Keadby Variation - 1 Pump full power

Thermal Extents, Oxygen and Un-ionized Ammonia

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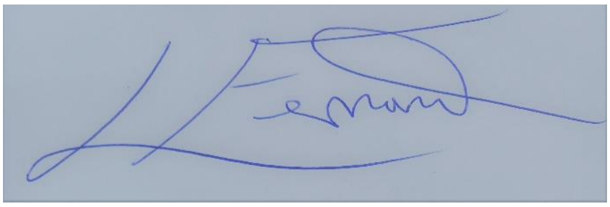

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EXECUTIVE SUMMARY

Keadby Generation Ltd, a wholly owned subsidiary of SSE (SSE) operates the Keady 1 gas-fired power station (the site) in Trentside, Keadby, Scunthorpe, North Lincolnshire, DN17 3EF and is regulated by the Environment Agency (EA) under the Environmental Permit (EP) EPR/YP3133LL.

In early 2022, SSE identified an issue with one of the two cooling water intake pumps, one of which was taken out of service whilst the issue was identified and rectified. By design, Keadby requires two pumps in service during normal running. There is no standby pump. As a result, the volume of cooling water that was being abstracted was reduced and consequently the differential temperature at the point of discharge increased.

Following discussions with the EA, SSE is seeking a permit variation to allow discharge at full thermal capacity on one cooling water pump. Subsequent to this submission the EA responded with a request for specific modelling of the likely plume under the one pump scenario. The updated modelling was designed to address potential for issues associated with the extent of the thermal plume, potential for a barrier to fish migration (thermal occlusion), the potential for enhanced un-ionized ammonia concentrations and changes to oxygen concentration and saturation.

Extent of the thermal plume.   The extent of the surface plume to the 2ºC isotherm is slightly greater in the latest simulations compared to the APEM 2011, work using a similar power station cooling requirement. There is no plume at the bed.

Barrier to fish migration. Analysis of the rivers cross section indicates that the cross sectional criteria will not be exceeded, with typical values of the cross section above the 2ºC limit being around 3-13%, with a brief period at low water slack which reaches 19% of the cross section.

Un-ionized ammonia. The power station cooling water does not discharge increased ammonia, however the increased temperature can increase unionized ammonia concentrations in the receiving waters. Results of the modeling indicate that the discharge is not predicted to cause an exceedance of the EQS.

The oxygen content of the river is generally good with values in excess of 8 mg/l. Oxygen supersaturation can be detrimental to fish health. Analysis indicates that values in excess of 120% are only predicted to occur in the near vicinity of the discharge and only at the surface, with oxygen concentration at 100% saturation within 500 m of the discharge for most scenarios.

1. INTRODUCTION

Keadby Generation Ltd, a wholly owned subsidiary of SSE (SSE) operates the Keadby 1 gas-fired power station (the site) in Trentside, Keadby, Scunthorpe, North Lincolnshire, DN17 3EF and is regulated by the Environment Agency (EA) under the Environmental Permit (EP) EPR/YP3133LL.

In early 2022, SSE identified an issue with one of the two cooling water intake pumps, one of which was taken out of service whilst the issue was identified and rectified. By design, Keadby 1 requires two pumps in service during normal running. There is no standby pump. As a result, the volume of cooling water that was being abstracted was reduced and consequently the differential temperature at the point of discharge increased.

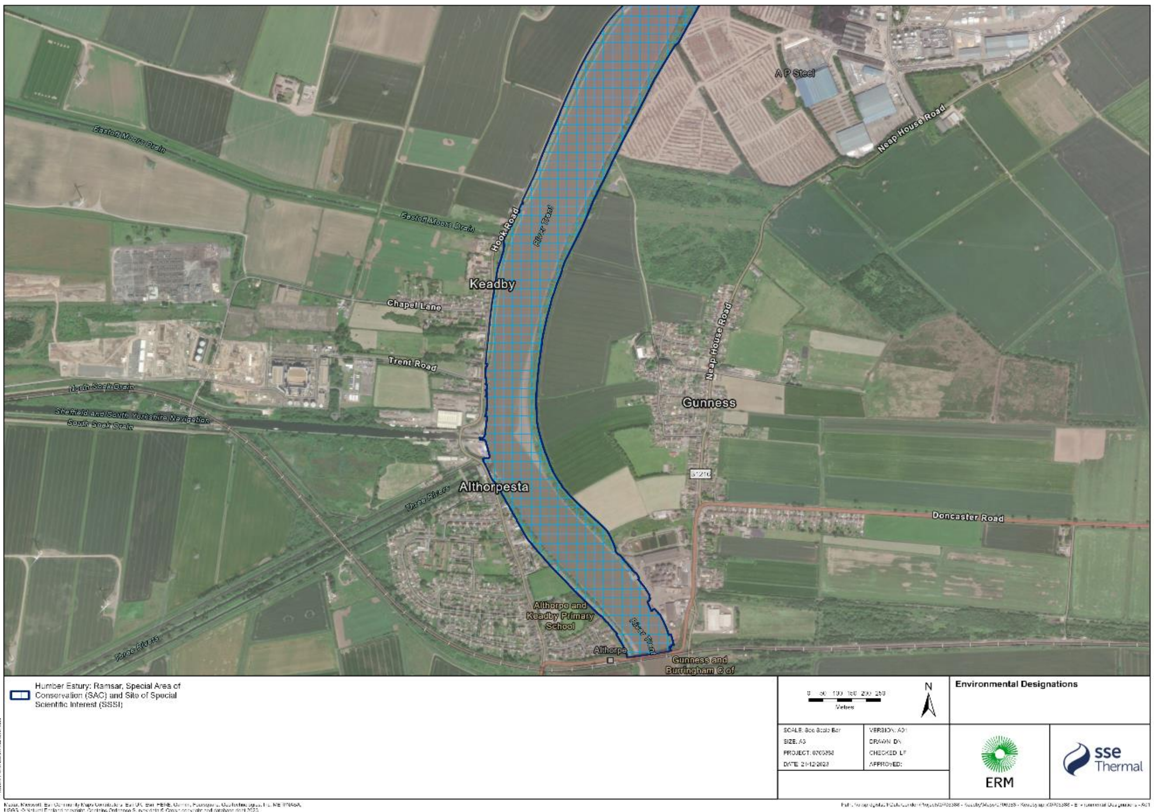
SSE did not wish to breach its permit conditions, consequently the site has had to modify its running and reduce capacity on several occasions over the last few months to avoid exceeding differential temperature limits previously agreed with the EA as part of Improvement Condition 3 (IC3). These limits were agreed based on the operation of two cooling water pumps.

As of 14th October 2021, IC3 was completed and agreed with the EA for several differential temperature limits for the cooing water discharge dependent on the volume of water discharged. SSE has been in discussion with the EA confirming the need for a permit variation to include the additional operating scenario. It was recommended by the EA that a variation application was submitted to cover the one-pump operating scenario.

SSE has applied for a permit variation to include an additional one-pump operating scenario of the cooling water pumps serving Keadby 1. This change will include an updated differential temperature limit on the cooling water discharged to the river Trent via emission point W1 (similarly to that agreed as part of IC3).

This variation was submitted as Permit Variation (EPR/YP3133LL) document dated 31st August 2022. This variation based its assessment of potential impacts on evidence from previous modelling conducted by APEM using the CORMIX model associated with the total heat content of the discharge. Subsequent to this submission the EA responded with a request for specific modelling of the likely plume under the one pump scenario, including the small discharge from the adjacent Keadby 2 power station (0.11 m^3/s). The updated modelling was designed to address potential for issues associated with the extent of the thermal plume, potential for a barrier to fish migration (thermal occlusion), the potential for enhanced un-ionized ammonia concentrations and changes to oxygen concentration and saturation. The discharge is to an area designated as an SAC and SSSI (Figure 1-1).

FIGURE 1-1 LOCATION AND DESIGNATED HABITATS



1.1 BACKGROUND INFORMATION AND DATA

1.1.1 ENVIRONMENTAL DATA

Aquatic Data for many water quality determinands has been recorded at the sampling site ID is MD-36693490 at Keadby (Tidal) within the River Trent, which is 1.8km upstream of the outfall site, across 2 years 2014 and 2015. Water temperature and Salinity are available over a longer time span of 2003 – 2015. The recorded temperatures indicate a clear seasonal cycle, where as salinity variation is low; generally around 0.13 ppt but peaks in September at 0.6 ppt. Therefore the river at this location, from a chemical water quality perspective is a tidal fresh water system.

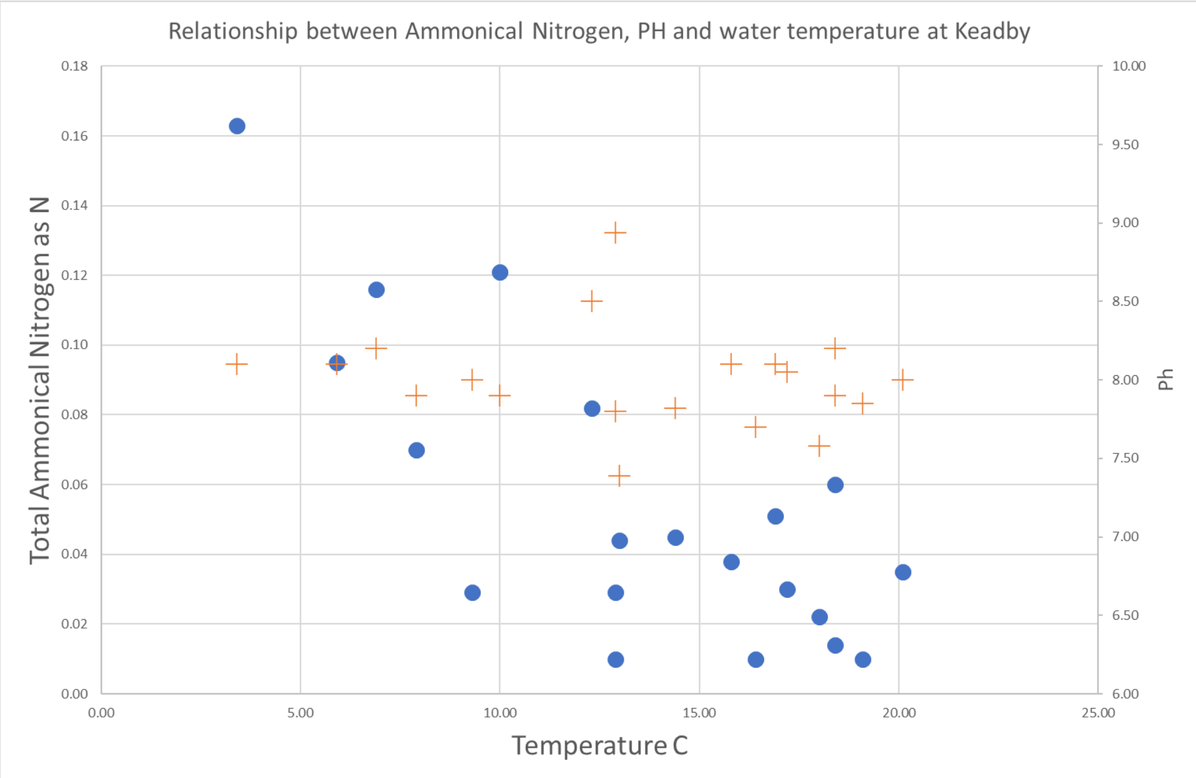
The data download is included in Appendix A. Table 1-1 presents the values employed for the assessment of oxygen saturation and un-ionized ammonia.

