Brine Dispersion Modelling – CORMIX Modelling Results

Aldbrough Hydrogen Pathfinder

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0653313

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ACRONYMS AND ABBREVIATIONS

Acronyms	Description
°C	Degrees Celsius
AA	Annual Average
AGS	Aldbrough Gas Storage
EA	Environment Agency
EQS	Environmental Quality Standard
kg/m^3	Kilogram per cubic meter
km^2	Square kilometres
m	Meter
m^2	Square meters
m/s	Meter per second
m^3/s	Cubic meters per second
m^3/h	Cubic meters per hour
MAC	Maximum Allowable Concentration
mg/l	Milligram per litre
OCGT	Open Cycle Gas Turbine
ppt	Parts per thousand
PSU	Practical Salinity Unit
ppm	Parts per million

Acronyms	Description
Sm^3	Standard cubic meter. Gas storage. This unit represents the Gas volume at a temperature of 15°C, pressure of 101.325 kPa (1 atm)
SSE	SSE Hornsea Limited

1. INTRODUCTION

SSE Hornsea Limited (SSE) is applying for Planning Permission, Environmental Permit and Marine Licence to construct and operate an electrolytic hydrogen production, storage and energy generation facility, known as Aldbrough Hydrogen Pathfinder. Located at SSE Hornsea Limited's existing Aldbrough Gas Storage site, the Aldbrough Hydrogen Pathfinder Project is an important building block in the development of a thriving Humber hydrogen economy, underpinning the region's decarbonisation and supporting economic growth in the wider region.

1.1 PROJECT BACKGROUND AND THE NEED FOR MODELLING

The Proposed Development will comprise the construction of facilities for the production, storage and retrieval of electrolytic hydrogen and its conversion into low carbon electricity by an Open Cycle Gas Turbine (OCGT). This has the following two main components.

- Facilities for the production, storage and retrieval of electrolytic hydrogen and its conversion into low carbon electricity by an OCGT; and
- Reinstatement of an existing brine discharge pipe and associated infrastructure requiring work on the marine environment and intertidal areas.

Electrolytic hydrogen will be produced from a Proton Exchange Membrane Electrolyser using power sourced from the grid through Renewable Power Purchase Agreements, in compliance with the United Kingdom's (UK) Low Carbon Hydrogen Standard. Water will be abstracted from an existing borehole within the existing AGS facility and will be treated (demineralised) prior to use. Salt cavern storage will be secured by converting one of the Aldbrough Gas Storage (AGS) facilities' existing natural gas storage caverns (Aldbrough 1 Cavern) for hydrogen storage. The produced and stored hydrogen will be distributed via a dedicated above ground pipe to the OCGT, which will operate on up to 100% hydrogen and will export power back to the National Grid during times of low renewable power availability. The by-product oxygen from the electrolysis process will be vented to atmosphere.

Environmental Resources Management (ERM) has been commissioned by SSE to carry out a Effluent Discharge Study to support the Environmental Permit and Marine Licence applications for the Proposed Development. This includes the modelling and analysis of a variety of scenarios to evaluate the brine plume under varying conditions and includes the following two phases.

<u>Phase 1</u>

- Aldbrough 1 Cavern, which is currently an operational natural gas storage cavern, will be converted to store hydrogen for the Proposed Development.
- The natural gas in the cavern will be displaced by rewatering the cavern with abstracted groundwater, this groundwater is heated up to stop condensates forming.
- The ground water may stay in the caverns for up to 12-18 months and become salt saturated.
- As hydrogen is produced the water in the cavern will be displaced by the volume of hydrogen.
- Before discharge the salt saturated cavern water is diluted with groundwater to cool it and reduce its salinity to prevent the crystallisation of salt in the pipework. The discharge also includes a small component of brackish water from the demineralisation plant. It is therefore

a dense discharge, but not a fully saturated brine. The period of this discharge will be approximately 12 months.

<u>Phase 2 (Continued operation)</u>

- Once all the cavern water has been displaced the continued operational phase consists of a much smaller continuous discharge of brackish water for the remainder of the operational lifetime of the development (25 years).
- This discharge is made up of reject water from the demineralization plant. The demineralization plant uses groundwater to produce ultra pure water for conversion to hydrogen using an electrolyser. The discharge of any contaminants is concentrated by 2.7 times compared to groundwater alone.

Discharge properties are detailed within Section 2.1 below.

An H1 risk assessment[1] has been conducted, the 1st stage of which is screening the discharge against the relevant EQS (Environmental Quality standards). This screening has determined that for those substances which were detected in the borehole water samples above the limits of detection, only Copper and Zinc where above the EQS and therefore need to be modelled. In addition (for Phase 2 only), it is anticipated that due to the ammonium present in the discharge, the unionised ammonia concentration, which is a function of the ammonium concentration, temperature and salinity in the discharge, will exceed the EQS.

During Phase 1, the brine plume is dense and will sink to the seabed; therefore, could have biological impacts at the seabed as aquatic receptors are exposed to elevated salinities and two metals: copper and zinc.

During Phase 2, the discharge is brackish and the plume will be buoyant: therefore, no impact to the seabed due to salinity, thus potential impact comes from the two metals of concern: copper, zinc and unionized ammonia.

The purpose of this study is to model the spatial and temporal extent of the effluent discharge from the existing (reinstated) diffuser for the two different phases of the project. This report describes the implementation and results of a model to assess the size and configuration of the effluent plumes.

1.2 EA MODELLING REQUIREMENTS FOR BRINE DISCHARGE

Recognising that brine discharges are of a different nature to other discharges, the EA has produced and distributed an advisory note[2]. Key Point from that document are:

- All negatively buoyant discharges need to undergo statistical modelling.
- Excess salinity should not exceed 40 ppt at a mixing zone boundary of 250 m.
- Where sensitive species exist, excess salinity should be assessed based on species sensitivity.

[1] Aldbrough Hydrogen Pathfinder - Supporting Information Document ERM 2025
[2] Proposed Brine Limits in Transitional and Coastal Waters – EA Marine Modelling Team 2025

- Contaminants exist in extracted waters. When these waters are concentrated, it is important to check that the concentrating up effect does not cause these chemicals to exceed EQS in the discharge effluent.

1.3 CHOICE OF MODEL

A variety of numerical modelling tools can be used to model effluent plumes and brine dispersal, e.g. Delft 3D, Telemac 3D, FVCOM, MIKE 3D, MOHID, GETM. These models simulate the whole of the water column and replicate tidal flows through a tidal period. While many of these models have unstructured grids, which can give high horizontal resolution, they have relatively poor vertical resolution and will not be particular good at modelling a dense brine plume which is on the seabed, which may only be 20 cm thick. It is rare for vertical resolution to be less <1m and because they have to distribute a parameter over the whole of a grid cell, they will inevitably overestimate mixing and thus state there is no impact, when a potential bed impact could occur. An alternative approach, which is grid cell independent and therefore better represents the mixing (or lack of), is to use a near field empirical model.

CORMIX (Version 12.0), was selected as being the most appropriate of the nearfield models. CORMIX has been used world-wide and is recognized internationally. It is an approved model by the United States Environmental Protection Agency (USEPA). In the UK, CORMIX has been used for a number of projects, most recently to simulate the brine dispersal from a desalination plant associated with the Sizewell C development[3]. The model is recognized as being appropriate for computing dilution rates, the extent of the mixing zone, and computing trajectories in the near field.

CORMIX is a steady-state model, i.e., each application represents a single snapshot of the 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 scenarios provide a range of plume configurations and bound the plume size. To develop these plume bounds, ERM evaluated two scenarios (see Table 2-1 for descriptions) with a total of 10 simulations reflective of varying ambient conditions.

