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Folketinget vedtog den 4. juni 2021 lov om anlæg af Lynetteholm. I medfør af lov om anlæg af Lynetteholm bemyndiges Udviklingsselskabet By & Havn I/S til at anlægge halvøen Lynetteholm i Københavns Havn.

Forud for vedtagelsen af loven var der udført vurderinger af projektets påvirkninger af miljøet. Miljøvurderingerne blev i regi af Espoo-konventionen sendt til det svenske kontaktpunkt med henblik på at modtage eventuelle bemærkninger fra de svenske myndigheder. Den ansvarlige danske myndighed er Trafikstyrelsen, som har oplyst, at de væsentlige temaer i dialogen med de svenske myndigheder er saltudvekslingen gennem Øresund og klapningen.

For så vidt angår første del om saltudvekslingen, har de svenske myndigheder ønsket at få verificeret beregninger i de udførte miljøvurderinger af en uafhængig tredjepart. Dette ønske er imødekommet, og det hollandske institut Deltares har nu udarbejdet sin uafhængige vurdering, som vedlægges dette svar.

I forhold til klapningen er det et vilkår for tilladelsen, at Udviklingsselskabet By & Havn I/S skal etablere en overvågning, der sikrer, at der alene klappes sediment, når der ikke er strømforhold, som indebærer, at sedimentspredningen kan medføre skade på svenske Natura 2000-områder. Endvidere er der etableret en gruppe med deltagelse af svenske myndigheder, som har til hensigt at sikre dialog om klapningen og overvåge miljøkonsekvenserne.

Den første rapport om sedimentspredningen blev offentliggjort i begyndelsen af marts måned. Rapporten vedlægges.

Næste møde i konsultationsprocessen mellem Trafikstyrelsen og de svenske myndigheder er planlagt til den 5. april 2022.

Med venlig hilsen

Trine Bramsen

Deltares

Independent review of the Hydrodynamic Studies on the impact of Lynetteholm on exchange of water and salt through Øresund

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Summary

This review of the Hydrodynamic Studies on the impact of Lynetteholm on the exchange of water and salt through the Øresund evaluates the report of the Hydrodynamic Studies by DHI and additional material provided in response to questions to By & Havn and DHI, considering the methodology, the set-up and verification of the modelling, the interpretation of the model results and the conclusions with respect to the exchange of water and salt.

The key results of the Hydrodynamic Studies on the impact of Lynetteholm on the exchange of water and salt through the Øresund are the estimate of the blocking effect for flow and salt at Drogden Sill of -0.19% and -0.24% for Main Proposal 1 and 2 of the Lynetteholm land reclamation, respectively, with a 95% confidence range of ±0.12%. These results, indicating a reduced exchange, are based on a relative approach in which the Main Proposals 1 and 2 of Lynetteholm are compared to the reference situation using a 3D numerical model of the Øresund and the conditions of 2018. The 95% confidence range of ±0.12% for Lynetteholm is half of the ±0.25% confidence range established in the Øresund Link modelling.

The main findings of the review are:

- The blocking effect defined in the Hydrodynamic Studies is an appropriate measure for changes in the exchange of water and salt through the Øresund. (Note that a negative blocking effect means that the exchange is weakening).
- The approach based on the Øresund model with fixed boundary conditions is valid as long as Lynetteholm does not affect the hydrodynamic conditions at the locations of the open boundaries.
- The set-up and calibration of the models is not well documented, but the horizontal and vertical grid resolution and the type of model (software, physical processes) are appropriate for the purpose.
- The verification of the models is limited, e.g. a verification of currents or transports trough the Øresund is missing. The additional comparison during the review of the computed exchange of water and salt through the Øresund to global numbers from literature supports that the model and the selected conditions based on 2018 are appropriate for the evaluation of the blocking effect of Lynetteholm.
- Therefore, the blocking effect of -0.19% and -0.24% resulting from the Hydrodynamic Studies for Main Proposal 1 and 2 at Drogden Sill is considered realistic. Based on the review we find a 95% confidence range of ±0.25% more reasonable.

It is outside the scope of the review to evaluate whether the blocking effects found are acceptable and/or negligible or not.

In case the above estimates of the blocking effect and confidence range are considered not fully acceptable and/or negligible further substantiation might be needed. For this the following suggestions can be made.

- Since the approach to estimate the impact of Lynetteholm on the exchange of water and salt assumed that Lynetteholm does not influence the boundary conditions of the Øresund model, it would be useful to learn to which degree this estimate is conservative or not, either from previous studies or literature, or from a sensitivity study with a numerical model of the Baltic Sea and the Danish Straits.
- It could be useful to improve the reporting of model set-up, calibration and verification. This could help to provide more confidence in the quality of the models. Particularly, the verification of the transports in the Øresund model should be considered. Such a verification for 2018 or for another year could enhance the confidence in the model performance, e.g. by showing that calibration on water levels

and water level gradients and certain aspects of salinity is sufficient to obtain correct water and salt transports.

- A 95% confidence range smaller than ±0.25% is perhaps achievable but would require further substantiation.

Contents

1 Introduction

1.1 Background

Lynetteholm is a development project of By & Havn involving an artificial island off the coast of Copenhagen, see Figure 1.1. The project involves a land reclamation of 275 ha in the Øresund area. For the project an environmental impact assessment (EIA) has been performed, see [1]. The Hydrodynamic Studies for the EIA have been carried out by DHI.

Figure 1.1 Artist impression of the Lynetteholm land reclamation in the center with Copenhagen in the foreground and the Øresund with the Swedish coast in the background (Source: By & Havn).

In a presentation given by By & Havn to Deltares the result of the Hydrodynamic Studies was summarized in short as follows:

- The environmental impact assessment (EIA) of Lynetteholm, documents that Lynetteholm will influence the exchange of water and salt through Øresund.
- The reduction in exchange flow (the blocking) is calculated to approximately 0.25%.
- The impact is negligible compared to existing fluctuations in the Baltic Sea.
- In time the blocking effect will be compensated by effects of climate change.

Since it has been concluded that the artificial island Lynetteholm will affect the exchange flow between the North Sea and the Baltic Sea through the Øresund, meetings have been held with Danish and Swedish Authorities on the environmental impact of Lynetteholm under the Espoo Convention 1991, as required by international and Danish legislation. Under the Espoo Convention or by other legislation no formal and objective criteria or requirements are in place for acceptance of the results of the transboundary environmental impact.

We further understand that the results of the Hydrodynamic Studies presented in the Espoo meetings gave rise to discussion. This resulted in the request for an independent review of which the scope was agreed upon in the Espoo meetings. The present report describes this independent review carried out by Deltares.

1.2 Set-up of the review

1.2.1 Aim and scope

The objective of the independent review is to evaluate the methodology, the execution of the modelling, the interpretation of the results and the conclusions drawn in the Hydrodynamic Studies with respect to the impact of Lynetteholm on the exchange of water and salt through Øresund.

In the presentation by By & Havn the scope of the review was defined as follows:

1. Impact of Lynetteholm on exchange of water and salt through the Øresund (Blocking effect).
2. The calculation grid (bathymetry, location of the north and south edges of the model, resolution of the calculation grid, consistency in the setups in order to eliminate the effect of numerical noise…).
3. The driving forces (boundary conditions for salt, temperature, water level and current, waves, wind…) including whether the uncertainty in the model's boundary data is assessed in the final conclusion on environmental impacts.
4. The selected time period is representative and sufficient to accommodate long-term changes in current conditions.
5. The quality of calibration and validation of the model in the Sound (current, water level, salt, temperature…).

This scope was agreed between the Swedish and the Danish Authorities.

1.2.2 Received input

On 8 and 11 October 2021 the following reports were received by Deltares from By & Havn:

1. *DKBS2 Hydrodynamic Model Setup and Validation.* DHI Technical Note (translated from Danish), see [2].
2. *Construction of Lynetteholm, EIA – Technical Background Report No 1, Hydraulic Surveys*[1] *(Selected Chapters).* DHI Report, (Translation of parts from report in Danish of 2 November 2020), see [3].
3. *Anlæg af Lynetteholm, VVM – Teknisk Baggrundsrapport nr. 1, Hydrauliske undersøgelser*. Complete DHI report in Danish, see [4].