TABLE 1-1 SUMMARY OF KEY DATA VALUES

	Ph	Oxygen	Temperature	Total Ammonia
Value	8.01 Annual Average	7.87 mg/l (Summer Months avg Jun, Jul, Aug)	19.1 – 95th centile of temperature	0.0653 mg/l

The data also shows (see Figure 1-2) a strong relationship between ammoniacal nitrogen (blue dots) and water temperature and the expected seasonal plant growth cycle. Therefore, extreme summer temperatures using the mean values of ammoniacal nitrogen concentration are considered to be appropriate (and a conservative estimate) for the un-ionized ammonia calculations. For pH (orange crosses) there is no clear link with temperature and therefore average pH is used in this assessment.

FIGURE 1-2 RELATIONSHIP BETWEEN AMMONICAL NITROGEN AND PH



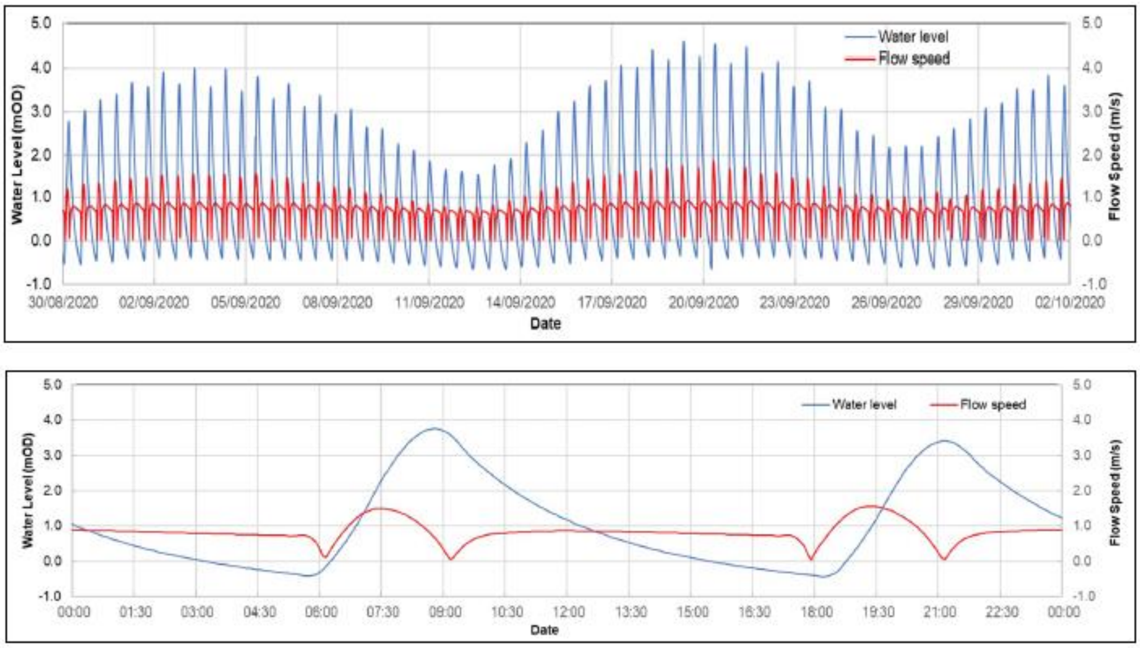
1.1.2 TIDAL VELOCITY AND ELEVATIONS.

Tidal velocity and elevations have been taken from the AECOM 2022 report. An important feature to note is the significant asymmetry in the tidal shape in that the ebb tide, with water flowing north towards the Humber occurring for much longer than the incoming (flood) tide. It is also important to note the shape of the velocities on the ebb tide. For example at high water slack there is a period for approximately 30 min when velocities are less than 50 cms^{-1} and at around 15 cms^{-1} for 15 mins, thereafter velocities rapidly return to above 75 cms^{-1} for the remaining ebb period, before a similar feature at low water slack.

TABLE 1-2 TIDAL LEVELS KEADBY ODN (ORDANCE DATA NEWLYN)

MHWS	MLWS	HW (95^{th} Centile)	LW (5^{th} Centile)
4.3	-0.4	3.7	-0.4

FIGURE 1-3 TIDAL ELEVATIONS AND VELOCITY (FROM AECOM 2022)



2. MODELLING SETUP

2.1 MODEL SELECTION

To determine the size of this thermal plume, the near-field model, CORMIX (Version 12.0), was chosen. CORMIX[1] has been applied to many similar cases and is recognized by many environmental agencies world wide as an appropriate model for computing trajectories, dilution rates, and mixing zone dimensions.

CORMIX has a number of different modules, applicable to different plume scenarios. Tests were under taken to identify which module would most effectively represent the plume, considering that the plume will be strongly buoyant . Details on the tests performed and the setup of the discharge configuration employed for the modeling are presented in Section 2.2.

CORMIX is a steady-state model, i.e., each application represents a single snapshot of the thermal plume under a selected static combination of ambient and discharge conditions. However, ambient conditions are not static, and to represent the dynamic nature of these ambient conditions, a series of simulations are developed. These simulations provide a range of thermal plume configurations and bound the thermal plume size. To develop these thermal plume bounds, ERM performed eight (8) scenarios to represent the varying ambient conditions. Details of each scenario are presented in Section 2.3.

A typical CORMIX application requires three types of data as inputs:

- A description of the effluent (i.e., flow and temperature);
- The dimensions, location, and configuration of the discharge structure; and
- The properties and characteristics of the receiving waterbody—in this case, the River Trent (i.e., depth, flow rate, and temperature).

SSE has supplied operational information, such as effluent temperature, discharge locations, and planned flow rates. Ambient water quality condition data was obtained from a previous CORMIX study completed for the location (AECOM, 2022) which was undertaken as part of the Keadby 3 application. Details of the ambient conditions used can be found in Section 1.1.

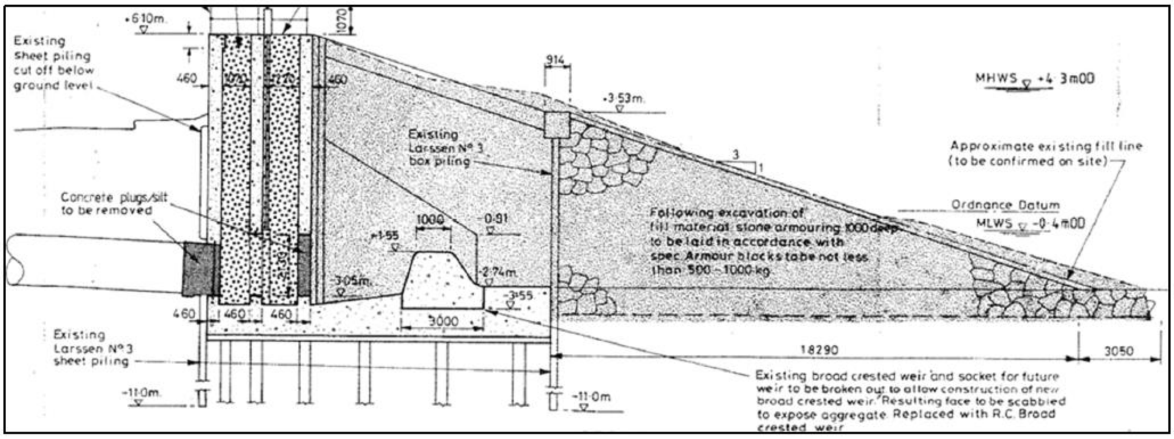
2.2 DISCHARGE OUTFALL MODELING CONFIGURATION

Evident from aerial image below is that the discharge is set back in an indent from the main river at the position given in Table 3. The discharge consists of a pipe diameter of 1.83 m with discharge in to the indent at -3.05 m ODN, as presented in Figure 2-1. There is also sill so that’s its height is about level with the top of the pipe a short distance (approx. 3m) from the discharge. The effect of this sill is that at low water the sill and river levels are similar. Due to the large buoyancy of the discharge and the momentum of the discharge, the effect of the sill will be to constrain the initial flow upwards and sideways, so that the volume of water between the discharge pipe and the sill will contain the discharge effluent. In effect the indent becomes full of high

[1] http://www.CORMIX.info/

temperature discharge water. This can therefore be considered as source to the adjoining channel.