The selected scenarios consist of a combination of ambient currents. For the brine plume (Scenario A), model results consist of dilution of the plume, the distance to reach 2 parts per thousand (ppt) excess salinity, and the distance to reach the corresponding EQS for each metal of concern. Excess salinity is defined as the difference between the effluent salinity and the ambient salinity. For the effluent plume Scenario B, model results consist of dilution of the plume and the distance to reach the EQS for each of the three metals of concern. Each scenario modelled five simulations for the number of tidal currents needing to be considered for that scenario.

[3] Cefas BEEMS Technical Report TR552 Sizewell C Desalination Discharge Assessment available from https://infrastructure.planninginspectorate.gov.uk

2. CORMIX MODEL SETUP

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

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

SSE supplied operational information used as input to CORMIX, such as effluent planned flow rate. To gather ambient water quality conditions, data was obtained from a previous study for the region[4].

Due to the nature of CORMIX as steady-state model, these simulations are static events, and do not accurately model the dynamic effects of spatially varying tides. Also in this study, the effect of wind has not been included, instead choosing the conservative option of no wind. Thus, the results from these simulations presenting the largest plumes can be considered as those due to the tide only.

2.1 DISCHARGE PROPERTIES

Two discharge configurations were evaluated during this study. Details of each project phase corresponding to these configurations are shown in Table 2-1. The discharge rate, temperature, salinity, and density for each scenario were provided by SSE and are listed in Table 2-2.

Phase 1 effluent's primary constituent of concern is the elevated salinity, but also includes an assessment of the copper and zinc concentrations. Phase 2 primary constituents of concern are the two metals: copper and zinc.

The existing diffuser that will be used (Figure 2-1) is a line diffuser with multiple risers with four ports on each riser. For this project, to be conservative, it is assumed that only two of the risers are operational. The sizing details of the diffuser are listed in Table 2-3.

Due to the limitations of CORMIX, the diffuser of two risers with four ports on each could not be replicated in the model. Instead, as a conservative substitute, four risers each with two ports was used. These ports had the same cross-sectional area as a port from the original design, 0.071 m^2. Another CORMIX limitation applied to the length of the diffuser. In CORMIX, a linear diffuser must be equal to or greater than the ambient depth at discharge. This required the diffuser to be 10 m long rather than the estimated 4 m between the two original risers. The diffuser was oriented perpendicularly with the ambient current (Figure 2-2).

[4] Institute of Estuarine and Coastal Studies. (2004). (rep.). Proposed Joint Venture Underground Gas Storage Facility: Aldbrough, East Yorkshire Assessment of Potential Construction and Operational Environmental Impacts with respect to Coastal Works: Supplementary Information.

TABLE 2-1: EFFLUENT SCENARIO DEFINITIONS

Scenario	Corresponding Project Phase	Phase Details
Scenario A	1	Cavern dewatering and process effluent discharge (~1st 12 months)
Scenario B	2	Demineralization plant effluent discharge only (from ~12 months onwards)

TABLE 2-2: EFFLUENT PROPERTIES FOR EACH SCENARIO APPLIED FOR CORMIX MODELLING

Effluent Constituent	Scenario A	Scenario B
Temperature	16.5°C	10°C
Salinity	111.5 ppt	5.4 ppt
Copper (AA/MAC[a])	5.84/8.44 ug/l	15.21/22.11 ug/l
Zinc (AA/MAC)	54.50/64.62 ug/l	141.30/169.26 ug/l
Unionised ammonia (AA)		24.8 ug/l
Flow rate	159.9 m^3/h	3.9 m^3/h
Density[b]	1085.9 kg/m^3	1003.9 kg/m^3

Source: Atkins, 2024 By e-mail.

Note: [a] AA = Annual Average concentration; MAC = Maximum Allowable Concentration

[b] Density was computed using the provided salinity and temperature

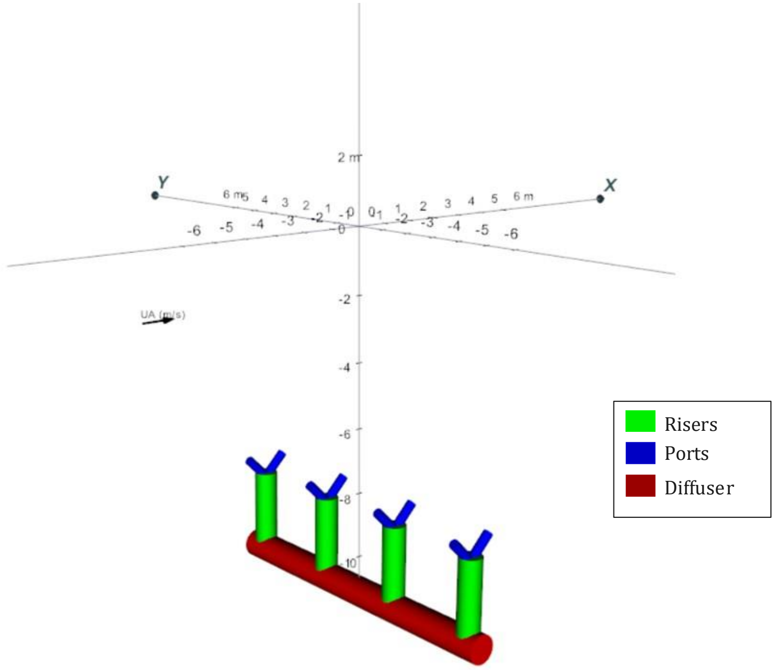
FIGURE 2-1: LINEAR DIFFUSER DESIGN, ONLY TWO RISERS OPERATIONAL (8 PORTS)

TABLE 2-3: LINEAR DIFFUSER WITH TWO RISERS SIZING

Component	Value
Length between risers[a]	4 m
Single Port Diameter	0.30 m
Single Port Area	0.071 m^2

Source: Atkins, Provided by email 2024
Note: Length provided in table is based on original diffuser design, not the configuration used during modelling.

FIGURE 2-2: CORMIX DIFFUSER CONFIGURATION



2.2 AMBIENT CONDITIONS

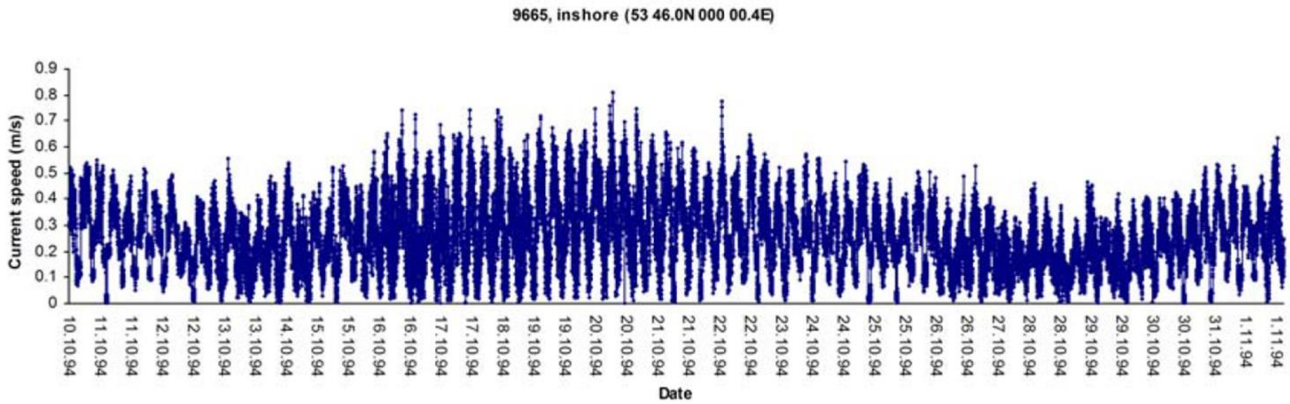
2.2.1 CURRENTS

To determine ambient current speeds, data was sourced from the previous study[5] and from investigation of the data held at the BODC. Statistics were completed for the various tidal station locations. Tidal currents were determined, and values for the flood/ebb, neap, and spring tides were selected for input. This provided a range of values, starting from the smallest tidal currents magnitude to the largest.

