

Eemshaven site evaluation

Cooling water availability



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| Client | Ministerie van Economische Zaken en Klimaat |
| Contact | |
| Reference | Contract: DGBI-I&K/22565754 |
| Keywords | Cooling water, plume dispersion, recirculation, CORMIX, Delft3D, dynamic coupling, power plant, intake, outfall |

Document control

| | |
|-----------------------|-----------------------|
| Version | 2.0 |
| Date | 19-03-2026 |
| Project nr. | 11209639-011 |
| Document ID | 11209639-011-GEO-0003 |
| Pages | 84 |
| Classification | |
| Status | Final |

Summary

The Dutch government is considering developing two new large nuclear power plants in the Netherlands and has selected multiple possible locations for this. For the government to decide on the site selection, the feasibility of a new nuclear power plant (NPP) needs to be assessed for each site. The Ministry of Economic Affairs and Climate Policy (EZK) has requested Deltares to evaluate the Eemshaven as a potential location for a new nuclear power plant regarding the cooling water availability (i.e., environmental criteria and recirculation). This ensures the availability and access to sufficient cooling water both from an operational point of view, as well from an environmental impact perspective.

The objective of this study is to assess the cooling water availability and in particular the plume dispersion of a proposed Eemshaven NPP cooling water discharge (and other discharges in the area) in relation to the governing environmental (and other design) criteria for different Eemshaven NPP intake and outfall options. This assessment will provide information to EZK about the site selection and feasibility of different options for cooling water systems and will be used as input to their further studies and to the detailed cooling water modelling in the next phase of this project. The studies carried out are not intended to be complete and are therefore not a guarantee that if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

The available information for the Eemshaven site was inventoried and presented. This inventory includes descriptions and analyses of the bathymetry, environmental criteria and relevant ambient conditions at the project site. A complete overview of the environmental criteria for the Eemshaven project location is presented in the 'Voorstel regelgevend kader warmtelozingen centrale Eemshaven', Deltares (2025). Together with EZK, potential Eemshaven NPP intake and outfall designs were identified and agreed to be simulated.

The assessment was carried out by means of a hydrodynamic Delft3D 4 model that simulates the dispersion of the new nuclear power plant cooling water discharge, together with additional existing discharges in the area. This (detailed) model was set up around the Eemshaven project area and nested in in-house available models. When submerged outfalls were considered, the Delft3D 4 model was dynamically coupled to a database of near-field CORMIX results. With this coupled modelling system it was possible to simulate different intake and outfall configurations under various ambient conditions relevant for the applicable environmental temperature criteria and forcings that affect the plume dispersion.

Based on this study, the following conclusions have been drawn:

General

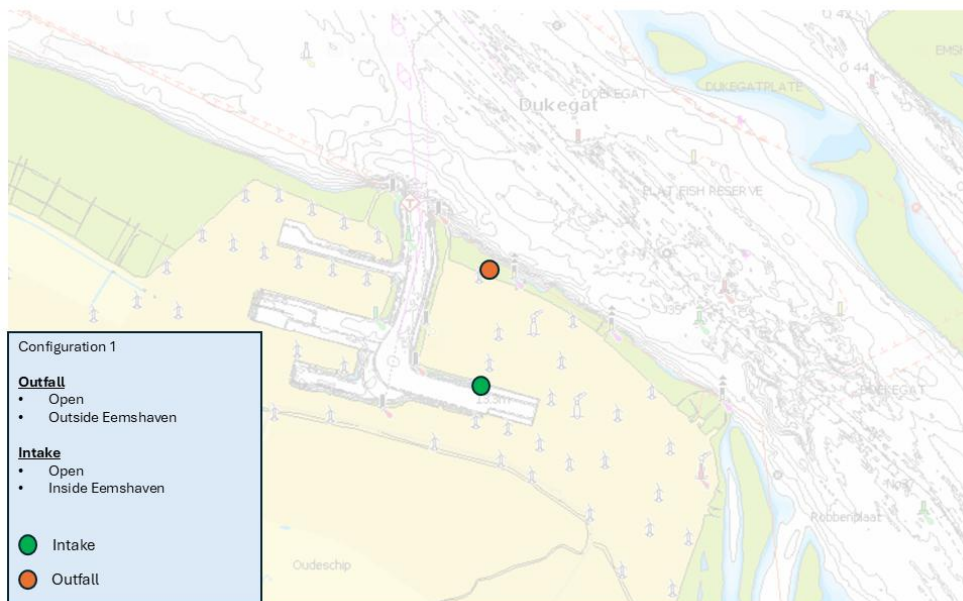
- The CIW 2004 (temperature) mixing zone and average temperature increase criteria were used for the evaluation of different Eemshaven NPP cooling water configurations. Compliance with other possible criteria (e.g., on other water/ecological parameters) would need to be evaluated in a full environmental impact assessment study. The Ems-Dollard has characteristics of both coastal waters and estuarine waters. The area northwest of the Eemshaven is considered coastal water, the Eemshaven and the area southwest of the Eemshaven are considered estuarine waters for which different criteria apply:

- Mixing zone (area classified as estuarine water): The maximum permitted mixing zone area is 25% of the cross-sectional area of the water body. The mixing zone is defined as the 25°C temperature contour. This criterion should be fulfilled at least 98% of the time.
- Mixing zone (area classified as coastal water): The 25°C temperature contour should not reach the seabed.
- Average temperature increase: The average temperature of the water body may not increase more than 2°C and/or increase above 25 °C for areas classified as estuarine and coastal water and 'schelpdierwater'.
- The selection of a representative ambient 98th percentile temperature is not trivial from the available data in the Ems-Dollard estuary. In this study, the 98th percentile water temperature was computed from 6 years of data for a location close to the Eemshaven and corresponds to 21.5 °C. A representative ambient 98th percentile temperature of 21.5 °C results in a relative mixing zone definition of +3.5 °C above ambient.
- No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different intake and outfall options for the Eemshaven NPP were selected. For this study, 8 intake and outfall configurations were considered. These 8 configurations include variations in the location of the intake and outfall and the type of intake and outfall structure (open or submerged).
- A maximum thermal discharge capacity of 6000 MW_{th} was selected for this assessment, with a flow of 159.5 m³/s and a temperature increase of +9 °C.
- A detailed 3D hydrodynamic Delft3D 4 model was set up and nested in a well-validated overall model. This new detailed model has sufficient horizontal resolution (~40 m) in the area of interest. Alternative Eemshaven NPP intake and outfall designs were incorporated in the model by means of bathymetric changes, structures and dynamic coupling to a database of nearfield simulations of the thermal discharge. Results of these simulations are presented as temperature footprints at the surface and the seabed and percentages of the total cross-section covered by the mixing zone.
- Baseline simulations were performed for the present situation with the thermal discharges of RWE Magnum (1), RWE Eemshaven (2) and ENGIE Eemshaven (3) included, see below figure. For simulations with the Eemshaven NPP only the existing thermal discharges of the RWE Magnum and RWE Eemshaven were considered. The thermal discharge of ENGIE Eemshaven was excluded in these future scenarios.
- If, at a later stage, alternative configurations are considered (for example scenarios in which other existing plants are partially or fully decommissioned) this may result in different outcomes, as the associated thermal discharges are no longer present. The same applies for configurations with additional thermal loads (for example scenario's where existing plants remain operational based on changing electricity market dynamics and regulations).



Figur S.1 Overview existing plants in the project area.

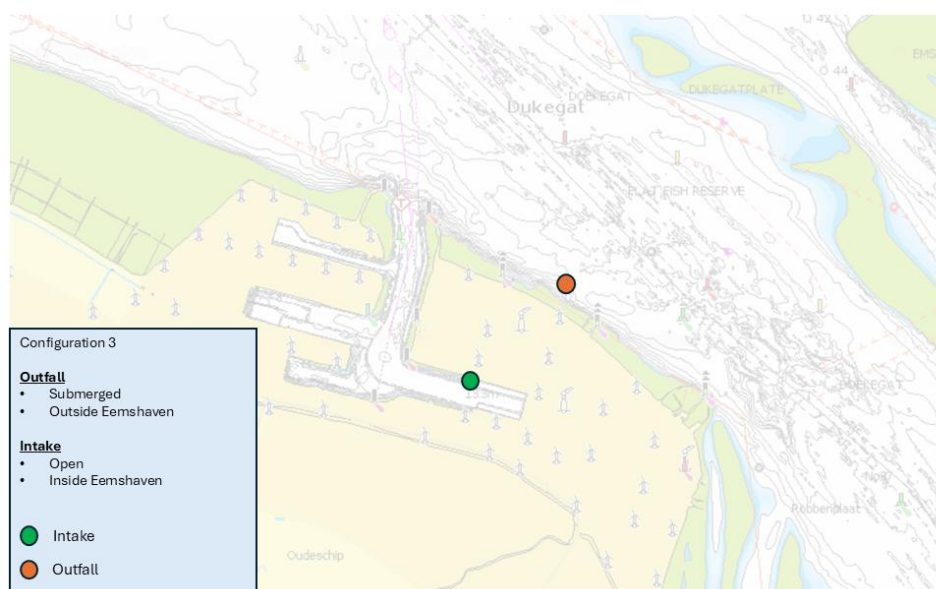
- Since the Eemshaven NPP of Configuration 8 is located at the existing plot of the RWE Eemshaven, an additional sensitivity simulation was performed with the new Eemshaven NPP and the existing RWE Magnum power plant intake and outfalls only, i.e. excluding the RWE Eemshaven (i.e. Case 9).
- An overview of the simulated scenarios is presented in the below figures and table.



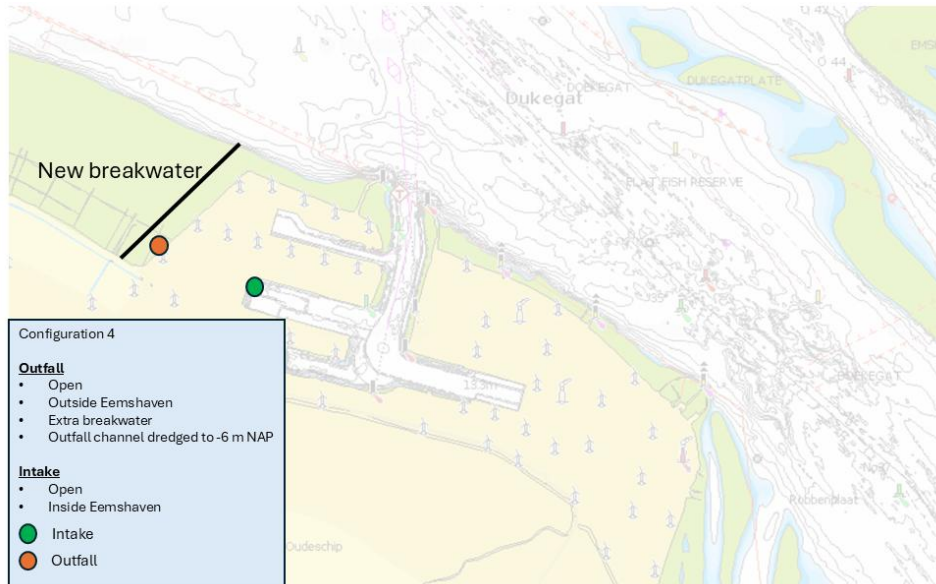
Figur S.2 Eemshaven NPP intake and outfall Configuration 1.



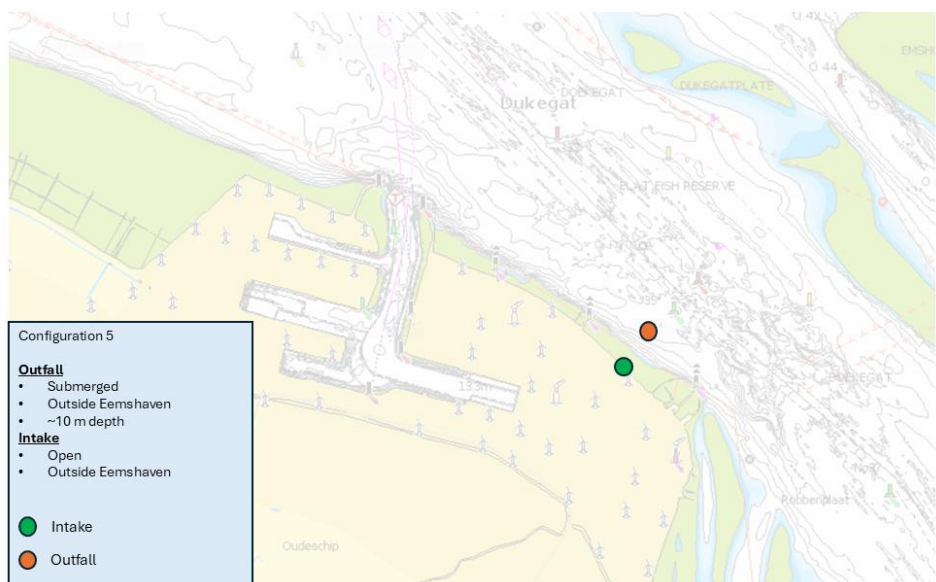
Figur S.3 Eemshaven NPP intake and outfall Configuration 2.



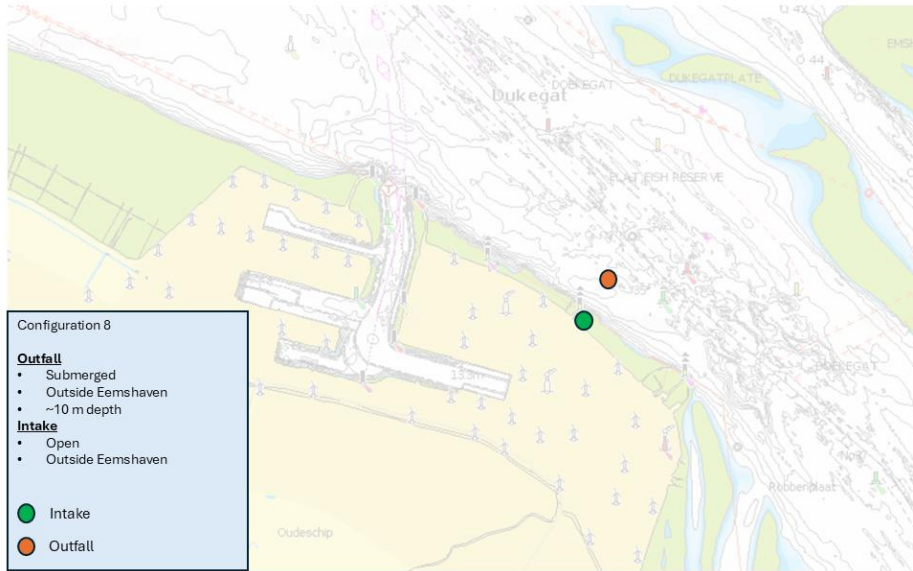
Figur S.4 Eemshaven NPP intake and outfall Configuration 3.



Figur S.5 Eemshaven NPP intake and outfall Configuration 4.



Figur S.6 Eemshaven NPP intake and outfall Configuration 5.



Figuur S.9 Eemshaven NPP intake and outfall Configuration 8.

Table S.1 Overview of simulation cases carried out in this study.

| Case | NPP config | Existing discharges | Discharge char. NPP | Comment |
|------------|------------|-----------------------|---------------------|-----------------------------------|
| Baseline 1 | - | RWE E + RWE M + ENGIE | - | Present situation |
| Baseline 2 | - | RWE E + RWE M | - | Present situation, excl. ENGIE |
| 1 | 1 | RWE E + RWE M | 159.5 m3/s +9 °C | Different I/O configurations |
| 2 | 2 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 3 | 3 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 4 | 4 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 5 | 5 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 6 | 6 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 7 | 7 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 8 | 8 | RWE E + RWE M | 159.5 m3/s +9 °C | |
| 9 | 8 | RWE M | 159.5 m3/s +9 °C | Excl. ENGIE and Eemshavencentrale |

Plume behaviour

- Due to the lower density of the cooling water, the thermal plume is expected to rise to the surface and spread in NW and SE direction (main channel orientation) by the relatively large tidal flows near the project site.
- Submerged outfalls, as opposed to open outfalls, rapidly mix the cooling water with ambient water, reducing the temperature increase around the outfall (~ 500m) due to the cooling water discharge. At distances of more than 500 m only a limited difference in the maximum excess surface temperature increase is expected between submerged and open outfalls. Near the seabed very little difference in the expected maximum temperature is expected between an open and submerged outfall.
- The Ems-Dollard estuary includes shallow tidal flats. Discharging close to tidal flats (ENGIE discharge location, Baseline 1 / Case 2) results in limited mixing with ambient water and a relatively high excess temperature around the outfall and near the bed.

Environmental criteria

- The maximum computed cross-sectional area covered by the mixing zone (temperature increase > 3.5 °C) is around or below 12% for all cases. This is lower than the critical threshold value of 25% specified in the CIW criteria.
- While a submerged outfall (for example Case 3) will rapidly locally mix the discharged water and lead to a lower temperature close to the outfall and seabed, a higher percentage of the cross-sectional area is expected to be covered by the mixing zone compared to an open outfall (e.g. Case 1).
- The maximum computed cross-sectional average temperature increase (as a conservative interpretation of the average temperature increase of the water body) is in all cases below 2 °C (absolute temperature is therefore by definition lower than the 25 °C criterion).

- Both in the present situation (Baseline 1 / Baseline 2) and in Cases 1 to 8, the mixing zone (temperature increase > 3.5 °C) is expected to reach the seabed in different areas around the Eemshaven depending on the intake and outfall configuration:
 - In the present situation (Baseline 1) the ENGIE thermal discharge has limited dilution around the outfall and maximum increased temperatures are expected on the seabed of more than 3.5 °C at distances of approximately 2.5 km south of the discharge location. However, these areas are classified as estuarine waters for which estuarine mixing zone criteria apply, in which the seabed temperature is not explicitly considered. The mixing zone is not expected to reach the seabed in coastal waters (northwest of Eemshaven).
 - In the present situation without the ENGIE Eemshaven in operation (Baseline 2) only locally (<500 m) around the existing outfalls, the near-bed temperature is expected to exceed the +3.5 °C CIW criterion. The area where the mixing zone reaches the seabed is classified as estuarine waters.
 - For Case 1 the near-bed temperature increase of more than +3.5 °C is computed at alongshore distances up to 4.5 km southeast of the discharge location of Configuration 1. The computed +3.5 °C near-bed temperature contour is not expected to reach the area northwest of the Eemshaven for which the CIW coastal criterion applies.
 - When Eemshaven NPP is located at the site of the existing ENGIE Eemshaven plant (Case 2), the same area south of this discharge location will be subject to increased temperature as in Baseline 1. Due to the larger thermal load of the NPP, the mixing zone at the seabed does extend further south, approximately 7 km. The computed mixing zone of Case 2 is not expected to reach the seabed in coastal waters.
 - In Case 3 the mixing zone at the seabed is expected to locally reach distances up to 2 km from the outfall locations. These areas are however classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.
 - For Case 4 a relatively high increased temperature at the seabed is computed in the (shallow) area around the discharge. The increased temperature are explained by the limited initial mixing by the open outfall compared to a submerged diffuser option. The computed mixing zone (+3.5 °C contour) near the seabed extends approximately 1 km to the northwest from the point of discharge. This area is partially coastal water. The computed mixing zone at the seabed for Case 4 is smaller compared to the computed mixing zone at the seabed of Case 2, due to the deeper water in the vicinity of the outfall of Configuration 4.
 - For Case 5 the submerged outfall (similar to Case 3) rapidly mix the cooling water with ambient water reducing the increased temperatures around the outfall due to the cooling water discharge. Case 5, however, does show a slightly larger maximum mixing zone extent compared to Case 3, as the combined mixing zone extent (+3.5 °C contour) at the seabed is expected to locally reach distances up to 3.5 km from Eemshaven NPP outfall location. Main reason for this increase in mixing zone extent is the expected increase in recirculation (due to the proximity of the NPP intake), which results in a higher discharge temperature. However, the areas near the seabed with an increased maximum temperature above +3.5 °C are classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.
 - The outfall of Case 6 is more distant from the existing outfalls compared to most other cases. Therefore, less interaction between the outfall plumes is expected. The combined mixing zone is expected to reach the seabed only locally around the outfall in the near-field region (<200 m) and near the existing outfalls. The area around the Case 6 outfall is classified by the CIW criteria as coastal water in which the mixing zone should not reach the seabed.
 - Case 7 includes an extension of the intake channel, compared to Case 6. This extension has no substantial effect on the expected plume dispersion and recirculation. Main findings and conclusions on the dispersion and recirculation of cooling water for Case 6 therefore also apply to Case 7.

- Case 8 results in an expected near-bed temperature increase above the critical threshold value of +3.5 °C at distances up to 1 km. The computed mixing zone of Case 8 is not expected to reach the seabed in coastal waters northwest of the Eemshaven.
- For Case 9 (same outfall configuration as Case 8, but excluding the RWE Eemshavencentrale) it is computed that only locally (<200 m) the mixing zone will reach the seabed.

Recirculation

- If the new Eemshaven NPP intake is located inside the Eemshaven (Case 1, Case 3 and Case 4), the computed temperature at the intake is typically around 1.3 – 1.5 °C and max 1.7 °C above ambient conditions. If the Eemshaven NPP intake is located outside the Eemshaven and close to the existing discharges (Case 2, Case 5 and Case 8), a higher temperature is computed at the intake of around 1.5 °C – 2.4 °C (mean) and maximum exceeding 4 °C above ambient conditions.
- Due to the new Eemshaven NPP, the mean and maximum temperature at the existing intakes of RWE Magnum and RWE Eemshaven is expected to increase by about 0.5 – 1.3 °C compared to the present situation (Baseline 1).

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1 Introduction

1.1 Project background

The Dutch government is considering developing two new large nuclear power plants in the Netherlands and has selected multiple possible locations for this. For the government to decide on the site selection, the feasibility of a new nuclear power plant needs to be assessed for each site. Furthermore, possible ‘vendors’ (i.e., developers) may need to carry out their own technical studies towards an initial design of such a plant, including all hazard and safety considerations. EZK wants to provide these vendors with initial technical information for them to base their studies on.

EZK has requested Deltares to evaluate the Eemshaven as a potential location for a new nuclear power plant regarding the cooling water availability (i.e., environmental criteria and recirculation). This ensures the availability and access to sufficient cooling water both from an operational point of view, as well from an environmental impact perspective.



Figure 1.1 Project site and key locations.

The access to sufficient cooling capacity is crucial for the proper and safe operation of the new nuclear power plant. It is therefore important to assess the availability and access to sufficient cooling water both from an operational point of view, as well as from an environmental impact point of view, for the different locations under consideration for the new plant. To assist in these considerations and as input to environmental considerations, Deltares carried out a numerical modelling study to make a first assessment on the availability (capacity) of cooling water and possible options for the cooling water intake and outfall for the new plant.

1.2 Objectives

The objective of this initial cooling water study for the new nuclear power plant is to assess the cooling water availability/capacity in the Eemshaven area. Specifically:

- Assess the combined plume dispersion of the new nuclear power plant cooling water discharge and other discharges in the area in relation to the applicable environmental temperature criteria for different intake and outfall options.
- Assess the combined recirculation potential of different intake and outfall options and other cooling water discharges (i.e., the combined temperature increase at the nuclear power plant intake) in the project area, as well as the temperature increase at the existing intakes.

This study aims to provide EZK and potential developers with an initial indication of the feasibility of investigated cooling water configurations based on temperature criteria. The studies carried out are not intended to be complete and are therefore not a guarantee that if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

1.3 Scope of work

The objective was studied by means of a new numerical hydrodynamic model that simulates the dispersion of the new nuclear power plant cooling water discharge. This (detailed) model was set up around the project area and nested in the in-house available validated models of the Ems-Dollard estuary (Van Maren, 2015). To adequately model the outfall plume, this detailed model was run in three-dimensional mode and with a sufficiently high model grid resolution.

The model simulated different intake and outfall configurations and structures under various, relevant ambient conditions. The intake and outfall configurations were agreed with EZK and the ambient conditions scenarios were based on the applicable environmental criteria and forcings that affect the plume dispersion. Model results were subsequently analysed and presented in relation to the environmental temperature criteria.

1.4 Reader

This report follows the same structure as other cooling water availability studies for different possible locations for a new nuclear power plant. The report starts with the project information available to the present study in Chapter 2. Data on the bathymetry, intake and outfall design options and environmental criteria etc. are inventoried here. Chapter 3 describes the setup of the Delft3D hydrodynamic model. The results of the plume dispersion and recirculation modelling are described in Chapter 4 and Chapter 5 presents the conclusions of this study.

2 Project information

In this chapter, the available information relevant to the plume dispersion and recirculation of the proposed nuclear power plant at Eemshaven is inventoried and presented. This inventory includes descriptions and analyses of the bathymetry, environmental criteria, ambient conditions at the project site, intake and outfall characteristics and discharge options.

2.1 Bathymetry

Bathymetry data was derived from Baseline j24 (2024) and Baseline j22 (2022) (Baseline GIS-application of RWS). The selected bathymetry data covers part of the North Sea, the Wadden Sea and Ems-Dollard Estuary and has sufficient extent to be directly used for the full domain of the numerical models. The data represents the bathymetric conditions around 2024. Locally, around Eemshaven, data of Baseline j22 was used to replace erroneous data from Baseline j24. The data is provided in the horizontal coordinate system Amersfoort / RD new (EPSG code 28992) and referenced in the vertical to NAP. The data is presented in Figure 2.1 and Figure 2.2.

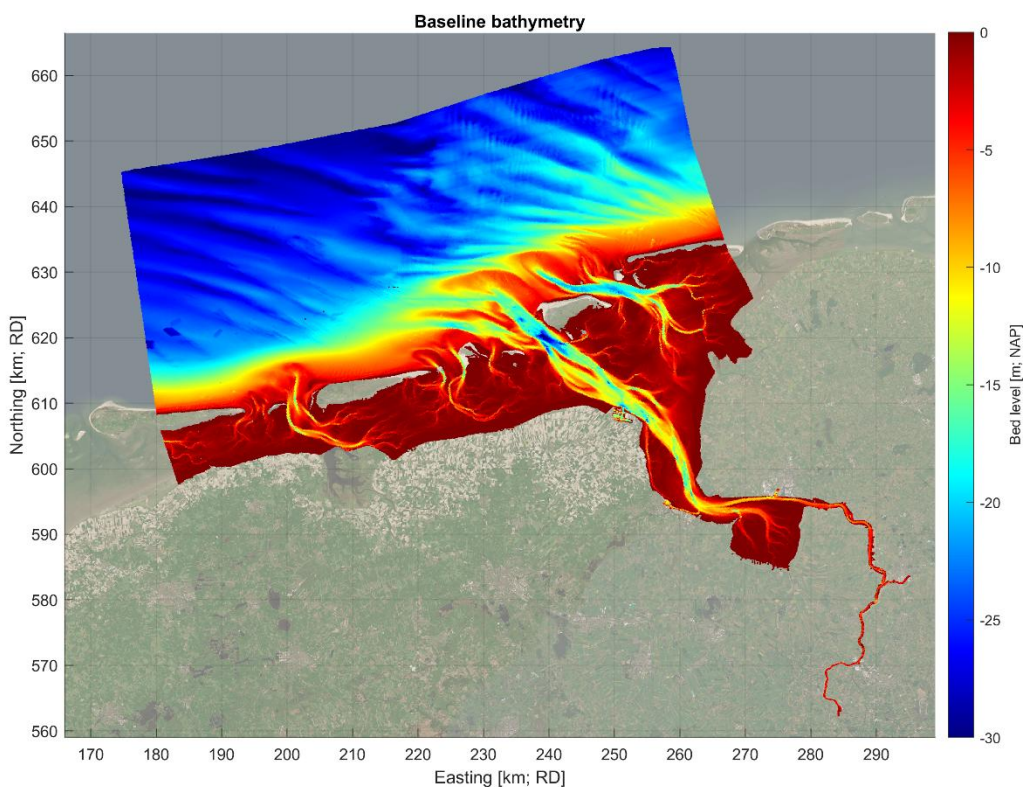


Figure 2.1 The bathymetry data (source: Baseline).

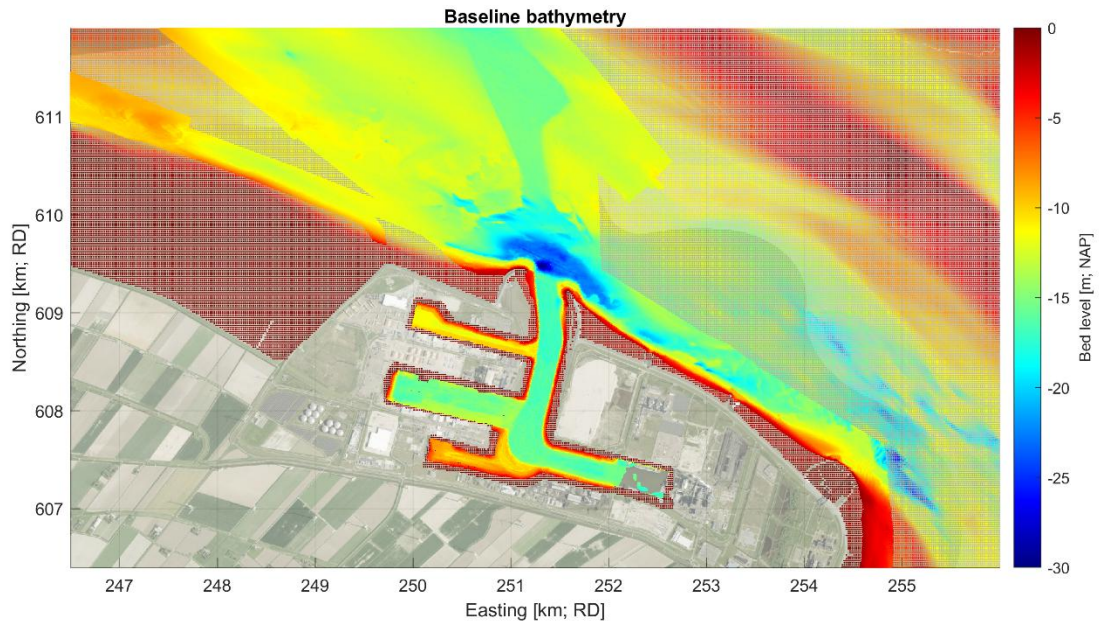


Figure 2.2 The bathymetry data around the Eemshaven (source: Baseline).