FIGURE 2-1: PLAN CONFIGURATION OF DISCHARGE LOCATION

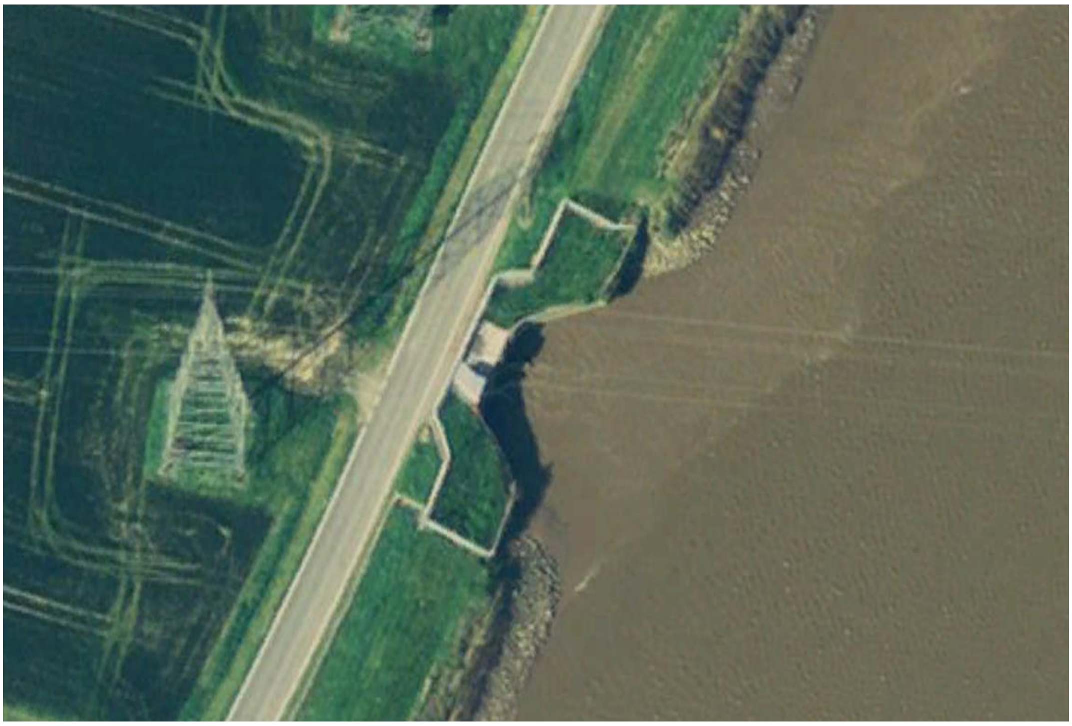


Source: *AECOM 2022*

The CORMIX3, CORMIX's Surface (Shoreline) Discharges module, was therefore used as this considers the discharge an outfall channel, with depth -1.55 m ODN, which corresponds to the depth of the broad crested weir located at the front of the discharge pipe, as presented in Figure 2-1. The width of the channel was taken to be 10 m. This value was taken from a measurement of the width of the interior concrete wings shown in Figure 2-2. The channel was oriented to discharge into the river perpendicularly and had a flat bottom slope. The local depth at the outfall location was set to be the same as the average ambient depth for the corresponding scenario.

A CORMIX module (CORMIX 1 Single Port Module) which represents the discharge pipe configuration more accurately was trialed but was not stable at water depths beneath high water.

FIGURE 2-2: AERIAL VIEW OF DISCHARGE LOCATION



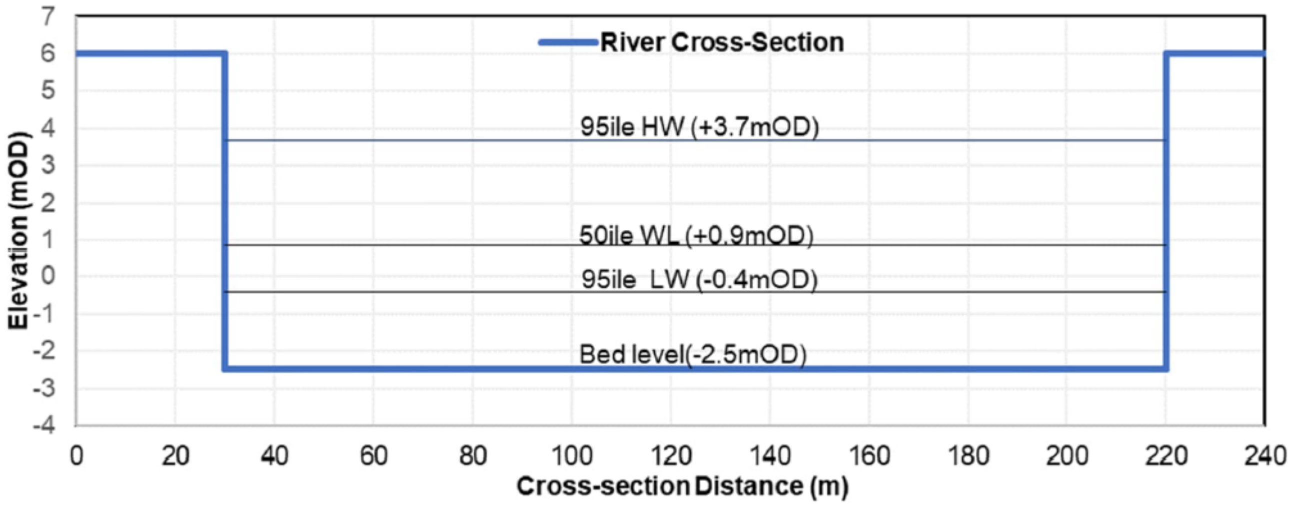
Source: *Google Earth Pro*

TABLE 2-1 LOCATION OF DISCHARGE

Lat	53	35	59.52	N	53.59987		Northing	412219
Long	0	44	14.56	W	0.737378		Easting	483654

It is also important to note that the river in CORMIX is represented by a one-dimensional channel and is further simplified to a rectangular cross-section with an average depth and width over the area of interest. The schematized channel that represents the river channel is presented in Figure 2-3.

FIGURE 2-3: SCHEMATISED RIVER CHANNEL



Source: *AECOM 2022*

2.3 SCENARIO DEVELOPMENT

A total of 8 scenarios were developed, one for each of the different tidal stages of this system as stated in the AECOM 2022. These tidal stages include low water, flood tide, high water, and ebb tide. The flood tide stage at this location lasts approximately 3 hours whilst the ebb tide stage lasts 9 hours. Due to these long periods of time for each of these stages, two scenarios correspond to the flood tide stage, three for the ebb tide stage and one each at high and low water. The variations between the scenarios include differences in water levels and ambient velocities. Table 2-2 contains the varying input conditions for each scenario.

TABLE 2-2: VARYING INPUT PARAMETERS FOR EACH SCENARIO

Scenario Name	Tidal Stage	Tidal Velocity (m/s)	Tide Level (mOD)	Water Depth (m)
1	Low Water 1	0.11	-0.4	2.1
2	Flood Tide 1	0.58	0.2	2.7
3	Flood Tide 2	0.84	0.6	3.1
4	High Water	0.11	3.7	6.2
5	Ebb Tide 1	0.75	2.54	5.04
6	Ebb Tide 2	0.86	0.9	3.4
7	Ebb Tide 3	0.77	0	2.5
8	Low Water 2	0.89	-0.4	2.1

Source: *AECOM 2022*

3. RESULTS

3.1 THERMAL PLUMES.

The modelling indicates that the thermal plume is predicted to be extremely buoyant. Figure 3-1 shows the shape of the plume as assumed by CORMIX3. In this particular case since the discharge is close to the shore, the maximum values of the plume are expected to lie along the bank. Whilst CORMIX does model conditions at the discharge, it does not model or interact with the subsequent geographic positions. Hence the plots below have been generated in GIS by assuming a direction of discharge unchanged by changes in bathymetry, or river topography. In a canalised channel, such as occurs in the vicinity of the discharge, this is a valid assumption.

FIGURE 3-1: ASSUMED CROSS-SECTIONAL SHAPE

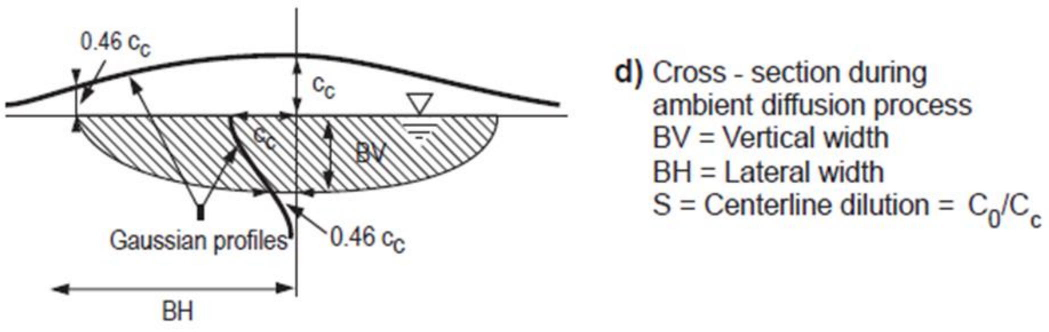


Figure 5.5 *Cross-sectional Distributions of CORMIX Predicted Jet/Plume Sections.*

Source: *CORMIX Manual (Doneker and Jirka, 2021)*

The plots in Figure 3-2 to Figure 3-6 indicate the expected shape of the plume from high water (Scenarios 4, 5,6,7,1) to low water, for the 1st 800m downstream. It is worth noting that in Scenarios 1 and 4, the slack water conditions last for 20 mins with low velocities of 0.11 m/s. It would be expected that the plume would travel 130m in that time and not as far as the extent shown below. After the period of low velocity at high water slack (Scenario 4 Figure 3-2) the rapidly increasing river flow results in the plume, which is much more tightly constrained (Scenario 5 Figure 3-3) and mixes down as well. Therefore the plume is long and thin and hugs the bank; this is also true for Scenarios 6 and 7 (Figures 3-4 and 3-5). As the water level drops towards low water then the river flow drops for a brief period around low water slack; the shape of the plume at this time is highly buoyant but spreads across the river (Figure 3-6).

