Deltares

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Subject
Indication dike height nucleair power plants

Dear Sir, Madam,

For the design of new nucleair power plants nine potential sites across four locations are assessed according to the site selection proces (MER procedure): Sloegebied (Borssele), Terneuzen, Maasvlakte II, and Eemshaven. The power plants will be located on a platform, possibly protected by a dike ring. The Ministry of Economic Affairs and Climate (EZK) asked Deltares to provide an indication of the required crest level of a such a dike ring.

1 Introduction

Since the lead time for the foreseen study was short, in terms of only days, Hydra-NL has been used to determine the required crest levels. This required a number of assumptions and simplifications, related to the schematization, sea level rise, critical overtopping discharge, etc. Some of them have been mentioned in Par 2.3. A more fundamental assumption is that storms are the major hazards and the effect of tsunamis or earthquakes can be neglected. Once more details about the design of a dike ring is known, these aspects can be taken into account more accurately. Therefore, the calculated required crest levels in Chapter 2 are explicitly not suited for use in a final design of a dike as flood protection of the power plant or for licensing purposes of these developments. These should be treated as indicative figures, similar to the results from the 'very preliminary Hydra-NL computations' in Deltares (2024).

The indicative figures may be used in a first estimate of the required amount of space for a flood protection of the power plant at the different sites. This may provide relevant information on the possibilities for the layout of the area at the different sites and thus for a comparison of the suitability of the sites by Antea (MER) or Ammentum (review of the Technical feasibility).

For further refinement of the flood protection design, the recommendations in Deltares (2024) and (2025) should be followed.

In the following (Chapter 2) a brief description of the Hydra-NL computations for the determination of required crest level is given, followed by the setup and results of the computations.

2 Hydra-NL computations

2.1 Determination of required crest level

Given a dike profile and a critical overtopping discharge it is possible to determine the required crest level for various return periods. This is an iterative process in which the required crest level is adapted until the probability that the amount of overtopping exceeds the critical overtopping discharge equals the normative exceedance probability (inverse of the return period under consideration). The probabilistic software-tool Hydra-NL[1] facilitates these calculations. Within this process, combinations of the stochastic variables wind speed, wind direction and sea water level are translated to local hydraulic loads in terms of water level and wave conditions, such as significant wave height, spectral wave period and wave direction. From these hydraulic loads the amount of wave run-up and wave overtopping is determined. The probability of occurrence of those combinations of stochastic variables leading to failure, i.e. overtopping discharges exceeding the critical overtopping discharge, determine the total failure probability.

2.2 Basic Hydra-NL information

In this study Hydra-NL version 2.8.2 has been used, with standard input data for the stochastic variables[2]. The distributions for the stochastic variables wind speed and sea water level include statistical uncertainty. Hydra-NL needs a database that links realisations of these stochastic variables to local hydraulic loads at specific locations along a dike trajectory.

In this study four databases have been used, including the output location surrounding the potential site locations (obtained from the IPLO stack[3]):

- Eemshaven: WBI2017_Waddenzee_Oost_6-6_v03.sqlite
- Maasvlakte II: Havens_Maasvlakte_Europoort_v01.sqlite
- Sloegebied: WBI2017_Westerschelde_30-4_v03.sqlite
- Terneuzen: WBI2017_Westerschelde_30-4_03.sqlite

The computations have been carried out in “test mode”. This allows us to specify the value for sea level rise (see Section 2.3.5) explicitly.

Apart from statistical uncertainty Hydra-NL computations include model uncertainties. These values are also stored in the databases mentioned above.

2.3 Background information and assumptions

2.3.1 Dike profile and orientation

Assuming the power plant will be built within one of the four areas outlined in Figure 1, the dike rings protecting these areas from flooding will be considered. In theory, a dike breach can occur everywhere within the dike ring. However, only one cross section per dike ring is considered in this study. The choice for the particular cross section is based on expert judgement, where the highest water levels and waves may occur.

