operation without relying on undocumented timings. The intention is not to reproduce exact gate behaviour but to ensure that the model captures realistic episodic exchanges between the dock and the Humber Estuary. This allows the thermal and hydrodynamic effects of such events to be represented for assessment purposes. Within the model, lock gates were implemented as nodestring boundaries with water levels raised and lowered during opening periods. TUFLOW FV does not currently support explicit gate mechanics within 3D domains, so this approach reproduces the hydraulic effect of gate operation rather than its physical mechanics. This limitation does not affect the suitability of the model for assessing the influence of gate-driven exchanges.
Cooling System Discharge:	Following discussions with the client, an upper limit of 2000m^3 of point-source discharge within any 12-hour period was confirmed. Although actual daily volumes may be lower, this maximum rate (≈46.3L/s) was applied continuously between 8am and 8pm each day for the full simulation. Discharge temperature was varied in line with each modelled scenario.

Timestep:	Timestep Limits == 0.1, 10 *(seconds)* TUFLOW FV uses an adaptive timestepping process to maintain model stability. CFL == 0.8 *(Courant–Friedrichs–Lewy condition – limit timestep so characteristic wave travel stays under one cell)*
Initial Conditions:	Restart file applied throughout for all simulations – generated based on output of a separate warm up simulation which gradually filled the Humber Estuary and King George Dock to the required levels.
Key Simulation Parameters:	**General** Cell Dry/Wet Depths == 0.01, 0.02 *(Cell wetting and drying depths in metres)* **Horizontal Turbulent Mixing** Momentum Mixing Model == Smagorinsky *(Horizontal eddy viscosity calculation method)* Global Horizontal Eddy Viscosity == 0.4 *(Constant horizontal eddy viscosity in m^2/s)* Global Horizontal Eddy Viscosity Limits == 0.05, 99999 *(Minimum and maximum horizontal eddy viscosity limits in m^2/s)* **Horizontal Scalar Mixing** Scalar Mixing Model == Smagorinsky *(Scalar mixing calculation method)* Global Horizontal Scalar Diffusivity == 0.2 *(Horizontal diffusivity in m^2/s)* Global Horizontal Scalar Diffusivity Limits == 0.05, 99999 *(Minimum and maximum horizontal diffusivity limits in m^2/s)* **Vertical Mixing** Vertical Mixing Model == External *Vertical momentum and scalar mixing model – set to General Ocean Turbulence Model* Global Vertical Eddy Viscosity Limits == 0.0001, 1 *(Minimum and maximum vertical eddy viscosity limits in m^2/s)* Global Vertical Scalar Diffusivity Limits == 0, 1 *(Vertical diffusion limits in m^2/s)* Turbulence Update dt == 1800 *(Frequency of vertical turbulence mixing, eddy-viscosity, and scalar-diffusivity term updates)*
Non-Default Parameters:	No non-standard parameter changes required.
Further Comments:	-

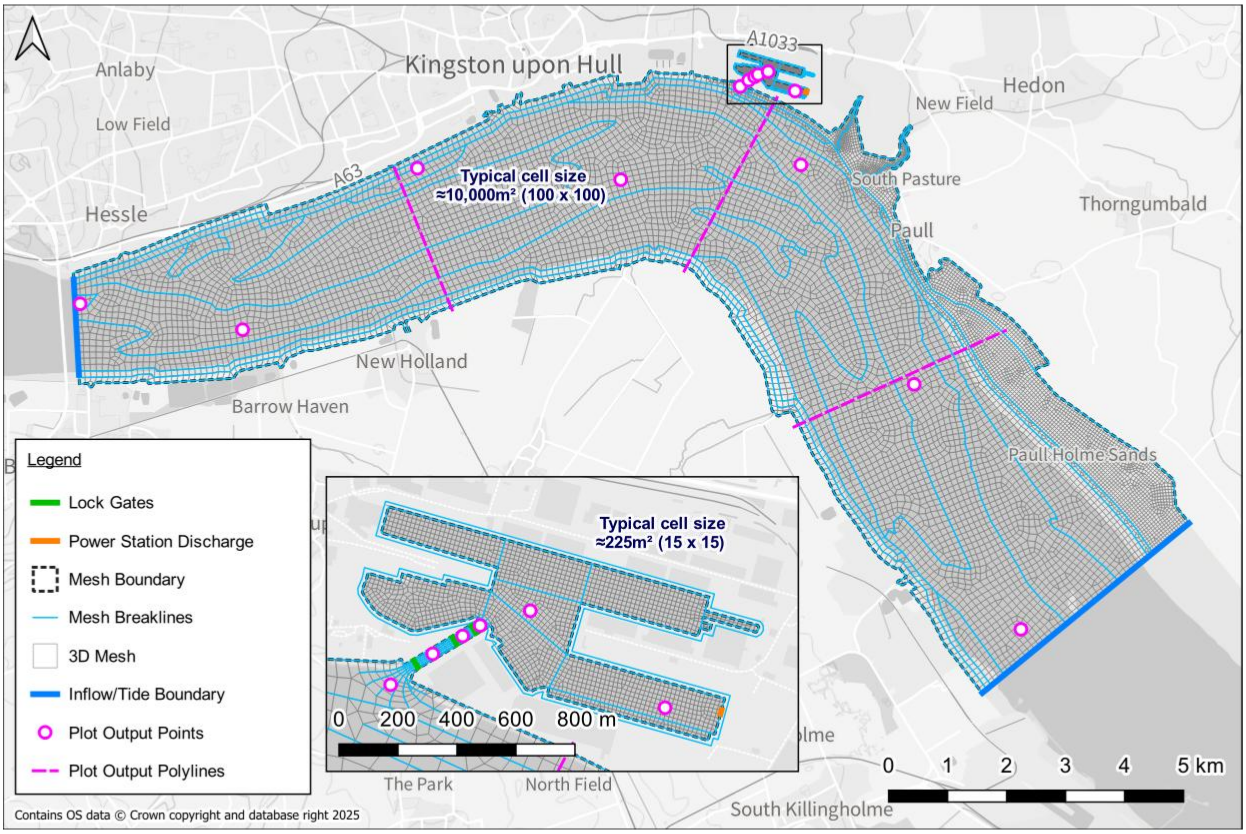


Figure 2: Model extent

2.2 Simulated Scenarios

2.2.1 The model was used to simulate a range of potential discharge temperatures ranging from the current permitted temperature of 28°C, up to 40°C, as well as a "no discharge" scenario for reference.

2.3 Model Assumptions and Limitations

2.3.1 The 3D thermal–hydrodynamic model has been developed using industry-standard methods and in accordance with current EA modelling expectations for estuarine assessments. The model is designed to provide a proportionate assessment of thermal behaviour in King George Dock and the Humber Estuary. As with all hydro-thermodynamic models, several simplifications were required, however, none are expected to materially affect the conclusions of this study.

1) Tidal Boundary Conditions

Upstream and downstream tidal boundaries use astronomical tide curves with a phase shift rather than modelling the full Humber. This captures the dominant tidal forcing that controls flushing and mixing. Given the scale of the assessment and the focus on routine operational conditions, the simplified approach is appropriate and does not limit the validity of the results.

2) Ambient Temperature Representation

Boundary water temperatures were derived from ERA5 reanalysis data linked to water temperature via a preliminary model. While this cannot reproduce all short-term local thermal variability, it provides a stable, seasonally representative signal suitable for assessing plume behaviour over long simulation periods.

3) Lock-Gate Operations

In the absence of operational records, a representative synthetic opening schedule was used to ensure the dock–estuary exchange is reflected in the model. Gate opening was implemented hydraulically via nodestring level changes due to current TUFLOW FV 3D limitations. This approach captures the hydraulic effect of episodic exchanges and is sufficient for evaluating thermal dispersion.

4) Bathymetry and Topography

Geometry is based on a composite of recent surveys and EA datasets, with refinement concentrated in key areas. While fine-scale structural detail is not resolved, the mesh adequately captures the form and connectivity of the system relevant to tidal flows and temperature mixing.

5) Surface Roughness

A uniform Manning's 'n' roughness coefficient was applied as the assessment does not hinge on fine-scale bed resistance. At estuary scale, tidal mixing dominates over small variations in roughness, and roughness is not expected to materially alter plume behaviour or overall hydrodynamics.

6) Turbulence and Mixing Representation

Standard Smagorinsky horizontal mixing and GOTM vertical turbulence schemes have been applied. These provide realistic mixing behaviour for estuarine-scale processes; unresolved micro-turbulence effects occur at scales far below the thermal footprint being assessed.

7) Discharge Representation

A conservative maximum daily discharge rate was applied consistently. This intentionally errs on the side of higher thermal loading, ensuring that the model provides a robust upper-bound assessment of potential impacts.

8) Initial Conditions

The model was initialised using a warm-up restart file. This ensures a dynamically stable state, and any residual differences in antecedent temperatures or stratification are negligible compared to tidal mixing.

2.4 Model Health and Verification

2.4.1 A review of the simulation logs and diagnostic outputs shows that no spatial warnings or message features were generated for any run, indicating that the solver operated without instability events.

2.4.2 Timesteps remained within a sensible range throughout (never falling below approximately 0.2 seconds), and water levels, velocities, and circulation patterns were stable across all simulations.

2.4.3 In the absence of observed thermal data for comparison, formal validation of water temperature is not possible; however, the numerical behaviour of the model is sound, and the consistency of hydrodynamic and thermal responses across scenarios provides confidence in the robustness of the simulations.

2.5 Results Summary

2.5.1 To support the Environmental Interpretations Report, the results presented in the following section focus on the temperature thresholds and compliance metrics requested, including absolute temperature limits, uplift limits, and relevant percentile statistics for WFD TraC waters, European marine sites (SPA and SAC), shellfish waters, and the assessment of potential thermal barriers to fish movement. The requested statistics are provided in Table 2.

Table 2: Temperature thresholds informing the assessment

Absolute Threshold at Edge of Mixing Zone	Uplift Above Ambient	Relevant Statistic	Applicable To	Requirement / Rationale	Modelling Output Required
23°C	/	Annual 98th percentile	WFD TraC waterbody	Absolute temperature must not exceed 23°C at the 98%ile.	98%ile absolute temperature (surface and bed); plan showing areas ≥23°C for baseline (28°C) and maximum scenario (40°C) if relevant.
/	+3°C	Annual 98th percentile	WFD TraC waterbody	Uplift above natural background must not exceed 3°C for more than 2% of the year.	98%ile temperature rise (surface and bed); plan showing areas with >3°C uplift from true ambient (no-discharge background).
28°C	/	Annual 98th percentile	SPA (European marine site)	Absolute temperature at edge of mixing zone must not exceed 28°C at the 98%ile.	98%ile absolute temperature outputs with 28°C threshold applied.
/	+2°C	Maximum (MAC)	SPA	Maximum uplift must not exceed 2°C.	Maximum temperature rise (surface and bed).
21.5°C	/	Annual 98th percentile	SAC (where designated for estuary/embayment habitat or salmonids)	Absolute temperature must not exceed 21.5°C at the 98%ile.	98%ile absolute temperature outputs with 21.5°C threshold applied.
/	+2°C	Maximum (MAC)	SAC	Maximum uplift must not exceed 2°C.	Maximum temperature rise (surface and bed).

Absolute Threshold at Edge of Mixing Zone	Uplift Above Ambient	Relevant Statistic	Applicable To	Requirement / Rationale	Modelling Output Required
/	+2°C	Annual 75th percentile	Shellfish waters (WFD protected area)	Uplift must not exceed 2°C for at least 75% of samples.	75%ile uplift (surface and bed), if plume extends into shellfish waters.
/	+2°C across >25% of channel	Annual 98th percentile	Migratory fish (thermal barrier assessment)	Mixing zone must not occupy >25% of channel cross-sectional area at 98%ile conditions.	Cross-sections showing 98%ile uplift distribution; only required if plume extends significantly across channel.
/	/	Annual 99th percentile	Potential EA requirement	Included in EA pre-application discussions; not required for current assessment.	None

2.5.2 The results of all thermal–hydrodynamic simulations, presented in Figure 3 to Figure 10, consistently demonstrate that the proposed discharge has a negligible influence on water temperatures within King George Dock or the wider Humber Estuary. Across all scenarios, including the maximum 40°C discharge case, temperature patterns within the dock and estuary are overwhelmingly governed by ambient seasonal conditions, tidal mixing, and estuarine circulation rather than by the discharge itself. The plume remains highly localised, rapidly diluted, and does not materially alter the background thermal regime under any modelled condition.

2.5.3 Given the consistency of these outcomes across baseline, elevated temperature, and no discharge scenarios, the model results are considered conclusive. The assessment has been undertaken using conservative assumptions for discharge volume, discharge temperature, ambient conditions, and operational behaviour, and the negligible thermal response observed under these upper-bound conditions demonstrates that the system is overwhelmingly controlled by natural tidal and seasonal processes. As such, there is no technical or regulatory justification for further refinement of the model inputs, boundary conditions, or scenario design, as any additional modelling would not alter the conclusion that the discharge produces no material thermal impact within King George Dock or the Humber Estuary.

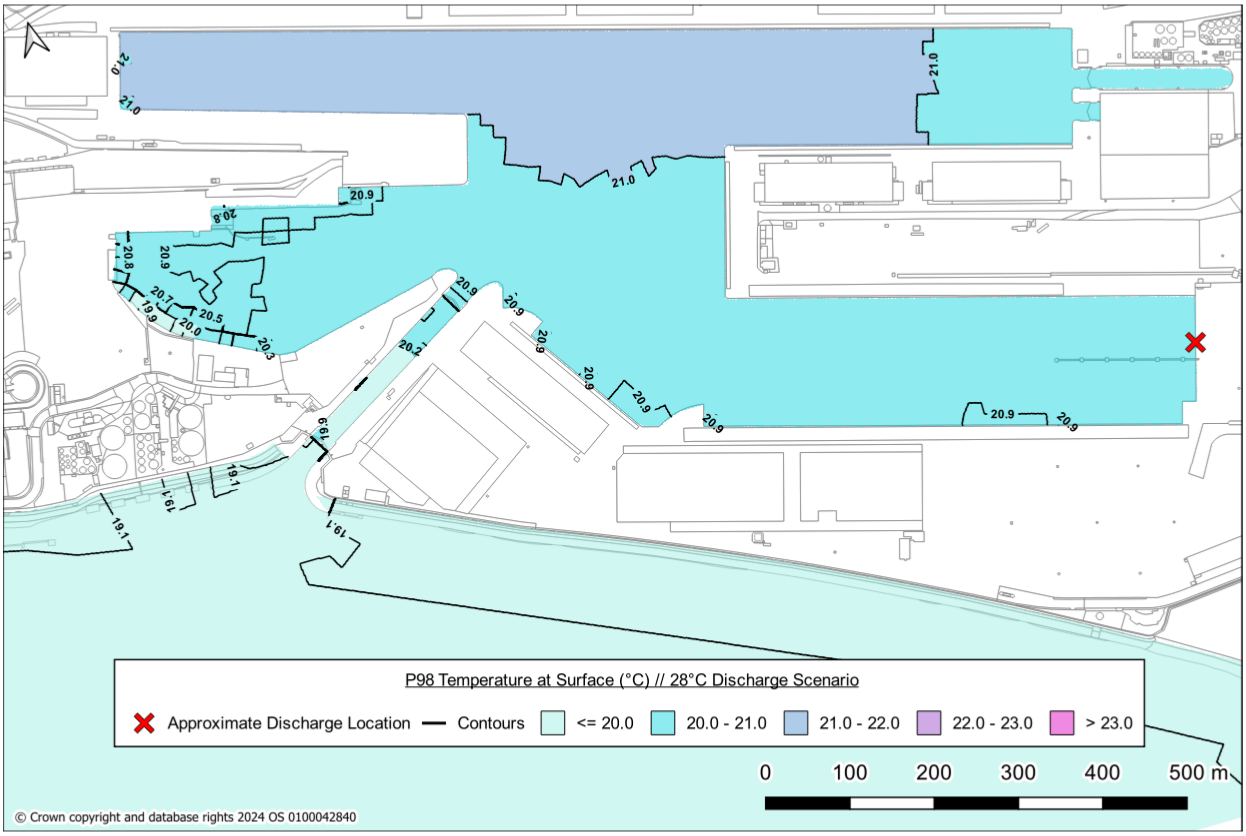


Figure 3: 98th %ile temperatures (surface), 28°C discharge scenario (baseline)

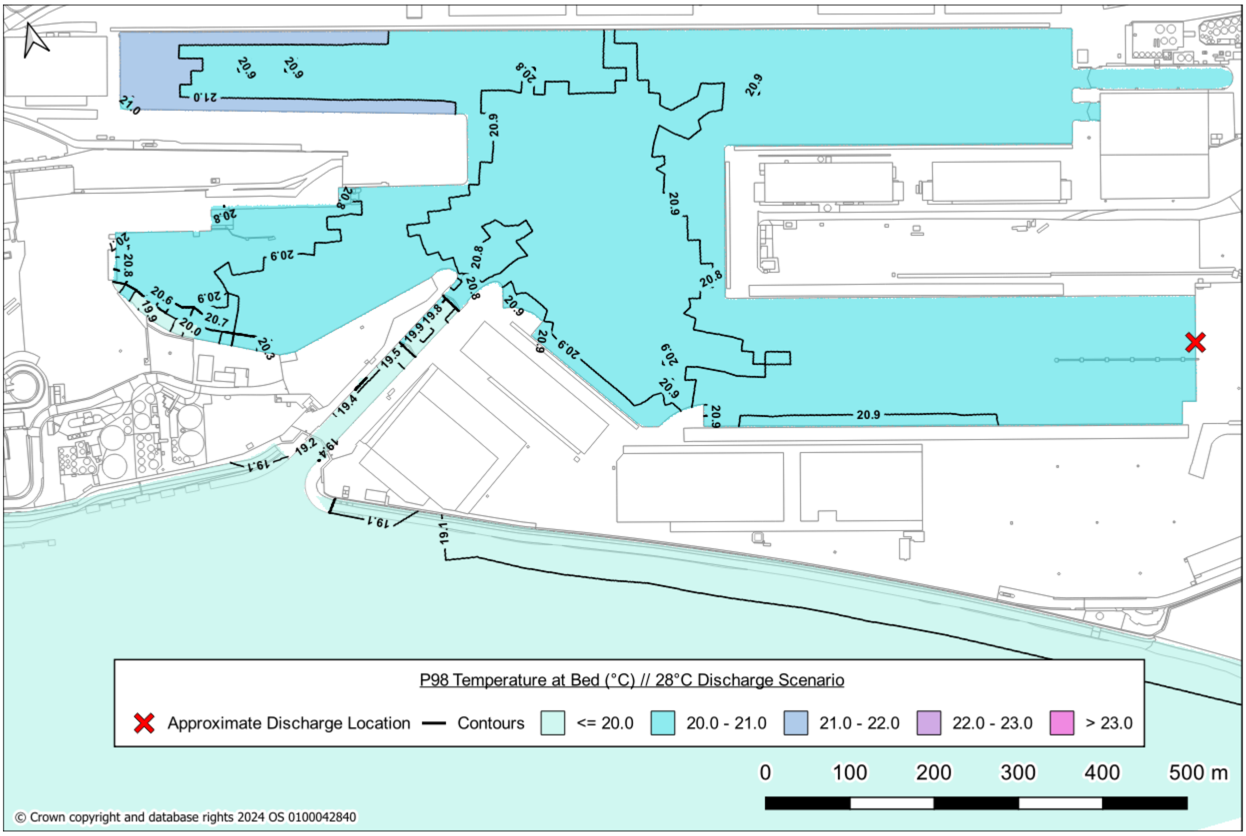


Figure 4: 98th %ile temperatures (dock bed), 28°C discharge scenario (baseline)

