Terneuzen site evaluation

Cooling water availability

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Summary

The Dutch government is considering developing additional nuclear power plants in the Netherlands and has selected, amongst others, Terneuzen as possible location for this. Deltares was requested by The Ministry of Economic Affairs (EZK) to perform, amongst others, a detailed modelling study on the availability of cooling water at Terneuzen. This will provide initial technical information to possible vendors (i.e., developers) which need to carry out their own technical studies towards an initial design of such a plant.

The objective of this cooling water study is to assess the cooling water availability/capacity in the Terneuzen area. Specifically, to assess the combined plume dispersion and recirculation of the new Terneuzen cooling water discharge (and other discharges in the area) in relation to the applicable environmental criteria. This will be assessed for different intake and outfall options. This study aims to provide 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.

The available information for the Terneuzen project 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 Terneuzen intake and outfall configuration is presented in the ‘Voorstel regelgevend kader warmtelozingen centrales Borssele en Maasvlakte’, Deltares (2023). Together with EZK, potential Terneuzen intake and outfall designs, discharge characteristics and discharge options were identified and agreed to be simulated.

To assess the plume dispersion and recirculation of discharged cooling water in the Terneuzen area, a detailed far-field model was set up in Delft3D 4. This far-field model simulates the important hydrodynamic processes for the plume dispersion and heat exchange with the atmosphere with sufficient horizontal and vertical resolution. Hydrodynamic boundary conditions were derived from in-house available and validated overall models of the Western Scheldt. For design options that consider a submerged outfall, the near-field behaviour of the submerged outfall thermal plume was assessed by means of the CORMIX expert system. CORMIX computes the hydrodynamic behaviour of the outfall plume close to the outfall including the plume trajectory and dilution under influence of the ambient conditions. The results of the near-field assessment were subsequently coupled to the far-field model with use of Deltares’ C-SUMO (Coupled Subgrid Model) system.

With the coupled Delft3D-FLOW model and near-field results of CORMIX, different simulations were performed for representative scenarios (i.e. different intake and outfall configurations, locations, different thermal discharge capacities, discharge characteristics and ambient conditions). The modelling results were subsequently analysed and presented in relation to the environmental criteria with regard to temperature.

Based on the available information and modelling results, the following main conclusions are drawn:

- For the present first assessment of different Terneuzen cooling water configurations, only the CIW 2004 (temperature) mixing zone and average temperature increase criteria were used:
    - Mixing zone. For the Western Scheldt the mixing zone is defined as the 25 °C temperature contour. The cross-sectional area covered by the mixing zone should be less than 25% of the total cross-sectional area. This criterion should be fulfilled 98% of the time. In tidal harbours the mixing zone is defined as the 30 °C temperature contour. Here the same criterion applies that any cross-sectional area covered by the mixing-zone should be less than 25% of the total cross-sectional area.
    - Average temperature increase. The average temperature of the water body may not increase by more than 2 °C and/or increase above 25 °C.
    - Ambient water temperature. The 98th-percentile ambient temperature at Bath (the edge of the Western Scheldt at the border between the Netherlands and Belgium) is 22.5 °C. With this 98th percentile background temperature the mixing zone definition (relative to background conditions) is the +2.5 °C contour.
- It is noted that compliance with possible other criteria (e.g., on other water parameters) would need to be evaluated in a full environmental impact assessment study in a next phase of the project. For a complete overview of the environmental criteria, see Deltares (2023).
- 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 Terneuzen plant were selected.
- For this study, 5 different intake and outfall configurations were considered. These 5 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 capacity, 3 different combinations of flowrate and temperature increase between the intake and the outfall were assessed: i) a discharge of 205 m^3/s and a temperature increase of +7 °C, ii) a discharge of 159.5 m^3/s and a temperature increase of +9 °C and iii) a discharge of 119.5 m^3/s and a temperature increase of +12 °C.
- A lower thermal discharge capacity of 4000 MW_{th} was also evaluated, with a discharge characterized by Q=106.5 m3/s and temperature increase of +9 °C.
- An overview of the simulated scenarios is presented in the below figure and table.

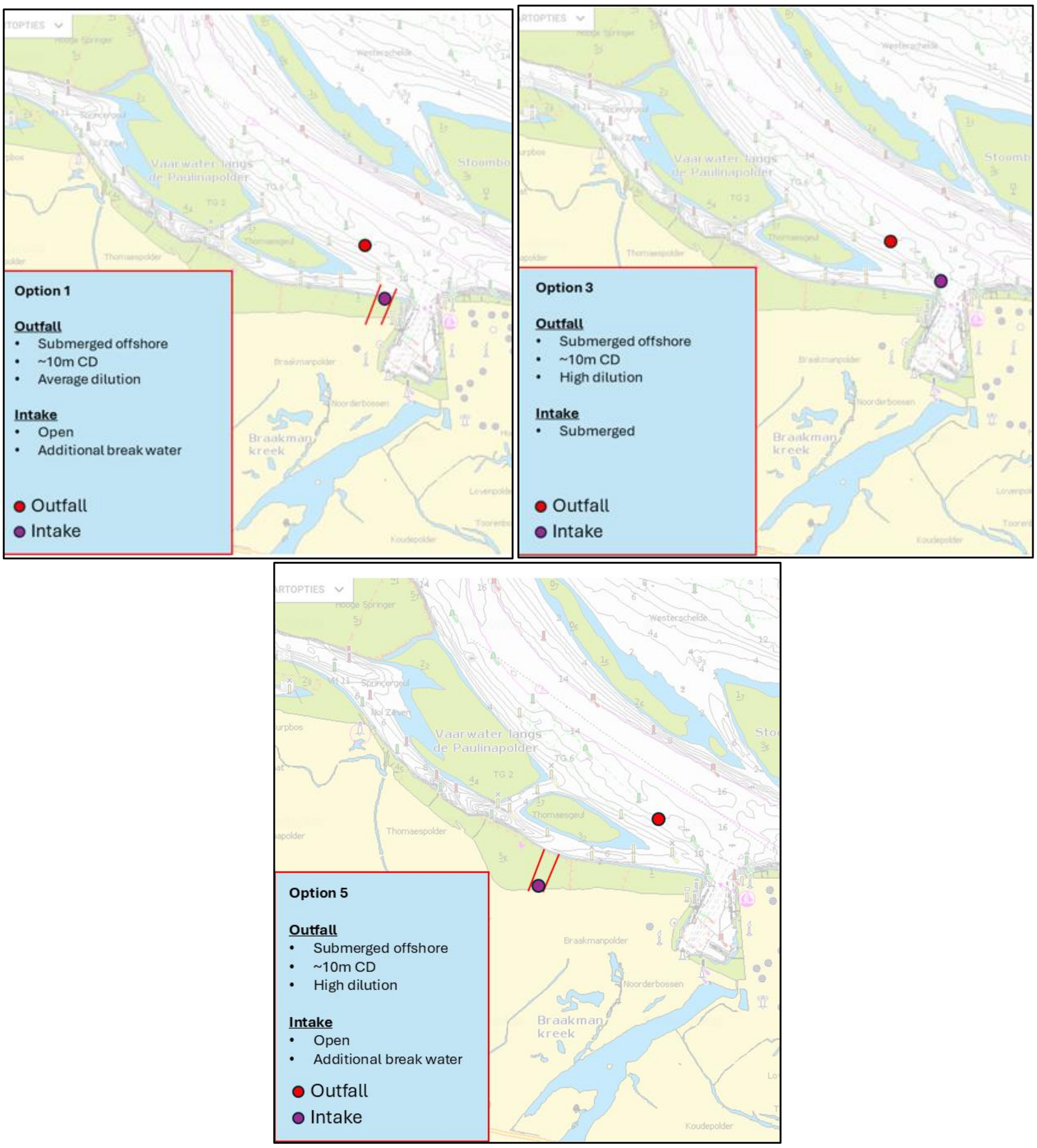

Figure-S 1 Different Terneuzen power plant intake and outfall configurations modelled in this assessment. Only Configurations 1, 3 and 5 are shown, noting that Configurations 2 and 4 are the inverse of Options 1 and 3.

Tabel-S 1 Overview of simulated scenarios

Case	Thermal Capacity (MW_{th})	Discharge rate / Temperature increase	Intake/Outfall Configuration	**Description**
0	-	-	-	Present situation
1	6000	159.5 m^3/s +9 °C	1	Open intake at the shoreline, submerged outfall 1.5 km offshore in the Western Scheldt close to the main navigation channel.
2	6000	159.5 m^3/s +9 °C	2	Submerged intake 1.5 km offshore in the Western Scheldt close to the main navigation channel, open outfall at the shoreline (reverse of configuration 1).
3	6000	159.5 m^3/s +9 °C	3	Submerged intake in the Western Scheldt close to the Braakmanhaven, submerged outfall 1.5 km offshore in the Western Scheldt.
4	6000	159.5 m^3/s +9 °C	4	Submerged intake 1.5 km offshore in the Western Scheldt, submerged outfall in the Western Scheldt close to the Braakmanhaven (reverse of configuration 3).
5	6000	205.0 m^3/s +7 °C	1	Case 1, but higher discharge rate, lower excess temperature (with respect to case 1).
6	6000	119.5 m^3/s +12 °C	1	Case 1, but lower discharge rate, higher excess temperature (with respect to case 1).
7	4000	106.5 m^3/s +9 °C	1	Case 1, but lower thermal discharge capacity.
8	6000	159.5 m^3/s +9 °C	1	Case 1, but optimised outfall design (i.e. increased near-field mixing)
9	6000	159.5 m^3/s +9 °C	5	Case 1 / Configuration 1, but intake located 2 km to the West.

- 4 existing thermal discharges were included in this assessment to assess the cumulative plume dispersion and recirculation in the Terneuzen area. These 4 discharges include the N.V. Elektriciteits Productiemaat-schappij Zuid-Nederland (EPZ), Sloe Centrale BV, Zalco BV and Dow Benelux BV.

Plume behaviour

- Due to the buoyancy of the warmer cooling water, the thermal plume is expected to rise to the surface and spread in NW and SE direction by the tidal flow.
- Submerged outfalls (as opposed to open outfalls) rapidly mix the cooling water with ambient water, effectively reducing the temperature increase around the outfall.
- For submerged outfalls, the computed maximum extent of the mixing zone (+2.5 °C contour) *near the surface* is about 3 km in the NW direction and between 5-6 km in the SE direction, whereas *near the bottom* the computed mixing zone reaches a maximum distance of less than 1 km from the outfall location.
- The submerged diffusers modelled in Cases 1, 3, 6 and 9 return similar maximum mixing zone extents at the surface and bottom layers of the water body. Diffusers modelled in Cases 4, 5, 7, and 8 return a different plume extent: Case 4 shows that the diffuser's proximity to the port of Terneuzen results in a computed mixing zone that extends into the port; and Case 5 (reduced discharge temperature), Case 7 (lower operation capacity – 4000 MWth) and Case 8 (optimized near-field mixing) shows a smaller computed mixing zone extent, especially *near the bottom* in the order of ~500 m in either flow direction.
- The modelled open outfall (Case 2), results in a computed plume extent *near the surface* of about 7 km in both NW and SE directions, whereas *near the bottom* the computed mixing zone reaches a maximum distance of 7 km in the NW direction and 2 km in the SE direction. In both surface and bottom layers, the computed mixing zone extends into the

Terneuzen port (Braakmanhaven). The larger extent of the thermal plume modelled in this scenario – with respect to the submerged diffusers – is due to the lower dilution in the near-field close to the outfall.

Environmental criteria

- Two different sets of cross-sections were used to assess the compliance with the CIW criteria: one that covers the entire width of the Western Scheldt, and a second set that covers only the main channel where the effluent is discharged (i.e. the southern part of the Western Scheldt). This distinction is made due to uncertainty in the interpretation of the CIW criteria with respect to the cross-sectional area and presence of tidal flats in the middle of the Western Scheldt.
- When evaluating environmental compliance *with the full cross-sectional area of the Western Scheldt*, the maximum computed cross-sectional area covered by the mixing zone is around or below 10% for all cases except for Case 4, where the maximum covered cross-sectional area is about 20%. These values are all lower than the critical threshold value of the CIW criteria (i.e., 25%). Moreover, the computed cross-sectional average temperature increase in the water body is typically about 1 °C and remains below the 2 °C limit value.
- The following conclusions hold when evaluating the environmental compliance *with the cross-sectional area of the main channel:*
  - The maximum computed cross-sectional area covered by the mixing zone in Cases 1, 3, 5, 6, 8 and 9 is around 25% - the CIW threshold value. Cases 2, 4, and 7 return a different computed covered percentage, namely:
    - Case 2 (open outfall): maximum cross-sectional cover below 20%. Although the open outfall results in higher temperatures near the discharge point, it affects a smaller cross-sectional area compared to the submerged diffuser options, making it more favorable with respect to this CIW criterion.
    - Case 4 (outfall in the main channel close to the Terneuzen port / Braakmanhaven): maximum cross-sectional cover of 35%.
    - Case 7 (reduced thermal load): maximum cross-sectional cover of 15%.
  - Case 5 (reduced discharge temperature) and Case 8 (increased initial mixing) reduce the percentage of the cross-sectional area covered by the mixing zone compared to Case 1. While computed values of Case 5 and 8 are still above the critical value of 25%, combinations of these design alternatives can be used to further reduce the mixing zone of the cooling water discharge.
  - The computed cross-sectional average temperature increase in the water body is typically between 1 °C and 1.8 °C for all cases, except for Case 4 where the criterion of 2 °C is temporarily reached.

Recirculation potential

- Different intake locations were evaluated per modelled case. Cases 1, 5, 6, 7 and 8 evaluate the same intake location (open intake). Cases 2 and 4 assess the same submerged intake location. Case 3 has a submerged intake near the port entrance. In Case 9 the intake is situated more to the West compared to, for instance, Case 1.
- Regardless of the proposed location of the Terneuzen intake, the computed *average* temperature increase at the intake is about 1° C in all cases, while the computed *maximum* is about 1.5 °C – except for Case 2 and Case 4 for which a maximum temperature increase of 1.8 °C and 2.1 °C is computed, respectively.
- The computed additional average temperature increase at the existing intakes located in the Borssele area (EPZ, Sloe centrale and Zalco) is about 0.5 °C or less due to the Terneuzen nuclear power plant. At the existing intake located in the Braakmanhaven (Dow Benelux), the computed additional *average* temperature increase ranges from 0.7

°C to 2.2 °C (from 0.2 °C in Case 0 to 0.9 – 2.4 °C above background conditions), while the *maximum* computed temperature increase ranges from 0.9 °C to 3.1 °C (from 0.3 °C in Case 0 to 1.2 – 3.4 °C above background conditions).

Contents

1 Introduction

1.1 Project background

The Dutch government is considering developing two nuclear power plants in the Netherlands and has selected, amongst others, Terneuzen as a potential location for this. For the government to make a decision to proceed with this development, possible vendors (i.e., developers) 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.

Deltares received a request from EZK to perform two studies: (1) A site survey in preparation for a nuclear power station at Terneuzen according to IAEA's Site Evaluation for Nuclear Installations guidelines at a high level of detail. (2) A detailed modelling study on the availability of cooling water at Terneuzen. This feasibility study will form input to the vendor’s information package and considers different scenarios and possible options for the intake and outfall of the cooling water system (but no specific design). This includes the main aspects that are relevant to the limitation of cooling water.

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 caried 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 Terneuzen 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 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, based on the model developed for the previous Borssele cooling water study (Deltares, 2024), and nested in the in-house available models of the Western Scheldt. 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 plant capacities, discharge characteristics, and 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

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 Terneuzen 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.

The Terneuzen site is situated in the Western Scheldt, across the Borssele site (see Deltares, 2024). For the present study, the Borssele study was used as a basis for the modelling. This chapter is largely adopted from the Borssele study, but included in this report for reference.

2.1 Bathymetry

The latest bathymetry data for the Western Scheldt was obtained from the RWS Baseline database software. The selected bathymetry data covers part of the North Sea and the complete Western Scheldt and has sufficient extent to be directly used for the full domain of the numerical models. The data represents the bathymetric conditions around 2019 with a resolution of about 14x14 to 20x20 m. 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. For presentation purposes the data is presented in the WGS 84 (latitude/longitude) coordinate system.

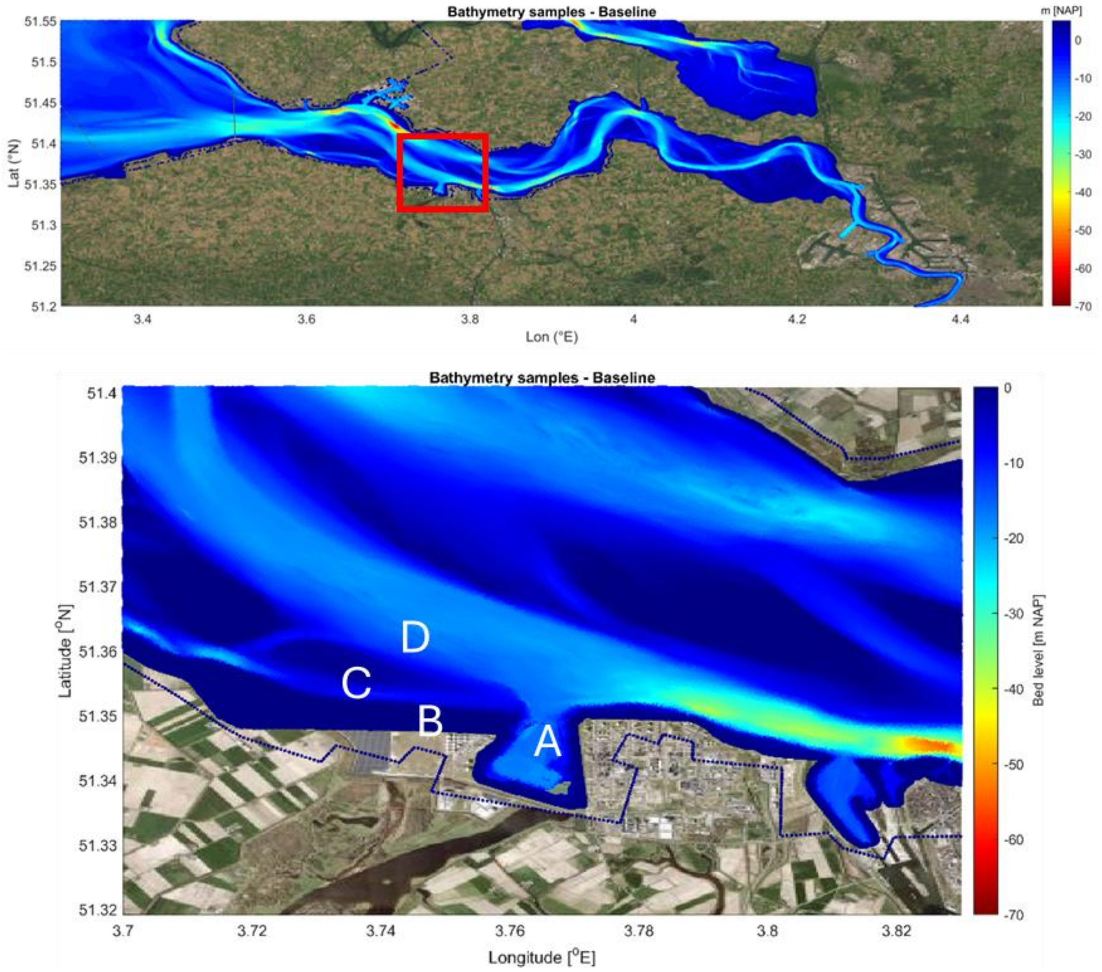

Figure 2-1 The bathymetry data of the Western Scheldt (top) and near the project site (bottom).

This dataset shows that the Western Scheldt consists of multiple tidal flats and gullies with depths up to -65 m NAP. In the Terneuzen harbour area (Area A in Figure 2-1) depths are typically up to -15 m NAP. In front of the proposed Terneuzen power plant site, the foreshore (Area B in Figure 2-1) is shallow (tidal flats) for about 400-500 m, followed by a rather narrow channel of about 5 m depth (Area C in Figure 2-1). Further offshore a shallow area is present (east of the Thomaesgeul), followed further offshore (about 1.5 km from shore) by a wider (more than 1 km) navigation channel with depths between 10 m and 15 m (Area D in Figure 2-1). The total width at this part of the Western Scheldt is about 5 km to 7 km.

2.2 Environmental criteria

The new nuclear power plant intake and outfall configuration and cooling water discharge needs to comply with environmental temperature criteria in place. For Terneuzen the same environmental criteria are considered as for the Borssele site. A full overview of the environmental criteria for the intake and outfall configuration in the project area is therefore presented in the *'Voorstel regelgevend kader warmtelozingen centrales Borssele en Maasvlakte',* Deltares (2023). 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. In summary, these criteria state:

- **Mixing zone**. For the Western Scheldt the mixing zone is defined as the 25 °C temperature contour. The cross-sectional area covered by the mixing zone should be less than 25% of the total cross-sectional area. This criterion should be fulfilled 98% of the time. In tidal harbours the mixing zone is defined as the 30 °C temperature contour. Here the same criterion applies that any cross-sectional area covered by the mixing-zone should be less than 25% of the total cross-sectional area.
- **Average temperature increase**. The average temperature of the water body may not increase by more than 2 °C and/or increase above 25 °C.

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 system 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 for this preliminary cooling water study.

Recirculation criteria
No recirculation criteria are available for het 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 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 2-2 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

Location	98th-percentile temperature (°C)
Bath	22.5
Baalhoek	22.3
Hansweert boei OHMG	21.8
Vlakte van de Raan	20.7

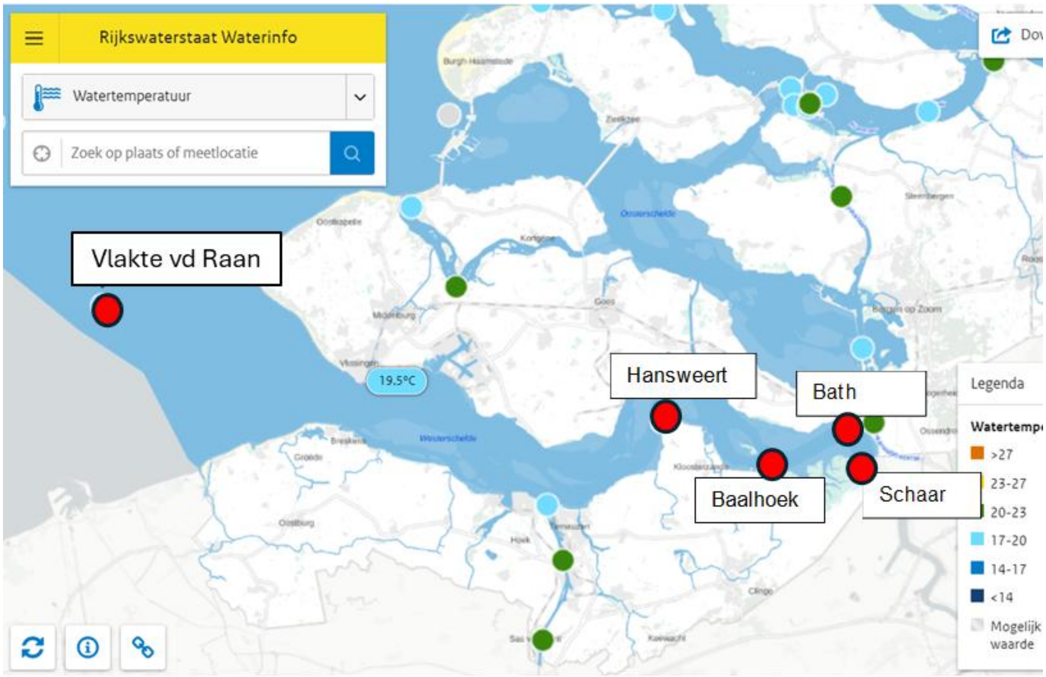

Figure 2-2 Locations of the ambient water temperature measurements (www.waterinfo.rws.nl)

The edge of the water body is defined by the CIW criteria as the edge of the Western Scheldt at the border between the Netherlands and Belgium near Bath and Schaar. After review of the data of the two stations, data from Schaar was omitted due to the low temporal resolution, discontinuous measurements and bias from day-time observations. The 98th-percentile ambient temperature at Bath is 22.5 °C. Reference is made to Deltares (2023) for a more detailed assessment of these water temperatures. The 98th-percentile ambient temperature at the project site itself is between approximately 20.7 °C (Vlakte van de Raan) and 21.8 °C (Hansweert boei). No substantial differences in temperature over the water depth are expected due to the high tidal flow velocities in the Western Scheldt.

2.4 Ambient hydrodynamic conditions

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 Vroom et al. (2015) were analysed in Deltares (2024) for the Borssele site investigation and used for the present study as well, due to its vicinity. Figure 2-3 present the river flows of the contributories of the Western Scheldt for 2013. The black line indicates the sum of all riverine flows. Low river flows occurred around end September/ beginning of October with flows around 20 to 40 m^3/s, while peak flows in 2013 were around 550 m^3/s. Furthermore, Figure 2-4 presents the total flow past the Borssele project site (blue line). The total flow includes the local tidally-driven flows. For reference, the red line in Figure 2-4 shows the total river flows of Figure 2-3. These figures show that the tidal flow at the project is typically an order 100-1000 larger than the river flows. This means that the contribution of the river flows to the total flow regime in the plant’s vicinity is insignificant.

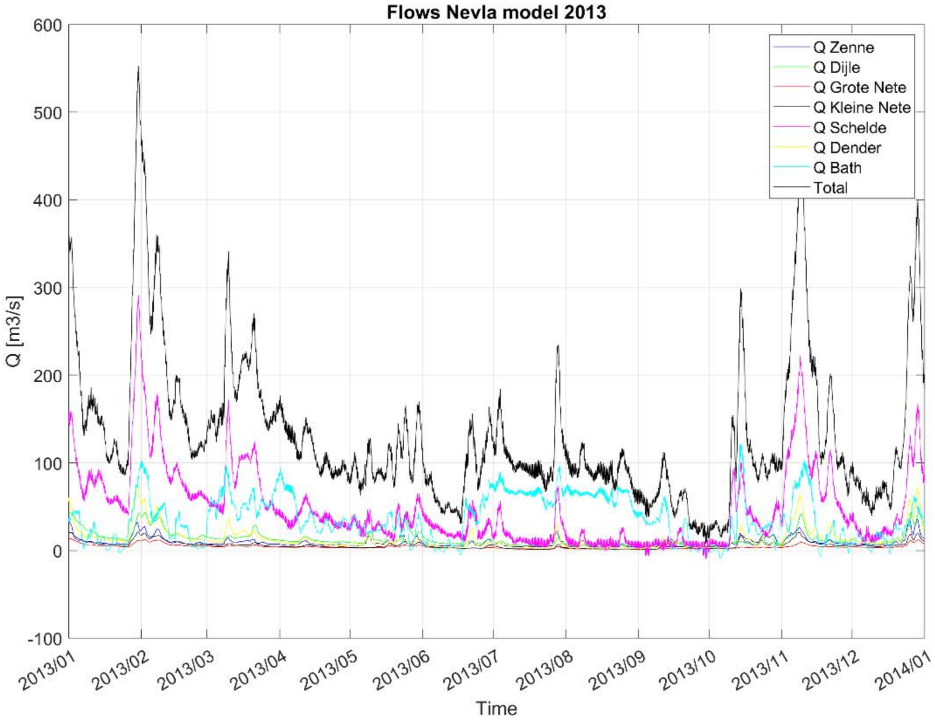

Figure 2-3 River flow conditions at the Western Scheldt for 2013.