Of the DHI reports provided by By & Havn, the first report [2] ('DKBS2 report') describes the model setup and validation of the updated large scale numerical model of the Belt Sea and the Baltic Sea, the DKBS2 model. This model is applied in hindcast and forecast mode as part of DHI's Water Forecast service. The model has been applied for the period 2008 – 2017 (10 years) to demonstrate the ability of the model to simulate water level variations, circulation and stratification in the system.

The second report ('Øresund report'), see [3] and [4], is the most important report for the review. This report describes the modelling work carried out to estimate the impact of two versions of the Main Proposal for Lynetteholm on the local hydrodynamic conditions (water levels, currents, salinity, temperature, waves) and the exchange of water and salt between the Baltic Sea and the Kattegat through the Øresund. This has been done by comparing the computational results of a detailed Øresund model for the two Lynetteholm variants and the existing situation for the year 2018. The boundary conditions for 2018 were obtained with help of the DKBS2 model. The impact on the exchange of water and salt through the Øresund is presented in terms of a blocking parameter, determined from the computational results.

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[1] or 'Hydrodynamic Studies'

The report also describes the discharge and mixing of surplus water from the borrow area and the environmental pollutants emitted during the construction and operational phases, as well as the effects of waste during digging associated with the replacement of the gyttja-containing sediments found along the entire outer perimeter. However, this review only considers the aspects related to the exchange flow.

The present review addresses the exchange of water and salt through the Øresund in the operational phase. The DHI reports focus on the result of the model simulations. For the review a clear picture of the underlying question and context regarding the impact on the exchange of water and salt through the Øresund is also needed. Some additional information was found in the Environmental Impact Report [1] and in a text book on the Baltic Sea [5].

Furthermore, during the review additional questions were asked to By & Havn and DHI on the methodology followed to address the question, and on various aspects of the modelling and the analysis of the results. In this respect the following additional information has been received and included in the review:

- An update of Figure 6-126 in [3] and [4] to cover the entire year 2018 instead of the first 6 months (19 January 2022), see [7].
- An Excel file with an additional blocking analysis for flow and salt for the most decisive cross-section, the Drogden Sill, by combining the data of the East and West Peberholm sections (21 January 2022), see [8].
- A memo addressing the representativity of the evaluation period of 2018 and providing further background on the blocking effect and further details on the set-up and calibration of the Øresund model (24 January 2022), see [9].

All input received in Danish has been assessed using general available translation functionality from MS Word or Google Translate. Although this method of translation might have its limitations, it was considered sufficient for the purpose of the review.

1.2.3 Approach and reading guide

With the aim and scope mentioned above, the independent review of the Hydrodynamic Studies on exchange of water and salt through the Øresund addresses the following subjects:

- The evaluation of the methodology
- The evaluation of the set-up of the models
- The evaluation of the verification of the models
- The evaluation of the impact of Lynetteholm on the exchange of water and salt through the Øresund.

Each subject is closed with a conclusion section. The review ends with a synthesis of findings and overall conclusions.

A clear problem definition is essential for conducting a proper review. Therefore, we will first discuss in Chapter 2 the extent to which the Lynetteholm plans affect the geometry of the area of interest, and the physical processes that might be influenced by these plans. This leads to the problem definition, which forms the basis of the review.

In Chapter 3 the methodology including the general modelling approach based on the DKBS2 and the Øresund models and the blocking effect as a measure for the influence of Lynettehom is reviewed.

The review of the set-up of the DKBS2 model and the Øresund model in Chapter 4 aims to verify whether key aspects like the model grid resolution, model bathymetry, (location of) open boundary conditions, etc. are suitable for the purpose of the study. Furthermore, the substantiation of the physical and numerical input parameters will be verified on the basis of the reports and additional enquiries.

In the reports of the Hydrodynamic Studies the performance of the calibrated models is verified in simulations of which the results have been compared with measurements. The quality of the verification of the models for the reproduction of currents, water levels, salinity and water temperature will be inspected. Lastly, the fitness of the models for the intended (relative) approach will be evaluated. These results will be evaluated as presented and described in the reports, see Chapter 5.

In Chapter 6 the determination of the impact of Lynetteholm on the water and salt exchange through the Øresund is reviewed.

The review is concluded with a discussion of the various intermediate findings and the assessment of their relevance for the end result of the study. Based on this, a final conclusion on the validity of the outcome of the Hydrodynamic Studies with reference to the exchange flows through the Øresund will be given, together with some recommendations, see Chapter 7.

1.2.4 Limitations of the review

The review of the Lynetteholm Hydrodynamic Studies is limited to the exchange of water and salt through Øresund. In the review, the models and the results of the simulations have been evaluated as presented and described in the reports, i.e. without access to the original input and output files of the numerical models. Furthermore, no new simulations have been carried out for this review by DHI, or by Deltares. Finally, since By & Havn indicated that no legal criteria for acceptance of effects on the exchange flow exist, the review does not address the question whether the resulting effects of Lynetteholm on the exchange of water and salt through the Øresund are acceptable or not. This is beyond the scope of the review.

2 Discussion of problem definition

Good insight in the setting of the problem is essential for the review. Therefore, we will first describe our understanding of the way in which the Lynetteholm plans affect the geometry of the area of interest, and which (physical) processes might be influenced by these plans. This provides the basis for the problem definition. This is especially relevant since the problem definition is not explicitly described in the reports provided.

2.1 Area of interest and proposed layouts of Lynetteholm

The area of interest and proposed layouts of the artificial island Lynetteholm are described in the Øresund report [3]. Lynetteholm is located in the Øresund on the east side of Copenhagen. The Øresund is the eastern of the three Danish Straits that connect the Baltic Sea to the North Sea. A bathymetry map of the Øresund with geographical names is given in Figure 2.1. The eastern part, including Ven island, belongs to the Swedish territorial waters. The western part of the Øresund, including Santholm and Lynettehom, is part of the Danish territorial waters. The shallowest cross-section, Drogden Sill, is located south of Santholm, and is intersected by the channels of Drogden and Flinterenden. Lynetteholm will block the Kongedybet channel, the smaller of two channels north of Drogden, see Figure 2.2. This is