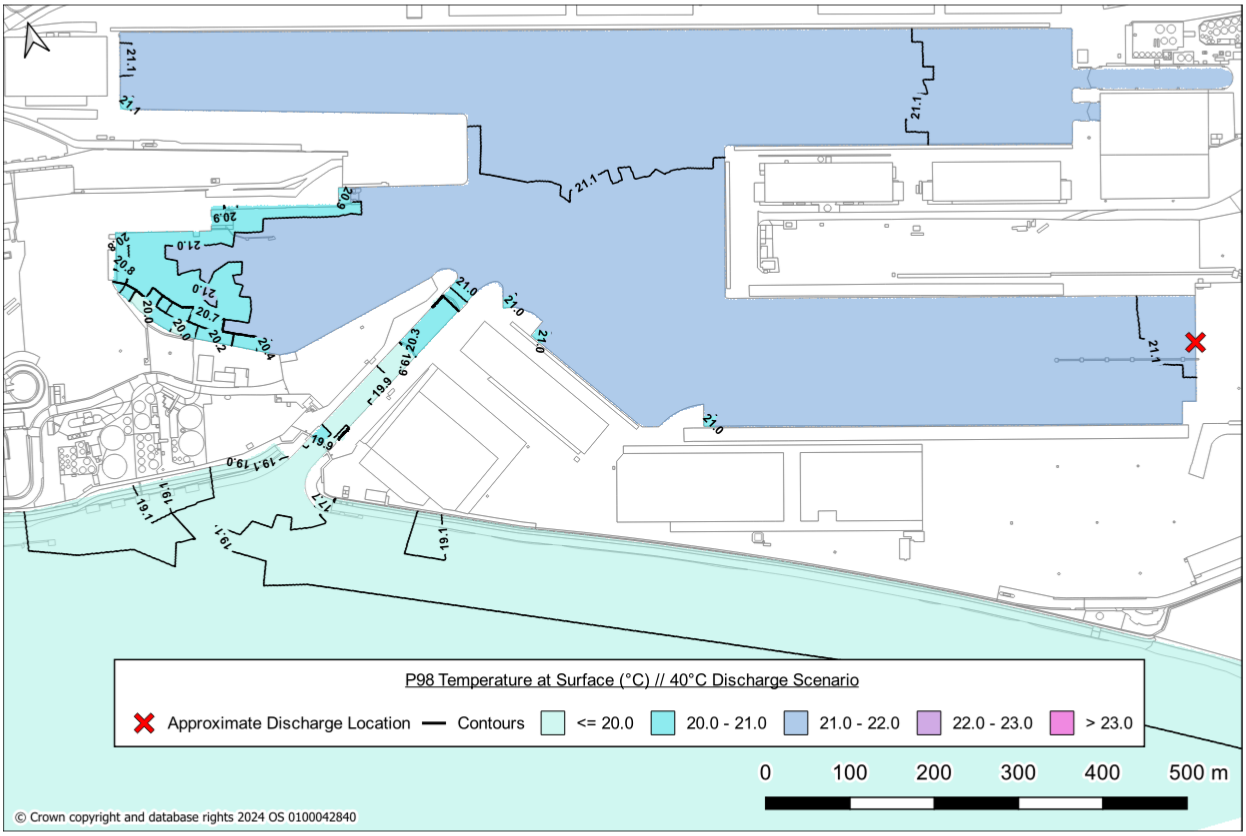


Figure 5: 98th %ile temperatures (surface), 40°C discharge scenario

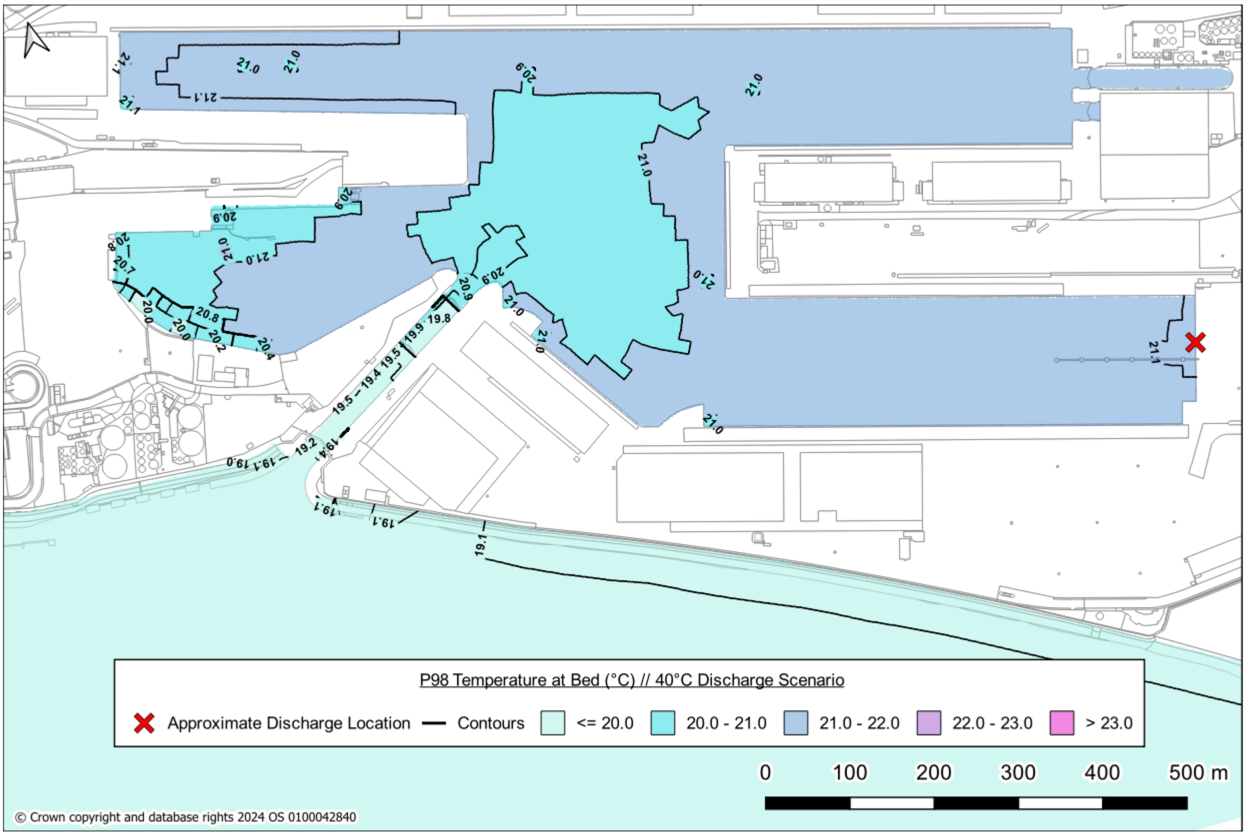


Figure 6: 98th %ile temperatures (dock bed), 40°C discharge scenario

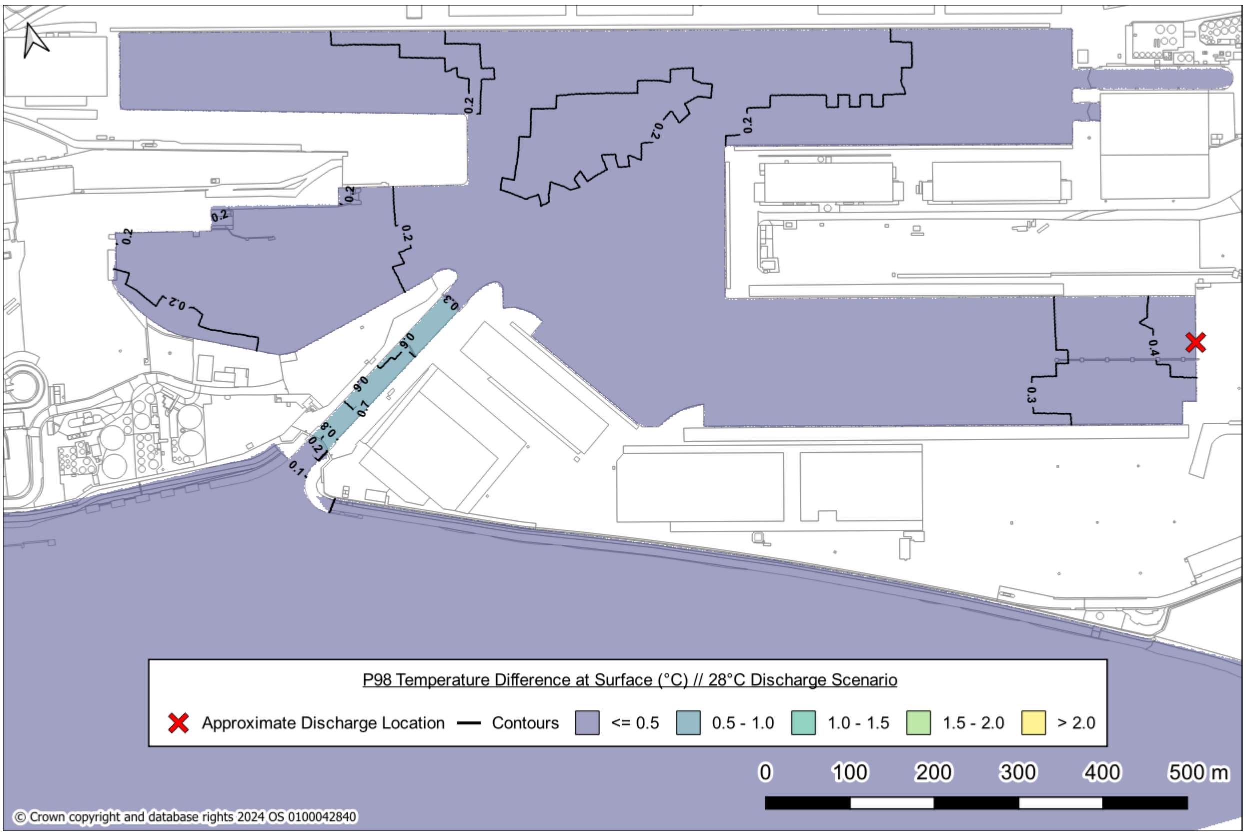


Figure 7: Difference in 98th %ile temperatures, 28°C discharge vs no discharge

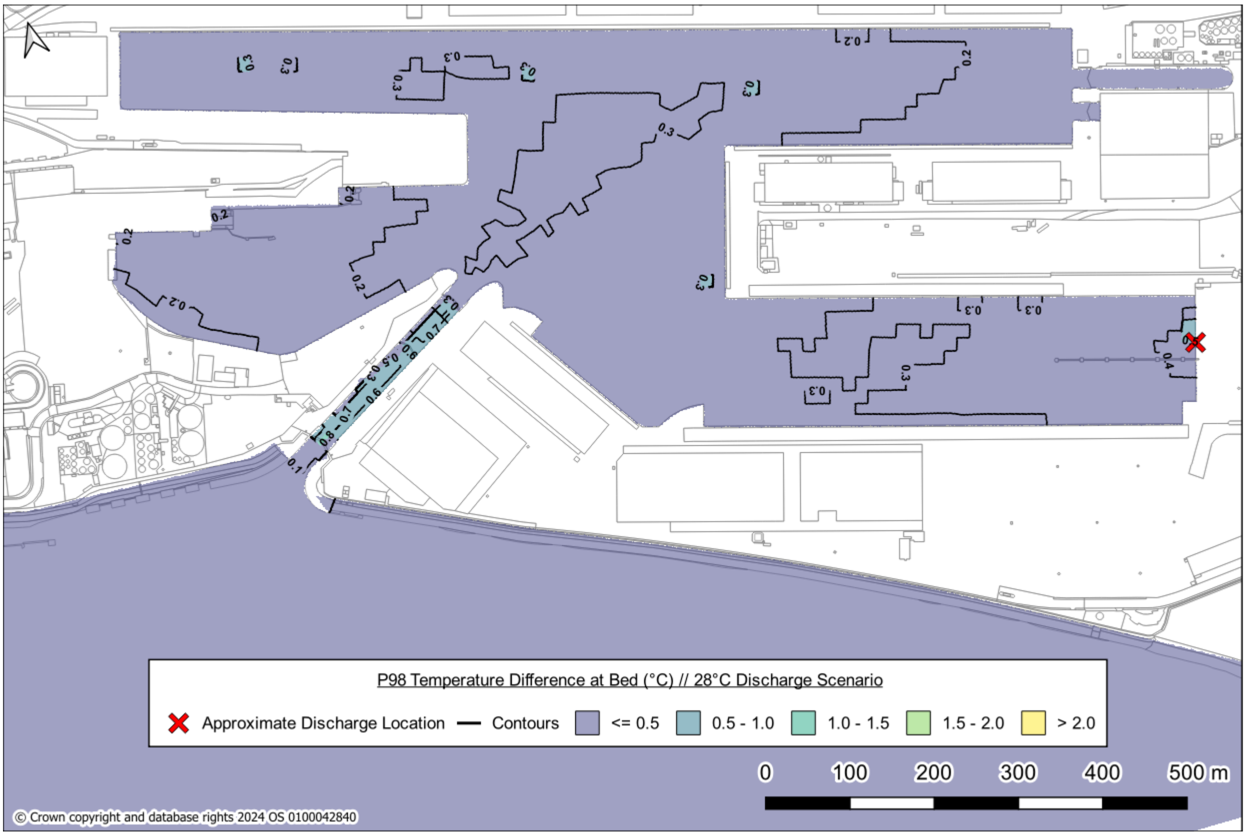


Figure 8: Difference in 98th percentile temperatures (dock bed), 28°C discharge vs no discharge)

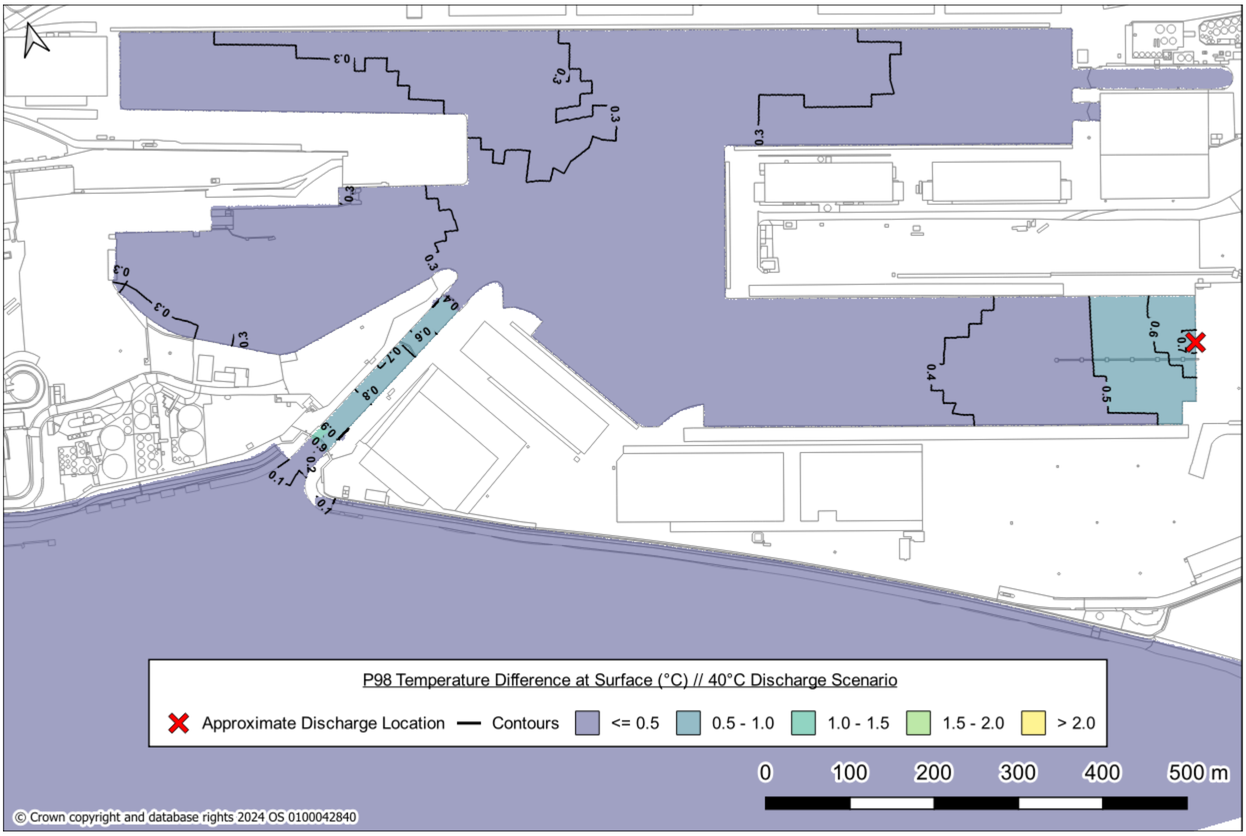


Figure 9: Difference in 98th %ile temperatures (surface), 40°C discharge vs no discharge

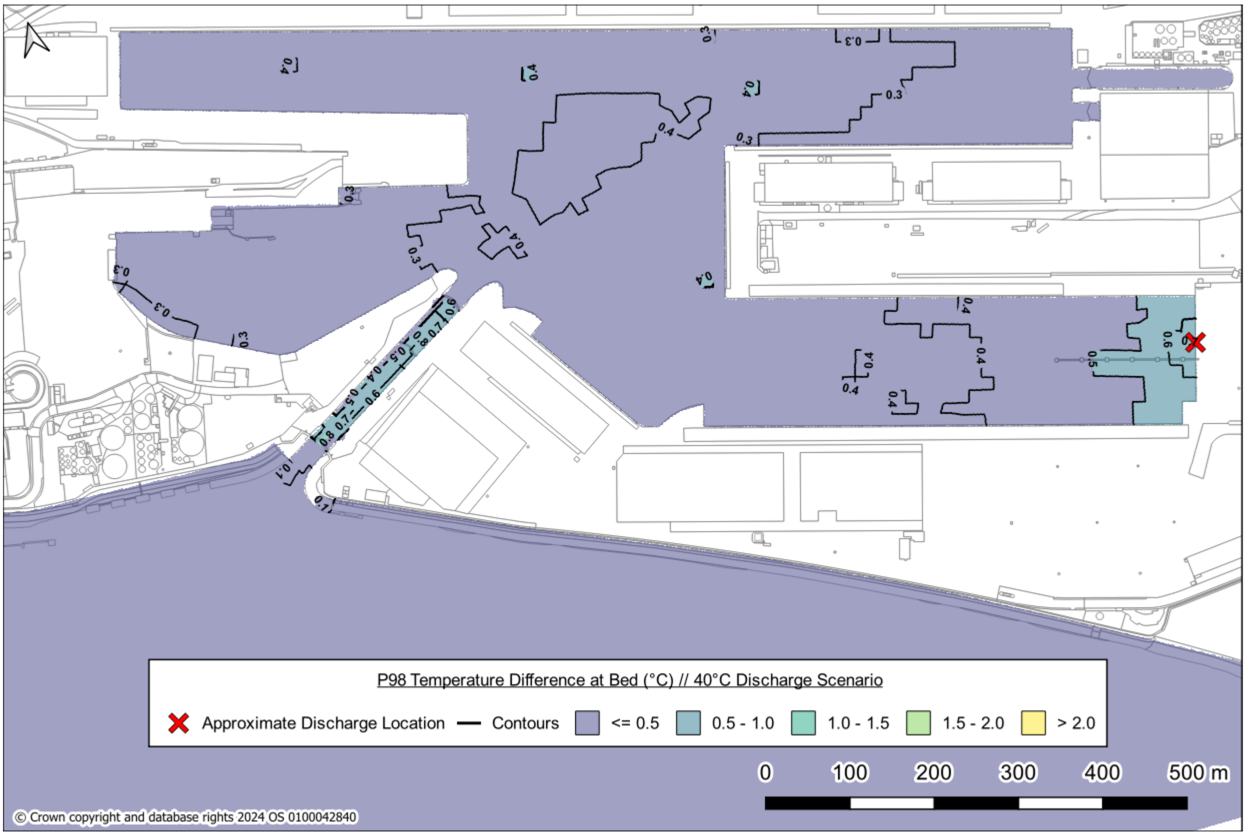


Figure 10: Difference in 98th %ile temperatures (dock bed), 40°C discharge vs no discharge

3. Conclusions and Recommendations

3.1 Conclusions

3.1.1 A bespoke 3D thermal–hydrodynamic TUFLOW FV model of King George Dock and the Humber Estuary has been developed using industry-standard methods to assess the potential effects of increasing the permitted discharge temperature from Saltend Power Station. The model incorporates full tidal dynamics, stratified mixing, seasonal ambient temperature variability, and a representative operational schedule for the lock gates.