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[1] *To be downloaded from the IPLO site ([Hydra-NL | Informatiepunt Leefomgeving](#))*
[2] *The standard input of Hydra-NL will automatically be installed when installing Hydra-NL.*
[3] *[STACK - Deellink bestanden](#)*

This is a fair approximation, because the prevailing stochastic variables for this failure mechanism (water overtopping the dike) to occur are the local water level and wave height and the values of these stochastic variables are highly correlated. In other words, it is very likely the failure of the dike due to the considered failure mechanism will be located at the cross-section where the water levels and waves are expected to be the highest.
The cross sections are indicated in Figure 2.1. Since the Borssele area is not within a present dike ring a cross section was considered of the dike ring close to the area, protecting the present Borssele power plant. Maasvlakte is not surrounded by a dike ring. The dike in the northwestern part of the Maasvlakte protects the Maasvlakte from high wave loads from northwestern direction and was considered here.

Figure 2.1 Possible locations (white areas) for a nuclear power plant at Paulinapolder near Terneuzen (left upper), Eemshaven (right upper), Sloehaven near Vlissingen/Borssele (left lower) and Rotterdam - Maasvlakte II (right lower). The selected cross sections and Hydra-NL locations (Par. 0) are indicated by red lines and dots respectively.

The four dike profiles considered are estimated from AHN and schematized as in Figure 2.2. These profiles do not account for potential foreshores. The roughness factor of the revetment has been set to 1 uniformly, assuming a smooth profile. The orientations and actual crest levels of the cross sections have been presented in Table 2.1. Note that the resulting crest levels are sensitive to the choices with respect to profile, orientation and roughness.

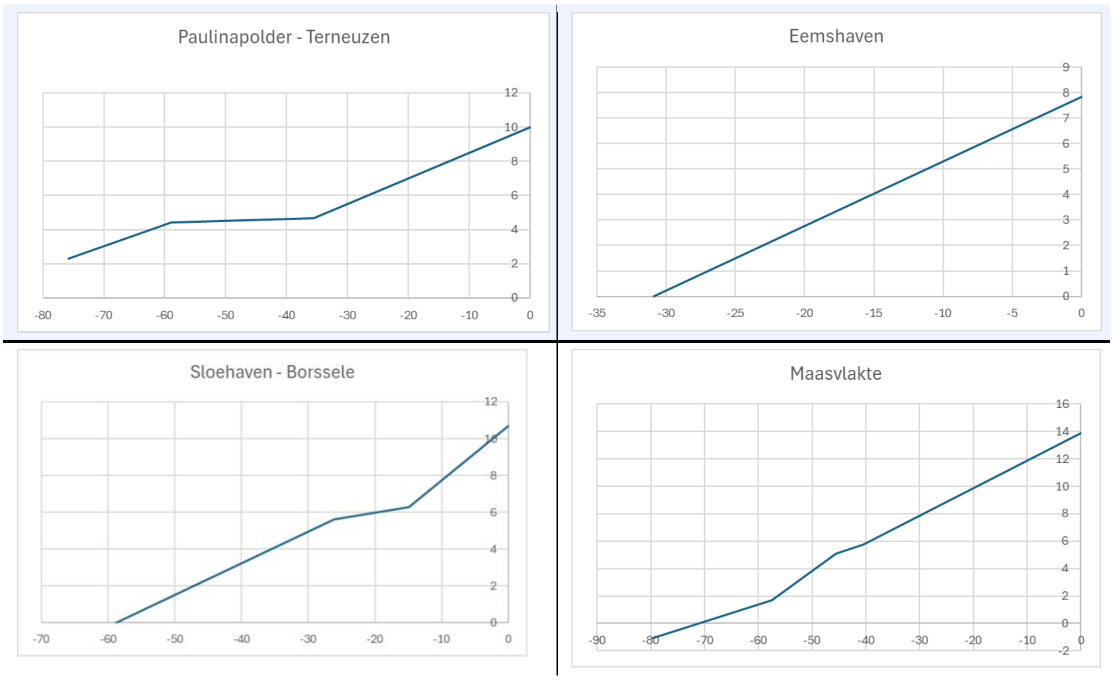

Figure 2.2 *Dike profiles considered for Hydra-NL computations at Paulinapolder (left upper), Eemshaven (right upper), Sloehaven near Borssele (left lower) and Rotterdam - Maasvlakte II (right lower). On the vertical axis the profile height [m NAP], on the horizontal axis the location [m] at the revetment with the crest at 0.*

Table 2.1 *Dike orientation and actual crest level of considered cross sections*

Power plant area	Dike orientation [ºN]	Actual crest level [m + NAP]
Terneuzen	5	10.0
Eemshaven	20	8.4
Sloegebied	230	10.7
Maasvlakte II	350	13.9

2.3.2 Critical overtopping discharges

The critical overtopping discharge is determined by the amount of water that is allowed within the dike ring and/or by the resistance to erosion of crest and inner slope of the dike and/or by operational criteria. This is unknown at this moment. Therefore computations have been carried out for three values of the critical overtopping discharge: 1, 10 and 50 l/s/m.