This dataset shows that the Ems-Dollard Estuary consists of multiple tidal flats and gullies with depths up to -30 m NAP. In the Eemshaven area depths are typically between -10 m NAP and -15 m NAP. The Eemshaven harbour has depths typically up to -15 m NAP. The total width of the Ems-Dollard estuary is about 15 km.

2.2 Environmental criteria

The intake and outfall configuration of the new nuclear power plant and its cooling water discharge need to comply with environmental temperature criteria in place. A full overview of the environmental criteria for the intake and outfall configuration for the Eemshaven area is therefore presented in the 'Voorstel regelgevend kader warmtelozingen centrale Eemshaven', Deltares (2025). The focus of the present assessment is on the quantitative temperature criteria that can be evaluated by means of numerical modelling. These environmental criteria include the CIW 2004 (Rijkswaterstaat 2004) criteria for thermal discharges. The Ems-Dollard has characteristics of both coastal waters and estuarine waters. Therefore, the temperature criteria for both types of water bodies are considered. In summary, these criteria state:

- **Mixing zone (area classified as estuarine water):** The maximum permitted mixing zone area is 25% of the cross-sectional area of the water body. The mixing zone is defined as the 25 °C temperature contour. This criterion should be fulfilled at least 98% of the time.
- **Mixing zone (area classified as coastal water):** The 25 °C temperature contour should not reach the seabed.
- **Average temperature increase:** The average temperature of the water body may not increase more than 2°C and/or increase above 25 °C for areas classified as estuarine and coastal water and 'schelpdierwater'.

Coastal- and estuarine water criteria

Environmental criteria distinguish different types of water bodies for which different criteria apply. The Ems-Dollard estuary has characteristics of both coastal- and estuarine waters. Information from the Water Framework Directive (WFD, in Dutch KRW) indicates that the transition between these two waterbodies in the Ems-Dollard is situated close to the Eemshaven, see Figure 2.3 (*European Parliament & Council of the European Union, 2000*). In this figure the blue area indicates the estuarine water body. For estuarine systems, a maximum allowed percentage of the cross-sectional area (25%) may be covered by the

mixing zone ($>25^{\circ}\text{C}$). For coastal waters, the mixing zone should not reach the seabed. This information implies that the area northwest of the Eemshaven should be evaluated for impingement of the mixing zone on the seabed and the area around the Eemshaven and further Southeast should be evaluated based on the maximum percentage of the cross-sectional area covered by the mixing zone.

This information needs to be verified for practical application. In this study, the percentage of the cross-sectional area covered by the mixing zone is computed for the whole domain, but may apply only in parts of the area. Similar, the maximum temperature increase at the bottom is computed and presented for the whole area. This allows for independent evaluation when more information on the application of the environmental criteria becomes available.



Figure 2.3 Boundary coastal / estuarine water body. (Source KRW).

Average temperature increase

In the new 'Nationaal Waterprogramma' 2022-2027 (*Ministerie van Infrastructuur en Waterstaat, 2022*) Eems-Dollard is classified as 'Schelpdierwater'. In the present assessment, the average temperature increase (over the cross-sectional area) is calculated and presented for a large number of cross-sections along the axis of the Eems-Dollard estuary and coastal area. For the interpretation of the results a conservative maximum allowed temperature increase of 2°C for each considered cross-section is assumed.

For permitting of the eventual cooling water system, a full environmental impact assessment will be needed that also includes an assessment of the impact on water quality and ecology. Compliance of the cooling water discharge with the CIW 2004 criteria is only a part of this environmental impact assessment. A full environmental impact assessment, or assessment against other criteria than temperature criteria, is not part of the present scope of work of this preliminary cooling water study.

Recirculation criteria

No recirculation criteria are available for the present assessment. The simulated recirculation potential at each intake will be presented such that it allows for independent further use.

2.3 Ambient water temperature

Application of the environmental criteria requires quantification of the ambient (background) water temperature near the project site. The background temperature is defined in the CIW 2004 criteria as the representative temperature at the edge of the water body. Water temperature data was downloaded from the water info data portal (www.waterinfo.rws.nl) and analysed to derive the 98th-percentile water temperature (as per the CIW criteria, (Rijkswaterstaat, 2004)). Results are summarised in *Table 2.1*. Figure 2.4 shows the locations of the ambient water temperature measurements that cover a period of 20 years (2002-2022).

Table 2.1 98th-percentile temperatures of the ambient water at different locations.

| Station | Start date | End date | frequency | In plume existing outfalls | 98 th perc. |
|--------------------------|------------|------------|-----------|----------------------------|------------------------|
| Bocht van Watum | 20-1-2000 | 11-12-2023 | Weeks | | 22.0 |
| Bocht van Watum noord | 20-1-2000 | 11-12-2009 | Weeks | | 21.3 |
| Delfzijl | 1-1-2000 | 31-12-2001 | Day | | 21.6 |
| Eemshaven | 1-1-2000 | 22-8-2022 | 10 min. | + | 22.7 |
| Eemshaven stroommeetpaal | 1-1-2017 | 31-12-2023 | 10 min. | + | 21.5 |
| Groote Gat noord | 20-1-2000 | 11-12-2023 | Weeks | | 23.2 |
| Huibertgat oost | 20-1-2000 | 11-12-2023 | Weeks | | 21.1 |
| Randzelgat Noord boei | 14-1-2024 | 2-1-2025 | 10 min. | | 21.4 |
| Stroommeetpaal Eemshaven | 14-1-2024 | 13-1-2025 | 10 min. | + | 21.6 |



Figure 2.4 Locations of the ambient water temperature measurements (www.waterinfo.rws.nl).

Selection of a representative ambient 98th percentile temperature is not trivial from the available data in the Ems-Dollard estuary. Ideally, a representative measurement point (1) should be located in the current-carrying part of the estuary at the edge of the waterbody and located outside the plume extent of existing cooling water discharges that are part of the assessment, (2) have a high measurement frequency (i.e., 10 min) and (3) cover a prolonged and recent period of time. Based on these selection criteria station 'Eemshaven Stroommeetpaal' was selected to be most representative, which is located close to the project site. The 98th percentile water temperature computed from 6 years of data - retrieved from RWS water info portal - corresponds to 21.5 °C. The mixing zone is defined as the area with a temperature increase of +3.5 °C (25 °C - 21.5 °C) above ambient temperature.

2.4 Ambient hydrodynamics

The environmental criteria require that the plume dispersion is assessed for low flow conditions past the plant. To assess the flow conditions at the site, model results from Van Maren (2015) were analysed in proximity of the Eemshaven. Figure 2.5 presents the simulated water level and total flow past the Eemshaven for 2012. This figure illustrates that the total flow is tide dominated with neap-tide conditions in January/February 2012. The water level variation is tide dominated with a typical tidal range in the order of 2 m. Indirectly, the water level variation is important for the environmental criteria (cross-sectional area covered by the mixing zone), see Section 2.2. Figure 2.5 shows that lowest water levels occurred in January/February 2012.

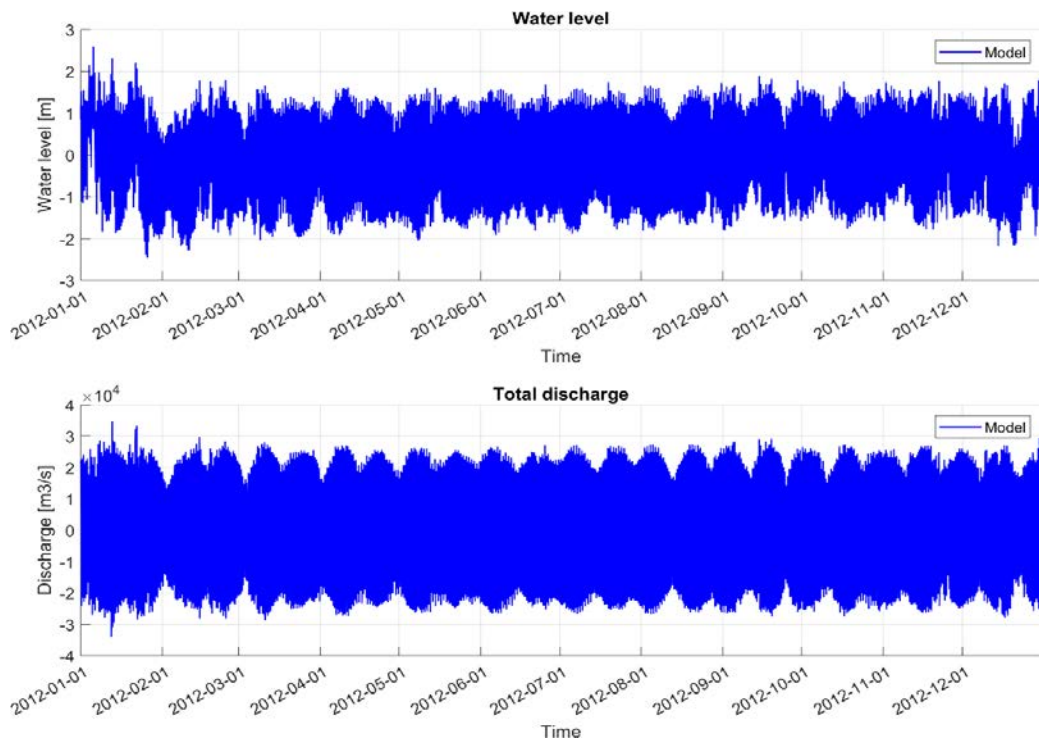


Figure 2.5 Simulated water level (top) and total flow past the Eemshaven (bottom) for 2012.

2.5 Present outfalls near the Eemshaven

The environmental criteria state that for the present assessment, the outfall plume dispersion of all thermal discharges in the project area should be considered to account for potential cumulative effects. No detailed information on nearby industrial discharges were available. Data used in the present assessment is based on publicly available data. Three different existing thermal discharges were identified: the Magnumcentrale, Eemshavencentrale and the Eemscentrale. For all discharges a discharge temperature of +8 °C was assumed.

Table 2.2 presents an overview of the existing discharges and estimated characteristics. Figure 2.6 shows the locations of the plants. It is noted that the Eemscentrale of Engie is only occasionally operational and serves as a backup for times with high power demand.

Table 2.2 Existing discharges in the Eemshaven area.

| Power plant | Elec. power (Mwe) | Efficiency (%) | Thermal discharge (MWth) | Temperature increase (°C) | Specific heat (J/g°C) | Discharge (m ³ /s) |
|--------------------------------------------|-------------------|----------------|--------------------------|---------------------------|-----------------------|-------------------------------|
| Magnumcentrale (1) (RWE M) ¹ | 1410 | 58 | 1021 | 8 | 4.186 | 30.5 |
| Eemshavencentrale (2) (RWE E) ² | 1560 | 46 | 1831 | 8 | 4.186 | 54.7 |
| Eemscentrale (3) (ENGIE) ³ | 1800 | 56 | 1414 | 8 | 4.186 | 42.2 |



Figure 2.6 Overview existing plants in the project area: (1) Magnumcentrale RWE, (2) Eemshavencentrale RWE and (3) Eemscentrale ENGIE.

2.6 Eemshaven nuclear power plant cooling water discharge

The purpose of this cooling water study is to evaluate different intake and outfall options for the proposed nuclear power plant in Eemshaven in relation to the environmental criteria in place. No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different cooling water discharge characteristics and intake and outfall options for the nuclear power plant were selected to be assessed in the present study.

¹ * <https://benelux.rwe.com/locaties-en-projecten/magnumcentrale/>

² ** <https://benelux.rwe.com/locaties-en-projecten/kolencentrale-eemshaven/>

³ *** <https://www.engie.nl/over-ons/moderne-centrales/eemscentrale>

2.6.1 Thermal discharge capacity, flow and discharge temperature

The maximum electrical capacity of the new power plant is currently estimated at 2x1600 MWe with an estimated efficiency of 35%. The proposed power plant (2x1600 MW electrical capacity) has a total thermal capacity of 4600 MW_{th} per unit. This results in $(4600-1600)*2 = 6000$ MW_{th} of heat discharge for a once-through cooling system. A discharge of 159.5 m³/s and a temperature increase of +9 °C was assumed.

2.6.2 Intake and outfall options

For the new cooling water system, 8 intake and outfall configurations were assessed (as agreed with EZK). Configurations differ by the locations of the intake and outfall and type of intake/outfall (submerged or open). The intake and outfall configurations are summarised below:

- Configuration 1: Open intake in the Eemshaven. Open outfall outside the Eemshaven, close to the entrance.
- Configuration 2: Intake and outfall at the existing intake and outfall location of the Eemscentrale (ENGIE); Open intake and outfall outside the Eemshaven. Note that the outfall is in relative shallow water (~5 m).
- Configuration 3: Open intake in the Eemshaven. Submerged outfall offshore and outside the Eemshaven at a depth of approximately 10 m.
- Configuration 4: Open intake in the Eemshaven. Open outfall outside and west of the Eemshaven. For this configuration an additional breakwater is considered to deflect the heated discharge offshore. For this assessment it was assumed that the outfall channel will be dredged to -6 m NAP.
- Configuration 5: Open intake northeast of the Eemshaven. Submerged outfall 500 m offshore and northeast of the Eemshaven.
- Configuration 6: Open intake outside and west of the Eemshaven. Submerged outfall outside and northwest of the Eemshaven. For this configuration an additional breakwater is considered at the intake. For this assessment it was assumed that the intake channel will be dredged to -6 m NAP.
- Configuration 7: Same as Configuration 6, but with a longer intake channel.
- Configuration 8: Same as Configuration 5, but both the intake and outfall relocated 350 m in northwest direction.

Furthermore, a sensitivity test was performed with Configuration 8 and the existing outfalls in the area. Configuration 8 (Case 8) considers the area of the existing Eemshavencentrale of RWE and the new nuclear power plant is likely to replace this existing power plant. Therefore an additional simulation was performed excluding the Eemshavencentrale, see Section 4.1.

No sensitivity tests were performed regarding the design parameters of the intake and outfall system of the envisaged nuclear power plant, like different discharge characteristics, total thermal load, additional structures and/or optimised near-field mixing of an outfall diffuser. Furthermore, no detailed designs of the intake and outfall structure have been made for the intake and outfall structures due to the preliminary nature of this assessment. It is however noted that specific criteria exist for the intake and outfall structures. This includes, amongst others, criteria for fish entrainment and impingement of the intake structure to which the intake needs to comply.

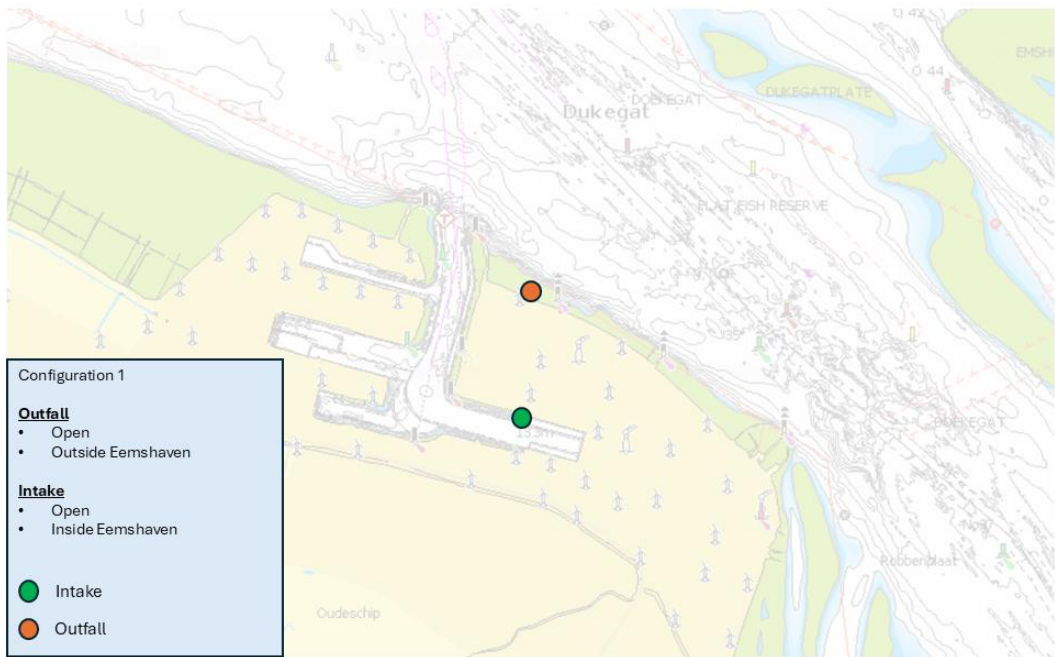


Figure 2.7 Eemshaven NPP intake and outfall Configuration 1.

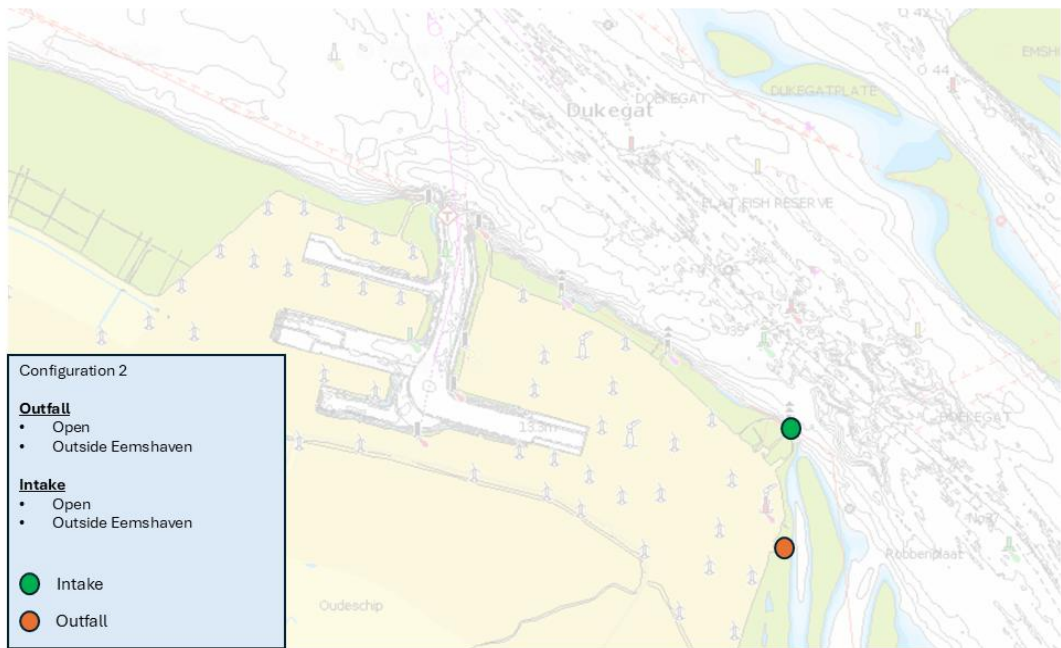


Figure 2.8 Eemshaven NPP intake and outfall Configuration 2.

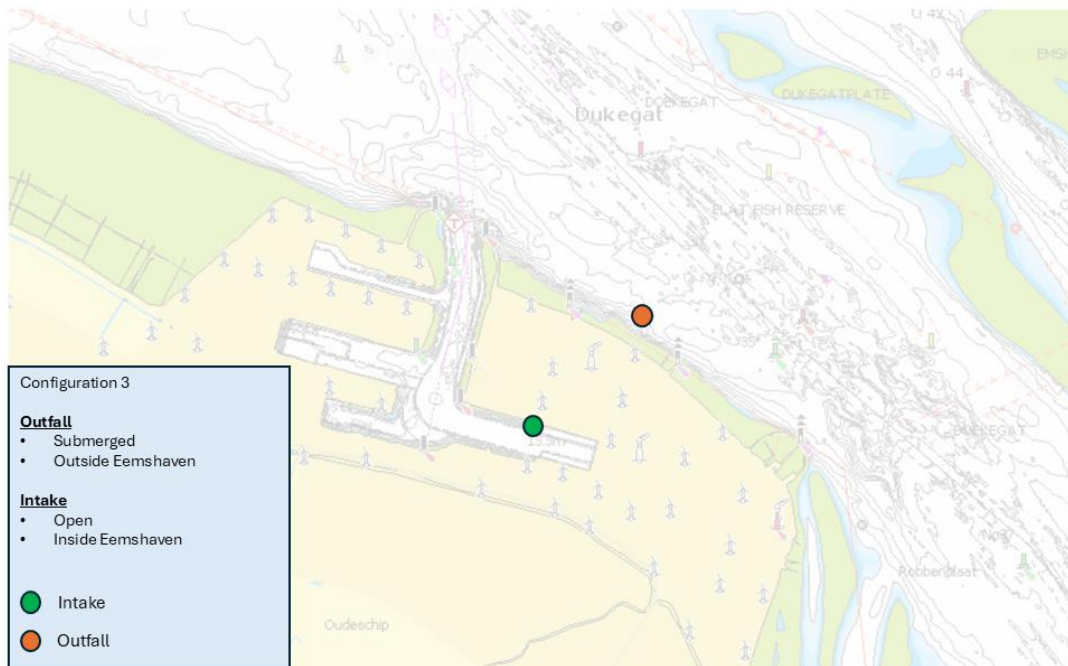


Figure 2.9 Eemshaven NPP intake and outfall Configuration 3.

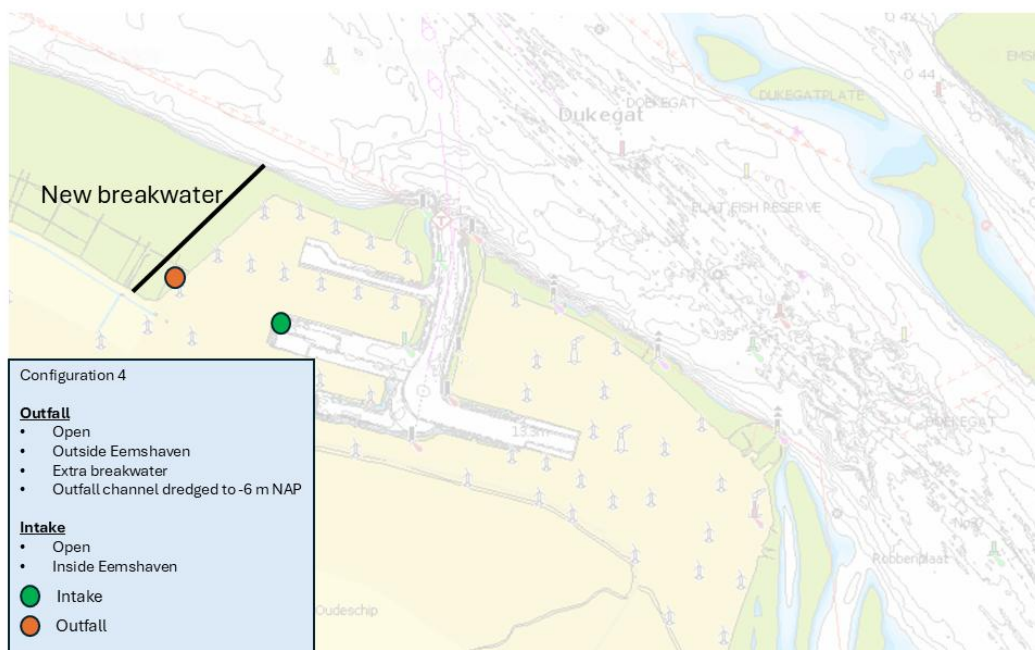


Figure 2.10 Eemshaven NPP intake and outfall Configuration 4.

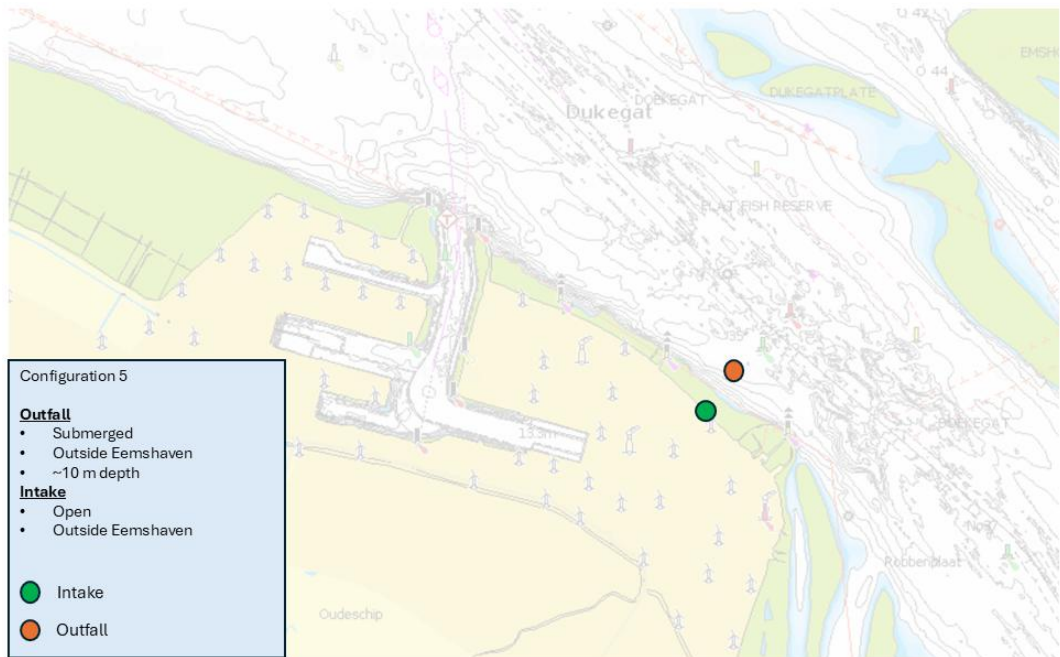


Figure 2.11 Eemshaven NPP intake and outfall Configuration 5.



Figure 2.12 Eemshaven NPP intake and outfall Configuration 6.

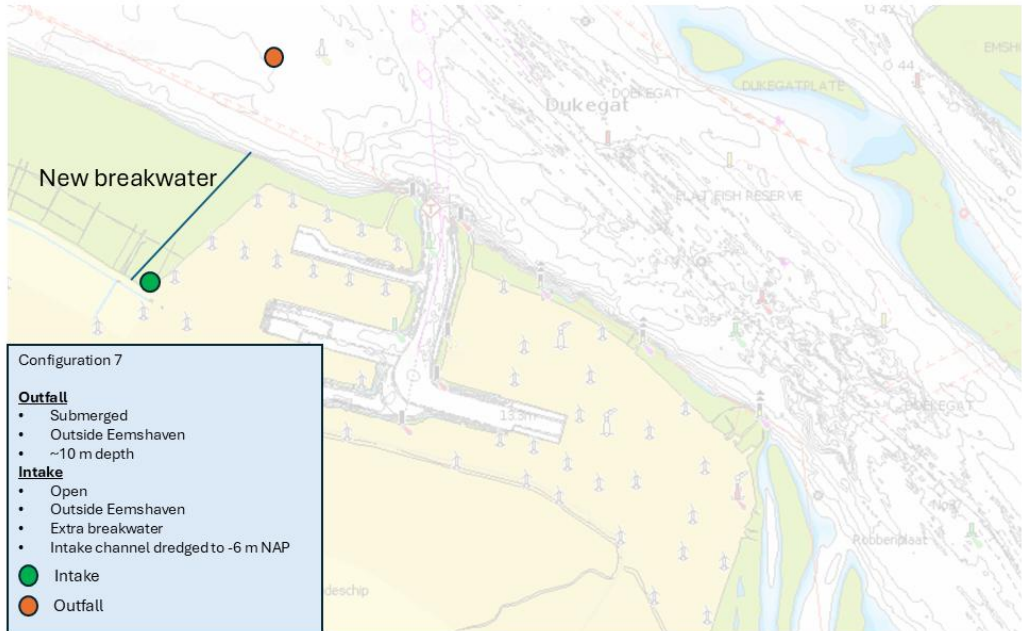


Figure 2.13 Eemshaven NPP intake and outfall Configuration 7.

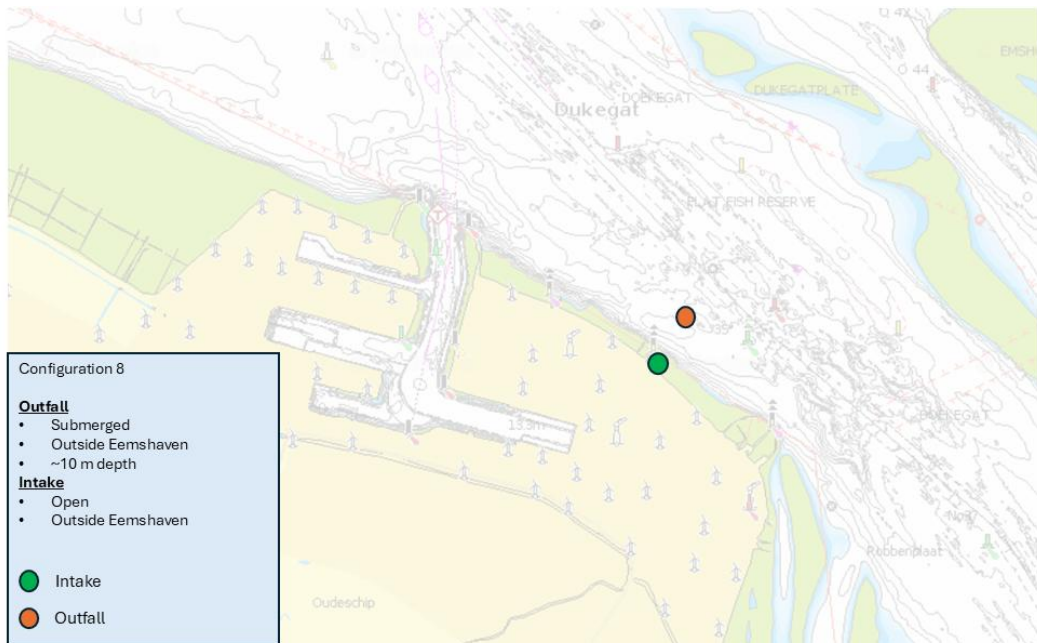


Figure 2.14 Eemshaven NPP intake and outfall Configuration 8.