Directionality of the ambient tidal current depends on the phase of the tide. During the flood phase, the current is southward while during the ebb it is northward. Whether it is flood or ebb, the current is aligned parallel with the coast. Details on the full inputs for the model are presented in section 2.3. Figure 2-3 show velocities from a 6-week deployment taken from approximately 6 km south of the diffusor but a similar distance offshore in similar water depth (12 – 13 m). The instrument was recording 0.8 m above the bed, so reflective of near bed current velocities and therefore appropriate for defining the characteristics of the plume. The tidal velocities mid water will be larger than those recorded near bed, this has led to peak velocity. It is worth noting that near the bed there does not appear to be consistent asymmetry in the tidal flow. While the southward flowing tide is often stronger, it is not always so. It should also be noted that at neap tides the velocity does not drop to zero but there is a minimum velocity of approximately 0.1 m/s.

[5] Institute of Estuarine and Coastal Studies. (2004). (rep.). Proposed Joint Venture Underground Gas Storage Facility: Aldbrough, East Yorkshire Assessment of Potential Construction and Operational Environmental Impacts with respect to Coastal Works: Supplementary Information.

FIGURE 2-3 CURRENT MEASUREMENTS FROM NEAR BED MOORING AT SIMILAR DEPTH TO DISCHARGE LOCATION



2.2.2 WATER CHARACTERISTICS

Temperature and salinity data were taken from the physical processes chapter of the recent Aldbrough Hydrogen Storage Project PEIR[6]. Two seasons, winter and summer, were analysed to determine which would produce the most conservative modelling estimate. Winter conditions reflect low water temperatures and summer conditions reflect higher water temperatures. Salinity data was also sourced from a previous study[7]. The salinity for both seasons is approximately 34 ppt, with salinity slightly higher at 34.25 ppt for the winter season. The season selected for the model was summer as it presented the greater density difference between the ambient water and the effluent. Details on the full inputs for the model are shown in Section 2.3.

2.3 SCENARIO SELECTION

A total of 2 scenarios, with 5 tidal states (10 total simulations) were developed to represent varying ambient conditions to represent worst-case scenarios. The details of these conditions are shown in Table 2-4, with seasonally specific salinity and temperatures for each scenario. Each simulation is only valid for specific time frames which correspond to the duration of the tidal states (Table 2-4). The time for which a tidal condition occurs depends on if there is neap or a spring tide condition; the table below shows the approximate time a simulation is valid for and the maximum distance that a plume could be expected to be advected in that time. The timings come from applying a 0.1 m/s valid around each mid-point; i.e. the 0.3 m/s is valid from 0.2 m/s to 0.4 m/s.

[6] Chapter 12 Marine Physical Environment available at https://static1.squarespace.com/static/624efcd615aed55907aefc52/t/666c6a78a3a7280f1a9f3df7/1718381183048/AHS+PEIR+Chapter+12+Marine+Physical+Environment.pdf

[7] Institute of Estuarine and Coastal Studies. (2004). (rep.). Proposed Joint Venture Underground Gas Storage Facility: Aldbrough, East Yorkshire Assessment of Potential Construction and Operational Environmental Impacts with respect to Coastal Works: Supplementary Information.

TABLE 2-4: SIMULATION AMBIENT CURRENT DEFINITIONS

Simulation Name	Ambient Current, m/s	Tidal State	Duration of condition and approximate max distance Neap Tide	Duration of condition and approximate max distance Spring Tide
1	0.1	Slack	20 min, 200m	20 min, 200 m
2	0.3	Mid Neap	60min, 1070m	30min, 370m
3	0.5	Peak Neap Mid Spring	80min, 2240m	40min, 1310m
4	0.75	Mid Spring	-	50min, 2320
5	1	Peak Spring	-	40min, 2130

CORMIX's Multi-Port module, CORMIX2, was selected for the assessment as it allows the release of a submerged effluent through a multi-port diffuser. The wind speed was taken to be 0 m/s as a conservative assumption. Input data for CORMIX is presented in Table 2-5. Parameters such as depth and bed roughness coefficient were determined based on previous experience. Conservative maximum and minimum values were also selected for ambient velocity, ambient salinity, and ambient temperature, based on available information and permutated to test a variety of scenarios.

TABLE 2-5: CORMIX INPUT DATA FOR SCENARIOS

Parameter	Value
Port type (surface/subsurface)	Subsurface
Port Height above Channel Bottom	2 m
Port area	0.071 m^2
Vertical angle, theta	45° (Pointed slightly upward)
Horizontal angle, sigma	270° (Perpendicular to ambient flow)
Effluent flow rate	159.9 m^3/h (Scenario A); 3.9 m^3/h (Scenario B)

Parameter	Value
Effluent temperature	16.5°C (Scenario A); 10°C (Scenario B)
Effluent water quality module	Brine and Heated Discharge (Scenario A) Conservative Constituent Discharge (Scenario B)
Waterbody type (bounded/unbounded)	Unbounded
Bed roughness (Manning's or Chezy coefficient)	Manning's: 0.025
Ambient Salinity	Summer: 34 ppt (Scenario A & B)
Ambient Temperature	Summer: 15.9°C (Scenario A & B)
Average water depth	10 m
Water depth at discharge structure	10 m
Ambient Wind Speed	0 m/s
Ambient Ammonium	100 ug/l
Ambient Unionised ammonia	2.9 ug/l
Ambient Copper	0.53 ug/l
Ambient Zinc	3.4 ug/l

3. RESULTS

In this section, the results of each scenario are examined. For Scenario A which is a dense plume, the EA have a requirement of < 40 ppt at 250m from the discharge location. Background Salinity is typically 34 but can be up to 35 ppt. Therefore an excess of 5 ppt is relevant (and highly conservative) for determining where the 40 ppt threshold is. In addition and mindful of biota that may be present the 2ppt excess value is also shown and the distance to reach the EQS for each metal of concern.

Many intertidal and coastal biological species are naturally exposed to a high range of salinity. However, literature reviews of biological impacts of salinity indicate that physiological impacts are rarely observed below salinity increases of 2–3 ppt above the ambient conditions[8]. It has also been noted from similar previous studies that 2 ppt excess salinity has been considered a valid limit[9].

For Scenario B results are presented as the dilution along the length of the plume and the distance to reach the EQS for each metal of concern, it should be noted this is centre line concentration and concentrations away from the centre line will be less.

The effluent plumes were modelled as a near bottom discharge using CORMIX2. Dependent on the discharge rates and the ambient current, the plumes enter the ambient water with a low velocity. Due to this, the plumes' development follows the ambient current direction in both states of the tide for both scenarios.

The worst-case distance to reach excess salinity limits and water quality standards, based upon distance travelled and time duration, for each scenario are shown in Table 3-1.