FIGURE 3-2 SCENARIO 4 HIGH WATER SLACK

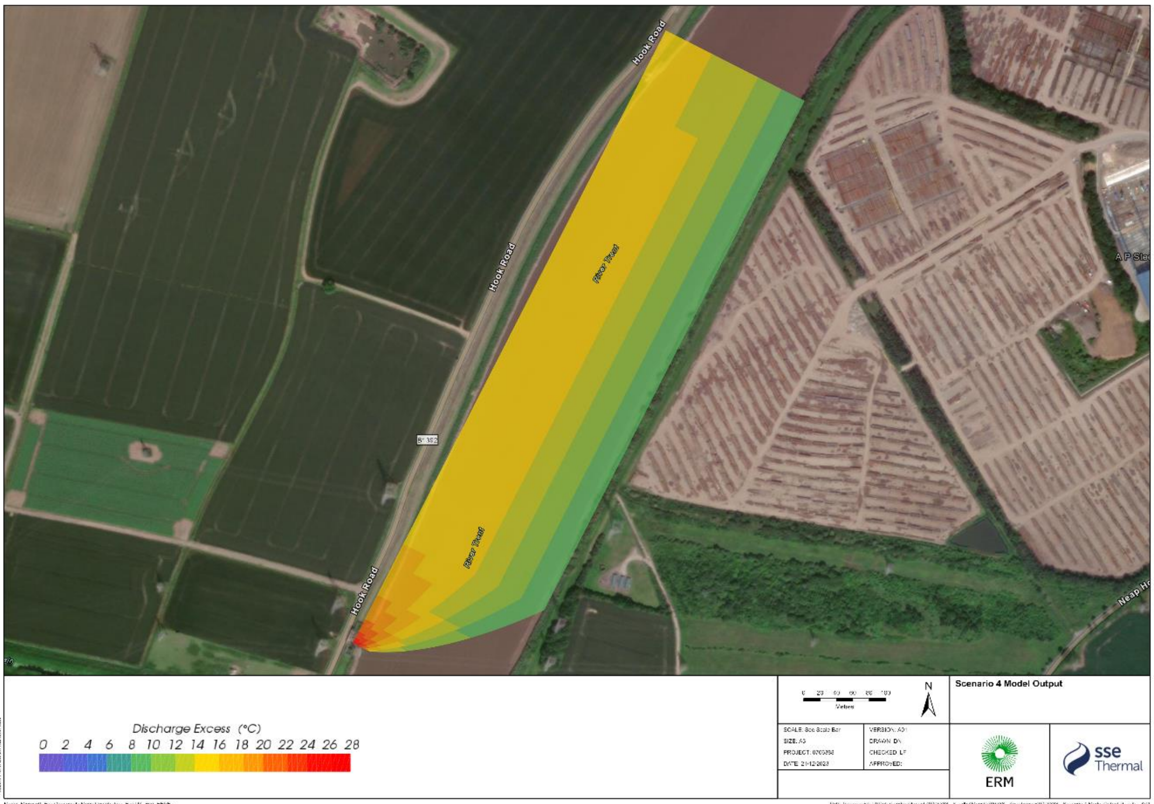


FIGURE 3-3 SCENARIO 5: 1- 3HRS AFTER HW

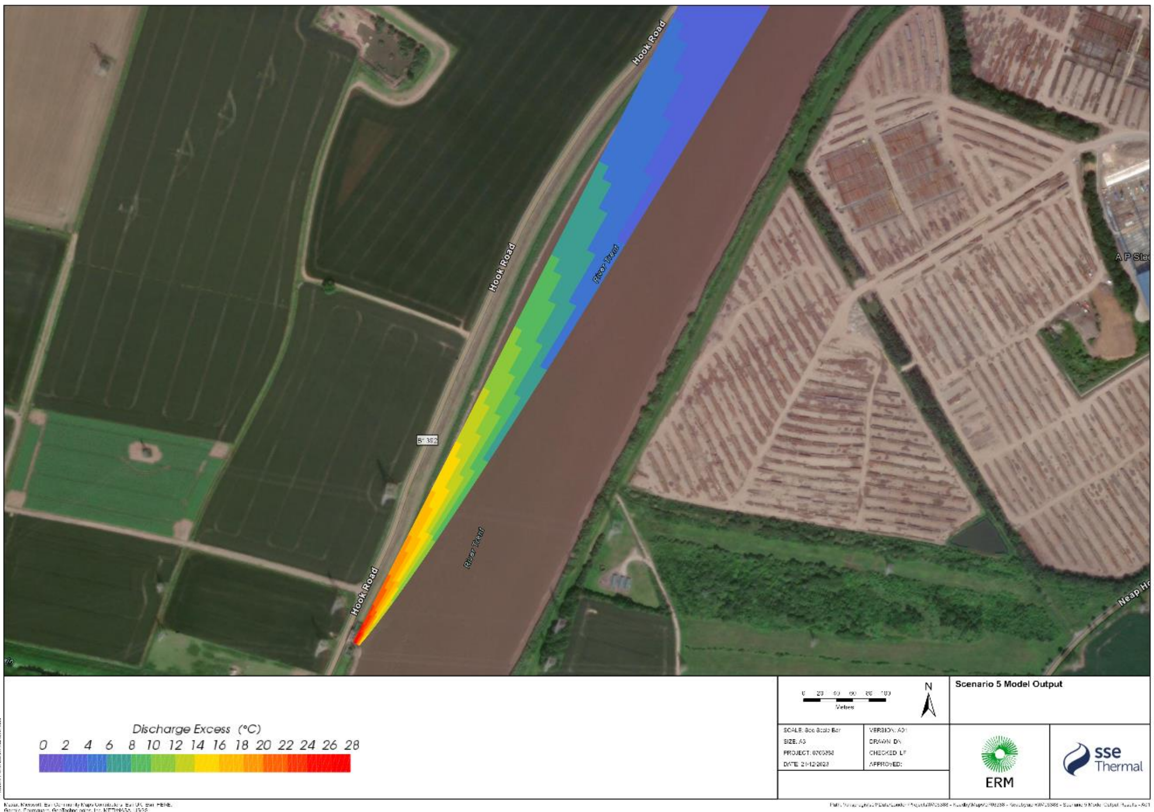


FIGURE 3-4 SCENARIO 6: 3- 6 HRS AFTER HW

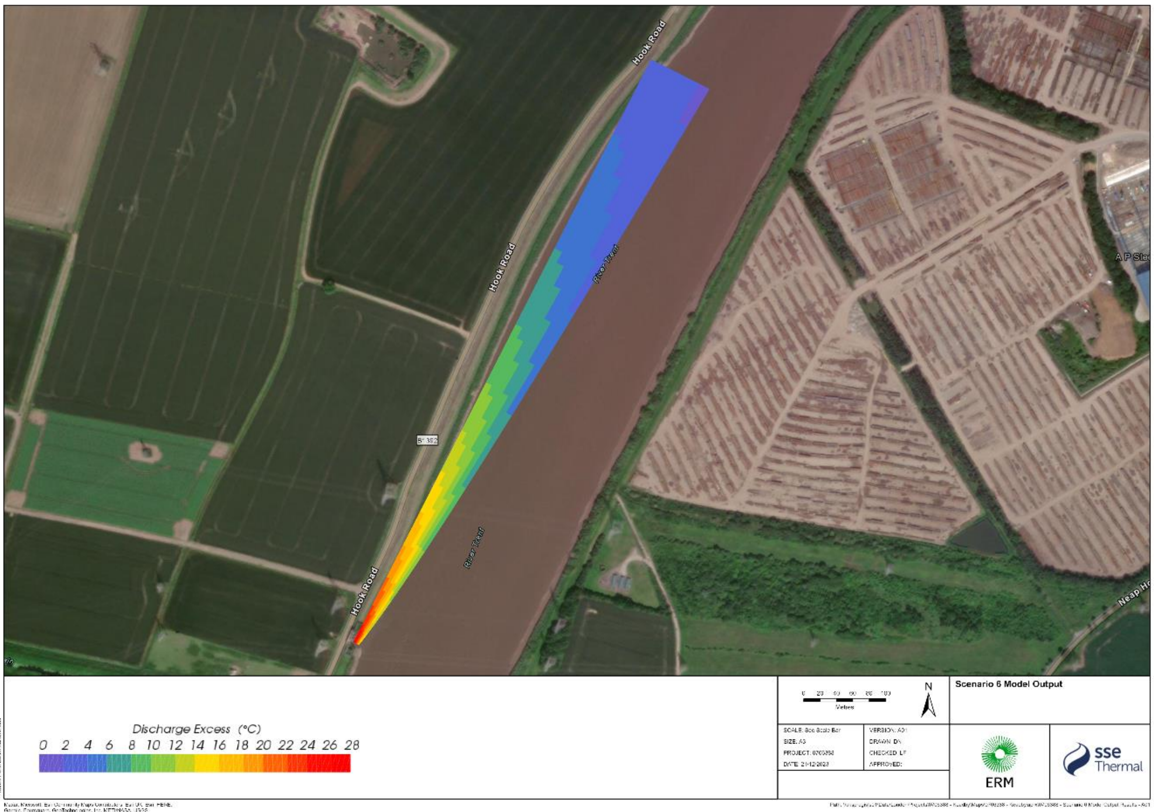


FIGURE 3-5 SCENARIO 7: 6 - 9 HRS AFTER HW

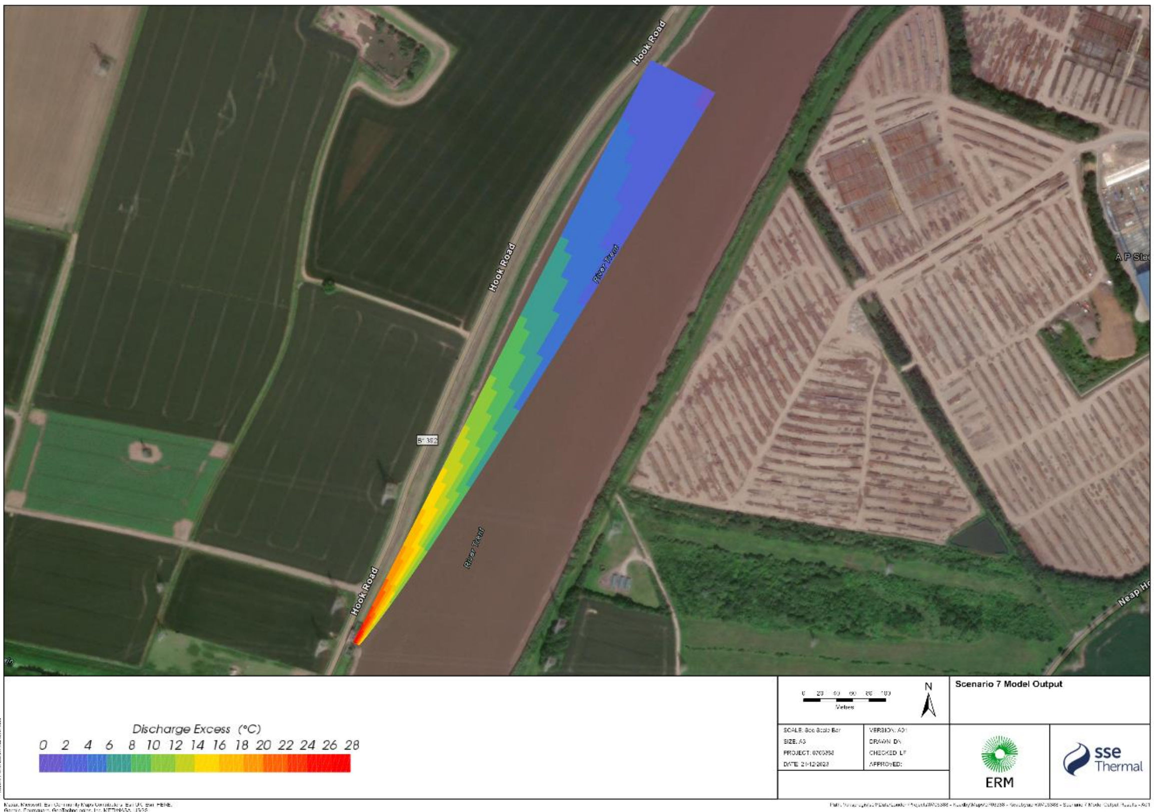
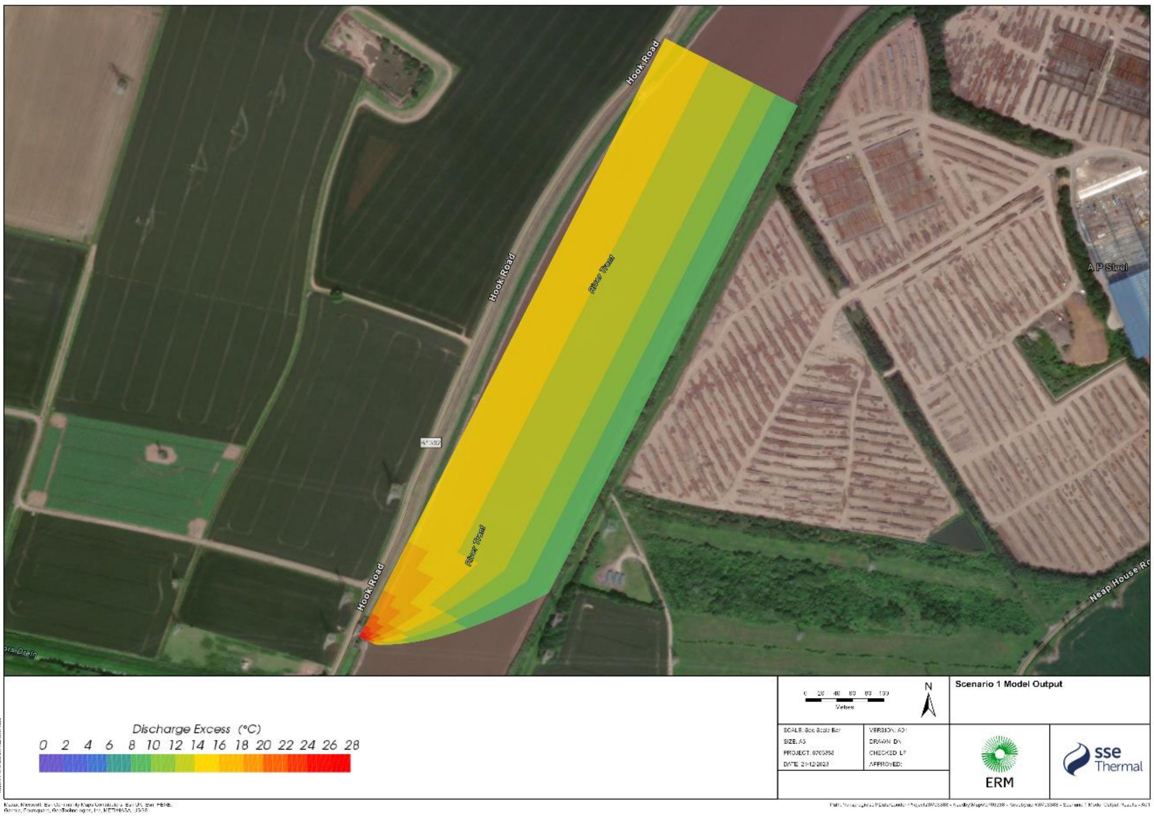


FIGURE 3-6 SCENARIO 1: LOW WATER SLACK



3.2 CROSS SECTIONS

The images below present a cross-section of the model output looking down stream of the discharge. With the discharge on left hand of the image. The scenario at high water (Figure 3-7) shows a thin buoyant plume which spreads across channel to the far bank. Figure 3-8 is representative of most of the