3 Setup of the detailed Delft3D 4 model

To assess the plume dispersion and recirculation of discharged cooling water in the project area, a detailed far-field model is needed. This far-field model should be capable of simulating the important hydrodynamic processes for the plume dispersion with sufficient horizontal and vertical resolution as well as the heat exchange with the atmosphere. In the present assessment, a dedicated three-dimensional model was setup in Delft3D 4. Hydrodynamic boundary conditions for this detailed model were derived from an available validated overall model of the Ems-Dollard Estuary. Simulations were performed with version 6.04.00.140726 of the Delft3D-FLOW software. This chapter presents the modelling approach and setup of the detailed Delft3D 4 model.

3.1 Overall model

An overall validated hydrodynamic Delft3D 4 model of the Ems-Dollard Estuary was available from van Van Maren (2015). This model simulates the 3D hydrodynamic conditions, including salinity, at the Ems-Dollard Estuary. This model was used to derive boundary conditions for the detailed model. This overall model covers the Ems-Dollard Estuary, part of the Wadden Sea and part of the North Sea, see Figure 3.1. This three-dimensional model (i.e. 10 sigma layers) was set up for the year 2012 and validated in detail for water level, currents and suspended sediment concentration, see Figure 3.2. Hydrodynamic conditions are written to the output file with an interval of 10 minutes for specific locations (i.e., boundary locations of the detailed model).

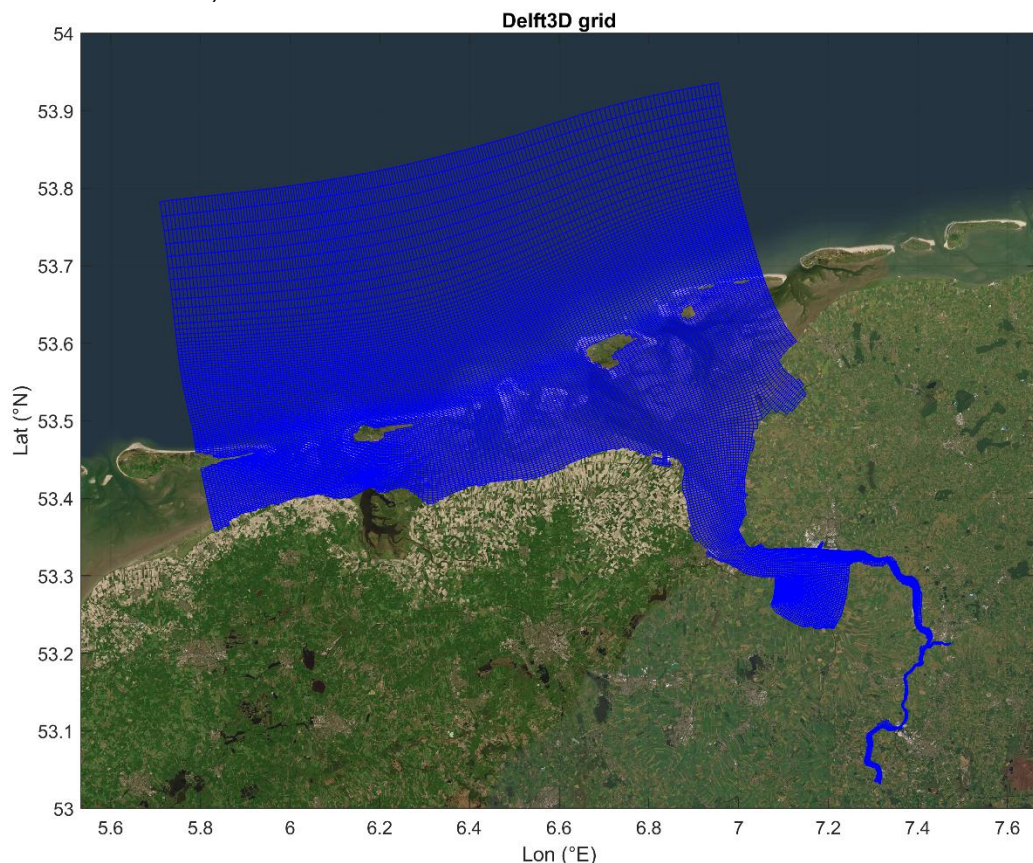


Figure 3.1 Model domain of the overall model.

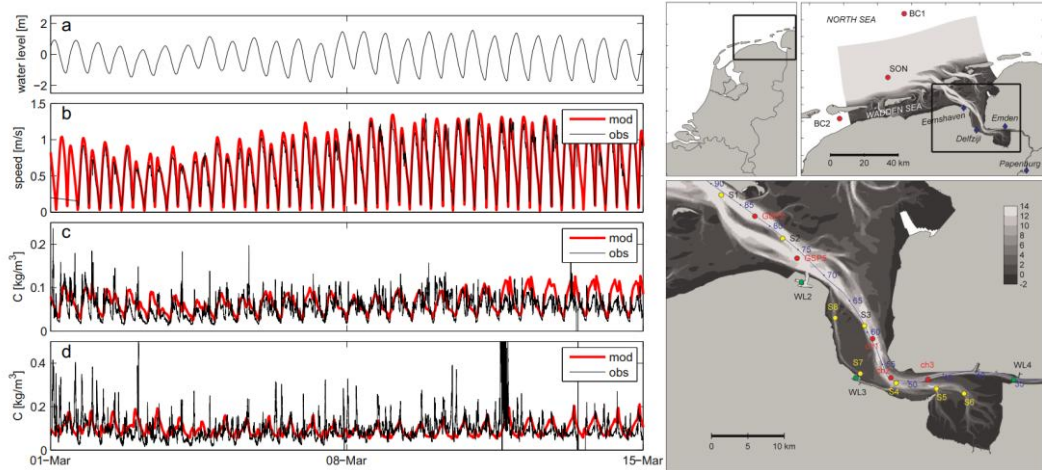


Figure 3.2 Current validation of the Ems-Dollard Estuary overall model at location GSP5 (approximately 2 km from Eemshaven).

3.2 Computational grid detailed model

A new detailed hydrodynamic model was set up to simulate the dispersion and mixing of the present and proposed cooling water discharges. The computational grid covers an area of about 50 km in alongshore direction and about 70 km inland up to the river Eems, see Figure 3.3 and Figure 3.4. The model extent was based on sensitivity tests with the overall model, in which the maximum expected travel distance of the discharged cooling water was assessed. The computational grid makes use of the curvilinear grid approach with high resolution near the project site and lower grid resolution at the model boundaries. Near the project site the model grid has a resolution of about 40 m by 40 m. Towards the model boundaries the grid resolution increases to more than 800 m by 300 m. In total the grid consists of 202 x 499 grid cells.

The horizontal coordinate system of the grid is Amersfoort / RD new. In the vertical the sigma approach was used for the vertical grid layer distribution. This means that the grid layers are distributed according to a fixed percentage of the local water depth. The present model contains 10 vertical layers which are uniformly distributed. With depths typically between 5 m to 15 m in the area of interest, the vertical model resolution is typically between 0.5 m and 1.5 m. This sigma approach ensures that the high resolution of the vertical grid is concentrated near the (edge of) the thermal plume to accurately simulate the dispersion of cooling water within feasible simulation times.

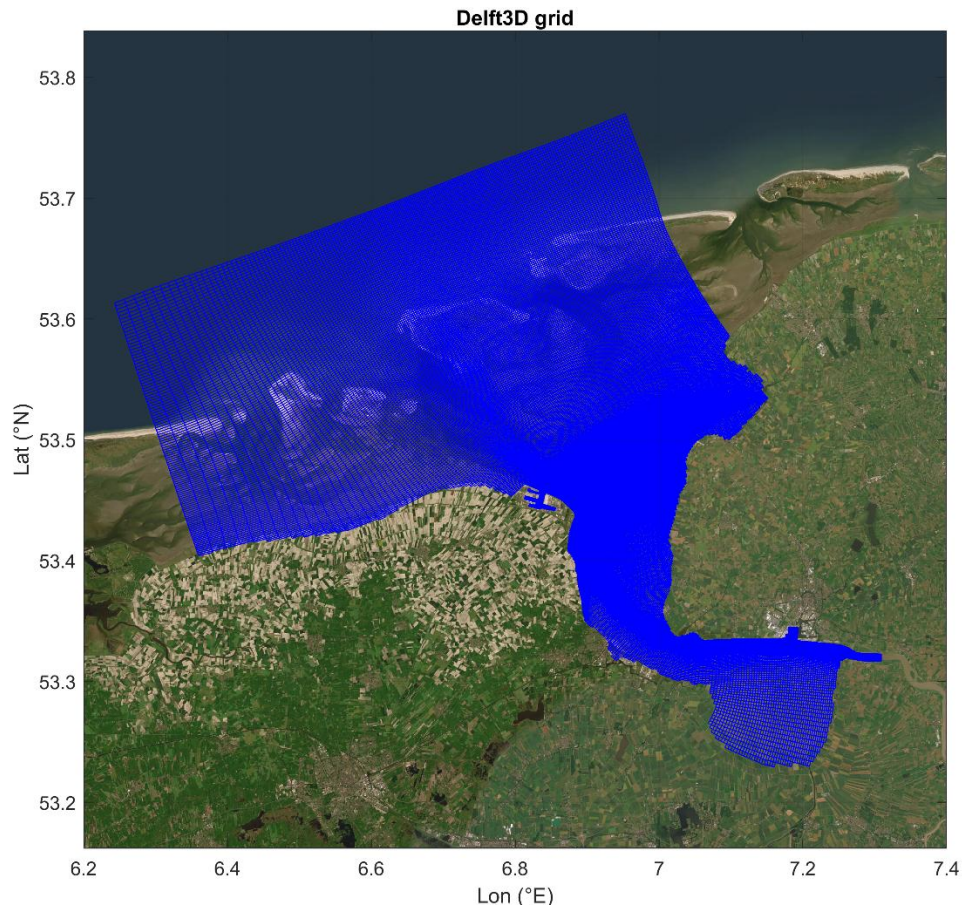


Figure 3.3 Computational grid of the detailed Delft3D 4 model.

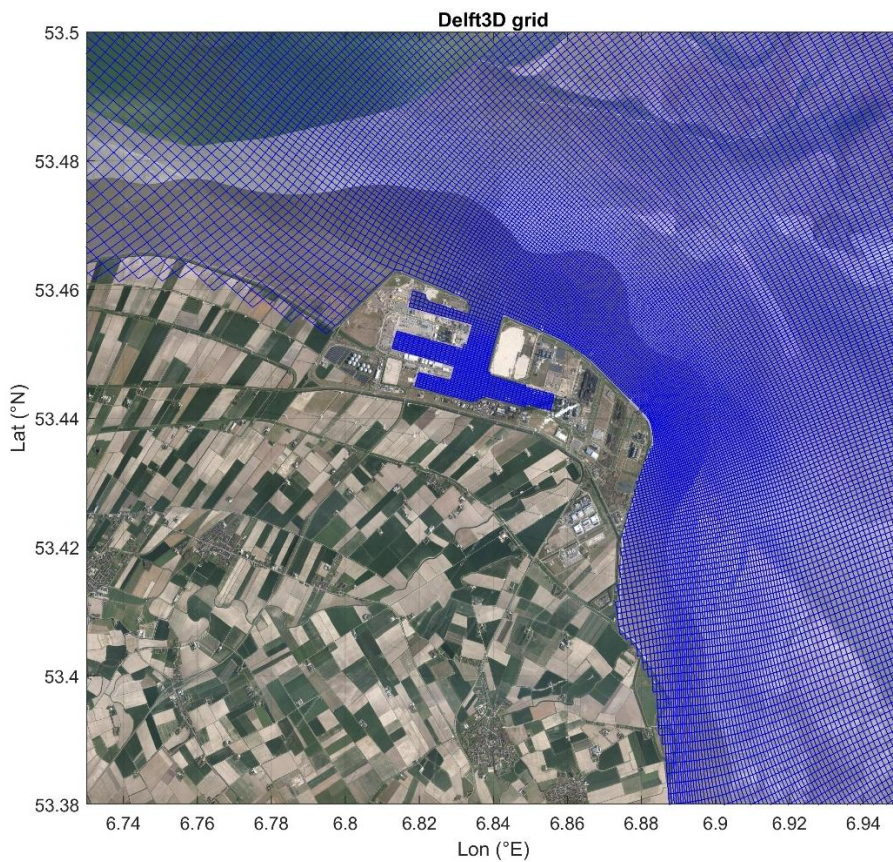


Figure 3.4 Computational grid of the detailed Delft3D 4 model (zoom).

3.3 Model bathymetry

The model bathymetry was based on the RWS Baseline data, see Section 2.1. Since this data has a higher resolution than the model grid, data was directly interpolated to each grid point. Since the survey data was already provided relative to NAP, no changes needed to be made to the vertical reference of the data, except that the model depth is defined positive downward. The final model bathymetry is presented in Figure 3.5. Depending on the simulation for the new intake and outfall options, small changes to the bathymetry were made around the intake and outfall channel to ensure sufficient depth at these locations.

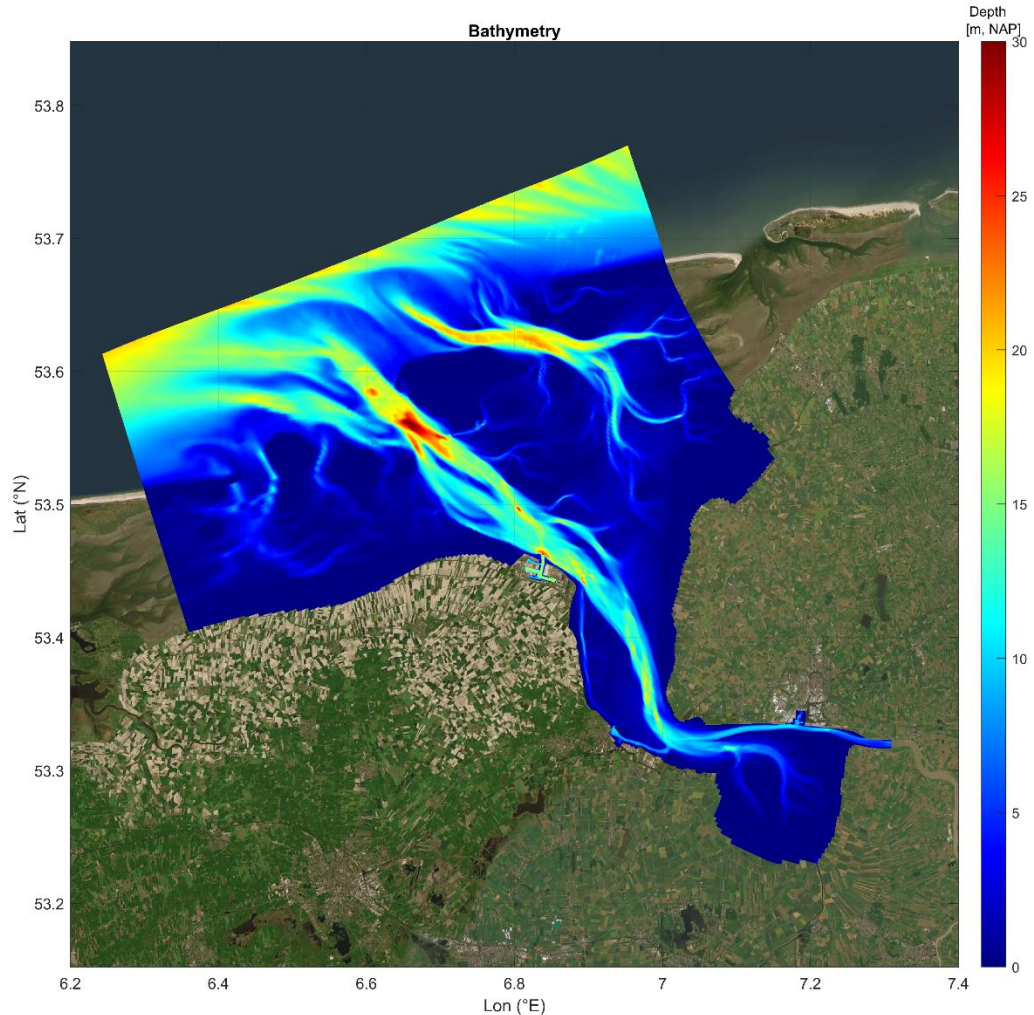


Figure 3.5 Bathymetry of the detailed Delft3D model.

3.4 Boundary conditions

The detailed Delft3D 4 model has multiple open boundaries: at the offshore boundary in the North Sea, the water level variation is prescribed and at the southwestern and northeastern boundaries (North Sea / Wadden Sea), current velocities are prescribed. The open boundary at the Ems is a total discharge boundary. Water level, current and discharge time series were derived for the full year of 2012 from the overall hydrodynamic model, see Section 3.1. Since the overall model was forced with both tidal and non-tidal (e.g., wind and river) conditions, large-scale current conditions were properly included in the detailed model. The detailed Delft3D 4 model was verified against the results of the validated overall model to ensure that the model provides accurate results. Figure 3.6 shows the simulated water levels and current magnitudes by the overall and detailed model for a location offshore of the Eemshaven close to GSP5. This figure illustrates the hydrodynamic conditions during the simulation and shows

that the simulated hydrodynamic conditions with the validated overall model are accurately transferred to the detailed model. The figure shows that the modelled water levels are identical in both the detailed and overall model and that the differences in current magnitude are very limited. The detailed model is therefore judged to be fit for use in this study.

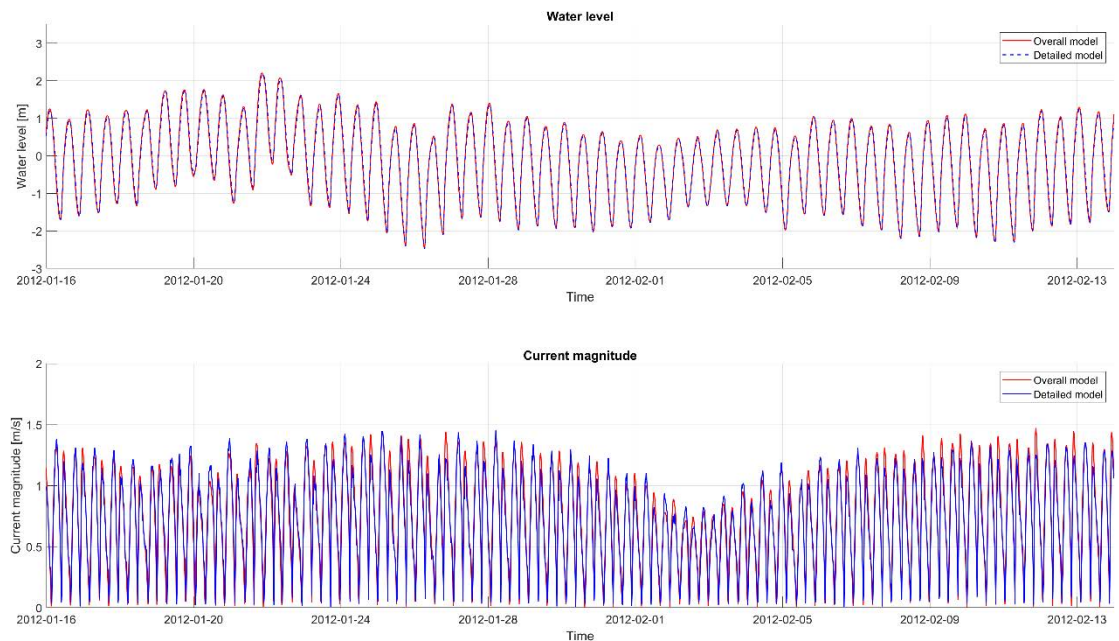


Figure 3.6 Verification of the detailed model setup.

A constant background temperature was applied at the boundaries. For the salinity, timeseries from the overall model were derived by means of nesting. The same spatially uniform wind time series were applied as in the overall model. Furthermore, the Thatcher-Harleman time lag was set to 720 minutes to account for the plume dispersion (in case very low effluent concentrations still reach the open boundary) and tidal flow conditions at the boundaries.

For the temperature modelling, the excess temperature heat flux model of Delft3D 4 was selected (Sweers, 1976). This heat flux model calculates the net heat flux based on the temperature difference between the air and the water surface and the wind conditions. By setting the background temperature equal to the air temperature and both constant in time, the impact of the outfall could be derived directly from the modelling. Since part of the CIW criteria is based on maximum temperatures above background conditions, this approach is considered the most suitable for the present assessment. In all simulations a uniform background water and air temperature. However, the exact background temperature is not important for the results since in the analysis of the simulations the background temperature was subsequently subtracted from the modelling to obtain the excess temperature due to operation of the outfall only. For interpretation of results and to assess the compliance with environmental criteria, the ambient temperatures were considered as derived in Section 2.3 (i.e. 21.5 °C).

3.5 Near-field schematisation of submerged outfalls

Different types of outfalls were considered in the present assessment. Open outfalls are typically shore-based structures with limited initial mixing and are simulated directly in Delft3D 4. Submerged outfalls aim to rapidly mix the cooling water with ambient water in the first tens of meters. The mixing close to the submerged outfall depends on the discharge momentum, small-scale turbulence and other non-hydrostatic processes. Further away from

the outfall the spreading and mixing of discharged cooling water depends on ambient (hydrodynamic) conditions like the bathymetry, currents, meteorological conditions etc. These different stages of the outfall plume are typically classified as the near-field and far-field zone. Since a single model cannot assess these two zones simultaneously, both near and far-field assessments need to be performed to accurately assess the spreading and mixing of an outfall plume.

In the present assessment the near-field behaviour of the submerged outfall thermal plume was assessed by means of the CORMIX expert system (www.mixzon.com). CORMIX computes the hydrodynamic behaviour of the outfall plume close the outfall including the plume trajectory and dilution. The results of the near-field assessment are subsequently coupled to the far-field model with use of Deltares' C-SUMO (Coupled Subgrid Model) system. This ensures that the near-field characteristics of the plume behaviour are included in the overall modelling assessment in a physically correct way.

Since no detailed outfall design was specified in this first assessment, a number of sensitivity tests with different submerged outfall configurations (e.g., diffuser configurations) were performed with CORMIX to obtain a typical and realistic near-field behaviour and near-field dilution. For reference, the schematic design eventually considered in this assessment consisted of 8 discharge ports all pointing in offshore direction at an average local depth of 10 m, see Figure 3.7.

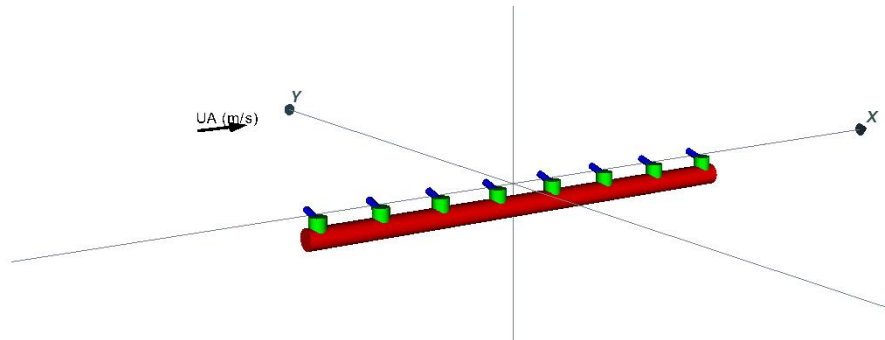


Figure 3.7 Schematic representation of the submerged outfall configuration.

The expected plume behaviour of this schematic submerged outfall design was assessed for various ambient conditions and CORMIX schematisations. CORMIX simulations were performed with water level variations from -2 m to 3 m with steps of 1 m, current speeds from 0.25 to 1.75 m/s with increments of 0.25 m/s, and current directions corresponding to flood and ebb events. For this outfall design and considered ambient conditions, the dilution varies between approximately a factor of 2.4 for low water levels and low current conditions, and a factor of 4.7 for high water levels and strong currents at the end of the near-field. An example of the CORMIX model output is presented in Figure 3.8. It is noted that CORMIX does not consider large-scale re-entrainment, i.e., build-up of effluent near the outfall, and dynamic tidal conditions. The effective dilutions may therefore in practice be lower and thus excess temperatures higher compared to what is computed in the near-field simulations alone. The build-up of effluent is however properly simulated in the Delft3D 4 far-field model by means of the C-SUMO coupling method.

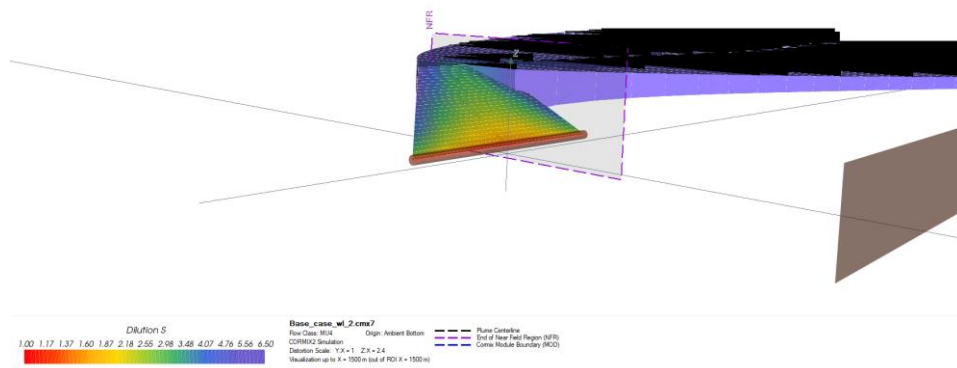


Figure 3.8 Example of simulated plume trajectory and dilution with CORMIX.

The near-field results are stored in a look-up table database which is coupled to Delft3D 4 using Deltares C-SUMO software. C-SUMO facilitates the coupling of different near-field and far-field models, as well as databases with results from dedicated near-field assessments. During a far-field simulation, C-SUMO selects the best representative case from the set of near-field results based on the ambient conditions at that moment. For this assessment, the plume dimensions and dilution that best fit the water level and current conditions (speed and direction) are selected and mapped on the far-field grid. The interval for which the near-field results are updated in the far-field model is 60 minutes. The information stored in the database includes information on the x-y-z coordinates of the plume centreline, the plume width, the plume thickness and the dilution along its trajectory. The location where the plume will spread under the influence of ambient (current) conditions and the far-field Delft3D model has sufficient resolution, was considered as the end of the near-field and will be simulated using a far-field model. The plume trajectory and dilution up to this point will be used in the far-field model.

For accurate representation of the plume trajectory and near-field mixing in Delft3D 4, the Distributed Entrainment Sinks Approach (DESA) of Choi and Lee (2007) was used. In the near-field the plume entrains ambient water. The DESA-method uses series of sources and sinks in the Delft3D 4 model to represent the mixing of the plume with ambient water, this is illustrated in Figure 3.9.

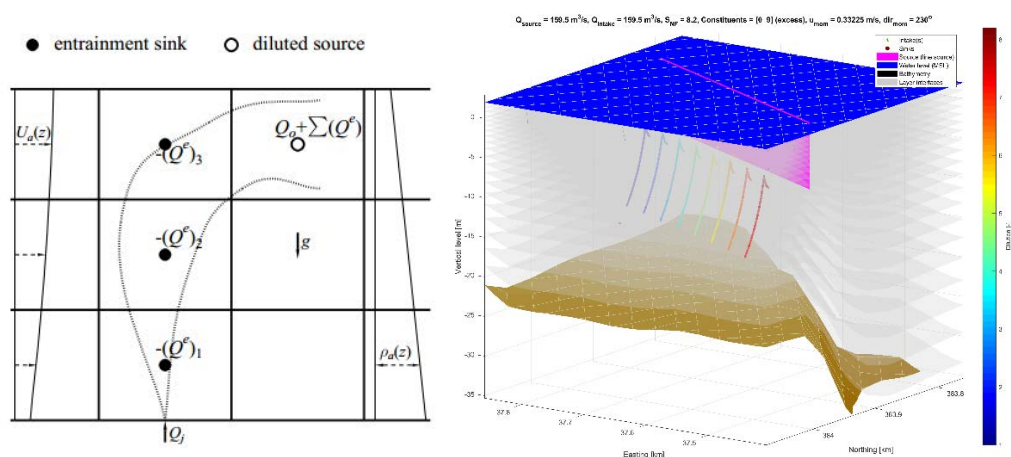


Figure 3.9 Schematics of the DESA-method (left) to represent the near-field plume mixing in the far-field model by series of sources and sinks (from: Choi and Lee, 2007) and the DESA-method approach for a 8 port diffuser in the present assessment.

This dynamic coupling with the DESA-method ensures that the plume characteristics are well represented in the far-field model domain which allows for a more accurate assessment of the outfall plume dispersion compared to traditional modelling methods.

3.6 Other model parameters

Various other Delft3D 4 model parameters were set based on experience and/or validation of the plume dispersion in other projects:

- A spatially varying bottom roughness was used with Manning coefficients between 0.015 and 0.023, consistent with the validated overall model.
- Initial conditions for salinity were derived from the overall model.
- The background horizontal eddy viscosity and diffusivity were set to 1 m²/s.
- The 3D turbulence was computed by the k-Epsilon model.
- A uniform background vertical viscosity of 1*10⁻⁵ m²/s was used.
- The simulation period was set from 14 January 2012 to 14 February 2013. Note that only the last 14 days (i.e., a spring-neap tidal cycle) were considered in the remainder of the report.
- The model time step was set to 0.2 min.
- Model output was generated at a 10-minute interval for point locations and 30-minute interval for map output.
- Gravity was set to 9.813 m/s².
- The air density was set to 1.205 kg/m³.

4 Modelling results of the plume dispersion

With the coupled Delft3D 4 model and near-field database, different simulations were performed for representative scenarios (i.e., different intake and outfall configurations, different scenarios for existing discharges, structures etc.) for the project site. The objective of the present assessment is to assess the expected plume dispersion in relation to the environmental temperature criteria and the recirculation towards all intakes. This chapter presents an overview of the simulated scenarios and their results in relation to these operational and environmental criteria.

4.1 Overview of the simulations

This initial study is an indicative assessment of cooling-water availability for a potential nuclear power plant at the Eemshaven. Detailed information of future operational conditions of the nuclear and/or existing plants was not available. Consequently, in consultation with EZK and based on the considered intake and outfall configurations and existing thermal discharges in the project area, 9 simulations were defined to assess combined plume dispersion. In addition, 2 simulations excluding a nuclear power plant discharge were carried out to represent the present baseline conditions.