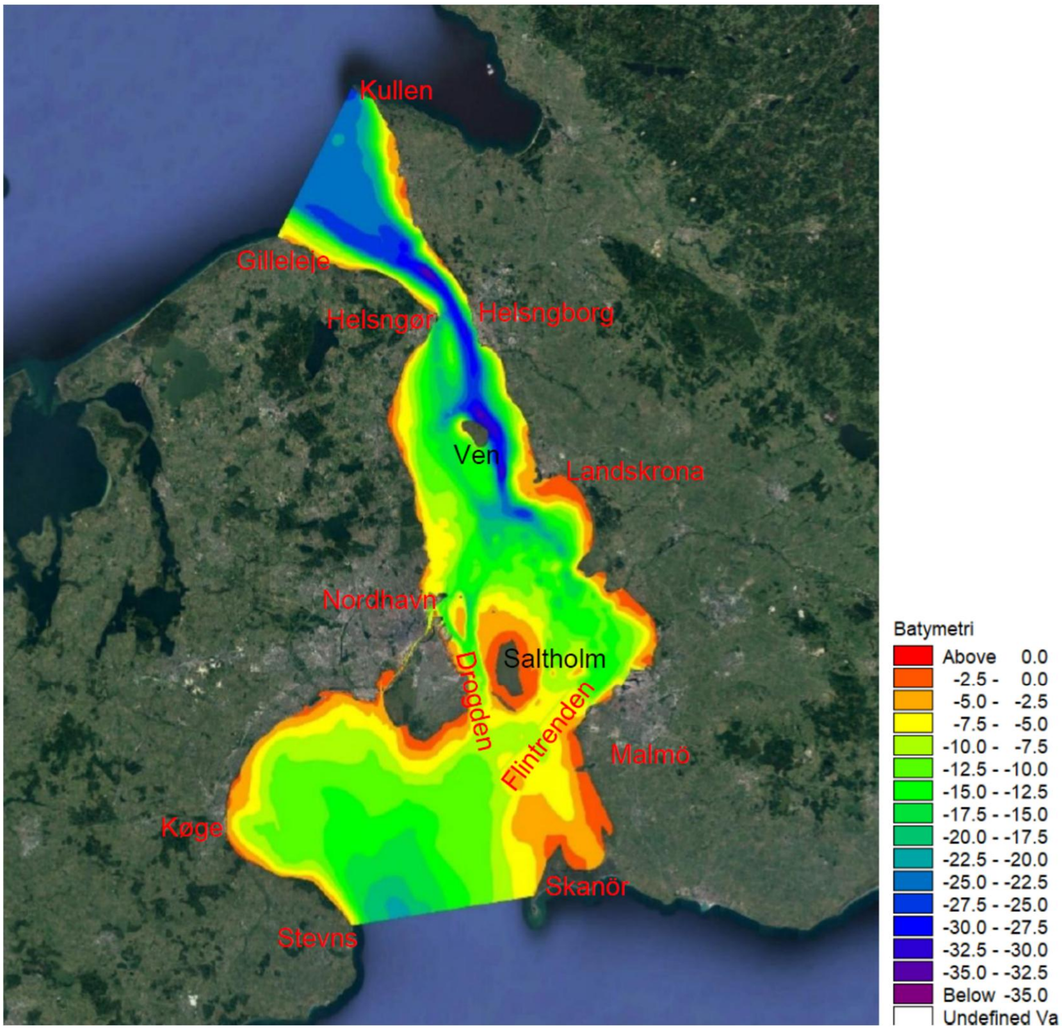

Figure 2.1 Øresund model area with bathymetry and geographical names (Source: Figure 4-1 in [3])

illustrated in more detail in Figure 2.3 where the contours of Main Proposal 1 and 2 of Lynetteholm are shown on top of the bathymetry. Main Proposal 1 is a reclamation without a coastal landscape (pink curve) and Main Proposal 2 is a reclamation containing a coastal landscape (red curve). The difference between the investigated layouts (Figure 2.3) and the final layouts (Figure 2.4) is relatively small and does not affect the blocking of Kongedybet [3]. The depths in the figures are given with reference to DVR90, the Dansk Vertikal Reference 1990.

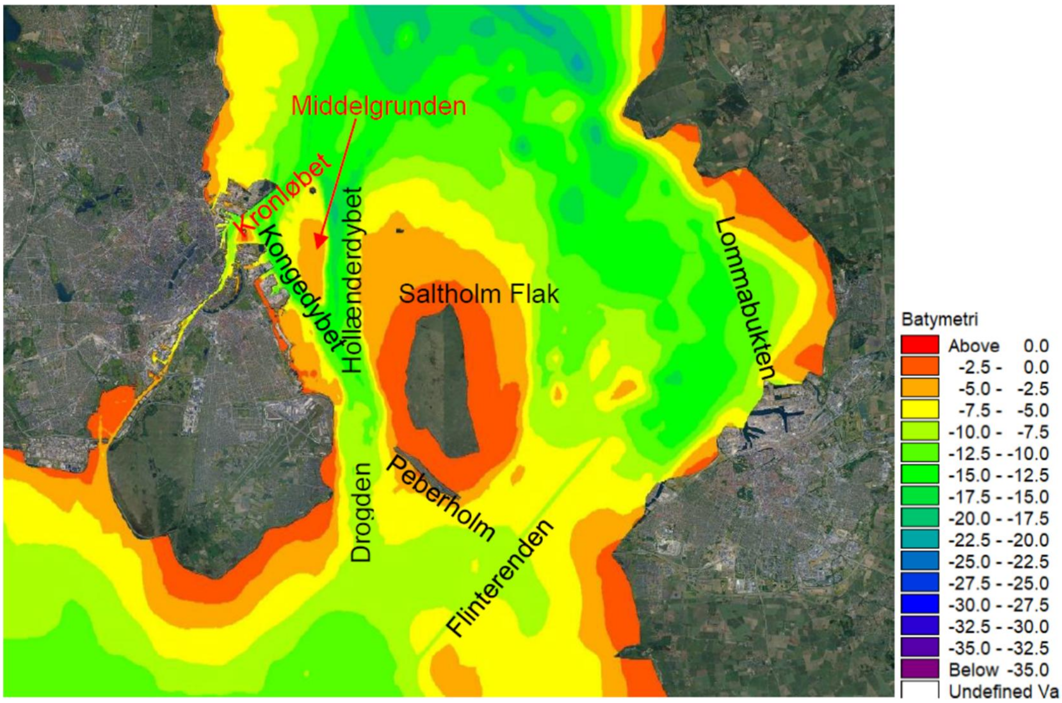

Figure 2.2 Bathymetry with channels, banks and islands in the southern part of the Øresund (Source: Figure 4-2 in [3]).

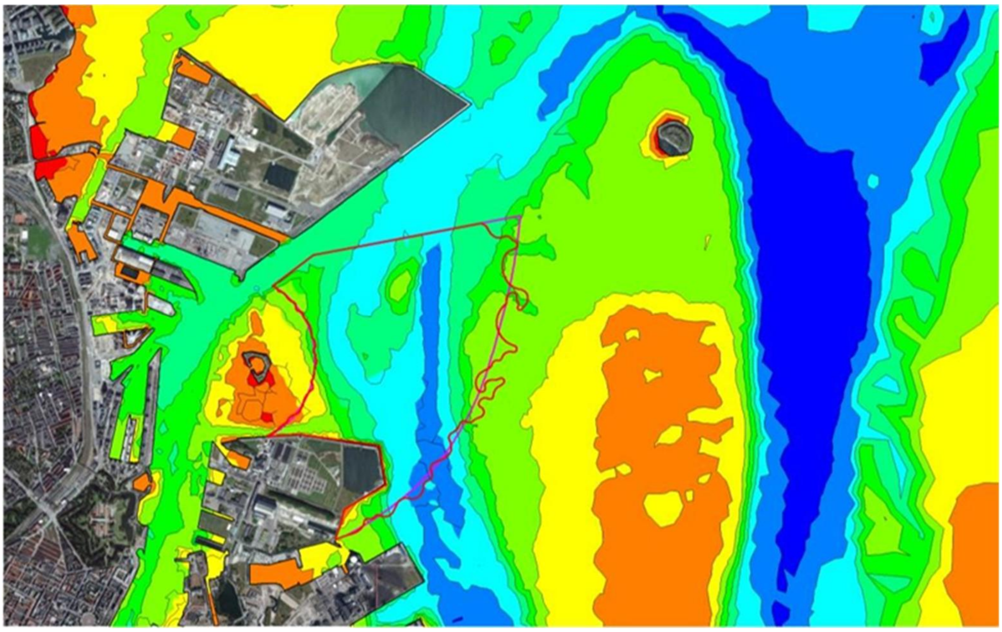

Figure 2.3 Indication of investigated layouts for Main Proposal 1, a reclamation without a coastal landscape (pink curve) and Main Proposal 2, a reclamation containing a coastal landscape (red curve). (Source: Figure 3-3 in [3]).

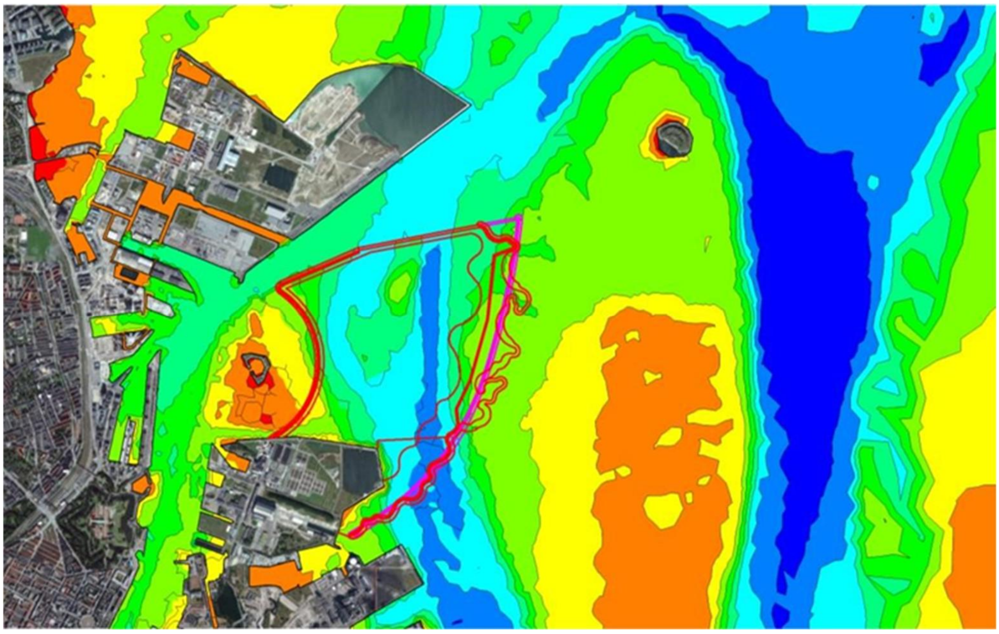

Figure 2.4 Indication of final layouts for Main Proposal 1 (pink curve) and Main Proposal 2 (red curve). The red curves show the top of the coastal profile, the water line and where the foot of the profile reaches the natural seabed. (Source: Figure 3-3 in [3]).