TABLE 3-1: WORST CASE DISTANCE TO REACH EXCESS SALINITY LIMIT OR EQS FOR EACH SCENARIO

Constituent Name	Scenario A Distance, m	Scenario A Corresponding Simulation Name	Scenario B Distance, m	Scenario B Corresponding Simulation Name
Excess Salinity (5, 2 ppt)	<2, 81.2	A-1	N/A	N/A
Copper	0.12	A-2	0.18	B-3
Zinc	13.5	A-1	3.59	B-5

[8] /4/ Jenkins, S., Paduan, J., Roberts, P., Schlenk, D., Weis, J., 2012. Management of Brine Discharges to Coastal Waters Recommendations of a Science Advisory Panel. Southern California Coastal Water Research Project. State Water Resources Control Board Technical Report, 694, 101pp.

[9] /1/ Cefas BEEMS Technical Report TR552 Sizewell C Desalination Discharge Assessment available from https://infrastructure.planninginspectorate.gov.uk

Constituent Name	Scenario A Distance, m	Scenario A Corresponding Simulation Name	Scenario B Distance, m	Scenario B Corresponding Simulation Name
Unionised Ammonia			0.05	B-1

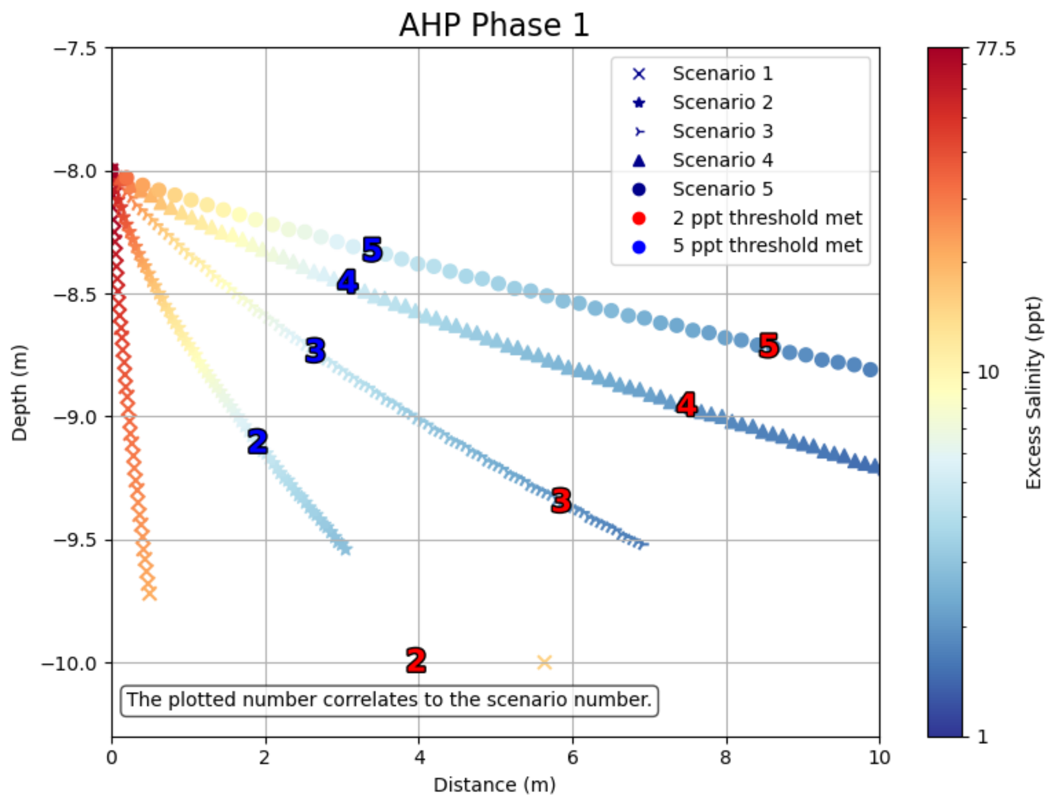
3.1 SCENARIO A RESULTS

This simulates effluent with a salinity of 111.5 ppt and a density of 1085 kg/m^3. This dense plume resulted in seabed interaction with all five of the simulations. In all of the simulations, the 2 ppt excess salinity limit was able to be reached within the tidal state validity durations (shown in section 2.3). Due to the diffuser configuration of four risers with two ports on each riser, the effluent at the discharge point forms individual plumes from each riser. After a distance, these individual plumes merge together to form a merged effluent plume. Of the five simulations, two of them, Simulations A-1 (slack tide) and A-2 (mid-neap tide), reached the 2 ppt excess salinity once the effluent plume had become a merged plume (Table 3-2). The other three simulations, Simulations A-3 (peak neap/mid-spring tide), A-4 (mid-spring tide), and A-5 (peak spring tide), were able to reach 2 ppt excess salinity prior to the plumes merging into one effluent plume. Simulation A-5 had the longest distance to become a singular effluent plume, but the shortest time to reach the excess salinity limit. For excess temperature (Figure 3-2), the difference between the effluent and ambient waters is minimal at 0.6 degrees. This small difference combined with the quick dilution of the plume, results in the excess temperature from the effluent being within 0.01 degrees of the ambient temperature within 10 m from the discharge.

TABLE 3-2: SCENARIO A PLUME DETAILS AT AND TIME TO REACH 2 PPT EXCESS SALINITY

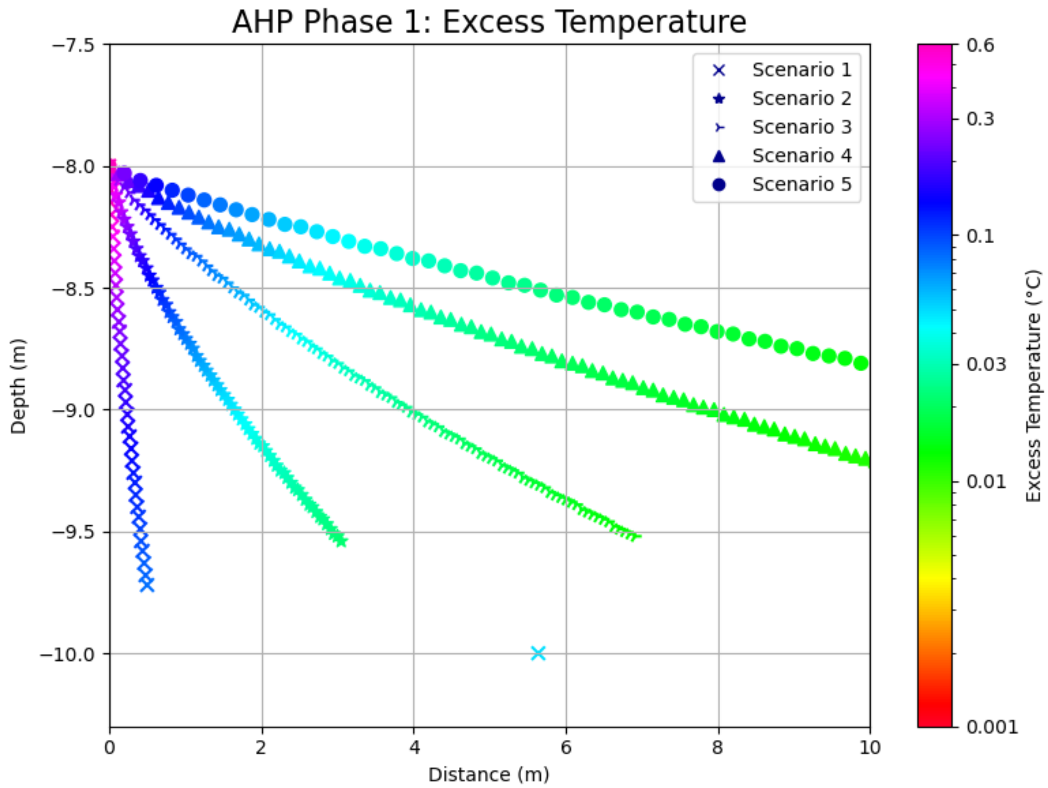
Simulation Name	Distance as Individual Plumes from Risers, m	Distance to reach 5 ppt Excess Salinity, m	Distance to Reach 2 ppt Excess Salinity, m	Time to 2 ppt Excess Salinity, min
A-1	0.51	<2	81.2	11.3
A-2	3.08	1.88	3.97	0.19
A-3	6.91	2.63	5.9	0.19
A-4	13.3	3.04	7.5	0.16
A-5	21.1	3.36	8.6	0.13

FIGURE 3-1: SCENARIO A - EXCESS SALINITY VERSUS DISTANCE FROM DISCHARGE



Note: Distance is restricted to 10 m therefore Simulation A-1 does not reach 2 ppt excess salinity in this plot.