3.1.2 Across all scenarios, including the highest-temperature discharge case (40°C), model results show that the thermal plume remains highly localised within the dock with negligible impact to the estuary. Ambient seasonal temperature variations and tidal mixing dominate the thermal regime, with the discharge contributing only a very small increase in water temperature in the immediate vicinity of the outfall.

3.1.3 Key ecological thresholds, including absolute temperature limits, uplift limits above ambient, and percentile-based compliance metrics for WFD TraC waters, SPA and SAC designations, and thermal-barrier considerations, are met comfortably for all simulated scenarios. No scenario results in exceedance of the 23°C, 28°C, or 21.5°C absolute temperature thresholds at the edge of the mixing zone, nor any exceedance of the 2–3°C uplift criteria.

3.1.4 Thermal responses within the Humber Estuary are overwhelmingly governed by tidal state, meteorological conditions and natural estuarine circulation rather than the temperature of the power-station discharge. Spatial patterns, plume extents and percentile statistics remain consistent across all tests, indicating that variations in discharge temperature between 28°C and 40°C do not materially influence the estuary-scale thermal environment.

3.1.5 Model diagnostics, including mass balance, timestep stability, and absence of instability messages, confirm that the simulations are numerically robust.

3.1.6 Based on the modelling undertaken, it is concluded that increasing the discharge limit to 32°C (and assessing up to 40°C for future-proofing) would have a negligible effect on water temperatures in King George Dock or the Humber Estuary. The proposed permit variation is therefore unlikely to result in measurable ecological impacts within the assessed waterbodies.

3.2 Recommendations

3.2.1 The modelling undertaken for this assessment provides a robust basis for understanding the thermal behaviour of the Saltend Power Station discharge within King George Dock and the Humber Estuary. The results show that the discharge has a negligible effect on local or estuary-scale temperatures, even under the upper-bound 40°C scenario. These findings can be used with confidence to support the proposed environmental permit variation.

3.2.2 No further hydraulic or thermal modelling is considered necessary for the purposes of the permit variation application. The simulations already represent a conservative, upper-bound assessment of thermal loading, and additional model refinements would be unlikely to change the overall conclusions.

3.2.3 If operational conditions, cooling-system design, or future discharge volumes were to change materially, it may be appropriate to revisit the modelling. However, the very limited thermal footprint observed in all scenarios suggests that only substantial changes in discharge magnitude or duration would warrant re-assessment.

3.2.4 The ecological implications of the results should be interpreted alongside the accompanying Environmental Interpretations Report (Appendix A). That report consolidates the thermal outputs against the relevant WFD, SPA, SAC, shellfish-water and thermal-barrier thresholds, all of which are comfortably met in the current analysis.

3.2.5 Stakeholder engagement with the Environment Agency should highlight the consistency of the thermal response across scenarios, the dominance of tidal and ambient processes, and the demonstrably negligible influence of the elevated discharge temperature. These factors collectively support the case for granting the permit variation.

Appendices

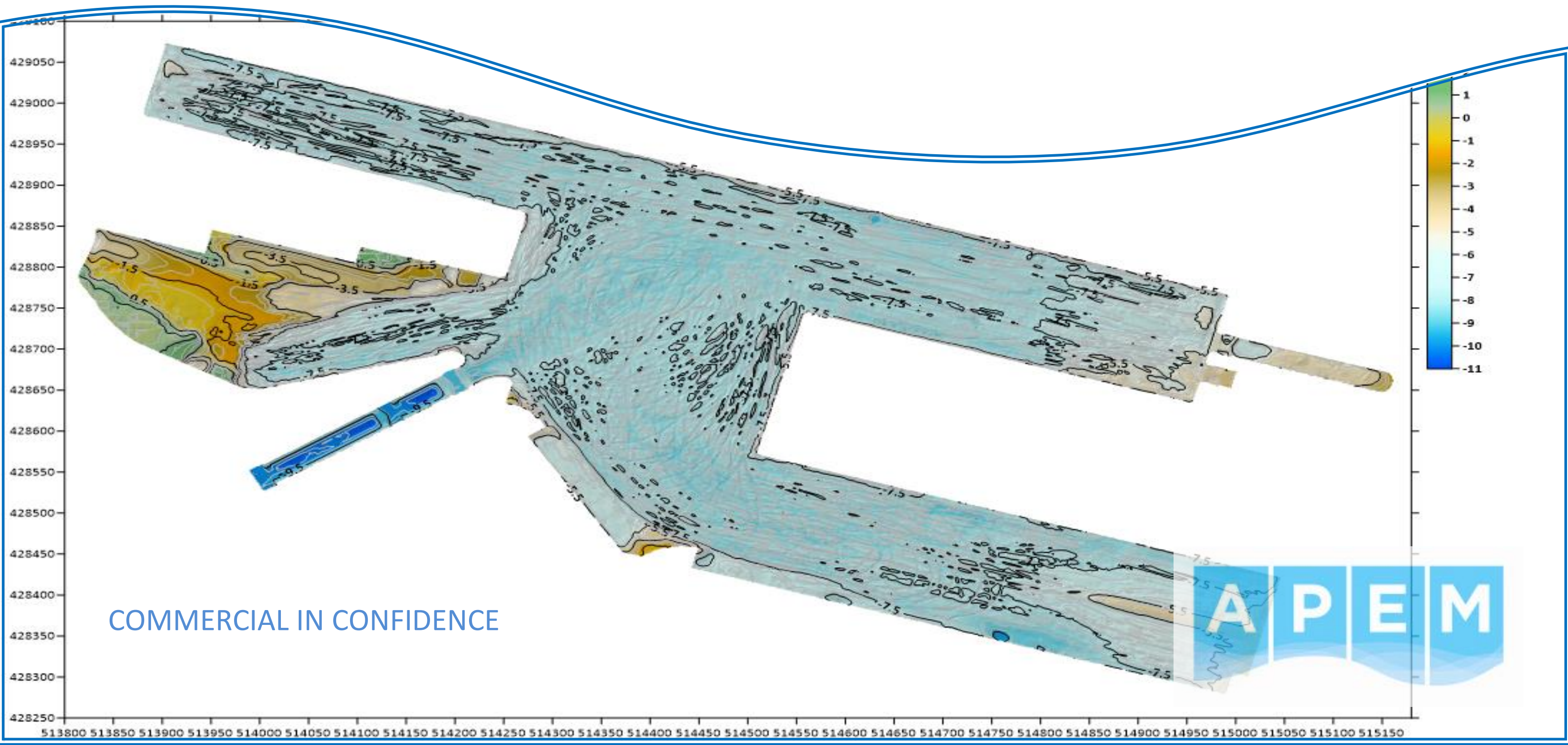
Appendix A – Environmental Interpretations Report

Mabbett & Associates Ltd

Saltend Power Station Thermal Discharge:

Environmental interpretations

Richard Wells, Richard McCulloch



COMMERCIAL IN CONFIDENCE

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Report should be cited as:

"*APEM (2024). Saltend Power Station Thermal Discharge: Environmental interpretations. APEM Report P00012515. Mabbett & Associates Ltd, November 2024, v1.0, 43 pp.*"

Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
1.0	29.11.24	/	/	Issue	RW

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1. Introduction

1.1 Project background

Mabbett & Associates Ltd (Mabbett) have been commissioned to undertake thermal modelling of proposed/scenario discharges from Saltend power station near Hull into the nearby docks (and subsequent Humber Estuary).

The power station's existing permit allows discharge at ambient temperatures +8°C, up to 28°C. During the summer of 2022 the maximum permitted discharge was reached, which meant that the discharge had to be halted, increasing the risk of legionella pneumophila build up in the cooling towers. With the expectation that elevated summer temperatures are only going to become more commonplace, the power station wishes to apply for a revised permit to discharge with an increased maximum temperature threshold. The power station has undertaken pre-application consultations with the Environment Agency (EA), who have requested additional supporting information on the potential impact of this permit change on the physicochemical properties of the water body and the associated biology/ecology.

1.2 APEM scope

APEM undertook an upfront bathymetric survey of the King George's dock to provide high resolution bathymetric data to inform Mabbett's model build. Bathymetric survey methods and data are reported separate to this report.

In parallel with the bathymetric survey APEM undertook a single water quality survey campaign of in-situ parameters from within the dock (**Section 3.2**), to supplement background water quality data which are available for the wider River Humber (**Section 3.1**).

Further to the survey elements above, APEM were requested to interpret the Mabbett thermal modelling results in the context of relevant environmental temperature thresholds.

This report presents a review of Mabbett's modelling outputs in the context of direct thermal thresholds, along with a systematic, albeit rapid (proportional to the scale of the predicted changes) desk-based assessment of the potential for thermal impact on the designated species that are associated with the various Estuarine designations (which would directly inform any future HRA Stage 2 assessment should this separately be required).

This report also presents an indirect thermal water quality assessment, limited to dissolved oxygen (DO) and ammonia, based on worst case / enveloping assumptions and combinations of summary statistics from the temperature modelling outputs (Mabbett) and the DO in-situ survey (APEM).

2. Regulatory Background

There are no explicit Water Framework Directive (WFD) standards for temperature in transitional and coastal (TraC) waters, in the same way that WFD temperature standards are set for rivers (WFD Directions, 2015). An EA guidance note (Jonas 2015) indicates appropriate regulatory targets for TraC waters and sets out the regulatory drivers that have informed these targets. This EA guidance note has been used as the basis for the assessment of compliance of Saltend power station's cooling water discharge against water temperature targets.

Intertidal areas, should these prove to be relevant, would require separate assessment; it would be inappropriate for intertidal areas to contribute towards statistics of exceedance due to their intermittent wetting (as recognised by Jonas (2015)) and the nature of intertidal water quality background variation and the associated ecological communities are very different to those in the subtidal.

Jonas (2015) recognises that in estuarine channels there may be a need to assess the potential for a thermal plume to cause a thermal barrier to fish movements. Turnpenny and Liney (2006) recommend that in order to minimise temperature increases that may affect migratory fish species the thermal plume should be contained within "25% of the channel cross-sectional area for 95% of the time". Turnpenny and Liney (2006) recommend that "for water of high ecological status an uplift of 2°C is applied". This value is consistent with that set as a maximum allowable temperature for the edge of the plume mixing zone for Special Areas of Conservation (SACs) that include sensitive migratory species such as salmonids. The temperature modelling assessment considerations of the Humber Estuary in connectivity with the Saltend power station therefore considers thermal barriers to fish migration by assessing the potential for the cross-sectional area of the estuary to be affected by a temperature increase of >2°C (across >25% of a cross section for >5% of the time).

Table 1 sets out the temperature thresholds, as confirmed by Jonas (2015), that are used in the assessment of potential effects to subtidal areas.

Table 1: Water quality thermal assessment criteria applied in this assessment (consistent with Jonas 2015)

Max temp (absolute temp) at edge of mixing zone	Deviation from ambient (uplift) at edge of mixing zone	Relevant statistic	Applicable to assessment of:
23°C	NA for relevant statistic	annual 98th percentile	WFD TraC waterbody
NA for relevant statistic	3°C	annual 98th percentile	WFD TraC waterbody

Max temp (absolute temp) at edge of mixing zone	Deviation from ambient (uplift) at edge of mixing zone	Relevant statistic	Applicable to assessment of:
28°C	NA for relevant statistic	annual 98th percentile	European marine site – SPA
NA for relevant statistic	2°C	maximum	European marine site – SPA
21.5°C	NA for relevant statistic	annual 98th percentile	European marine site – SAC[1]
NA for relevant statistic	2°C	maximum	European marine site – SAC[1]
NA for relevant statistic	2°C	annual 75th percentile	Shellfish waters (WFD protected area)
NA for relevant statistic	2°C across >25% of channel	annual 98th percentile[2]	Thermal barrier to migratory fish

[1]Any SAC designated for estuary or embayment habitat and/or salmonid species
[2]As proposed by BEEMS (2011)

Common Implementation Strategy (CIS) Guidance for the WFD (EC 2010) provides guidance on mixing zones (noting the focus on chemical inputs). The principle of mixing zones acknowledges that a standard for a chemical or a physical parameter such as temperature may be exceeded in a discharge, providing dilution is sufficiently rapid to avoid an intolerable impact upon the biology of the receiving water beyond the mixing zone. The mixing zone approach allows temperature compliance to be assessed in recognition of temporal and spatial considerations. Jonas (2015) defines a mixing zone as:

> *"the part of a body of surface water which is adjacent to the point of discharge and within which the targets may be exceeded, provided that the environmental objectives of the Water Framework Directive are met within the water body as a whole. This definition reflects the working definition of a mixing zone provided within the CIS Guidance on Mixing Zones pursuant to Article 4(4) of the Directive 2008/105/EC (EC December 2010)."*

3. Background water quality conditions

3.1 Environment Agency data

3.1.1 WFD water body status

Saltend power station's discharge within King George's Dock, is located within the HUMBER LOWER transitional WFD water body (ID GB530402609201). It is located approximately 3 km downstream from the boundary of the HUMBER MIDDLE transitional WFD water body (ID: GB530402609202).

Table 2 and **Table 3** outline a summary of the WFD status and classifications under the WFD Cycle 3 for the HUMBER MIDDLE and HUMBER LOWER water bodies (not all supporting elements shown).

Table 2: HUMBER MIDDLE Water Body (Water Body ID: GB530402609202) WFD Cycle 3 classification

Classification Item	2019	2022
Ecological	**Moderate**	**Moderate**
Biological quality elements	**Moderate**	**Moderate**
Angiosperms	Moderate	Moderate
Saltmarsh	Moderate	Moderate
Fish	Good	Good
Macroalgae	Good	Good
Fucoid Extent	Good	Good
Phytoplankton	High	High
Physico-chemical quality elements	**Moderate**	**Moderate**
Dissolved Inorganic Nitrogen	Moderate	Moderate
Dissolved oxygen	High	High
Supporting elements (Surface Water)	**Moderate**	**Moderate**
Mitigation Measures Assessment	Moderate or less	Moderate or less
Specific pollutants	**High**	**High**
Un-ionised ammonia	High	High
Chemical	**Fail**	**Does not require assessment**

Table 3: HUMBER LOWER Water Body (Water Body ID: GB530402609201) WFD Cycle 3 classification

Classification Item	2019	2022
Ecological	**Moderate**	**Moderate**
Biological quality elements	**Moderate**	**Moderate**
Angiosperms	Moderate	Moderate
Saltmarsh	Moderate	Moderate
Fish	Good	Good
Invertebrates	Moderate	Moderate
Infaunal Quality Index	Moderate	Moderate
Macroalgae	High	High
Opportunistic Macroalgae	High	High
Phytoplankton	High	High
Physico-chemical quality elements	**Moderate**	**Moderate**
Dissolved Inorganic Nitrogen	Moderate	Moderate
Dissolved oxygen	High	High
Supporting elements (Surface Water)	**Moderate**	**Moderate**
Mitigation Measures Assessment	Moderate or less	Moderate or less
Specific pollutants	**High**	**High**
Un-ionised ammonia	High	High
Chemical	**Fail**	**Does not require assessment**

3.1.2 Environment Agency water quality data

The six closest Environment Agency water quality monitoring sites to the Saltend power station discharge are detailed in **Table 4** (three of these monitoring sites are located within the HUMBER MIDDLE WFD waterbody and three are located within the HUMBER LOWER WFD waterbody). It should be noted that these monitoring sites are all located within the Humber Estuary and not within the docks where the power station's discharge location is immediately located (however the docks do form part of the HUMBER LOWER Water Body.

Table 4: Environment Agency water quality monitoring sites closest to Saltend power station within the HUMBER MIDDLE and HUMBER LOWER water bodies.

HUMBER MIDDLE Monitoring Site	Cycle 2	Cycle 3
HUMBER NO.28 BUOY 2.6KM NE HESSLE SAND HU506426	2019, 2016, 2015	2019
HUMBER NEAR HESSLE SAND 0.5 KM O/S HU504425	2019, 2015, 2016	2019
HUMBER BUOY 26 0.5 KM O/S HULL MARINA HU510427	2019, 2016, 2015	2019
HUMBER LOWER Monitoring Site	**Cycle 2**	**Cycle 3**
R.HUMBER COMMITTEE SITE 7702 HUMB7702	2019, 2015, 2016	2019
HULL WWTW - 250M PLUME AT LOW WATER 49105028	2019, 2015, 2016	2019
RIVER HUMBER AT SALT END JETTY 49100424	2019, 2015, 2016	2019

Of specific relevance to this assessment are those monitoring parameters that can be directly or indirectly affected by the temperature discharge, notably temperature, dissolved oxygen and ammonia. Cycle 2 and 3 water quality data for these parameters were extracted and analysed from these six Environment Agency monitoring sites. **Table 5** sets out the mean, 98%ile and 75%ile water temperature, dissolved oxygen (both mg/l and % saturation) and ammonia (ammoniacal nitrogen as N) levels averaged in relation to the years 2015, 2016 and 2019. Salinity data (ppt) across the six monitoring sites are presented on **Figure 1** and **Figure 2**. Salinity data are used in particular to define site specific thresholds and conversions (**Section 6**). The King George's Dock is located within the 'mid' estuary which is saline, but never achieving full seawater salinity. There is a difference in salinity evident across the EA sites which corresponds to distance 'downstream' or seaward; there is also a broad seasonal salinity influence as is normal for estuaries (greater freshwater inflows during the winter reducing estuary salinity in the mid or mixing zone).

Table 5: Summarised WFD cycle 2 and 3 water quality data from the six Environment Agency monitoring sites closest to Saltend power station.