ebbtide (or flood tide) and shows the effect of the strong tidal flow which constrains the plume to one side of the channel. The plume is still strongly bouyant and becomes quite thin and is eventually mixed down once it has lost significant excess heat. Figure 3-9 shows the condition at low water slack; it is similar to the high water configuration in that it spreads across the entire channel, but occupies a much greater volume of the cross section of the channel, as the water depth is low.

FIGURE 3-7 SCENARIO 4 CROSS SECTION AT HIGH WATER SLACK

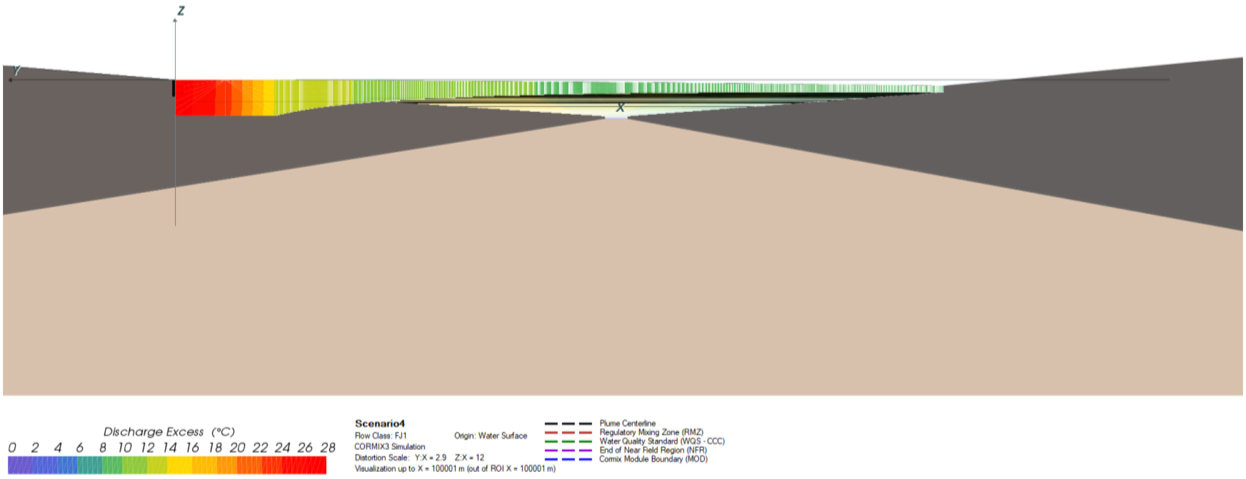


FIGURE 3-8 SCENARIO 6 REPRESENATIVE OF MOST OF THE EBB TIDE

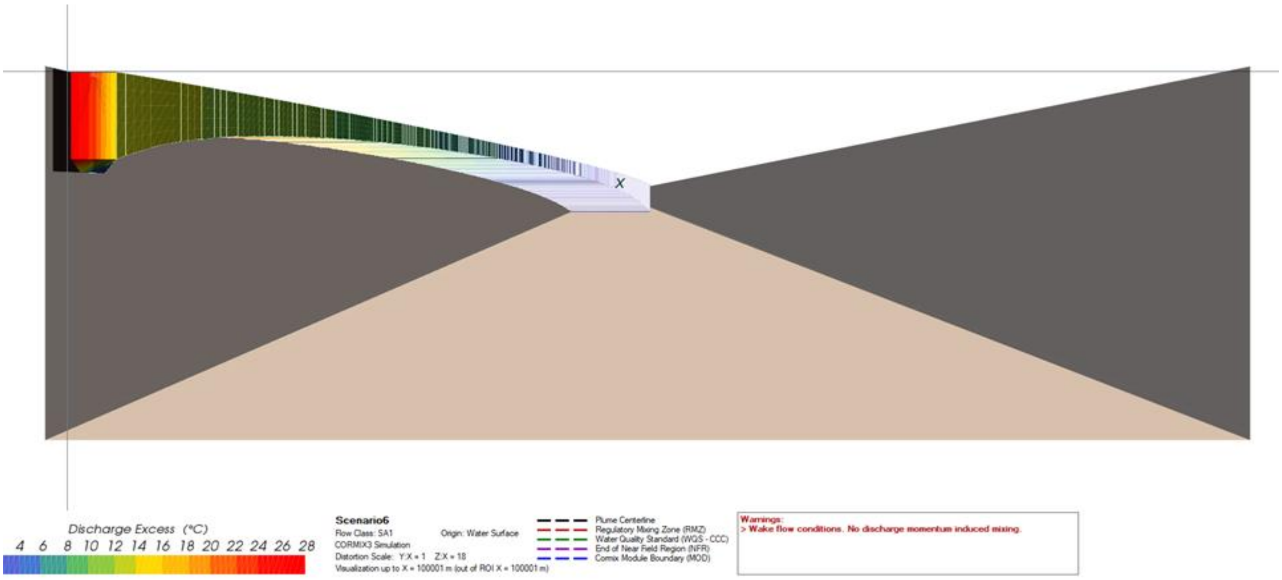
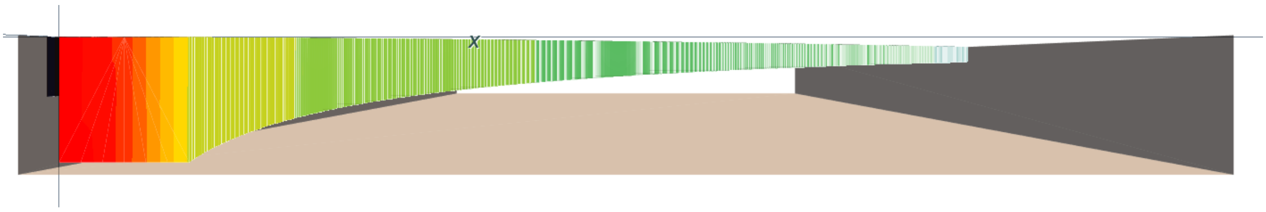