2.2 Water and salt exchange through the Danish Straits

Through the Øresund and the other Danish Straits (Little Belt and Great Belt) water is exchanged between the North Sea and the Baltic Sea. These exchange flows are extensively described in a general textbook on the physical oceanography of the Baltic Sea [5]. The exchange flows are a determining factor for the environmental conditions in the Baltic Sea. Especially the irregularly occurring major inflows of oxygen rich and saline water are important with respect to eutrophication, the most serious environmental problem in the Baltic Sea. In view of this, a concise description of the exchange flows through the Øresund and the other Danish Straits based on [5] has been included in the review for further reference.

Table 2.1 describes the global water and salt balance of the Baltic Sea, based on Figure 4.1 and 4.9 in [5]. Generally, the outflow estimated at about 1660 km^3/yr is 480 km^3/yr larger than the inflow estimated at 1180 km^3/yr, due to the river discharges and the net result of precipitation and evaporation in the Baltic Sea. Typically, the exchange flows are much larger

Table 2.1 Global water and salt balance Baltic Sea

	Water Balance (km^3/yr)	**Salt Balance (G ton/yr)**	**Salinity (psu)**
Rivers	440		
Precipitation - Evaporation	40 (215- 175)		
Inflow Danish Straits	1180	30	25
Outflow Danish Straits	1660	30	18
	Volume (km^3)	**Salt content (G ton)**	**Salinity (psu)**
Baltic Sea	21205	159	7.5

than the net outflow. The Øresund contributes to about 25-30% [5] (3/11 or 27% in [2]) to the total exchange flow through the Danish Straits.
On the long-term, the inflow and outflow of salt are in balance at approximately 30 G ton of salt per year. This corresponds to almost 1/5 of the salt content of the entire Baltic Sea each year. The mean salinity at inflow is estimated at 25 psu, which is higher than the mean salinity at outflow estimated at 18 psu, corresponding to the difference between inflow and outflow volumes. The freshwater input to the Baltic Sea varies over the year and is largest from April – July. This results in a seasonal variation of the exchange flows. The major inflows therefore usually occur from September – January. Recent Major Baltic Inflow (MBI) events have been reported for January 1993, January 2003, see [5] and an extreme event in December 2014, see [10]. In 1993 and 2003 the inflow was about 310 and 200 km^3 for Little Belt, Great Belt and Øresund combined, see Par.5.4.3. in [5]. It was estimated that 0.85 G ton salt flowed in via the Øresund during the 2003 MBI, 42% of the total salt transport during this event. For the 2014 event the estimates are 320 km^3 for the total inflow volume, of which 198 km^3 had a high salinity, and a total salt inflow of 4 G ton, see [11]. Of this 60 km^3 high salinity water (30%) and 1.38 G ton salt (35%) flowed through the Øresund.

As described in [5], the outflow thought the Straits exists of low-density surface water from the stratified Baltic Sea, while high salinity and dense North Sea water flows toward the Baltic Sea in the bottom layer. Strong vertical mixing occurs in the Straits. Therefore, at the sills like Drogden Sill in the Øresund, no steady two-layer flow exists. On the contrary, the flow on the sills is predominantly barotropic and depending on the water level difference and the wind. Due to vertical mixing the inflowing water to the Baltic Sea is less saline than North Sea water, and the outflowing water is more saline than the Baltic surface water. The strength of the inflow, the duration of the events and the mixing in the Straits determine the amount of salt that enters the Baltic Sea. A large part of the total inflow of salt is caused by more regular occurring moderate events. Major inflows, occurring on average once in 10 years, also play an important role, however.

The time-scales of the hydrodynamic processes involved are quite long, given a typical residence time of about 30 years for the Baltic Sea [5] and the occurrence of major inflow events on a decadal scale. This means that in principle any changes in the Danish Straits that influence the exchange flow will take more than 30 years to reach a new (dynamic) equilibrium.

On a somewhat longer time-scale, in the order of 100 years, climate change is expected to influence the environmental conditions in the Baltic Sea as well. Several aspects related to climate change may affect the hydrodynamic processes either directly, or indirectly via changes in the exchange flows through the Danish Straits, for example: relative sea level rise, changes in fresh water run-off to the Baltic Sea, changes in temperature and changes in the local wind climate, see [5]. Such changes may also affect the occurrence of major inflow events. The influence of the changes on the thermohaline circulation of the Baltic Sea can be explored by numerical modelling but it is understandable that the uncertainty in such studies is fairly large. Furthermore, the assessment of environmental effects of climate change would require a more integral approach of hydrodynamics, water quality and ecology as other processes than the hydrodynamics are probably also affected.

2.3 Discussion and research questions

First of all, in the Hydrodynamic Studies the problem of the assessment of the impact of Lynetteholm on the Baltic Sea environment has been simplified by using the impact on the exchange of water and salt through the Danish Straits as an approximation for the environmental effect on the Baltic Sea. In this review this is regarded as a starting point and not evaluated further.

In the Øresund the Drogden Sill is the main bottleneck for the exchange flow, as described in the previous Section. According to the proposals, Lynetteholm will block the Kongedybet, one of the two channels west of Santholm that lead to Drogden Sill from the north. It is conceivable that this blockage may for instance locally influence the saline inflow to the Baltic Sea. On the other hand, the exchange flows east of Santholm, and further away in the Little Belt and the Great Belt, will not be hindered and may even partly compensate any blockage that may occur in the channels west of Santholm. From that perspective it is considered appropriate to study at least the exchange flows throughout the entire Øresund.

If the impact of Lynetteholm on the exchange of water and salt through the Øresund would be negligible, there is no reason to expect influence on the exchange through the other Danish Straits and on the long-term response of the Baltic Sea circulation. For this reason these aspects may be disregarded and the Hydrodynamic Studies may focus on the exchange flow through the Øresund only, and justify these limitations afterwards when proven that the influence of Lynetteholm is negligible indeed.

Given the variability of the exchange flows it will be necessary to select a natural period or perhaps an artificial sequence of conditions which is sufficiently representative for the exchange phenomena occurring for the situation that Lynetteholm is operational, like average transports, seasonal variations, regular moderate inflow events, and exceptional inflow events. It is also necessary to evaluate the effects on both water and salt transport as these may differ in principle, and to address the accuracy of the estimated effects.

The investigation in the Hydrodynamic Study should therefore answer the following research questions:

- What is a representative natural period or an artificial sequence of conditions to investigate the effect of Lynetteholm on the exchange of water and salt through Øresund?
- How large and variable is the water and salt exchange through the Øresund under the selected conditions for the existing layout (without Lynetteholm)?
- How large and variable is the water and salt exchange through the Øresund under the selected conditions for Main Proposal 1 and 2 of Lynetteholm?
- What is the effect of Lynetteholm, based on the differences in the exchange of water and salt in comparison to the reference situation, and how accurate is this?

A judgement whether the found differences are acceptably small or not, is not part of the review. Nevertheless, attempts that have been made in the reports provided by By & Havn to put the resulting differences into perspective will be commented.

3 Evaluation of the methodology

The next step in the review is to evaluate whether the methodology including the general modelling approach is able to meet the objective of the Hydraulic Studies and answer the research questions with respect to the effect of Lynetteholm on the exchange flows through the Øresund. The methodology has not been explicitly described in the reports and therefore the description below is derived from the reports [2], [3] and [4] and memo [9]. Any review remarks are clearly indicated as such. The chapter ends with a short evaluation of the methodology applied.