It is further noted that:

- The ENGIE Eemshaven power plant was excluded from the scenario simulations because it primarily operates as a backup facility during peak demand or emergency situations and is inactive for most of the time, with additional uncertainty regarding its long-term operation due to limited operating hours. In consultation with EZK, ENGIE was therefore not included in the future model scenarios but was considered as part of the baseline conditions to represent a conservative 'worst-case' present situation.
- For all scenarios (except Case 9), RWE Eemshaven was included in the modelling as the most conservative assumption, while the new nuclear power plant may be constructed at the existing location of RWE Eemshaven. In this initial assessment multiple potential plots and intake and outfall configurations were considered for a new nuclear power plant at Eemshaven, including options involving tunnelling of cooling-water flows to non-adjacent locations and co-existence of the new nuclear power plant and RWE Eemshaven while sharing intake and outfall location (similar to Borssele and Terneuzen). In consultation with EZK, it was therefore decided to include RWE Eemshaven in all modelling cases as a conservative assumption, irrespective of the nuclear power plant location.
- After the initial simulations, an additional simulation (Case 9) was performed based on Configuration 8 in which the proposed nuclear power plant would replace the RWE Eemshaven power plant and its existing thermal discharge.

If, at a later stage, alternative configurations are considered (for example scenarios in which other existing plants are partially or fully decommissioned) this may result in different outcomes, as the associated thermal discharges are no longer present. The same applies for configurations with additional thermal loads (for example scenario's where existing plants remain operational based on changing electricity market dynamics and regulation). Based on this initial exploratory study, no immediate indications of fundamental constraints on the potential feasibility of a nuclear power plant at the Eemshaven have been identified. However, this aspect should be regarded as a point of attention and addressed in more detail in a subsequent project phase.

A complete overview of the performed simulations is presented in Table 4.1.

Table 4.1 Overview of simulation cases carried out in this study.

| Case | NPP config | Existing discharges | Discharge char. NPP | Comment |
|-------------------|------------|-----------------------|----------------------------------|-----------------------------------|
| Baseline 1 | - | RWE E + RWE M + ENGIE | - | Present situation |
| Baseline 2 | - | RWE E + RWE M | - | Present situation, excl. ENGIE |
| 1 | 1 | RWE E + RWE M | 159.5 m ³ /s +9 °C | Different I/O configurations |
| 2 | 2 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 3 | 3 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 4 | 4 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 5 | 5 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 6 | 6 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 7 | 7 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 8 | 8 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 9 | 8 | RWE M | 159.5 m ³ /s +9 °C | Excl. ENGIE and Eemshavencentrale |

4.2 Typical flow and outfall plume behaviour

The Ems-Dollard Estuary is a tidal estuary connected to the North Sea. The vertical tide at the North Sea and the emptying and filling of the Ems-Dollard Estuary creates strong flows near the Eemshaven. Figure 4.1 and Figure 4.2 show the typical depth averaged flow conditions under ebb and flood conditions. Near the project site the maximum flow velocities are over 1 m/s.

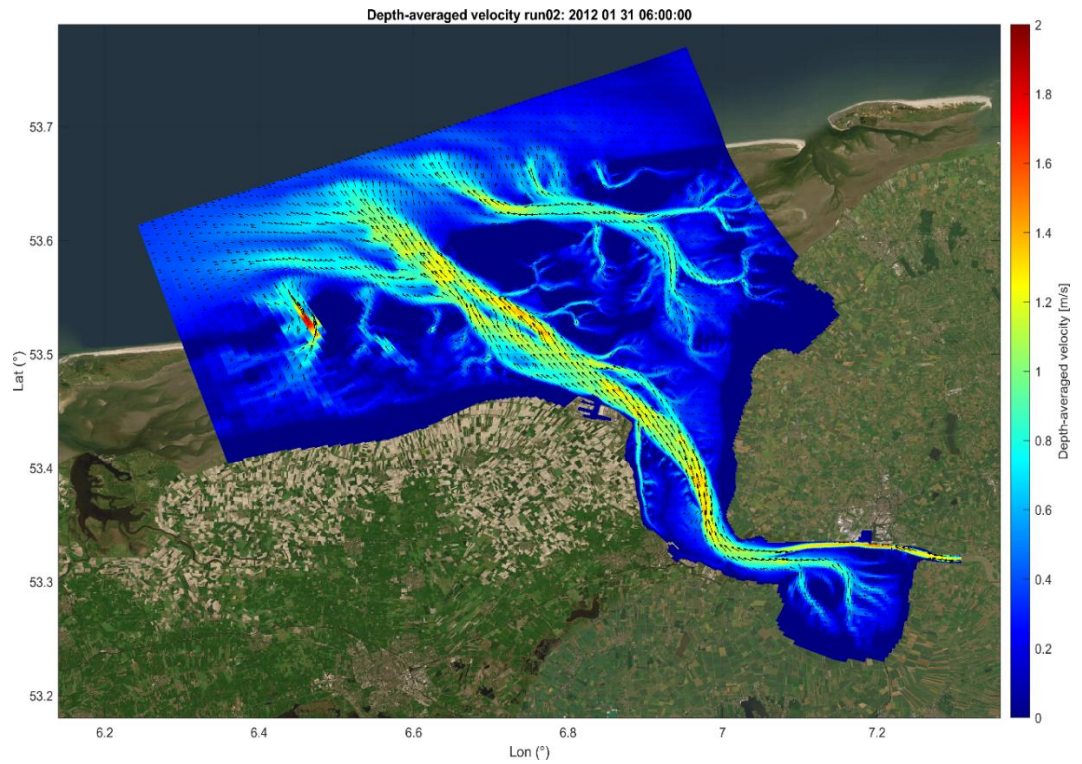


Figure 4.1 Typical depth-averaged flow conditions under ebb conditions.

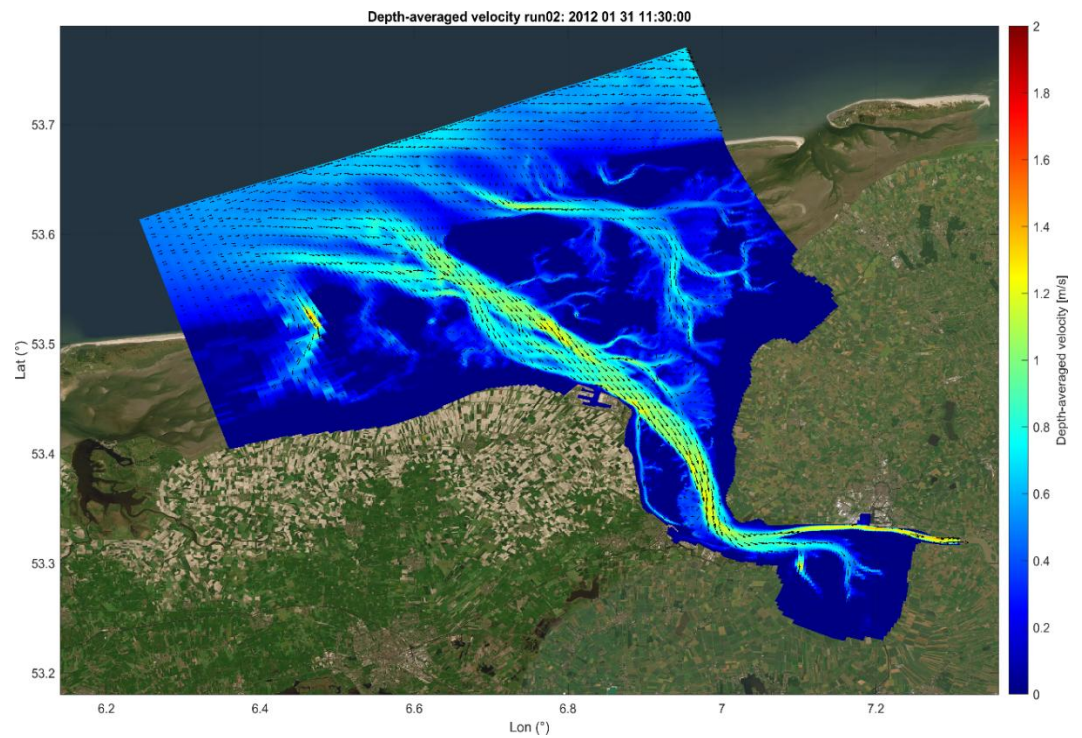


Figure 4.2 Typical depth-averaged flow conditions under flood conditions.

The spreading and mixing of the cooling water effluent depend on, amongst others, these local hydrodynamic conditions around the outfall and the density difference of the outfall plume with the ambient water. The thermal outfall plume is expected to spread near the water surface (due to its buoyancy) before hydrodynamic conditions cause the plume to mix or heat exchange with the atmosphere causes the outfall plume to cool down.

When the new nuclear power plant discharge is located in the Ems-Dollard Estuary these hydrodynamic conditions and the outfall configuration mainly determine the plume dispersion and mixing. Figure 4.3 shows the typical plume dispersion and maximum excess temperature footprints at the surface. Due to the high current velocities (well over 1 m/s) the plumes are dispersed in northwest-southeast direction following the main geometry of the Ems-Dollard Estuary. These high flow velocities and velocity differences cause the thermal plume to rapidly mix with the ambient water. A higher excess temperature is typically expected in shallow areas where limited ambient water and some lower flow velocities are available for mixing.

The spreading and mixing of the new thermal outfall plume also depends on the type of intake and outfall structures. More information on the plume dispersion of each intake and outfall configuration is presented in Section 4.4.2.

4.3 Presentation of results

Model results are summarized and presented in relation to the environmental thermal criteria, see Section 2.2.

CIW coastal mixing zone criterion

The CIW criterion for coastal waters states that the 25°C temperature contour should not reach the seabed. Maximum (and mean) excess temperature footprints of each simulation were therefore generated to visualise the combined plume dispersion for the existing outfalls (Base case) and the new Eemshaven NPP cooling water discharge. These footprints present the increase in temperature above the background temperature due to operation of all outfalls in the area. These footprints are not instantaneous model results of the plume dispersion but combined from 672 (half-hourly interval for 14 days) individual map plots, see Figure 4.3. Figure 4.4 illustrates the difference between a mean and maximum temperature footprint.

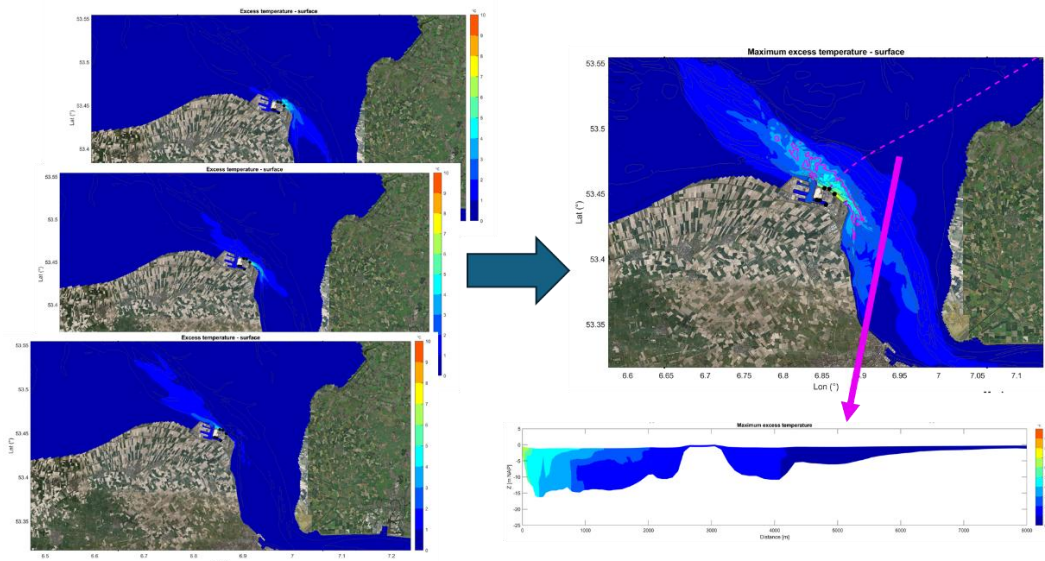


Figure 4.3 Visualisation of the maximum footprint generated from instantaneous model results.

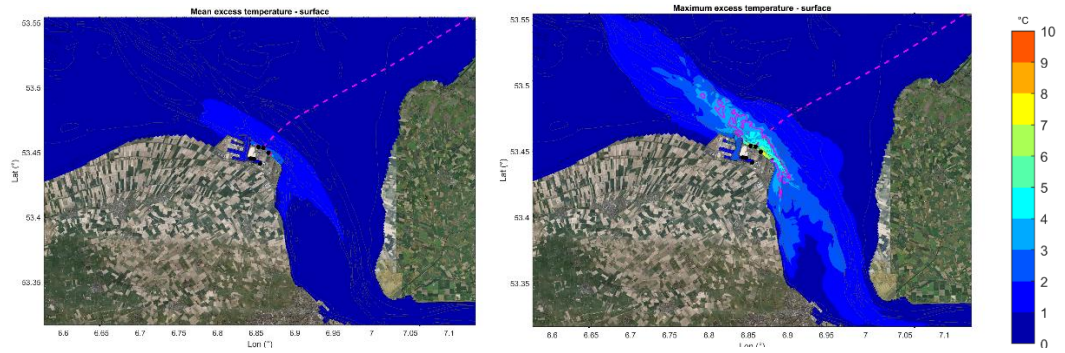


Figure 4.4 Mean (left) and maximum (right) surface temperature increase footprint generated from instantaneous model results.

The footprints are generated for the near-surface and near-bottom for a clear view of the three-dimensional plume dispersion. The solid magenta line shows the +3.5 °C contour relevant for the CIW coastal mixing zone criteria (i.e. The 25°C temperature contour should not reach the seabed). Note that the CIW coastal mixing zone criterion only applies for part of the project area (northwest of the Eemshaven and near-bottom), see Section 2.2, but for illustrative purposes the mixing zone of +3.5 °C is presented for the full domain.

Additionally, for illustrative purposes a cross-section in the Ems Estuary was drawn for which the temperature increase was derived from the model results to further illustrate the three-dimensional spreading of the plume, see Figure 4.5. The magenta dashed line in the map plots shows the location of the visualised cross-section.

The black dots illustrate intake and outfall locations. Note that near-field results are excluded from the footprints. Locally around the outfall (i.e. < 200 m), higher temperatures may be expected. Furthermore, due to the frequency of the model output, some discontinuity may exist in the maximum excess temperature footprints. For interpretation of the results the temperature contour furthest away from the discharge points is considered for the mixing zone extent.

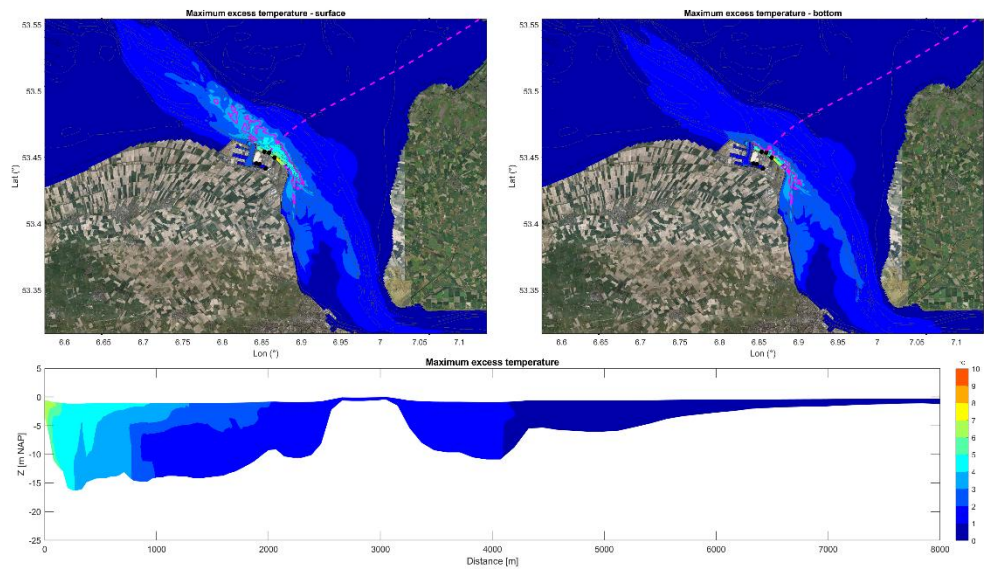


Figure 4.5 Simulated maximum temperature increase due to the combined thermal discharges (Case 3).

CIW estuarine mixing zone criterion

For compliance with the CIW 2004 criteria for the estuarine mixing zone, the percentage of the cross-sectional area covered by the mixing zone ($T > 25\text{ °C}$) needs to be determined. The CIW estuarine mixing zone criterion may only apply to the area southeast of the Eemshaven (see Section 2.2) and does not explicitly specify which cross-sectional area should be used. For the present analysis however all grid lines of the Delft3D model are used as cross-sections, see Figure 4.6. These cross sections are roughly perpendicular to the thalweg axis. Figure 4.7 shows each 10th gridline of the model grid, but in the analysis, all model gridlines are used. Note that harbor areas are omitted from the cross-sectional areas and that dry areas are omitted from the total cross section. Furthermore, areas not part of the current-carrying part of the river were also omitted from the total cross section.

For each simulation, each output time step and each cross-section the percentage of the cross-sectional area covered by the mixing zone was calculated. An example presentation of the results is shown in Figure 4.7. The cross-sections are numbered (from North to South) on the horizontal axis. The results are visualised with a coloured line for each output timestep. Given the assumed 98th background temperature of 21.5 °C , see Section 2.3, the 25 °C mixing zone is interpreted here as a $+3.5\text{ °C}$ excess temperature mixing zone. The computed temperature increase was subsequently compared to these excess temperature values to assess the percentages of the cross section that exceed this value. Note that for configurations including a submerged outfall, the near-field region is excluded from the far-field model results, as this zone is not explicitly modelled in the far-field model. The near-field region is typically 2 – 3 % of the total cross-sectional area.

CIW average temperature increase criterion

CIW 2004 criteria also state that the average temperature of the water body may not increase by more than 2 °C and/or increase above 25 °C . Given a background temperature of 21.5 °C , the cross-sectional average temperature increase criterion ($< +2\text{ °C}$) is the more conservative criterion. The results are presented like the mixing zone criteria with the average temperature per cross-section, see Figure 4.7 (bottom).

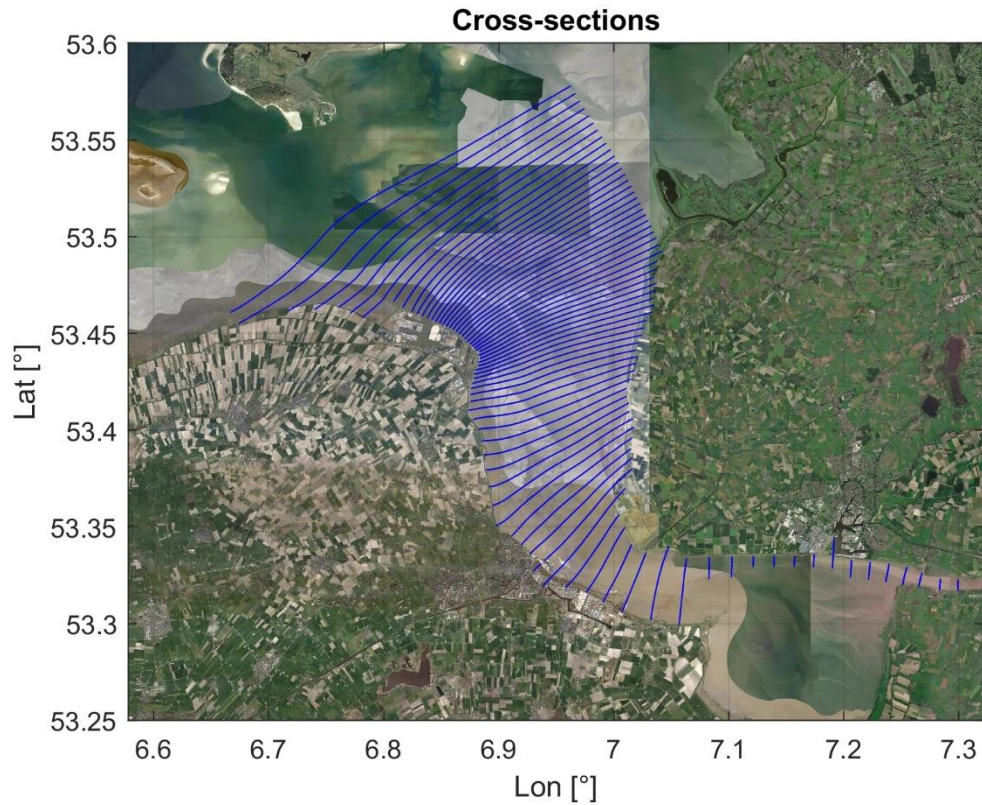


Figure 4.6 Overview of the cross-section sets (blue lines) used for the CIW 204 discharge criteria.

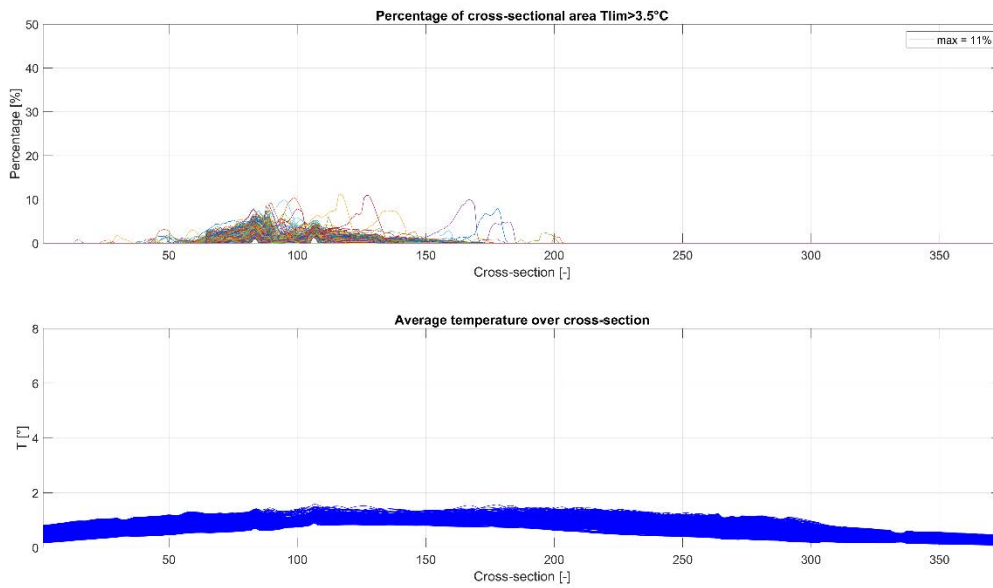


Figure 4.7 Example of the presentation of model results in relation to the environmental criteria.

4.4 Model results

Model results are presented for different Eemshaven NPP intake and outfall configurations and existing discharges. Appendix A presents the complete overview of the recirculation potential for all simulations and intakes. Appendix B presents the mean temperature footprints of each simulation.

4.4.1 Baseline scenarios

Two simulations were performed for the present (i.e. Baseline) situation at the Eemshaven.

4.4.1.1 Baseline 1

A simulation was performed with the present discharges in the area only, including the Eemscentrale of ENGIE. This simulation was performed to distinguish the contribution of the existing outfalls and the new nuclear power plant outfall for the combined plume dispersion and recirculation for Case 1 to 9. Baseline 1, including the Eemscentrale of ENGIE, is the adverse scenario for the present situation as it includes all present outfalls operating at full capacity (in reality the Eemscentrale of ENGIE is only used as backup). Figure 4.8 shows the simulated maximum temperature increase footprint due to the existing outfalls (Baseline 1).

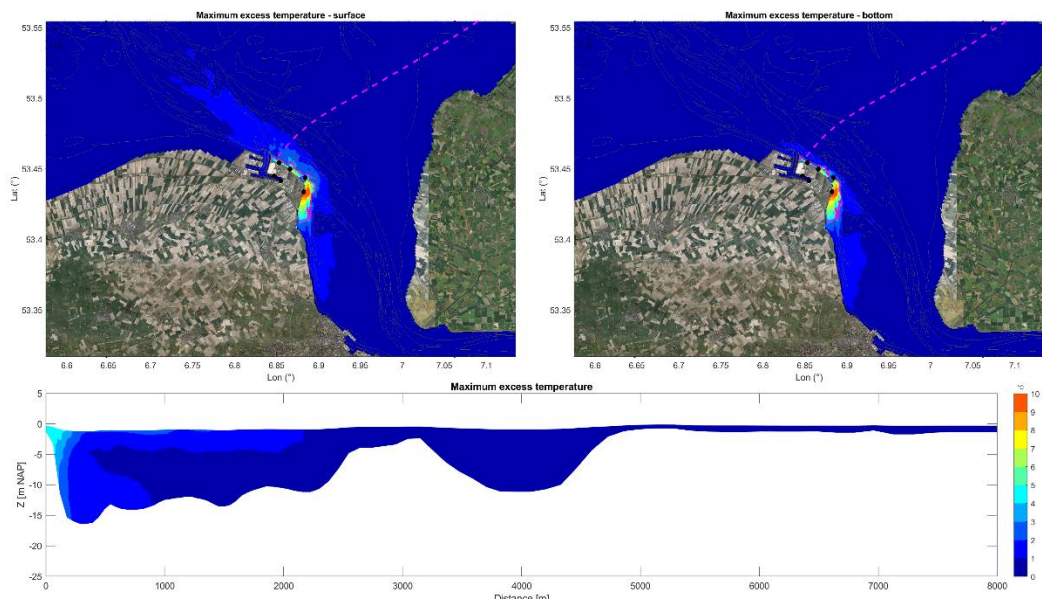


Figure 4.8 Simulated maximum temperature increase footprint due to the existing thermal discharges (Baseline 1).

Figure 4.8 shows that the temperature increase around the Eemshaven is most pronounced in northwest and southeast direction. This is due to the high flow conditions at the project site and geometry of the Ems-Dollard Estuary. The highest temperature increase is found around the outfall of the ENGIE Eemscentrale. This thermal discharge has limited dilution around the outfall due to the limited water depth and the maximum increased temperature near the seabed is expected to exceed 3.5 °C at distances of approximately 2.5 km south of the discharge location. Around the other existing outfalls only locally an excess temperature higher than the +3.5 °C threshold value is expected. These areas are however classified as estuarine waters for which estuarine mixing zone criteria apply. The mixing zone is not expected to reach the seabed in coastal waters.

Figure 4.9 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems-Dollard Estuary for Baseline 1. This figure shows that the simulated maximum percentage of the cross-sectional area covered by the mixing zone is less than 5% in the existing Baseline 1 situation (i.e. existing outfalls only). The three locations with an increase in the percentage of the cross-sectional area covered by the mixing zone are respectively the Magnumcentrale, the Eemshavencentrale of RWE and the Eemscentrale of ENGIE. The computed average temperature increase over each cross section is well below 2 °C.

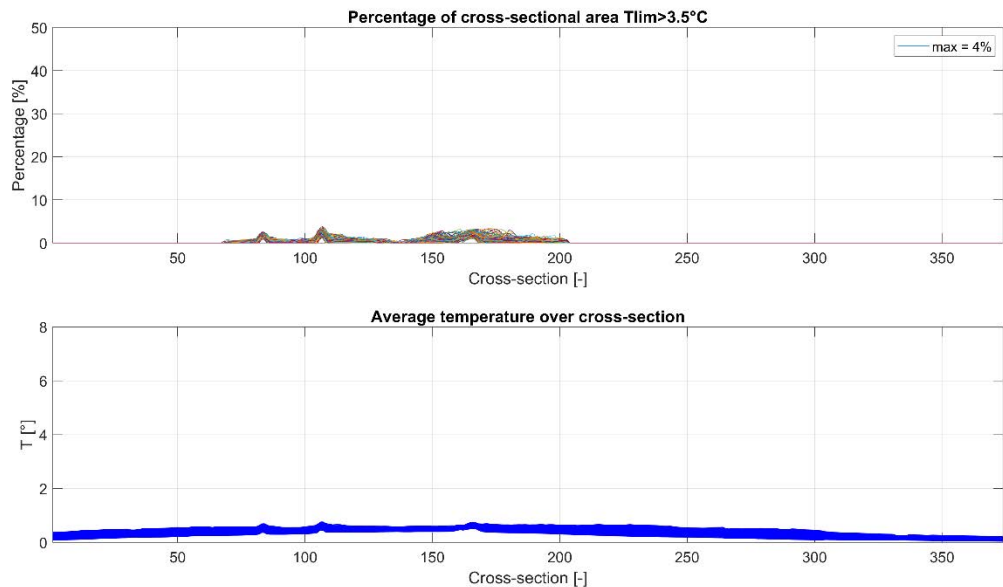


Figure 4.9 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Baseline 1.

For Baseline 1, the computed mean and maximum temperature increase at the existing Magnumcentrale and the Eemshavencentrale of RWE intakes is typically about 0.5 °C to 0.7 °C. At the intake of the Eemshavencentrale of ENGIE the computed excess temperature increase is typically around 1.4 °C (mean) and with a computed maximum of 2.8 °C, see Table 4.2.

Table 4.2 Simulated excess temperature (°C) at each intake for Baseline 1.

| Intakes | RWE01 | | RWE02 | | Engie | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |

4.4.1.2 Baseline 2

Since the Eemscentrale of ENGIE only operates occasionally, an additional simulation was performed with only the Magnumcentrale and the Eemshavencentrale of RWE operational, i.e. Baseline 2. This simulation serves as a reference for the present situation under normal operational conditions. Figure 4.10 shows the simulated maximum temperature increase footprint for Baseline 2.

Figure 4.10 shows (in comparison with Figure 4.8) reduced excess temperatures around the Eemshaven as the total discharged heat is reduced by about 33%. Especially in the area around the ENGIE Eemscentrale outfall, the high excess temperatures computed in Baseline 1 are strongly reduced. Figure 4.10 further shows that only locally (<500 m) around the existing outfalls the near-bed temperatures are expected to exceed the +3.5 °C threshold value of CIW criterion. Consistent with Baseline 1, the mixing zone is not expected to reach the seabed in coastal waters.