	Temperature of Water (°C)	Oxygen, Dissolved as O2 (mg/l)	Oxygen, Dissolved, % Saturation (%)	Ammoniacal Nitrogen, Filtered as N (mg/l)
Mean	11.3	9.1	89.2	0.040
98%ile	18.4	12.0	100.1	0.162
75%ile	16	10.6	93.1	0.047

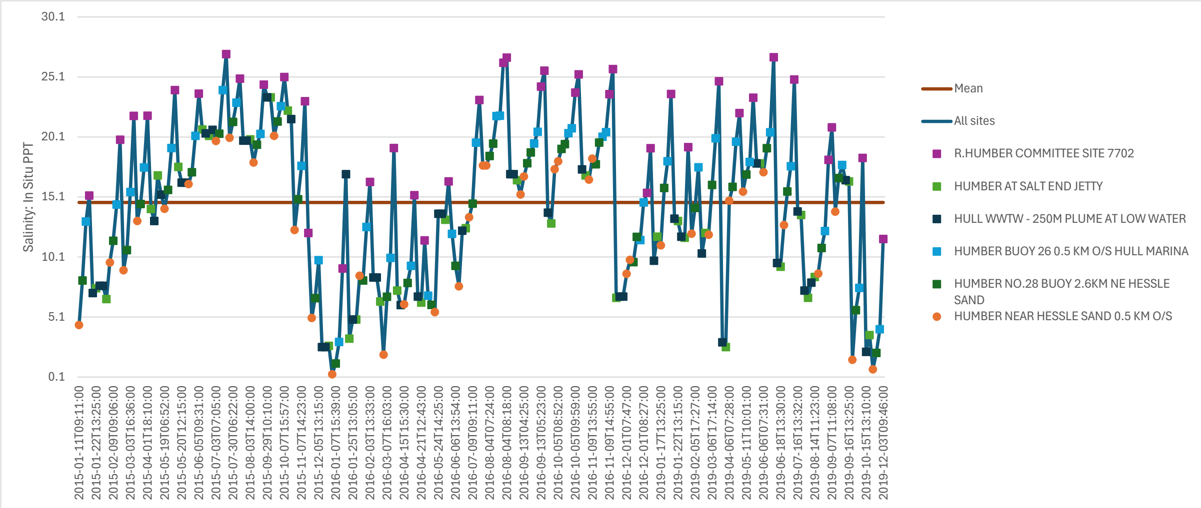

Figure 1: Salinity levels (ppt) from the six Environment Agency monitoring sites closest to the Saltend discharge across relevant WFD cycle 2 and 3 years

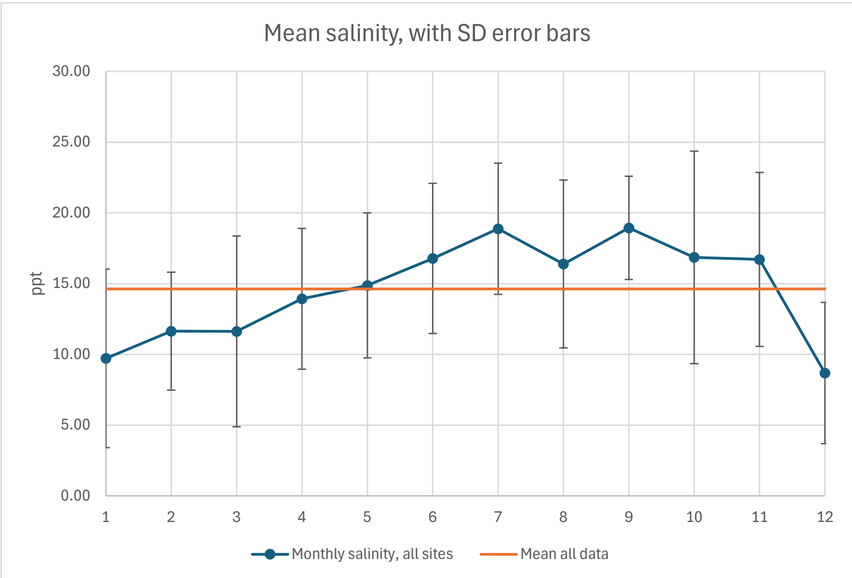

Figure 2: Mean monthly salinity levels from the six Environment Agency monitoring sites closest to the Saltend discharge

3.2 Site specific survey water quality data

APEM undertook a single water quality survey campaign of *in-situ* parameters from within the dock (November 2023). The locations of the six sample sites are shown on **Figure 3**. Profile graphs of water depth versus different water quality in-situ parameters (water temperature, salinity, pH and dissolved oxygen (% saturation and mg/l concentration)) are shown in **Figure 4** to **Figure 8**.

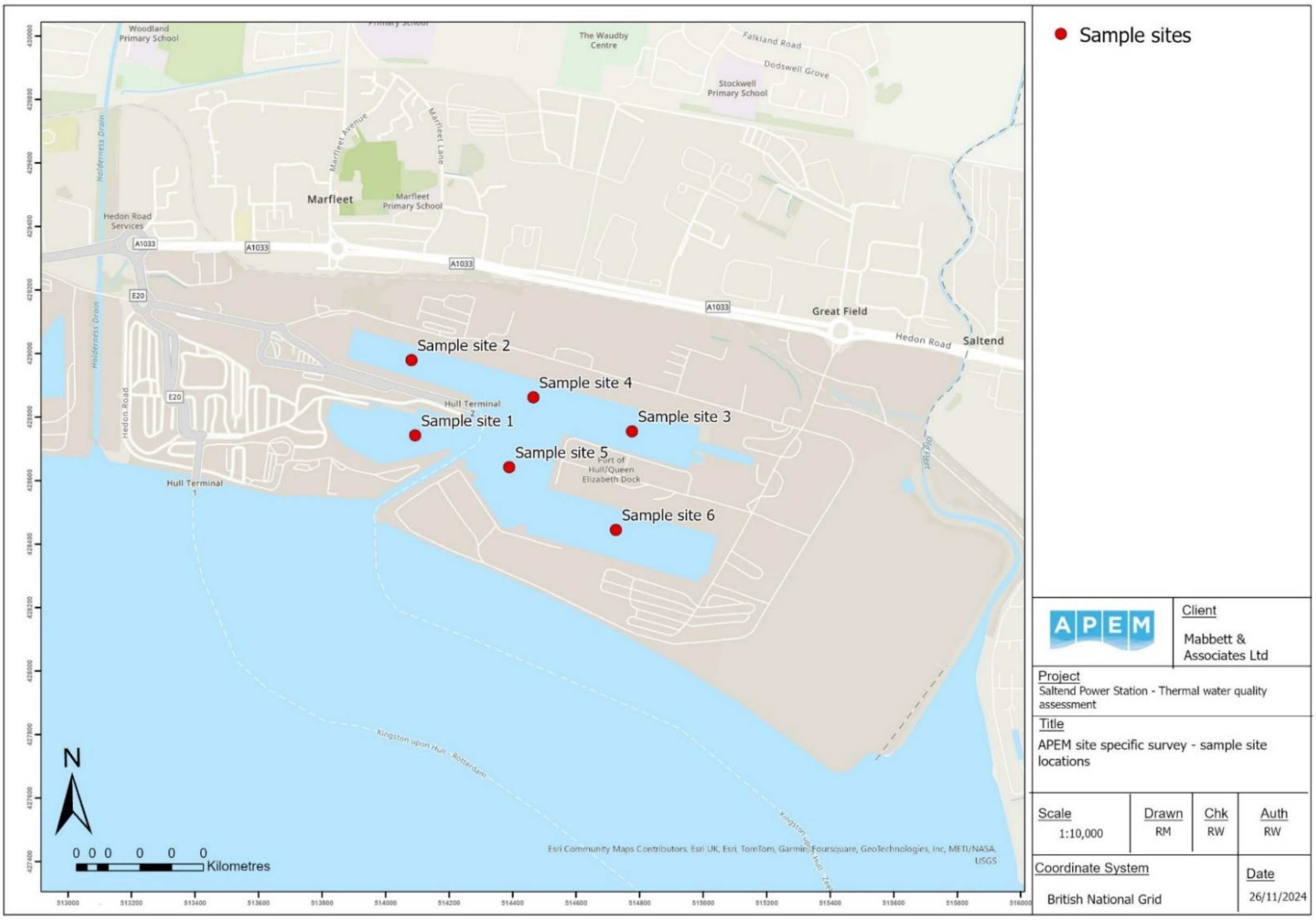

Figure 3: Locations of APEM site specific water quality survey samples sites

The *in-situ* data taken together confirms that the King George's Dock is well mixed, both vertically and horizontally. There may be a greater potential for vertical stratification during peak summer months (not sampled) however this is deemed relatively unlikely given the mixing that will be afforded by regular locking, ship movements and relatively large wind fetch length.

All *in-situ* parameter measurements were found to lie within the range of the wider (EA) Humber data for the time of year sampled. Temperature data were very similar across all sites and depths with no thermocline evident. Dissolved Oxygen (DO) data (concentrations and %saturation) were all very similar (across sites) and at healthy concentrations/levels. The very bottom samples showed some decline in DO, which is normal and likely indicative of sediment oxygen demand in the very bottom water that is directly influenced by sediments; notably this does not show at all above -10 m water depth. A similar change in pH is evident in the very bottom waters, however again the scale of change is very slight and all in the range of 'healthy' water quality conditions. Salinity increases slightly with depth as to be expected, however not to the degree that would indicate a 'salt wedge' or halocline.

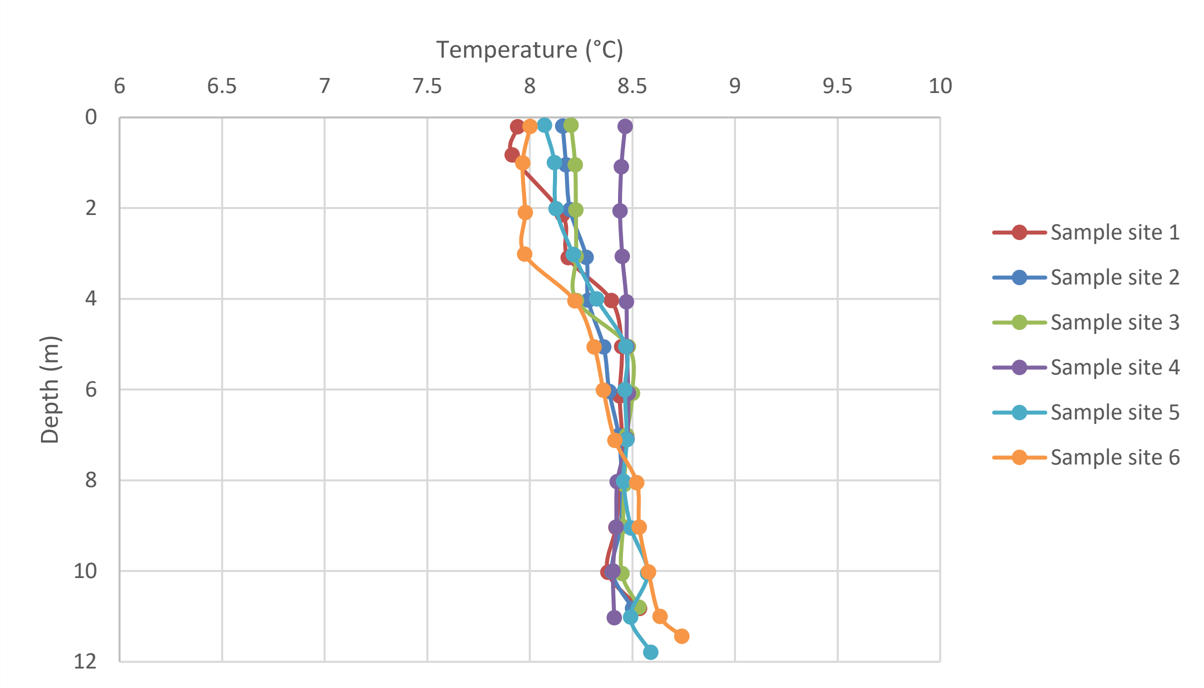

Figure 4: Profile graphs of water depth versus temperature across six sample sites from APEM site specific water quality survey

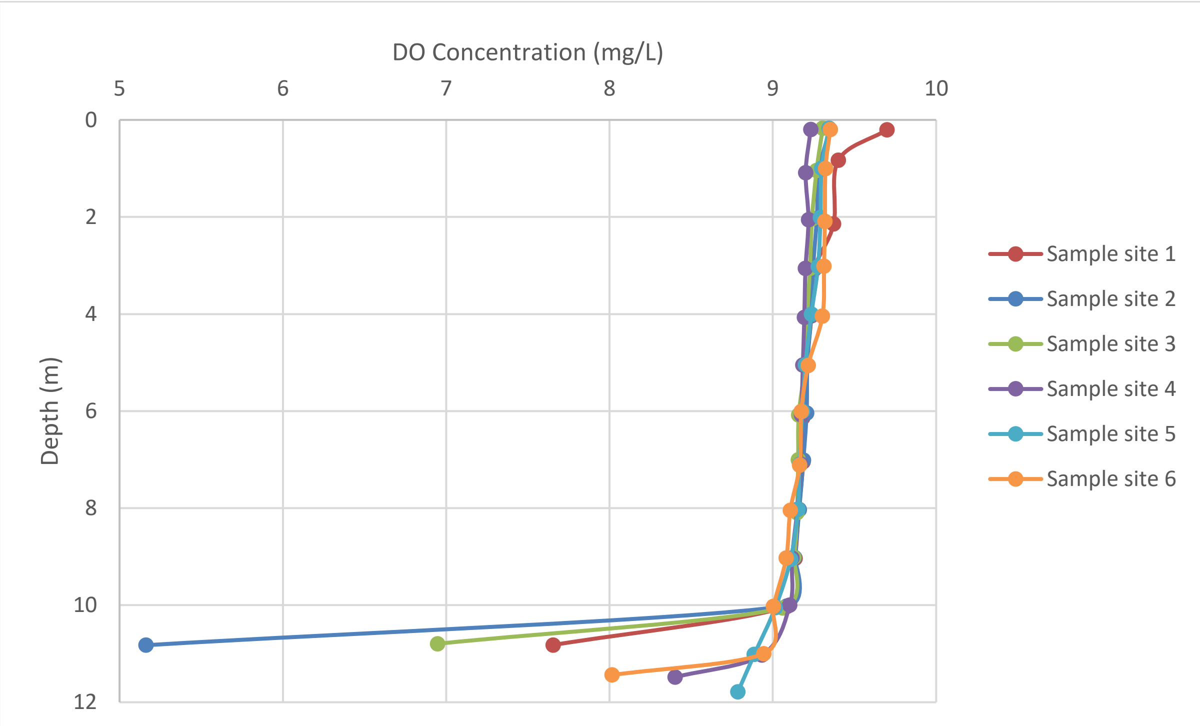

Figure 5: Profile graphs of water depth versus dissolved oxygen concentration across six sample sites from APEM site specific water quality survey

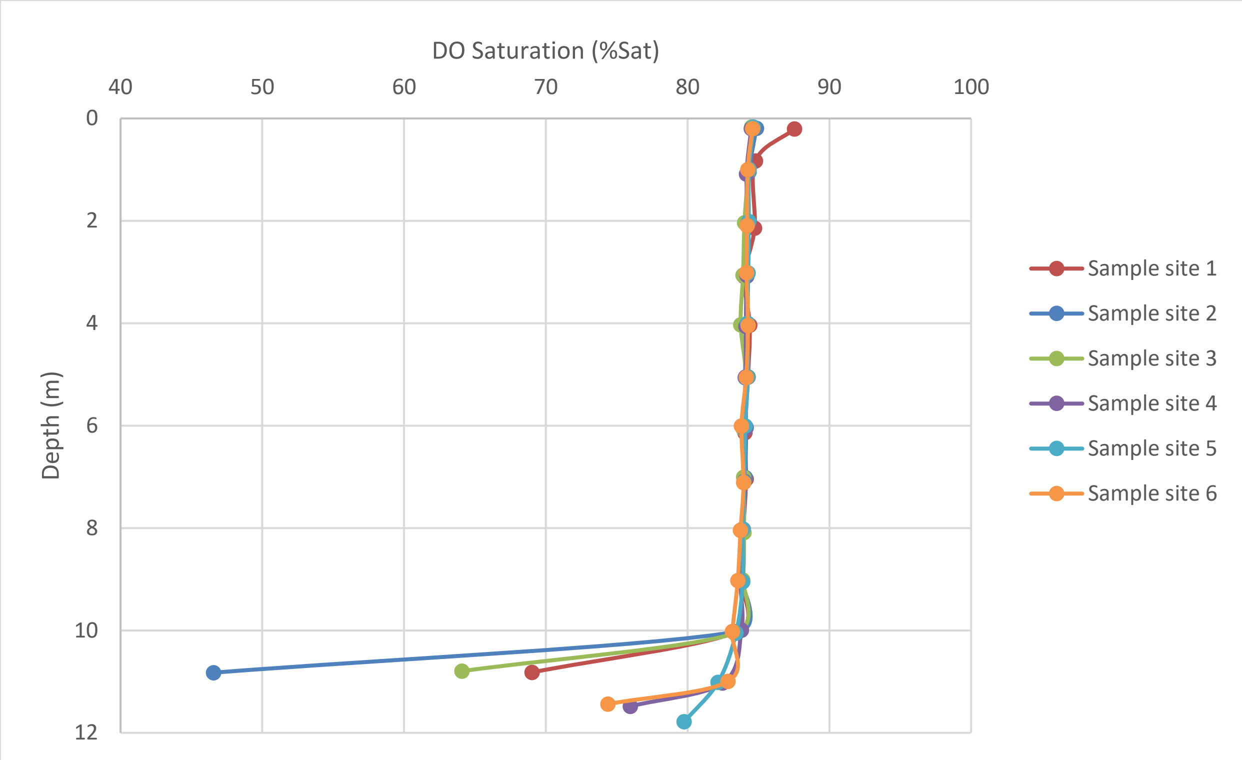

Figure 6: Profile graphs of water depth versus dissolved oxygen % saturation across six sample sites from APEM site specific water quality survey

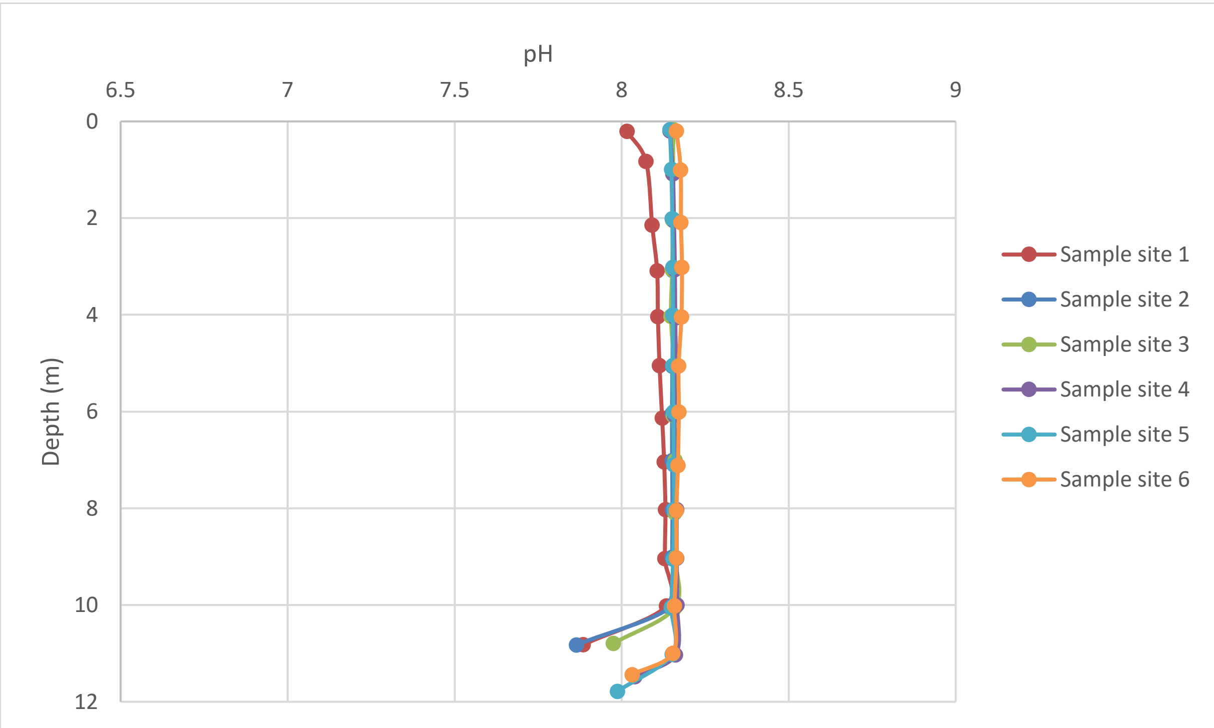

Figure 7: Profile graphs of water depth versus pH across six sample sites from APEM site specific water quality survey