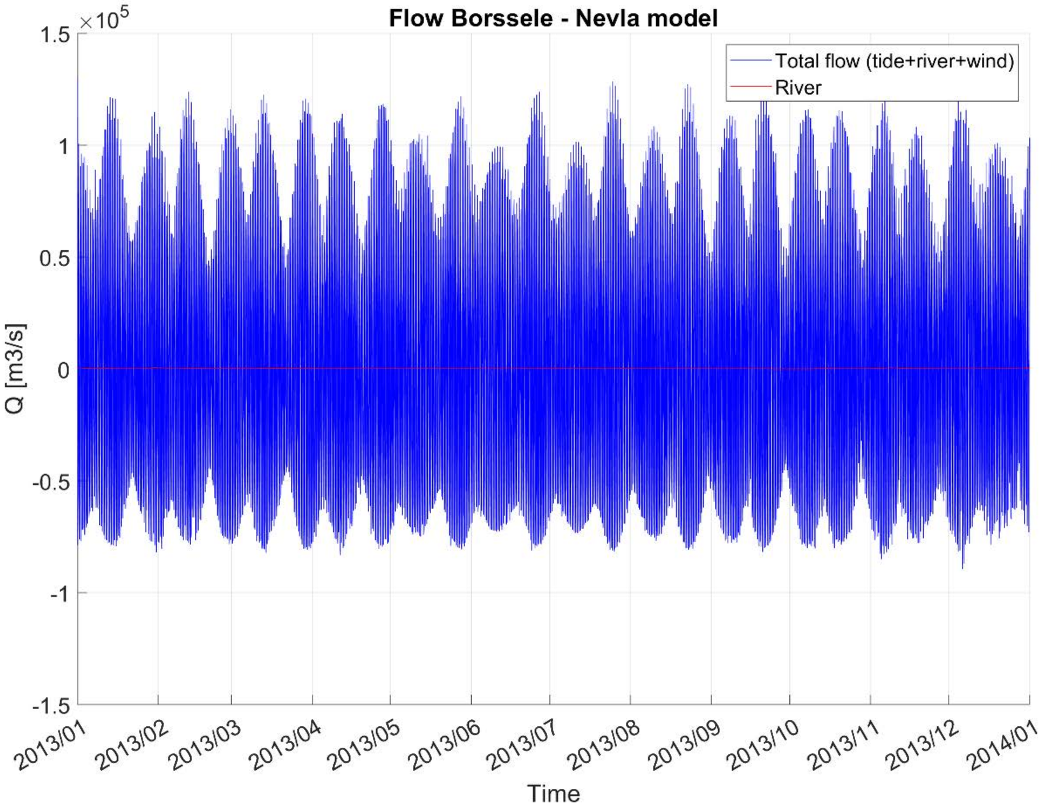

Figure 2-4 Simulated total flow past the Borssele project site for 2013. Red line shows the river flow part of the total flow.

2.5 Present outfalls in the Terneuzen area

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. Table 2-2 presents an overview of the existing discharge locations and characteristics. Figure 2-5 shows the locations of the intake and outfalls.

Table 2-2 Existing discharges in the Borssele 2 project area.

Name company	**Coordinates**		**Once-trough cooling**	
Existing	Cooling water intake	Cooling water outfall	Max. flow	Max. heat-load dT
N.V. Elektriciteits Productiemaatschappij Zuid-Nederland (EPZ)	X 38947 ^{*1} Y 383298 ^{*1}	X 38530 ^{*2} Y 383820 ^{*2}	23.2 m^3/s	980 MW_{th} +10.1 °C
Sloe Centrale BV	X 37756 ^{*1} Y 386179 ^{*1}	X 36247 ^{*2} Y 385974 ^{*2}	19 m^3/s	480 MW_{th} +6.0 °C
Zalco B.V	X 37704 ^{*1} Y 386518 ^{*1}	X 37766 ^{*1} Y 386502 ^{*1}	0.08 m^3/s (300 m^3/hr)	12,5 MW_{th} +36.0 °C
Dow Benelux B.V.	X 42287 ^{*1} Y 374083 ^{*1} and X 42287 ^{*1} Y 374083 ^{*1}	X 43013 ^{*1} Y 374702 ^{*1}	14.9 m^3/s (53600 m^3/hr)	698 MW_{th} +11.2 °C

Figure 2-5 Overview existing intakes and outfalls in the project area.

2.6 Terneuzen nuclear power plant cooling water discharge

The purpose of this cooling water study is to evaluate different intake and outfall options and discharge characteristics for the proposed nuclear power plant in Terneuzen 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.

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. Since it is unknown at this point at which temperature increase the cooling water will be discharged, 3 different combinations of discharge flow and temperature increase between the intake and the outfall are considered:

- Discharge option 1: A discharge of 205 m^3/s and a temperature increase of +7 °C.
- Discharge option 2: A discharge of 159.5 m^3/s and a temperature increase of +9 °C.
- Discharge option 3: A discharge of 119.5 m^3/s and a temperature increase of +12 °C.

Next to the assessment of a thermal discharge of 6000 MW_{th}, also a thermal discharge of 4000 MW_{th} is assessed, which is the lower end of the expected range and is associated with a possible different type of reactor.

2.6.2 Intake and outfall options

For the new cooling water system, 5 intake and outfall configurations were assessed (as agreed with EZK), see Figure 2-6. 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 at coastline and submerged outfall (diffuser) in the main channel about 1.5 km offshore.
- **Configuration 2 (inverse of Configuration 1) -** Open outfall at the coastline and submerged intake close to the main navigational channel about 1.5 km offshore at a depth of ~10 m.
- **Configuration 3 -** Submerged intake in the main channel and submerged outfall (diffuser) in the main channel.
- **Configuration 4 (inverse of Configuration 3) -** Submerged intake in the main channel and submerged outfall (diffuser) in the main channel.
- **Configuration 5 -** Submerged outfall (diffuser) in the main channel about 1.5 km offshore (same location as Configuration 1). Open intake at the coastline, but 2 km west of Configuration 1.

Next to the intake and outfall configurations, different sensitivity tests were performed to assess the effect of design parameters of the nuclear power plant on the compliance of the intake and outfall system with environmental regulations and potential recirculation of cooling water. These sensitivity tests include:

- Discharge characteristics: the total flow of the intake and outfall and the temperature increase over the condenser. Sensitivity tests were performed for a temperature increase over the condenser of +7 °C, +9 °C and +12 °C.
- A reduction of the total thermal load, i.e. 4000 MWth instead of 6000 MWth. For this the total flow was reduced.
- Optimization of the initial mixing of the submerged outfall diffuser (port diameter modified to increase initial dilution).

To summarize, a total of 8 different simulations were performed. An overview of these simulations is presented in the table below.

Table 2-3 Overview of simulation cases carried out in this study

Case	Intake/Outfall Configuration	Thermal Capacity (MW_{th})	Discharge rate / Temperature increase	Description
0	-	-	-	Present situation
1	1	6000	159.5 m^3/s +9 °C	Different I/O configurations
2	2	6000	159.5 m^3/s +9 °C	
3	3	6000	159.5 m^3/s +9 °C	
4	4	6000	159.5 m^3/s +9 °C	
5	1	6000	205.0 m^3/s +7 °C	Different discharge characteristics
6	1	6000	119.5 m^3/s +12 °C	
7	1	4000	106.5 m^3/s +9 °C	Different thermal discharge capacity
8	1	6000	159.5 m^3/s +9 °C	Outfall optimisation
9	5	6000	159.5 m^3/s +9 °C	Different intake configuration

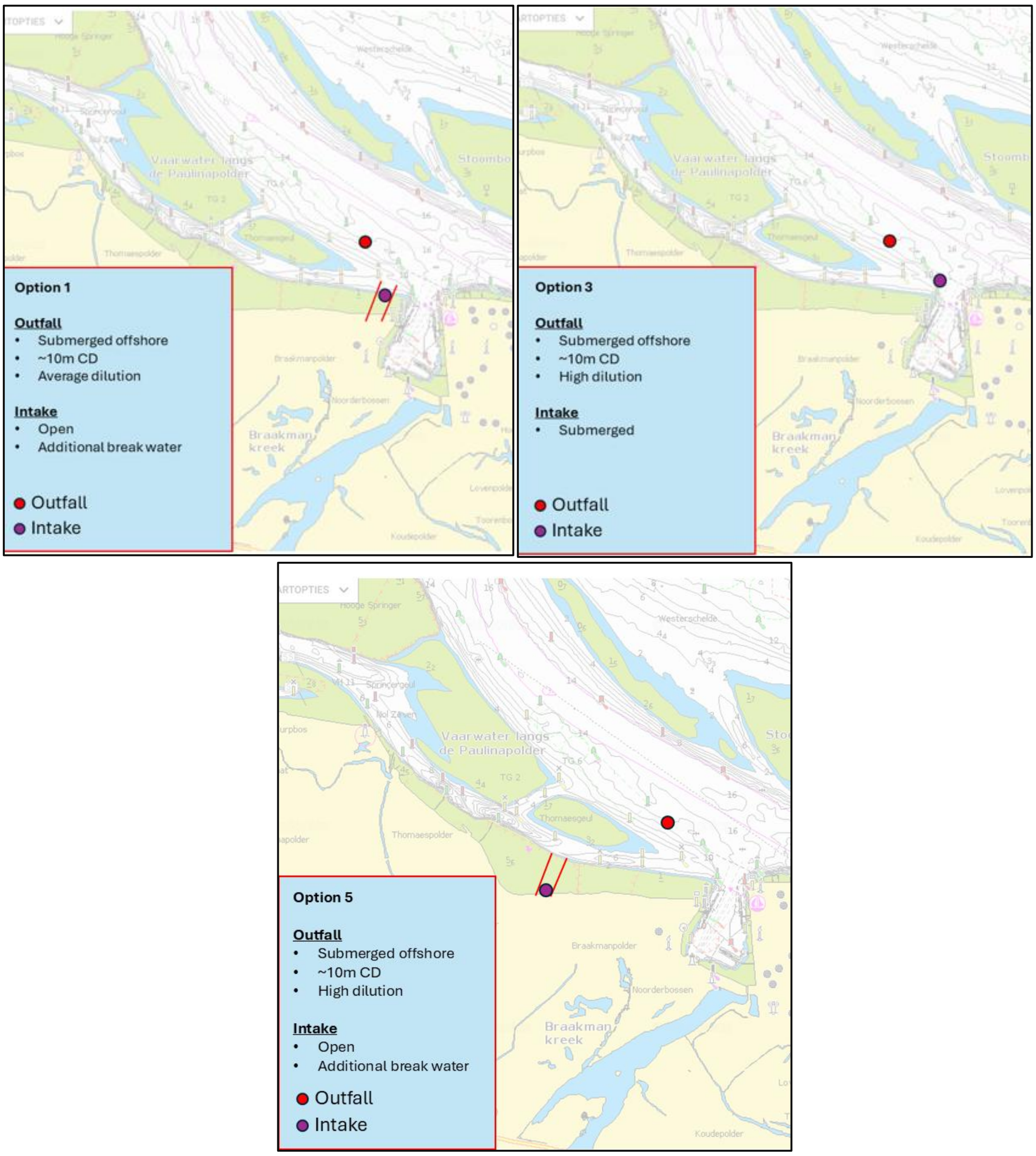

Figure 2-6 Different Terneuzen power plant intake and outfall configurations modelled in this assessment. Only Configurations 1, 3 and 5 are shown, noting that Configurations 2 and 4 are the inverse of Options 1 and 3.

When compiling these indicative configurations, not all factors that could influence the eventual feasibility of these configurations were taken into account. In this first phase of the project, the obvious aspects have been considered, but the developers, in consultation with the authorities, will have to look in more detail at the feasibility of the configurations considered by the developer. This applies to the heat aspect, but also other aspects such as operational, ecological and safety aspects.

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.

3 Setup of the detailed Delft3D 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 available validated overall models of the Western Scheldt. Simulations were performed with version 6.04.00.140726 of the Delft3D-FLOW software. This chapter presents the setup of the Delft3D 4 model and is largely adopted from Deltares (2024) since the detailed model developed in that study could be used as an efficient basis for the present study.

3.1 Overall model

The existing and validated in-house available Delft3D-NeVla model (Vroom et al. (2015)) was used as an overall model to derive hydrodynamic boundary conditions for the detailed model that was setup for this study (see section below). This model covers part of the North Sea, the Western Scheldt and upstream river sections to Gent and Mechelen, see Figure 3-1. This two-dimensional depth-averaged model was set up for the year 2013 and calibrated in detail for water level variation and currents, see Figure 3-2 and Figure 3-3. 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).

For the present assessment, the model bathymetry of the Delft3D-NeVla model was updated with the new bathymetry data, see Section 2.1.

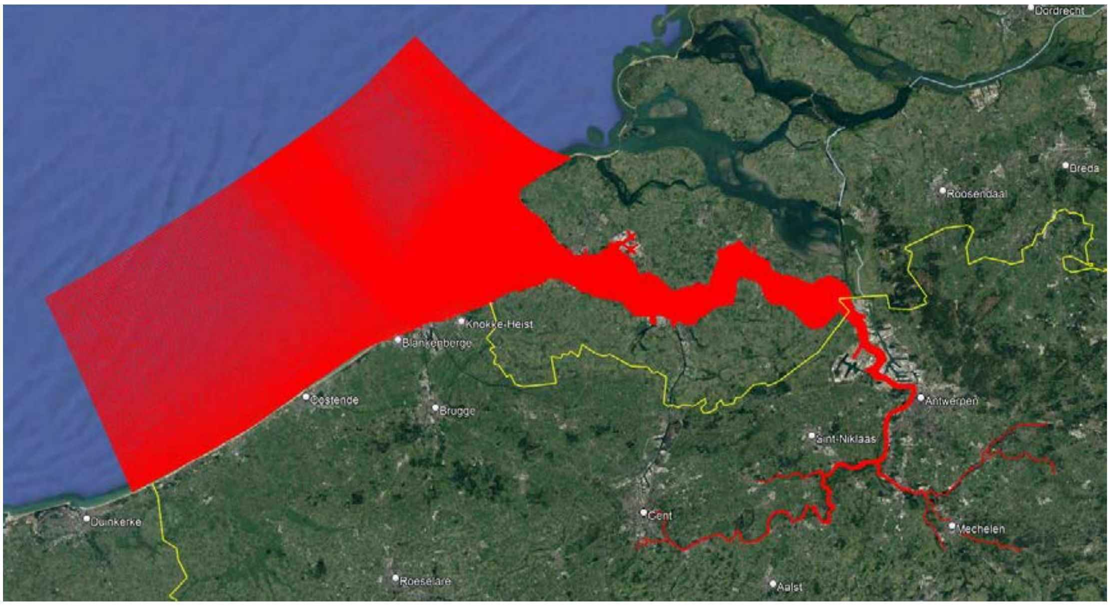

Figure 3-1 Model domain of the overall Delft3D-NeVla model.

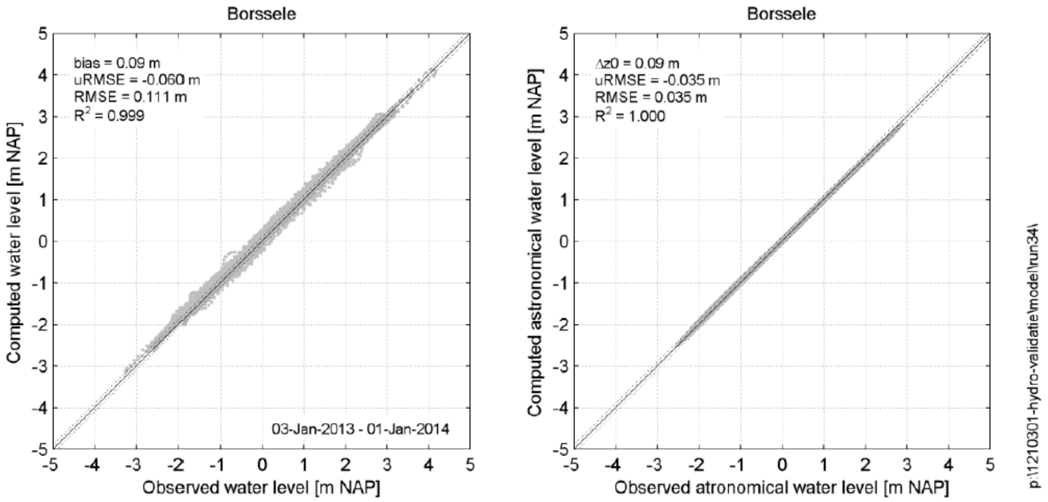

Figure 3-2 Water level validation of the Delft3D-NeVla overall model for the Borssele project site.

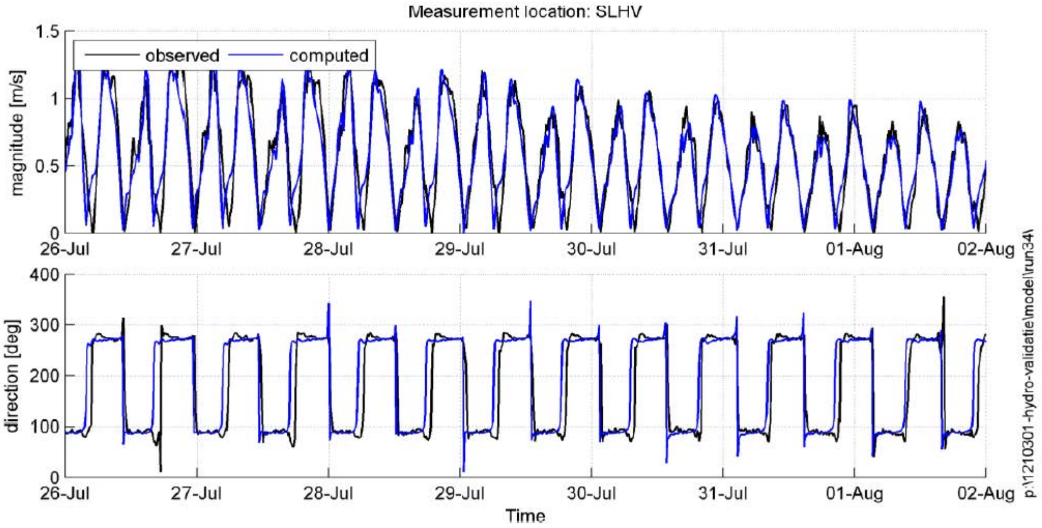

Figure 3-3 Current validation of the Delft3D-NeVla overall model for the project site.

3.2 Computational grid detailed model

A new detailed computational grid was set up for the project area. The grid covers an area of about 40 km in alongshore direction focussed on the Sloe area, see Figure 3-4. The model extent was based on the maximum expected distance the discharged cooling water could reach within a tidal cycle. 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 harbour the model grid has a resolution of about 20 m by 20 m to 40 m by 40 m. Towards the model boundaries the grid resolution increases to more than 100 m by 100 m. In total the grid consists of 291 x 455 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 20 vertical layers which are non-uniformly distributed. At the surface the layer thickness is equal to 2.5% of the water depth, while near the bottom the layer thickness increased to about 10%. This 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.

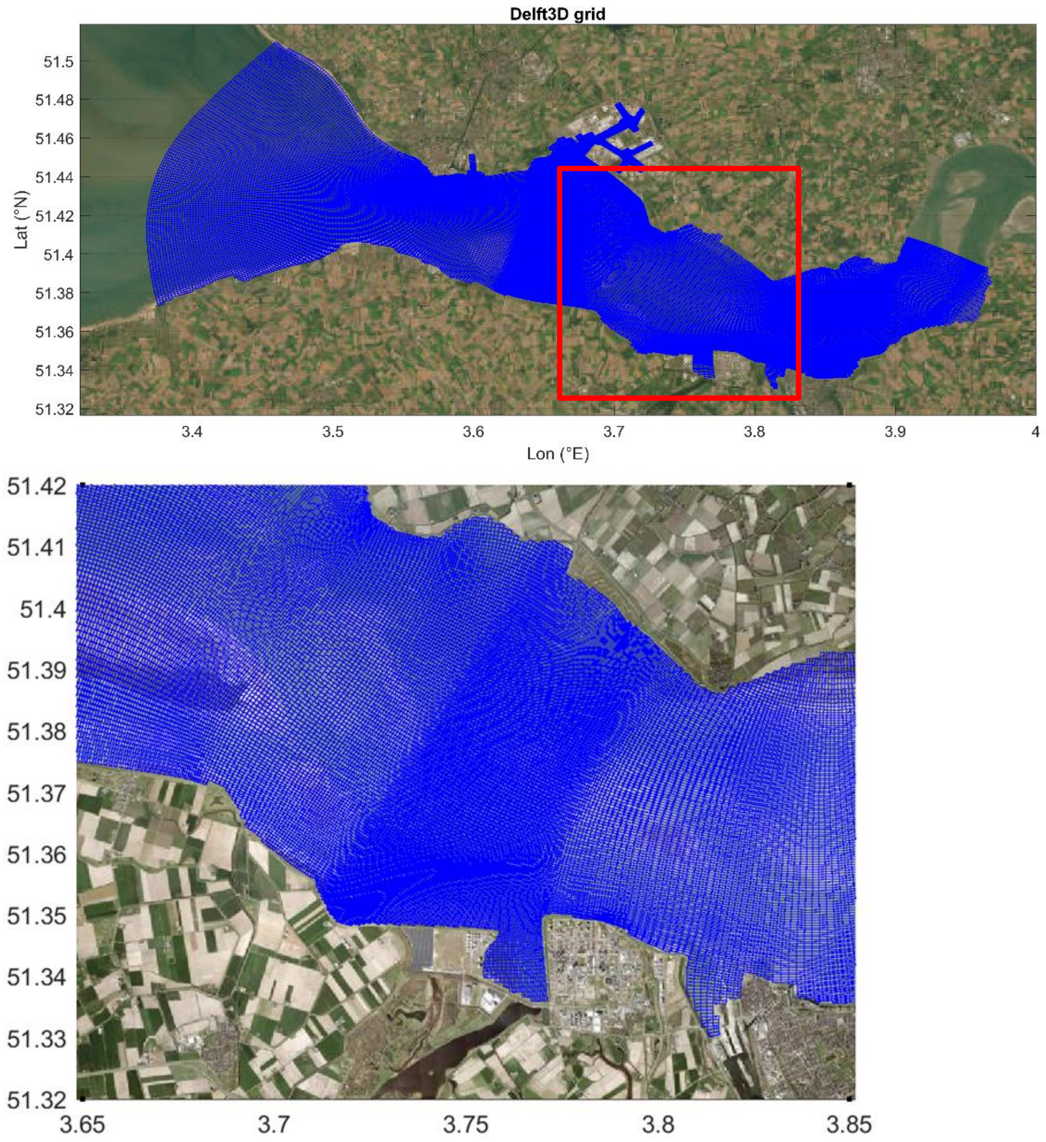

Figure 3-4 Computational grid of the detailed Delft3D model.

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 with reference 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.

Furthermore, the latest satellite images were analysed to obtain the latest status of breakwaters, jetties and/or other morphological features that could affect the hydrodynamics and plume dispersion in the area.

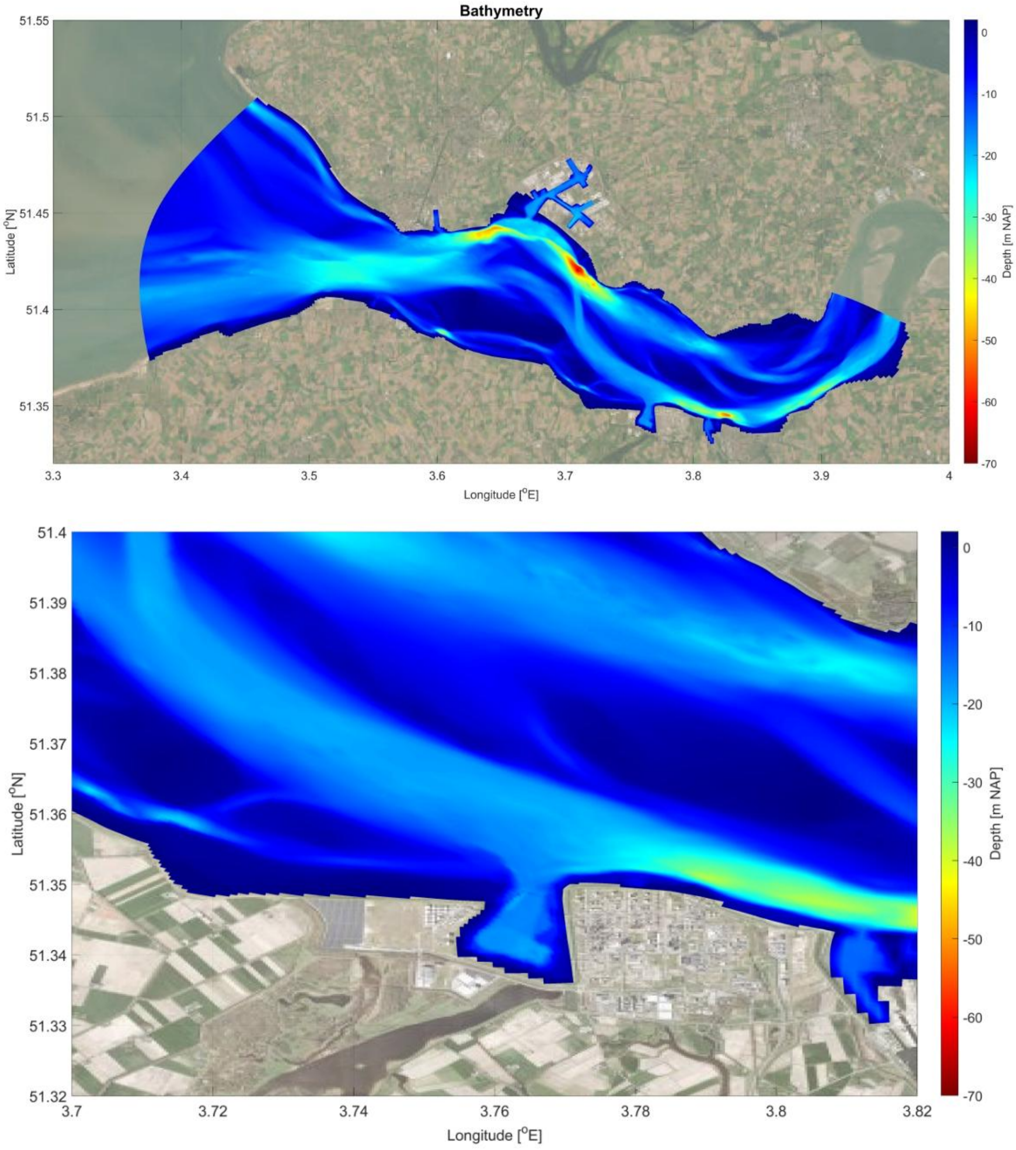

Figure 3-5 Bathymetry of the detailed Delft3D model.

3.4 Boundary conditions

The detailed Delft3D model has 2 open boundaries: at the offshore boundary in the North Sea the water level variation is prescribed and at the eastern boundary current velocities are prescribed. Water level and current time series were derived for the full year of 2013 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 model was verified against the results of the validated Western Scheldt 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 Sloehaven. This figure shows that the simulated hydrodynamic conditions with the validated overall model are accurately transferred to the detailed model.

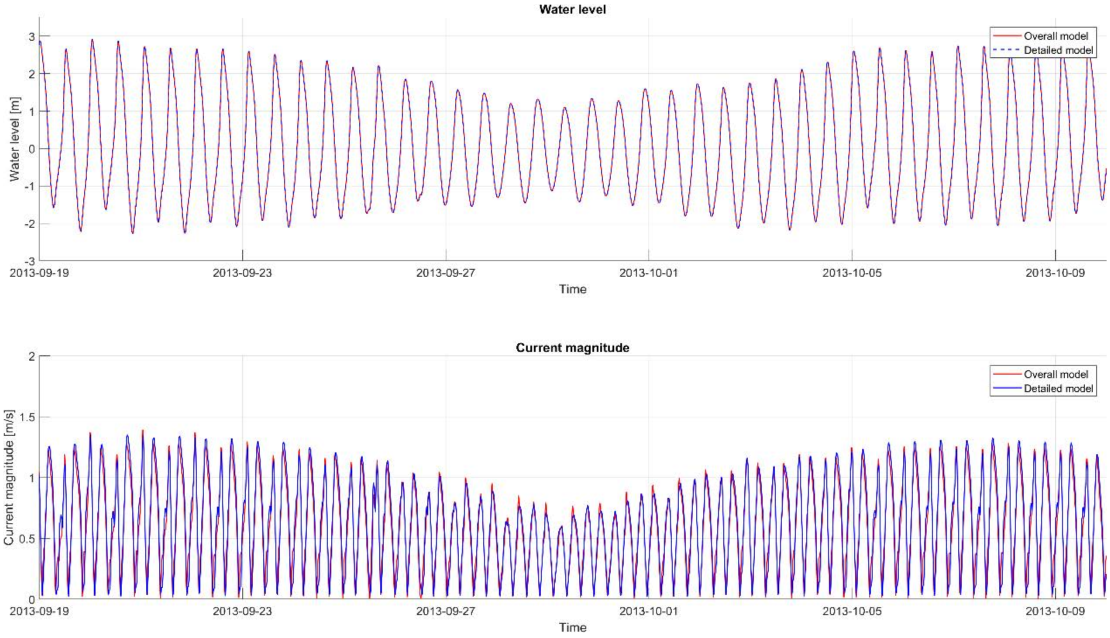

Figure 3-6 Verification of the detailed model setup

A constant background temperature was applied at the boundaries. For the salinity, a constant background salinity of 29 ppt was forced to the model boundaries. In Deltares (2024), sensitivity tests were performed with temporally and spatially varying salinity conditions, but no significant differences were simulated with respect to the plume dispersion. Spatially uniform wind time series were applied based on observations at KNMI station Vlissingen. Corrections were made to this data to account for offshore wind conditions, see Vroom et al. (2015). Furthermore, the Thatcher-Harleman time lag was set to 720 minutes to account for the plume dispersion and tidal flow conditions at the boundaries.