3.1 Numerical modelling approach

The impact of Lynetteholm on the exchange of water and salt through the Øresund has been investigated by numerical modelling of the hydrodynamics in this area. The focus is on the modeling of the hydrodynamics in the Øresund, see [3]. We note that this makes it possible to model the exchange flows in much more detail than would be possible when the other straits and the entire Baltic Sea were included since that involves a much larger area and very long simulations periods. Strictly speaking this approach is only valid when the influence of Lynetteholm is negligible at the locations of the open boundaries, see the argument in Section 2.3. Some compensation of any adverse effects on the exchange flow in the channels west of Santholm via the channel east of Santholm is possible, however.

Furthermore, the effects have been determined via a relative approach: for selected conditions the results of simulations for two proposals of the Lynetteholm layout have been compared to the results of a simulation for the existing situation (without Lynetteholm) under the same conditions [3]. We note that the advantage of this relative approach is that uncertainties in the simulations (e.g. model set-up, conditions) have less effect on the accuracy of the impact of Lynetteholm which is being estimated.

All simulations have been performed under the same conditions, which means that the same initial condition, atmospheric forcing, boundary conditions and river discharges haven been applied. The initial and boundary conditions have been derived from a larger scale model, the operational three-dimensional model of the Baltic Sea, Belt Sea, Kattegat and Skagerrak, the DKBS2 model [3]. Water level measurements along the Øresund have been used to improve the water level boundary conditions, see [9].

For the representative natural period or an artificial sequence of conditions to investigate the operational phase of Lynetteholm (see Section 2.3) the year 2018 was selected, a full recent year to cover all seasonal variations due to varying river discharges and the annual cycle in water temperatures, see Par.4.2.4 in [3]. A more detailed explanation for the selection of 2018 as a representative year to investigate the blocking effect was given in [9], considering the annual net flow, the occurrence of many weak and stronger inflow and outflow events, including two small or medium size MBI's. Furthermore, it was noted in [9] that by considering a full year the resulting blocking effect is less sensitive for the actual period selected, compared to the 72 day's simulations carried out at the time in the studies for the Øresund-Link. We note that ideally, an extreme MBI, e.g. of December 2014, would also have been part of the simulations.
Although the operational phase of Lynetteholm is somewhere in the future, we accept the approach to select the conditions of a recent year for all simulations. This year should contain the relevant physics to a sufficient degree (see further our evaluation in Section 5.2.4).

The system used to investigate the effects of Lynetteholm on the exchange of water and salt through the Øresund is defined in [3] by:

- The geometry (bed level) in an area covering the entire Øresund from the Gilleleje – Kullen cross-section in the north to the Stevns – Skanör cross-section in the south and including Copenhagen Harbour as shown in Figure 2.1.
- The 3D hydrodynamic processes governing the development of water levels, currents, salinity and temperature.
- The driving forces existing of water levels (tides, surges), currents, salinity and water temperature at the open boundaries, and winds, atmospheric pressure gradients, atmospheric heating and cooling.

According to DHI the cooling water recirculation of the Amager Power Station (Par. 4.3 and 6.2 in [4]), which is affected by Lynetteholm, was not included in the investigation of the blocking effect. Since the changed cooling water recirculation may in principle have some effect on the density currents in the channels west of Santholm, it would have been appropriate to motivate the neglect of this process.

3.2 Software

The Hydrodynamic Studies are carried out using the MIKE 3 software, see [2] and [9]. For the DKBS2 model also the version is documented (version 2017), see [2]. For the Øresund model this information is not reported.

The DKBS2 model is applied with MIKE 3 in hydrostatic mode (Par 2.1 in [2]). We assume that the same holds for the Øresund model.

3.3 Blocking effect

The key parameter in the Hydrodynamic Studies to evaluate the impact of Lynetteholm on the exchange of water and salt through the Øresund is the blocking effect (*dq*) defined as

$$dq = \frac{\sum(|Q_L| - |Q_B|)}{\sum|Q_B|}$$

with Q being the water transport (m^3/s) through a vertical cross section (Drogden Sill), index *L* referring to the situation including Lynetteholm, and index *B* referring to the baseline or reference situation, see Par 6.1.6. in [3]. The summation is carried out over the entire evaluation period (2018). A similar formula holds for the blocking of the salt transport (kg/s). According to [9] this approach has been successfully applied in the studies for the Øresund-Link.

For interpretation purposes we rewrite the blocking effect in terms of average inflow of water and salt and net outflow of water. Using $\sum|Q|/T = \overline{Q_{In}} + \overline{Q_{Out}} = \overline{2Q_{In}} + \overline{Q_{net}}$ with summation period *T*, the blocking effect for flow can be expressed as

$$dq_w = \frac{\overline{Q_{In\,L}} - \overline{Q_{In\,B}}}{(\overline{Q_{In\,B}} + 0.5\overline{Q_{Net}})}$$

in which the overbar indicates long-term averaging, Q_{In} stands for the inflow of water, *L* for Lynetteholm and *B* for Baseline. Q_{Net} is the net outflow through Øresund, assumed for simplicity independent of the situation with regard to Lynetteholm.
In a similar way the blocking effect for salt can be expressed as

$$dq_s = \frac{\overline{S_{In\,L}} - \overline{S_{In\,B}}}{S_{In\,B}}$$

in which S_{In} stands for the inflow of salt. The average net salt transport is assumed to be zero[2] under current conditions.

These expressions confirm that the blocking effect as defined in the Hydrodynamic Studies is an appropriate measure for changes in the exchange of water and salt through Øresund. Note that a negative blocking effect means that the exchange is weakening, and a positive blocking effect that the exchange increases.

In the Hydrodynamic Studies, the integration or summation has been carried out for a full calendar year (2018), averaging the effects of the seasonal cycle. Spin up effects at the beginning of the simulation should be excluded from the evaluation. Furthermore, upon request the blocking effect is evaluated at Drogden Sill [8], where the flow is considered generally barotropic, meaning that locally the density currents can be neglected. Accuracy estimates of the blocking effect are derived from the Øresund Link studies [3], [9].

3.4 Interpretation of blocking effect

In an effort to put the computed effect of the Lynetteholm land reclamation on the water and salt exchange thought the Øresund into perspective, DHI made a comparison with estimates of the effect of the expected sea level rise and with the blocking criteria applied for the Øresund Link.

The sea level rise was implemented in the Øresund model by simply increasing all water level initial and boundary conditions by a few centimeters. All other aspects of the model set-up remained unchanged. Basically, this means that the model zone existing of sigma-layers including initial and boundary conditions was stretched a little bit. Furthermore, the duration of the simulation was limited to the first half year of 2018, according to the plots in [3]. Next, the period in which the blocking effect by Lynetteholm is approximately neutralized by the effect of sea level rise is estimated on the basis of a sea level rise of 1.55 mm /year.
As mentioned in Section 2.2, sea level rise is one aspect of climate change, and other changes, e.g. in North Sea conditions and wind climate may also affect the exchange of water and salt in the Danish Straits. Without further motivation or background information we have our doubts on the validity of this approach. In Section 6.3 we provide further comments on this approach.

In the discussion of the results in reports [3] and [4] the final conclusion is based on comparison with the accuracy of the 'Zero Solution' that was required for the Øresund Link (apparently described in [6]). We think that this can be of use, if the requirements of that time are still valid, and e.g. confirmed by later long-term monitoring (from 2000 – present). This will also be discussed further in Section 6.3.

3.5 Conclusion

The methodology to estimate the impact of Lynetteholm on the exchange of water and salt through the Danish Straits by numerical modelling of the hydrodynamics in only the Øresund area is acceptable when it proves that the influence of Lynetteholm on the exchange through Øresund is negligible. Some compensation of adverse effects on the exchange flow in the channels west of Santholm is possible via the channel east of Santholm.

The impact of Lynetteholm on the exchange of water and salt through the Øresund is based on the determination of the blocking effect of Lynetteholm from simulations of the situation

[2] This holds in principle for all Danish Straits combined, see Section 2.2. Individual straits may differ somewhat.

with and without Lynetteholm for representative conditions. For these conditions the full year of 2018 has been selected. The simulations have been carried out using the MIKE 3 software. The review confirmed that the blocking effect as defined in the Hydrodynamic Studies is an appropriate measure to quantify changes in the exchange of water and salt through Øresund. Furthermore, for the accuracy estimate of the blocking effect reference is made to the results of the Øresund Link studies.