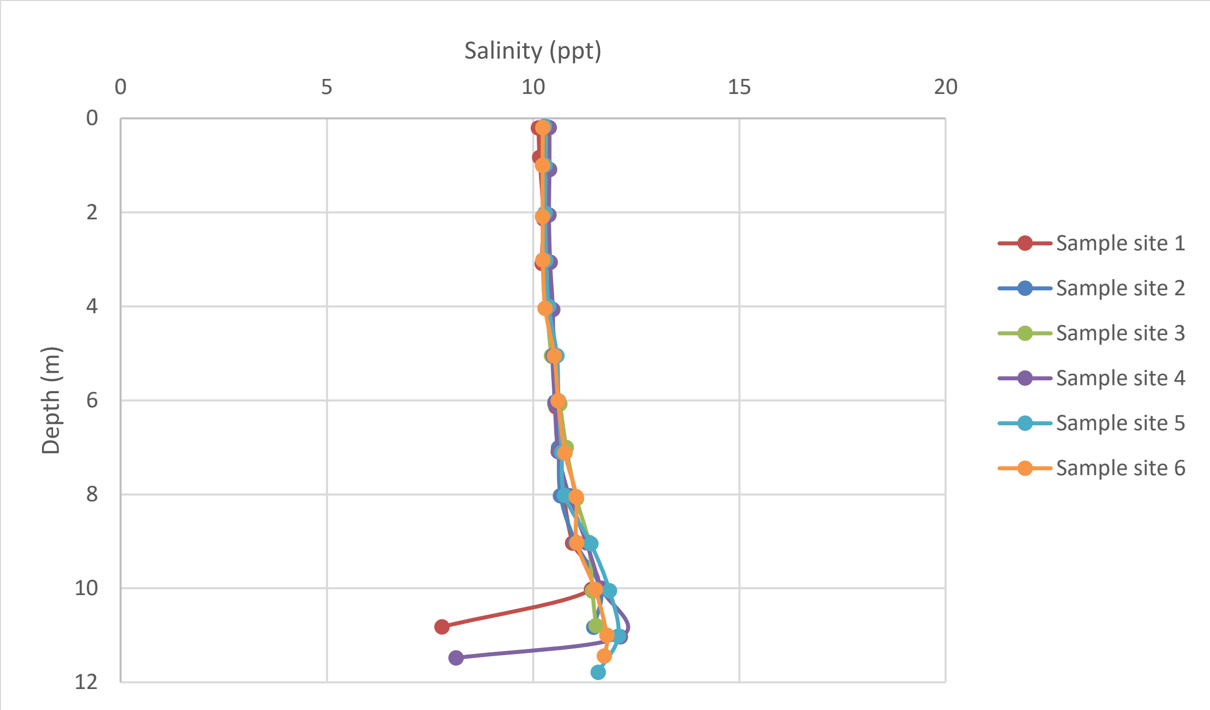

Figure 8: Profile graphs of water depth versus salinity across six sample sites from APEM site specific water quality survey

4. Thermal modelling results

Modelled annual 98th percentile absolute temperatures (at surface and bed) provided by Mabbett are presented as visual plots within **Figure 9** to **Figure 12** for both a current max temperature scenario (28°C) and the maximum proposed temperature scenario (40°C). Modelled annual 98th percentile temperature rise (at surface and bed) relative to no discharge (i.e. change from an absolute baseline) are presented within **Figure 13** to **Figure 16**.

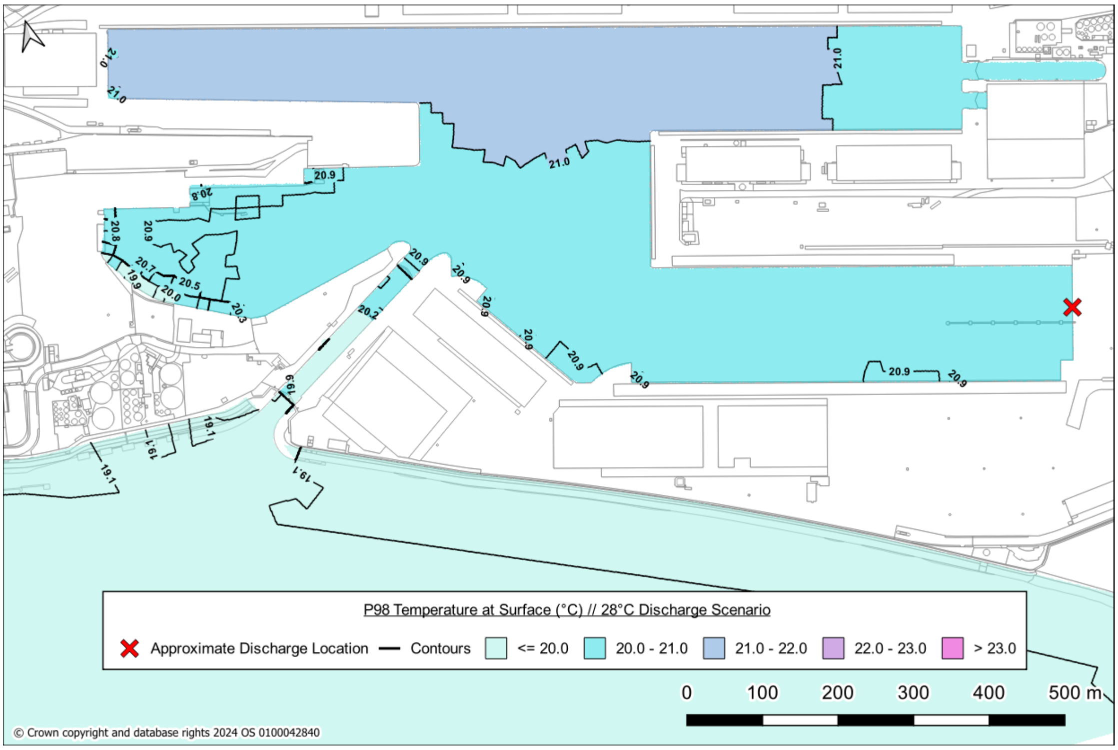

Figure 9: 98th percentile temperatures across the dock surface, 28°C discharge scenario (i.e. existing max discharge)

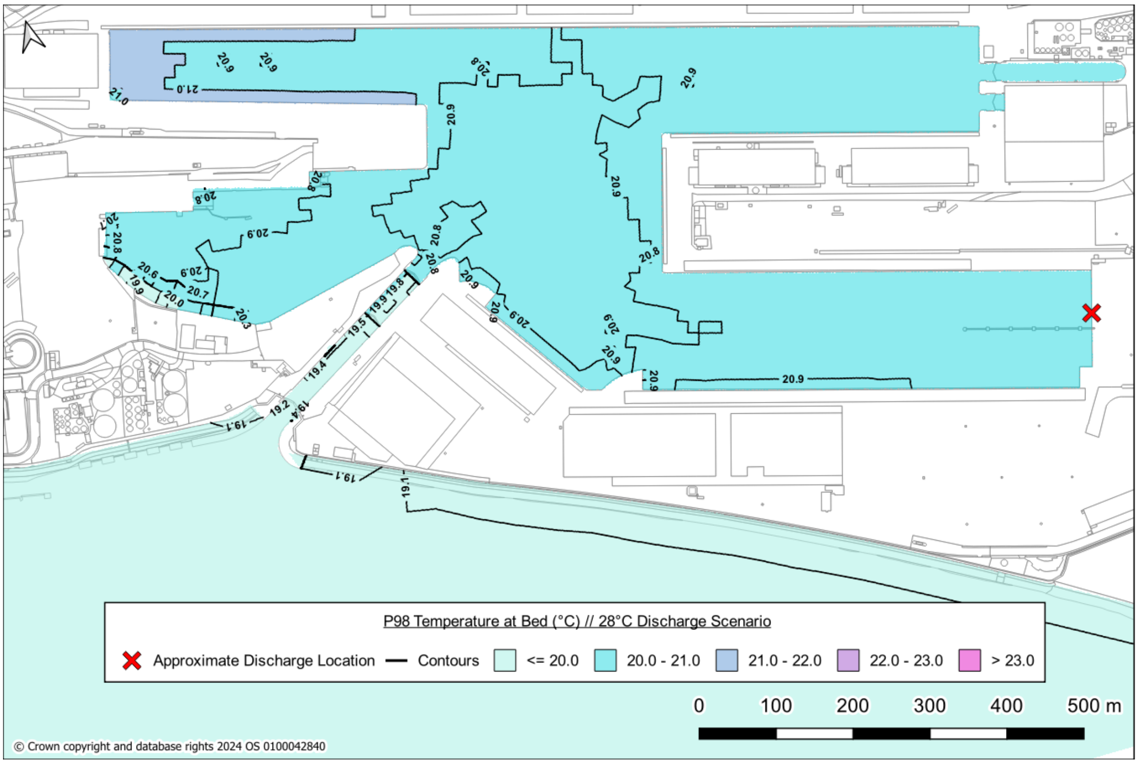

Figure 10: 98th percentile temperatures across the dock bed, 28°C discharge scenario (i.e. existing max discharge)

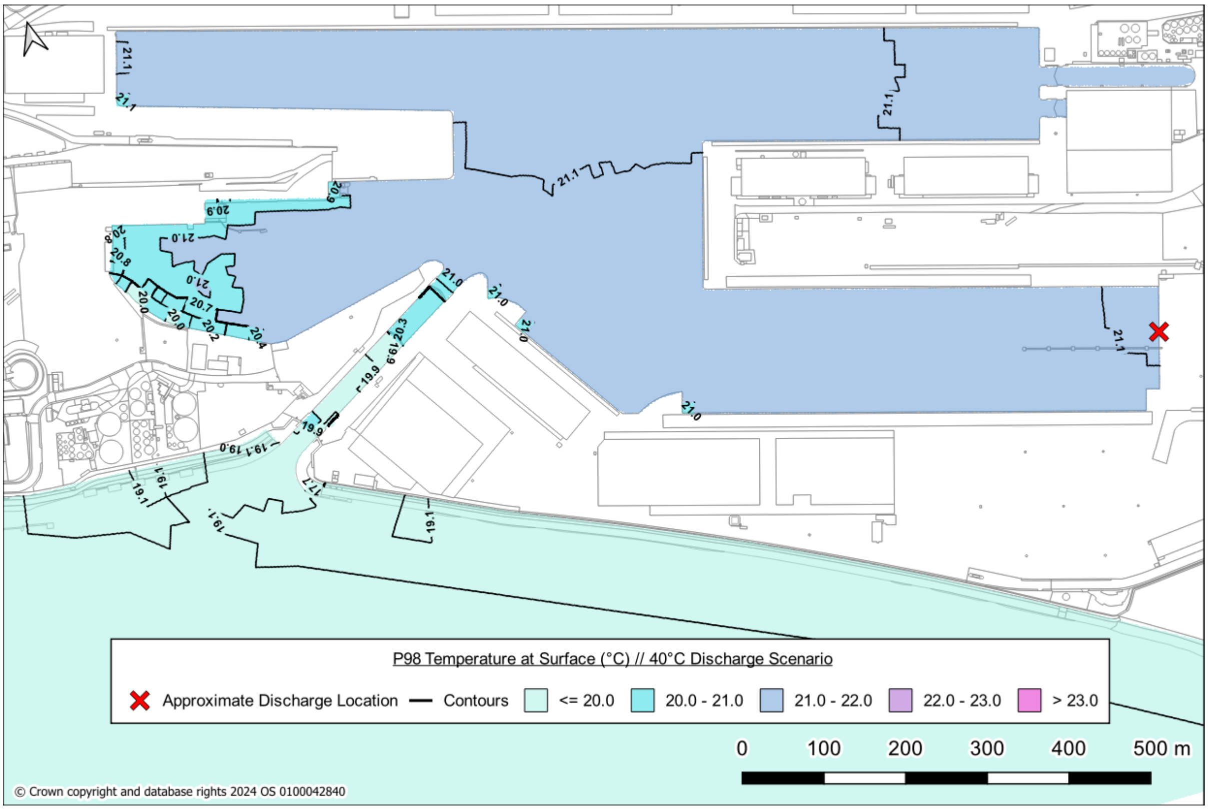

Figure 11: 98th percentile temperatures across the dock surface, 40°C discharge scenario

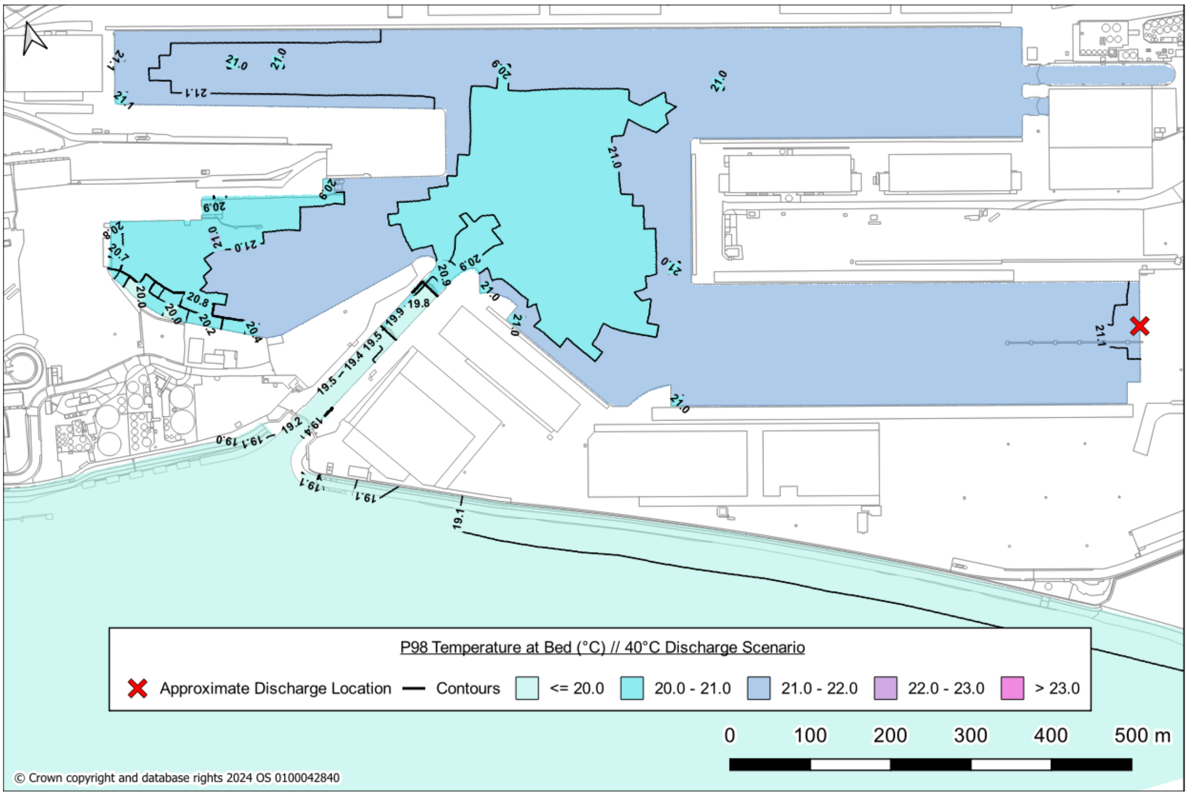

Figure 12: 98th percentile temperatures across the dock bed, 40°C discharge scenario

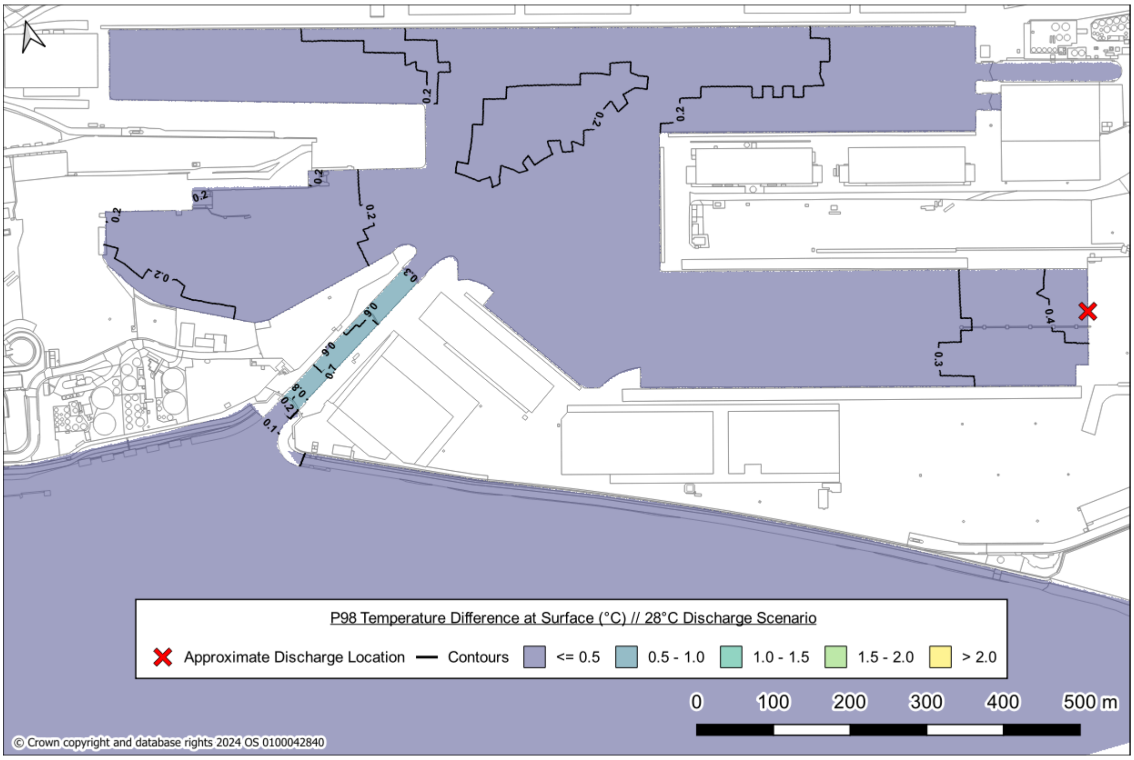

Figure 13: Difference in 98th percentile temperatures across the dock surface, 28°C discharge scenario vs no discharge

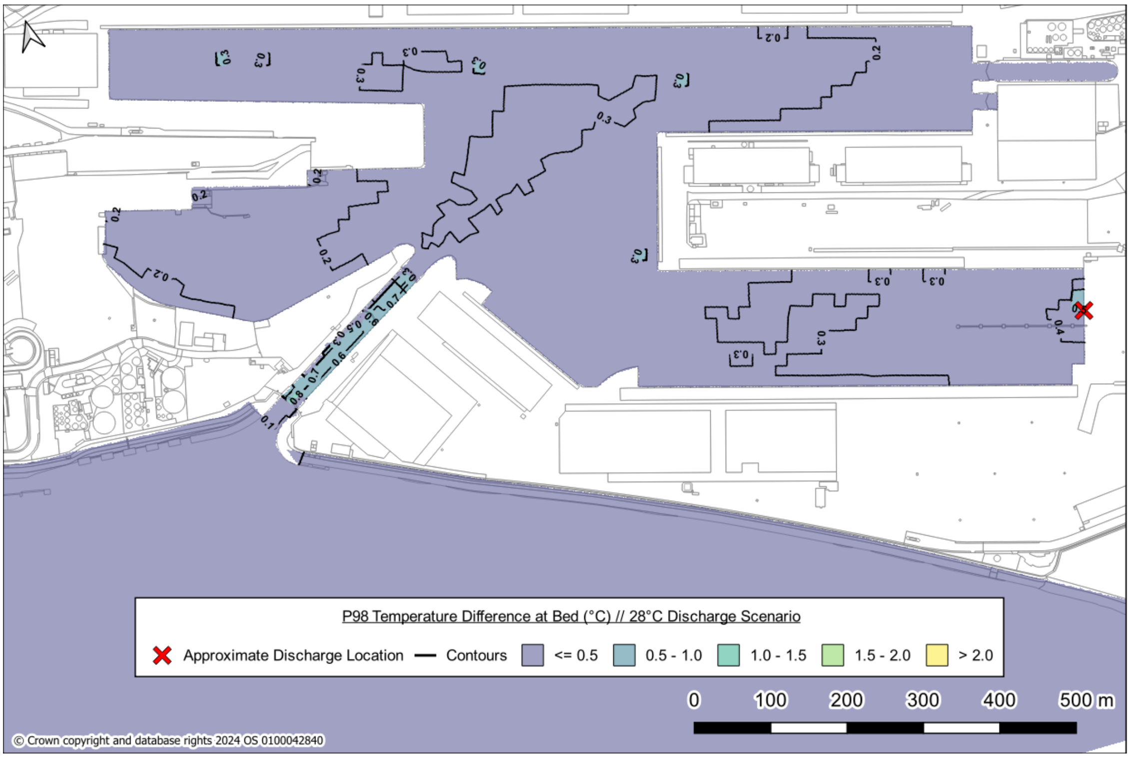

Figure 14: Difference in 98th percentile temperatures across the dock bed, 28°C discharge scenario vs no discharge