FIGURE 3-2: SCENARIO A - EXCESS TEMPERATURE VERSUS DISTANCE FROM DISCHARGE



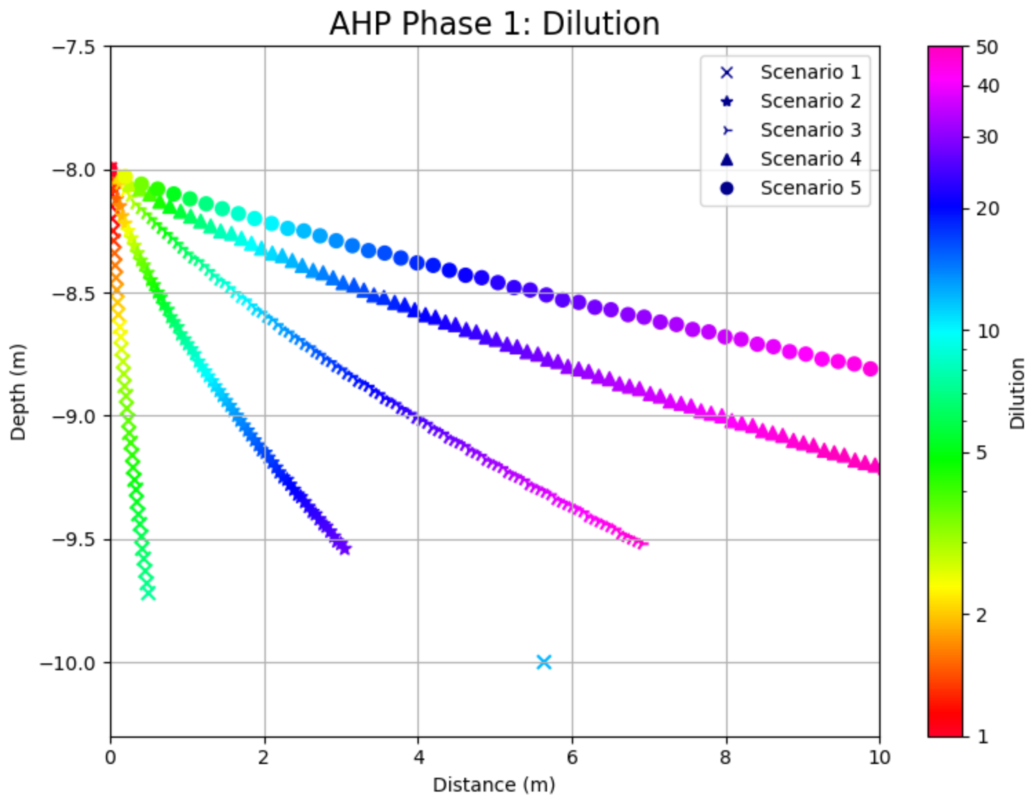
Note: Distance is restricted to 10 m.

Overall, both copper and zinc were able to reach their respective EQSs within 14 m from the discharge point (Table 3-3). Within 10 m from the discharge point, dilution values can reach up to 50 for some of the simulations (Figure 3-3). For both constituents, the EQSs are annual average based. Copper required a lower dilution to reach its EQS compared to zinc, which resulted in shorter distances from the discharge to reach the dilution. Within 0.15 m, copper for each simulation was able to achieve its required dilution. For zinc, simulations A-2 through A-5 were able to achieve the required dilution within 3.5 m. Simulation A-1 was able to reach zinc's EQS within 14 m from the discharge point. In relation to excess temperature, it is evident from Figure 3-2 that due to the high mixing, the excess temperature is rapidly brought down to very low levels (< 0.1 ^{o}C). Other discharge conditions with higher discharge temperatures would be less dense and therefore result in stronger mixing and would also be rapidly brought down to very low excess levels. The low temperature high salinity scenario modelled represents the worst case density which is the worst case in relation to mixing and therefore produces conservative estimates for the plume extent.

TABLE 3-3: SCENARIO A PLUME DETAILS AT AND TIME TO REACH EQS FOR EACH CONSTITUENT FOR ANNUAL AVERAGE

Constituent Name	Water Quality EQS (AA), ug/l	Simulation Name	Required Dilution to Reach EQS (accounting for ambient)	Distance to Reach Required Dilution, m
Copper	3.76	A-1	1.65	0.07
		A-2		0.12
		A-3		0.06
		A-4		0.02
		A-5		0.009
Zinc	6.8	A-1	15.0	13.5
		A-2		1.86
		A-3		2.58
		A-4		2.98
		A-5		3.28

FIGURE 3-3: SCENARIO A - DILUTION VERSUS DISTANCE FROM DISCHARGE



3.2 SCENARIO B RESULTS

Scenario B is relevant to the operational phase of the project. This resulted in an effluent with a salinity of 5.4 ppt and a density of 1003.9 kg/m^3. Overall, copper and zinc were able to reach their respective EQSs within 4 m from the discharge point (Table 3-4). Within 10 m from the discharge point, dilution values can reach above 50 for some of the simulations (Figure 3-4) and within 80m from the discharge point, dilutions were above 280 (Figure 3-5). For copper and zinc, the EQSs are annual average based. Copper required a lower dilution to reach its EQS compared to zinc, which resulted in shorter distances from the discharge to reach the dilution. Within 0.2 m, copper for each simulation was able to achieve its required dilution. For zinc, the required dilution within 4 m of the discharge point.

TABLE 3-4: SCENARIO B PLUME DETAILS AT AND TIME TO REACH EQS FOR EACH CONSTITUENT FOR ANNUAL AVERAGE

Constituent Name	Water Quality EQS (AA), ug/l	Simulation Name	Required Dilution to Reach EQS (including ambient conditions)	Distance to Reach Required Dilution, m
Copper	3.76	B-1	4.51	0.16
		B-2		0.16
		B-3		0.18
		B-4		0.14
		B-5		0.13
Zinc	6.8	B-1	40.6	1.22
		B-2		2.36
		B-3		2.96
		B-4		3.39
		B-5		3.59
Unionised Ammonia	21	B-1	1.37	0.05
		B-2		0.05
		B-3		At initial discharge
		B-4		At initial discharge
		B-5		At initial discharge