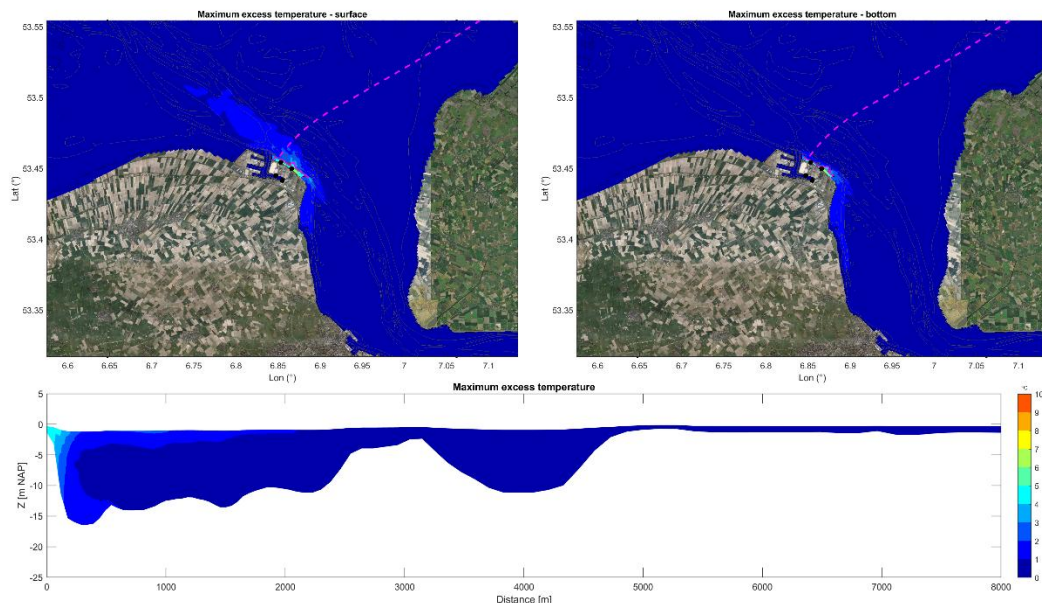


Figure 4.10 Simulated maximum temperature increase footprint due to the existing thermal discharges (Baseline 2).

Figure 4.11 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems-Dollard Estuary for Baseline 2. This figure shows that the simulated maximum percentage of the cross-sectional area covered by the mixing zone is 3%, and slightly (i.e. 1%) smaller compared to the Baseline 1 situation. Furthermore, the computed average temperature increase over each cross section is well below the 2 °C criterion for Baseline 2.

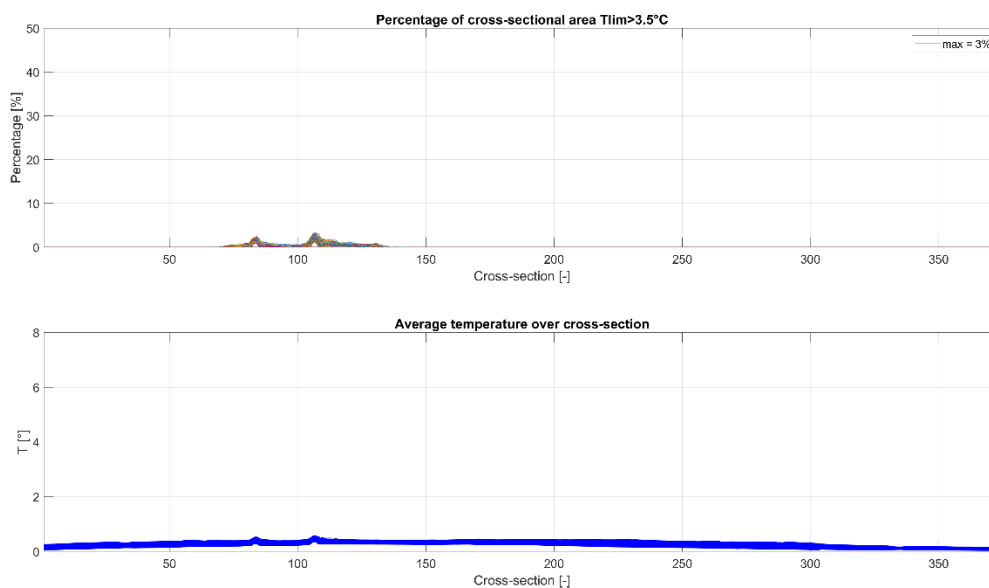


Figure 4.11 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Baseline 1.

Compared to Baseline 1, the computed temperature increase at the existing intakes in Baseline 2 is typically 0.1 °C – 0.2 °C lower with the computed mean average temperature increase around 0.4 °C and maximum around 0.4 °C – 0.5 °C, see Table 4.3.

Table 4.3 Simulated excess temperature (°C) at each intake for Baseline 2.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |

4.4.2 Results of different intake and outfall configurations

In this section, the model results for the different intake and outfall configurations are compared. For equal comparison, all configurations in this paragraph had a total thermal discharge capacity of 6000 MW, a discharge flow rate of 159.5 m³/s and a temperature increase of +9 °C between the intake and the outfall. Furthermore, all simulations (except for Case 9) were performed with the existing discharges of the Magnumcentrale and Eemshavencentrale of RWE only as this was deemed the most representative situation for future conditions. To limit the number of figures in the report, the most relevant figures are presented, i.e. the maximum temperature increase footprints, the percentage of the cross-sectional area covered by the mixing zone and the average temperature increase for the relevant cross-sections. A full overview of the model results can be found in the appendix.

4.4.2.1 Case 1

In Case 1, the intake and outfall Configuration 1 consist of an open intake in the Eemshaven and an open outfall outside and on the north side of the Eemshaven close to the port entrance, see Figure 4.12. Figure 4.13 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

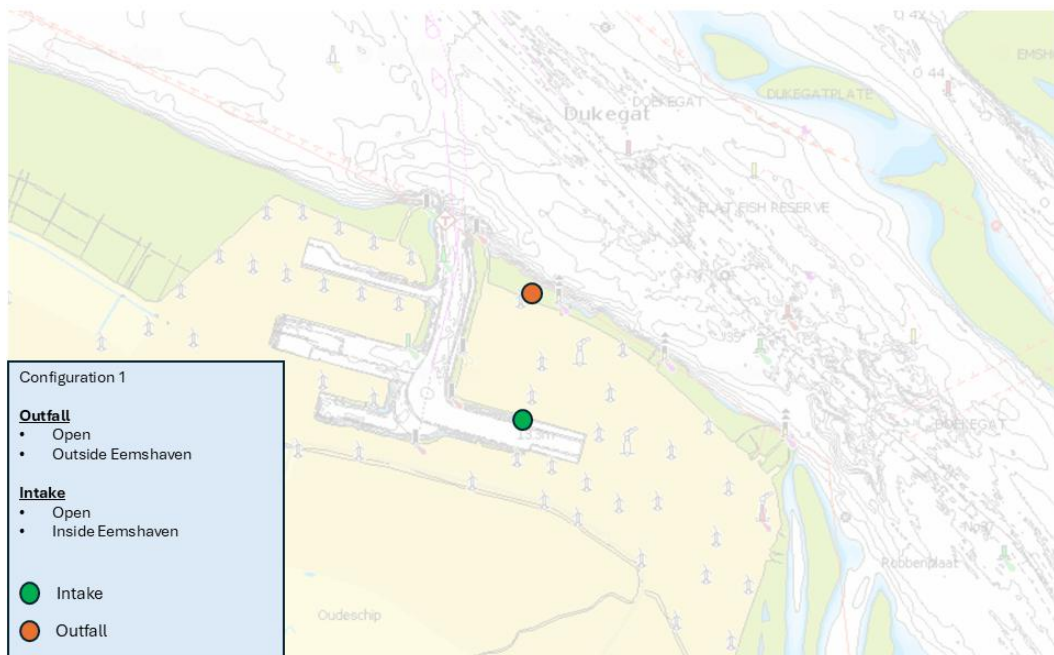


Figure 4.12 Eemshaven NPP intake and outfall Configuration 1.

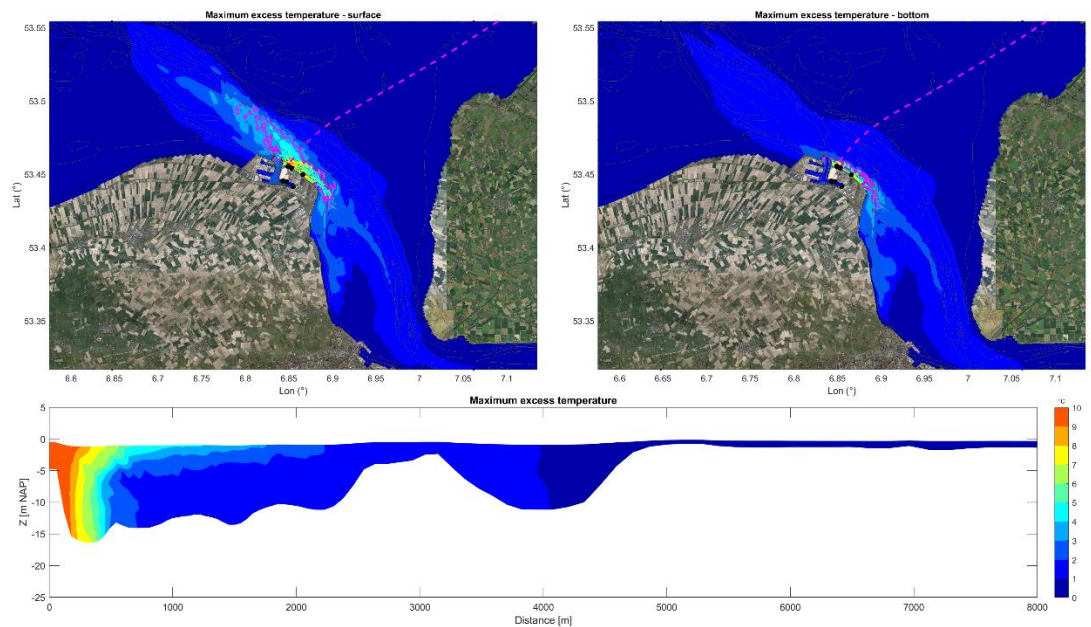


Figure 4.13 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 1.

Figure 4.13 shows that the strong currents in front of the Eemshaven rapidly deflect the combined outfall plume in NW and SE direction. A maximum surface temperature increase of 3.5 °C is computed at alongshore distances of up to 6 km towards the northwest and up to 4.5 km towards the southeast of the discharge location of the new nuclear power plant. The near-bed temperature increase of +3.5 °C is computed at alongshore distances of up to 4.5 km southeast of the discharge location of the new nuclear power plant of Configuration 1. The computed +3.5 °C near-bed temperature contour is not expected to reach the area northwest of the Eemshaven for which the CIW coastal criterion applies. The mean temperature increase around the outfall for Case 1 is typically lower due to the dynamic behaviour of the plume, see Appendix B.

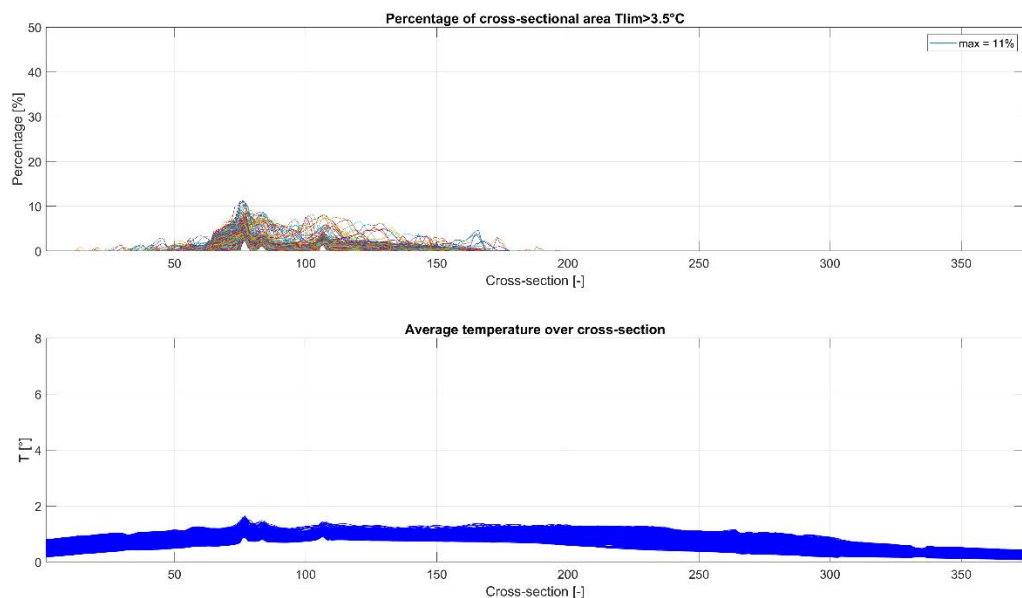


Figure 4.14 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 1.

Figure 4.14 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections for Case 1. This figure shows that the simulated maximum percentage of the cross-sectional area covered by the mixing zone is 11%. Furthermore, the computed average temperature increase over each cross section is below 2 °C for Case 1.

Table 4.4 summarises the simulated excess temperatures at each intake for Case 1. For reference Baseline 1 and Baseline 2 are added to the table. This table shows that the computed excess temperatures at the intake of the new Eemshaven NPP (with the intake in the Eemshaven) is approximately 1.3 °C on average, with a computed maximum of 1.6 °C. The mean and maximum excess temperature at the existing intakes is expected to increase by 0.7 – 1.1 °C to intake temperatures between 1.2 °C and 1.8 °C.

Table 4.4 Simulated excess temperature (°C) at each intake for Case 1.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 1 | 1.5 | 1.8 | 1.2 | 1.5 | | | 1.3 | 1.6 |

4.4.2.2 Case 2

In Case 2/ Configuration 2, the Eemshaven NPP intake and outfall use the existing intake and outfall locations of the ENGIE Eemscentrale, see Figure 4.15. Figure 4.16 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

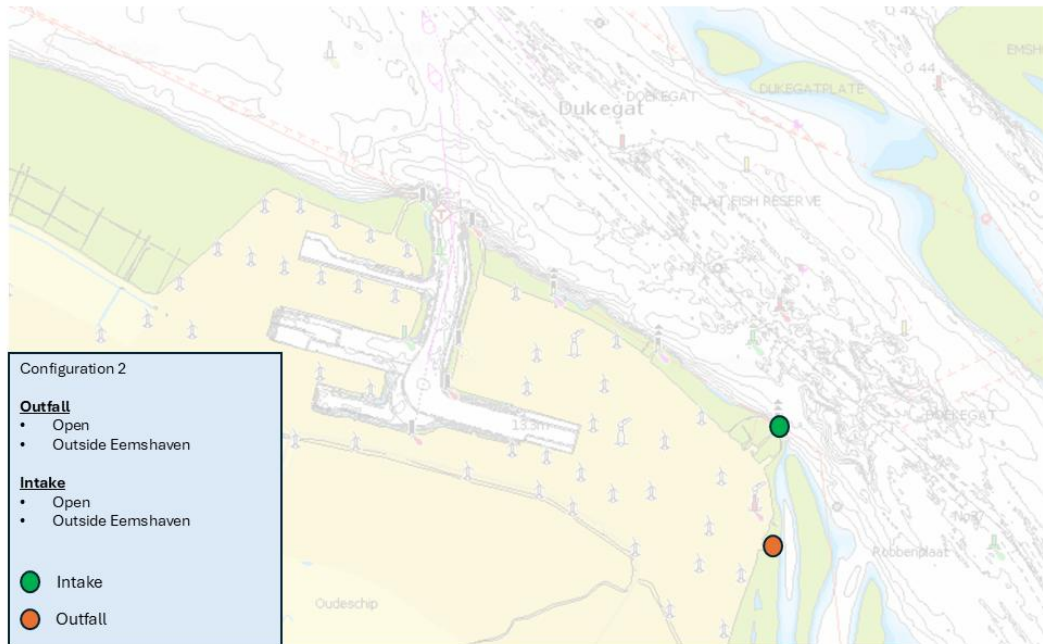


Figure 4.15 Eemshaven NPP intake and outfall Configuration 2.

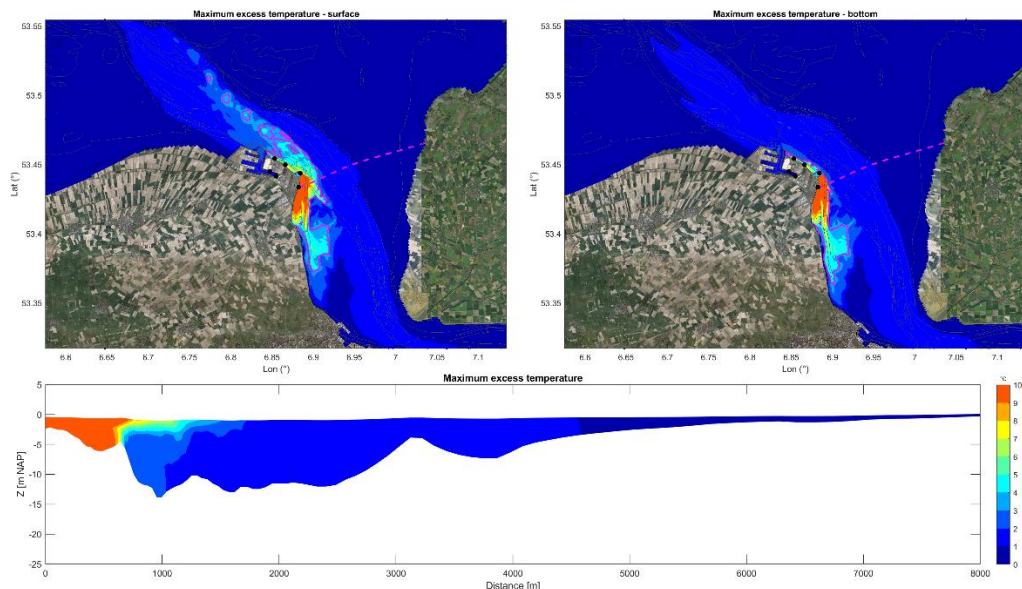


Figure 4.16 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 2.

Figure 4.16 shows that when the ENGIE discharge is replaced by the Eemshaven NPP (Baseline 1 to Case 2) the same shallow area south of this discharge location will be subject to increased temperatures. Due to the larger thermal load of the new Eemshaven NPP, the mixing zone at the seabed does extend further south, approximately 7 km. Compared to other cases, Case 2 has limited initial mixing and the largest area around the outfall subject to high temperature changes due to operation of the Eemshaven NPP. The computed mixing zone of Case 2 is not expected to reach the seabed in coastal waters northwest of the Eemshaven.

Figure 4.17 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems Estuary for Case 2. With a

computed maximum percentage of the cross-sectional area covered by the mixing zone of 12%, this remains well below the critical threshold value of 25% of the CIW criteria. Furthermore, the computed average temperature increase over each cross section is below 2 °C for Case 2.

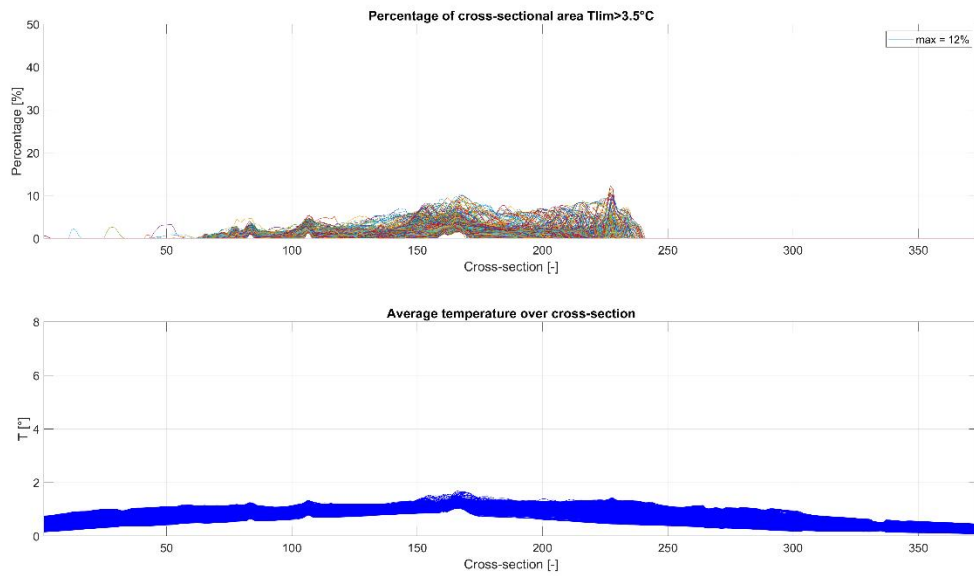


Figure 4.17 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 2.

The computed excess temperature at each intake for Case 2 is presented in Table 4.5. This table shows that the computed mean excess temperature at the new nuclear power plant intake is approximately 2.4 °C, with a maximum excess temperature of 5.4 °C. These relatively high recirculation values compared to other cases is explained by the fact that the intake of the Eemshaven NPP Configuration 2 is relatively close to the existing and new thermal discharges. The computed combined mean and maximum recirculation towards the intakes of the existing plants is typically in the order of 1.0 °C -1.4 °C.

Table 4.5 Simulated excess temperature (°C) at each intake for Case 2.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 2 | 1.2 | 1.4 | 1.0 | 1.2 | | | 2.4 | 5.4 |

4.4.2.3 Case 3

In Case 3 / Configuration 3, the open intake is located in the Eemshaven and a submerged outfall is located offshore and outside the Eemshaven at a depth of approximately 10 m, see Figure 4.18. The submerged outfall aims to rapidly mix the thermal discharge with ambient water and deflect the outfall plume away from the Eemshaven area. Figure 4.19 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

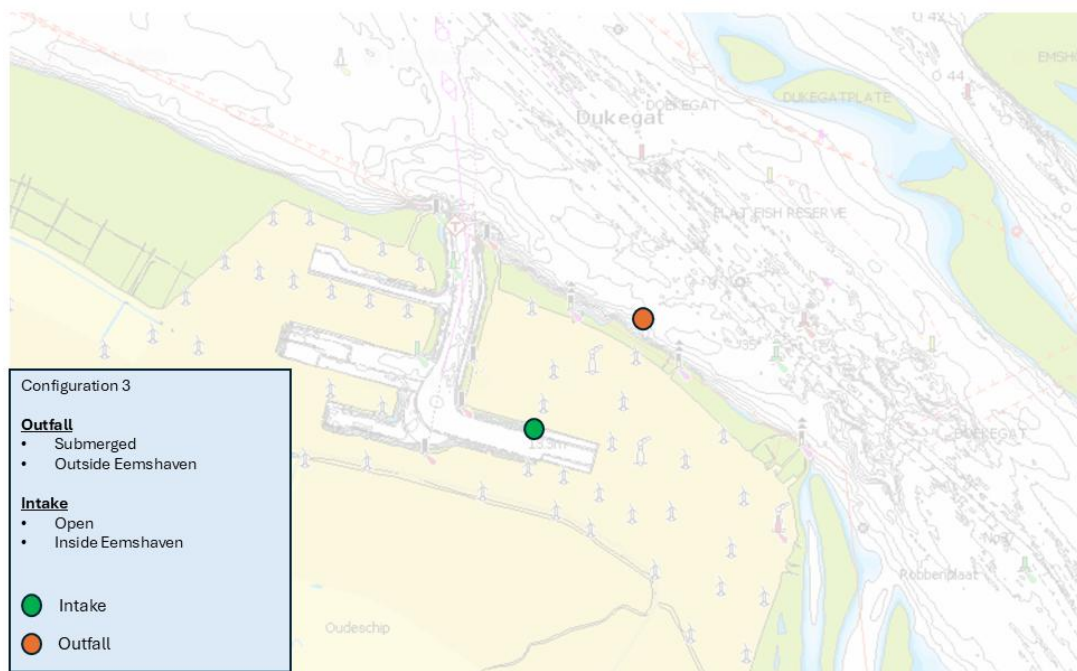


Figure 4.18 Eemshaven NPP intake and outfall Configuration 3.

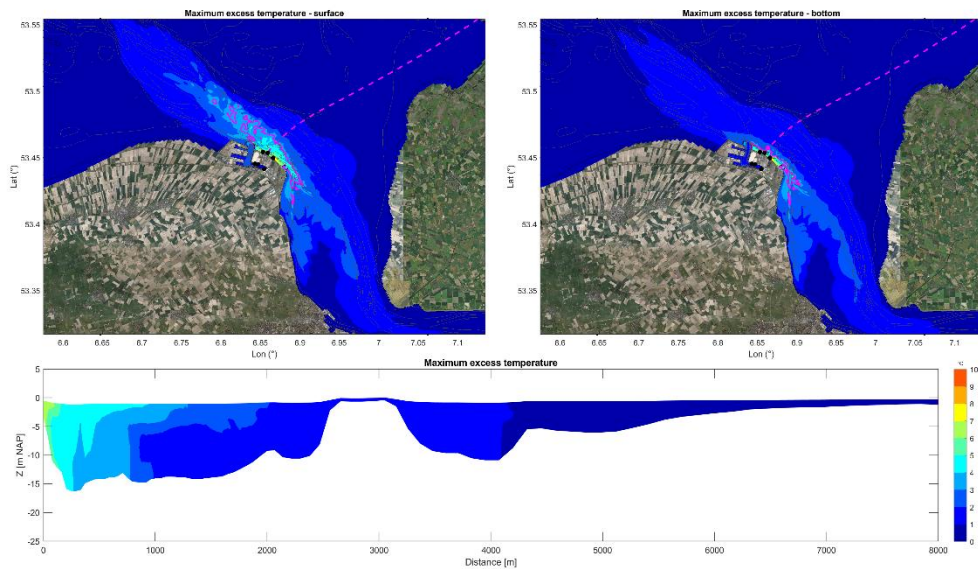


Figure 4.19 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 3.

Figure 4.19 shows that a submerged outfall (in contrast to an open outfall like Case 1) rapidly mixes the cooling water with ambient water, reducing the (surface) temperature increase around the outfall (~ 500 m). At distances of more than 500 m only a limited difference in the maximum excess surface temperature increase is expected between submerged and open outfalls (compare for example with Case 1). Near the seabed very little difference in the expected maximum temperature is expected between an open and submerged outfall. The combined mixing zone (+3.5 °C) at the seabed is expected to locally reach distances up to 2 km from the outfall locations. These areas are however classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.

Figure 4.20 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems Estuary for Case 3. With a computed maximum percentage of the cross-sectional area covered by the mixing zone of 11%, this remains well below the critical threshold value of 25% of the CIW criteria and does not show a substantial difference with an open intake option (Case 1). Furthermore, the computed average temperature increase over each cross section is below 2 °C for Case 3.

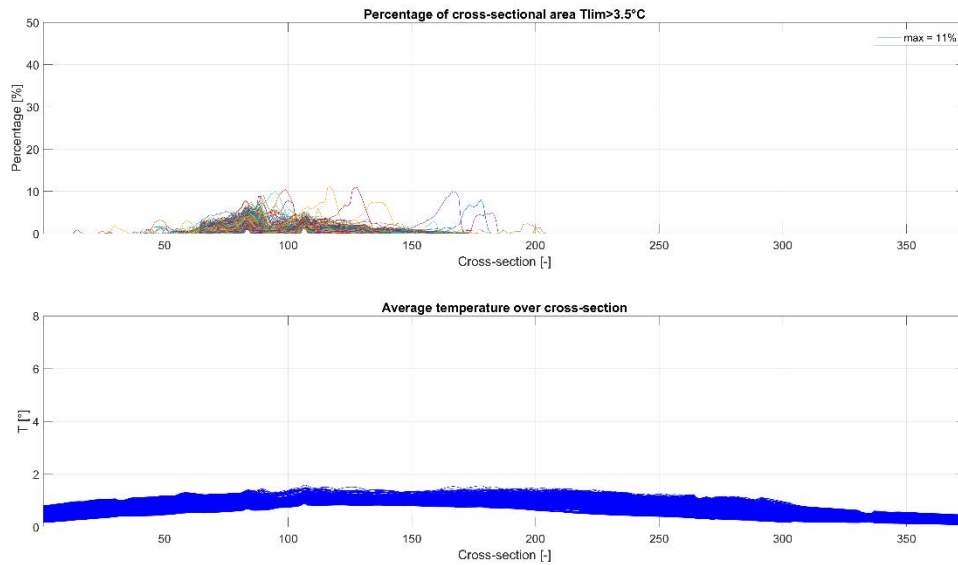


Figure 4.20 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 3.

Table 4.6 summarises the computed recirculation at each intake for Case 3. These computed values only show a marginal difference of 0.1 °C compared to Case 1 (open outfall, same intake location).

Table 4.6 Simulated excess temperature (°C) at each intake for Case 3.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 3 | 1.4 | 1.7 | 1.2 | 1.5 | | | 1.4 | 1.6 |

4.4.2.4 Case 4

In Case 4 / Configuration 4, an open intake is located in the west part of the Eemshaven and an open outfall outside and west of the Eemshaven, see Figure 4.21. For this configuration an additional breakwater is considered to deflect the thermal discharge offshore. Figure 4.22 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

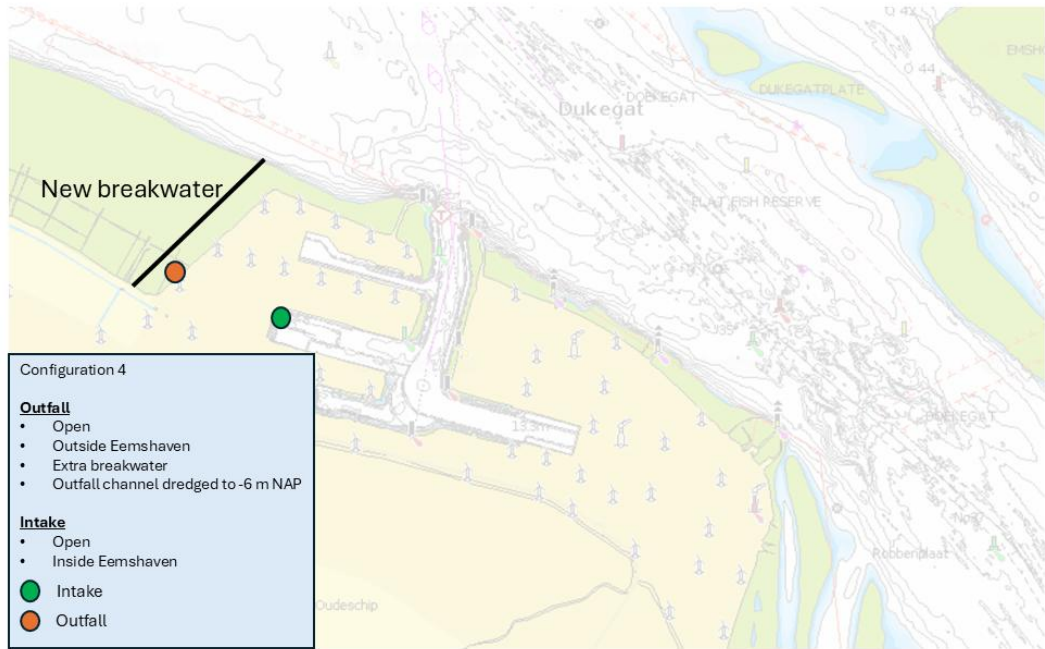


Figure 4.21 Eemshaven NPP intake and outfall Configuration 4.