FIGURE 3-9 SCENARIO 1 LOW WATER SLACK



4. ANALYSIS OF RESULTS

The EA existing thermal standards specify that a temperature uplift above 2°C, should not occupy more than 25% of the cross section of an estuary for more than 5% of the time (UKTAG 2008). Evident from the cross sections above, the plume which is strongly buoyant is predicted to mostly lie on the surface until it has lost heat when it then mixes down. Quantitative analysis of each scenario is shown in the Tables below. The analysis indicates that most scenarios occupy only a small fraction of the river cross section above 2°C. The only exception to this is at low water slack when the cross section in excess of 2°C reaches up to 19%, though still less than the 25% criteria. It should also be noted that the period of low water slack is only approximately 20 min every 12 hrs, i.e. 2.8% of the time, less than the EA 5% criteria.

4.1 THERMAL OCCLUSION CROSS SECTION

TABLE 4-1 PERCENTAGE OF CROSS SECTION ABOVE 2 °C

Scenario 1 Low Water --0.4 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	9%
200 m	19%
500 m	19%
1000 m	19%

Scenario 3 Flood tide 0.6 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	1%
200 m	1%
500 m	2%
1000 m	7%

Scenario 2 Flood tide 0.2 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	1%
200 m	1%
500 m	3%
1000 m	7%

Scenario 4 HW 3.7 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	3%
200 m	7%
500 m	7%
1000 m	7%

Scenario 5 EBB 2.5 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	1%
200 m	1%
500 m	1%
1000 m	3%

Scenario 7 EBB 0 ODN	
Cross >2C at Distance from Discharge	**Value**
100 m	1%
200 m	1%
500 m	3%
1000 m	9%

Scenario 6 EBB 0.9 ODN	
Cross >2C at Distance from Discharge	**Value**

Scenario 8 Low -0.4 ODN	
Cross >2C at Distance from Discharge	**Value**

100 m	1%
200 m	1%
500 m	2%
1000 m	6%

100 m	1%
200 m	1%
500 m	4%
1000 m	13%

TABLE 4-2 DISTANCE ALONG CENTRE LINE (M) FOR EACH SCENARIO USING 19.1°C AMBIENT FOR THE SURFACE PLUME .

Scenario Name	**Tidal Stage**	**Tidal Velocity (m/s)**	2°C excess	21.5 °C absolute	28 °C absolute.
1	Low Water 1	0.11	15 °C excess after 20 min		
2	Flood Tide 1	0.58	1370	1251	532
3	Flood Tide 2	0.84	1021	931	405
4	High Water	0.11	16 °C excess after 20 min		
5	Ebb Tide 1	0.75	1250	1141	491
6	Ebb Tide 2	0.86	1019	932	404
7	Ebb Tide 3	0.77	1051	961	416
8	Low Water 2	0.89	891	814	355

It should be emphasized that this is a surface plume, with no interaction with the bed except at the point of discharge. Analysis of the cross section shows that the cross sectional criteria is not exceeded, with typical values of the cross section above the 2 °C limit being around 3-13%, except during slack tide when it may reach 19%.

4.2 UN-IONIZED AMMONIA

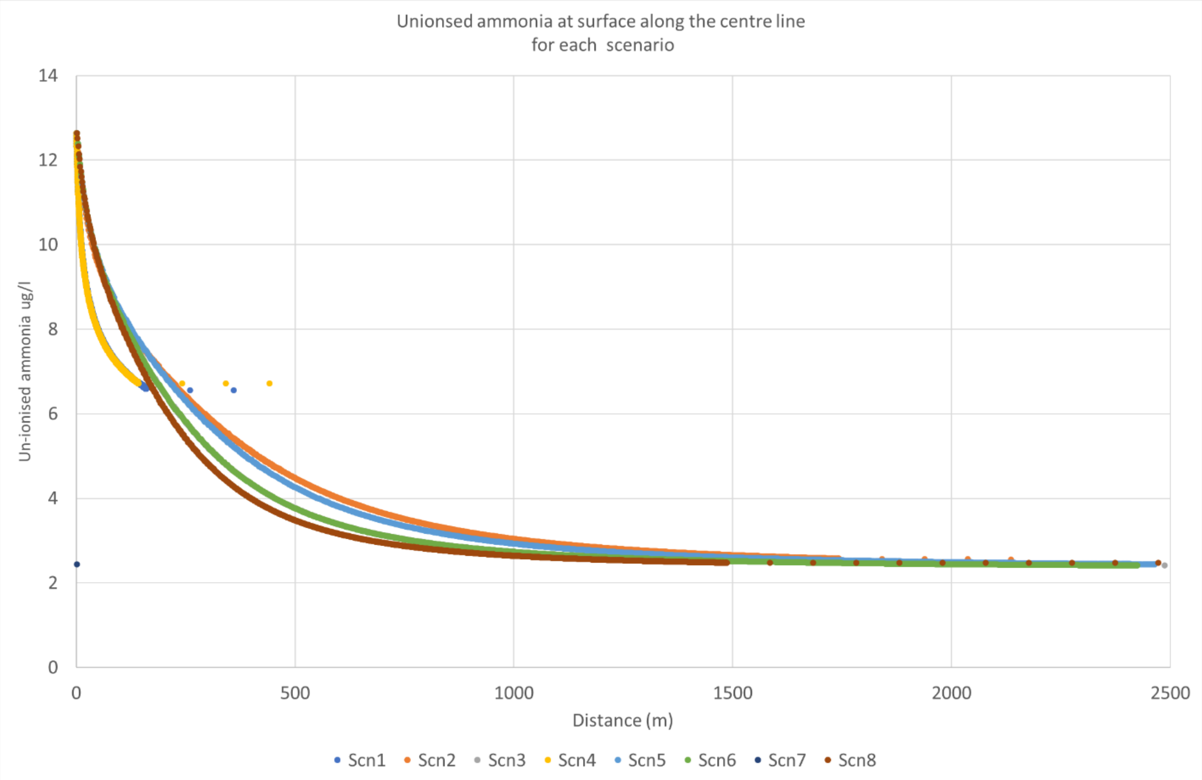
Ammonia enters freshwater bodies from sewage effluent inputs, from industrial and agricultural activities and from the breakdown of organic matter. In general, the un-ionized form of ammonia is more toxic than the ionized form. At higher pH values, un-ionized ammonia represents a greater proportion of the total ammonia concentration. Temperature increase also raises the relative proportion of un-ionized ammonia, but this effect is much less marked than for pH change. A greater percentage of ammonia will also be in the un-ionized form when the salinity is lower.

The concentration of un-ionized ammonia can therefore be derived from knowledge of the total ammoniacal nitrogen concentration (i.e. NH4 as N), the salinity, the pH and temperature using the EA calculator. The EQS for un-ionized ammonia is 21 µg/l expressed as an annual average.

Although the power station is not discharging nitrogen into the water course, it is changing the temperature and this will in turn affect the Ammoniacal nitrogen : un-ionized ammonia ratio, increasing the un-ionized element.

Figure 4-1 demonstrates the modelled un-ionized ammonia concentration along the centre line of each simulation, using peak summertime river temperatures of 19.1 ⁰C and therefore a discharge temperature of 47.1 ⁰C degrees with mean values of pH, 8.01 and ammoniacal nitrogen 0.0653 mg/l. The results show initially high values of 12 ug/l which then drop as the temperature decreases away from the discharge. There are no predicted values above 21 ug/l, thus the EQS is not predicted to be exceeded.