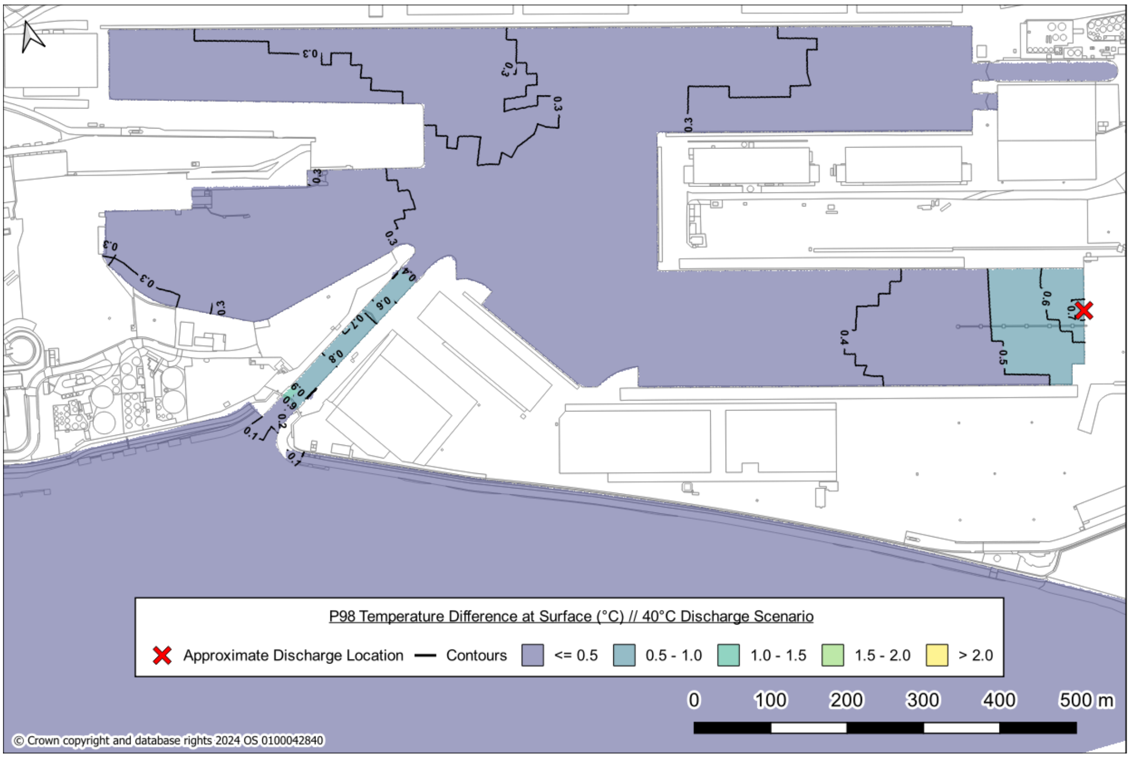

Figure 15: Difference in 98th percentile temperatures across the dock surface, 40°C discharge scenario vs no discharge

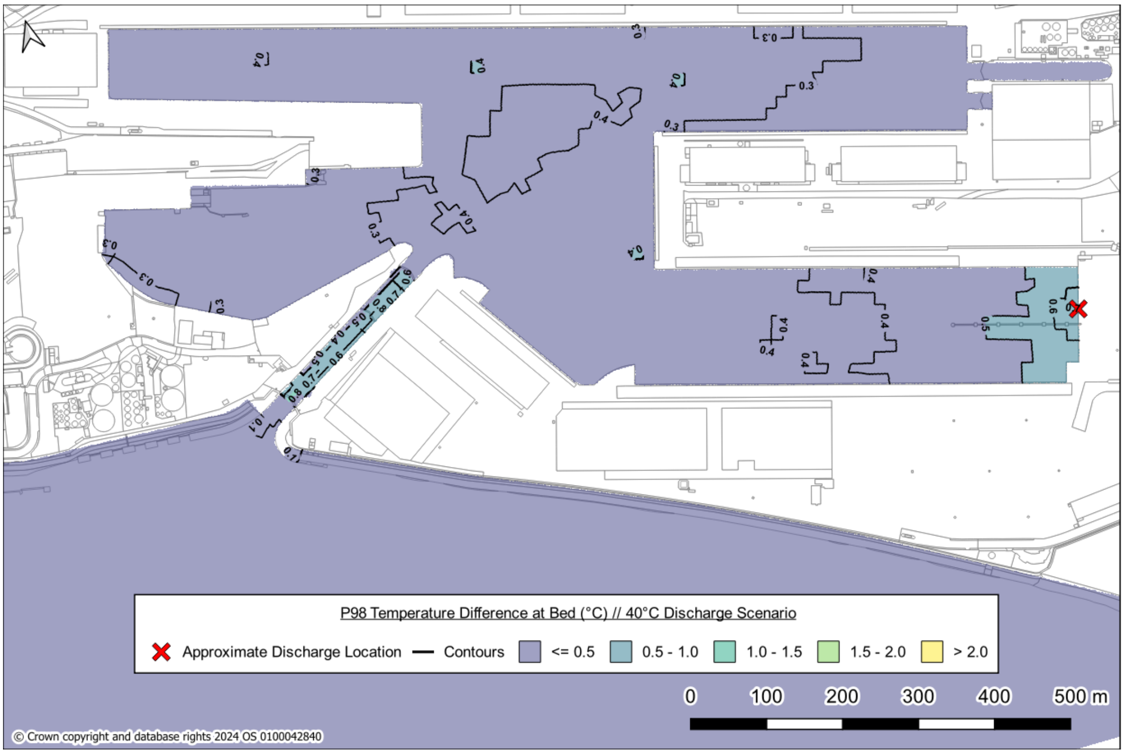

Figure 16: Difference in 98th percentile temperatures across the dock bed, 40°C discharge scenario vs no discharge

As demonstrated in **Figure 9** to **Figure 16**, the modelled dispersion of temperature is rapid across both the dock bed and surface, as evidenced by the rapid decrease in temperature with distance from the outfall. At the maximum temperature scenario (40°C), the maximum temperature uplift observed within the docks at any location (relative to an absolute baseline of no discharge) is +1°C, (**Figure 15** and **Figure 16**) with a maximum absolute temperature of 21.1°C (**Figure 11** and **Figure 12**).

The elevated temperature plume is restricted only to the dock area, with temperatures across both the bed and surface reducing to broadly ambient / background levels upon reaching the estuary. Under the maximum temperature scenario (40°C), there is only a negligible temperature uplift of 0.2°C observed within the estuary itself (**Figure 15** and **Figure 16**) with a maximum absolute temperature of 19.1°C (**Figure 11** and **Figure 12**).

5. Temperature threshold assessments

5.1 Temperature threshold assessment - Water Framework Directive

Saltend power station's discharge within the King George's Dock is located within the HUMBER LOWER WFD transitional waterbody.

As set out in **Table 1**, there are two separate thermal criteria in relation to WFD requirements. To meet Good ecological potential requirements (irrespective of the current classification of the WFD waterbody) the 98th percentile temperature must not exceed 23^{o}C and temperature uplift must be <3^{o}C (**Table 1**) (which represents the boundary of any WFD threshold 'mixing zone' – should this be required).

As evidenced on **Figure 9** to **Figure 12**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature greater than 21.1^{o}C (at both the current max temperature scenario (28°C) or the maximum proposed temperature scenario (40°C)). Therefore, the WFD criteria of ≤23^{o}C (98th percentile) is met within the HUMBER LOWER WFD transitional waterbody.

Similarly, as evidenced on **Figure 13** to **Figure 16**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature uplift greater than +1^{o}C (at both the baseline temperature scenario (28°C) and the maximum temperature scenario (40°C)). Therefore, the WFD criteria of a temperature uplift <3^{o}C (98th percentile) is also met within the HUMBER LOWER WFD transitional waterbody (no mixing zone considerations required).

Consequently, thermal water discharge from Saltend power station meets all WFD requirements within the HUMBER LOWER WFD transitional waterbody and would not be expected to cause adverse impacts (i.e. no deterioration) to WFD temperature supporting elements.

5.2 Temperature threshold assessment - Shellfish waters (WFD protected area)

Saltend power station's discharge location is not located in proximity to any designated shellfish waters (WFD protected area), with the closest site being located approximately 80 km to the south (West Wash Shellfish Waters). Given the distance and lack of connectivity between the discharge location and any designated shellfish waters, it is concluded that thermal water discharges from Saltend power station will not cause adverse impacts to shellfish waters via direct thermal water quality pathways.

It should also be noted that with the thermal criteria set out in **Table 1** in relation to shellfish water requirements (the 75th percentile temperature uplift must be <2^{o}C), there are no associated areas of the thermal plume at either the dock bed or surface with a temperature uplift greater than +1^{o}C. As such, even if theoretically there was a designated shellfish water located in proximity, this criteria would be met and there would be no expected adverse impacts.

5.3 Temperature threshold assessment - Special Protection Areas (SPAs)

Saltend power station's discharge location within King George's Dock is adjacent to the Humber Estuary SPA.

As set out in **Table 1**, there are two separate thermal criteria associated with SPAs. To demonstrate no potential adverse effect to SPA features the 98th percentile temperature must not exceed 28^{o}C at the SPA and temperature uplift must be <2^{o}C (**Table 1**).

As evidenced on **Figure 9** to **Figure 12**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature greater than 21.1^{o}C (at both the current max temperature scenario (28°C) or the maximum proposed temperature scenario (40°C)), with a maximum temperature of 19.1^{o}C observed within the SPA itself. Therefore, the SPA criteria of ≤28^{o}C (98th percentile) is met within the Humber Estuary SPA.

Similarly, as evidenced on **Figure 13** to **Figure 16**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature uplift greater than +1^{o}C (at both the current max temperature scenario (28°C) and the maximum temperature scenario (40°C)), with a negligible temperature uplift of +0.2^{o}C observed within the SPA itself. Therefore, the SPA criteria of a temperature uplift <2^{o}C is met within the Humber Estuary SPA.

Consequently, thermal water discharges from Saltend power station (under current and proposed max scenarios) meet all SPA requirements for the Humber Estuary SPA and would not be expected to cause adverse impacts to SPA features via direct thermal water quality pathways. It is also noted that the thermal plume is restricted to the area of the docks, and the discharge is not located within the Humber Estuary SPA itself. Should any future Habitats Regulations Assessment be required (presuming to HRA Stage 2 assessment), the conclusions here would support a conclusion of No Adverse Effects on Integrity (No AEoI) with regards the Humber Estuary SPA.

5.4 Temperature threshold assessment - Special Areas of Conservation (SACs)

Saltend power station's discharge location within King George's Dock is adjacent to and linked to the Humber Estuary SAC.

As set out in **Table 1**, there are two separate thermal criteria associated with SACs designated for estuary or embayment habitat and/or salmonid species. To demonstrate no potential adverse effect to SAC features the 98th percentile temperature must not exceed 21.5^{o}C at the SAC and temperature uplift within the SAC boundary must be <2^{o}C (**Table 1**).

As evidenced on **Figure 9** to **Figure 12**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature greater than 21.1^{o}C (associated with both the maximum current temperature scenario (28°C) and the maximum proposed temperature scenario (40°C)), with a maximum temperature of 19.1^{o}C observed within the SAC itself. Therefore, the SAC criteria of ≤21.5^{o}C (98th percentile) is met within the Humber Estuary SAC.

Similarly, as evidenced on **Figure 13** to **Figure 16**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature uplift greater than +1.5^{o}C (under both the baseline max temperature discharge (28°C) and the proposed maximum temperature scenario (40°C)), with a negligible temperature uplift of +0.2^{o}C observed within the SAC itself. Therefore, the SAC criteria of a temperature uplift <2^{o}C is met within the Humber Estuary SAC.

Consequently, thermal water discharges from Saltend power station (under current and proposed max scenarios) meet all SAC requirements within the Humber Estuary SAC and would not be expected to cause adverse impacts to SAC features via direct thermal water quality pathways. It is also noted that the thermal plume is restricted to the area of the docks, and the discharge is not located within the Humber Estuary SAC itself. Should any future Habitats Regulations Assessment be required (presuming to HRA Stage 2 assessment), the conclusions here would support a conclusion of No Adverse Effects on Integrity (No AEoI) with regards the Humber Estuary SAC.

5.5 Temperature threshold assessment - Thermal barrier to migratory fish

Jonas (2015) recognised that in estuarine channels there may be a need to assess the potential for a thermal plume to cause a thermal barrier to fish movements. As set out in **Table 1**, the thermal criteria associated with migratory fish are that the 98th percentile temperature uplift must not exceed 2°C across >25% of the channel (**Table 1**).

As outlined by Turnpenny and Liney (2006) and BEEMS (2011), lethal and preferential temperature limits of migratory fish species commonly found in transitional and coastal waters are indicated in **Table 6**. This includes sea lamprey, with river and sea lamprey listed as Annex II species present as a qualifying feature within the Humber Estuary SAC.

Table 6: Temperature limits of migratory fish species commonly found in transitional and coastal waters (Turnpenny and Liney (2006) and BEEMS (2011))

Species	Lethal temperature (°C)	Temperature preference (°C)
Sea lamprey	31	17.8 – 21.8
Salmon	27.8	9 – 17
Sea/Brown trout	25-27.2	8 - 17

As evidenced on **Figure 13** to **Figure 16**, there are no associated areas of the thermal plume at either the dock bed or surface with a temperature uplift greater than +1°C (associated with either the current max temperature scenario (28°C) and the proposed maximum temperature scenario (40°C)). The maximum absolute temperature observed is 21.1°C, which is significantly under all of the fish species lethal temperature limits outlined in **Table 6**, and is also still within the preferential temperature range for sea lamprey (17.8 – 21.8°C) which are listed as Annex II species present as a qualifying feature within the Humber Estuary SAC. It should also be noted that the thermal plume is restricted to the area of the docks and is not located within the Humber Estuary channel itself, with the temperature uplift within the estuary a negligible 0.2°C. Therefore, the thermal criteria associated with migratory fish that the temperature uplift must not exceed 2°C across >25% of the channel is met for the Humber Estuary (and the migratory channel).

Consequently, the proposed thermal water discharge from Saltend power station is not expected to cause adverse impacts to migratory fish via direct thermal water quality pathways.

6. Indirect water quality assessments

6.1 Indirect water quality assessments – Dissolved Oxygen

This ‘indirect’ water quality assessment assesses potential indirect effects of scenario temperature increases on Dissolved Oxygen (DO) concentrations in the local water environment (King George’s Dock and the local reaches of the Humber).

6.1.1 Indirect DO Assessment objective

Water temperature directly affects the amount of oxygen that can be dissolved in water as increasing temperature reduces the solubility of gases, particularly oxygen. The solubility of oxygen also declines as salinity increases.

The objective of this assessment is to present the potential change to DO concentrations associated with proposed Saltend Power Station thermal discharge scenarios. The technical appendix sets out the context of background DO conditions and appropriate regulatory thresholds, the assessment method, and provides results (based on the Mabbett thermal model temperature predictions).

6.1.2 Method basis

The method focuses on the potential for water temperature to directly affect DO solubility. It is recognised that other indirect influences (positive and negative) on DO concentrations could propagate from water temperature change (e.g. change in rate of Biochemical Oxygen Demand (BOD) exertion, change in rate of re-aeration) and these are not incorporated into the assessment method. The adoption of precautionary oxygen demand values is in part designed to allow for other minor influences that are not able to be quantified with accuracy (**Section 6.1.5**).

The method outlined here is consistent with that applied within pre-planning Environmental Impact Assessment studies at other large thermal discharge power stations, including the proposed Tilbury Energy Centre power station on the Thames (APEM 2018), as well as the large thermal discharge associated with Hinkley Point C (HPC) (e.g. Cefas 2011).

6.1.3 Dissolved oxygen environmental thresholds

Dissolved Oxygen (DO) is classified as a 'physicochemical quality element' under the WFD and the current Environmental Quality Standards (EQS's) for DO are dictated principally by classification status according to the Water Framework Directive Directions 2015[1].

The long term transitional and coastal waters EQS associated with Good status is salinity dependent and defined as:

Good status (mg/l) as 5th percentile = 5 – (0.028 x (salinity))

6.1.4 Background dissolved oxygen data

Environment Agency monitoring stations

The EA has a network of water quality monitoring stations located throughout the Estuary at which regular water sampling is conducted. A large number of these stations are used for WFD classification purposes, as set out on the EA's catchment data explorer website (HUMBER MIDDLE water body: https://environment.data.gov.uk/catchment-planning/WaterBody/GB530402609202 ; HUMBER LOWER water body: https://environment.data.gov.uk/catchment-planning/WaterBody/GB530402609201) (c.f. **Section 3.1.1**). The King George's Dock forms part of the HUMBER LOWER water body, however it is located towards the boundary with the HUMBER MIDDLE water body, hence relevant water quality data were collated (for relevant WFD Cycle 2 and Cycle 3 years) for the six locations set out in **Table 7**. Samples are analysed for a suite of determinands including, of direct relevance here, DO and salinity.

Table 7: Environment Agency water quality monitoring sites

[1] Defra (2015). The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015

HUMBER MIDDLE Monitoring Site	Cycle 2	Cycle 3
HUMBER NO.28 BUOY 2.6KM NE HESSLE SAND HU506426	2019, 2016, 2015	2019
HUMBER NEAR HESSLE SAND 0.5 KM O/S HU504425	2019, 2015, 2016	2019
HUMBER BUOY 26 0.5 KM O/S HULL MARINA HU510427	2019, 2016, 2015	2019
HUMBER LOWER Monitoring Site	**Cycle 2**	**Cycle 3**
R.HUMBER COMMITTEE SITE 7702 HUMB7702	2019, 2015, 2016	2019
HULL WWTW - 250M PLUME AT LOW WATER 49105028	2019, 2015, 2016	2019
RIVER HUMBER AT SALT END JETTY 49100424	2019, 2015, 2016	2019

Figure 17 presents monthly DO concentration data, for each of the EA sites (separate plots for each year). There is some variation in concentration between sites and between years as would be expected, however the seasonal sinusoidal concentration curve is clearly visible and consistent in character. The average of all monthly data is considered a good representative of the entire dataset.