For the temperature modelling, the excess temperature heat flux model of Delft3D 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 of 23 °C was used. These background temperatures are however 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. Sensitivity tests with different model background temperatures confirmed that small changes in background temperatures have no notable impact on the computed temperature increase due to thermal discharges, see the model results in the appendix.

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. 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 14 m, see Figure 3-7. Port diameters varied between approximately 2.5 m and 3 m depending on the discharge flowrate.

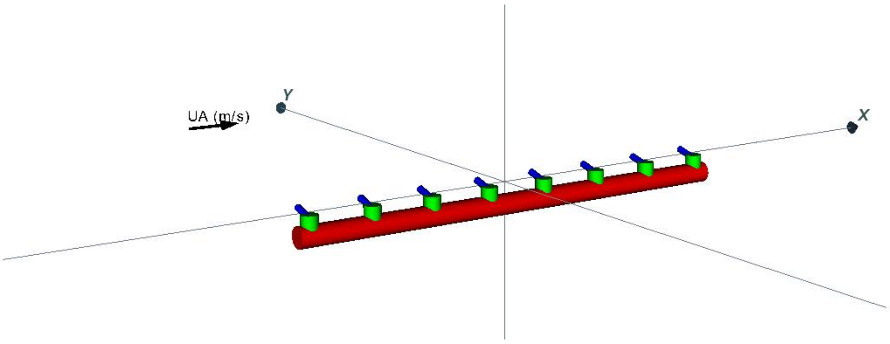

Figure 3-7 Schematic representation of the submerged outfall configuration

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 variation 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 2.5 for low water levels and low current conditions, and a factor of 4.5 with high water levels and 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 far-field model by means of the C-SUMO coupling method.

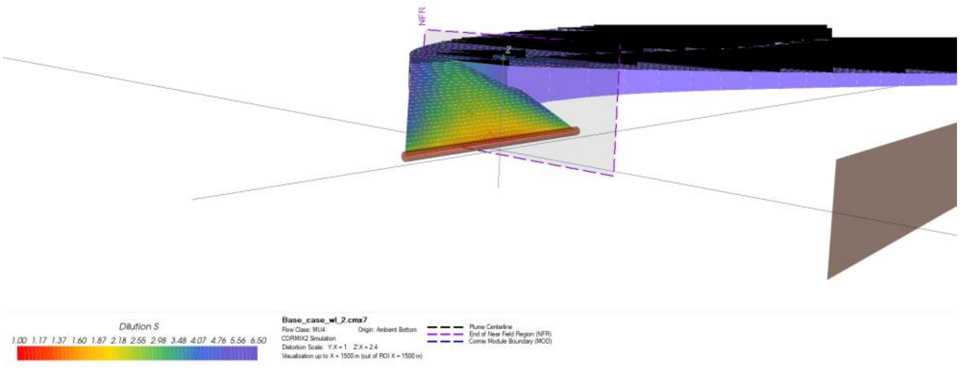

Figure 3-8 Example of simulated plume trajectory and dilution with CORMIX.

The near-field results are stored in a look-up table database which is coupled to Delft3D 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, 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 model to represent the mixing of the plume with ambient water, this is illustrated in Figure 3-9.

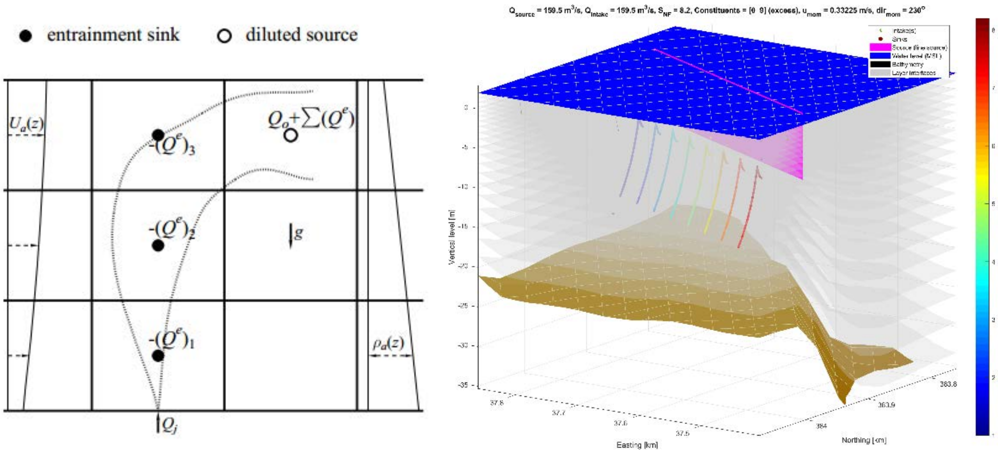

Figure 3-9 Schematics of the DESA-method (left) to represent the near-field plume mixing in the far-field model by series of sources and sinks (from: Choi and Lee, 2007) and the DESA-method approach for a 8 port diffuser in the present assessment.

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 0.021 and 0.027, consistent with the validated overall model.
- The background horizontal eddy viscosity and diffusivity were set to 1 m^2/s.
- The 3D turbulence was computed by the k-Epsilon model.
- A uniform background vertical viscosity of $1*10^{-5}$ m^2/s was used.
- The simulation period was set from 17 September 2013 to 10 October 2013, i.e., the period with the lowest river flow in 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 0.125 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/s^2.
- The air density was set to 1.205 kg/m^3.

4 Modelling results of the plume dispersion

With the coupled Delft3D model and near-field database, different simulations were performed with representative scenarios (i.e., different intake and outfall configurations, different thermal discharge capacities, discharge characteristics, 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

Based on the different intake and outfall configurations, discharge characteristics, thermal discharge capacities and optional structures, 9 simulations were formulated to assess the plume dispersion of the combined present and new power plant discharges. A simulation without the discharge from the Terneuzen nuclear power plant was performed to assess the present situation. All simulations were performed for the period of from 17 September 2013 to 10 October 2013. An overview of the performed simulations is presented in Table 4-1.

Table 4-1 Overview of the simulated modelling scenarios

Case	Thermal Capacity (MW_{th})	Discharge option/Cooling water Temperature increase	Intake/Outfall Location Configuration	Remarks
0	-	-	-	Present situation
1	6000	2 / +9 °C	1	Open intake at the shoreline, submerged outfall 1.5 km offshore in the Western Scheldt close to the main navigation channel.
2	6000	2 / +9 °C	2	Submerged intake 1.5 km offshore in the Western Scheldt close to the main navigation channel, open outfall at the shoreline (reverse of configuration 1).
3	6000	2 / +9 °C	3	Submerged intake in the Western Scheldt close to the Braakmanhaven, submerged outfall 1.5 km offshore in the Western Scheldt.
4	6000	2 / +9 °C	4	Submerged intake 1.5 km offshore in the Western Scheldt, submerged outfall in the Western Scheldt close to the Braakmanhaven (reverse of configuration 3).
5	6000	1 / +7 °C	1	Case 1, but higher discharge rate, lower excess temperature (with respect to case 1).
6	6000	3 / +12 °C	1	Case 1, but lower discharge rate, higher excess temperature (with respect to case 1).
7	4000	2 / +9 °C	1	Case 1, but lower thermal discharge capacity.
8	6000	2 / +9 °C	1	Case 1, but optimised outfall design (i.e. increased near-field mixing)
9	6000	2 / +9 °C	5	Case 1 / Configuration 1, but intake located 2 km to the West.

4.2 Typical flow and outfall plume behaviour

The Western Scheldt is a tidal estuary connected to the North Sea. The vertical tide at the North Sea and the emptying and filling of the Western Scheldt creates strong flows in the Western Scheldt. Figure 4-1 shows the typical depth averaged flow conditions under ebb (top) and flood (bottom) conditions. Near the project site the maximum flow velocities are over 1 m/s.

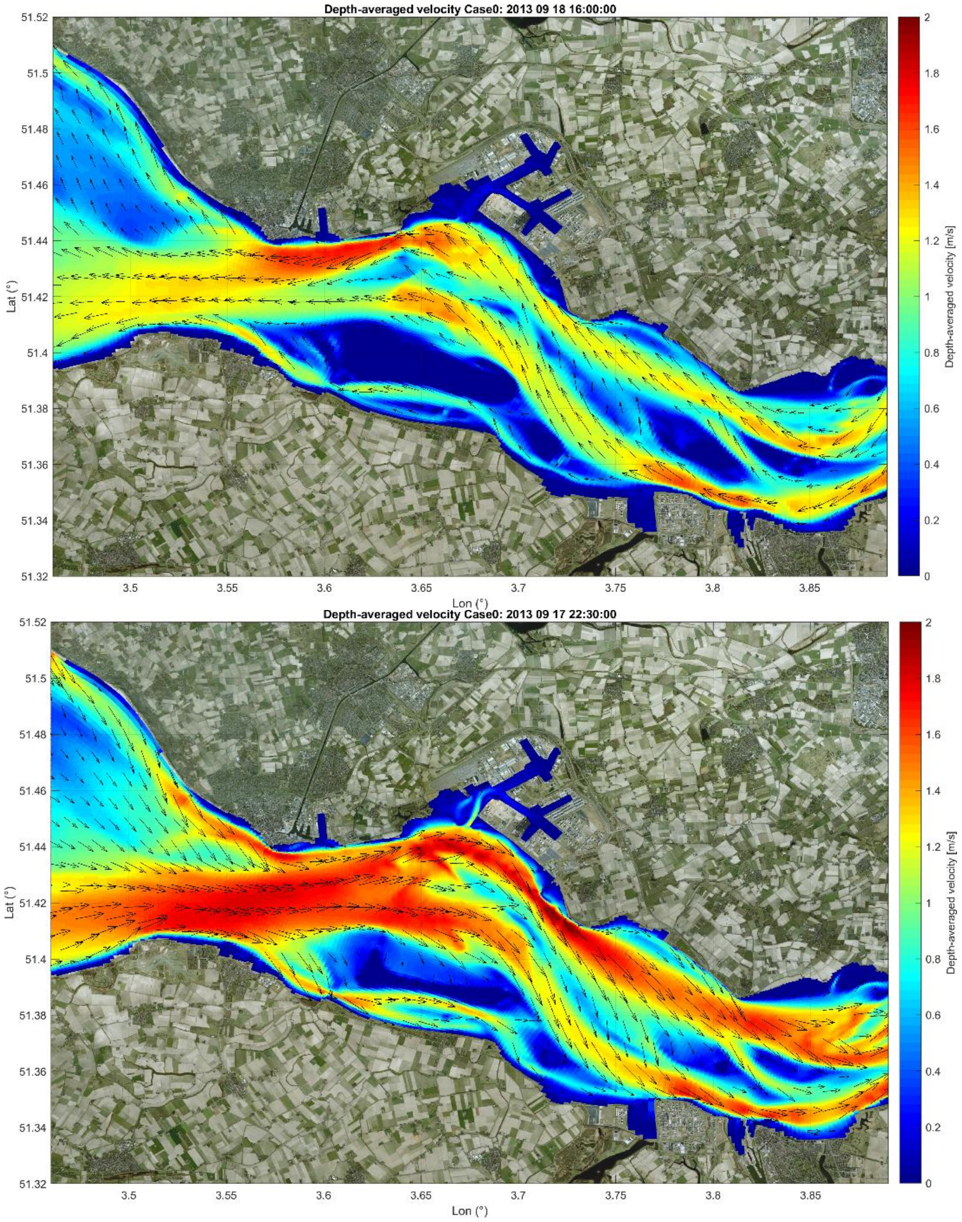

Figure 4-1 Typical depth-averaged flow conditions under ebb (top) and flood (bottom) conditions

The spreading and mixing of the cooling water thermal discharge 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 Terneuzen outfall is in the Western Scheldt the tidal flow conditions and outfall configurations mainly determine the plume dispersion and mixing. Figure 4-3 shows the typical excess temperature footprints (mean and maximum) at the surface. Due to the high current velocities (well over 1 m/s) the plumes are dispersed in NW-SE direction following the main geometry of the Western Scheldt. These high flow velocities and velocity differences cause the thermal plume to rapidly mix with the ambient water. Higher excess temperatures are typically expected in shallow areas where limited ambient water and some lower flow velocities are available for mixing.

The spreading and mixing of the Terneuzen outfall plume also depend 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.

4.3 Presentation of results

Model results are summarized and presented in relation to the environmental thermal criteria in a similar way as in the previous study (Deltares, 2024). Mean and maximum excess temperature footprints of each simulation were generated to visualise the combined plume dispersion for the existing outfalls (Base case) and new power plant 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 4-2. Figure 4-3 illustrates the difference between a mean and maximum temperature footprint.

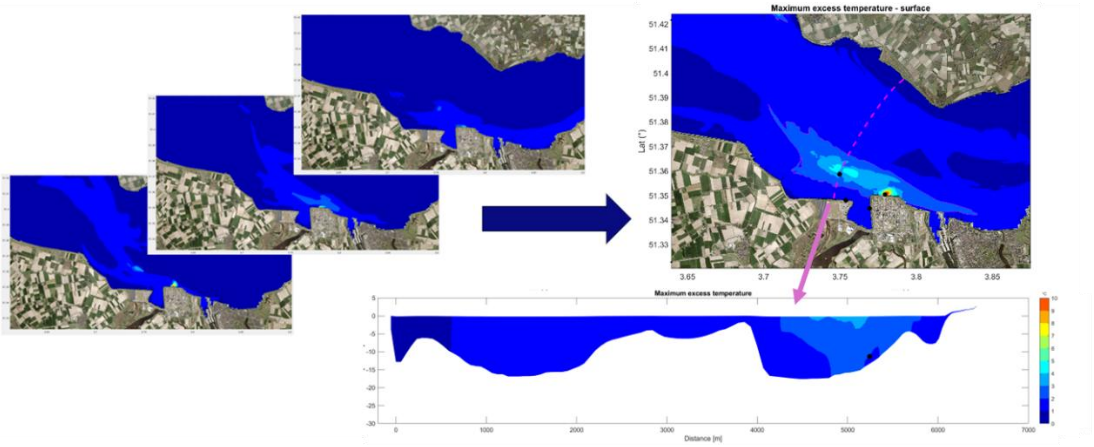

Figure 4-2 Visualisation of the maximum footprint generated from instantaneous model results.

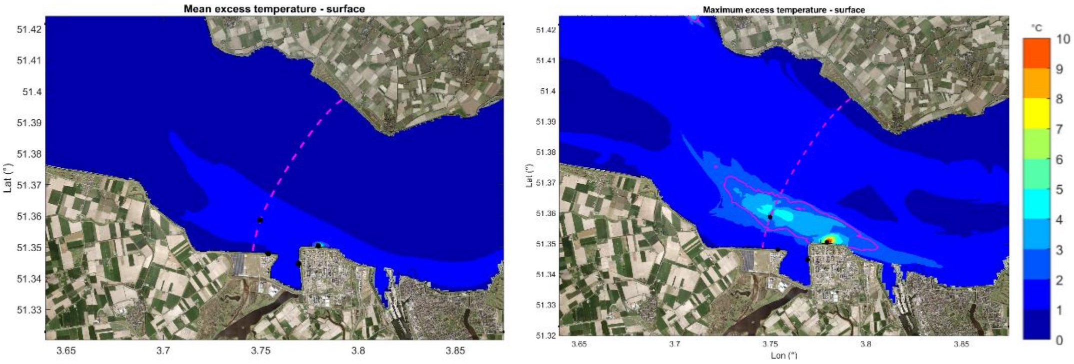

Figure 4-3 Mean (left) and maximum (right) surface temperature increase footprint generated from instantaneous model results.

The footprints are generated for the near-surface and near-bottom for a clear view of the three-dimensional plume dispersion. Additionally, a roughly North to South cross-section in the Western Scheldt was drawn for which the mean and maximum temperature increase was derived from the model results to further illustrate the three-dimensional spreading of the plume, see Figure 4-4. 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. For illustration purposes only, the solid magenta lines shows the (maximum or mean) +2.5 °C contour of the mixing zone.

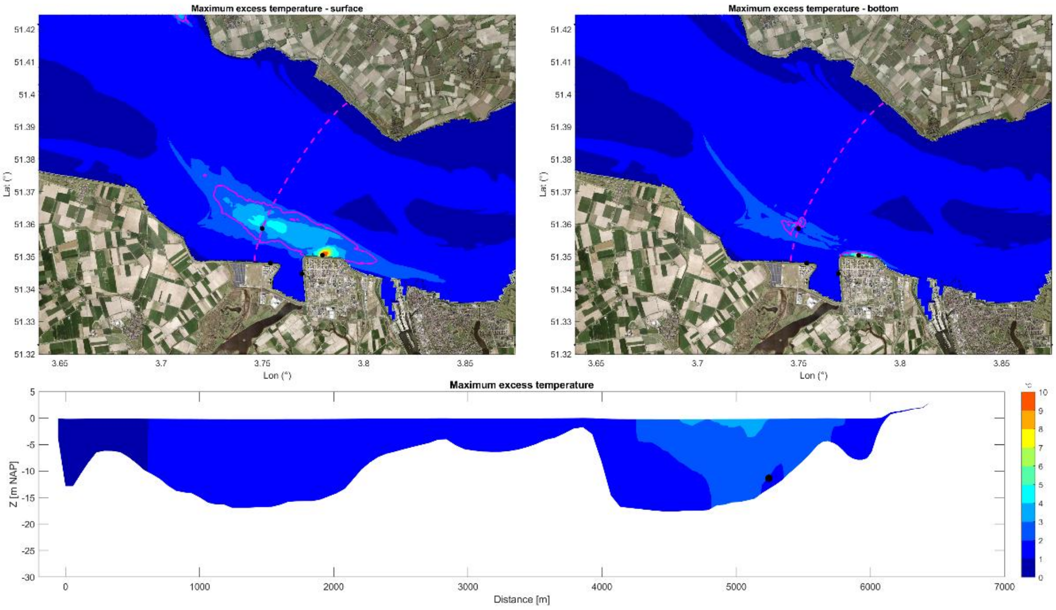

Figure 4-4 Simulated maximum temperature increase due to the combined thermal discharges (Case 1)

CIW mixing zone criterion
For compliance with the CIW 2004 criteria for the mixing zone, the percentage of the cross-sectional area covered by the mixing zone (T>25 °C) needs to be determined. The CIW criterion does not explicitly specify which cross-sectional area should be used. For the present analysis therefore all grid lines of the Delft3D model are used as cross-sections. This is roughly perpendicular to the thalweg axis.

Given that tidal flats just in front of Terneuzen split the Western Scheldt in multiple channels, **two sets** of gridlines were evaluated (see Figure 4-5):

- - The first set assumes the total cross-section in the Western Scheldt;
- - The second set considers only the main channel just in front of Terneuzen, see Section 4.5.

Each figure shows the 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.

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 4-6. The cross-sections are numbered on the horizontal axis. The results are visualised with a coloured line for each output timestep. To derive the mixing zone from the modelling results, the background temperature derived in Section 2.3 (22.5 °C) was subtracted from the critical threshold value for the mixing zone (Western Scheldt 25 °C – 22.5 °C = 2.5 °C). The computed temperature increase was subsequently compared to these excess temperature values to assess the percentages of the cross section that exceed this value.

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 22.5 °C (see previous paragraph), the cross-sectional average temperature increase criterion (< +2 °C) is the more conservative criterion. The results are presented like the mixing zone criteria with the average temperature per cross-section, see Figure 4-6 (bottom).

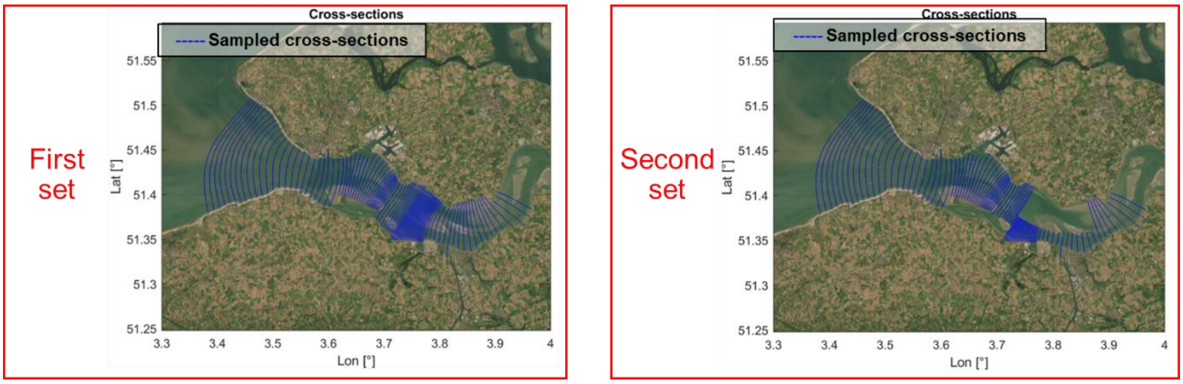

Figure 4-5 Overview of the cross-section sets (blue lines) used for the CIW 2004 discharge criteria.

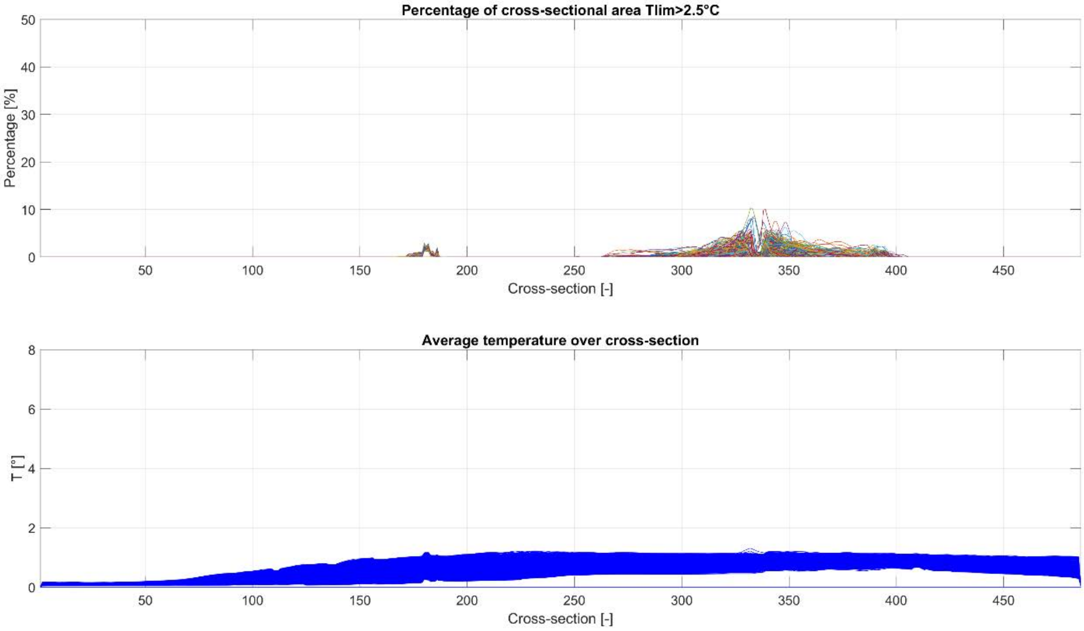

Figure 4-6 Example of the presentation of model results in relation to the environmental criteria.

4.4 Model results

Model results are presented for different Terneuzen intake and outfall configurations, thermal discharge capacities, discharge characteristics, and optimization on the diffuser design. Appendix A presents the complete overview of the recirculation potential for all simulations and intakes. Appendix B and C present the mean and maximum temperature footprints of each simulation. Appendix D show the model results in relation to the CIW mixing zone and average temperature increase criterion.

4.4.1 Baseline scenario - Case 0

A simulation was performed with the present discharges in the project area only, i.e., excluding the new nuclear power plant discharge. This simulation was performed to distinguish the contribution of the existing outfalls and the new power plant outfall for the combined plume dispersion and recirculation. Figure 4-7 shows the simulated maximum temperature increase footprint due to the existing outfalls.

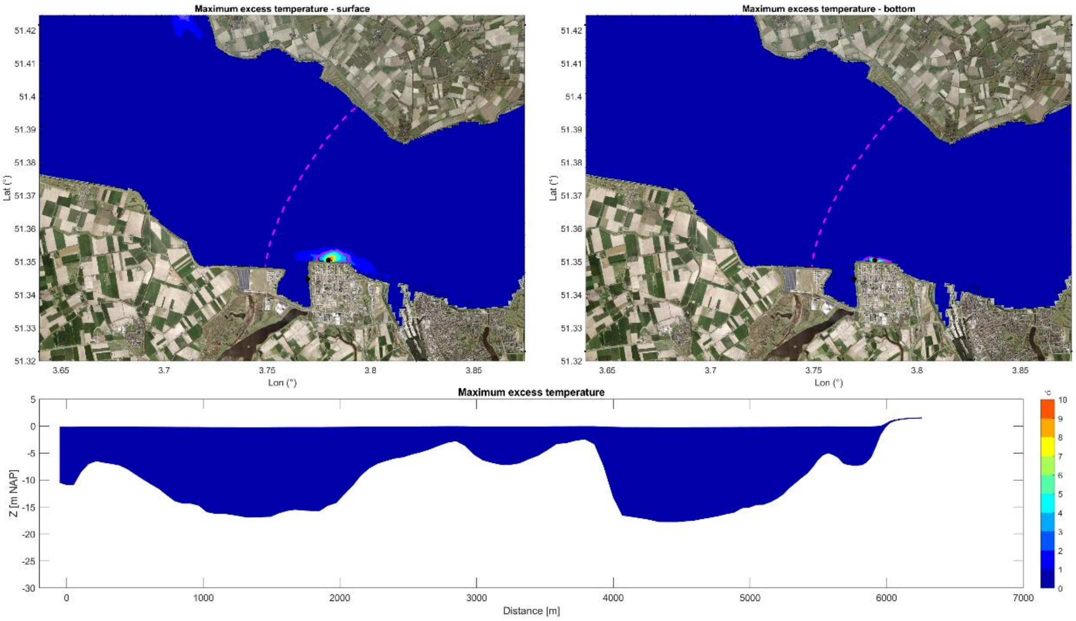

Figure 4-7 Simulated maximum temperature increase footprint due to the existing thermal discharges (Case 0).

Figure 4-7 shows that the maximum temperature increase due to the existing thermal discharges is most pronounced around the Dow Benelux BV discharge. Due to the strong tidal flows, the Dow Benelux BV plume mainly spreads in alongshore direction. Just visible in the maximum footprint is the EPZ thermal discharge on the opposite bank of the Western Scheldt, but due to its distance to the Terneuzen site, this outfall does not affect the temperatures near Terneuzen.

Figure 4-8 shows the percentage of the cross-sectional area (Set 1) covered by the mixing zone and the average temperature over the cross-sections in the Western Scheldt for Case 0. 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 situation (i.e. existing outfalls only). The two locations with an increase in the percentage of the cross-sectional area covered by the mixing zone are the EPZ and Dow outfalls.