In the Hydrodynamic Studies, two methods have been presented to provide some perspective on the computed blocking effects.
Firstly, in the Hydrodynamic Studies the blocking effects computed for Lynetteholm have been compared to requirements that were in place for the Øresund Link. We consider that this can be useful when it can be shown that such requirements are still valid.
Secondly, simulations have been carried out for sea level rise scenarios. For the reference situation and the two Main Proposals the water level was simply increased by 2 cm. Assuming a rate of sea level rise of 1.55 mm /year, the period in which the blocking effect by Lynetteholm is approximately neutralized by the effect of sea level rise, is estimated. We have strong reservations on the validity of this approach since sea level rise is only one aspect of climate change. In principle the relevance of sea level rise should be evaluated in comparison to other changes like those in the tide, temperature and salinity in the North Sea, and wind climate, precipitation, river run-off, and even water quality and ecological processes in the Baltic Sea.

4 Evaluation of model set-up

The review of the model implementation (or model set-up) aims to verify whether key elements like the grid resolution, applied bathymetry, boundary conditions, etc. meet with the formulation of the general approach. Furthermore, the substantiation of the physical and numerical input parameters will be verified on the basis of the reports and inquiries.

4.1 DKBS2 model

The set-up of the three-dimensional DKBS2 model is described in general terms in Chapter 2 of [2].

4.1.1 Computational mesh

The DKBS2 model covers the entire Baltic Sea and the Belt Sea, Kattegat and Skagerrak. Figure 4.1 shows a part of the computational mesh near Øresund. The horizontal resolution varies from 500 – 1000 m in Belt Sea coastal areas to 4 – 6 km in Baltic offshore areas [2]. Apparently, the mesh of the 3D model is defined in spherical coordinates (latitude, longitude), but details on the reference system are not reported.

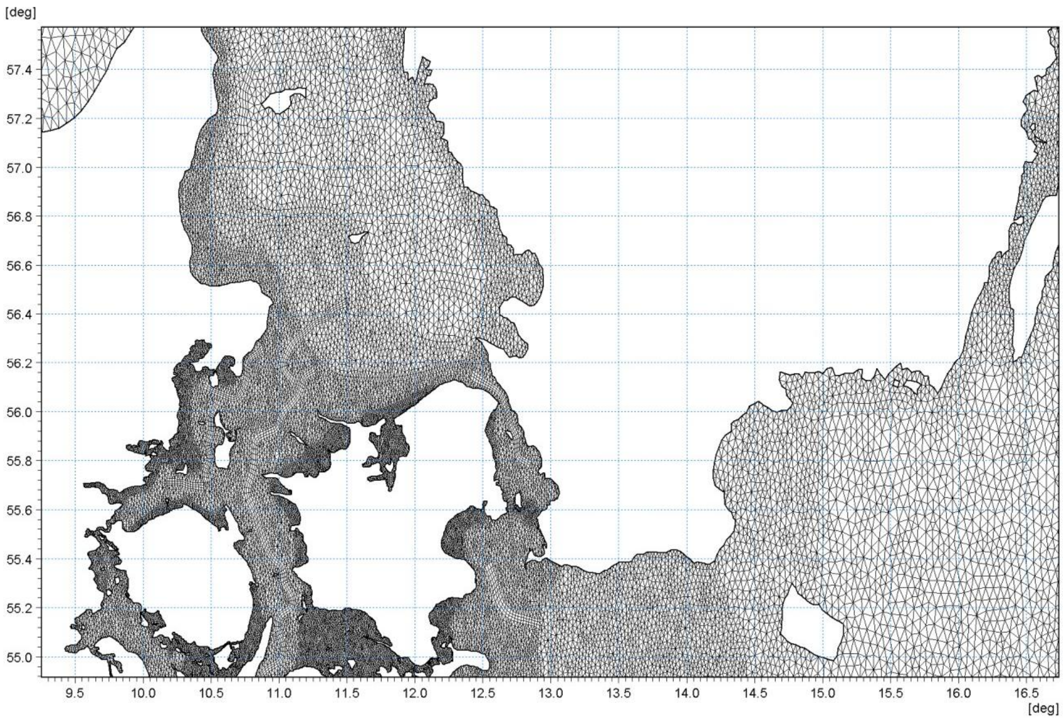

Figure 4.1 Computational mesh of the DKBS2 model near the Øresund (Source: Figure 2.3 in [2]).

The vertical mesh exists of 10 sigma-layers of equal thickness above -10 m of depth and 233 z-layers below that level with a layer thickness of 1 m until -220 m and increasing to 20 m at -610 m in Skagerrak [2]. At Drogden Sill in the Øresund, with depths up to -10 m, this results in a layer thickness of 1 m or less.

4.1.2 Bathymetry

The bathymetry is based on an available 500 m x 500 m bathymetric data set created during the Fehmarn Belt environmental studies (data of 2011 or earlier) [2]. It is questionable if this resolution combined with the grid is sufficient to include the details of the Drogden Channel and the Flinterden Channel given the limited fairway width of about 300 m and 360 m, respectively.

4.1.3 Simulation period and initial condition

Simulations have been presented for the period 2008-2017 to illustrate the performance of the model (see further Section 5.1). The origin of the initial condition at 1 January 2008 has not been discussed in [2], although this is relevant for a system with residence times of about 30 years, since a considerable part of the solution is determined by the initial condition. Furthermore, the simulation of 2018, which has been used for nesting of the Øresund model is not discussed.

4.1.4 Atmospheric forcing and boundary conditions

The atmospheric forcing is prescribed at hourly intervals with a resolution of 0.1° x 0.1° latitude and longitude (approximately 11 by 5.6 km at 60° N) and consists of wind, atmospheric pressure, precipitation, air temperature, cloud cover and relative humidity originating from a meteorological model (Par. 2.3 in [2]). Ice concentration fields are prescribed at hourly intervals with a resolution of 0.2° x 0.2°.

At the open boundary in the Skagerrak water levels, current velocities, salinity and temperature are used to specify the boundary conditions [2]. This data is provided by the UKNS2 model of the North Sea. Apparently, the tidal heights of the North Sea model needed to be improved, for which data of a global ocean tide model was used.

While the co-oscillating tide is prescribed at the open boundary in the Skagerrak, it is not mentioned whether the tide generating forces are applied to the model. Though water level variations in the Baltic Sea depend mostly on the atmospheric forcing, tides are also generated within Baltic Sea. Though the tides are generally weak, the tidal range may still reach 0.2 m in the Gulf of Finland.

Furthermore, the fresh water inflow of all major rivers is prescribed in the form of time-series with a daily or monthly interval. Several corrections for incomplete data were necessary to obtain a realistic estimate of the water balance [2]. Such estimates may have a large uncertainty, which influences the exchange flows. This was not addressed or investigated by means a sensitivity analysis.

The forcing and boundary conditions have not been evaluated further. The type of forcing and boundary conditions seem in general appropriate for this type of large-scale model, however. The verification in Section 5.1 will show the actual performance.

4.1.5 Physical input parameters

The description of the physical input parameters in Par. 2.6 of [2] is far from complete, and the parameters that are mentioned are not always clear (e.g. “default parameters”, missing wind velocities for the corresponding drag coefficients).

The review is therefore limited to comparing available parameters to the choices made for the Øresund model, see Section 4.2.5.

4.1.6 Numerical input parameters

In the report [2] no information is given on choices for numerical input parameters that determine the accuracy of the solution. We can only assume that the appropriate choices have been made that would result in a sufficient accurate and stable solution.

4.1.7 Calibration

The model covers a large area and has a reasonable resolution and suitable forcing to simulate the thermohaline circulation in the Baltic Sea. However, from the DKBS2 report is not clear what has been calibrated and how, and which parameters have not been calibrated but where specified on the basis objective information. Results of sensitivity simulations, e.g. with respect to river run-off, are not reported in [2].

Therefore, a conclusion on the suitability of the DKBS2 model for the application in the present project, will depend on the verification, which is discussed in Section 5.1.

4.2 Øresund model

The set-up of the three-dimensional Øresund model is partly described in Par. 4.2.3 of [3]. Additional information on the set-up and calibration of the Øresund model is given in [9].