FIGURE 3-4: SCENARIO B - DILUTION VERSUS DISTANCE FROM DISCHARGE – NEARFIELD

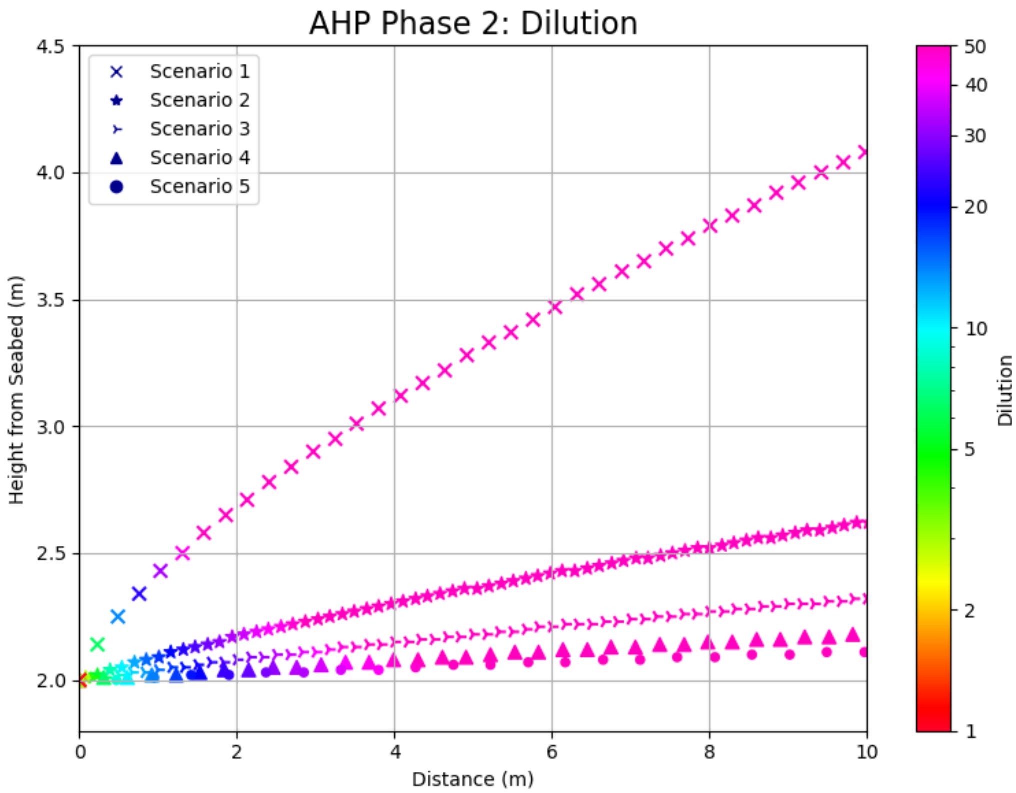
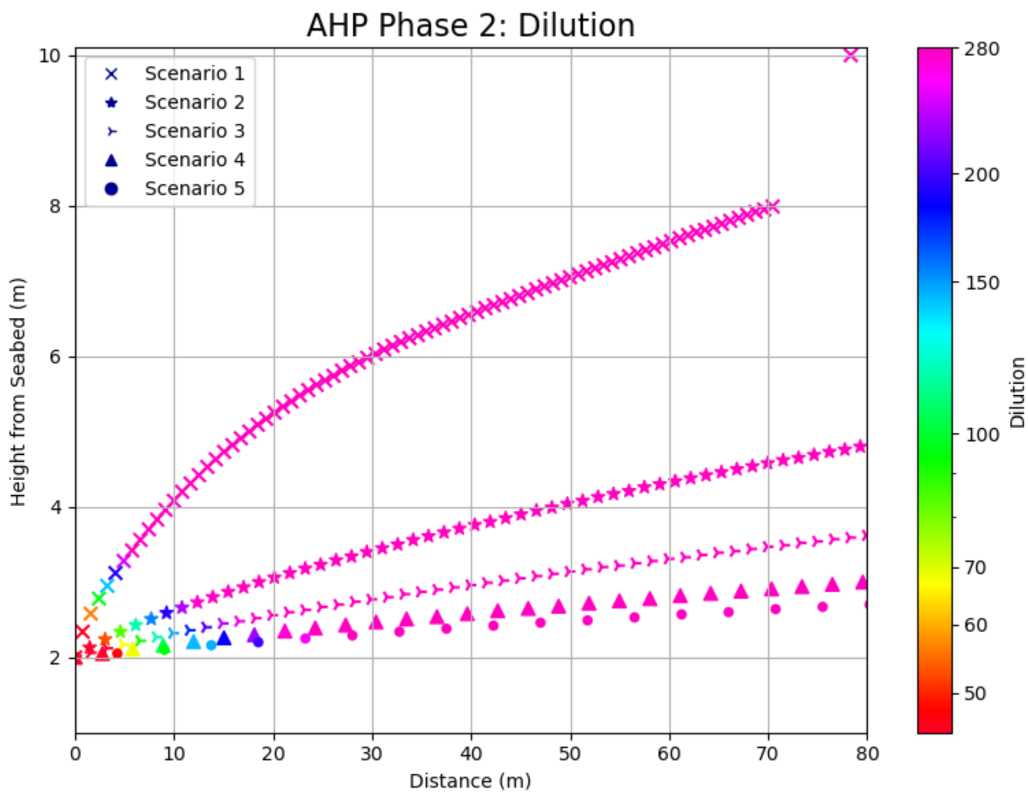