2.3.3 Normative exceedance frequencies

The legal values for normative exceedance frequencies vary per trajectory. Here only the results for one return period have been presented for all locations: 10.000 years. Note that the legal normative value at the current powerplant near Borssele equals 1/1.000.000 per year, so a factor 100 smaller.

2.3.4 Output locations

As already shown in Deltares (2025) the wave conditions close to the dike are strongly dependent on the upwind bed level and orientation of the dike. Waves may be breaking in the shallow in front of the dike area or being blocked by the dike. As a consequence the spatial variability of the wave conditions, and subsequently wave overtopping discharges and required crest level may be significant. In this study one Hydra-NL output location per trajectory has been considered. The location name, as included in the physical databases, has been given in Table 2.2. The locations are also indicated in Figure 2.1 by means of a red dot.

Table 2.2 Names of considered Hydra-NL locations

Power plant area	Hydra-NL location name
Terneuzen	WS_1_32-3_dk_00007
Eemshaven	WZ_1_6-6_dk_00156
Sloegebied	WS_1_30-4_dk_00006
Maasvlakte II	NZ_3_hy03_00002

2.3.5 Sea level rise

In 2023 KNMI published the projected effects of climate change for four different scenarios (see KNMI, 2023). The projected sea level rise with respect to the reference period 1991-2020 was estimated between +16 cm and +38 cm for 2050 (depending on the scenario considered), whereas sea level rise was expected to accelerate in the later stages of the century resulting in a sea level rise between +26 cm (low emission scenario IPCC SSP1-2.6) to +124 cm (wet/high emission scenario, IPCC SSP5-8.5) for 2100 (KNMI, 2023).

For the computations carried out here we consider a sea level rise of 1.24 m, which is added to the sea water level statistics in Hydra-NL. The reference year of these statistics is 2023, which means that 1.24 m is conservative. For safety assessment and design of dikes ENW recently advised to apply an average scenario. Since it is uncertain if the considerations for regular dikes also apply for dikes around power plants, the most extreme scenario has been applied here.

3 Results

In Table 3.1 the required crest levels have been presented as determined with Hydra-NL, with input described in Section 2.3.

Table 3.1 Required crest levels [m+NAP] for three critical overtopping discharges at the four potential sites

	Q_{crit} = 1 l/s/m	Q_{crit} = 10 l/s/m	Q_{crit} = 50 l/s/m
Terneuzen	9.04	8.42	7.99
Eemshaven	12.02	10.49	9.39
Sloegebied	10.70	9.41	8.55
Maasvlakte II	20.90	17.11	14.43

Note that the required crest levels are larger than the actual crest levels for most of the critical overtopping discharges. The reason for this is the strong sensitivity of the required crest level for the schematization (including the revetment roughness) and output location considered and the fact that the current legal normative exceedance frequency is not necessarily equal to 1/10.000 years. Furthermore, a sea level rise of 1.24 m + NAP is larger than considered at construction of any of the considered dike sections.

For further refinement of the flood protection design, the recommendations in Deltares (2024) and (2025) should be followed.

Attachment(s)
References

A References

Deltares (2024). Assessment of the platform level. Technical feasibility study Borssele 2. Deltares report 11209639-002-GEO-0021, 5 August 2024, Draft.

Deltares (2025). Nuclear Power Plant Site Evaluation: additional locations. Hydrodynamic and meteorological hazards. Deltares report 11209639-016-GEO-0002, d.d. 21 May 2025, Draft.

KNMI (2023), KNMI'23-klimaatscenario's voor Nederland, KNMI, De Bilt, KNMI-Publicatie 23.03. https://cdn.knmi.nl/system/ckeditor/attachment_files/data/000/000/357/original/KNMI23_klimaatscenarios_gebruikersrapport_23-03.pdf.