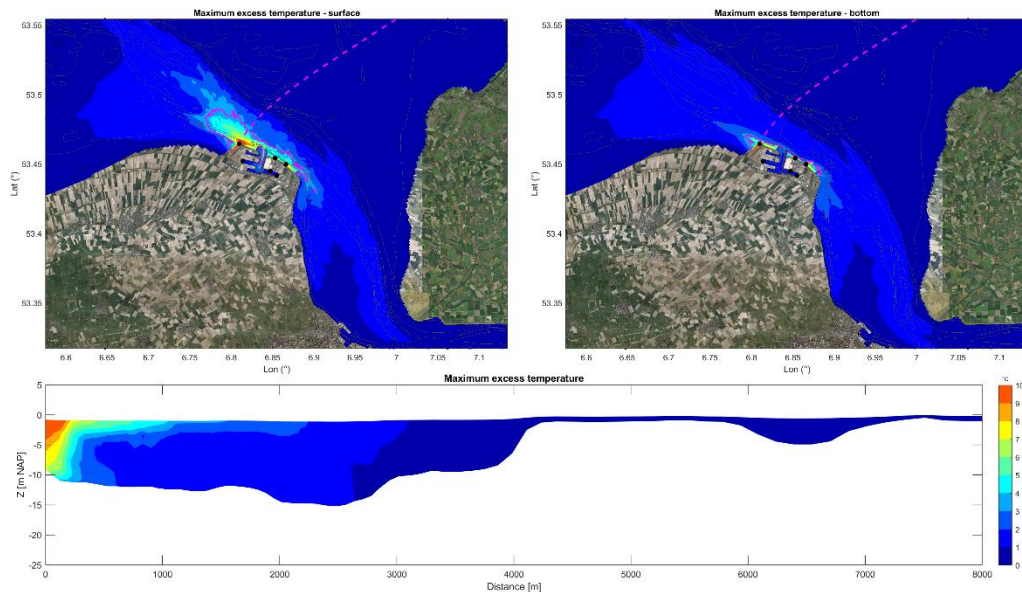


Figure 4.22 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 4.

Figure 4.22 shows for Case 4 relatively high increased temperatures at the seabed in the (shallow) area around the discharge. The increased temperature is explained by the limited initial mixing by the open outfall compared to a submerged diffuser option. The computed mixing zone ($+3.5\text{ }^{\circ}\text{C}$ contour) near the seabed extends approximately 1 km to the northwest from the point of discharge. This area is partially coastal water.

Figure 4.23 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections for Case 4. The computed maximum percentage of the cross-sectional area covered by the mixing zone is 5%. This maximum percentage remains well below the critical threshold value of 25% of the CIW criteria and is smaller compared to Case 1 to 3. This is explained by the location of the outfall and the

relatively large total cross-sectional area at the point of discharge. Furthermore, the computed average temperature increase over each cross-section is below 2 °C for Case 4.

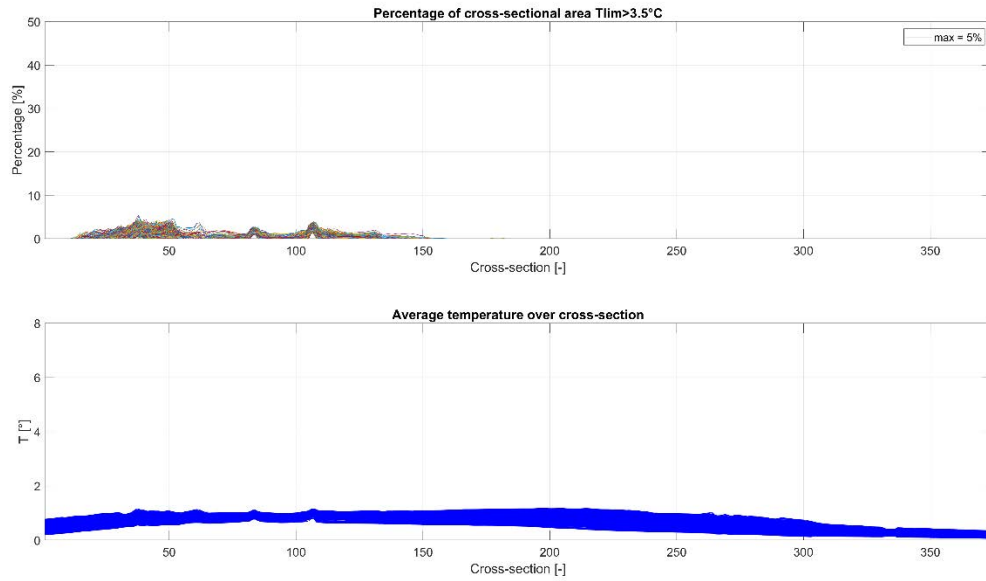


Figure 4.23 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 4.

Table 4.7 summarise the simulated excess temperatures at each intake for Case 4. While the intake and outfall location are different from Case 1 and 3, similar excess temperatures are computed at each intake. The computed mean and maximum excess temperatures at the Eemshaven NPP intake of Configuration 4 are respectively 1.5 °C and 1.7 °C.

Table 4.7 Simulated excess temperature (°C) at each intake for Case 4.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 4 | 1.4 | 1.6 | 1.4 | 1.5 | | | 1.5 | 1.7 |

4.4.2.5 Case 5

In Case 5 / Configuration 5 an open intake is situated outside and northeast of the Eemshaven, see Figure 4.24. A submerged outfall is situated about 500 m offshore from the intake and northeast of the Eemshaven. The difference with Case 3 is that the intake of Configuration 5 is located outside the Eemshaven, close to the existing outfalls and the submerged outfall is located more to the east. Figure 4.25 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

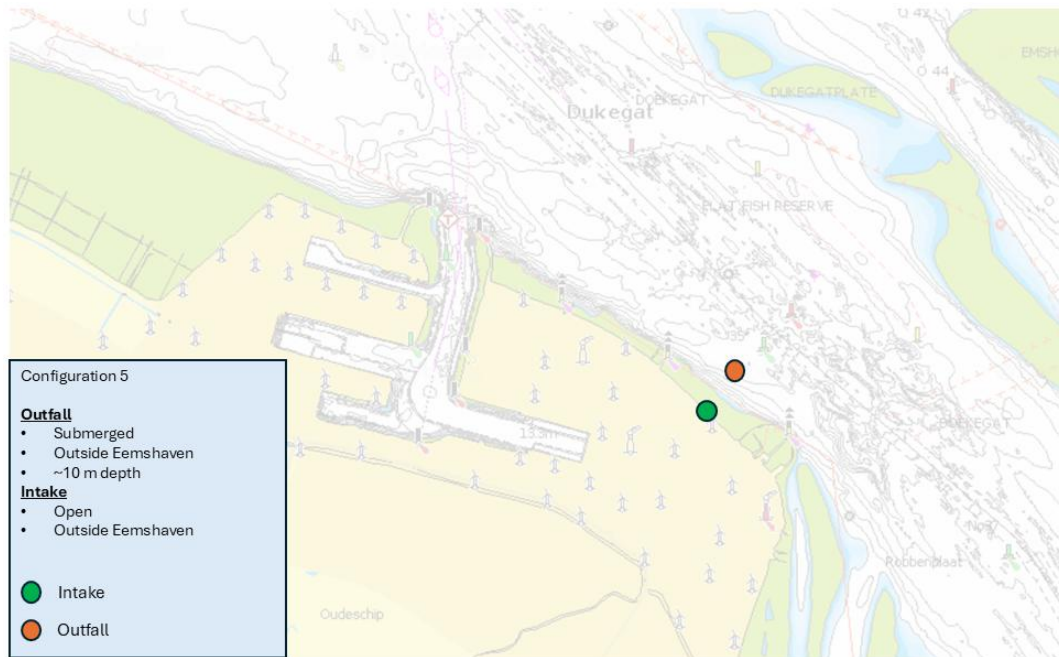


Figure 4.24 Eemshaven NPP intake and outfall Configuration 5.

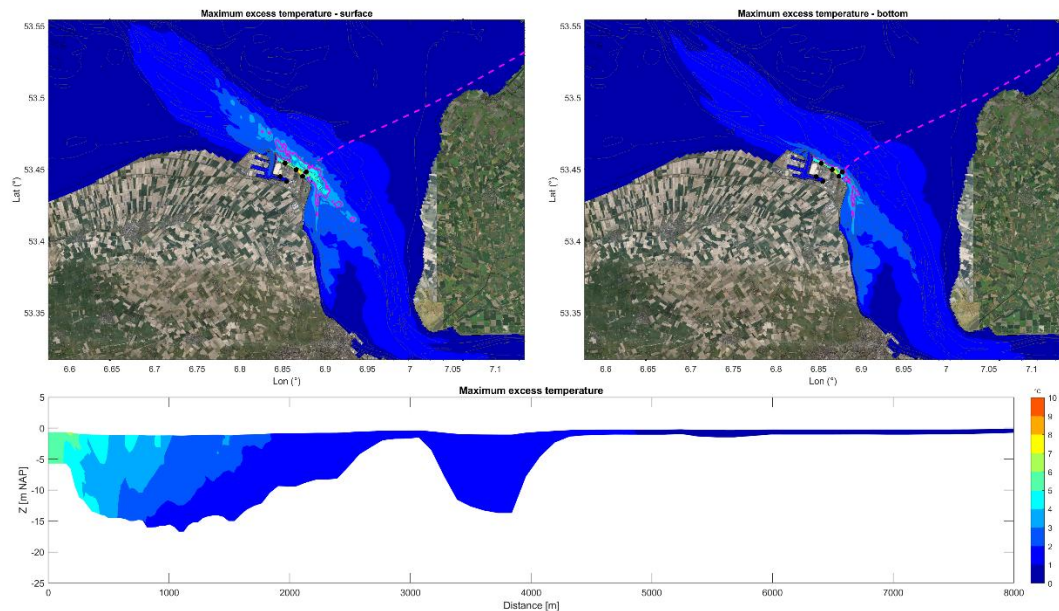


Figure 4.25 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 5.

Figure 4.25 shows that the submerged outfall (similar to Case 3) rapidly mix the cooling water with ambient water reducing the increased temperature around the outfall. Case 5 however, does show a slightly larger maximum mixing zone extent compared to Case 3 as the combined mixing zone extent (+3.5 °C contour) at the seabed is expected to locally reach distances up to 3.5 km from the new nuclear power plant outfall location. Main reason for this increase in mixing zone extent is the expected increase in recirculation and because of that, a higher discharge temperature. The areas near the seabed with increased maximum temperatures above +3.5 °C are classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.

Figure 4.26 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections for Case 5. With a computed maximum

percentage of the cross-sectional area covered by the mixing zone of 9%, this remains well below the critical threshold value of 25% of the CIW criteria. For Case 5 the computed average temperature increase over each cross section is below 2 °C.

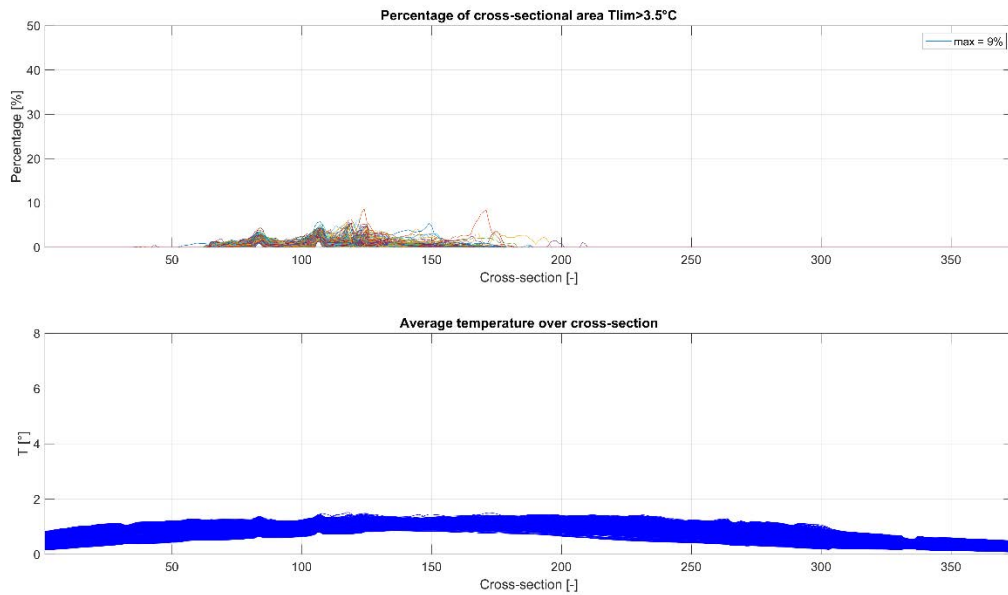


Figure 4.26 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 5.

Table 4.8 summarises the simulated excess temperature at each intake for Case 5. This table shows that the computed mean excess temperature at the Configuration 5 intake is about 1.7 °C and the maximum temperature increase is about 4.1 °C. This elevated recirculation towards the intake is a result of the close proximity of Eemshaven NPP intake compared to the existing and new outfalls.

Table 4.8 Simulated excess temperature (°C) at each intake for Case 5.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 5 | 1.3 | 1.5 | 1.1 | 1.3 | - | - | 1.7 | 4.1 |

4.4.2.6 Case 6

In Case 6 / Configuration 6 the open intake and submerged outfall are both located outside and northwest of the Eemshaven, see Figure 4.27. Figure 4.28 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

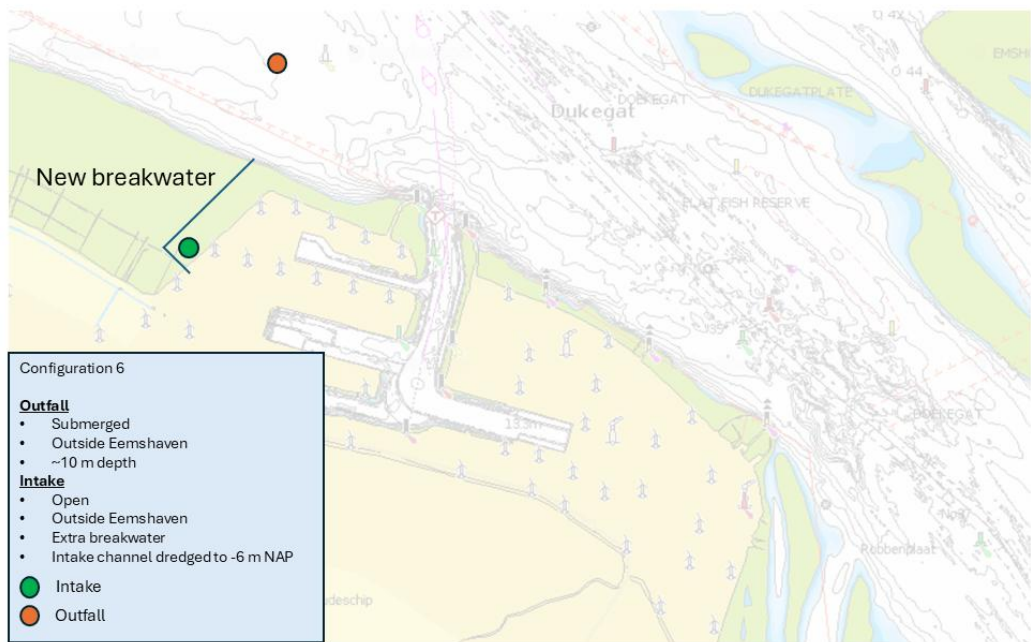


Figure 4.27 Eemshaven NPP intake and outfall Configuration 6.

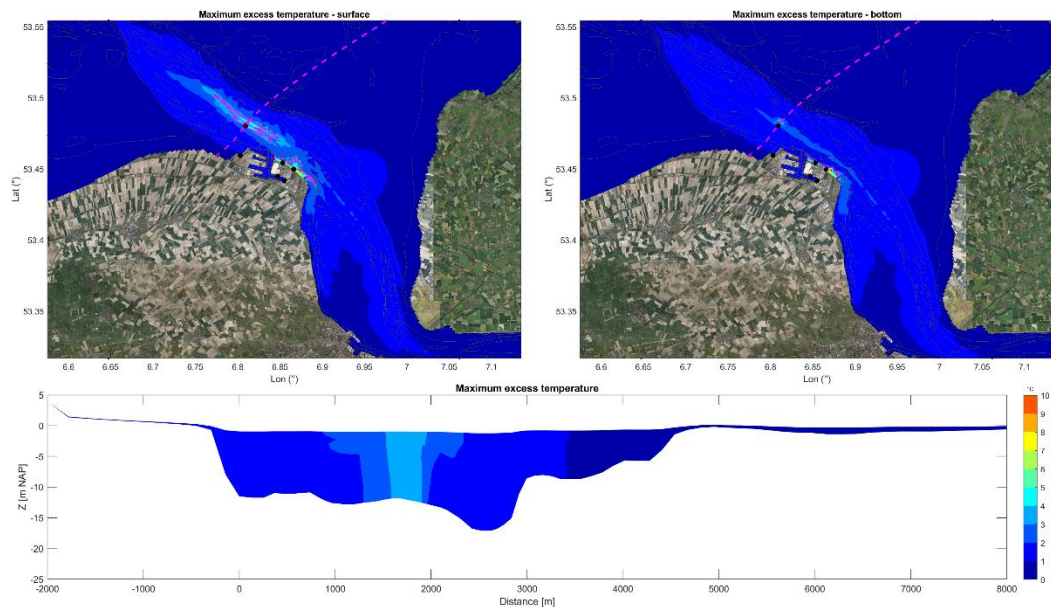


Figure 4.28 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 6.

Figure 4.28 shows that the thermal discharge gets rapidly diluted around the outfall and disperses in northwest and southeast direction. The outfall of Configuration 6 is more distant from the existing outfalls compared to, for instance, Case 5 and less interaction between the outfall plumes is expected. The combined mixing zone (+3.5 °C) is expected to reach the seabed only locally around the outfall in the near-field region (<200 m) and near the existing outfalls. The area around the Configuration 6 outfall is classified by the CIW criteria as coastal water.

Figure 4.29 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems-Dollard Estuary. With a computed maximum percentage of the cross-sectional area covered by the mixing zone of

4% and well below the critical threshold value of 25%. The outfall of Configuration 6 is relatively favourable for the estuarine criterion of the CIW criteria (if it would apply for this part of the Ems-Dollard), because the outfall is located in a relatively wide part of the Ems-Dollard Estuary and the submerged diffuser rapidly mixes the discharge heat with ambient water. The computed average temperature increase over each cross section is below 2 °C for Case 6.

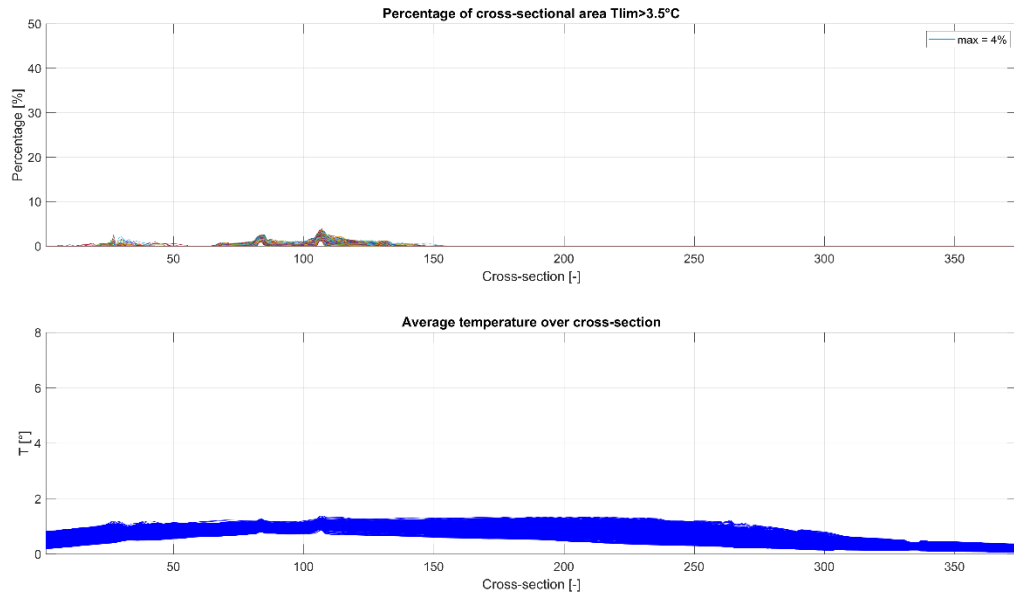


Figure 4.29 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 6.

The computed excess temperature increase at each intake for Case 6 is presented in Table 4.9. Due to the larger distance of the intake to the existing outfalls and positioning of the new outfall, the simulated excess temperature at the Configuration 6 intake is lowest of all considered cases which a mean temperature increase of 1.1 °C and a computed maximum increase of 1.4 °C. Furthermore, the influence of the Configuration 6 outfall on existing intakes is the lowest of all considered configurations with a computed mean and maximum temperature increase at each intake of 1.0 °C to 1.1 °C.

Table 4.9 Simulated excess temperature (°C) at each intake for Case 6.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 6 | 1.1 | 1.1 | 1.0 | 1.1 | - | - | 1.1 | 1.4 |

4.4.2.7 Case 7

Case 7 / Configuration 7 is very similar to Case 6. The only difference is the extended intake channel further south to enable the withdrawal of cooling water more south of Configuration 6, see Figure 4.30. Figure 4.31, Figure 4.32 and Table 4.10 show respectively the simulated maximum temperature increase footprint, the percentage of the cross-sectional area covered by the mixing zone and the computed increase in temperature at each intake. The extension of the intake channel has no substantial effect on the expected plume dispersion and recirculation. Main findings and conclusions on the dispersion and recirculation of cooling water for Case 6 therefore also apply for Case 7.

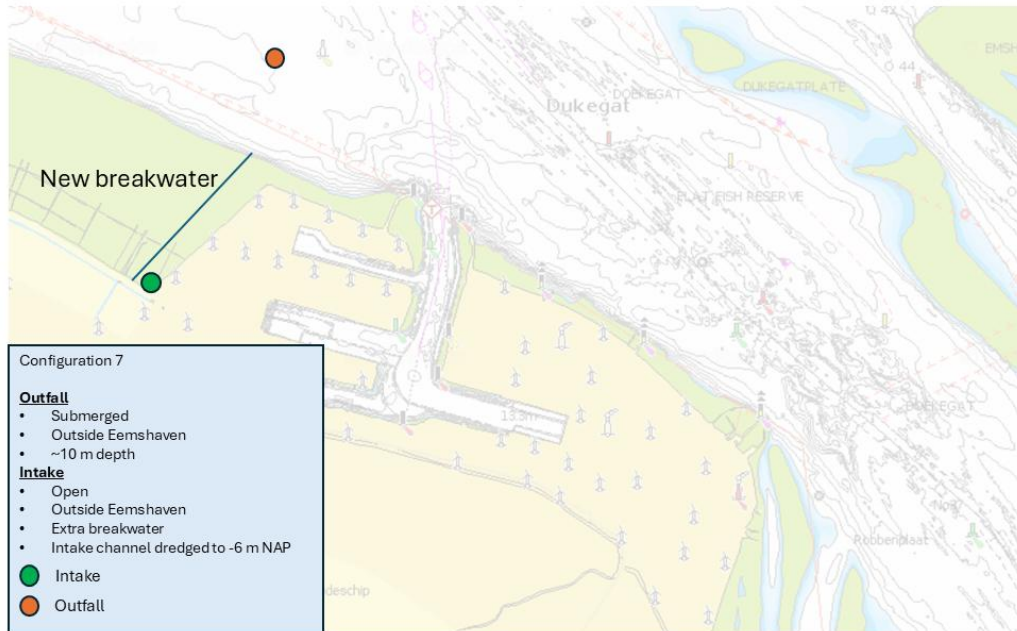


Figure 4.30 Eemshaven NPP intake and outfall Configuration 7.

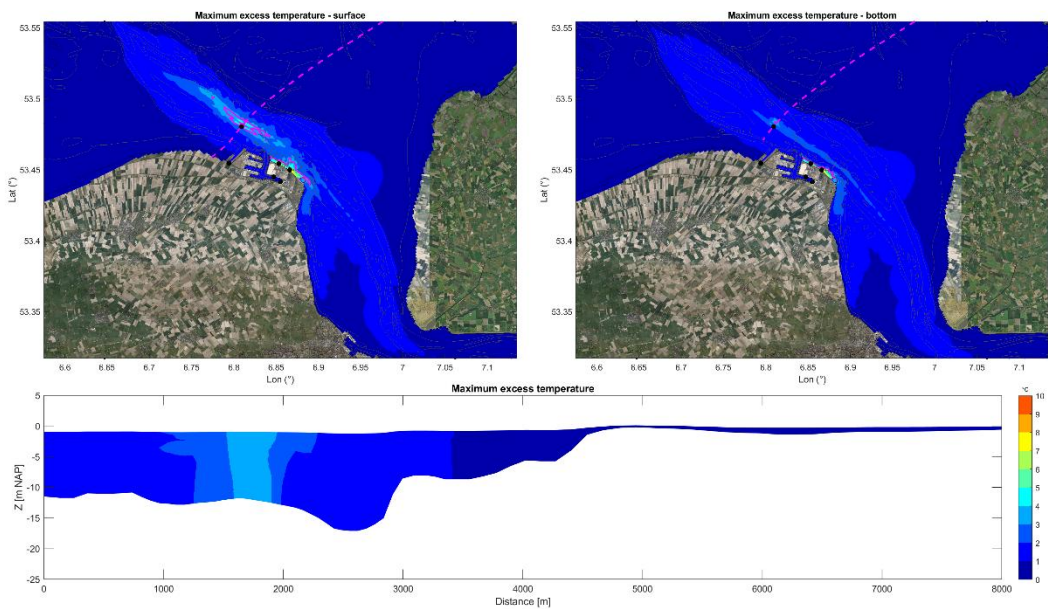


Figure 4.31 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 7.

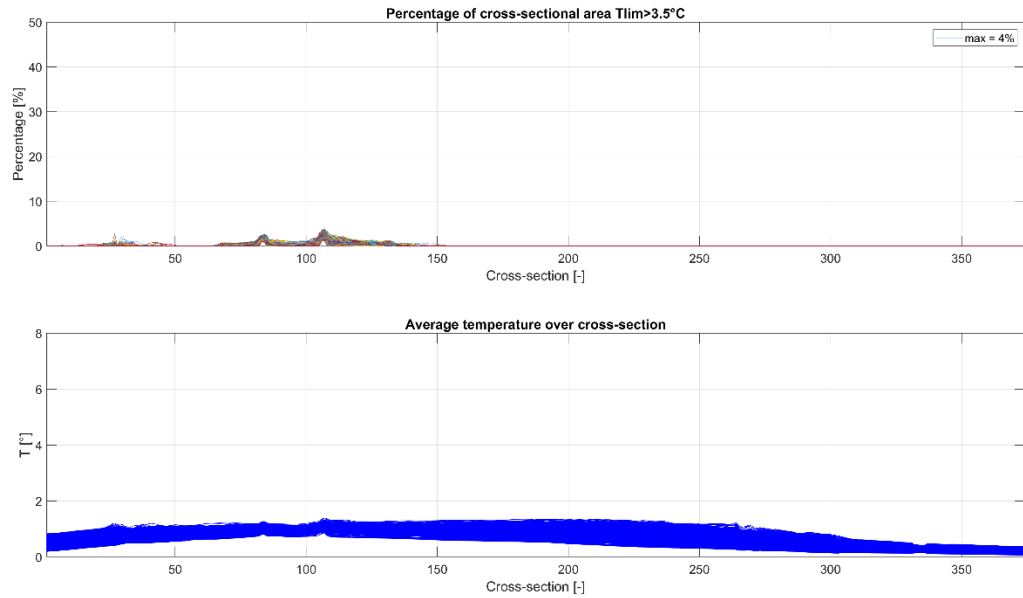


Figure 4.32 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 7.

Table 4.10 Simulated excess temperature (°C) at each intake for Case 7.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 7 | 1.1 | 1.1 | 1.0 | 1.1 | - | - | 1.1 | 1.4 |

4.4.2.8 Case 8

Case 8 / Configuration 8 is similar to Configuration 5, but both the intake and outfall are relocated 350 m in northwest direction, see Figure 4.33. Configuration 8 is considered because it would enable the construction of a nuclear power plant (and intake and outfall) in the area of the existing Eemshavencentrale of RWE. Figure 4.34 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Eemshaven NPP outfall.

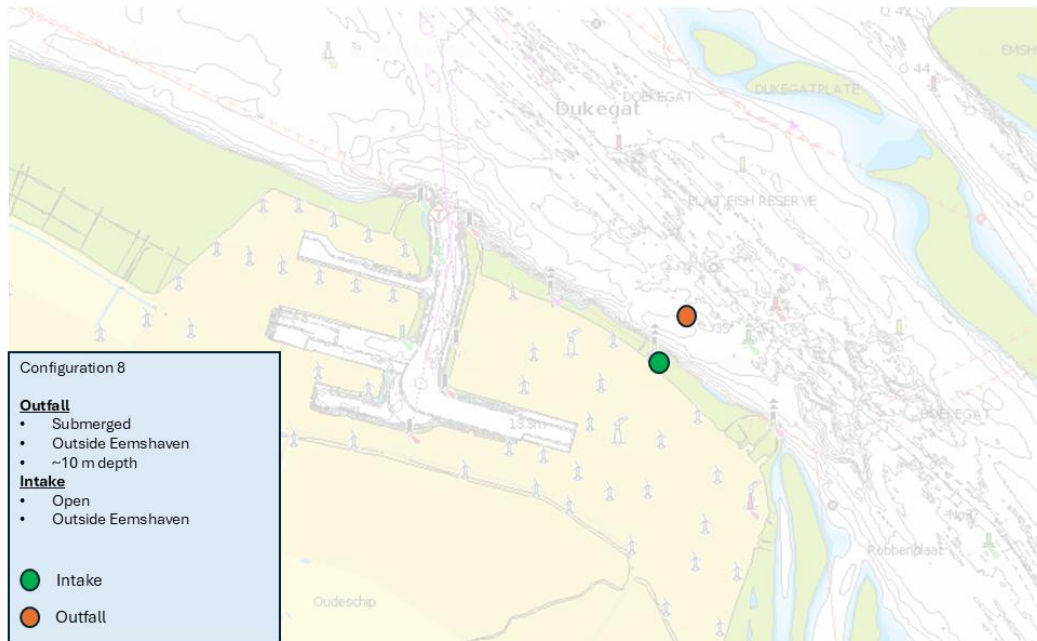


Figure 4.33 Eemshaven NPP intake and outfall Configuration 8.