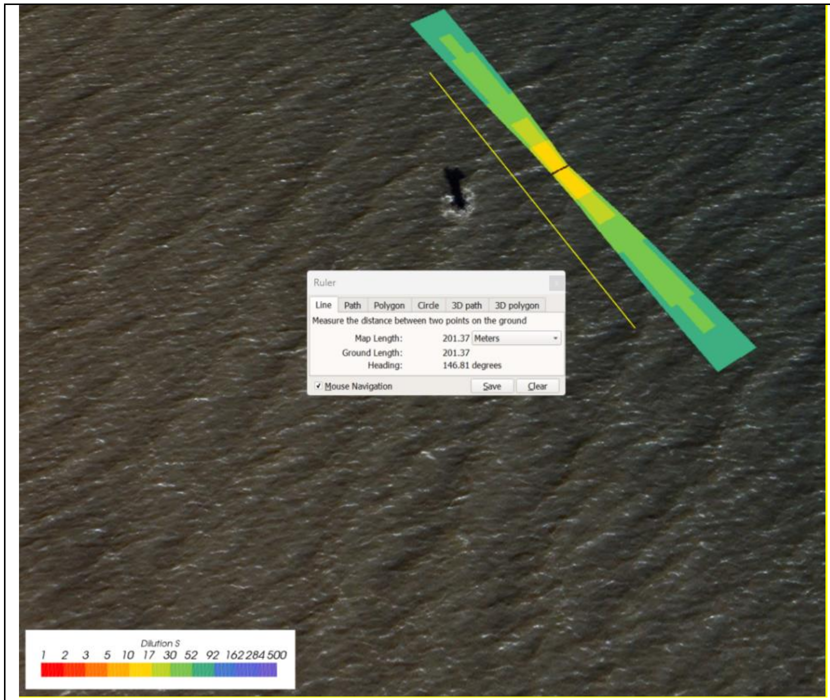
FIGURE 3-5: SCENARIO B - DILUTION VERSUS DISTANCE FROM DISCHARGE – FARFIELD



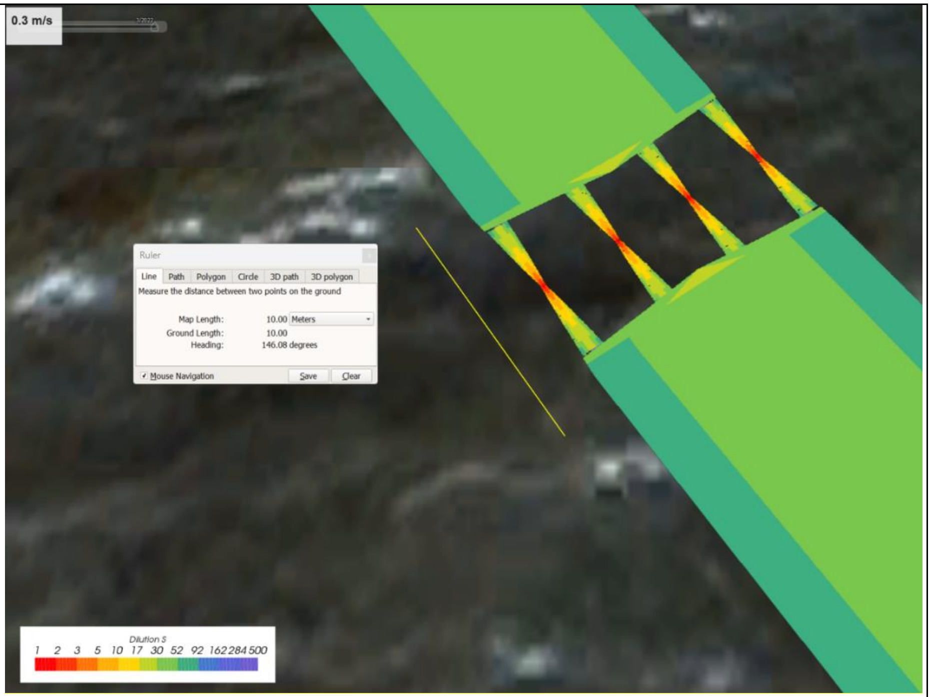
3.3 SPATIAL PLOTS THROUGH THE TIDAL CYCLE

The figure below shows the spatial extent of the brine plume through the seasonal cycle for Scenario A (Phase 1). It is only at slack water C1 and C2 where there is any impact at the bed at >2ppt excess. The dilution required for the 5 ppt excess is dilution of 15 which is the yellow/green boundary in the figures below and for 2 ppt excess is dilution of 39 (mid green). For the tidal states corresponding to conditions C3, C4 and C5, these are heavily zoomed in and therefore for clarity only show the impact on one state of the tide. At 5 ppt the plume only hits the bed at slack tide and reaches 5 ppt within 10m. The maximum seabed impact at above 2 ppt which occurs at slack tide for only 20 min on each tide and impacts an area of 1620m^2.

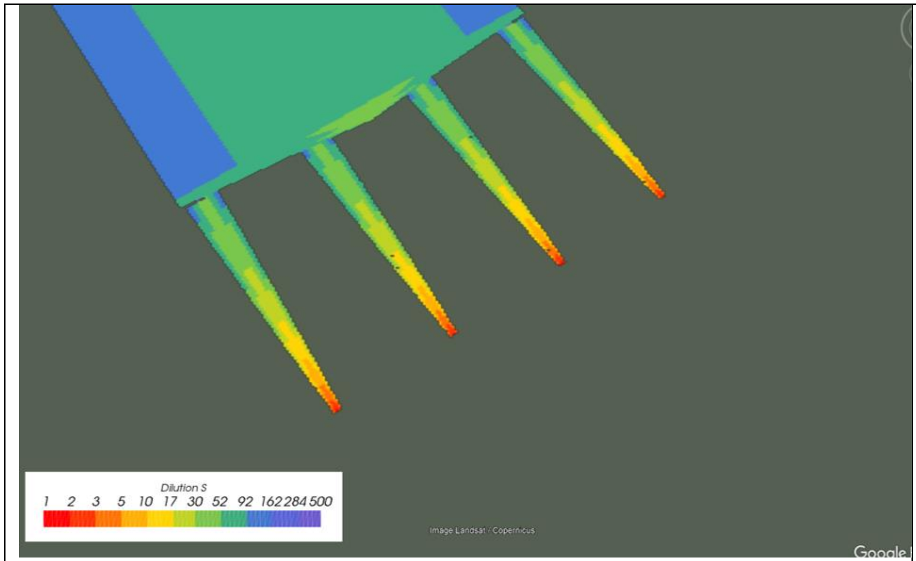
FIGURE 3-6 PLUME DISCHARGE THROUGH THE TIDAL CYCLE SCENARIO A (PHASE 1)