4.2.1 Computational mesh

The Øresund model covers the entire Øresund between the Gilleleje-Kullen section in the north and the Stevns-Skanör section in the south, where the open boundaries are located, see Figure 2.1. In Figure 4.2 the computational mesh is shown, existing of a unstructured mesh in the form of triangles and quadrangles [3]. Apparently, a local map projection has been used, with northing and easting as coordinates (unit: m). Details on the reference system are not documented in the report. Along the northern open boundary the mesh size is about 500 m and along the southern open boundary it is about 1 km, possibly in agreement with the mesh of the DKBS2 model in this area. In the central part of the Øresund model the grid is refined, and the highest resolution occurs near Lynetteholm. Also, the channels through Drogden Sill, (Drogden and Flinterden) seem to be resolved by the refined mesh.

The vertical mesh consists of combined z-sigma-layers. At the surface 10 sigma-layers of equal thickness are present above -15 m of depth and below that level z-layers with a gradually increasing layer thickness of 1.5 m to 3 m [3]. At Drogden Sill in the Øresund, with depths up to -10 m, the 10 sigma-layers result in a layer thickness of 1 m or less. In the channels near Lynetteholm, the Kongedybet and the Hollænderdybet with depths generally less than 15 m the layer thickness will be 1.5 m or less.

Above -10 m of depth, e.g. at Drogden Sill, the vertical resolution of the Øresund model and the DKBS2 model are identical (10 sigma-layers both). In areas with depths below -10 m the vertical resolution in the Øresund model is generally lower, e.g. at -15 m of depth the layer thickness is 1.5 m, compared to 1 m in the DKBS2 model. It is somewhat surprising that the more detailed model in the horizontal is less detailed in the vertical. According to DHI the vertical resolution in the Øresund model has been slightly reduced compared to the DKBS2 model in view of computational time.

4.2.2 Bathymetry

The bathymetry of the Øresund model is also shown in Figure 4.2. It has been derived from bathymetric survey data from By & Havn for the waters of Copenhagen. Elsewhere, data from nautical charts have been used [3]. Note that the higher resolution of the Øresund model, e.g. on Drogden Sill, and the adjustments of the deep channel bathymetry north of Ven (see Section 4.2.7), will affect the dynamics relative to the DKBS2 model.

According to DHI the geometry in the operational phase of Lynetteholm has not been adjusted for morphological changes compared to the current situation since the area of potential (local) erosion on the Middelgrunden exists of sand lenses combined with hard material for which it is not possible to predict the erosion. Some local capital dredging has also been neglected.

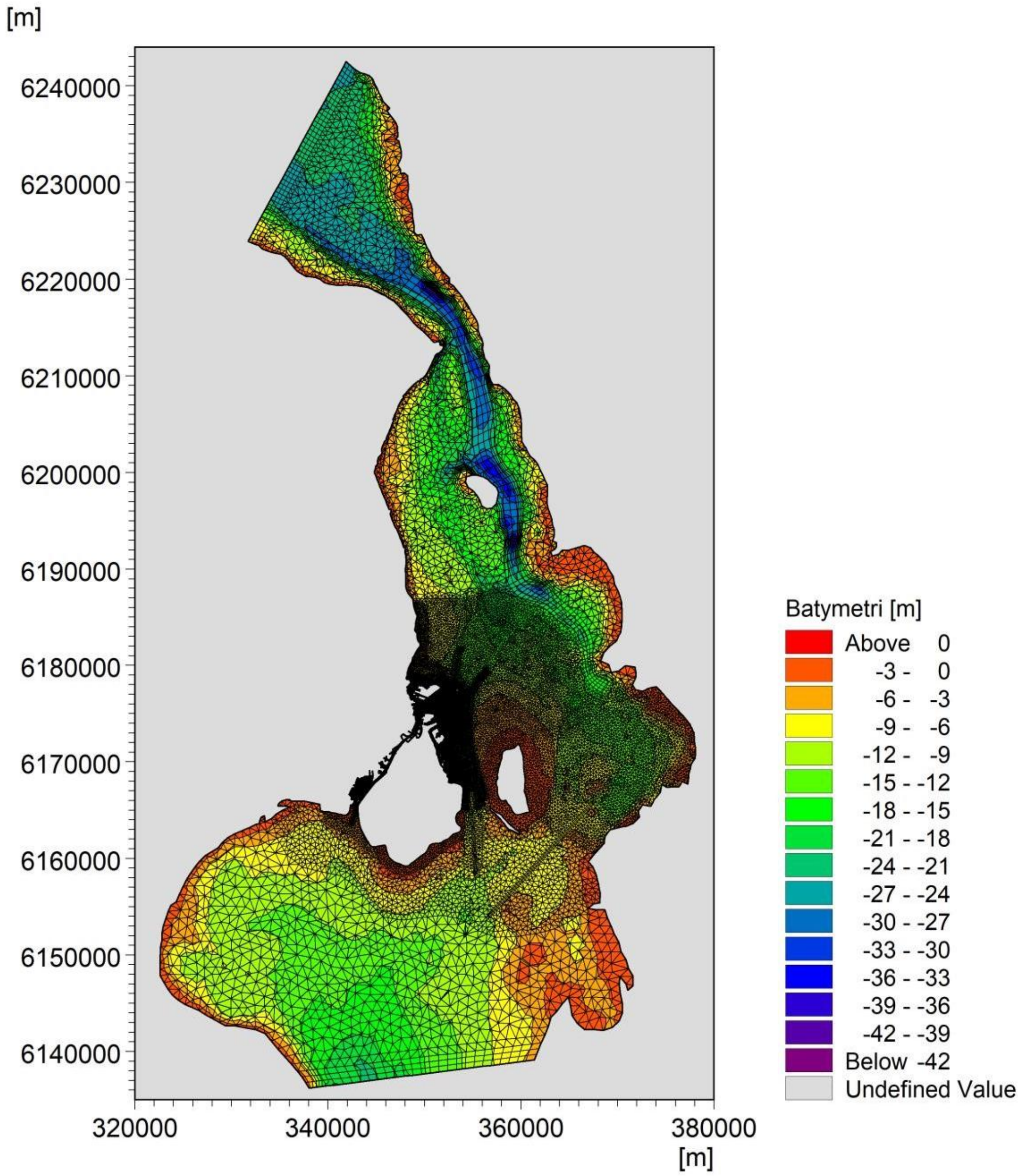

Figure 4.2 Computational mesh and bathymetry of the Øresund model (Source: Figure 4-5 in [3]).

4.2.3 Simulation period and initial condition

The simulations for the reference situation and for Main Proposal 1 and Main Proposal 2 of Lynetteholm have been carried out for the year 2018 and started from initial conditions interpolated from results of the DKBS2 model. A 7-day spin-up period (from 25 December 2017 on) was applied to let the interpolated DKBS2 conditions adjust to the Øresund model, and to the differences in layout at Lynetteholm [9]. This period should be sufficiently long for barotropic processes, but whether it is also sufficient for baroclinic processes and the effect of the land reclamation is hard to judge. No statement was given that this period proved to be sufficiently long, e.g. supported by sensitivity simulations.

4.2.4 Atmospheric forcing and boundary conditions

The atmospheric forcing is identical to the forcing of the DKBS2 model [9]. The resolution of 11 by 5.6 km (see Section 4.1.4) means that the model is roughly covered by 10 points in both north-south and east-west direction. Effects of the land-water transition on the atmospheric forcing, which may become relevant in smaller scale modelling, have not been mentioned.

We assume that the fresh water inflow to the Øresund model is also consistent with the DKBS2 model, although this is not stated in [3] or [9].

The boundary conditions have been interpolated from hourly data of the DKBS2 model, accounting for the difference in vertical resolution [9]. For water levels this is very coarse; 10 minute data would be more appropriate. No output has been provided to show that irregularities along the boundaries due to time and space interpolation are absent.

4.2.5 Physical input parameters

A description of the physical input parameters of the Øresund model is given in [9]. It is slightly more extensive than for the DKBS2 model. Notable differences are:

- The bed roughness length is 0.1 m in areas of less than 6 m deep in view of generally occurring vegetation, and 0.03 m in the remaining areas, based on calibration [9]. Note that in the DKBS2 model a much lower value of 0.005 m was used.
- According to DHI the Øresund model also includes extra friction to represent the Øresund bridge piers.
- The diffusivity factor for temperature and salinity in the horizontal: 'scaled eddy' is equal to 1, and in the vertical: 'scaled eddy' equal to 0.03 [9]. This is different from the DKBS2 model: horizontal 0-1.0 (temperature/salinity) and vertical 1.0 (temperature) / 0-1.0 (salinity) [2].