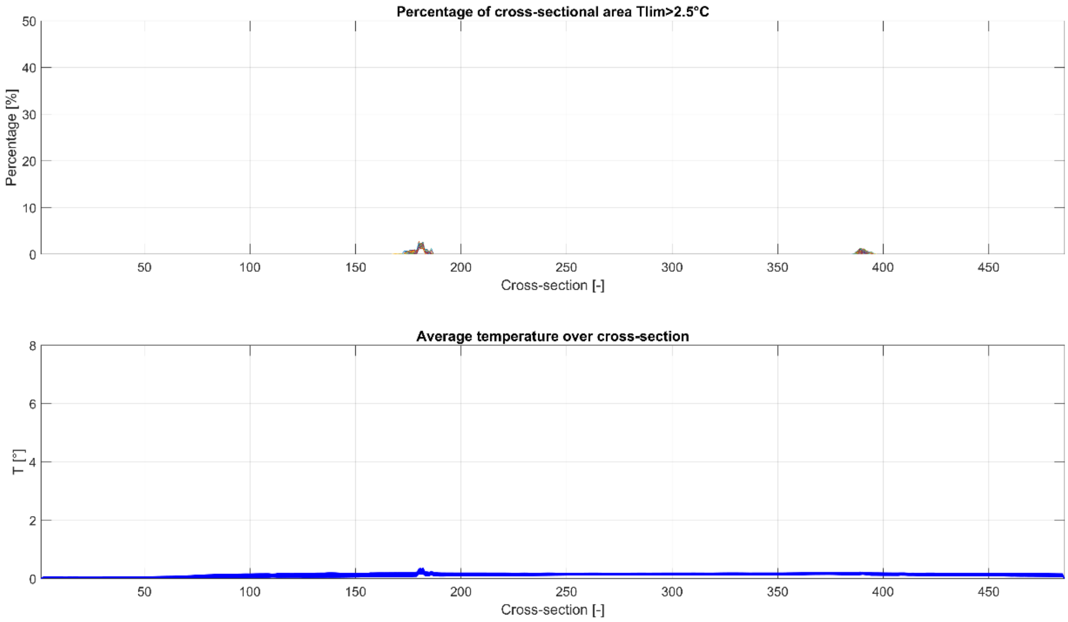

Figure 4-8 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 0, Set 1).

For the existing situation, the computed average temperature increase at the existing Dow Benelux intake is about 0.2 °C, whereas the maximum temperature increase is modelled to be in the order of 0.3 °C.

4.4.2 Results of different intake and outfall configurations (Cases 1, 2, 3, and 4)

In this paragraph 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 flowrate of 159.5 m^3/s and a temperature increase of +9 °C between the intake and the outfall. 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 (first set of cross-sections, see Figure 4-5). A full overview of the model results can be found in the appendix.

4.4.2.1 Case 1 - Configuration 1

In Case 1 the intake/outfall configuration 1 consists of an open intake located on the southern bank of the Western Scheldt, West of the entrance to the Braakmanhaven, and a submerged outfall located in the Western Scheldt about 1.5 km offshore. When the submerged outfall is located directly in the main channel of the Western Scheldt, rapid mixing of the outfall plume due to the diffuser and high hydrodynamic flow conditions is expected. Figure 4-9 shows the maximum temperature increase footprint for the combined plume dispersion of the existing outfalls and the new Terneuzen outfall.

The high current velocities around the submerged outfall cause the Terneuzen discharge plume to disperse mainly in NW and SE direction. A maximum (surface) temperature increase of 2.5 °C is computed at alongshore distances of up to 3 km towards the NW and up to 4 - 5 km towards the SE. Near the bed, the computed mixing zone reach a maximum distance of less than 1 km for this outfall configuration. The mean temperature increase around the submerged outfall for Case 1 is typically lower due to the dynamic behaviour of the plume, see Appendix B.

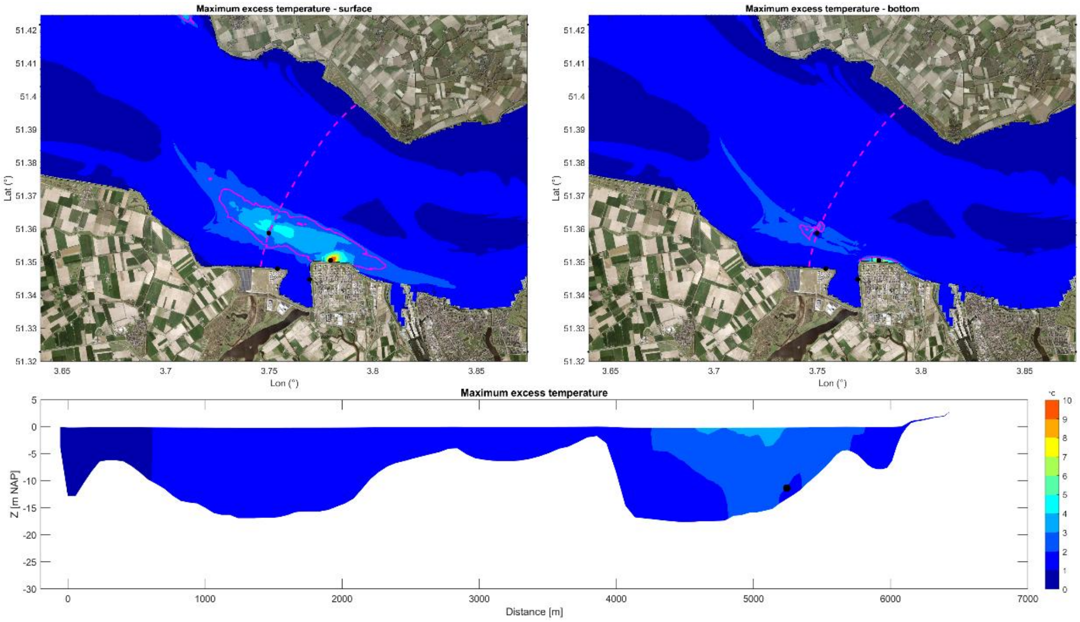

Figure 4-9 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 1: discharge of 159.5 m^3/s and a temperature increase of 9 °C.

Figure 4-10 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature for the cross-sections in the Western Scheldt. The computed maximum percentage covered by the mixing zone is about 10% and well below the CIW threshold value of 25%. The computed average temperature increase over the cross-sections of the full Western Scheldt is typically around 1 °C and always staying below the 2 °C limit value.

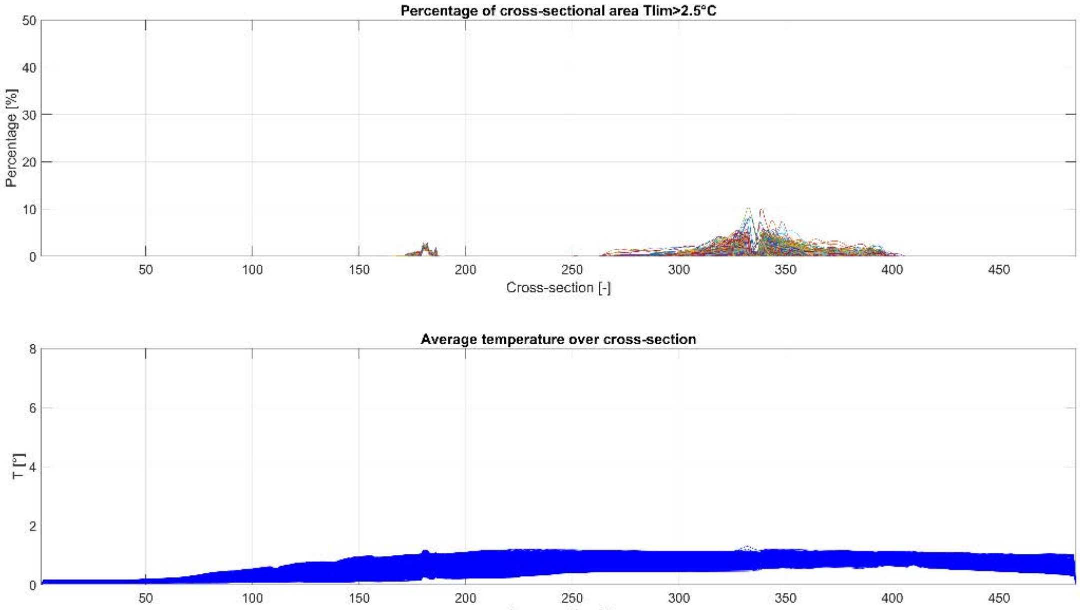

Figure 4-10 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 1, Set 1).

The combined recirculation (i.e., temperature increase at the intake location due to all discharges combined) towards the Terneuzen open intake is computed to be around 1.2 °C (mean) and 1.4 °C (maximum). The modelled temperature increase at the Dow Benelux intake located in the Braakmanhaven is about 0.9 °C on average (was 0.2 °C in Case 0), with a maximum of 1.2 °C (was 0.3 °C in Case 0).

4.4.2.2 Case 2 - Configuration 2

In Case 2 the intake and outfall locations are switched compared to Case 1. Here, the Terneuzen intake is modelled as a submerged intake in the Western Scheldt and the outfall is modelled as an open channel discharge just West of the entrance to the Braakmanhaven.

Figure 4-11 shows the maximum temperature increase for Case 2. The maximum temperature increase in the proximity of the open channel discharge is typically up to 10 °C (i.e., the initial discharge temperature including recirculation). From the cross-section presented in the bottom panel of Figure 4-11 it is also clear that further away from the open discharge, the warmer plume remains close to the water surface due to its buoyancy. Once the thermal plume disperses into the main channel, rapid mixing occurs due to the high tidal flow conditions. Nonetheless, a computed temperature increase of 2.5 °C is observed in the top layers extending about 4 km into the NW and 8 km into the SE. Near the bed this temperature increase covers a distance of around 3 km towards the NW.

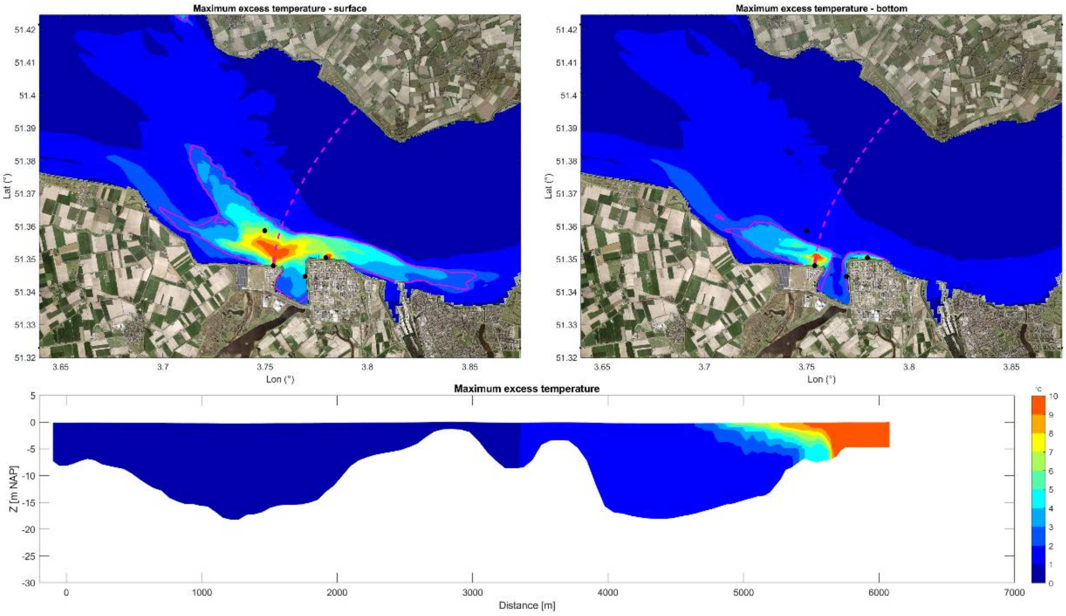

Figure 4-11 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 2: discharge of 159.5 m^3/s and a temperature increase of 9 °C.

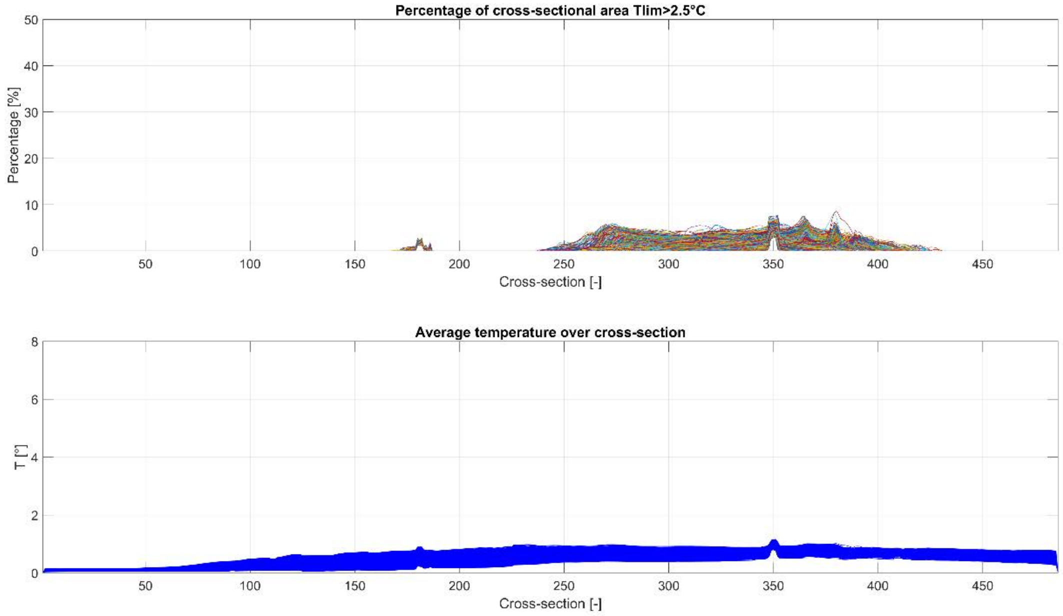

Figure 4-12 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 2, Set 1).

Figure 4-12 shows the percentage of the total cross-sectional area covered by the mixing zone. This percentage stays well below the 25% threshold value of the CIW 2004 criteria for the cross-sectional mixing zone extent with maximum values below 10%. Furthermore, the cross-sectional average temperature remains below the 2 °C threshold value of the CIW 2004 criteria for the average temperature increase.

The location of the Terneuzen intake modelled for Case 2 is located in the Western Scheldt (submerged) and Northwest of the open discharge. The simulated mean temperature increase above background at the Terneuzen intake is approximately 0.9 °C and the maximum temperature increase above background is around 1.8 °C. It is expected that the open Terneuzen discharge in the Western Scheldt will increase the temperature in the Braakmanhaven by around 2 – 3 °C. The modelled temperature increase at the Dow Benelux intake located in the Braakmanhaven is about 1.8 °C on average (was 0.2 °C in Case 0), with a maximum of 2.3 °C (was 0.3 °C in Case 0).

4.4.2.3 Case 3 - Configuration 3

In Case 3, the Terneuzen intake and outfall are both submerged and located offshore in the Western Scheldt. Figure 4-13 shows the simulated maximum temperature increase footprints for this case which are, given the same diffuser, discharge location and discharge characteristics, very similar to Case 1.

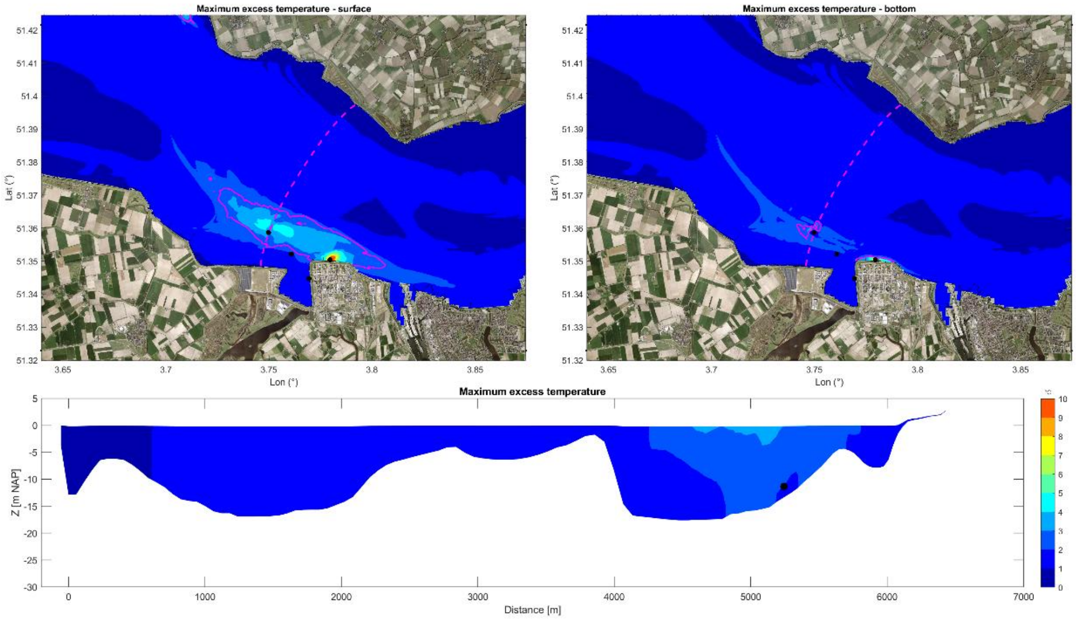

Figure 4-13 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 3: discharge of 159.5 m^3/s and a temperature increase of 9 °C.

The outfall plume is stratified and mainly disperses at the surface and in alongshore direction. The computed maximum temperature increase at the bottom locally exceeds 2 °C, whereas the temperature increase at the surface locally reaches 4 °C. The extent of the 2.5 °C plume is also comparable to the Case 1 scenario, where the computed plume extent at the surface reaches distances of up to 3 km towards the NW and up to 4 - 5 km towards the SE. Near the bottom, the computed mixing zone reaches a maximum distance of less than 1 km.

The simulated percentage of the total cross-sectional area covered by the mixing zone is also very similar to Case 1 with a maximum percentage of coverage up to 10%, see Figure 4-14, top panel. The cross-sectional average temperature is well below the 2 °C limit.

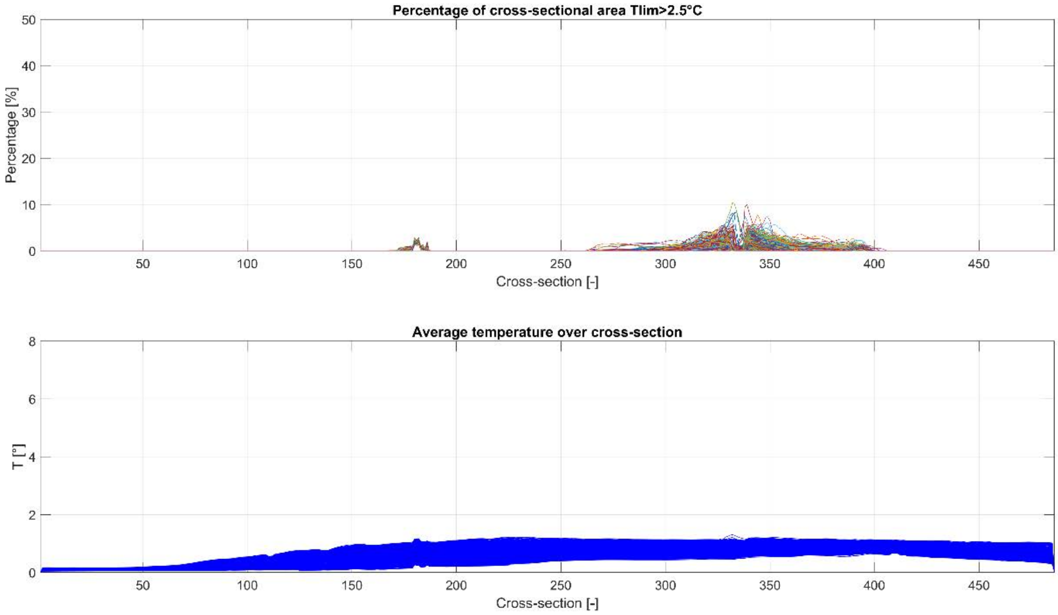

Figure 4-14 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 3, Set 1).

In Case 3, the Terneuzen intake (submerged) is located near the entrance to the Braakmanhaven, and southeast of the proposed submerged outfall. The simulated mean excess temperature at the Terneuzen intake for Case 3 is typically around 1.2 °C, with a maximum of 1.6 °C. These are similar values compared to the recirculation computed for Case 1. Likewise, the computed temperature increase at the existing intakes is similar to Case 1. The modelled temperature increase at the Dow Benelux intake located in the Braakmanhaven is about 0.9 °C on average (was 0.2 °C in Case 0), with a maximum of 1.2 °C (was 0.3 °C in Case 0).

4.4.2.4 Case 4 - Configuration 4

In Case 4, the location of the intake and outfall is reversed with respect to the locations modelled for Case 3. In this configuration the modelled outfall is located nearby the Braakmanhaven entrance and the intake (submerged) is placed 1.5 km offshore in the Western Scheldt. Figure 4-15 and Figure 4-16 show the simulated maximum temperature increase footprint and cross-sectional analyses.

The extent of the 2.5 °C thermal plume is similar to previous Case 1 and Case 3 (submerged discharges), extending alongshore into the NW and the SE directions in the order of a few kilometres. The difference between these cases is mainly the computed temperature increase in the Braakmanhaven. For Case 4, the temperature increases between 3 – 4 °C in the Braakmanhaven, whereas in Case 1 and Case 3 the temperature increases by 1 – 2 °C.

Regarding the mixing zone criteria, the maximum computed percentage of cross-sectional area covered by the mixing zone reaches around 20% at certain instances. This is explained by the build-up of effluent and low hydrodynamic conditions close to the outfall, see Figure 4-1. The computed average temperature increase along the cross-sections in the main channel remains below the 2 °C limit prescribed by the CIW criteria.

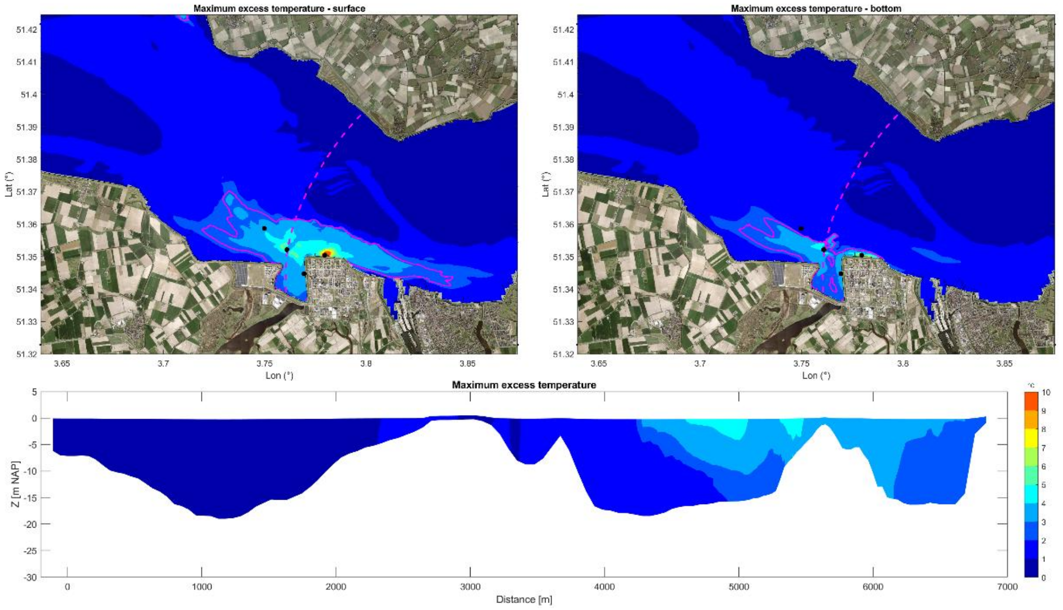

Figure 4-15 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 4: discharge of 159.5 m^3/s and a temperature increase of 9 °C.

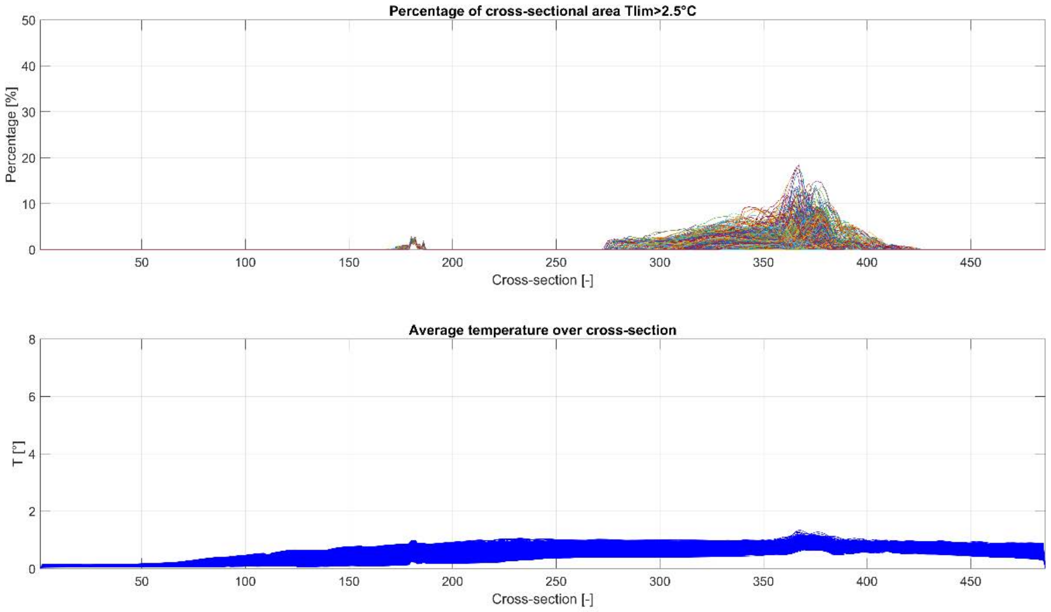

Figure 4-16 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 4, Set 1).

In terms of computed recirculation potential, the expected temperature increase above background at the Terneuzen intake is expected to be 1.0 °C (mean) and 2.1 °C (maximum) – similar to the values computed for Cases 1-3. Given proximity of the Terneuzen discharge to the Braakmanhaven entrance, the temperature increase at the Dow Benelux intake is about 2.4 °C on average (was 0.2 °C in Case 0), with a maximum of 3.4 °C (was 0.3 °C in Case 0), which is the highest computed excess temperature at the Dow intake for all cases.

4.4.2.5 Case 9 - Configuration 5

In Case 9, the intake is located about 2 km to the West with respect to the intake location of Case 1. The type and location of the outfall is the same for Case 9 and Case 1. Figure 4-17 and Figure 4-18 show the simulated maximum temperature increase footprint and cross-sectional analyses.

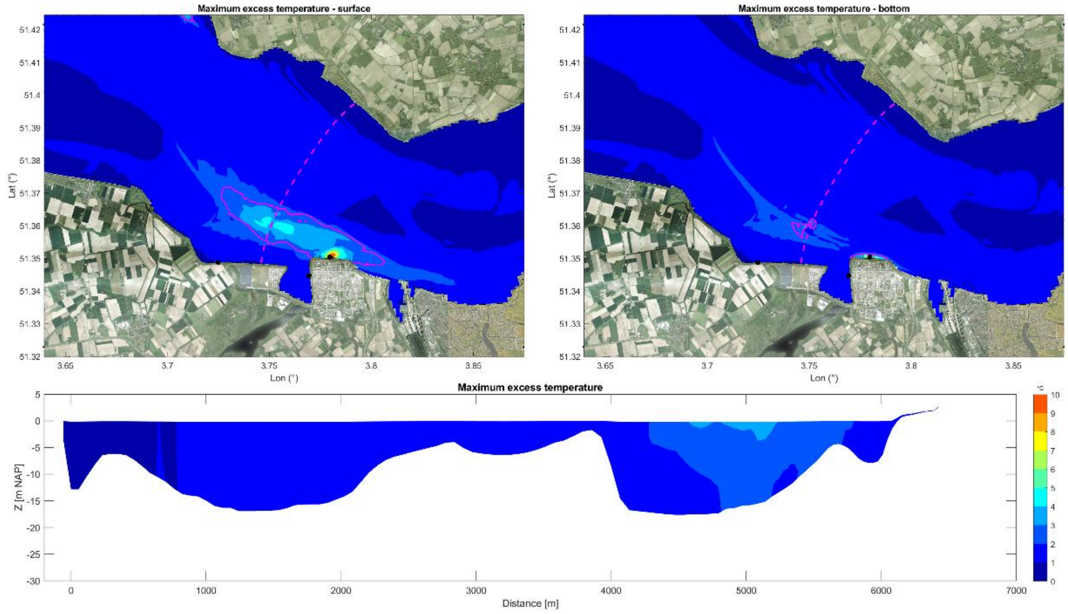

Figure 4-17 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 9: discharge of 159.5 m^3/s and a temperature increase of 9 °C.