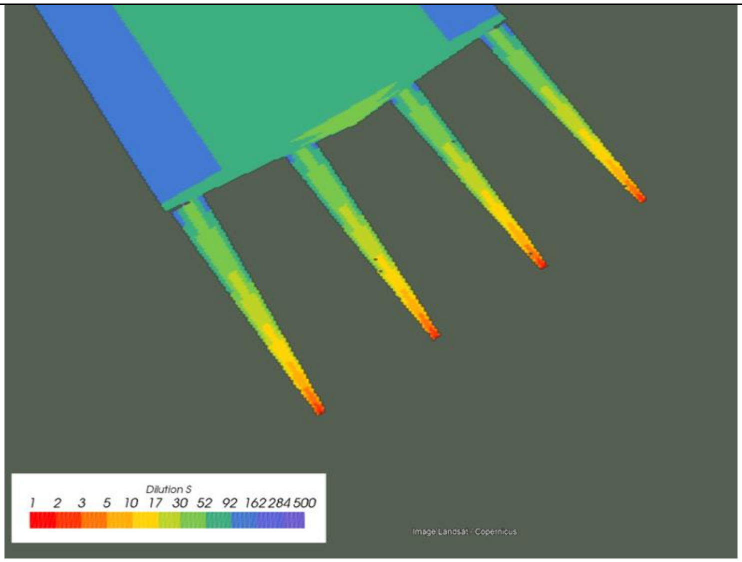
C-1 Slack 0.1 m/s



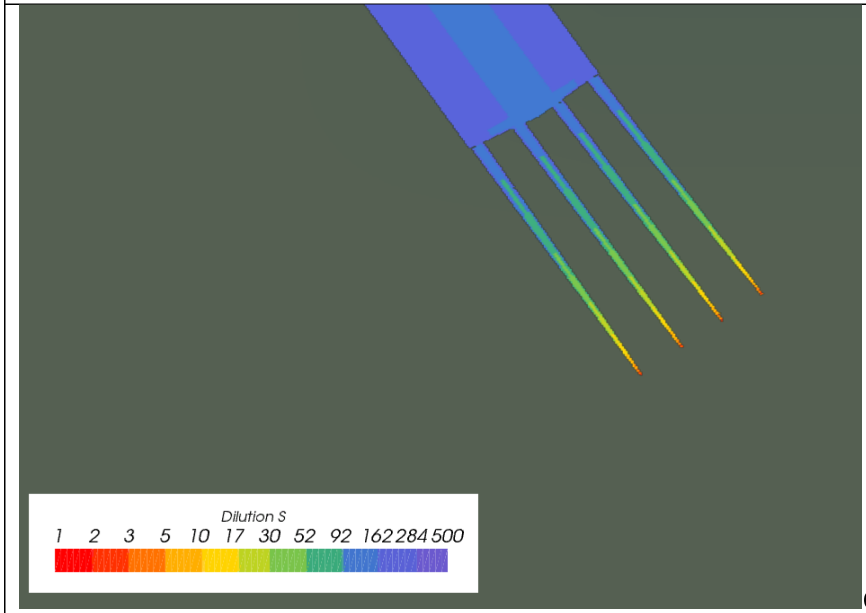
C2 – 0.3 m/s



C-3 0.5 m/s

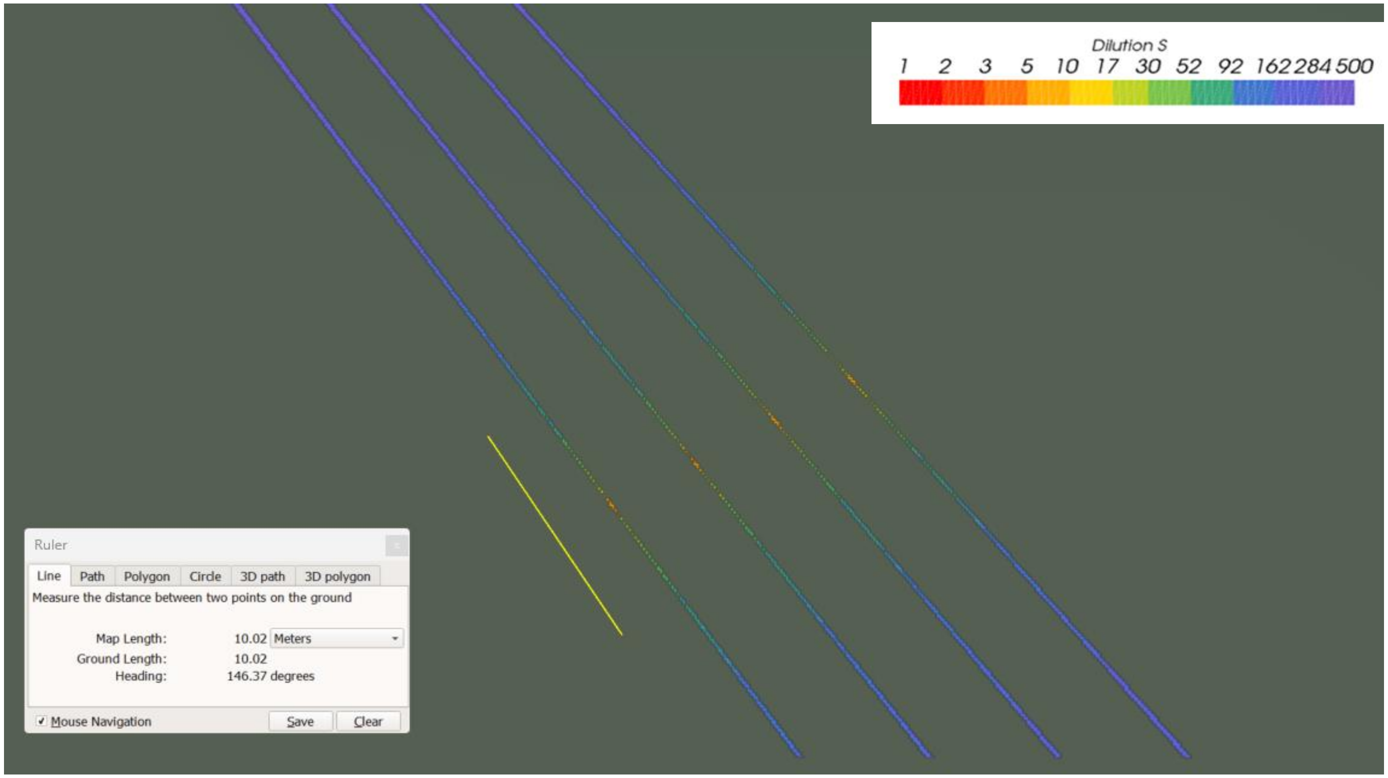


C-4 0.75 m/s



C-5 1.0 m/s

FIGURE 3-7 SCENARIO B (PHASE 2) WORST CASE TIDAL CONDITIONS C5



As described in section 3, Scenario B which corresponds to the operational discharge, rapidly dilutes due to the strong tidal current. As the discharge is buoyant the largest distances to the EQS occur when advection is strongest, i.e. the fastest tide (condition 5) and is therefore shown in Figure 3-7, evident is the thin narrow plumes from the discharge heads that do not interact with each other. A 10m scale marked in yellow helps identify how rapidly a dilution of 40 is reached, which is the dilution required for the zinc discharge to reach EQS (light green to green on the colour scale).

4. PRE-APPLICATION CONSULTATION WITH THE EA

Version 1.2 of this report, CORMIX setup and output files were provided to the EA on 7th February 2025 and were discussed as part of pre-application engagement for the Environmental Permit (ref. EPR/CP3225SW/P002). The EA noted that the CORMIX files (Mixon Inc) suggested that if this were the final design then there should be a comparison of the near field flow regime, using CORMIX 1. As such, a comparison was undertaken for Phase 1 only using CORMIX 1, with discharge from one port at approximately 40 m^3/h and compared with the CORMIX 2 with 4 ports at approximately 160 m^3/h. This comparison showed that in the near field, before the plumes merge, the results were considered identical. The EA confirmed via email on 9th May 2025 that they had no concerns or queries with this model comparison. A 2nd comparison was undertaken comparing the full volume discharge (160 m^3/h) from one port. The EA compared these results with the method of Roberts & Abessi 2014[10], which is an empirical near-field model, and have calculated the initial dilution. In terms of the near field mixing, it gives a similar response to the modelled comparison. The EA further confirmed the following on 11th June 2025:

"Based on our checks, and the fact that the mixing zone is well below 250m for brine to get to 40ppt and is also below 250m to get to a salinity change of <2ppt, we consider that the modelling is appropriate for submitting as part of a permit application and will be suitable for duly making the application"

5. DISCUSSION AND CONCLUSIONS

Overall, in both scenarios, all standards are met within 100 m for salinity and the constituents of concern. The following conclusions can be made for each of the scenarios:

5.1 CONCLUSIONS FOR PHASE 1 (12 MONTHS)

- Salinity:
  - Impact on the bed at >2 ppt is < for 5 m from heads for much of the time.
  - At 2 ppt, impact is to 81 m only at slack tide (Simulation A-1) –which is 20 minutes per tide (4 times a day).
  - Applying the standard of 5 ppt excess then impact is approximately 4 m .
  - Area above 2 ppt is 1620 m^2

[10] Abessi, O., and Roberts, P. J. W. (2014). "Multiport diffusers for dense discharges." J. Hydraul. Eng., 10.1061/(ASCE)HY.1943-7900.0000882,04014032

- Contaminants:
  - Groundwater comes from a chalk aquifer of good quality.
  - Copper and Zinc are the only substances that were measured in borehole water samples at values above the EQS.
  - Copper EQS reached in less than 1 m.
  - Zinc EQS reached at 13 m maximum for slack tide (Simulation B-1).

5.2 CONCLUSIONS FOR PHASE 2 (CONTINUED OPERATION)

- Mixed rapidly – no plume reaches the surface at levels exceeding the EQS.
- Phase 2 as buoyant does NOT have the potential for cumulative impact with other nonbuoyant discharges.
- Zinc EQS reached in less than 4 m for all states.
- Copper EQS reached in less than 1 m during all tidal states .
- Unionised ammonia discharges are near EQs at point of discharge thus reach EQ immediately on leaving the ports.
- Plumes are very narrow, areas above EQS are therefore very small.

5.3 OVERALL CONCLUSION

Neither phases will result in a significant ecological impact. Distances of exceedance of EQS either in the water column or at the bed are small. In relation to the impact of salinity on benthic species, in phase 2 scenario there is no impact at the bed. In phase 1 scenario impacts are of short duration on each tide and for a short time scale (12 months). The area in the immediate vicinity of the discharge will have already been subject to cofferdam construction and removal and was previously used and is currently permitted for a much larger brine discharge (which will not discharge concurrently – EA licence ref. WRA8220).

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