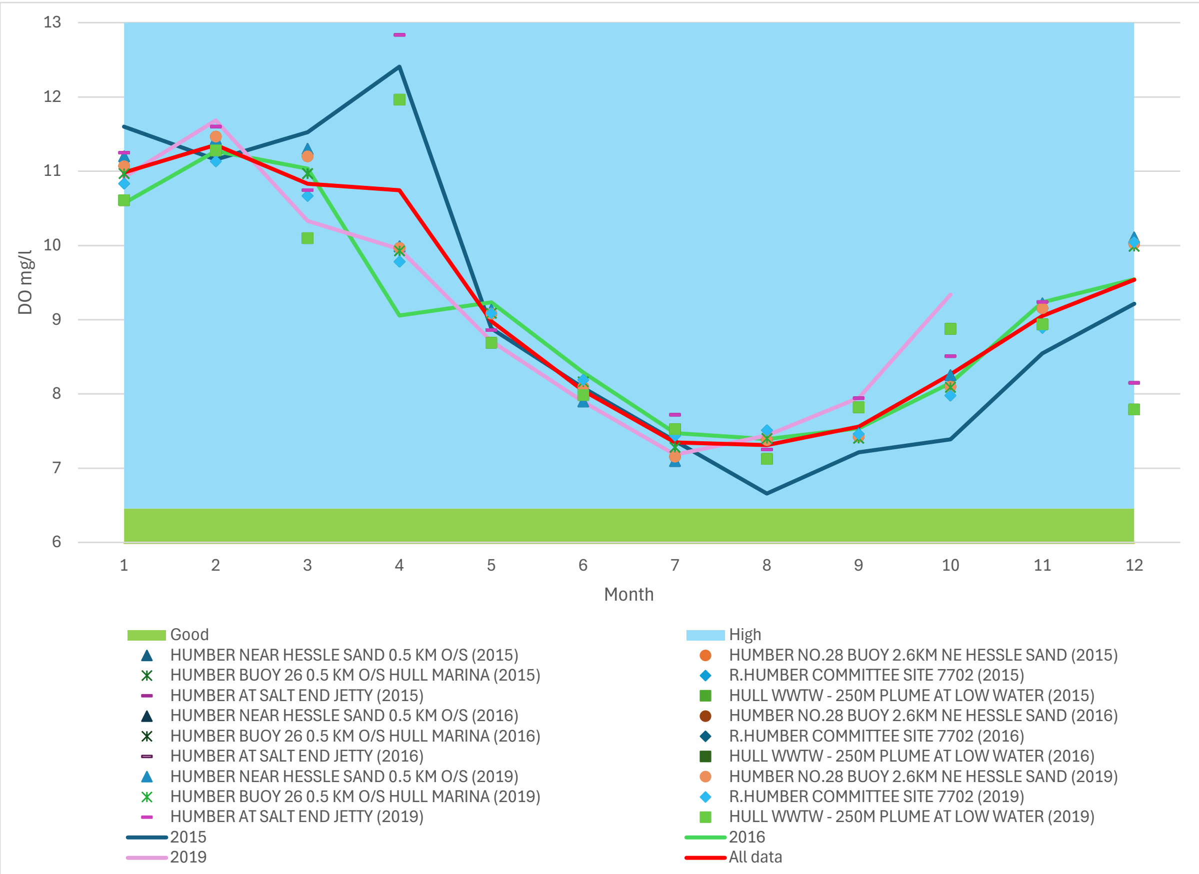

Figure 17: Monthly dissolved oxygen concentrations (mg/l) – site specific data, annual mean data, all data (mean).

These local EA data can be used to define site-specific DO WFD classification thresholds, together with the associated WFD result (indicative site-specific classification) given by the 5th percentile[2] - **Figure 18**. Note, for the purposes of this report the six sites set out in **Table 7** are used to define indicative location specific thresholds, recognising that these data straddle the boundary of two water bodies, and more distant monitoring data have been disregarded for this specific study (local indicative result of High Status is consistent with the EA's classification at water body scale).

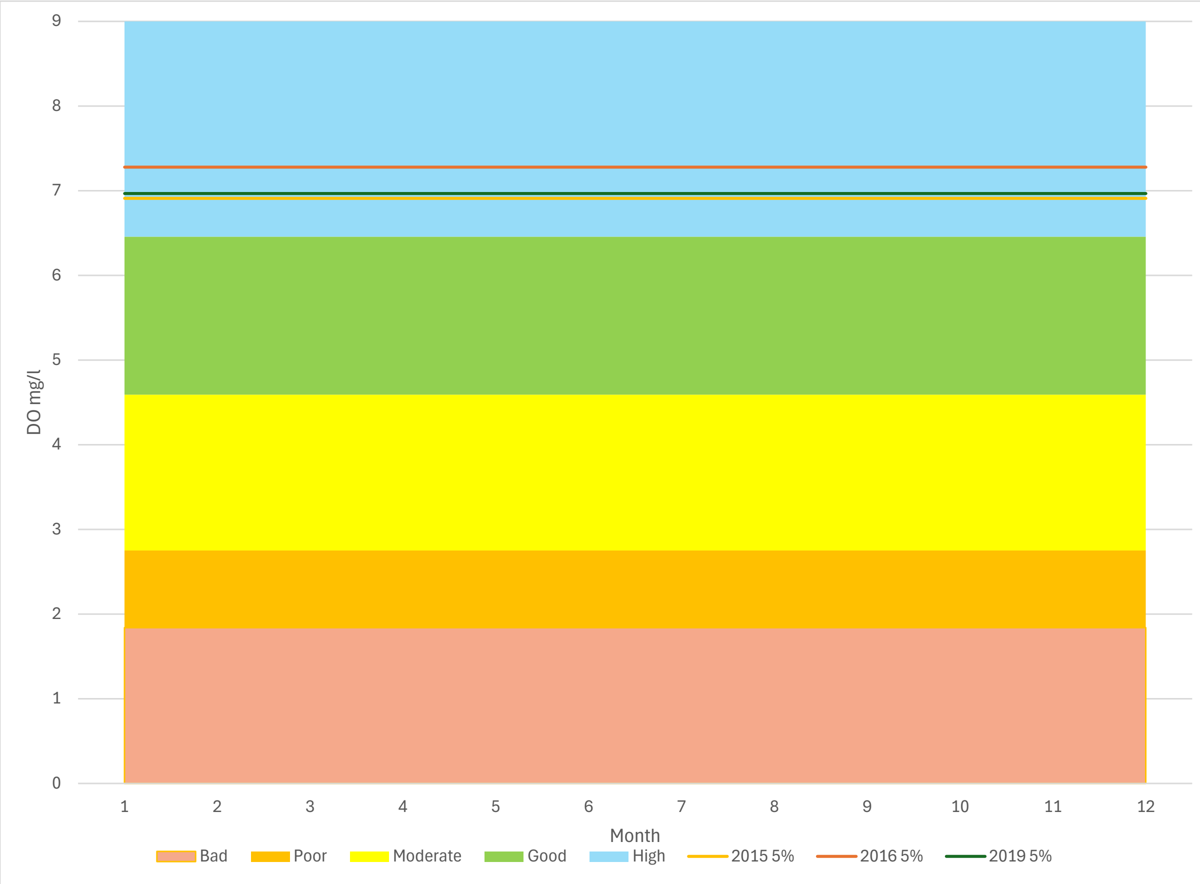

Figure 18: Site-specific dissolved oxygen WFD classifications and results (local EA data). Note the definition of WFD threshold class is site-specific based on salinity.

[2] EA WFD classification is based on annual data sets, albeit generally multiple, complete, consecutive years of data.

DO data were also recorded *in-situ* during the spot water quality and concurrent bathymetry surveys undertaken by APEM. DO profiles through the water column were collected at six locations within the Dock (**Figure 3**).

The *in-situ* data collected as part of the site specific surveys (presented in **Section 3.2**) from within the dock are consistent with the wider estuarine DO conditions (i.e. consistent with EA November concentrations in the estuary of c.9 mg/L).

In addition, the *in-situ* King George's Dock DO data indicated:

- good vertical mixing / a high degree of vertical homogeneity, from surface to 10 m depth, with decrease in oxygen at depth only measurable in the bottom metre of the water column;
- no DO variation with location across the dock – again indicating good levels of mixing throughout the dock.

6.1.5 Indirect DO assessment methodology

The assessment approach recognises that a background oxygen demand exists as a result of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). This demand (naturally) draws down the DO concentration from a theoretical fully saturated concentration to the observed background value. This background level of demand was applied to the modelled fully saturated conditions that would exist in the future following the temperature uplifted conditions due to scenario operation of the Saltend Power Station. Regarding the future scenario, the approach adopted was to assume a very simple, enveloped worst-case set of assumptions first, with the intention to then iterate should this initial precautionary assessment demonstrate potential for affects on DO. If the initial precautionary assessment demonstrates no potential for DO change, the assessment may conclude at that point (as was the case here).

The summary method steps applied were to:

- Step 1: Define the fully saturated (100%) DO concentrations under background conditions;
- Step 2: Define the extent of background oxygen consumption/demand (i.e. drawdown from 100% saturation) in the local area;
- Step 3: Establish predicted fully saturated DO concentrations during the (worst case) Saltend scenario discharge (or initial worst case enveloping scenario);

- Step 4: Apply a precautionary background oxygen demand value to the predicted DO levels during the worst case scenario, to derive predicted scenario (or initial worst case enveloping scenario) oxygen concentrations[3];
- Step 5: Compare predicted concentrations against site-specific DO WFD thresholds to establish the scale of change between the background scenario and the future scenario.

Step 1: Defining background fully saturated concentrations

Monthly average theoretical DO concentrations (100% saturation equivalent) based entirely on local temperature and salinity data were derived using solubility equations[4] developed by Benson & Krause (1980, 1984), which are consistent with UNESCO (1986). Mean 100% saturation concentrations per month were calculated (initially as per **Figure 19**).

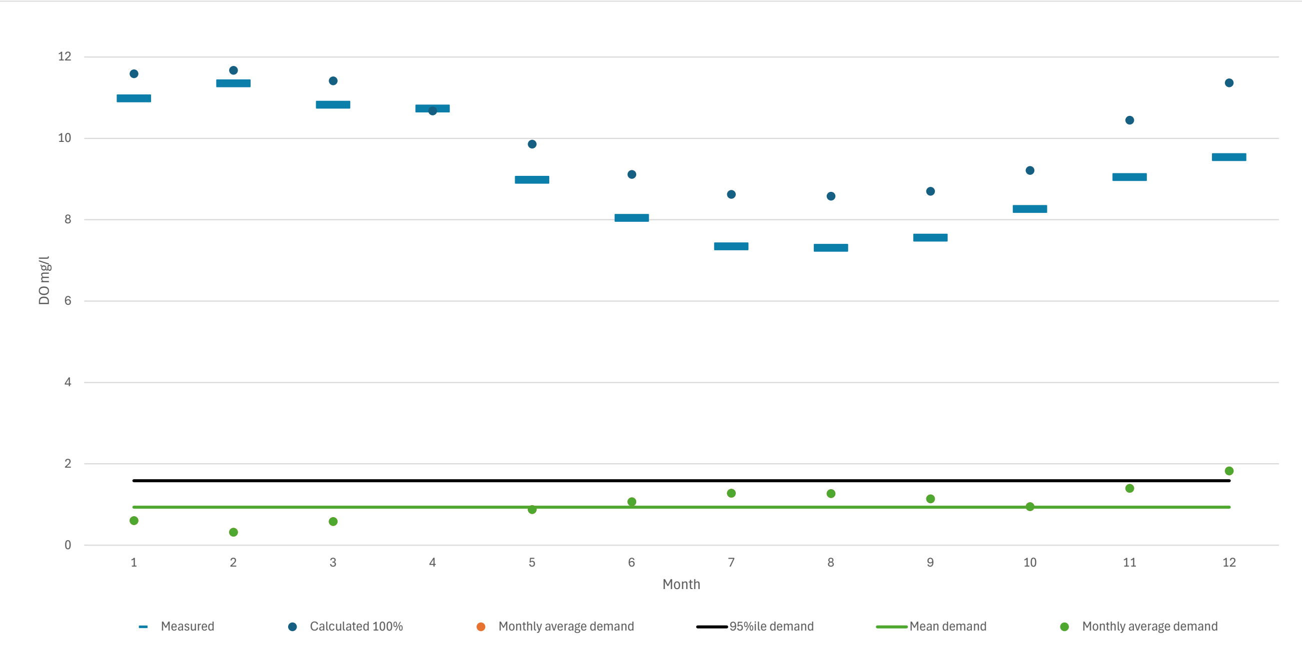

Figure 19: Site-specific dissolved oxygen WFD classifications and results (local EA data).

August had the lowest mean DO solubility potential, however, due to higher mean oxygen demand in July, the observed DO concentrations were also equivalent in July (**Figure 19**).

Step 2: Definition of background oxygen demand

The background measured (observed) mean monthly DO concentration (**Figure 19**, blue dashes) was subtracted from the fully saturated concentrations (**Figure 19**, blue dots) to

[3] By selecting a high oxygen demand value the resultant predictions of DO concentration are pessimistic i.e. a purposefully precautionary approach
[4] Available for spreadsheet download and manipulation from USGS (2017)

provide monthly average drawdown/demand values (i.e. 'Monthly average demand', **Figure 19**).

The background DO drawdown value varies slightly across the year, due to the multiple factors that contribute to the overall demand, which will include BOD and COD (including bed and suspended sediment oxygen demands), phytoplankton cycles and natural reaeration. The April observed values are skewed by two of the 18 April samples, which appear as high outliers that were taken on the same day (07/04/2015). Removal of these two samples for this exercise shows a consistent monthly curve as shown in **Figure 20**.

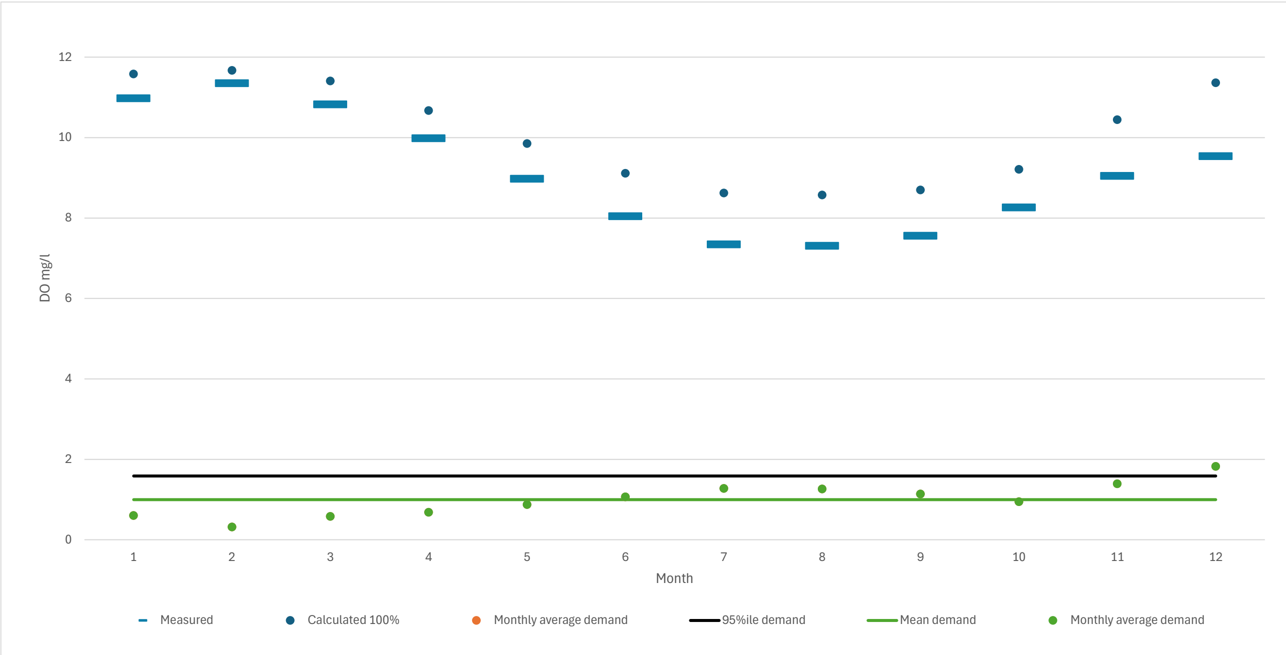

Figure 20: Site-specific dissolved oxygen WFD classifications and results (local EA data). Two data outliers (07/04/2015 data) removed.

The mean DO drawdown value across the year was 1.0 mg/l (**Figure 20**, green line) and there was only modest seasonal variation in monthly demand from this mean value (**Figure 20**). Given the DO WFD threshold is designed to use annual DO data sets, the annual mean drawdown value (i.e. 1.0 mg/l) could reasonably be applied within the assessment as a proxy for the demand across the year with the appropriate percentile considerations as dictated by WFD thresholds (Defra 2015) applied to the resultant concentration series. To ensure a precautionary approach was adopted for this assessment however, a worst case monthly drawdown value of 1.82 mg/l (**Figure 20**; December drawdown) was taken forward for use in the assessment and applied to all times of year. This value was deemed sufficiently precautionary to adequately account for any additional small-scale variation in other contributory DO demand factors (as indicated above) which could be caused by scenario temperature rise.

Step 3: Establishing 100% saturation concentrations for Saltend scenario discharge

For the purposes of this specific assessment a worst-case predicted Saltend temperature scenario was defined using the Mabbett thermal modelling outputs (initial enveloping scenario). The DO WFD threshold requires consideration of a scenario 95th percentile – the greatest 98th percentile temperature uplift from ambient seen at any point within the Dock, associated with the 40°C discharge scenario was 1.0°C. Note, using the 98th percentile temperature modelling output here ensures an initial precautionary approach. This uplift of 1.0°C was applied to all measured data (from relevant local EA survey data). Clearly, as shown by the thermal modelling output contour plots (**Figure 11**), a 1.0°C uplift would only be expected in very localised areas and its application across the entire study area for this specific assessment is done purposely to demonstrate the precautionary nature of the assessment. The scenario temperature and associated DO predictions are thus designed to represent a precautionary or enveloping worst case Saltend operation scenario, for illustrative purposes only, and which would be iterated should this show potential issues with regards DO.

The resultant temperature 'scenario data' were then combined with the same salinity data used in the background definition, and the solubility equations (Benson & Krause (1980, 1984)) were applied to calculate the theoretical 100% saturated DO concentrations, for this theoretical worst case set of parameters. Illustrative results are shown on Figure 21. The 'Scenario after baseline demand' applies the baseline demand, whereas the 'Scenario assuming worst case (95%ile) demand' assumes the 95%ile background monthly oxygen demand value irrespective of the time of year.