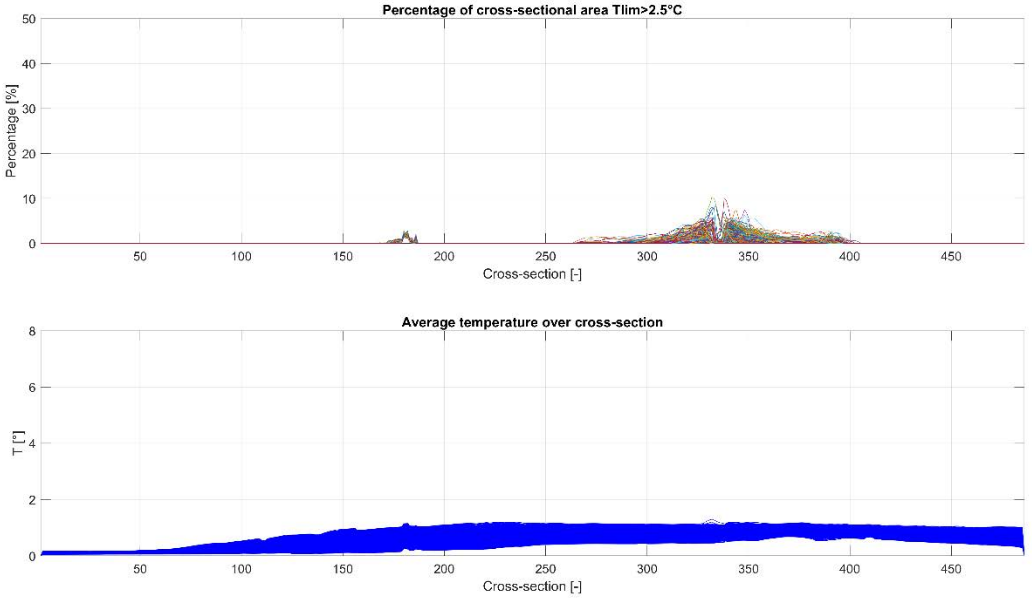

Figure 4-18 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 9, Set 1).

Similar to Case 1, the outfall plume is stratified and mainly disperses at the surface and in alongshore direction. The computed maximum temperature increase at the bottom locally around the outfall exceeds 2 °C, whereas the temperature increase at the surface locally reaches 4 °C. The extent of the 2.5 °C temperature contour is the same for Case 9 as for Case 1.

Figure 4-18 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature for the cross-sections in the Western Scheldt. The computed maximum percentage covered by the mixing zone For Case 9 is the same as for Case 1: about 10% and well below the CIW threshold value of 25%. The computed average temperature increase over the cross-sections of the full Western Scheldt is typically around 1 °C and always staying below the 2 °C limit value.

The combined recirculation (i.e., temperature increase at the intake location due to all discharges combined) towards the Terneuzen open intake of Case 9 is computed to be around 1.1 °C (mean) and 1.5 °C (maximum). These computed are very similar to the computed recirculation values of Case 1. The modelled combined temperature increase at the Dow Benelux intake located in the Braakmanhaven is about 1.1 °C on average (was 0.2 °C in Case 0), with a maximum of 1.5 °C (was 0.3 °C in Case 0) above background conditions. This is identical to Case 1.

4.4.3 Different discharge characteristics Terneuzen outfall (Case 5 and 6)

Next to the type and location of the Terneuzen intake and outfall, the discharge characteristics (i.e., discharge flow and temperature increase between intake and outfall) are important design parameters for operational conditions of the plant and the potential effects on the environment. For a given thermal load, a lower discharge flow through the condenser results in a higher temperature difference over the condenser and vice versa. A cooling water system with a lower flow rate is beneficial for e.g., the pump capacity needed, dimensions of the intake and outfall and the head losses in the system. However, a discharge with a higher temperature increase also needs a larger mixing to limit the water temperature increase around the outfall.

To assess the impact of the discharge characteristics, two simulations were performed with different discharge flow rates and temperature increase between the intake and outfall, namely: Q = 205 m^3/s & ΔT +7 °C (Case 5), and Q = 119.5 m^3/s & ΔT +12 °C (Case 6). Both simulations consider the same thermal load of 6000 MW. These simulations were performed for Configuration 1 only.

4.4.3.1 Case 5 – Configuration 1: higher discharge rate, lower excess temperature

In Case 5 a discharge with a temperature increase of +7 °C and a corresponding flow rate of 205 m^3/s was assessed. Figure 4-19 shows the maximum excess temperature footprints for Case 5. With respect to Case 1, a similar extent of the 2.5 °C thermal plume is computed at the surface and bottom layers, though with a slight reduction of the thermal plume extent.

The most significant difference between Case 5 and 1 is expected locally close to the outfall, as the local temperature increase is expected to be reduced by 2 °C. Further away from the outfall, the difference in temperature between Case 5 and Case 1 decreases.

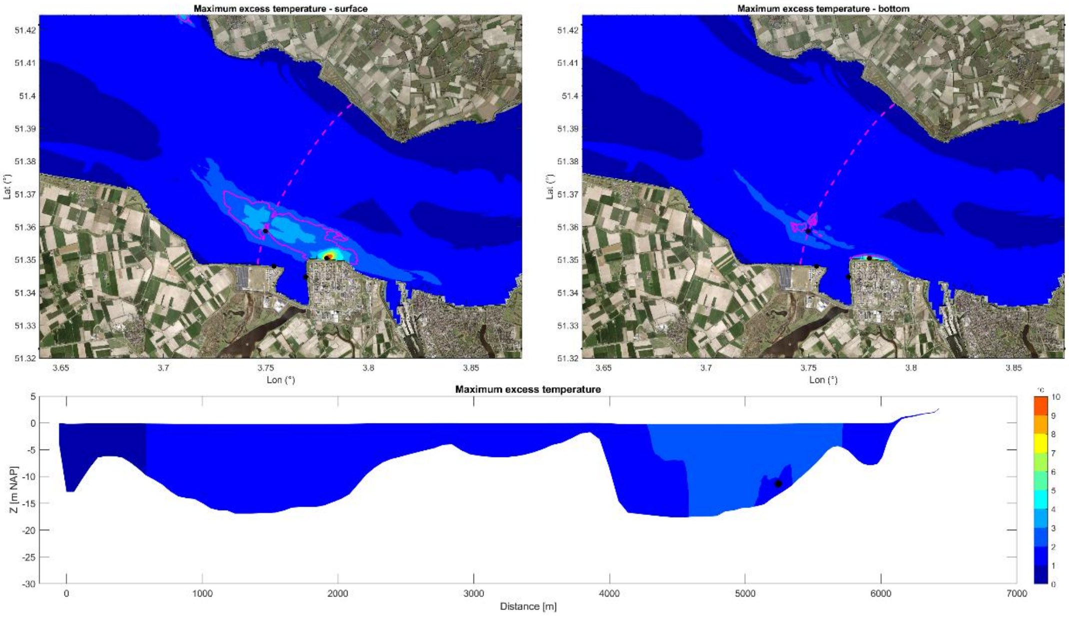

Figure 4-19 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 5: discharge of 205 m^3/s and a temperature increase of 7 °C.

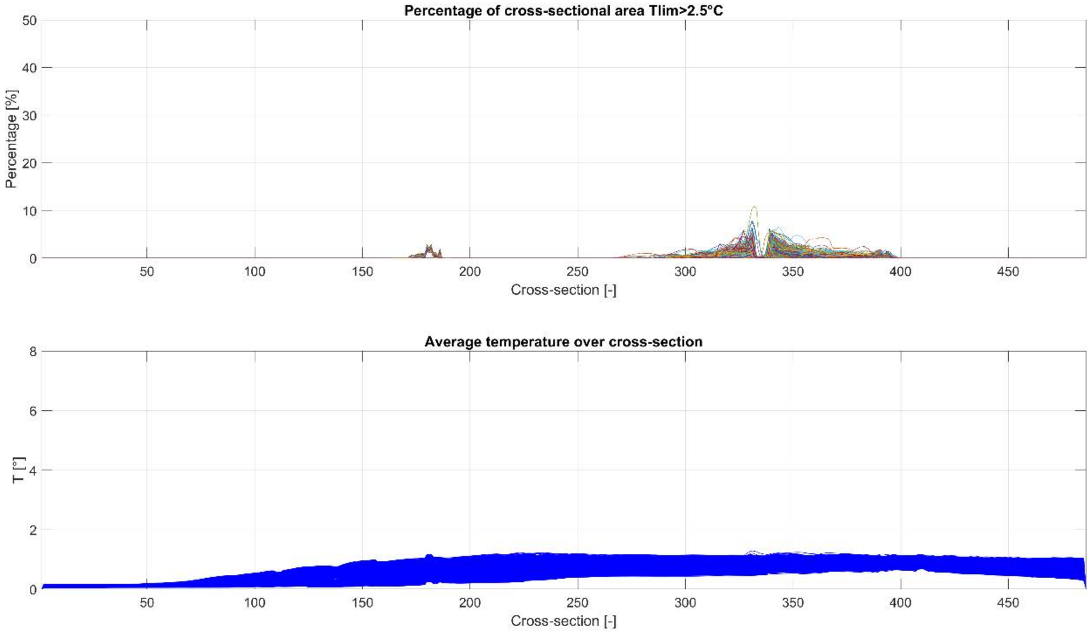

Figure 4-20 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom)) for the total cross-section in the Western Scheldt. (Case 5, Set 1).

Figure 4-20 shows the percentage of the cross-sectional area covered by the mixing zone for Case 5. The maximum percentage of the cross-sectional area covered by the mixing zone is about 10%, which is lower than the CIW threshold value of 25%. Regarding the average temperature increase, the threshold value of 2 °C is not reached.

No significant differences are expected in terms of the recirculation potential for the different intakes between Case 5 and Case 1.

4.4.3.2 Case 6 – Configuration 1: lower discharge rate, higher excess temperature

For Case 6 a temperature increase of +12 °C was assessed with a corresponding flowrate of 106.5 m^3/s. Figure 4-21 shows the maximum excess temperature footprints derived from this simulation. The 2.5 °C thermal plume has the same extent as Case 1 at the surface and near the bed. Locally, however, the excess temperature at the surface is expected to range between 5 – 6 °C, while for Case 1 the maximum excess surface temperature is expected between 4 – 5 °C. The higher values are directly related to the increased discharge temperature and the lower discharge rates.

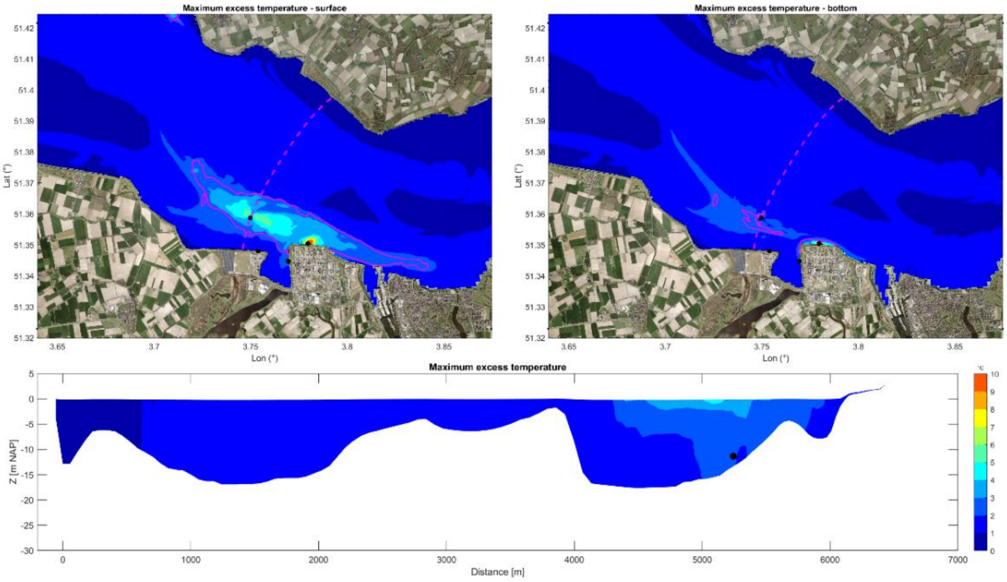

Figure 4-21 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 6: discharge of 119.5 m^3/s and a temperature increase of 12 °C.

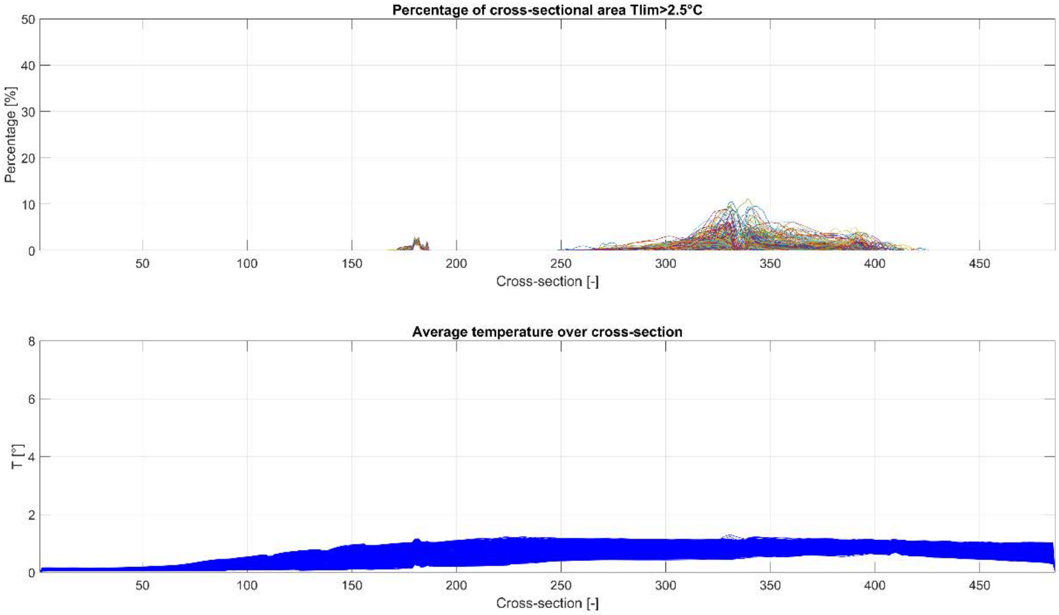

Figure 4-22 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 6, Set 1).

Figure 4-22 shows the percentage of the cross-sectional area of the Western Scheldt covered by the mixing zone for Case 6. The maximum percentage is in the order of 10%, which is below the 25% threshold value of the CIW criteria. The average temperature increase over the cross-sections stays below the threshold value of 2 °C.

In terms of recirculation potential, the discharge characteristics of Case 6 are not expected to change the mean temperature increase at the Terneuzen intake compared to Case 1. A slight increase is observed in the computed maximum temperature increase at the Terneuzen and Dow Benelux intakes, with values rising by 0.2 - 0.3 °C - from 1.4 °C to 1.6 °C at the Terneuzen nuclear intake and from 1.5 °C to 1.8 °C at Dow Benelux.

4.4.4 Thermal discharge capacity Terneuzen outfall (Case 7)

Additionally, a sensitivity simulation for Configuration 1 was performed with a decreased thermal discharge capacity to assess the effect of a lower thermal discharge on the plume spreading and mixing. For this simulation the thermal discharge capacity was reduced from 6000 MW_{th} to 4000 MW_{th}. To achieve this reduction, the discharge flow was reduced by 1/3 from 159.5 m^3/s to 106.5 m^3/s with the same temperature increase between intake and outfall (+9 °C). Figure 4-23 and Figure 4-24 show the results for Case 7. For comparison, Figure 4-9 and Figure 4-10 show the results for the full thermal capacity of a 6000 MW thermal discharge (Case 1).

Figure 4-23 shows that the temperature increase around the Terneuzen outfall typically decreases with lower thermal discharges. For the 4000 MW_{th} case the +2.5 °C temperature increase contour at the surface is about 1 km less in alongshore direction (compared to the 6000 MW case 1). The extent of the +1 °C plume is also reduced, largely remaining in the southern main channel of the Western Scheldt, instead of extending towards the northern channel too. Moreover, at the bottom layers the temperature increases only locally above +2 °C.

For the reduced thermal discharge capacity, the maximum percentage of the cross-sectional area covered by the mixing zone reaches a maximum of around 5%, which is about 5% lower than the simulated maximum percentages with the full thermal discharge capacity. The reduction in thermal discharge capacity also reduces the mean recirculation of the combined outfall plume towards the intake of the new Terneuzen plant by about 0.3 °C, from 1.2 °C – 1.4 °C (Case 1) to 0.9 °C – 1.1 °C.

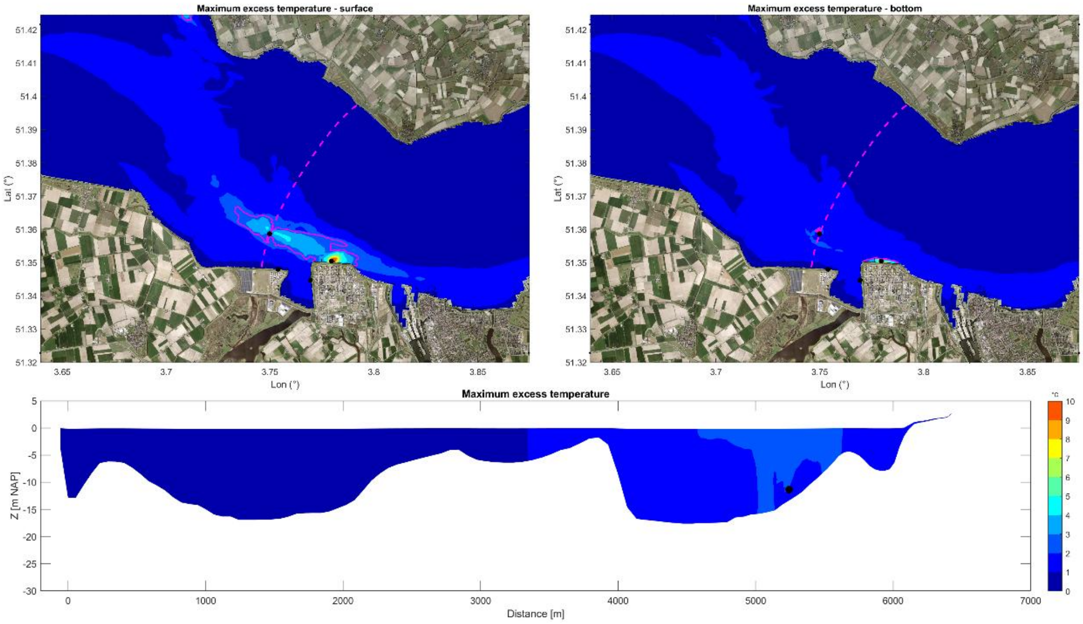

Figure 4-23 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 7: discharge of 106.5 m^3/s and a temperature increase of 9 °C.

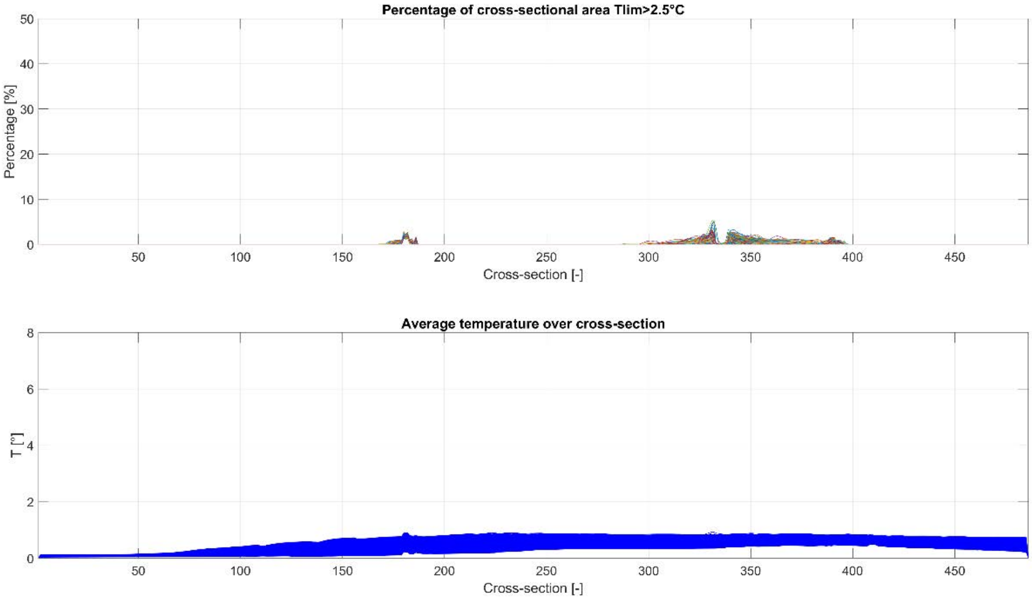

Figure 4-24 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 7, Set 1).

4.4.5 Terneuzen outfall design optimization (Case 8)

An additional sensitivity test was performed by optimization of the outfall design in terms of near-field mixing, while maintaining the original thermal capacity and discharge characteristics i.e. 6000 MW$_{th}$, Q = 159.5 m^3/s and ΔT +9 °C. The optimization concerning the diffuser design aims at increasing the dilution that can be achieved at the end of nearfield.

This adjustment consisted of a reduction of the port diameter. In Case 8, the typical end-of-nearfield dilution was increased to about 3.9 (was 3.1 for Case 1).

Figure 4-25 shows the extent of the combined thermal plume with an optimized design. At the surface, the 2.5 °C temperature increase contour is reduced by about 1 km in both Northwestern and Southeastern directions compared to Case 1. Moreover, locally the computed temperature increase near the outfall is reduced from a range of 4 – 5 °C to 3 – 4 °C. Near the bed, the extent of the + 2.5 °C thermal plume is reduced in all directions.

In terms of the cross-sectional area covered by the mixing zone, an overall reduction is observed compared to Case 1 (Figure 4-10), however, there is one instance where the maximum still reaches 10%, similar to Case 1. The average temperature increase over the same evaluated cross-sections remains below the 2 °C limit, similar to the results obtained for Case 1. In terms of recirculation potential, the mean excess temperature computed at all modelled intakes remains the same as the values found for Case 1.

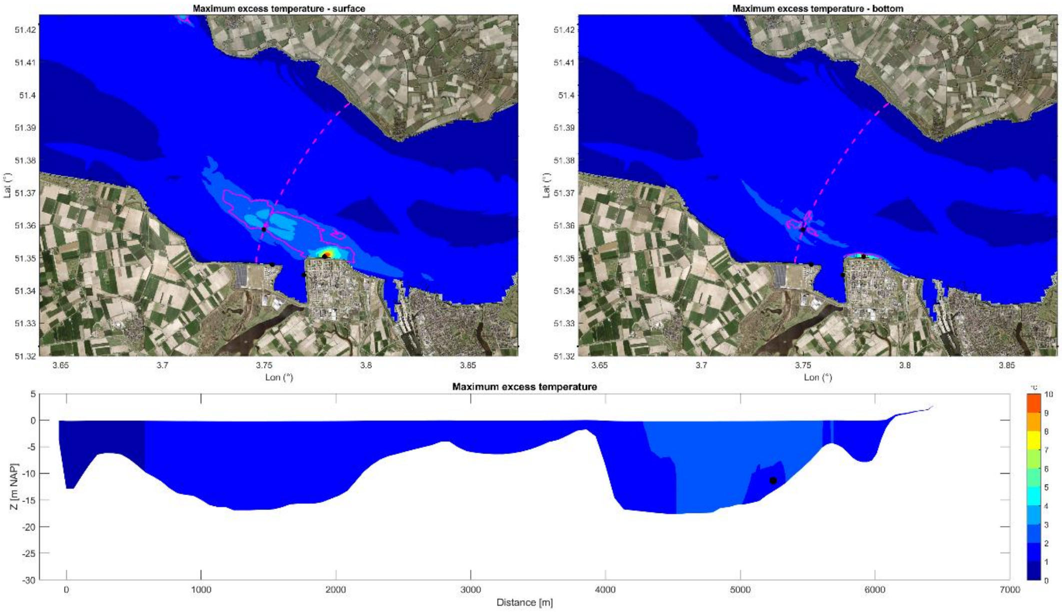

Figure 4-25 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge. Case 8: optimized diffuser design, discharge of 159.5 m^3/s and a temperature increase of 9 °C.

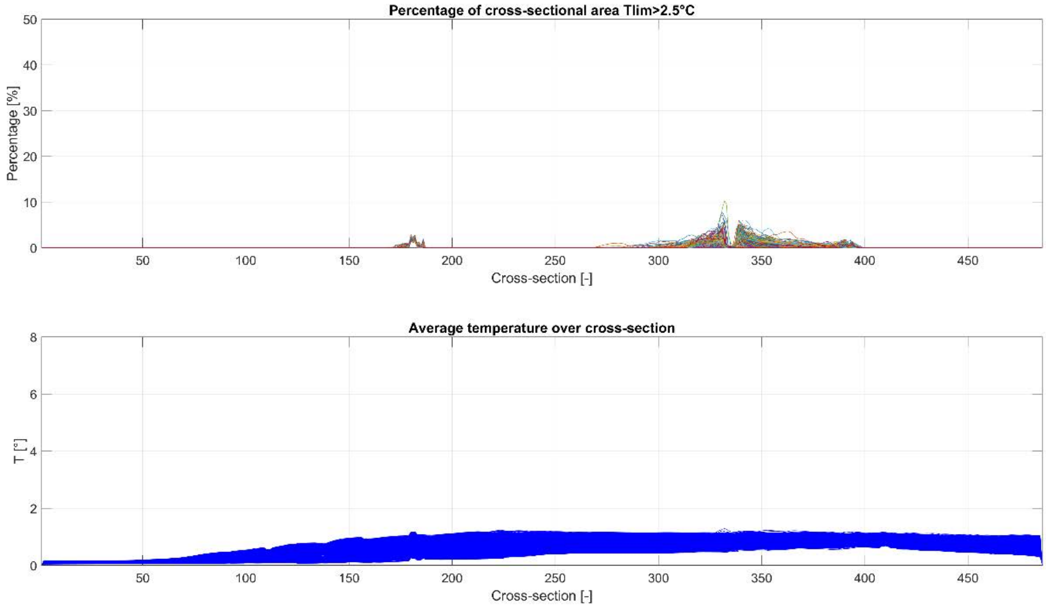

Figure 4-26 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the total cross-section in the Western Scheldt. (Case 8, Set 1).

4.5 Cross-sectional area of the CIW criteria.

The CIW criterion does not state which cross-sectional area should be used. The Western Scheldt near Terneuzen consists of multiple channels and intertidal and/or dry areas. In Section 4.4 model results were presented that show the percentage of the cross-sectional area covered by the mixing zone for the full cross-section of the Western Scheldt, i.e. Set 1 (see Section 4.3). As an additional sensitivity test, the model results were evaluated for environmental compliance with the local main channel only, i.e. Set 2 (See Figure 4-5). Appendix D shows the percentage of the cross-sectional area covered by the mixing zone for the full width of the Western Scheldt and the local main channel near the Terneuzen outfall for all cases.

Based on this analysis, the following conclusions are made on the environmental compliance with the cross-sectional area of the main channel only for the different Terneuzen intake and outfall design options:

- The maximum computed cross-sectional area covered by the mixing zone in Cases 1, 3, 5, 6, 8 and 9 is around 25% - the CIW threshold value. Cases 2, 4, and 7 return a different computed covered percentage, namely:
    - Case 2 (open outfall): maximum cross-sectional cover below 20%. Although the open outfall results in higher temperatures near the discharge point, it affects a smaller cross-sectional area compared to the submerged diffuser options, making it more favorable with respect to this CIW criterion.
    - Case 4 (outfall in the main channel close to the Terneuzen port / Braakmanhaven): maximum cross-sectional cover of 35%.
    - Case 7 (reduced thermal load): maximum cross-sectional cover of 15%.
- Case 5 (reduced discharge temperature) and Case 8 (increased initial mixing) reduce the percentage of the cross-sectional area covered by the mixing zone compared to Case 1. While computed values of Case 5 and 8 are still above the critical value of 25%, combinations of these design alternatives can be used to further reduce the mixing zone of the cooling water discharge.

- The computed cross-sectional average temperature increase in the water body is typically between 1 °C and 1.8 °C for all cases, except for Case 4 where the criterion of 2 °C is temporarily reached.