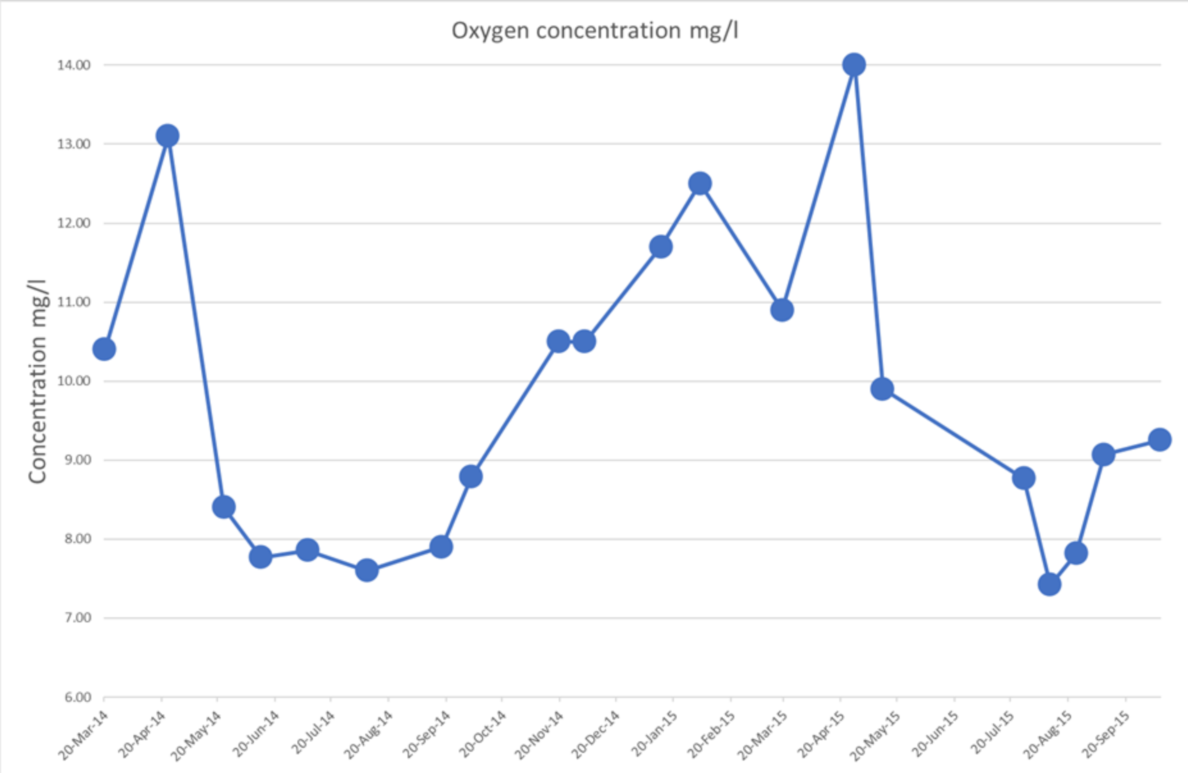
FIGURE 4-1 UN-IONIZED AMMONIA ALONG CENTRE LINE FOR EACH SCENARIO



4.3 DISSOLVED OXYGEN

The seasonal cycle of oxygen concentration for the River Trent near Keadby has peaks in April (see Figure 4-2), when the spring bloom is producing excess oxygen leading to high saturation values. The oxygen content of the river is generally >8 mg/l with 14 observations above 8 mg/l, 6 observation in the 7 – 8 mg/l range. From an oxygen only perspective this would classify as being in good condition.

FIGURE 4-2 SEASONAL CYCLE OF OXYGEN CONCENTRATION



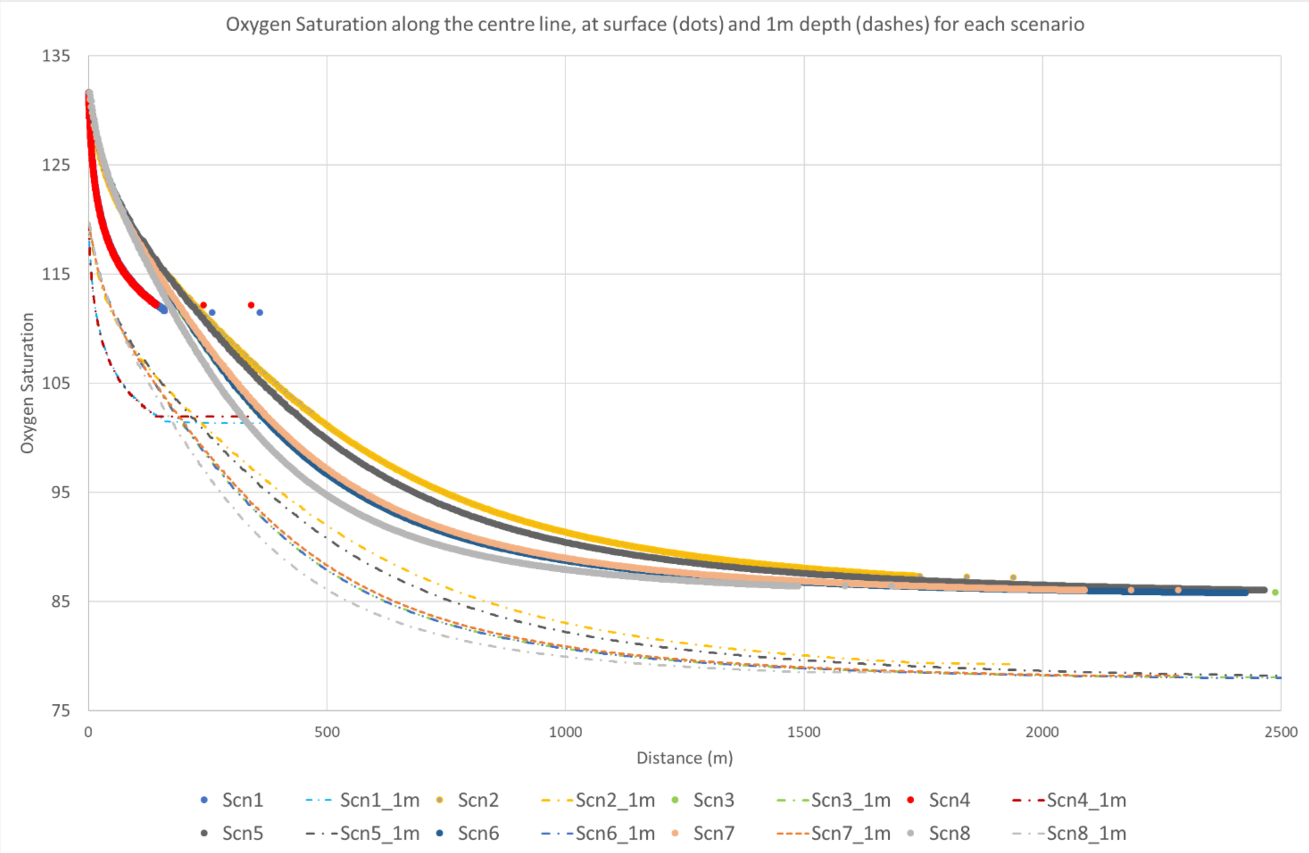
The oxygen content of water is usually a concern if it is too low, with concerns over potential oxygen sags resulting from reduced capacity of the warmer water to retain oxygen. As the background (natural) oxygen content of the water is high, this indicates that biological demand is low (and/or flushing times are high). Therefore, increasing the temperature of the whole water body by fractions of a degree, is not a primary concern, more of an issue are those temperature increases in the immediate discharge.

In the case of Keadby 1 power station, water is extracted from the Trent, rapidly heated by an additional 28 ºC and then discharged with no interaction with the atmosphere. The much warmer (maximum temperature 47 ºC) water has a lower capacity to dissolve oxygen, however the oxygen has not had time or opportunity to be expelled, therefore the discharge is supersaturated with oxygen.

Oxygen loss to the atmosphere is a slow process, even when supersaturated, and occurs slower than heat loss. So a potentially greater concern is supersaturation, where the insitu oxygen content is greater than the theoretical maximum saturation value. Values which are too high can be toxic to fish (Xue 2019) and values which are too low can lead to issues with sessile systems.

Figure 4-3 shows the predicted % of oxygen saturation, using the mean summer value of 7.87 mg/l, background temperature of 19.1 ºC and 28 ºC uplift along the centre line at the surface and at 1m depth since saturation is pressure dependant. Values of saturation less than 120% (Weitkamp and Katz 1980) are generally regarded as having little impact on fish. The results shows that values in excess of 120% are only predicted to occur in the near vicinity (<50m) of the discharge and only at the surface. With oxygen concentration at 100% saturation within 500m for most scenarios, this is a surface effect with water subsurface unaffected.

FIGURE 4-3 OXYGEN SATURATION ALONG THE CENTRE LINE FOR EACH SCENARIO



5. OTHER ISSUES, CHLORINATION AND METALS IN DISCHARGE

There are no chemicals in the main Keadby cooling water discharge. Antifoulant is not required when operating in the high excess temperature mode. However, there is a small volume of water abstracted from the canal water source which is used as boiler feed water, this water contains copper at 150 µg/l , the discharge is approximately 0.069 m3/s.

Keadby 2 power station also discharges small quantities of metals including copper (derived from its canal water source) at 150 µg/l in its discharge, which totals less than 0.11 m^3/s. i.e a total of 0.18 m^3/s. The annual average EQS for copper is 15 µg/l . These small discharges are added into the large 5.4 m^3/s of the cooling discharge before being discharged into the River, therefore the concentration of copper at the discharge is (0.18*150/5.58) = 4.8 µg/l which is below the AA EQS.

The discharges of Keadby 2 both standalone and in-combination with Keadby 1 were assessed and approved as part of the variation that brought Keadby 2 into the Environmental Permit.

Analysis undertaken during the course of this report indicates that the previously used value of 150 µg/l for the discharge concentration is a higher than perhaps it should be based on a re-assessment of the raw data.. A potential anomaly in the source water feed value of 37 µg/l has been included in the data set which is several times higher than the average. For this analysis, ERM has employed this outlier as a maximum value and concentrated this approximately 4 fold to simulate cycling of the water during cooling . A more appropriate value should be an annual average data of 7.7 ug/l.

6. COMPARISON WITH PREVIOUS WORK AND NORMAL OPERATING CONDITIONS.

There have been two previous sets of modelling at Keadby. From Apem 2011 "A pre-construction cooling water dispersion study of Keadby Power Station was undertaken by HR Wallingford during the design phase in 1991 using a one dimensional farfield model and a three dimensional midfield model from the HR Wallingford TIDEWAY system (HR Wallingford, 1992). This predicted that the thermal plume from the discharge would not present a thermal barrier to fish migration as it would not extend across the entire width of the river, being confined to the west bank with cooler water underneath. The model also concluded that "during all tests there were areas of water less than 3°C above ambient in the reach of the river beside the outfall". The discharge from the power station was modelled as 12m^3/s, with two alternative temperature scenarios: ΔT +10 °C and ΔT +5°C. This modelling was not however, verified with regular monitoring post-construction". In 2007 the Environment Agency undertook a Stage 3 Review of Consents study to investigate thermal loading on the Humber Estuary SAC (Environment Agency, 2007).

A report was therefore commissioned by SSE to monitor the plume, remodel and undertake a comparison. This was reported in the APEM 2011 report, "Keadby Thermal plume study and preliminary report". Which used insitu observations via a small boat program and remote thermal imaging to quantify the plume extents.