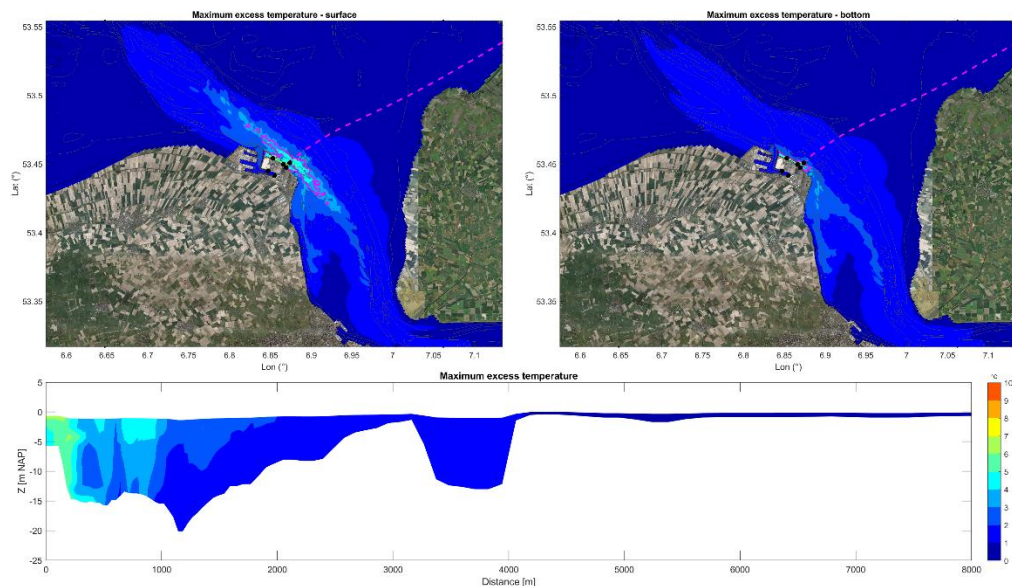


Figure 4.34 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 8.

Figure 4.34 shows that, similar to other configurations with a submerged outfall diffuser, the diffuser rapidly mixes the cooling water with ambient water reducing the increased temperatures around the outfall. The discharged cooling water spreads mainly in northwest and southeast direction. Case 8 results in a slightly smaller mixing zone at the seabed compared to Case 5. The relocation of the intake and outfall to the northwest results in an expected near-bed temperature increase above the critical threshold value of $+3.5\text{ }^{\circ}\text{C}$ at distances up to 1 km. The computed mixing zone of Case 8 is not expected to reach the seabed in coastal waters northwest of the Eemshaven.

Figure 4.35 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems Estuary for Case 8. With a computed maximum percentage of the cross-sectional area covered by the mixing zone of

9%, this remains well below the critical threshold value of 25% of the CIW criteria. This maximum percentage is in line with the computed maximum percentage computed for other configurations with a submerged diffuser in this area. The computed average temperature increase over each cross section is below 2 °C.

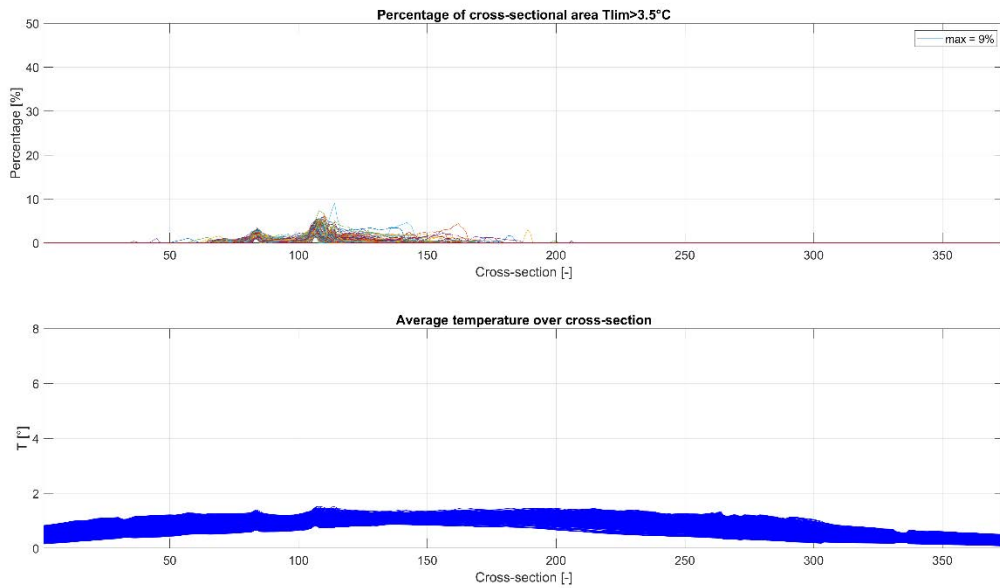


Figure 4.35 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 8.

Table 4.11 summarises the simulated excess temperature at each intake for Case 8. This table shows that the computed mean excess temperature at the Configuration 8 intake is about 1.6 °C and the maximum temperature increase is about 4.1 °C. In terms of expected recirculation towards the intake, there is no significant difference expected between Case 8 and Case 5.

Table 4.11 Simulated excess temperature (°C) at each intake for Case 8.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 8 | 1.3 | 1.5 | 1.1 | 1.3 | | | 1.6 | 4.1 |

4.4.3 Results of different existing discharges

For consistency, Case 1 to Case 8 all considered the same existing outfalls in operation, see Section 4.1. Configuration 8 (Case 8) considers however the area of the existing Eemshavencentrale of RWE and the Eemshaven NPP is likely to replace this existing power

plant. An additional simulation was therefore performed to address the scenario of a new nuclear power plant and only the existing Magnumcentrale in operation, i.e. Case 9.

4.4.3.1 Case 9

For Case 9, the existing discharges of Case 8 are reduced by ignoring the Eemshavencentrale of RWE. This scenario therefore only includes the new Eemshaven NPP and the Magnumcentrale in operation. Figure 4.36 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfall and the new nuclear power plant outfall.

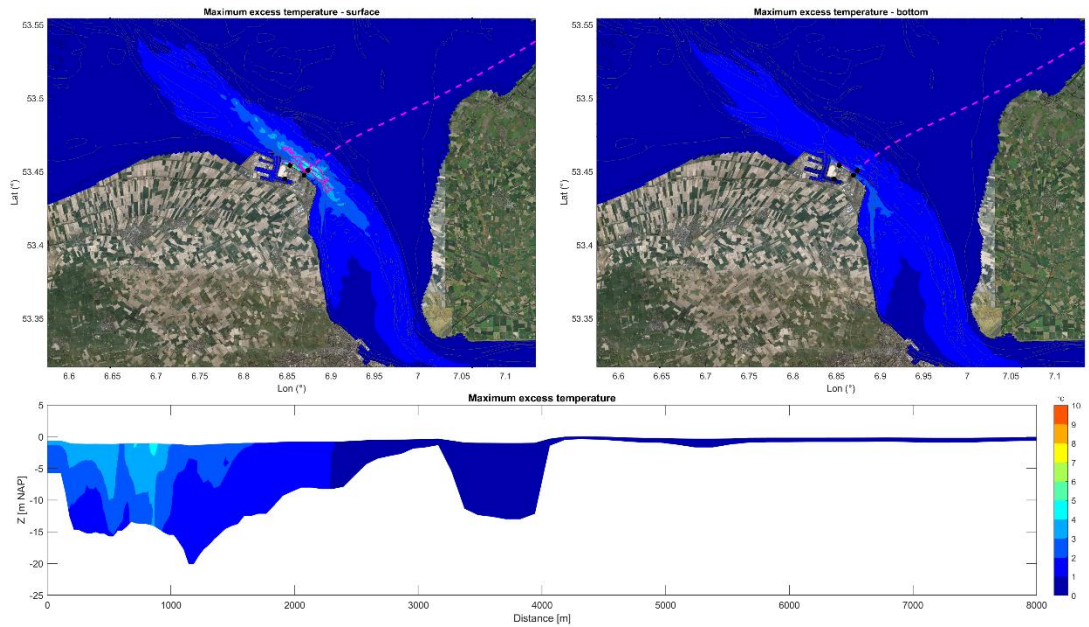


Figure 4.36 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new nuclear power plant discharge. Case 9.

Figure 4.36 shows that by reducing the total cooling water discharge rate in the area, the maximum increased temperature around the outfall also reduces. The reduced excess temperature results in a much smaller mixing zone at the seabed compared to Case 8. Only locally the mixing zone will reach the seabed in Case 9.

Figure 4.37 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Ems Estuary. For Case 9, the maximum percentage of cross-sectional area covered by the mixing zone is 4%, which is well below the critical threshold value of 25% of the CIW criteria.

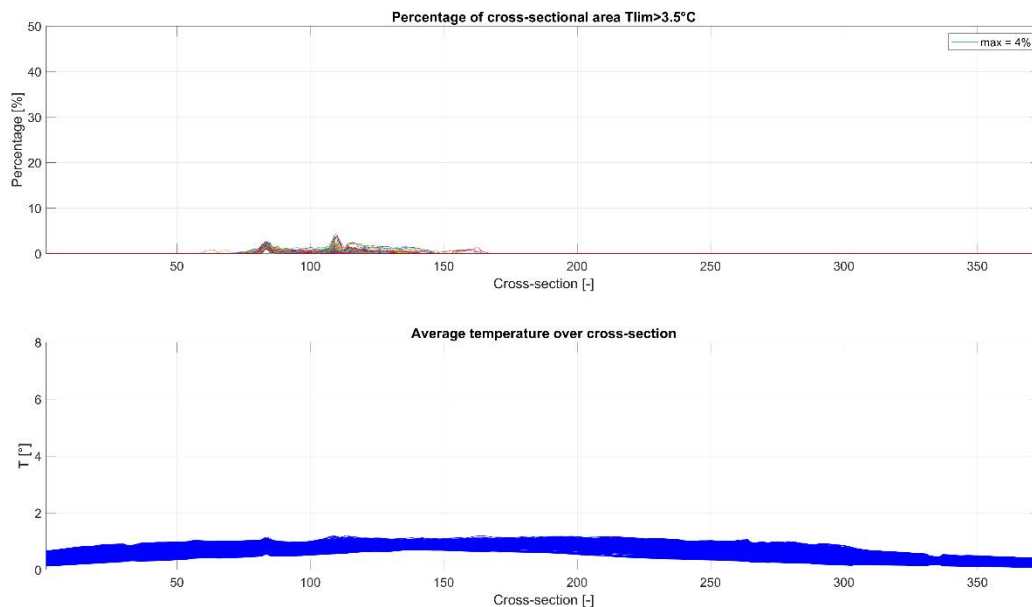


Figure 4.37 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom). Case 9.

Table 4.12 summarises the simulated excess temperature at each intake for Case 9. This table shows that the computed mean excess temperature at the new nuclear power plant intake reduces from 1.6 °C (Case 8) to 1.2 °C when the Eemshavencentrale of RWE is not considered. The computed maximum excess temperature reduces from 4.1 °C (Case 8) to 2.2 °C. Table 4.12 further shows that excluding the Eemshavencentrale will have a marginal effect on the intake temperature of the Magnumcentrale. The mean and maximum temperature increase at this intake are reduced by 0.3 °C (i.e. compared to Case 8).

Table 4.12 Simulated excess temperature (°C) at each intake for Case 9.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-------|-----|-------|-----|-------|-----|------|-----|
| | mean | max | mean | max | mean | max | mean | max |
| Baseline 1 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | | |
| Baseline 2 | 0.4 | 0.5 | 0.4 | 0.4 | | | | |
| Case 9 | 1.0 | 1.2 | | | | | 1.2 | 2.2 |

5 Conclusions

The objective of this numerical modelling study is to assess the cooling water availability and in particular the plume dispersion of the proposed Eemshaven NPP cooling water discharge (and other discharges in the area) in relation to the governing environmental (and other design) criteria for different Eemshaven intake and outfall options. This assessment will provide information to EZK about the site selection and feasibility of different options for cooling water systems and will be used as input to their further studies and to the detailed cooling water modelling in the next phase of this project. The studies carried out are not intended to be complete and are therefore not a guarantee that if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

The assessment was carried out by means of a hydrodynamic Delft3D 4 model that simulates the dispersion of the new nuclear power plant cooling water discharge, together with additional existing discharges in the area. This (detailed) model was set up around the Eemshaven project area and nested in in-house available models. When submerged outfalls were considered, the Delft3D model was dynamically coupled to a database of near-field CORMIX results. With this coupled modelling system it was possible to simulate different intake and outfall configurations under various ambient conditions relevant for the applicable environmental temperature criteria and forcings that affect the plume dispersion.

Based on this study, the following conclusions have been drawn:

General

- The CIW 2004 (temperature) mixing zone and average temperature increase criteria were used for the evaluation of different Eemshaven NPP cooling water configurations. Compliance with other possible criteria (e.g., on other water/ecological parameters) would need to be evaluated in a full environmental impact assessment study. The Ems-Dollard has characteristics of both coastal waters and estuarine waters. The area northwest of the Eemshaven is considered coastal water, the Eemshaven and the area southwest of the Eemshaven are considered estuarine waters for which different criteria apply:
 - Mixing zone (area classified as estuarine water): The maximum permitted mixing zone area is 25% of the cross-sectional area of the water body. The mixing zone is defined as the 25°C temperature contour. This criterion should be fulfilled at least 98% of the time.
 - Mixing zone (area classified as coastal water): The 25°C temperature contour should not reach the seabed.
 - Average temperature increase: The average temperature of the water body may not increase more than 2°C and/or increase above 25 °C for areas classified as estuarine and coastal water and 'schelpdierwater'.
- The selection of a representative ambient 98th percentile temperature is not trivial from the available data in the Ems-Dollard estuary. In this study, the 98th percentile water temperature was computed from 6 years of data for a location close to the Eemshaven and corresponds to 21.5 °C. A representative ambient 98th percentile temperature of 21.5 °C results in a relative mixing zone definition of +3.5 °C above ambient.
- No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different intake and outfall options for the Eemshaven NPP were selected. For this study, 8 intake and outfall configurations were

considered. These 8 configurations include variations in the location of the intake and outfall and the type of intake and outfall structure (open or submerged).

- A maximum thermal discharge capacity of 6000 MWth was selected for this assessment, with a flow of 159.5 m³/s and a temperature increase of +9 °C.
- A detailed 3D hydrodynamic Delft3D 4 model was set up and nested in a well-validated overall model. This new detailed model has sufficient horizontal resolution (~40 m) in the area of interest. Alternative Eemshaven NPP intake and outfall designs were incorporated in the model by means of bathymetric changes, structures and dynamic coupling to a database of nearfield simulations of the thermal discharge. Results of these simulations are presented as temperature footprints at the surface and the seabed and percentages of the total cross-section covered by the mixing zone.
- Baseline simulations were performed for the present situation with the thermal discharges of RWE Magnum (1), RWE Eemshaven (2) and ENGIE Eemshaven (3) included, see below figure. For simulations with the Eemshaven NPP only the existing thermal discharges of the RWE Magnum and RWE Eemshaven were considered. The thermal discharge of ENGIE Eemshaven was excluded in these future scenarios.
- If, at a later stage, alternative configurations are considered (for example scenarios in which other existing plants are partially or fully decommissioned) this may result in different outcomes, as the associated thermal discharges are no longer present. The same applies for configurations with additional thermal loads (for example scenario's where existing plants remain operational based on changing electricity market dynamics and regulation).



Figure 5.1 Overview existing plants in the project area.

- Since the Eemshaven NPP of Configuration 8 is located at the existing plot of the RWE Eemshaven, an additional sensitivity simulation was performed with the new Eemshaven NPP and the existing RWE Magnum power plant intake and outfalls only, i.e. excluding the RWE Eemshaven (i.e. Case 9).
- An overview of the simulated scenarios is presented in the below figures and table.

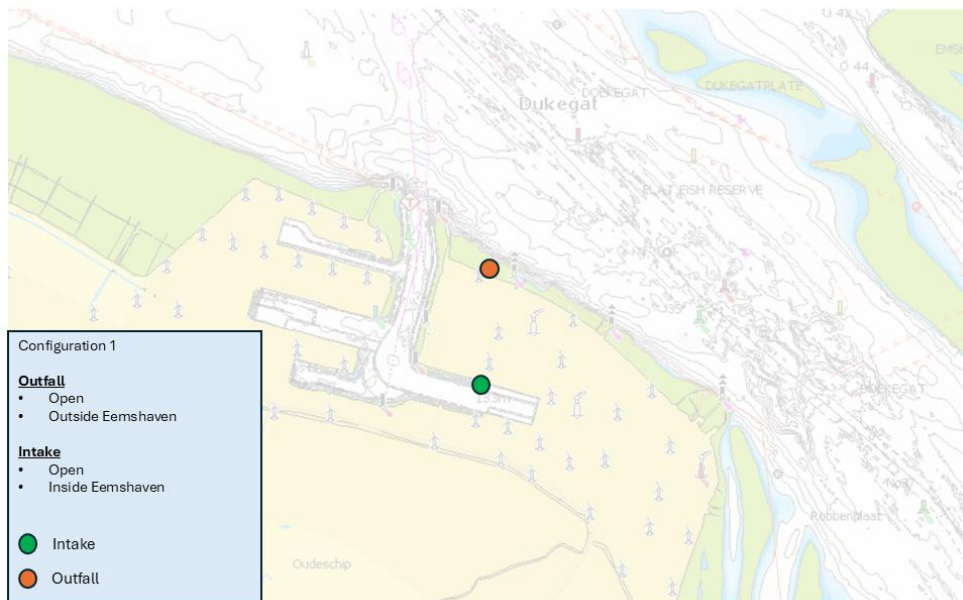


Figure 5.2 Eemshaven NPP intake and outfall Configuration 1.

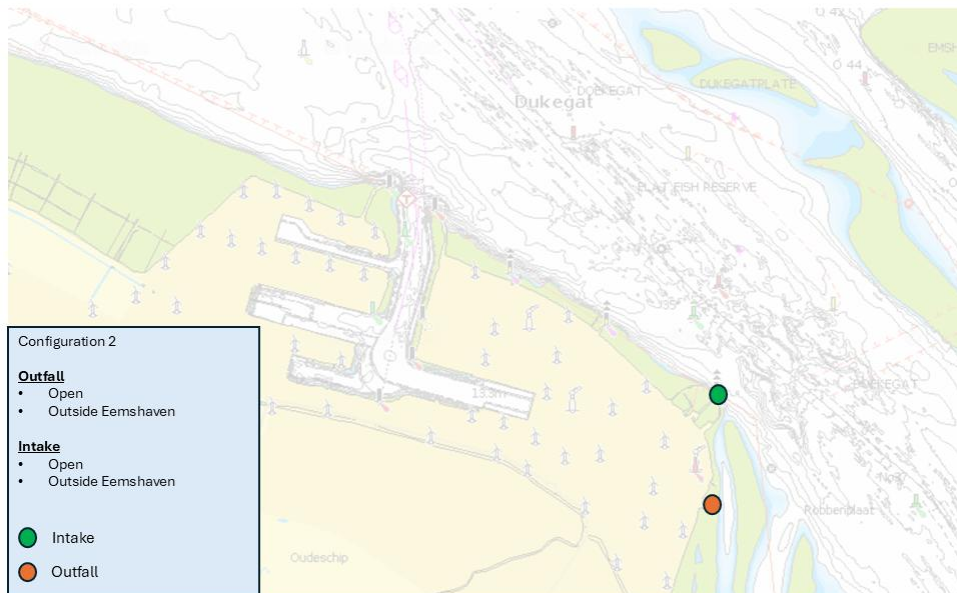


Figure 5.3 Eemshaven NPP intake and outfall Configuration 2.

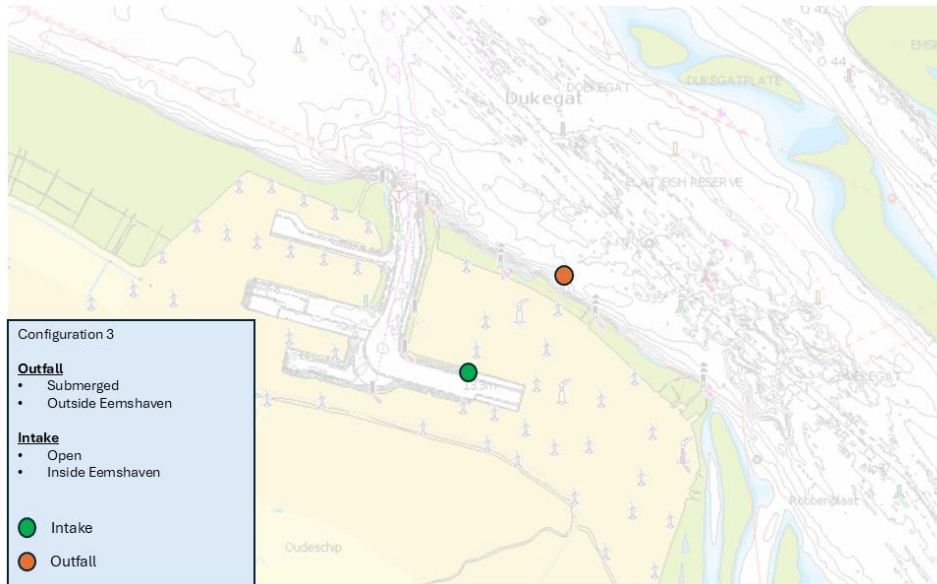


Figure 5.4 Eemshaven NPP intake and outfall Configuration 3.

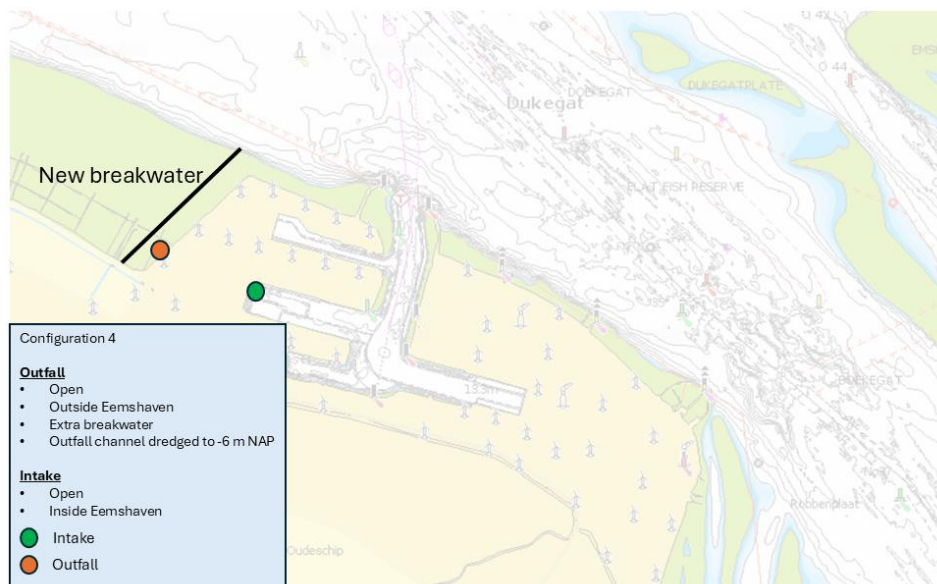


Figure 5.5 Eemshaven NPP intake and outfall Configuration 4.

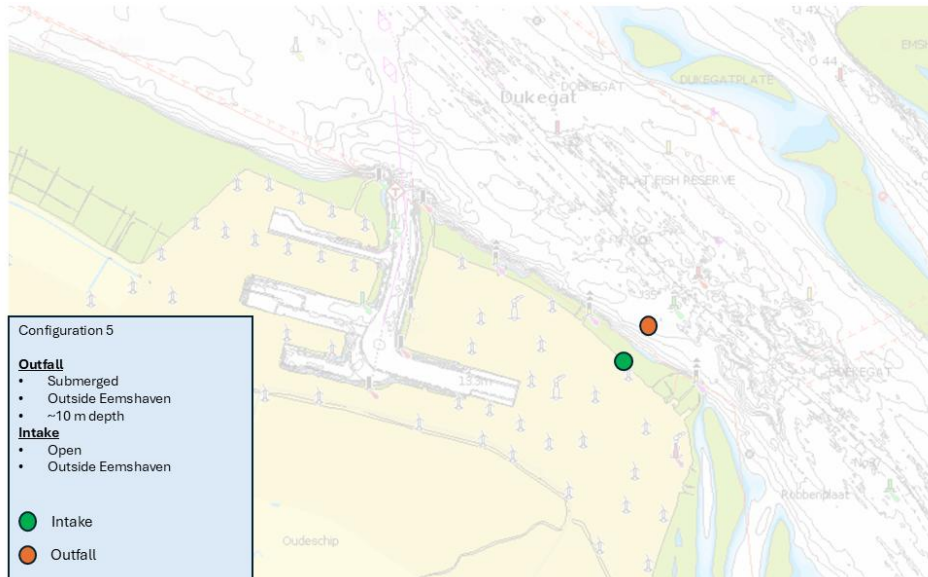


Figure 5.6 Eemshaven NPP intake and outfall Configuration 5.

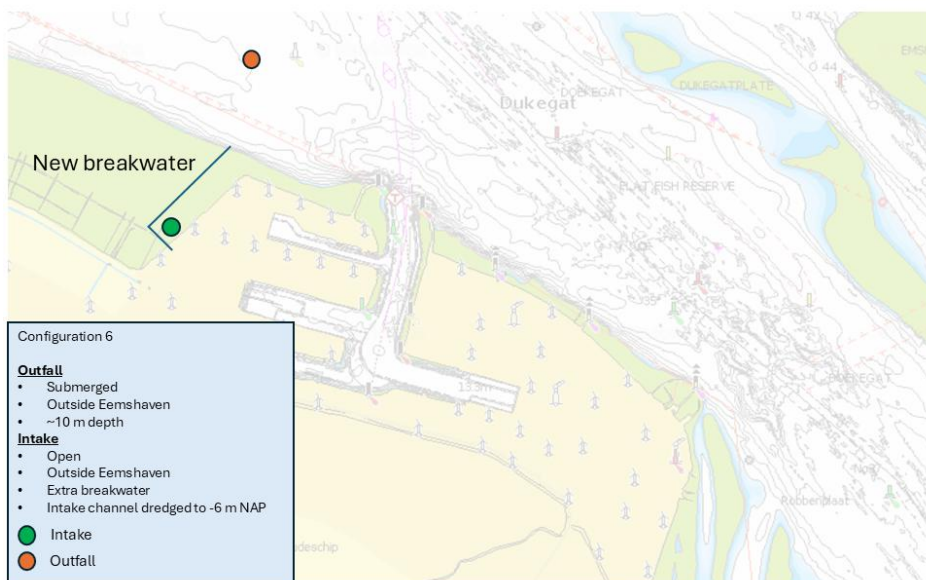


Figure 5.7 Eemshaven NPP intake and outfall Configuration 6.

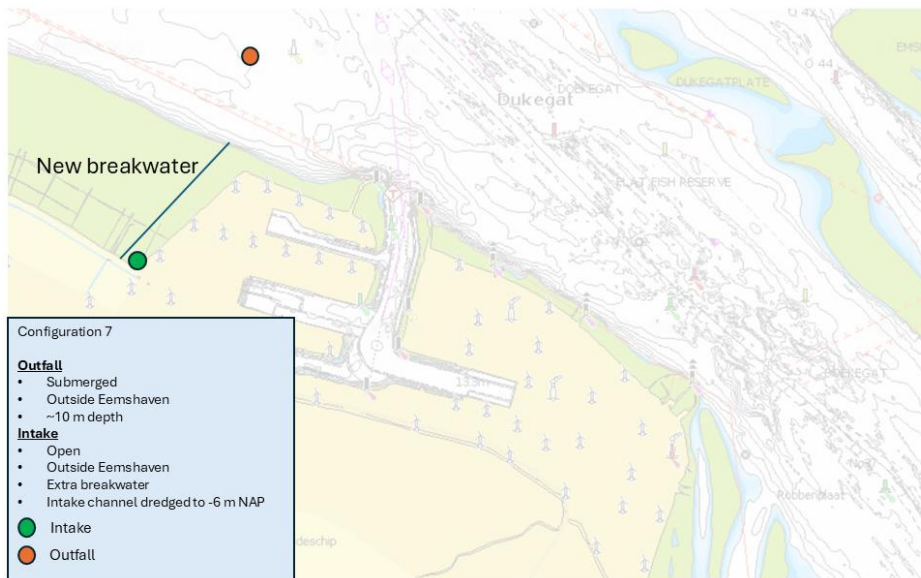


Figure 5.8 Eemshaven NPP intake and outfall Configuration 7.