5 Conclusions

The objective of this cooling water study is to assess the combined plume dispersion and recirculation potential of a new Terneuzen cooling water discharge in relation to the applicable environmental temperature criteria for different design alternatives. The result of this study will provide initial information to the Vendors about the feasibility of different indicative options for cooling water systems as input for their further studies. 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 objective was studied by means of a hydrodynamic Delft3D 4 model that simulates the dispersion of the Terneuzen cooling water discharge, together with additional existing discharges in the area. This (detailed) model was set up around the Terneuzen project area and nested in the in-house available models of the Western Scheldt. When submerged outfalls were considered, the Delft3D model was dynamically coupled to a database of near-field results of CORMIX. With this coupled modelling system it was possible to simulate different intake and outfall configurations, plant capacities, and discharge characteristics under various ambient conditions relevant for the applicable environmental temperature criteria and forcings that affect the plume dispersion.

The main information and results are summarised below and based on this, the following main conclusions are drawn:

Project information

- For the present first assessment of different Terneuzen cooling water configurations, only the CIW 2004 (temperature) mixing zone and average temperature increase criteria were used:
    - Mixing zone. For the Western Scheldt the mixing zone is defined as the 25 °C temperature contour. The cross-sectional area covered by the mixing zone should be less than 25% of the total cross-sectional area. This criterion should be fulfilled 98% of the time. In tidal harbours the mixing zone is defined as the 30 °C temperature contour. Here the same criterion applies that any cross-sectional area covered by the mixing-zone should be less than 25% of the total cross-sectional area.
    - Average temperature increase. The average temperature of the water body may not increase by more than 2 °C and/or increase above 25 °C.
    - Ambient water temperature. The 98th-percentile ambient temperature at Bath (the edge of the Western Scheldt at the border between the Netherlands and Belgium) is 22.5 °C. With this 98th percentile background temperature the mixing zone definition (relative to background conditions) is the +2.5 °C contour.
- It is noted that compliance with possible other criteria (e.g., on other water parameters) would need to be evaluated in a full environmental impact assessment study in a next phase of the project. For a complete overview of the environmental criteria, see Deltares (2023).
    - 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 Terneuzen plant were selected.

  - For this study, 5 different intake and outfall configurations were considered. These 5 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 capacity, 3 different combinations of flowrate and temperature increase between the intake and the outfall were assessed: i) a discharge of 205 m^3/s and a temperature increase of +7 °C, ii) a discharge of 159.5 m^3/s and a temperature increase of +9 °C and iii) a discharge of 119.5 m^3/s and a temperature increase of +12 °C.
- A lower thermal discharge capacity of 4000 MW_{th} was also evaluated, with a discharge characterized by Q=106.5 m3/s and temperature increase of +9 °C.
- An overview of the simulated scenarios is presented in the below figure and table.

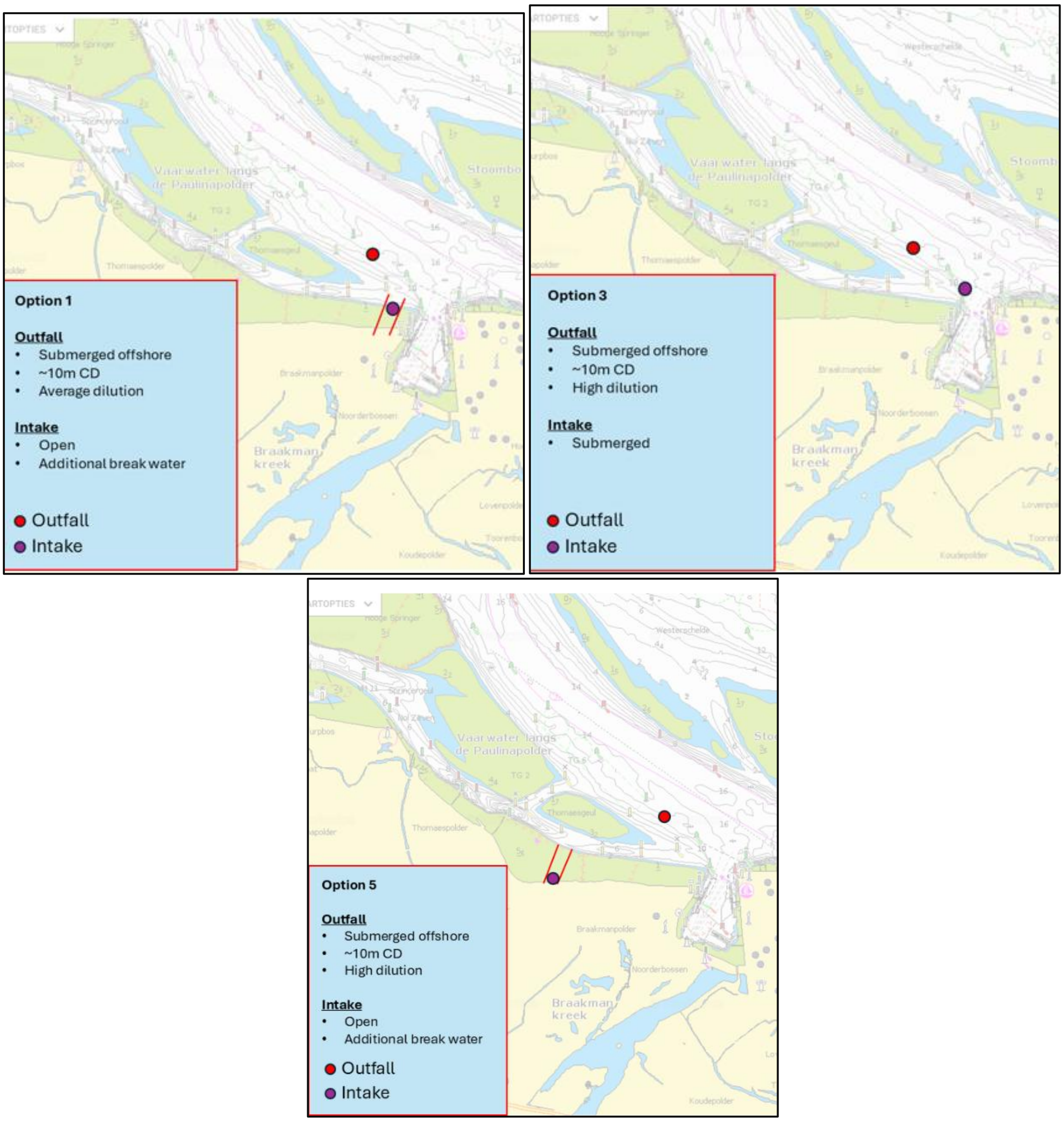

Figure 5-1 Different Terneuzen power plant intake and outfall configurations modelled in this assessment. Only Configurations 1, 3 and 5 are shown, noting that Configurations 2 and 4 are the inverse of Options 1 and 3.

Table 5-1Overview of simulated scenarios

Case	Thermal Capacity (MW_{th})	Discharge rate / Temperature increase	Intake/Outfall Configuration	**Description**
0	-	-	-	Present situation
1	6000	159.5 m^3/s +9 °C	1	Open intake at the shoreline, submerged outfall 1.5 km offshore in the Western Scheldt close to the main navigation channel.
2	6000	159.5 m^3/s +9 °C	2	Submerged intake 1.5 km offshore in the Western Scheldt close to the main navigation channel, open outfall at the shoreline (reverse of configuration 1).
3	6000	159.5 m^3/s +9 °C	3	Submerged intake in the Western Scheldt close to the Braakmanhaven, submerged outfall 1.5 km offshore in the Western Scheldt.
4	6000	159.5 m^3/s +9 °C	4	Submerged intake 1.5 km offshore in the Western Scheldt, submerged outfall in the Western Scheldt close to the Braakmanhaven (reverse of configuration 3).
5	6000	205.0 m^3/s +7 °C	1	Case 1, but higher discharge rate, lower excess temperature (with respect to case 1).
6	6000	119.5 m^3/s +12 °C	1	Case 1, but lower discharge rate, higher excess temperature (with respect to case 1).
7	4000	106.5 m^3/s +9 °C	1	Case 1, but lower thermal discharge capacity.
8	6000	159.5 m^3/s +9 °C	1	Case 1, but optimised outfall design (i.e. increased near-field mixing)
9	6000	159.5 m^3/s +9 °C	5	Case 1 / Configuration 1, but intake located 2 km to the West.

- 4 existing thermal discharges were included in this assessment to assess the cumulative plume dispersion and recirculation in the Terneuzen area. These 4 discharges include the N.V. Elektriciteits Productiemaat-schappij Zuid-Nederland (EPZ), Sloe Centrale BV, Zalco BV and Dow Benelux BV.

Plume behaviour

- Due to the buoyancy of the warmer cooling water, the thermal plume is expected to rise to the surface and spread in NW and SE direction by the tidal flow.
- Submerged outfalls (as opposed to open outfalls) rapidly mix the cooling water with ambient water, effectively reducing the temperature increase around the outfall.
- For submerged outfalls, the computed maximum extent of the mixing zone (+2.5 °C contour) *near the surface* is about 3 km in the NW direction and between 4 - 5 km in the SE direction, whereas *near the bottom* the computed mixing zone reaches a maximum distance of less than 1 km from the outfall location.
- The submerged diffusers modelled in Cases 1, 3, 6 and 9 return similar maximum mixing zone extents at the surface and bottom layers of the water body. Diffusers modelled in Cases 4, 5, 7, and 8 return a different plume extent: Case 4 shows that the diffuser’s proximity to the port of Terneuzen results in a computed mixing zone that extends into the port; and Case 5 (reduced discharge temperature), Case 7 (lower operation capacity – 4000 MWth) and Case 8 (optimized near-field mixing) shows a smaller computed mixing zone extent, especially *near the bottom* in the order of ~500 m in either flow direction.
- The modelled open outfall (Case 2), results in a computed plume extent *near the surface* of about 7 km in both NW and SE directions, whereas *near the bottom* the computed mixing zone reaches a maximum distance of 7 km in the NW direction and 2 km in the SE direction. In both surface and bottom layers, the computed mixing zone extends into the

Terneuzen port (Braakmanhaven). The larger extent of the thermal plume modelled in this scenario – with respect to the submerged diffusers – is due to the lower dilution in the near-field close to the outfall.

Environmental criteria

- Two different sets of cross-sections were used to assess the compliance with the CIW criteria: one that covers the entire width of the Western Scheldt, and a second set that covers only the main channel where the effluent is discharged (i.e. the southern part of the Western Scheldt). This distinction is made due to uncertainty in the interpretation of the CIW criteria with respect to the cross-sectional area and presence of tidal flats in the middle of the Western Scheldt.
- When evaluating environmental compliance *with the full cross-sectional area of the Western Scheldt*, the maximum computed cross-sectional area covered by the mixing zone is around or below 10% for all cases except for Case 4, where the maximum covered cross-sectional area is about 20%. These values are all lower than the critical threshold value of the CIW criteria (i.e., 25%). Moreover, the computed cross-sectional average temperature increase in the water body is typically about 1 °C and remains below the 2 °C limit value.
- The following conclusions hold when evaluating the environmental compliance *with the cross-sectional area of the main channel:*
  - The maximum computed cross-sectional area covered by the mixing zone in Cases 1, 3, 5, 6, 8 and 9 is around 25% - the CIW threshold value. Cases 2, 4, and 7 return a different computed covered percentage, namely:
    - Case 2 (open outfall): maximum cross-sectional cover below 20%. Although the open outfall results in higher temperatures near the discharge point, it affects a smaller cross-sectional area compared to the submerged diffuser options, making it more favorable with respect to this CIW criterion.
    - Case 4 (outfall in the main channel close to the Terneuzen port / Braakmanhaven): maximum cross-sectional cover of 35%.
    - Case 7 (reduced thermal load): maximum cross-sectional cover of 15%.
  - Case 5 (reduced discharge temperature) and Case 8 (increased initial mixing) reduce the percentage of the cross-sectional area covered by the mixing zone compared to Case 1. While computed values of Case 5 and 8 are still above the critical value of 25%, combinations of these design alternatives can be used to further reduce the mixing zone of the cooling water discharge.
  - The computed cross-sectional average temperature increase in the water body is typically between 1 °C and 1.8 °C for all cases, except for Case 4 where the criterion of 2 °C is temporarily reached.

Recirculation potential

- Different intake locations were evaluated per modelled case. Cases 1, 5, 6, 7 and 8 evaluate the same intake location (open intake). Cases 2 and 4 assess the same submerged intake location. Case 3 has a submerged intake near the port entrance. In Case 9 the intake is situated more to the West compared to, for instance, Case 1.
- Regardless of the proposed location of the Terneuzen intake, the computed *average* temperature increase at the intake is about 1° C in all cases, while the computed *maximum* is about 1.5 °C – except for Case 2 and Case 4 for which a maximum temperature increase of 1.8 °C and 2.1 °C is computed, respectively.
- The computed additional average temperature increase at the existing intakes located in the Borssele area (EPZ, Sloe centrale and Zalco) is about 0.5 °C or less due to the Terneuzen nuclear power plant. At the existing intake located in the Braakmanhaven (Dow Benelux), the computed additional *average* temperature increase ranges from 0.7 °C to 2.2 °C (from 0.2 °C in Case 0 to 0.9 – 2.4 °C above background conditions), while

the *maximum* computed temperature increase ranges from 0.9 °C to 3.1 °C (from 0.3 °C in Case 0 to 1.2 – 3.4 °C above background conditions).

6 References

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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.

	DowBenelux BV		**EPZ**		**SloeCentrale BV**		**Zalco BV**		**Terneuzen**	
	mean	max	mean	max	mean	Max	mean	max	mean	max
Case 0	0.2	0.3	0.2	0.4	0.3	0.6	0.4	0.6	-	-
Case 1	1.1	1.5	0.6	1.1	0.5	0.9	0.5	0.9	1.2	1.4
Case 2	1.8	2.3	0.5	0.9	0.4	0.8	0.5	0.8	0.9	1.8
Case 3	1.1	1.5	0.6	1.1	0.5	0.9	0.5	0.9	1.2	1.6
Case 4	2.4	3.4	0.5	1.0	0.5	0.8	0.5	0.9	1.0	2.1
Case 5	1.1	1.5	0.6	1.1	0.5	0.9	0.5	0.9	1.2	1.5
Case 6	1.1	1.8	0.6	1.1	0.5	0.8	0.5	0.9	1.2	1.6
Case 7	0.9	1.2	0.5	0.9	0.4	0.8	0.5	0.8	0.9	1.1
Case 8	1.1	1.4	0.6	1.1	0.5	0.9	0.5	0.9	1.2	1.5
Case 9	1.1	1.5	0.6	1.1	0.5	0.8	0.5	0.9	1.1	1.5

B Mean temperature footprints

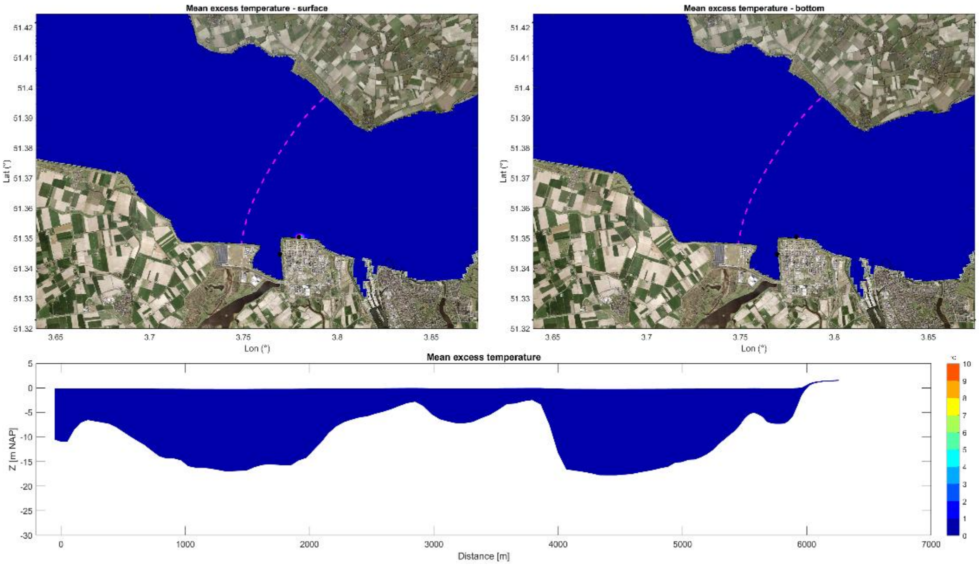

Figure B-1 Simulated mean temperature increase footprint due to the existing thermal discharges (Case 0).

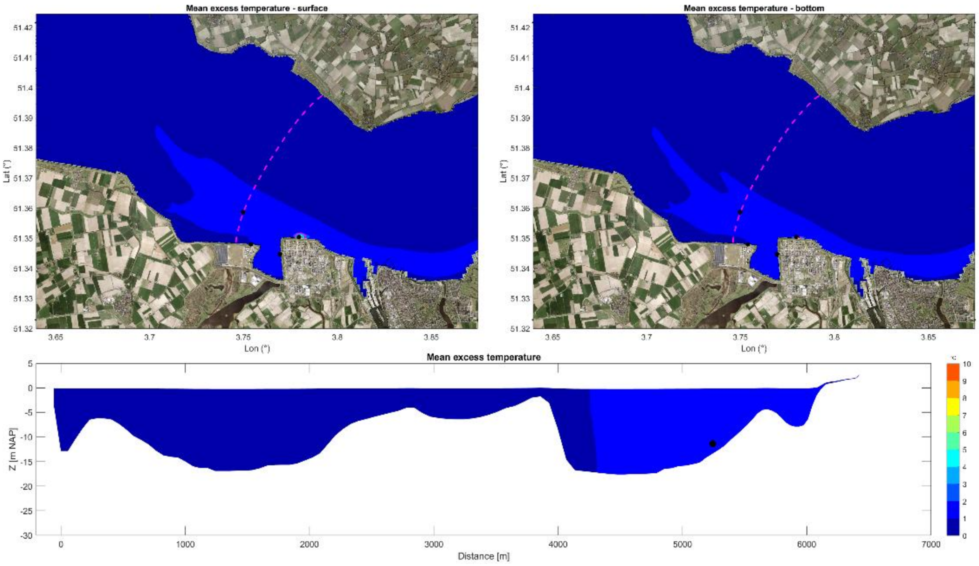

Figure B-2 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 1).

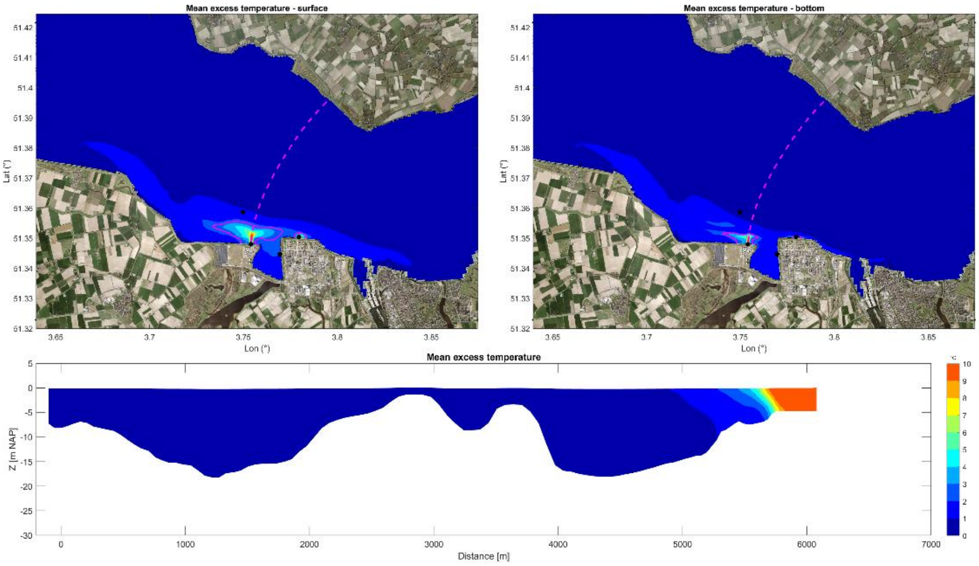

Figure B-3 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 2).

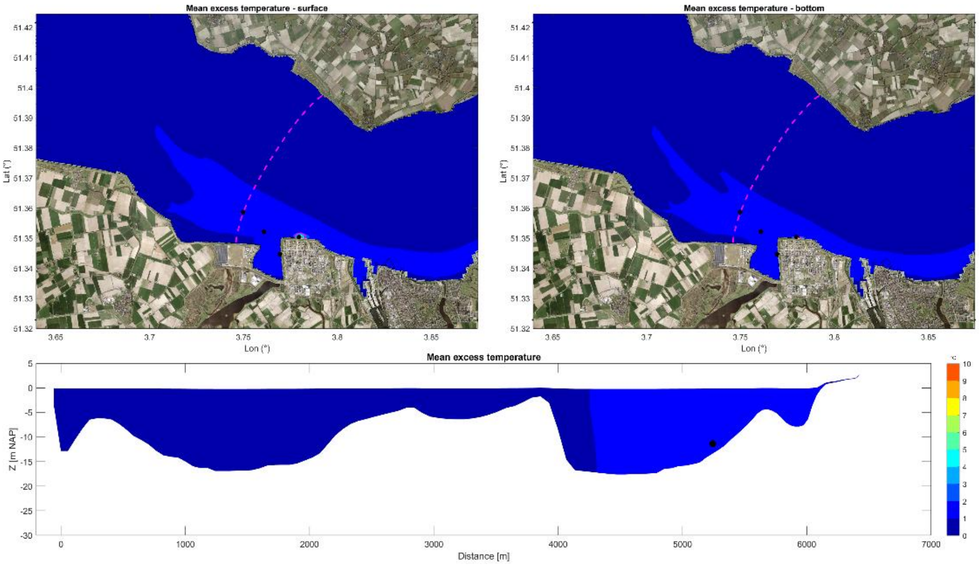

Figure B-4 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 3)

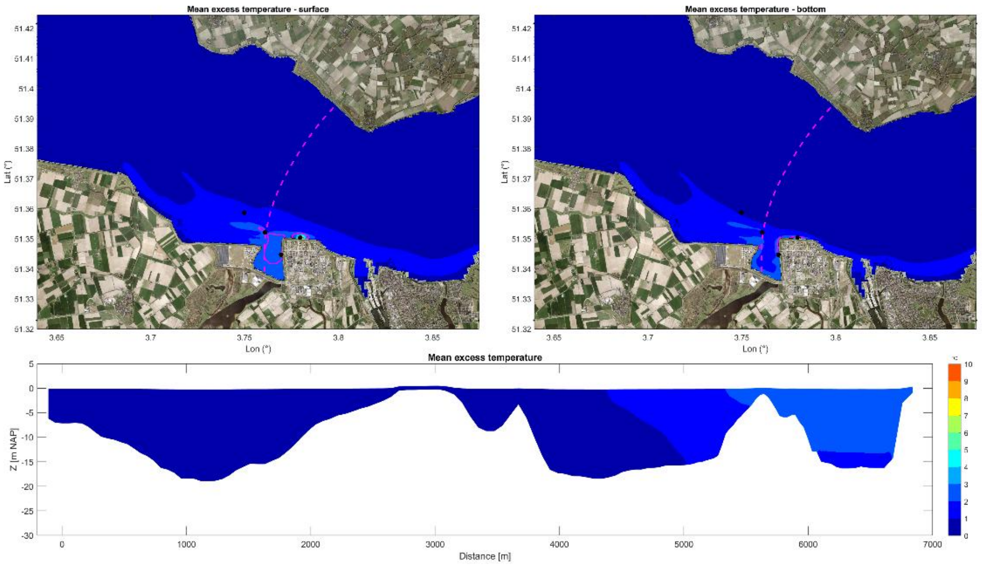

Figure B-5 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 4).

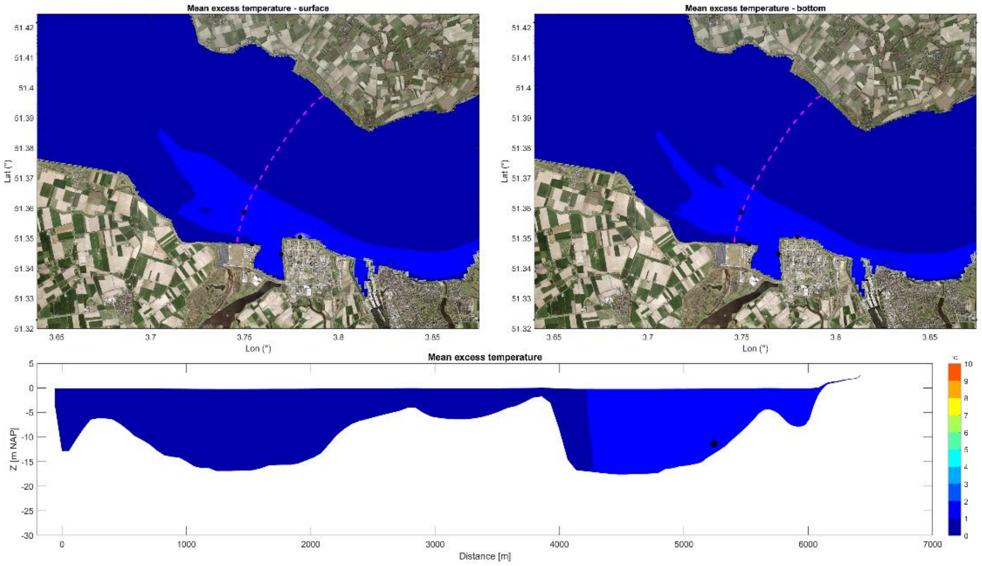

Figure B-6 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 5).

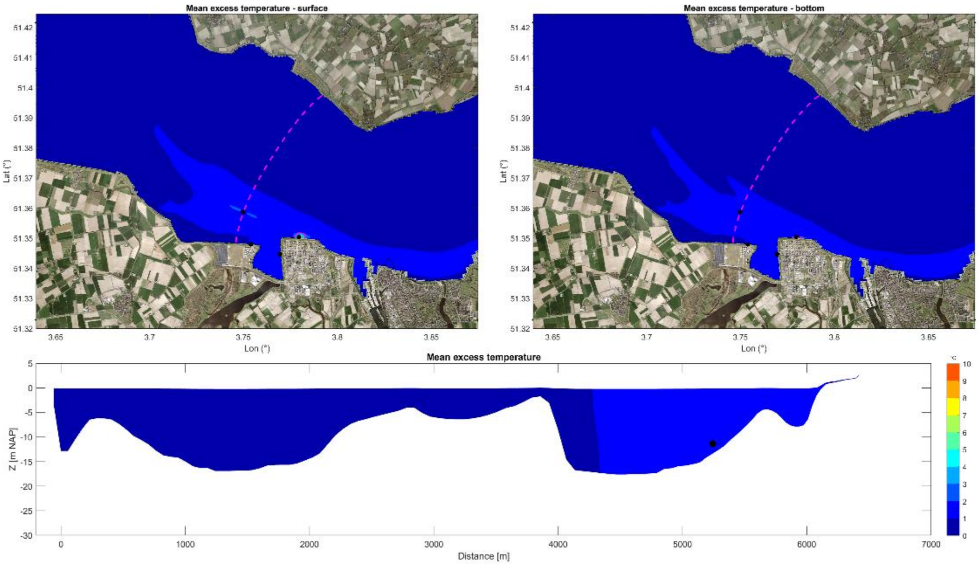

Figure B-7 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 6).

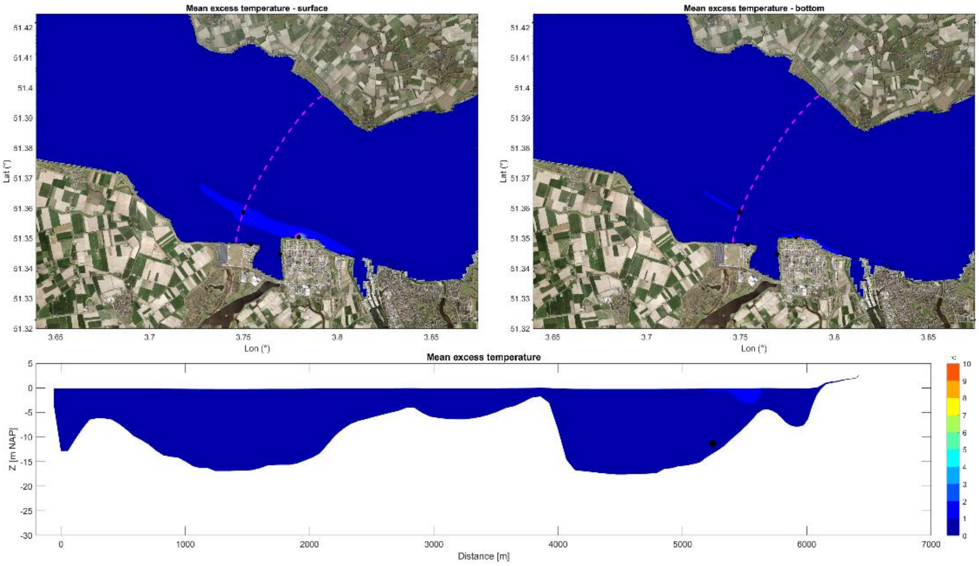

Figure B-8 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 7).