TABLE 6-1 SUMMARY OF OBSERVATIONS OF PLUME EXTENTS FROM APEM 2011

Table 3.1 Results of boat based and aerial surveys on 10th June

		28°C Isotherm Dimensions			21.5°C Isotherm Dimensions			+2°C Isotherm Dimensions			Channel Dimensions	
		Downstream extent (m)	Maximum width (m)	Depth at maximum extent (m)	Downstream extent (m)	Maximum width (m)	Depth at maximum extent (m)	Downstream extent (m)	Maximum width (m)	Depth at maximum extent (m)	Depth (m)	Width (m)
Boat Based**	High Water Slack	0***	22	2.5	54.7	86.7	2	72.3	97.7	2	4.5	200
	Mid Ebb	4.1	26.6	2	>124	41.9	0.5	>124	48.1	3	3.8	200
	Mid Flood	3.8	21	2	>124	48.6	1.5	>124	55.6	4	4.1	200
Thermal Imaging	High Water Slack	17	8		166*	61		666*	94		4.5	200
	Mid Ebb	47	20		489	37		683	47		3.8	200
	Mid Flood	39	30		634	39		1129	46.2		4.1	200
*image captured at start of high water slack so remnants of previous plume still visible												
** boat based data is at lower resolution, interpolated from 50m grid spacing												
*** plume extends straight out into the channel												

Because the ambient temperatures used for each report are not the same, and the discharge excess temperature are not the same, it is only worth while comparing the extent of the 2 °C extent which has been held as the barrier to migration, with previous work which has simulated the discharge of a similar thermal energy. In the APEM work, the scenarios included 3 ambient water temperatures 21.06 °C, 17.5 °C. 13.94 °C, and a scenario of moderate (13 °C) excess temperature discharge with full flow of 11.57 m3/s. These have similar discharge energy to the simulations in this report of a discharge at 28 °C excess at 5.4 m3/s.

TABLE 6-2 PLUME EXTENTS EXTRACTED FROM APEM 2011

Scenario	Distance to 2 °C isotherm along the centre line (m)
Run 2 Mid flood, High ambient	963
Run 4 mid flood, Medium Ambient	947
Run 6 Mid flood, Low Ambient	931
Run 14 mid ebb, High ambient	622
Run 16 mid ebb, Medium ambient	781
Run 18 Mid ebb, Low ambient	762

As can be seen from the above the ambient temperature has only a small effect on the plume extent. In comparison to the simulations in this report. For the flood tide these simulations which range (931m-963m) compare with (1021m – 1370m) for Scenarios 2 and 3 Flood tide (Table 4-2) and for the ebbtide the range is 622m – 781m, compared to 1051m – 1250m Scenarios 5 -7. It should be noted that the thermal imaging did record plume lengths of 1129m.

Broadly, the surface plume lengths (to 2°C) are longer for the higher excess temperature simulation. It could have been expected that the higher excess temperature would result in greater heat loss, to the atmosphere and potentially a reduced plume, however most of the reduction in heat loss is through horizontal and vertical mixing, and the higher initial discharge temperature inhibits vertical mixing, so the thin surface layer stays hotter for longer.

7. SUMMARY

The CORMIX modelling has considered discharges of excess temperatures of 28 ºC at the peak of summer using river-rine temperatures of 19.1 ºC. The plume is extremely buoyant, and is predicted to remain attached to the western edge of the Trent, during most phases of the flow. Only at slack water does it extend across the estuary and then for less than 5% of the time.

The extent of the surface plume to the 2ºC isotherm is slightly greater in the latest simulations compared to the APEM 2011, work using a similar power station cooling requirement.

Analysis of the cross section shows that the cross sectional criteria is not exceeded. With typical values of the cross section above the 2 ºC limit being around 3-13%, except during slack tide when it may reach 19%.

Un-ionized ammonia can be toxic to fish. The concentration of un-ionized ammonia is a function of the total ammoniacal nitrogen concentration (i.e. NH4 as N), the salinity, the pH and temperature. The EQS for un-ionized ammonia is 21 µg/l expressed as an annual average. The power station cooling water does not discharge increased ammonia, however the increased temperature can increase un-ionized ammonia concentrations. Results of the modelling indicate that the predicted discharge is unlikely to exceed the EQS.

The oxygen content of the river is generally good with values in excess of 8 mg/l. The concern of increasing temperature is not therefore that it will lead to be significantly reduced oxygen, but that the hot discharge may be supersaturated and could become detrimental to fish health. The results of the modelling indicate that values in excess of 120% should only occur in the near vicinity of the discharge and only at the surface, with oxygen concentration at 100% saturation within 500m for most scenarios.

8. REFERENCES

- AECOM 2022 Appendix A Water Modelling Assessment Environment Permit Variation Application for Keadby 3 . June 2022
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- UKTAG. 2008. UK Environmental Standards and Conditions Phase 2. UK Technical Advisory Group on the Water Framework Directive
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APPENDIX A EA WATER QUALITY INFORMATION

Date	Lead	Lead, Dissolved	pH	Temperature of Water	BOD : 5 Day ATU	Cadmium, Dissolved	Cadmium	Ammoniacal Nitrogen as N	Nitrogen, Total Oxidised as N	Ammonia un-ionised as N	Solids, Suspended at 105 C	Chloride	Carbon, Organic, Dissolved as C :- {DOC}	Chromium	Zinc, Dissolved	Chromium, Dissolved	Nickel, Dissolved	Iron	Copper, Dissolved	Copper	Zinc	Iron, Dissolved	Nickel	Oxygen, Dissolved, % Saturation	Oxygen, Dissolved as O2
	µg/l	µg/l	0.00	°C	mg/l	µg/l	µg/l	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	%	mg/l
13-Jan-15	5.65	0.29	8.10	5.90	1.27	0.06	0.12	0.10	7.79	1.28	43	67	5.22	2.58	10.20	< 0.5	3.45	1540	2.89	3.93	22.10	< 100	3.45	94	11.70
03-Feb-15	20.2	0.20	8.10	3.40	2.04	0.05	0.30	0.16	7.67	1.83	406	125	5.75	15.70	10.50	< 0.5	2.66	10700	3.55	12.70	69.70	< 100	9.20	94	12.50
19-Mar-15	6.39	0.21	8.20	6.90	1.81	0.06	0.08	0.12	7.72	1.69	71	72	5.78	3.81	10.00	< 0.5	4.38	1850	4.42	4.65	20.60	< 100	4.11	90	10.90
27-Apr-15	3.92	0.17	8.94	12.90	6.92	0.10	0.14	0.01	8.68	0.23	54	89	5.20	2.31	6.86	< 0.5	4.49	1040	4.26	6.33	20.20	< 100	4.40	133	14.00
12-May-15	4.65	0.31	7.80	12.90	3.07	0.07	0.09	0.03	6.58	0.42	66	72	5.17	2.95	8.56	< 0.5	3.47	1470	4.03	4.40	18.00	< 100	3.86	94	9.90
27-Jul-15	23.4	0.17	8.05	17.20	1.95	0.10	0.25	0.03	9.50	0.92	260	100	5.29	15.50	9.99	< 0.5	5.35	7070	3.91	12.80	56.30	< 100	11.10	91	8.77
10-Aug-15	71.5	0.10	7.85	19.10	1.16	0.06	0.30	0.01	8.39	0.25	617	88	4.33	36.10	6.88	< 0.5	4.17	15000	4.32	21.10	115.00	< 100	19.90	80	7.42
24-Aug-15	18.9	0.20	7.58	18.00	1.13	0.10	< 0.2	0.02	7.63	0.28	223	79	5.28	13.30	10.20	< 0.5	5.07	6370	5.56	11.00	49.30	< 100	10.10	83	7.82
08-Sep-15	9.05	0.25	7.82	14.40	< 1.87	0.08	0.08	0.05	8.56	0.75	105	80	5.13	5.61	8.87	< 0.5	6.90	2310	5.48	5.38	18.20	< 100	6.04	89	9.07
08-Oct-15	16.5	0.11	7.39	13.00	1.05	0.08	0.09	0.04	10.20	0.25	267	100	5.00	9.41	10.30	< 0.5	5.90	4750	4.54	5.75	25.90	< 100	5.66	88	9.25
20-Mar-14	20.1	0.13	8.00	9.30	1.64	0.05	< 0.2	0.03	7.73	0.50	225	30	4.67	11.90	8.14	< 0.5	3.52	5970	2.90	8.98	48.70	< 100	9.82	91	10.40
23-Apr-14	7.85	0.17	8.50	12.30	6.47	0.13	0.16	0.08	7.80	1.77	226	79	5.08	4.21	10.50	< 0.5	3.89	2540	3.87	3.89	22.50	< 100	3.10	123	13.10
23-May-14	11.7	0.20	8.10	16.90	1.63	0.09	0.12	0.05	7.31	1.54	162	68	4.90	5.91	8.59	< 0.5	4.39	2970	3.90	4.65	24.10	< 100	3.60	87	8.40
12-Jun-14	7.49	0.27	7.90	18.40	1.49	0.05	0.12	0.06	6.03	1.61	67	52	6.36	3.85	8.64	< 0.5	3.63	2360	3.57	5.08	26.20	< 100	3.27	83	7.77
07-Jul-14	3.64	0.17	8.20	18.40	1.12	0.10	0.10	0.01	7.72	0.47	44	71	4.98	1.66	11.90	< 0.5	4.87	873	4.39	5.29	17.50	< 100	5.04	84	7.86
08-Aug-14	16.5	0.13	8.00	20.10	< 1	0.09	0.11	0.04	9.15	1.33	154	78	4.97	9.81	9.61	< 0.5	5.25	4300	3.31	5.12	25.50	< 100	5.22	84	7.60
17-Sep-14	19	0.15	7.70	16.40	< 1	0.10	0.10	0.01	9.91	0.15	175	98	4.97	11.70	12.00	< 0.5	5.95	5750	4.21	7.27	37.40	< 100	7.85	81	7.90
03-Oct-14	24.3	0.15	8.10	15.80	1.06	0.13	< 0.2	0.04	11.00	1.06	241	98	5.13	13.30	14.30	< 0.5	6.05	7390	3.30	12.20	59.00	< 100	12.20	89	8.79
19-Nov-14	18.3	0.26	7.90	10.00	1.36	0.04	0.24	0.12	8.21	1.76	300	48	6.83	8.99	8.24	< 0.5	3.78	5800	3.88	10.10	51.70	< 100	8.29	93	10.50
03-Dec-14	4.51	0.27	7.90	7.90	< 1	0.07	0.09	0.07	8.65	0.87	33	57	6.23	2.45	11.20	< 0.5	4.11	1230	4.70	4.60	21.30	< 100	3.79	89	10.50

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