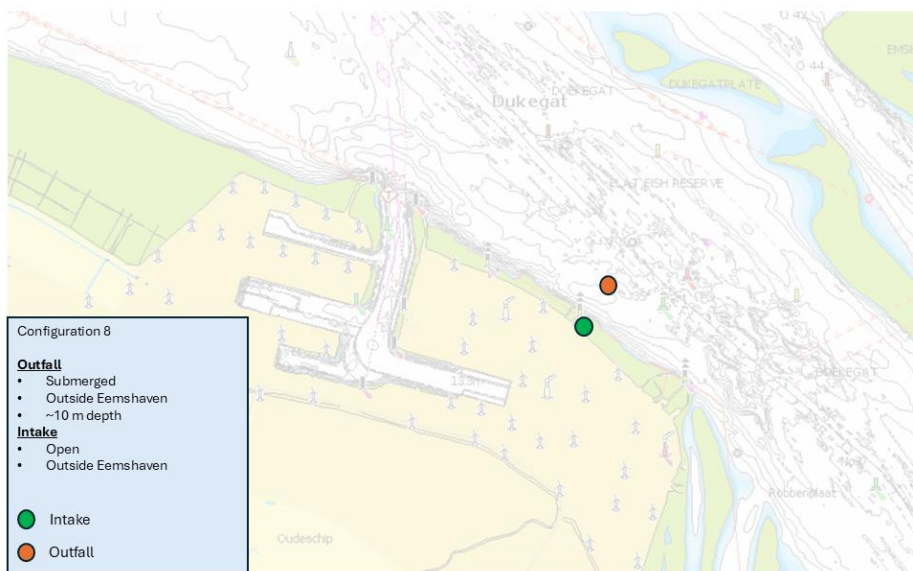


Figure 5.9 Eemshaven NPP intake and outfall Configuration 8.

Table 5.1 Overview of simulation cases carried out in this study

| Case | NPP config | Existing discharges | Discharge char. NPP | Comment |
|------------|------------|-----------------------|----------------------------------|-----------------------------------|
| Baseline 1 | - | RWE E + RWE M + ENGIE | - | Present situation |
| Baseline 2 | - | RWE E + RWE M | - | Present situation, excl. ENGIE |
| 1 | 1 | RWE E + RWE M | 159.5 m ³ /s +9 °C | Different I/O configurations |
| 2 | 2 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 3 | 3 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 4 | 4 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 5 | 5 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 6 | 6 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 7 | 7 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 8 | 8 | RWE E + RWE M | 159.5 m ³ /s +9 °C | |
| 9 | 8 | RWE M | 159.5 m ³ /s +9 °C | Excl. ENGIE and Eemshavencentrale |

Plume behaviour

- Due to the lower density of the cooling water, the thermal plume is expected to rise to the surface and spread in NW and SE direction (main channel orientation) by the relatively large tidal flows near the project site.
- Submerged outfalls, as opposed to open outfalls, rapidly mix the cooling water with ambient water, reducing the temperature increase around the outfall (~ 500m) due to the cooling water discharge. At distances of more than 500 m only a limited difference in the maximum excess surface temperature increase is expected between submerged and open outfalls. Near the seabed very little difference in the expected maximum temperature is expected between an open and submerged outfall.
- The Ems-Dollard estuary includes shallow tidal flats. Discharging close to tidal flats (ENGIE discharge location, Baseline 1 / Case 2) results in limited mixing with ambient water and a relatively high excess temperature around the outfall and near the bed.

Environmental criteria

- The maximum computed cross-sectional area covered by the mixing zone (temperature increase > 3.5 °C) is around or below 12% for all cases. This is lower than the critical threshold value of 25% specified in the CIW criteria.
- While a submerged outfall (for example Case 3) will rapidly locally mix the discharged water and lead to a lower temperature close to the outfall and seabed, a higher percentage of the cross-sectional area is expected to be covered by the mixing zone compared to an open outfall (e.g. Case 1).
- The maximum computed cross-sectional average temperature increase (as a conservative interpretation of the average temperature increase of the water body) is in all cases below 2 °C (absolute temperature is therefore by definition lower than the 25 °C criterion).

- Both in the present situation (Baseline 1 / Baseline 2) and in Cases 1 to 8, the mixing zone (temperature increase $> 3.5\text{ }^{\circ}\text{C}$) is expected to reach the seabed in different areas around the Eemshaven depending on the intake and outfall configuration:
 - In the present situation (Baseline 1) the ENGIE thermal discharge has limited dilution around the outfall and maximum increased temperatures are expected on the seabed of more than $3.5\text{ }^{\circ}\text{C}$ at distances of approximately 2.5 km south of the discharge location. However, these areas are classified as estuarine waters for which estuarine mixing zone criteria apply, in which the seabed temperature is not explicitly considered. The mixing zone is not expected to reach the seabed in coastal waters (northwest of Eemshaven).
 - In the present situation without the ENGIE Eemshaven in operation (Baseline 2) only locally ($<500\text{ m}$) around the existing outfalls, the near-bed temperature is expected to exceed the $+3.5\text{ }^{\circ}\text{C}$ CIW criterion. The area where the mixing zone reaches the seabed is classified as estuarine waters.
 - For Case 1 the near-bed temperature increase of more than $+3.5\text{ }^{\circ}\text{C}$ is computed at alongshore distances up to 4.5 km southeast of the discharge location of Configuration 1. The computed $+3.5\text{ }^{\circ}\text{C}$ near-bed temperature contour is not expected to reach the area northwest of the Eemshaven for which the CIW coastal criterion applies.
 - When Eemshaven NPP is located at the site of the existing ENGIE Eemshaven plant (Case 2), the same area south of this discharge location will be subject to increased temperature as in Baseline 1. Due to the larger thermal load of the NPP, the mixing zone at the seabed does extend further south, approximately 7 km. The computed mixing zone of Case 2 is not expected to reach the seabed in coastal waters.
 - In Case 3 the mixing zone at the seabed is expected to locally reach distances up to 2 km from the outfall locations. These areas are however classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.
 - For Case 4 a relatively high increased temperature at the seabed is computed in the (shallow) area around the discharge. The increased temperature are explained by the limited initial mixing by the open outfall compared to a submerged diffuser option. The computed mixing zone ($+3.5\text{ }^{\circ}\text{C}$ contour) near the seabed extends approximately 1 km to the northwest from the point of discharge. This area is partially coastal water. The computed mixing zone at the seabed for Case 4 is smaller compared to the computed mixing zone at the seabed of Case 2, due to the deeper water in the vicinity of the outfall of Configuration 4.
 - For Case 5 the submerged outfall (similar to Case 3) rapidly mix the cooling water with ambient water reducing the increased temperatures around the outfall due to the cooling water discharge. Case 5, however, does show a slightly larger maximum mixing zone extent compared to Case 3, as the combined mixing zone extent ($+3.5\text{ }^{\circ}\text{C}$ contour) at the seabed is expected to locally reach distances up to 3.5 km from Eemshaven NPP outfall location. Main reason for this increase in mixing zone extent is the expected increase in recirculation (due to the proximity of the NPP intake), which results in a higher discharge temperature. However, the areas near the seabed with an increased maximum temperature above $+3.5\text{ }^{\circ}\text{C}$ are classified as estuarine waters. The mixing zone is not expected to reach the seabed northwest of the Eemshaven.
 - The outfall of Case 6 is more distant from the existing outfalls compared to most other cases. Therefore, less interaction between the outfall plumes is expected. The combined mixing zone is expected to reach the seabed only locally around the outfall in the near-field region ($<200\text{ m}$) and near the existing outfalls. The area around the Case 6 outfall is classified by the CIW criteria as coastal water in which the mixing zone should not reach the seabed.
 - Case 7 includes an extension of the intake channel, compared to Case 6. This extension has no substantial effect on the expected plume dispersion and recirculation. Main findings and conclusions on the dispersion and recirculation of cooling water for Case 6 therefore also apply to Case 7.

- Case 8 results in an expected near-bed temperature increase above the critical threshold value of +3.5 °C at distances up to 1 km. The computed mixing zone of Case 8 is not expected to reach the seabed in coastal waters northwest of the Eemshaven.
- For Case 9 (same outfall configuration as Case 8, but excluding the RWE Eemshavencentrale) it is computed that only locally (<200 m) the mixing zone will reach the seabed.

Recirculation

- If the new Eemshaven NPP intake is located inside the Eemshaven (Case 1, Case 3 and Case 4), the computed temperature at the intake is typically around 1.3 – 1.5 °C and max 1.7 °C above ambient conditions. If the Eemshaven NPP intake is located outside the Eemshaven and close to the existing discharges (Case 2, Case 5 and Case 8), a higher temperature is computed at the intake of around 1.5 °C – 2.4 °C (mean) and maximum exceeding 4 °C above ambient conditions.
- Due to the new Eemshaven NPP, the mean and maximum temperature at the existing intakes of RWE Magnum and RWE Eemshaven is expected to increase by about 0.5 – 1.3 °C compared to the present situation (Baseline 1).

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A Recirculation potential

For all simulations the mean and maximum temperature increases computed at each modelled intake were derived and summarised in the table below.

Table A.1 Simulated excess temperature at each intake.

| Intakes | RWE01 | | RWE02 | | ENGIE | | NPP | |
|------------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|
| | Mean [°C] | Max [°C] | Mean [°C] | Max [°C] | Mean [°C] | Max [°C] | Mean [°C] | Max [°C] |
| Baseline01 | 0.6 | 0.7 | 0.5 | 0.6 | 1.4 | 2.8 | - | - |
| Baseline02 | 0.4 | 0.5 | 0.4 | 0.4 | - | - | - | - |
| Case 1 | 1.5 | 1.8 | 1.2 | 1.5 | - | - | 1.3 | 1.6 |
| Case 2 | 1.2 | 1.4 | 1.0 | 1.2 | - | - | 2.4 | 5.4 |
| Case 3 | 1.4 | 1.7 | 1.2 | 1.5 | - | - | 1.4 | 1.6 |
| Case 4 | 1.4 | 1.6 | 1.4 | 1.5 | - | - | 1.5 | 1.7 |
| Case 5 | 1.3 | 1.5 | 1.1 | 1.3 | - | - | 1.7 | 4.1 |
| Case 6 | 1.1 | 1.1 | 1.0 | 1.1 | - | - | 1.1 | 1.4 |
| Case 7 | 1.1 | 1.1 | 1.0 | 1.1 | - | - | 1.1 | 1.4 |
| Case 8 | 1.3 | 1.5 | 1.1 | 1.3 | - | - | 1.6 | 4.1 |
| Case 9 | 1.0 | 1.2 | - | - | - | - | 1.2 | 2.2 |

B Mean temperature footprints

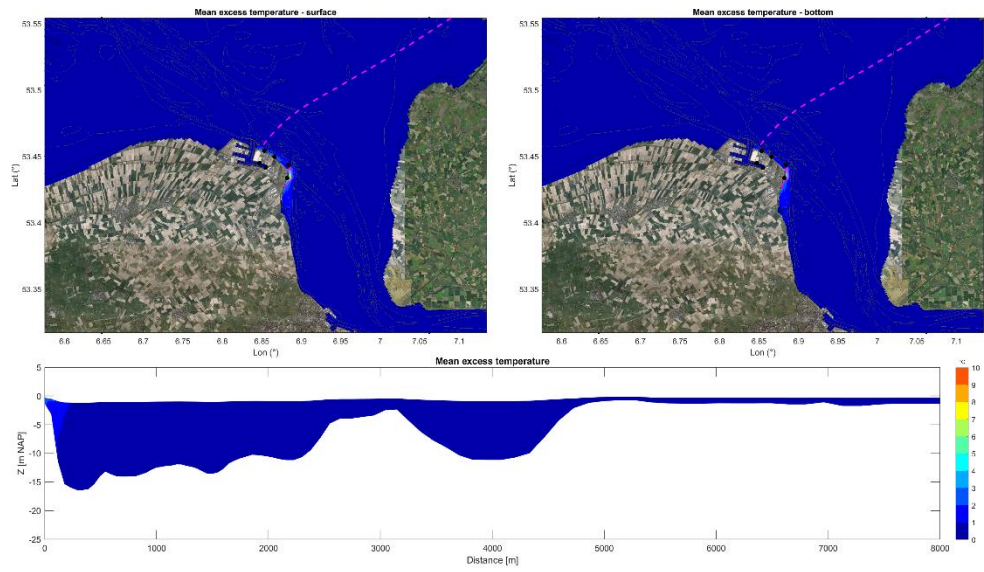


Figure B.1 Simulated mean temperature increase footprint due to the existing thermal discharges (Baseline 1).

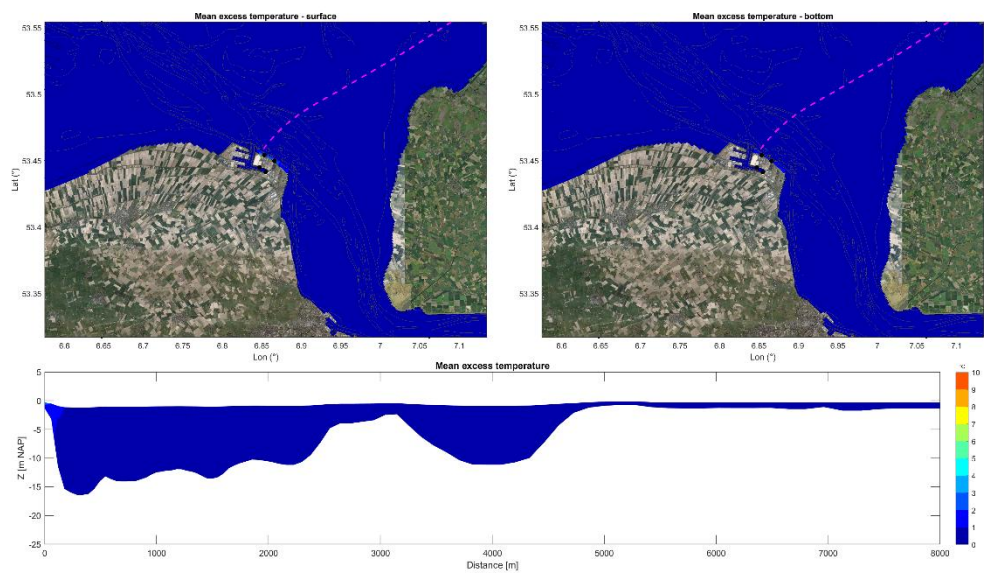


Figure B.2 Simulated mean temperature increase footprint due to the existing thermal discharges (Baseline 2).

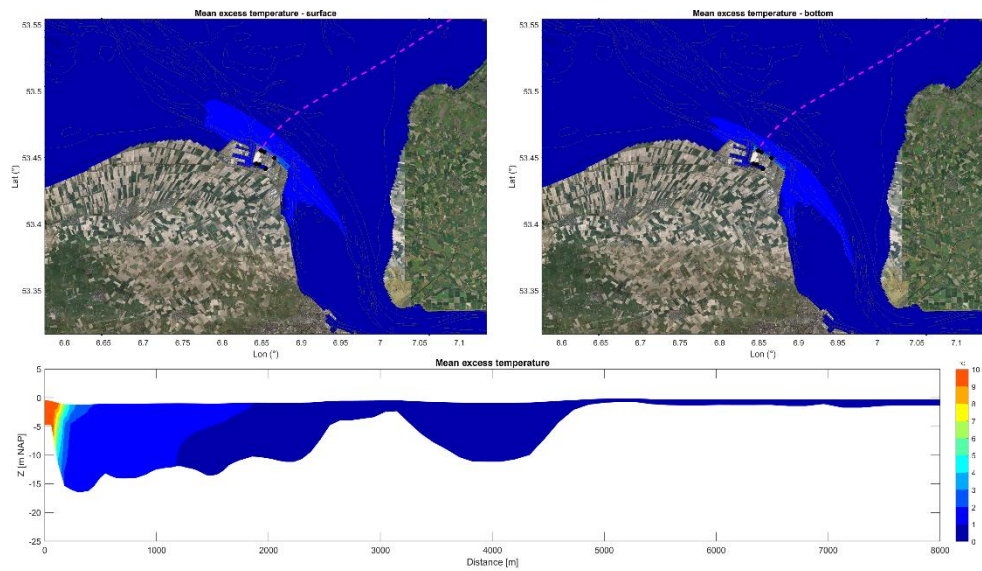


Figure B.3 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 1).

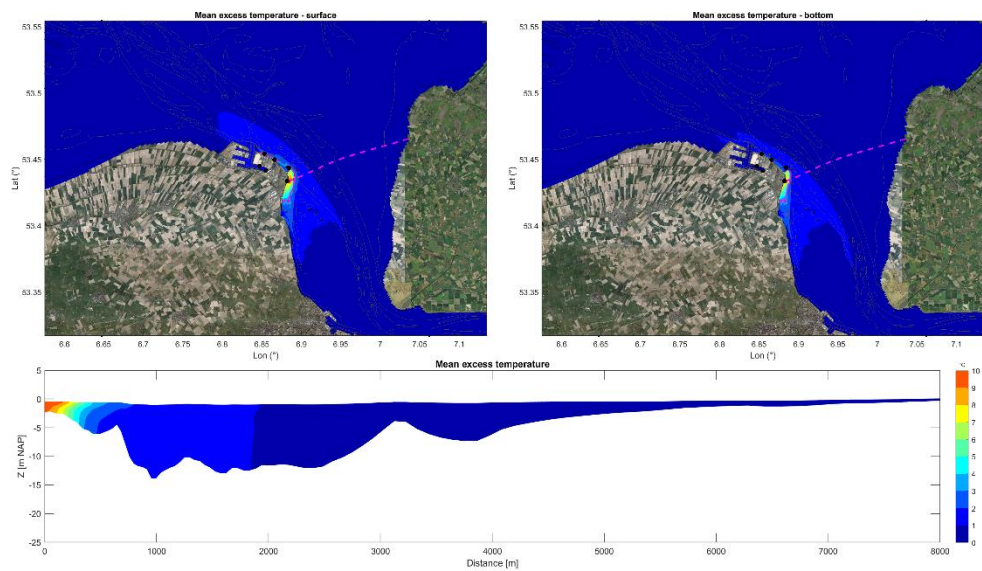


Figure B.4 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 2).

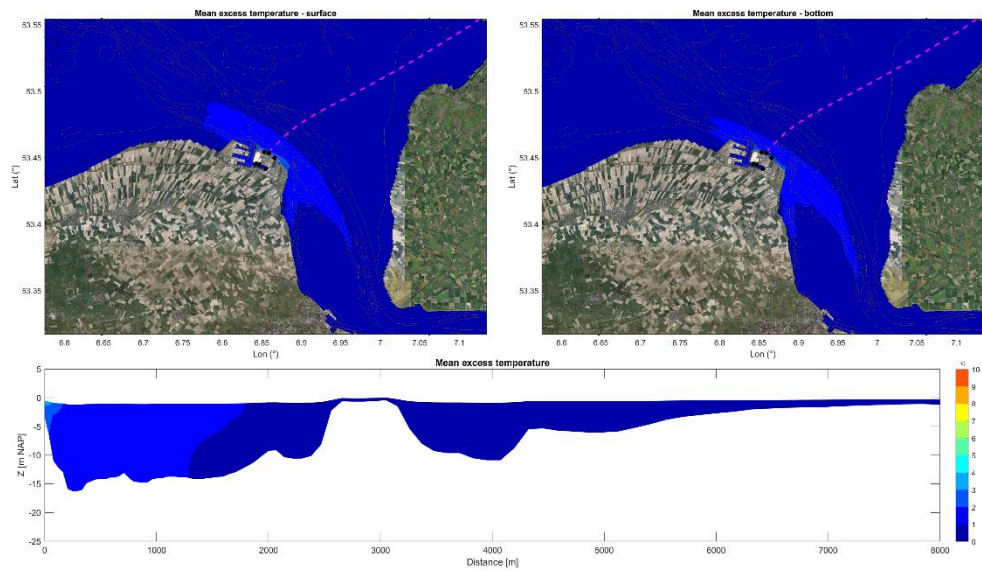


Figure B.5 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 3).

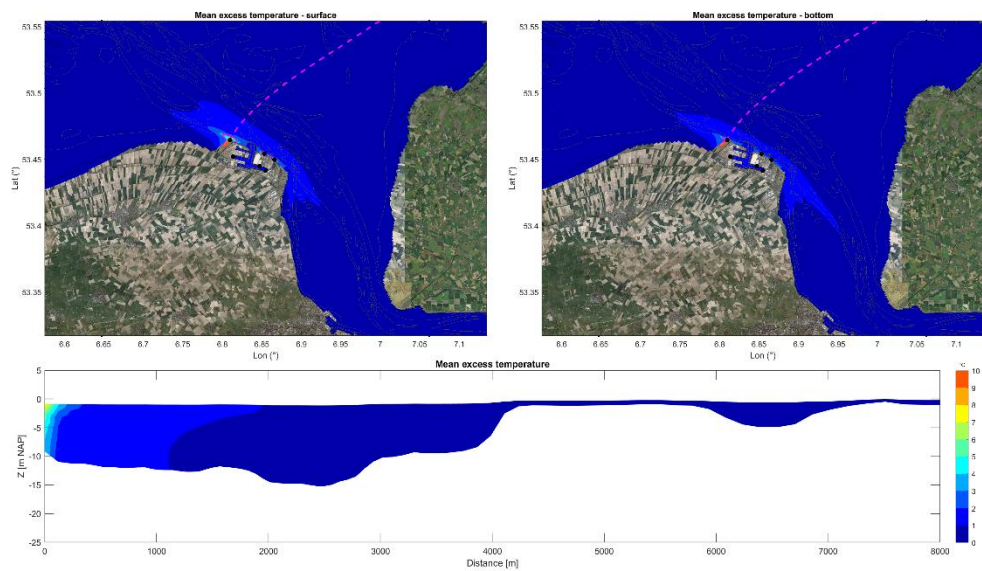


Figure B.6 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 4).

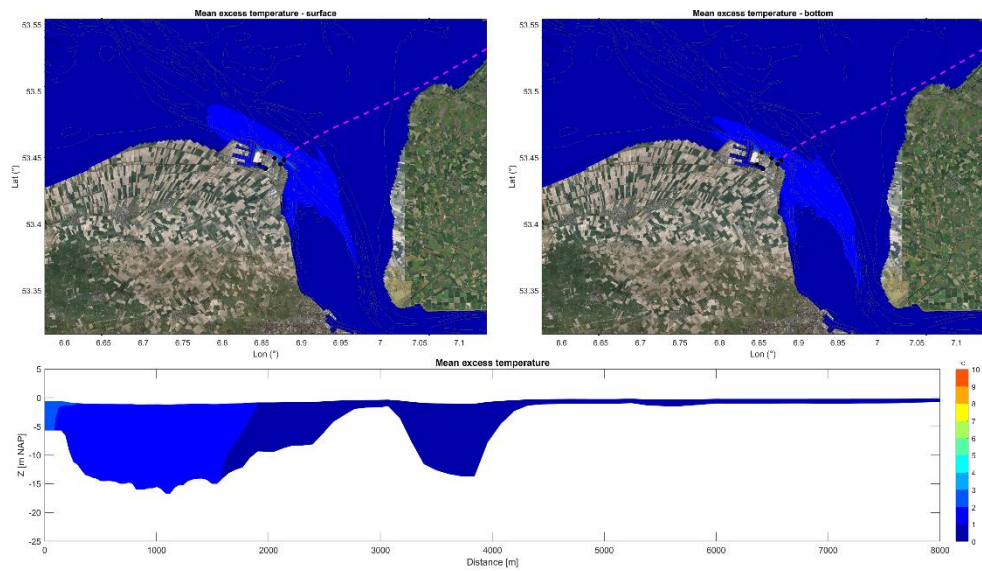


Figure B.7 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 5).

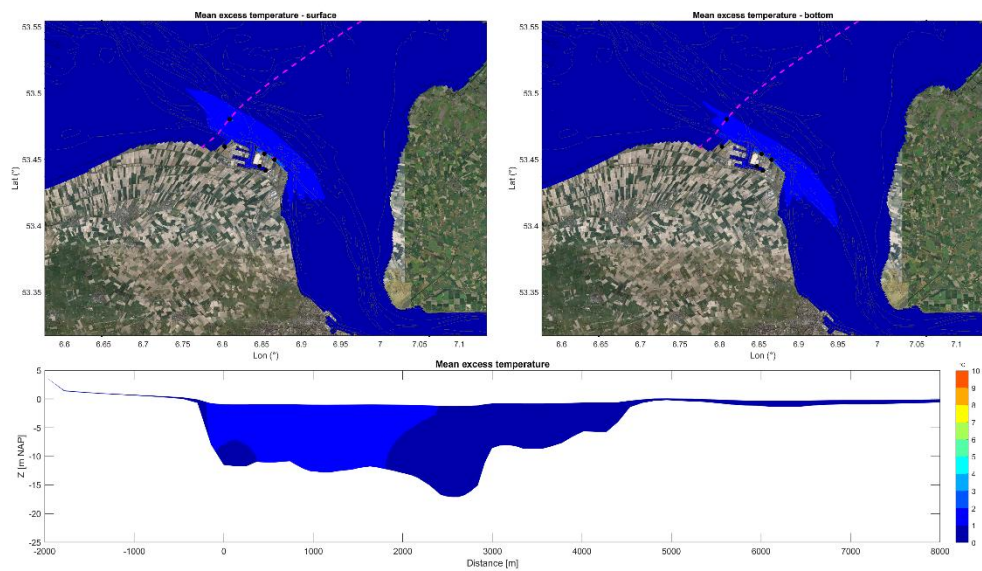


Figure B.8 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 6).

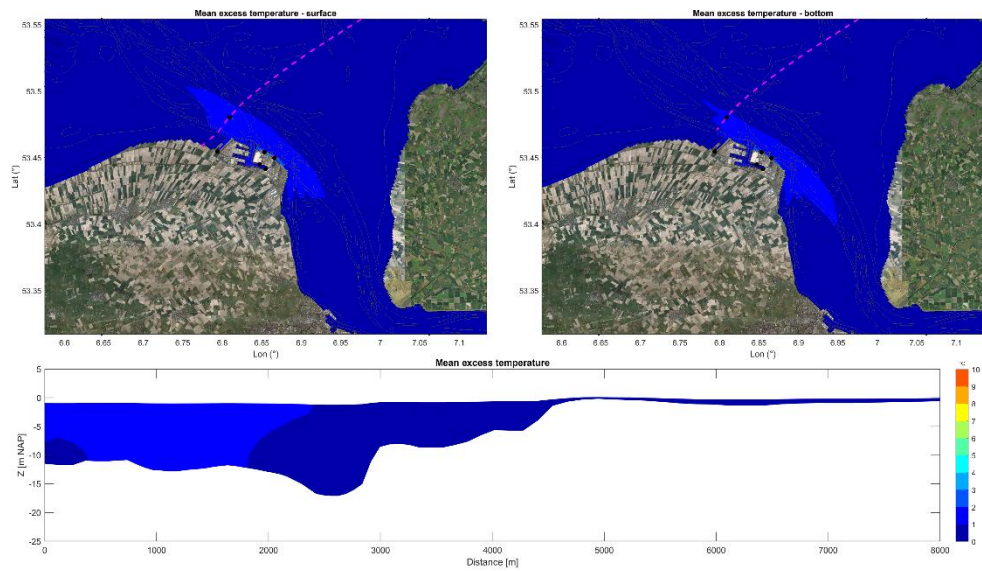


Figure B.9 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 7).

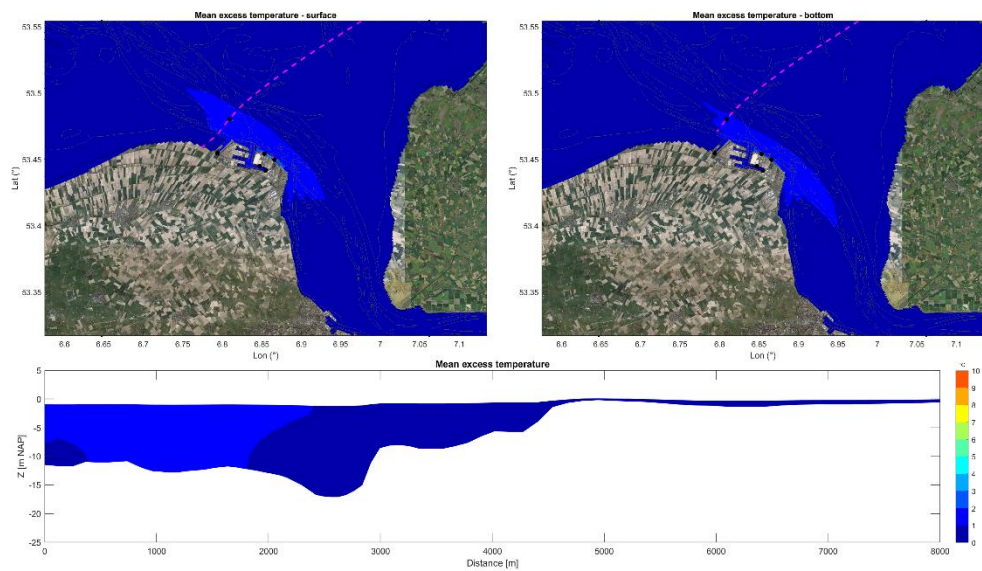


Figure B.10 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 8).

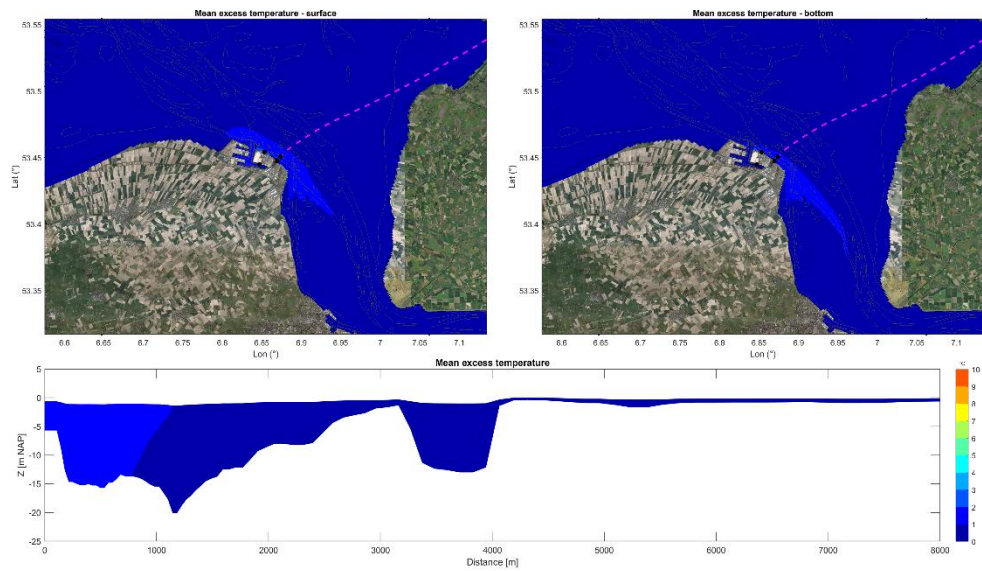


Figure B.11 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 9).

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