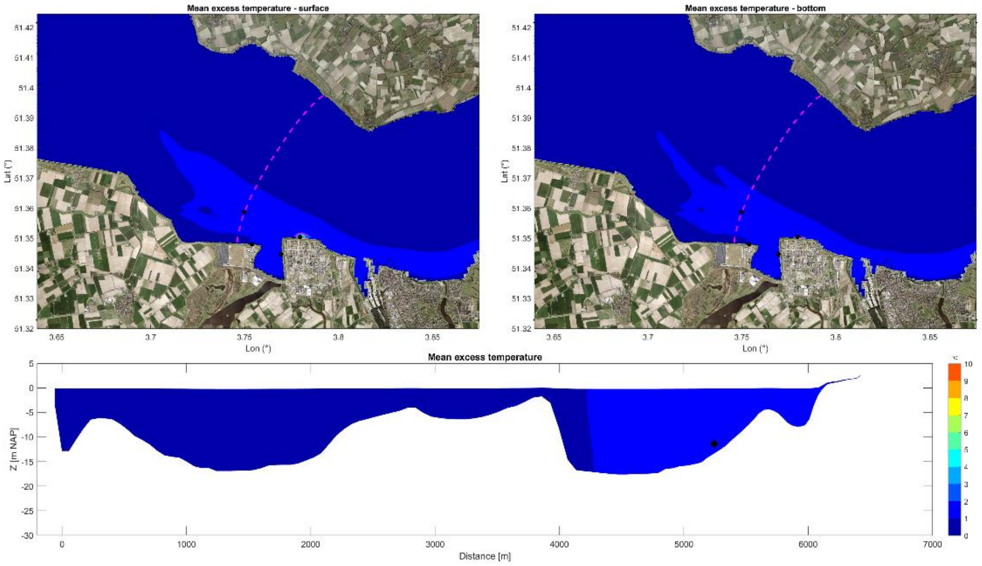

Figure B-9 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 8).

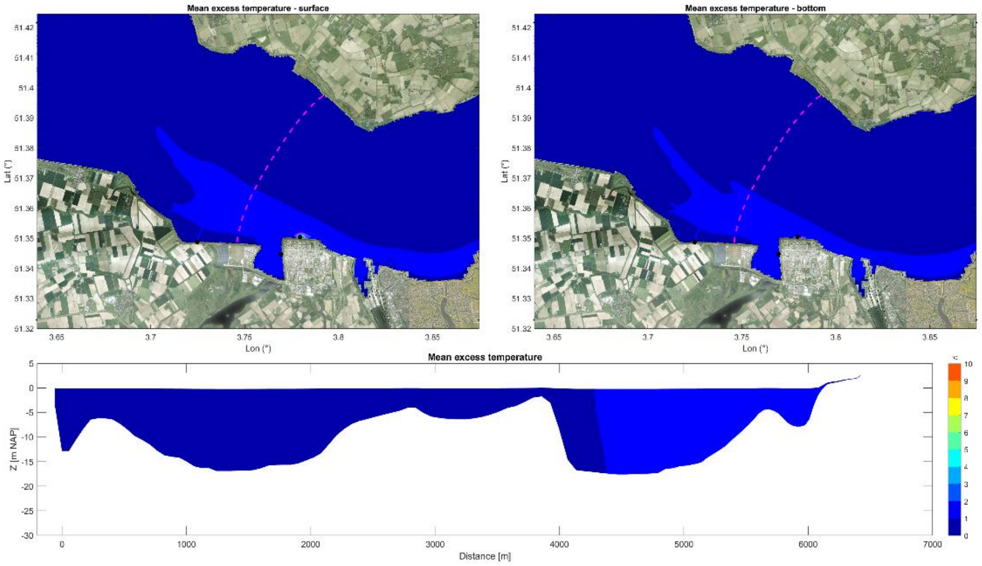

Figure B-10 Simulated mean temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 9).

C Maximum temperature footprints

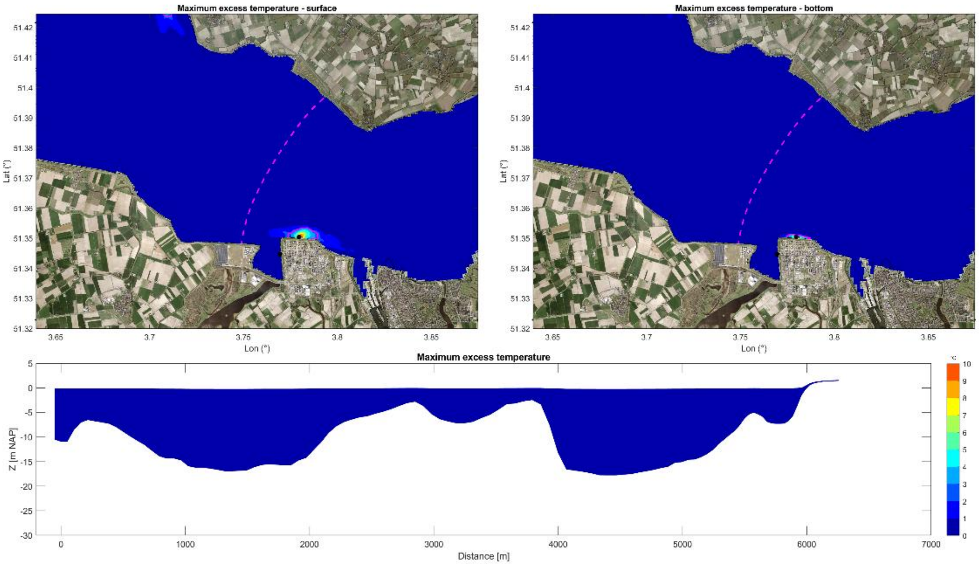

Figure C-1 Simulated maximum temperature increase footprint due to the existing thermal discharges (Case 0)

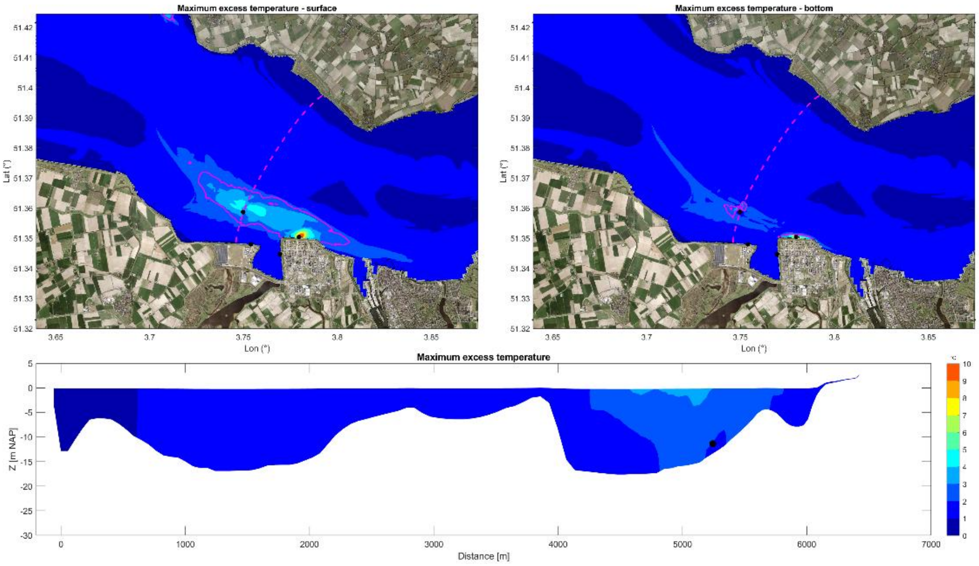

Figure C-2 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 1).

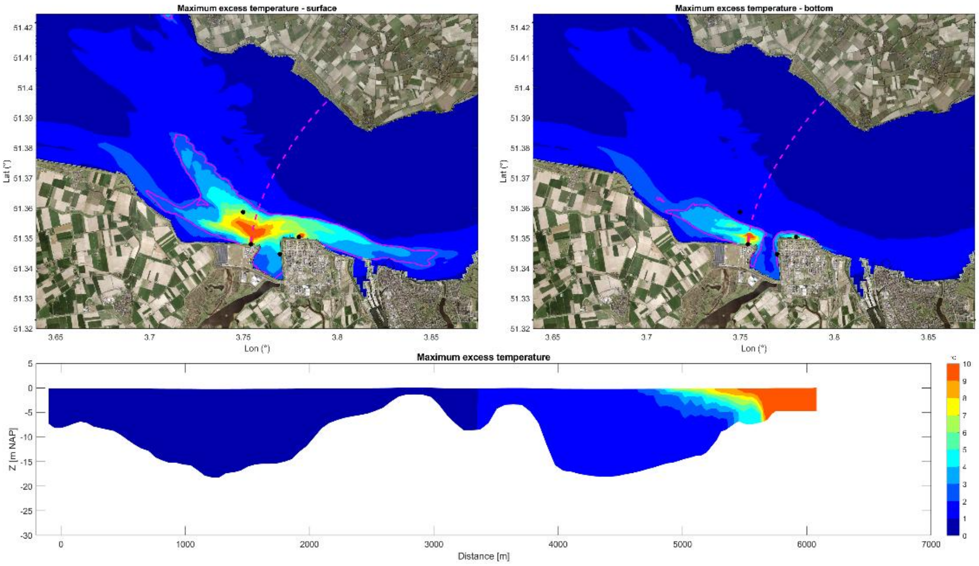

Figure C-3 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 2).

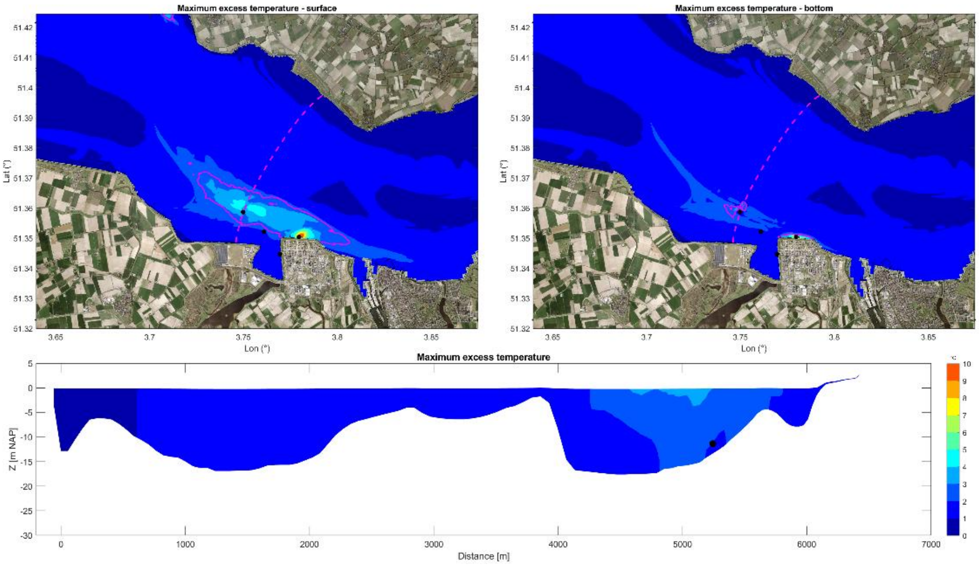

Figure C-4 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 3).

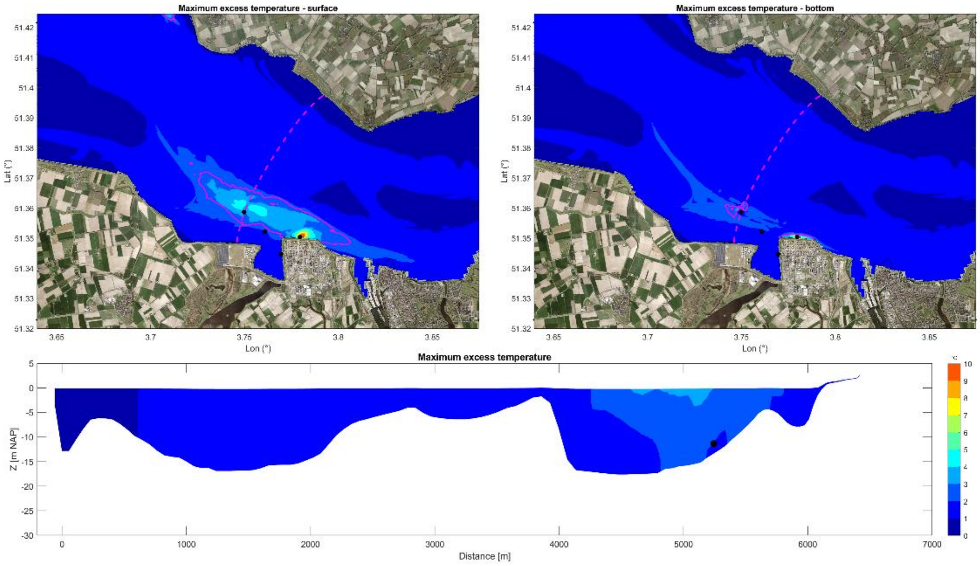

Figure C-5 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 4).

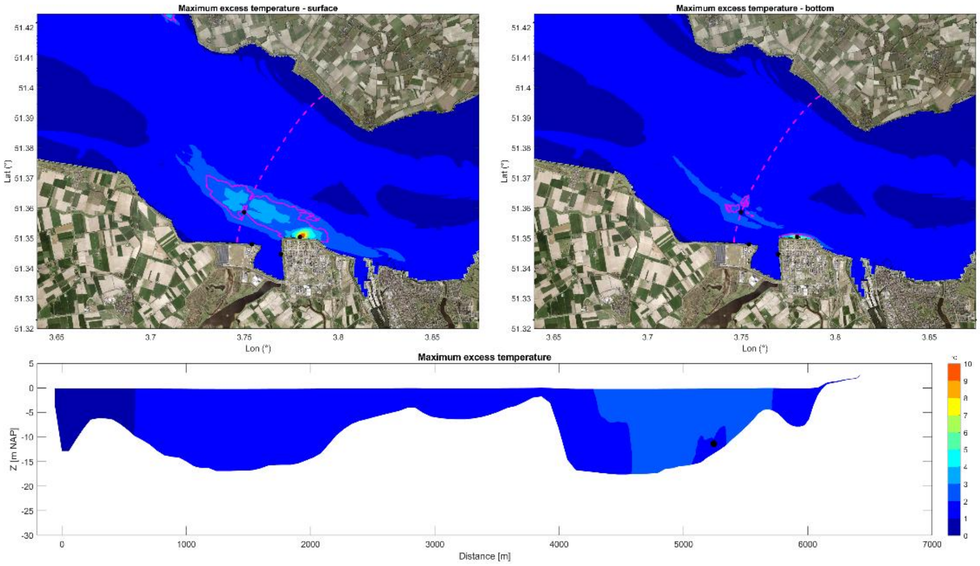

Figure C-6 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 5).

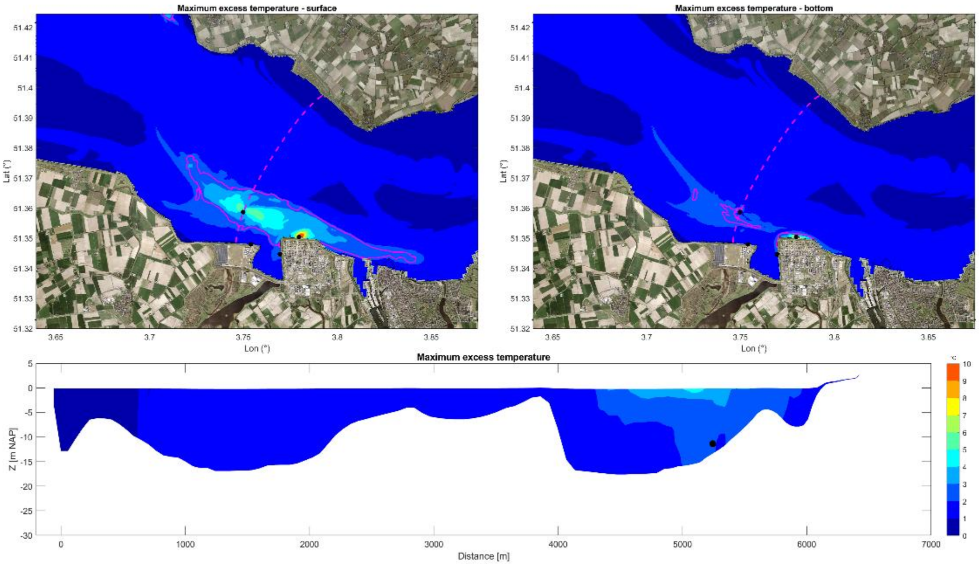

Figure C-7 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 6).

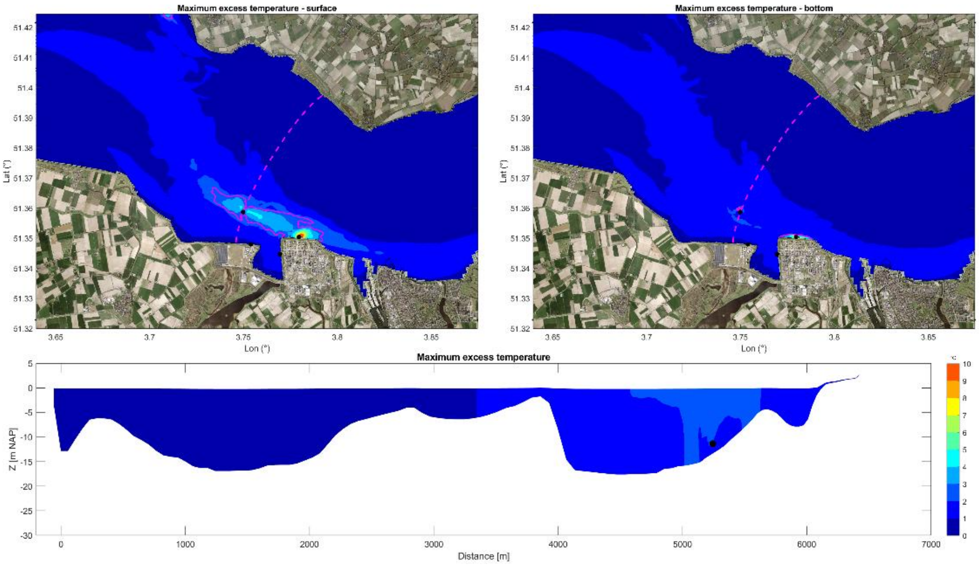

Figure C-8 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 7).

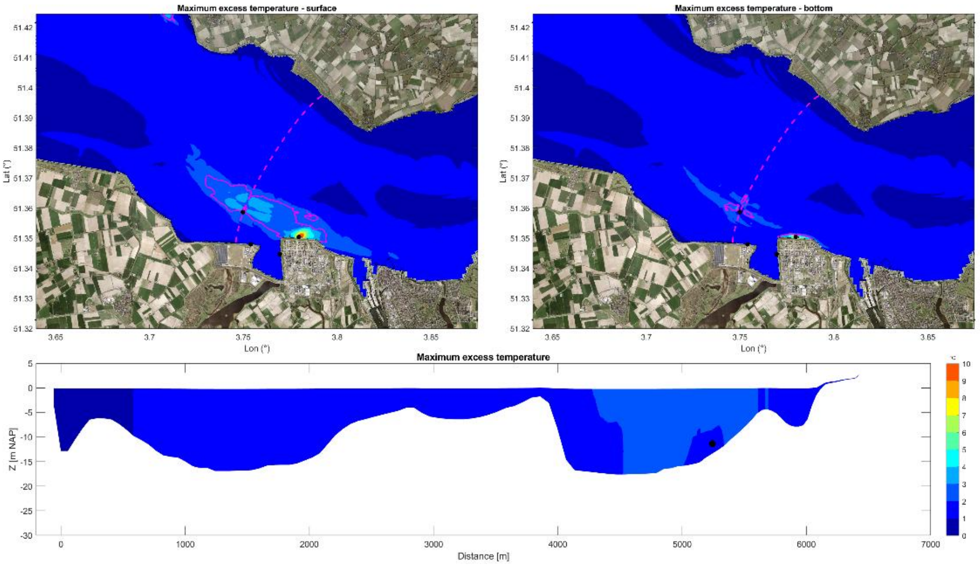

Figure C-9 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 8).

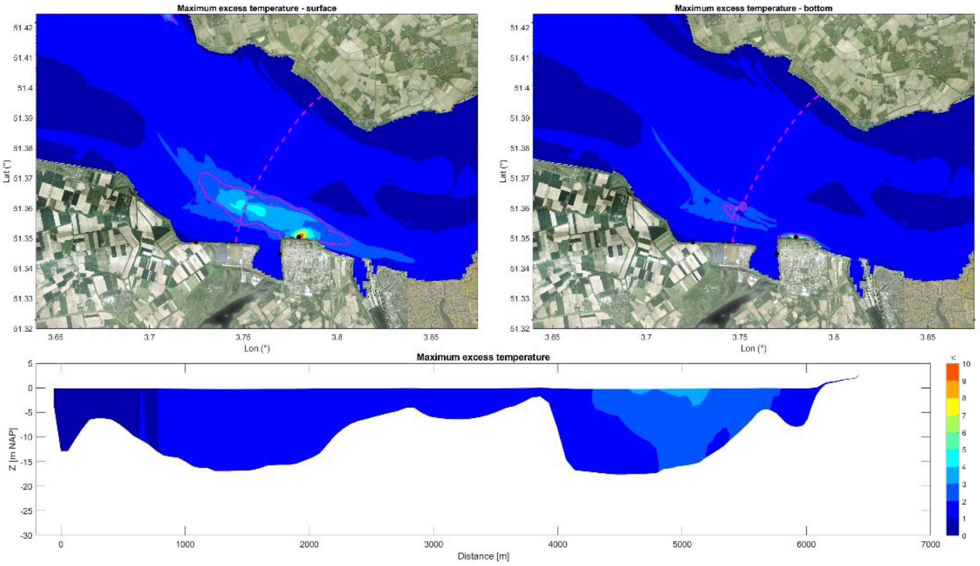

Figure C-10 Simulated maximum temperature increase footprint due to the existing thermal discharges and the new Terneuzen discharge (Case 9).

D CIW mixing zone and average temperature increase criterion

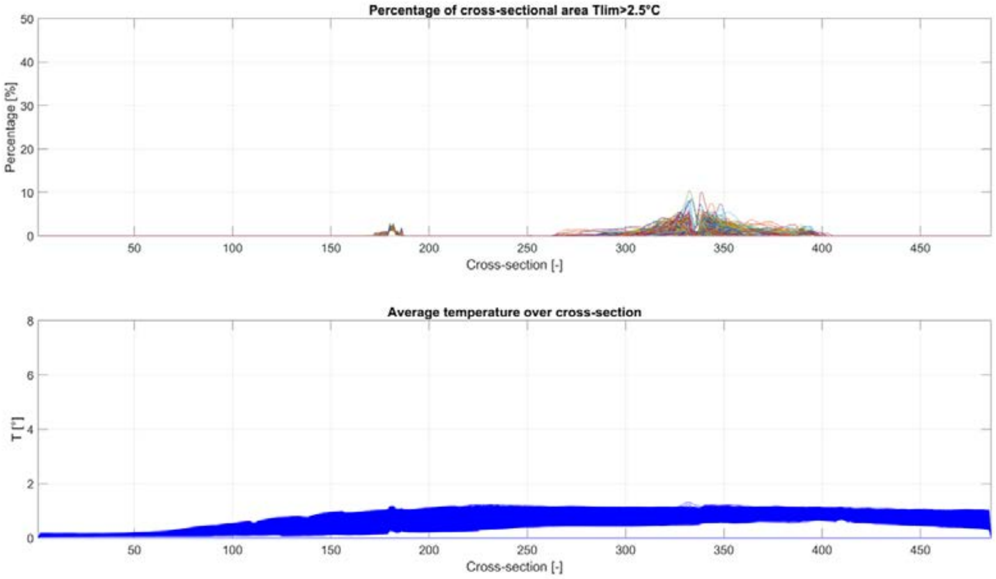

Figure D-1 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 1).

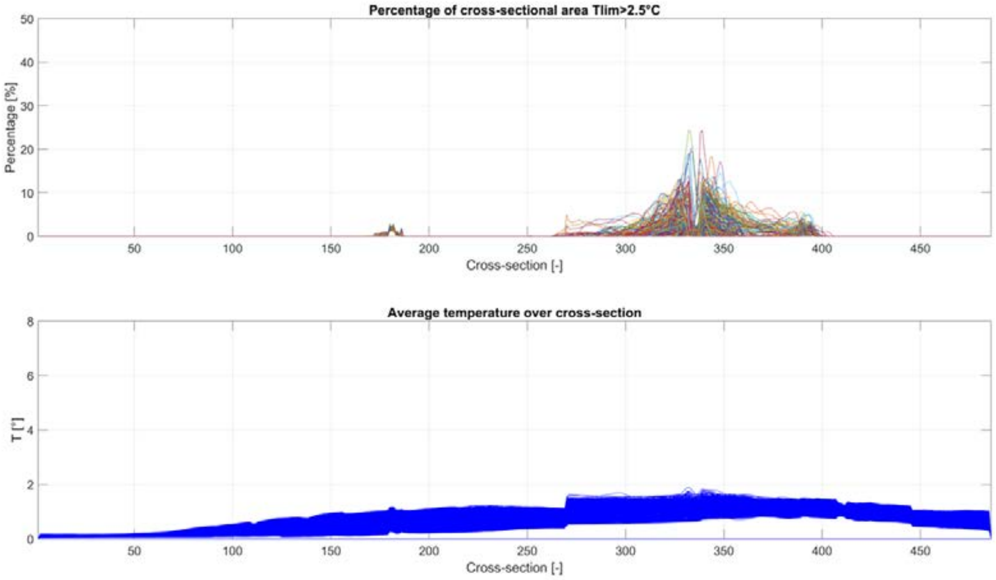

Figure D-2 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 1).

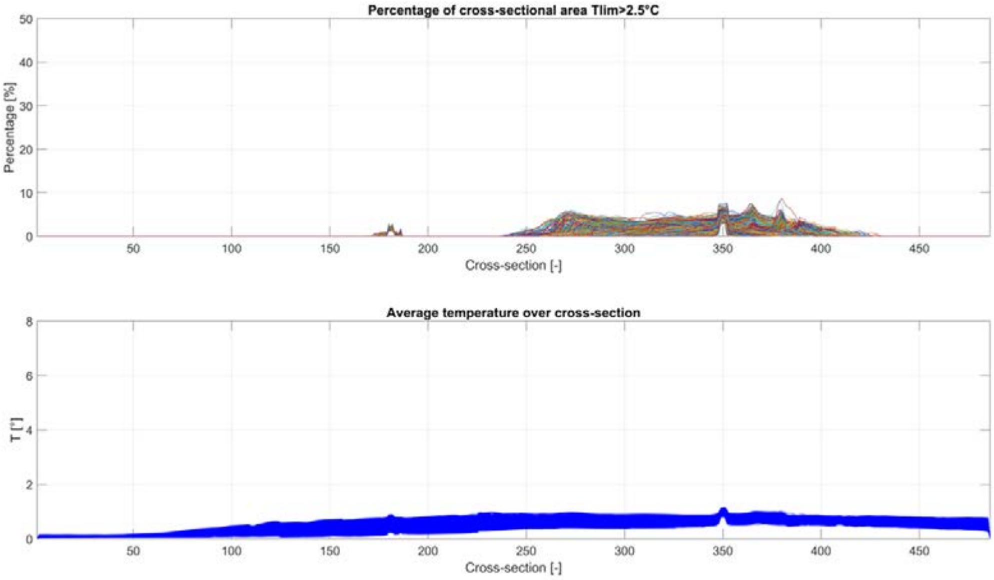

Figure D-3 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 2).