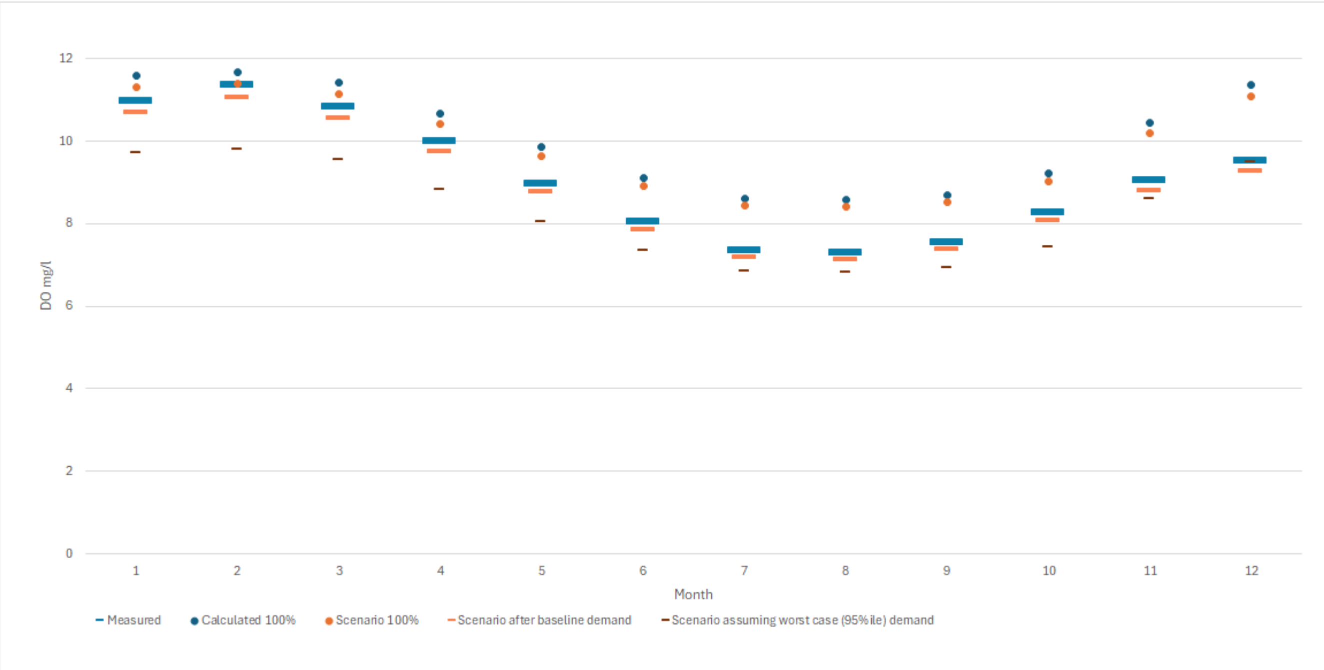

Figure 21: Effects of a 1.0°C uplift to the dissolved oxygen data (illustrative purposes only)

Step 4: Applying the background oxygen demand to the scenario data

The baseline temperatures were adjusted (each uplifted by 1°C) – representing a highly precautionary assessment, that relates to a blanket 1°C uplift across all survey locations within the Humber. As already noted, this is adopted as an initial enveloping scenario – clearly beyond any actual predicted modelling results.

The theoretical 100% saturation values for these adjusted temperatures were then calculated, before the baseline and worst case (95%ile) DO demand was applied across all months (**Figure 21**). Thus extremely precautionary future scenario DO concentrations were calculated, as 5th percentiles for WFD threshold comparison.

Step 5: Comparing against WFD thresholds

The HUMBER MIDDLE and the HUMBER LOWER water bodies are classified (2019 & 2022) as High Status for dissolved oxygen. The Environment Agency data identified in the proximity of the King George's Dock were downloaded and analysed and these data were also found to be consistent with High status (**Figure 18**).

Figure 22 shows the predicted effects on dissolved oxygen classification should temperature at all monitoring sites be uplifted by 1°C. As would be expected a reduction in DO concentration is exhibited, however there is no deterioration from High Status, either when background demand is applied (orange line, **Figure 22**) or when a 95% background demand is applied irrespective of the time of year (dashed black line, **Figure 22**).

This entire scenario is presented for illustrative purposes only, noting that the Mabbett thermal modelling outputs predict this maximum uplift of 1.0°C in some isolated spots only (order of a few m^2 only) and there are thus predicted to be zero or negligible temperature increase at all WFD monitoring locations.

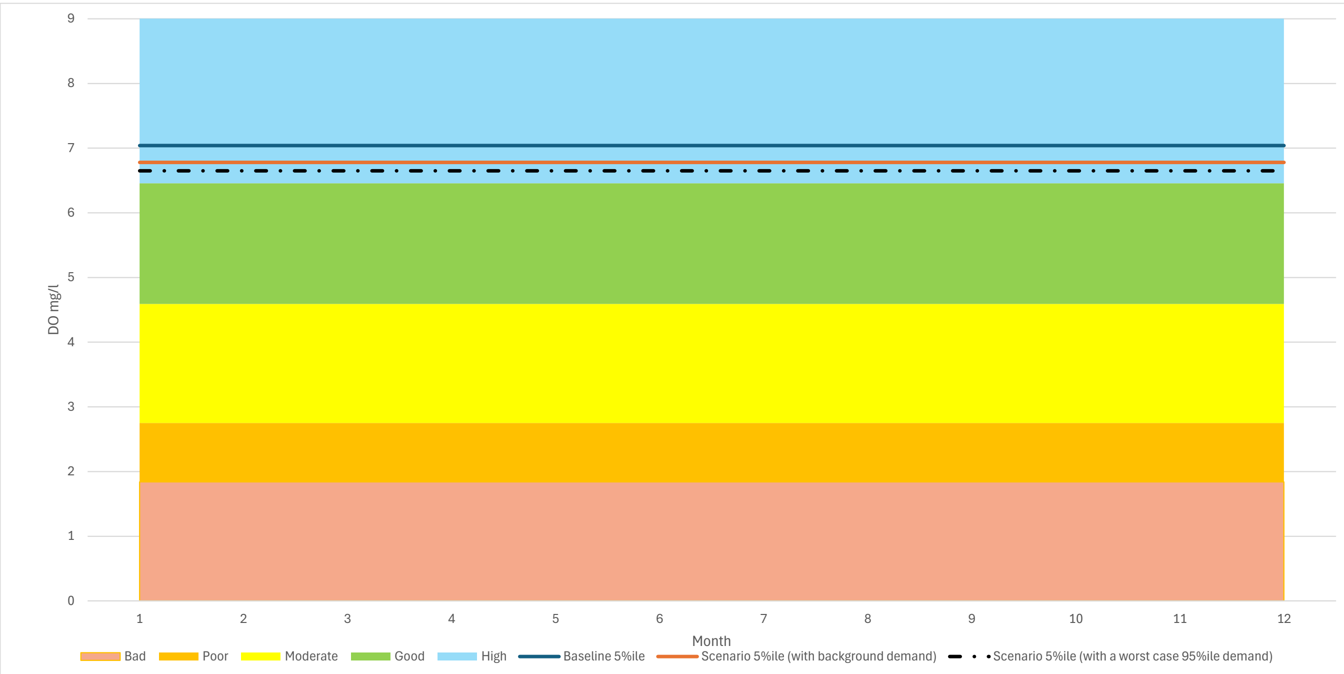

Figure 22: Site-specific dissolved oxygen WFD classifications and results (local EA data – solid lines). Illustrative temperature uplift scenario (assuming 1.0°C uplift to all sites).

All future scenario 5th percentile concentrations (derived in Step 4) of greater than 6.46 mg/L would therefore be consistent with High status conditions. There is no specific threshold for an acceptable area failing to meet a WFD objective for a WFD supporting element, consequently any assessment relating to areas that fail to meet good status for DO would be qualitative and based on professional judgement. This final qualitative assessment (**which is not required in this instance**) would be conducted taking into account the effect on the river channel (e.g. the extent to which the change impedes on the channel cross section), the size of the relevant WFD waterbody and any other pertinent considerations as appropriate (such as the temporal extent of exceedance, consideration of sensitivity and distribution of specific receptors of interest; EC 2010).

6.1.6 Indirect DO Assessment Results

Thermal model temperature predictions were used to inform an enveloping (exaggerated worst case) temperature uplift derived using the maximum 40°C discharge modelling uplift predicted for any one location.

For illustrative purposes, the maximum uplift (1.0°C) seen at any individual location was applied to all baseline monitoring data and the revised dissolved oxygen concentration calculated. Even under these extreme (and not realistic) parameter assumptions the DO threshold for High status is met. In reality, the area actually predicted to exhibit a temperature uplift of 1.0°C (or approaching this value) is extremely limited i.e. of the order of a few m^2 within a small portion of the navigation lock only (**Figure 15**). Thus any effects on dissolved oxygen are predicted (with high confidence) to be negligible.

6.1.7 Indirect DO Assessment Discussion

The method described here has been developed based on the following considerations:

- it is a quantitative approach, utilising the best available data (i.e. monitoring and survey data for DO, salinity and temperature);
- it allows for the use of the Saltend project thermal models, which provide the best predictions of project specific temperature rise and long-term background ambient temperature;
- it provides DO predictions in mg/l i.e. actual concentrations, rather than an alternative approach which may limit an assessment to just changes in percentage saturation; thereby allowing direct comparison of results against WFD thresholds;
- it would enable the identification and consideration of specific areas that fail to meet a given concentration (i.e. size of DO 'mixing zone') – however no failures are predicted in this instance.

The method does not account for any theoretical localised increases in bacterial respiration rates that may increase local demand. However the time lag associated with any increased respiration may well be greater than the residence time of bacteria within the higher temperature plume areas due to the extremely small areas of predicted temperature uplift. The well mixed nature of the dock is evidenced by the water quality profile data, and the close correlation of water quality parameter values in the Dock compared to the adjacent estuary. Consequently, any influence on local DO demand as a result of bacterial respiration rate change is anticipated to be negligible.

The method does not account for any DO supersaturation that may occur over a short time scale, which would have the effect of underestimating the available oxygen at such times. The effects of supersaturation are likely to be relatively short lived and of small scale, however exclusion of any such consideration promotes a precautionary assessment.

Temperature change may affect other indirect DO demand contributory factors such as temperature dependent COD (and Sediment Oxygen Demand (SOD)) and natural reaeration, however the demand value adopted in the assessment was deemed sufficiently precautionary to adequately account for any additional small scale variations. This assumption is supported by consideration of the small scale variation in the background DO drawdown across the year.

Overall the approach is considered to be an appropriate means to demonstrate the negligible scale of change to DO concentrations due to proposed scenario operation of the Saltend power station.

Changes in DO concentration (water quality change) are predicted to be negligible, including in terms of potential deterioration of water body status or the ability of the HUMBER MIDDLE or HUMBER LOWER water bodies to achieve High status for DO (i.e. the predicted changes would not jeopardise the ability of the water body to achieve its current (and target) future DO status).

For wider consideration, water quality is considered to be a pathway that can lead to effects on ecological receptors. The DO results are considered to represent a '**Negligible'** change to the DO water quality pathway due to the proposed maximum temperature discharge scenario of Saltend.

Should a WFD compliance assessment be required in the future, the results of this assessment would support a conclusion of no deterioration (regarding DO). Should a HRA screening assessment be required, the results of this assessment would support a conclusion of no Likely Significant Effects arising from DO change.

6.2 Indirect water quality assessments – Ammonia

This 'indirect' water quality assessment assesses potential indirect effects of scenario temperature increases on ammonia speciation in the local water environment (King George's Dock and the local reaches of the Humber).

6.2.1 Indirect Ammonia Assessment objective

The objective of this investigation was to determine the potential for increases in un-ionised ammonia concentrations as a result of proposed temperature discharges from Saltend power station and to characterise any change in the context of appropriate regulatory thresholds.

This investigation represents an initial screening level assessment, to assess the potential for water quality change in the context of WFD classifications and relevant Environmental Quality Standards (EQS's) and to inform potential effects on any changes to aquatic ecology receptors.

6.2.2 *Ammonia chemistry*

The primary ammonia inputs to the Humber Estuary are likely to be from sewage effluent inputs, from industrial and (upstream) agricultural activities and from the breakdown of organic material. Ammonia has two main forms:

- ammonium ion (NH_4^+); and
- un-ionised ammonia (NH_3).

In general the un-ionised form of ammonia is more toxic to aquatic life (primarily fish). The proportion of un-ionised ammonia increases with increasing temperature and pH, but decreases with increasing salinity. At a pH of 8.5, the proportion of un-ionised ammonia is approximately 10 times that at a pH of 7.5 and, for every 9°C increase in temperature, the proportion of un-ionised ammonia approximately doubles. Salinity has a far smaller effect on ammonia speciation (Johnson *et al*. 2007).

Ammonia is lost from water by volatilisation and, under aerobic conditions, it is oxidised by nitrifying bacteria to nitrite and then to nitrate. Ammonia is not expected to adsorb to soil particulate matter, suspended solids or sediment.

6.2.3 *Scheme interactions*

The existing Saltend discharge is not associated with any discharges of ammonia. It is considered, however, that the proposed scenario increases (to the maximum discharge temperature) could potentially influence ammonia speciation and therefore background concentrations due to increased water temperatures.

6.2.4 *Available data*

The Environment Agency has a network of water quality monitoring stations located throughout the Estuary (notably those set out in **Table 4**), which include monthly surface water sampling for a suite of determinands including:

- ammonia (ammoniacal nitrogen - NH_3 filtered as N);
- temperature (°C);
- pH; and
- salinity.

The data associated with WFD Cycle 2 and 3 were downloaded for those sites of most relevance to the discharge (**Table 4**); noting that these are spread across the border of the HUMBER MIDDLE and the HUMBER LOWER water bodies.

6.2.5 Environmental thresholds

Un-ionised ammonia is classified as a 'specific pollutant' under the Water Framework Directive (WFD) and the current Environmental Quality Standard (EQS) for un-ionised ammonia is dictated by the Water Framework Directions 2015 (Defra 2015). The long term (mean) salt water EQS is defined as 21 µg/l; there is no short term / maximum standard defined for un-ionised ammonia.

6.2.6 Screening methodology

The un-ionised ammonia concentrations were calculated based on the site-specific combination of the relevant water quality parameters, for two theoretical baseline scenarios and two theoretical future scenarios, as set out in **Table 8**. The range of scenarios have been defined to range from average background data (1. Baseline), to theoretical combination scenarios (Scenarios 3 and 4, **Table 8**) that represent worse than expected future conditions. The extreme scenarios effectively represent a +1°C uplift in temperature at all EA monitoring locations. +1°C is the maximum temperature uplift expected (from thermal model outputs) at any single location, thus the assessed scenario represents an extreme bounding scenario far in excess of any predicted actual future conditions.

In summary, scenarios 3 and 4 (**Table 8**) provide extreme bounding cases for this screening assessment (well in excess of what is predicted to be associated with the future operation of the Saltend discharge).

Table 8: Theoretical combinations of relevant water quality parameters that influence un-ionised ammonia concentrations.

Theoretical scenario name	Parameter combination
1. Baseline	All average data (ammonia, temp, pH, salinity)
2. Baseline Max	Max data for all parameters except min data for salinity
3. Baseline + Extreme Scenario	Average data; plus a +1°C increase across all sites
4. Baseline Max + Extreme Scenario	Max data (min for salinity); plus a +1°C increase across all sites

6.2.7 Un-ionised ammonia calculator

Calculations utilise specific equilibrium calculations as defined by the Environment Agency's un-ionised ammonia calculator (EA 2003). The EA calculator takes account of the effect of temperature, pH and salinity to define the relative proportion of un-ionised ammonia for a given total ammonia concentration.

6.2.8 *Indirect Ammonia Assessment Results*

The results of the un-ionised ammonia screening are presented in **Table 9**.

Table 9: Un-ionised ammonia screening results

	Temperature °C	Salinity ppt	pH as pH units	Ammonia µg/l	Un-ionised ammonia µg/l
1. Baseline (all average)	11.3	14.6	7.7	40.13	0.385
2. Baseline Max (min for salinity)	20.5	0.3	8.2	184.00	11.254
3. Baseline + Extreme Scenario	12.3	14.6	7.7	40.13	0.416
4. Baseline Max + Extreme Scenario	21.5	0.3	8.2	184.00	12.047

6.2.9 *Indirect Ammonia Assessment Discussion*

Indirect ammonia assessment results indicate that no sites fail to meet the long-term EQS for un-ionised ammonia (21 µg/l) under any of the (baseline or future bounding case) scenarios - **Table 9**.

The long-term EQS is designed to be used with average background data and therefore comparison of maximum background data (as per Scenarios 2 & 4) against a long-term average EQS (as applied here) is a highly precautionary approach. Furthermore, the assumption of a +1°C temperature rise at all EA monitoring locations represents a highly precautionary assessment approach.

In summary:

- the theoretical combination of maximum background values for ammonia, temperature and pH and minimum salinity is considered unrealistic, although useful in the context of providing a precautionary screening assessment;
- the comparison of maximum data against a long-term EQS is highly precautionary (and has only been undertaken in the absence of a short-term/maximum EQS);
- a theoretical uplift of +1°C to all survey data is highly precautionary given thermal modelling outputs find a +1°C at only spot locations (of the order of a few m^2 total);
- there are no predicted exceedances, compared with the long-term unionised ammonia EQS.

Based on this precautionary and bounding case assessment it is considered that indirect water quality change (due to increased water temperatures) on un-ionised ammonia concentrations in the Dock and the Estuary would not cause any breaches of the long-term EQS – even at the point of discharge. It is therefore proposed to screen out indirect temperature effects on ammonia from further assessment.

Changes in unionised ammonia concentration (water quality change) are predicted to be negligible with regards potential deterioration of the current WFD supporting element status (2022 Cycle 2 status of High).

As above, water quality is considered to be a pathway that can lead to effects on ecological receptors. Based on the results of this screening assessment the ammonia results are considered to represent a '**Negligible**' change to the water quality pathway due to future proposed operation of Saltend Power Station. Should a WFD compliance assessment be required in the future, the results of this assessment would support a conclusion of no deterioration (regarding ammonia). Should a HRA screening assessment be required, the results of this assessment would support a conclusion of no Likely Significant Effects arising from ammonia change.

7. Conclusions

Saltend power station's cooling water discharge to King George's Dock is located within the HUMBER LOWER transitional WFD water body. The dock is approximately 3 km downstream from the boundary of the HUMBER MIDDLE transitional WFD water body, and the adjacent estuary (connected via lock) is designated as the Humber Estuary SAC and SPA.

APEM undertook a single water quality survey campaign of *in-situ* parameters from within the dock. The *in-situ* data confirms that the King George's Dock is well mixed, both vertically and horizontally, with all *in-situ* parameter measurements found to lie within the range of the wider (EA) Humber data for the time of year sampled.

Modelled annual 98th percentile absolute temperatures and temperature rise relative to no discharge (at surface and bed) as provided by Mabbett indicate that dispersion of temperature is rapid across both the dock bed and surface, with the elevated temperature plume restricted only to the dock area and temperatures across both the bed and surface reducing to broadly ambient / background levels upon reaching the estuary.

A systematic review of the modelled temperature scenario outputs relative to relevant temperature thresholds has been undertaken. This review confirms that thermal water discharges from Saltend power station (under current and proposed max scenarios) meet all WFD, SPA and SAC requirements and would not be expected to cause adverse impacts (or WFD deterioration) to the HUMBER LOWER / HUMBER MIDDLE transitional WFD water bodies nor the Humber Estuary SAC / SPA via direct thermal water quality pathways. The proposed thermal water discharge from Saltend power station is also not expected to cause adverse impacts to migratory fish nor shellfish waters via direct thermal water quality pathways.

Indirect changes to Dissolved Oxygen (DO) and ammonia have been assessed, given potential for these water quality parameters to be affected by temperature. Changes in DO concentration are predicted to be negligible, including in terms of potential for the HUMBER MIDDLE or HUMBER LOWER water bodies to achieve High WFD status for DO. Changes in unionised ammonia concentration (water quality change) are predicted to be negligible, similarly with regards negligible potential for deterioration of the current (unionised) ammonia WFD supporting element status (2022 Cycle 2 status of High).

Should a WFD compliance assessment be required in the future, the results of this study would support a conclusion of no deterioration (specifically regarding temperature, DO and ammonia). Should any future Habitats Regulations Assessment be required (presuming to HRA Stage 2 assessment), the results of this current study would support a conclusion of No Adverse Effects on Integrity (No AEoI) with regards the Humber Estuary SAC and SPA.

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Appendix B – Limitations

Limitations

Client: The organisation identified on the report cover after “For”, being the commissioning party.

This report contains recommendations from Arthian, which are based on the information listed in the report and reflect the professional opinions of an experienced Environmental Consultant. Arthian obtained, reviewed, and evaluated information from the Client and others to prepare this report. The conclusions, opinions, and recommendations presented in this report are based on this information. However, Arthian does not guarantee the accuracy of the information provided and will not be held responsible for any opinions or conclusions reached based on information that is later proven to be inaccurate.

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