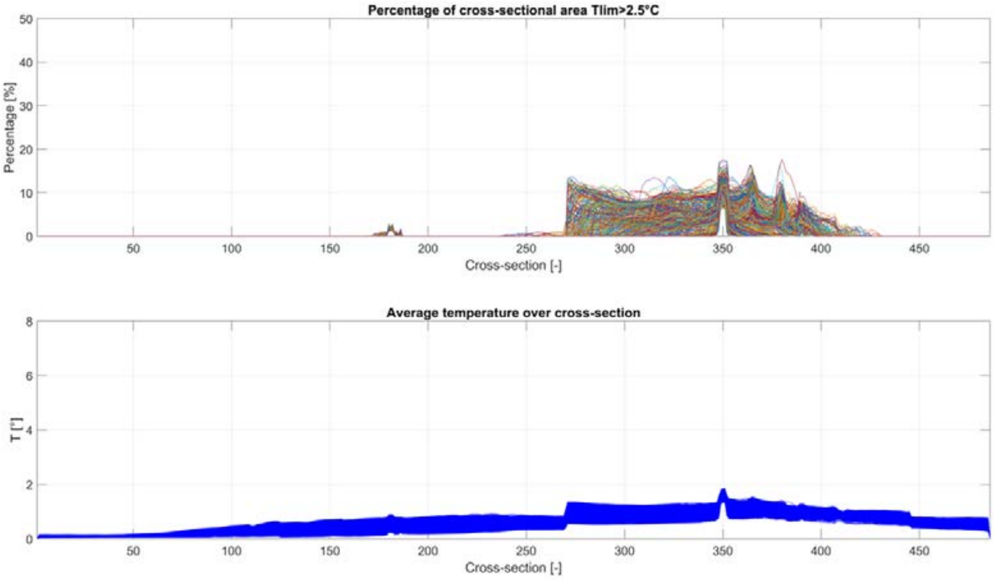

Figure D-4 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 2).

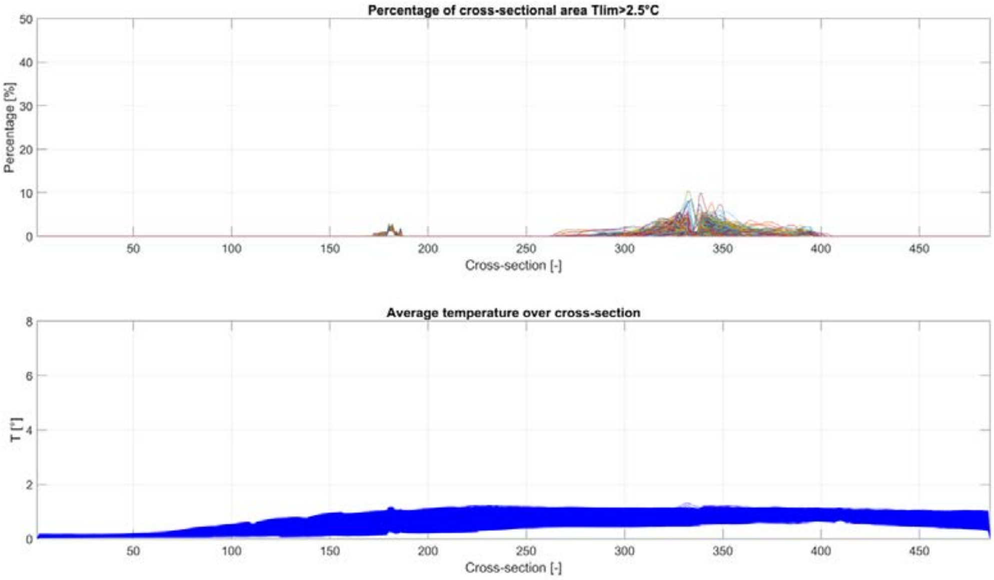

Figure D-5 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 3).

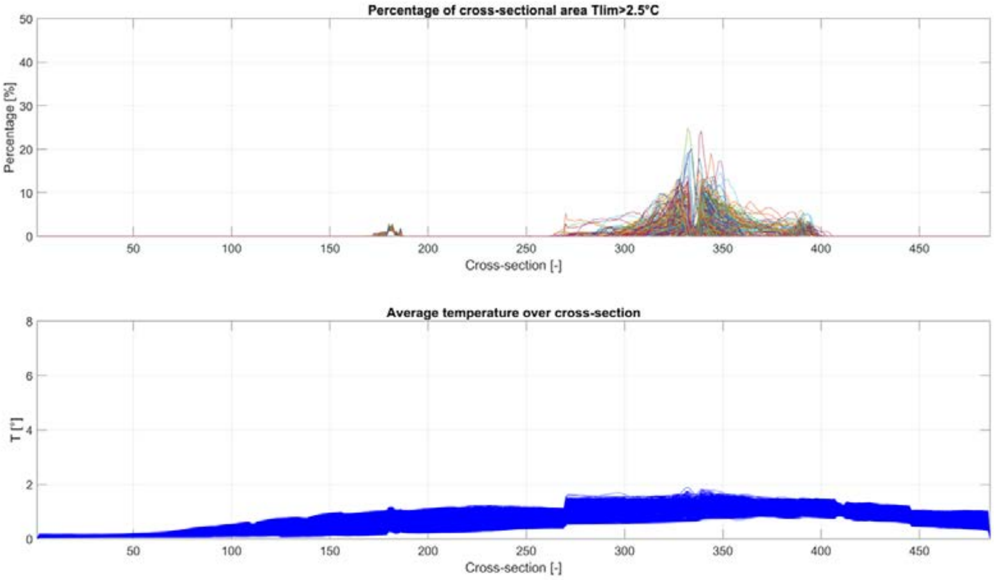

Figure D-6 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 3).

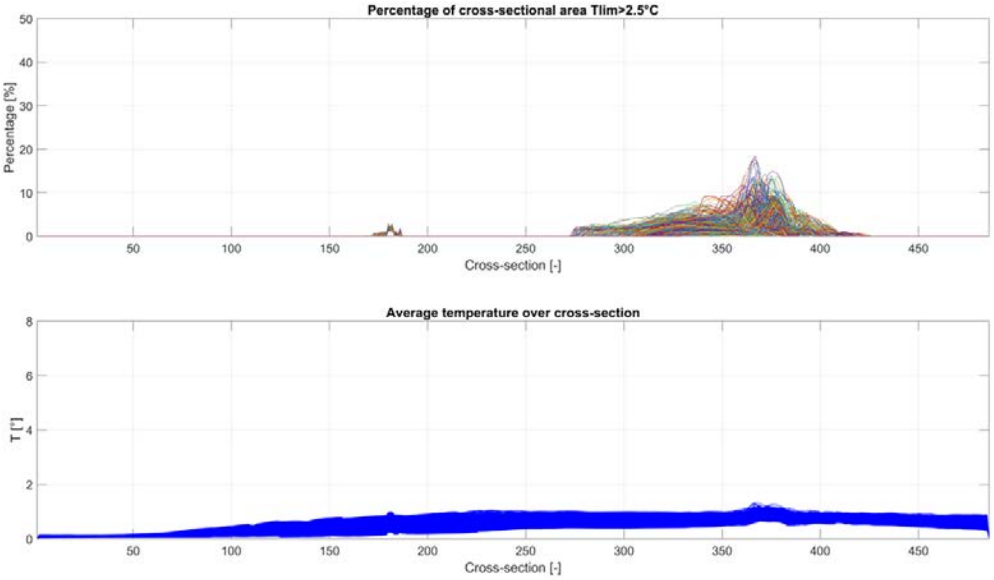

Figure D-7 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 4).

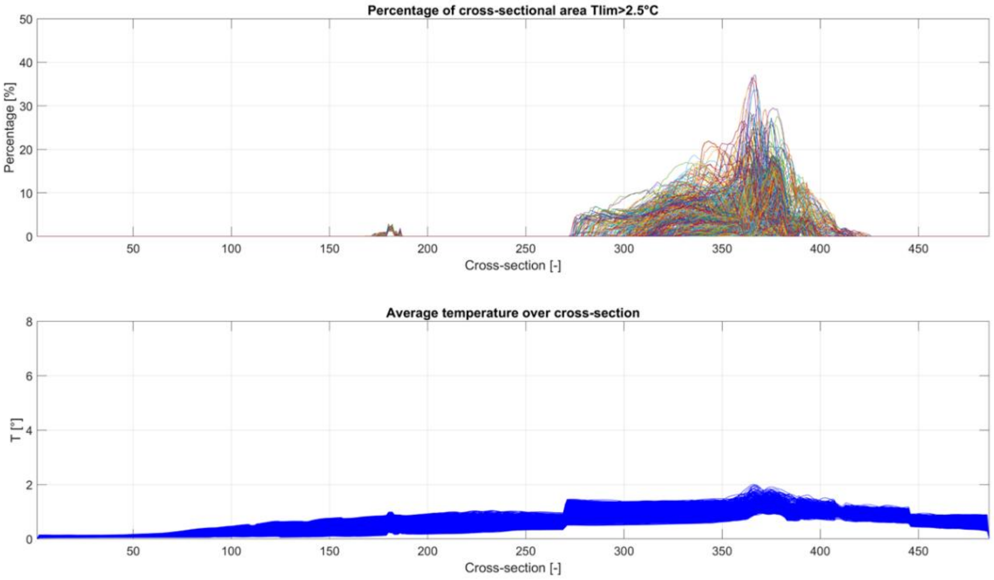

Figure D-8 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 4).

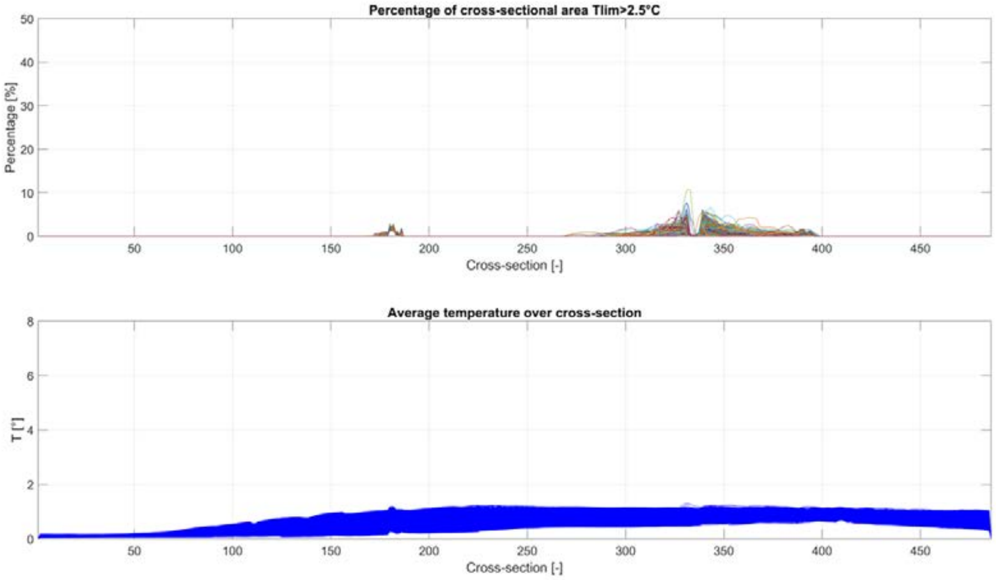

Figure D-9 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 5).

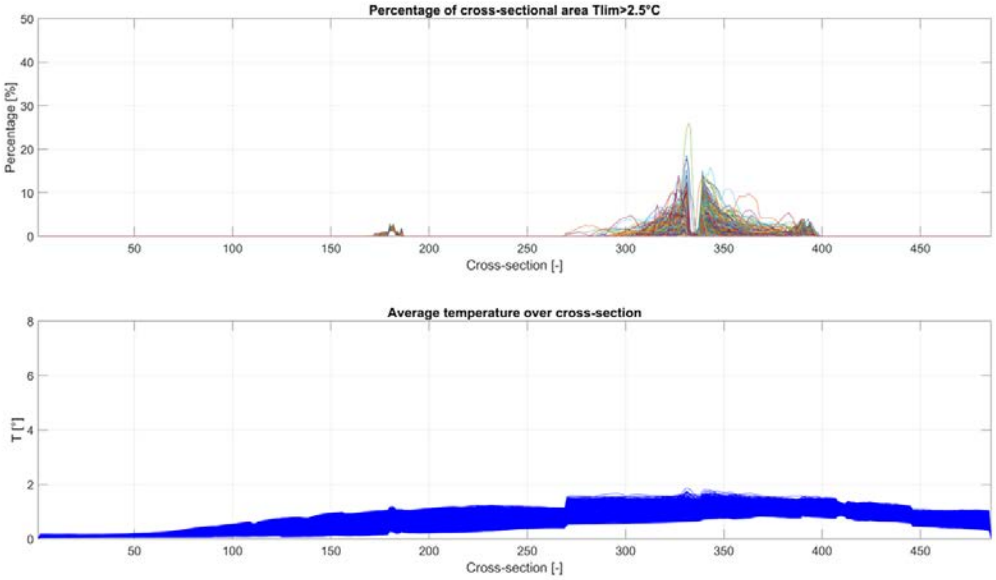

Figure D-10 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 5).

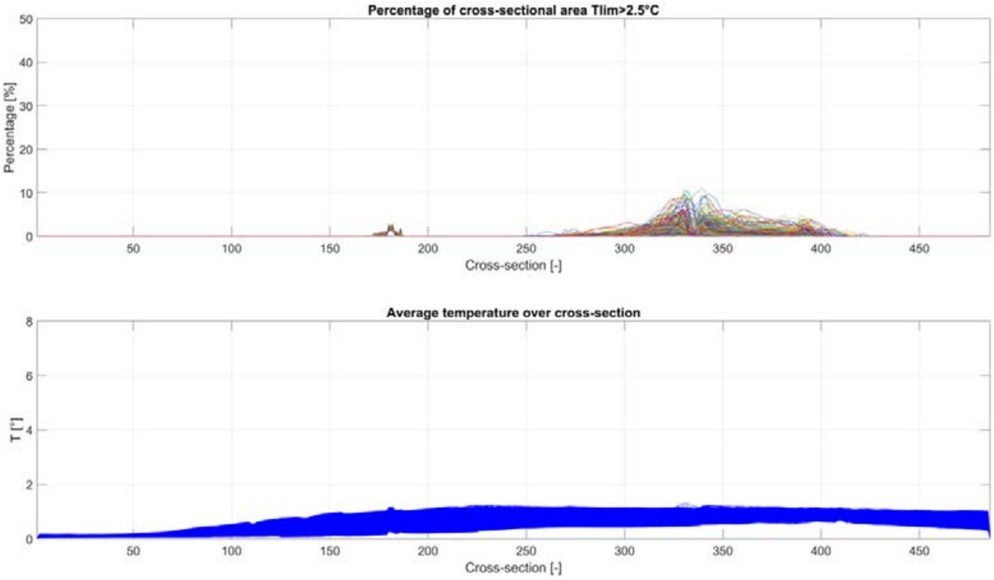

Figure D-11 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 6).

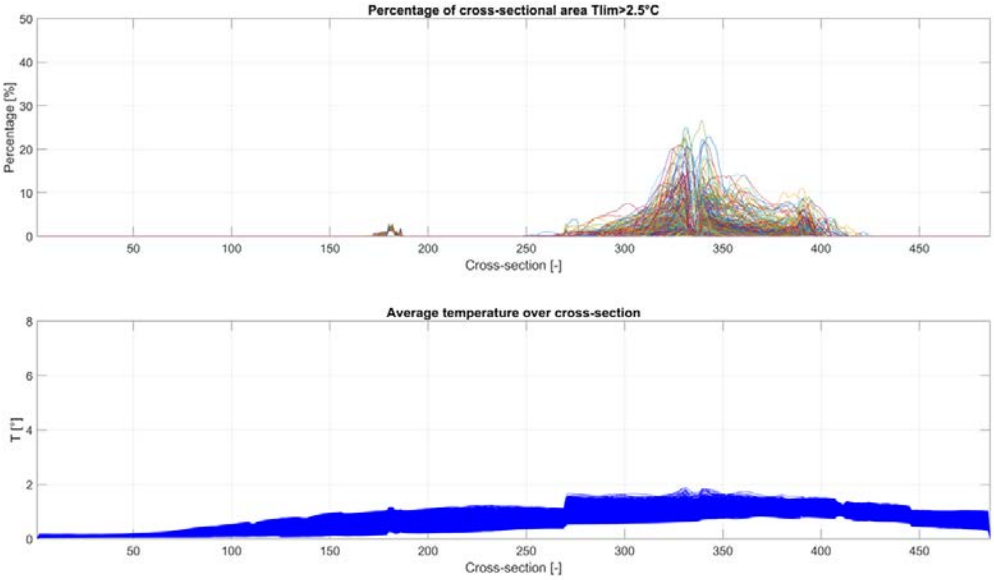

Figure D-12 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 6).

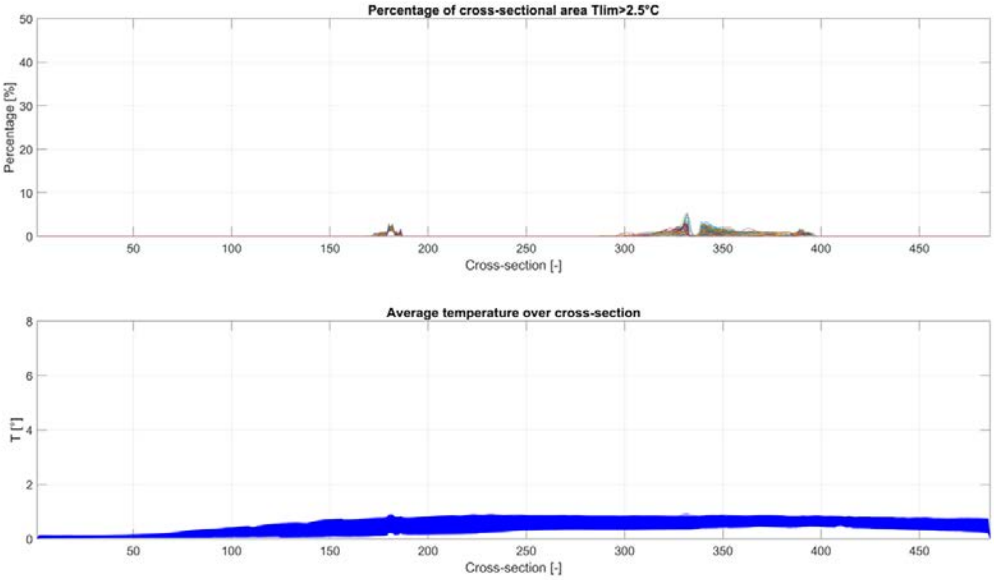

Figure D-13 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 7).

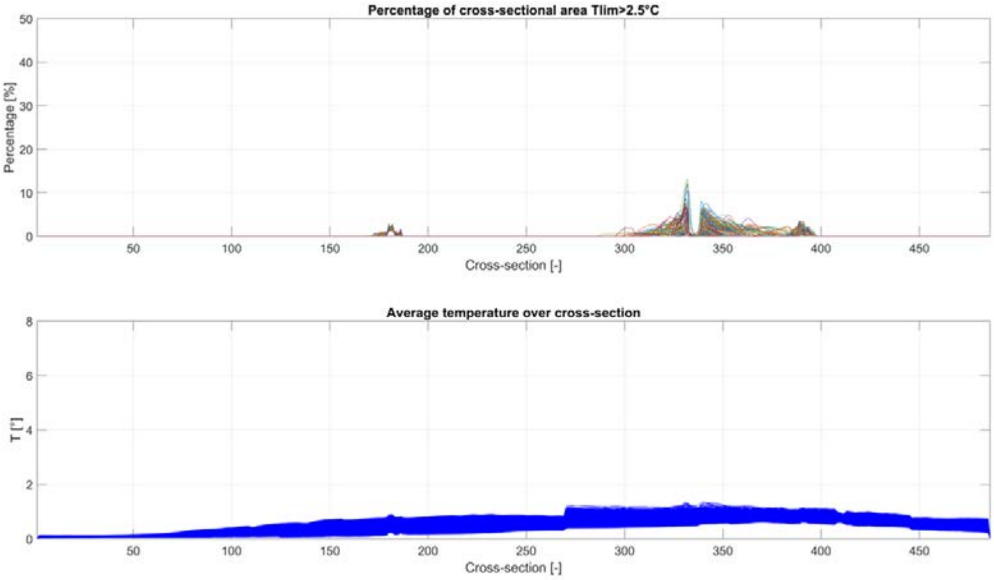

Figure D-14 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 7).

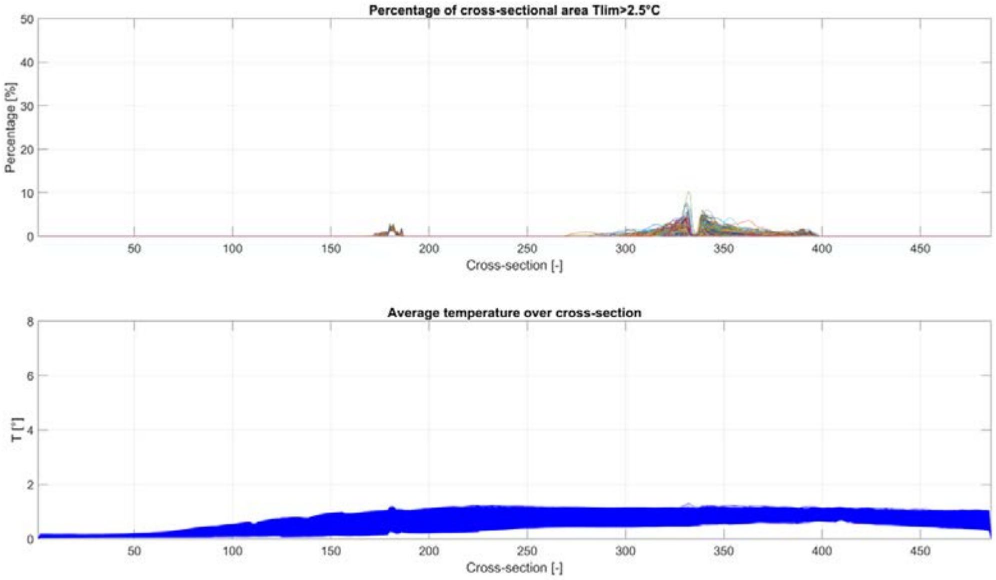

Figure D-15 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 8).

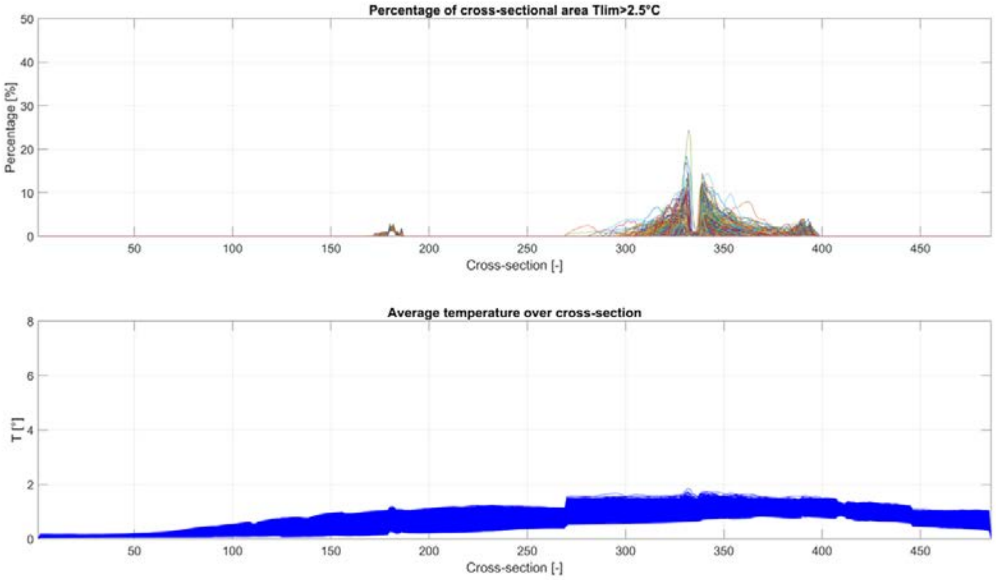

Figure D-16 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 8).

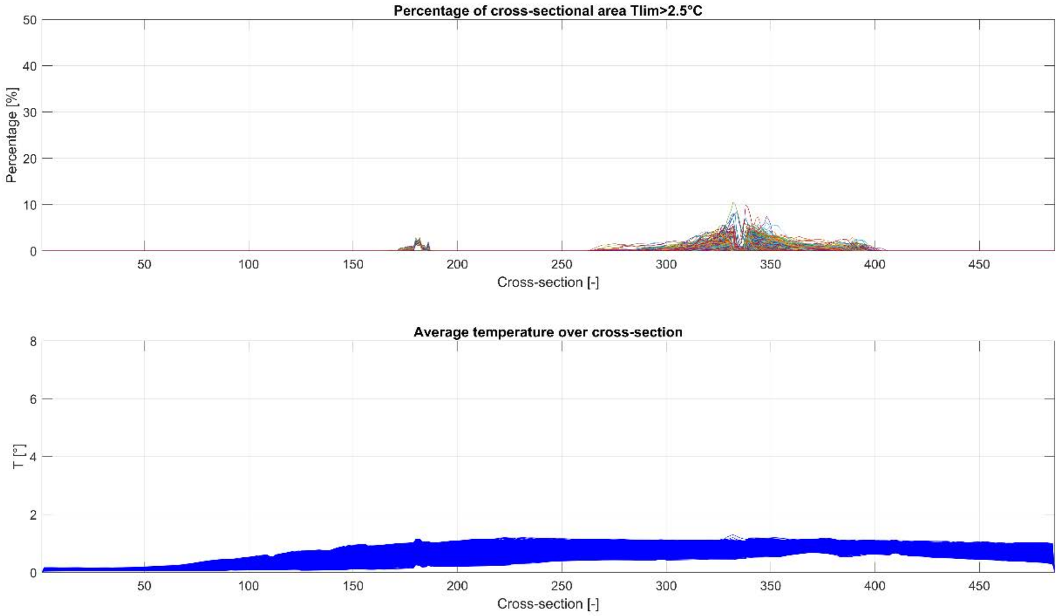

Figure D-17 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 1st set of cross-sections (Case 9).

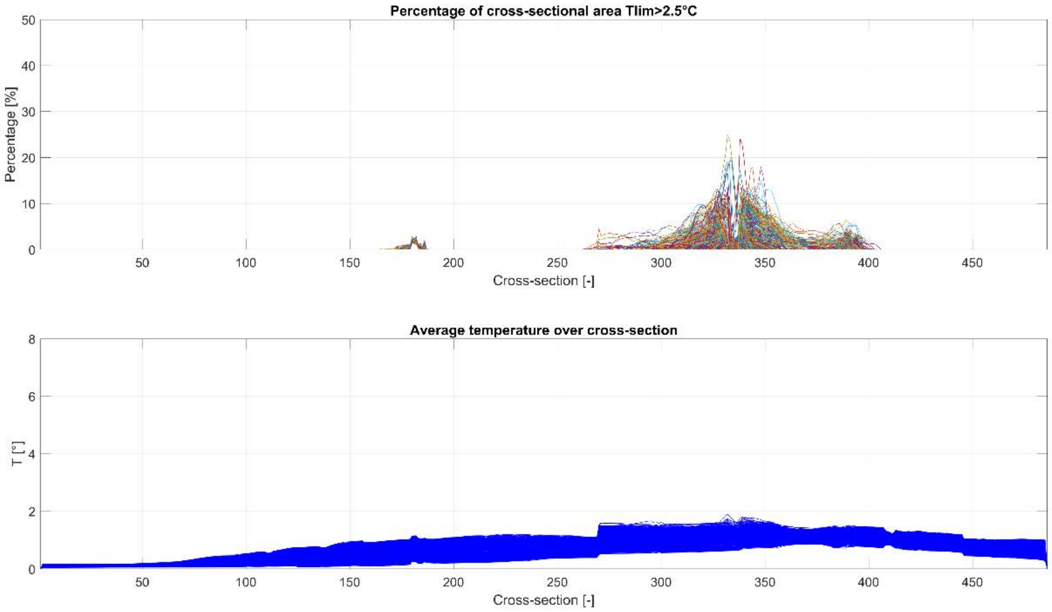

Figure D-18 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the 2nd set of cross-sections (Case 9).

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