Without explanation in the reports or further study of the software and the models we are not able to reflect further on the input parameters.

4.2.6 Numerical input parameters

In the report [3] or in [9] no information is given on choices for numerical input parameters that determine the accuracy of the solution.

4.2.7 Calibration

In the Øresund model the following parameters were adjusted during the calibration of the model, see [9]:

- The water level at the boundaries to reproduce the water levels in and water level gradients along the Øresund.
- The bottom roughness length and the scaling factors for dispersion on the basis of the vertical salinity profiles observed south of Ven Island and in Køge Bay.
- Furthermore, the deep channel bathymetry north of Ven was adjusted (smoothed) to reduce impact of artificial bumps blocking for the near-bed inflow of saline water.

It is not clear whether the calibration and the verification (see Section 5.2) have been carried out with independent data sets (e.g. over different periods).

The Øresund model was nested in the DKBS2 model and during the calibration of the Øresund model the water level boundary condition has been calibrated. In itself this can be considered as an improvement. By result, the transports through the Øresund are different compared to the DKBS2 model, while results of the DKBS2 model were accepted for the long-term effects in the Baltic Sea (see Section 5.1). Therefore, a discussion of the effect of the water level calibration on the transports though the Øresund would have been appropriate.

4.3 Conclusion

The reporting on the model set-up is such that a full assessment cannot be given in this review. Elements like model domain, grid resolution, applied bathymetry, atmospheric forcing, and the boundary conditions, are appropriate for the purpose. However, it is not clear whether the spin-up period is long enough, and if time interval of the boundary conditions is sufficient.

The physical input parameters cannot be fully verified on the basis of the input provided. Notable differences between the models, which describe the same exchange flows through the Øresund, are

- The Øresund model has a higher grid resolution in the horizontal, as may be expected, but a lower grid resolution in the vertical compared to the large scale DKBS2 model.
- The higher horizontal resolution of the Øresund model, e.g. on Drogden Sill, and the adjustments of the deep channel bathymetry north of Ven, will affect the dynamics relative to the DKBS2 model.
- The physical parameters may differ considerably, like the resistance due to bed friction and the parametrization of bridge piers of the Øresund bridge, and the diffusivity factors for temperature and salinity.

With respect to the numerical input parameters we need to trust that the appropriate choices have been made, resulting in sufficient accurate and stable solutions. Therefore, the verification of the models in Chapter 5 is to provide the main basis for confidence in the models.

Note that due to the calibration of the water level and water level gradients in the Øresund model, the results of the DKBS2 model basically serve to provide initial and boundary conditions for currents, salinity and temperature. The suitability of these conditions derived from the DKBS2 model for 2018 depend solely on the verification for the period 2008 – 2017, which is discussed in the next chapter.

5 Evaluation of model verification

The verification of the models has been assessed based on the results as presented and described in the reports and additional information provided, but without access to the original definition the numerical models and the output files of computations. The results of the DKBS2 model verification are discussed in Section 5.1 and the results of the Øresund model verification for the reference situation (without Lynetteholm) in Section 5.2.

5.1 Results of DKBS2 model verification

In Chapter 3 of the DKBS2 report [2] the model results have been verified with measured water levels, currents, salinities and temperatures. The flows through the Danish Straits have been compared to values from literature. The entire computation covers 10 years, from 2008 – 2017. The verification is generally presented for shorter periods, however.

5.1.1 Water levels

The computed water levels are compared to measured water levels for selected periods in 13 tide gauge stations distributed over model area in the DKBS2 report (Par. 3.1.1 in [2]):

- A period of one month (15 February to 15 March 2016) for 5 stations with tidal influence (Skagerrak, Kattegat and Danish Straits), and
- A period of 5 months (July -November 2016) for 8 stations in the inner Baltic where the water level variations are predominantly determined by the wind, although small tidal variations are also present in the Gulf of Finland (Helsinki, Kronstadt/Saint Petersburg) in both model and measurements.

Visual inspection of the presented plots (periods of the two sets not overlapping) show that in these periods the main variability is well represented, especially in the Baltic Sea. A numerical evaluation and/or a more detailed discussion of specific phenomena like tides, wind events (surges), water level differences over the Straits or MBI's, has not been presented, however.

5.1.2 Currents

The computed and measured currents are compared in 5 stations, of which 2 are located north of the Danish Straits in the Skagerrak and Kattegat, 2 are located in the Arkona Basin roughly several 100 kms southeast of the Straits and 1 in the Northern Gotland Basin in the middle of the Baltic Sea, see in the DKBS2 report (Par. 3.2.2 in [2]):

- Väderöarna (Skagerrak) at 4 m and 28 m depth July – September 2014,
- Läsö Ost Boj (Kattegat) at 2 m depth February – October 2009,
- Fino station (Arkona Basin) at 5 m and 20 m depth August 2013 – January 2014,
- BSH Arkona Becken (Arkona Basin) station at depth 5-6 m and 40 m March – July 2012,
- Huvudskär Ost Boj (Northern Gotland Basin) at depth 2m January – September 2016.

Time-series of current speed and direction and current roses have been compared for surface currents (between 2 and 6 m depth) and when available for the currents at a larger depth (20 – 40 m). The time-series vary in length from 3 – 9 month and are not overlapping. The interpretation of the quality of fit of current time-series and current roses is generally difficult as the measured currents near the surface may have been influenced by local variations in wind or by (subgrid) bottom topography near the bed. A discussion of specific phenomena occurring in these periods, like tides, storms and particular extreme MBI's (e.g. December 2014) is desirable but not available, however. The suggested fair agreement in the report is therefore not entirely convincing.

The integrated parameter of flow through the Danish Straits is discussed in Section 5.1.4.

5.1.3 Salinity and temperature

More important for the present investigation is the quality of the salinity and temperature development and stratification on both sides of the Øresund, since these parameters are used for nesting of the Øresund model. Salinity and temperature measurements at the surface, the bottom and sometimes and at an intermediate level have been graphically compared to time-series of modelled salinity and temperature for the period of 2008 – 2017 in 21 stations [2]. Unfortunately, there is no further discussion of these results in [2], for instance assessing the response of the model on the more extreme events (MBIs). The measurements, were roughly obtained with a monthly interval over periods varying between 5 and 9.3 years.

Focussing on the stations in or near the Øresund (AnholtE in the Kattegat, KBH431 in central Øresund, and BY2 in the Arkona Basin) we notice a strong variability in modelled salinity near the surface in the first two stations, in contrast to the third station where this is the case near the bottom. Such variability can only be very roughly compared with monthly measurements. The range of variation seems correct, however. The salinity near the bottom in the first two stations (high salinity ~ 33 psu) and near the surface in the third station (~8 psu) are much more stable and show a fair to good agreement with measurements.
Measured and modelled temperatures generally show a good agreement on seasonal and interannual time scales, with exception of the temperature minima near the bottom in particular years in AnholtE and KBH431. It is not clear what might have caused these deviations.

Salinity and temperature profiles to check the height of the modelled and measured thermoclines and pycnoclines were not presented in the DKBS2 report. It is recommended to verify those too. Salinity profiles in the Øresund during 2018 are discussed in Section 5.2.3.

Given the large scale of the model, the presented results show a good match with the measurements on the long-term (9 years), as well as on seasonal and interannual scales.

5.1.4 Water and salt exchange through the Danish Straits

The flows through the Danish Straits, Little Belt, Great Belt and Øresund have been graphically presented for 2011 in the DKBS2 report (Par. 3.2.1 in [2]). The mean outflow computed by the model for the period 2008 – 2017 is 533 km^3/year for all straits combined [2]. This is 11% higher that the value of 480 km^3/year mentioned in literature (see Table 2.1 and [5]). We consider this is an acceptable level of agreement for such a comparison, since the accuracy of mean outflow depends on the water balance of the Baltic Sea which depends on estimates of the inflow of rivers, precipitation and evaporation, where larger uncertainties are not uncommon. In the model the flows are roughly distributed between Little Belt, Great Belt and Øresund according to the ratio of 1:7:3 as shown on the basis of the instantaneous flow results of 2011 in [2]. This means that generally 27% of the water flows through Øresund. This is in agreement with the ratio of 25 -30% mentioned [5]. Using the 27% ratio and the 533 km^3/year for all straits combined, the mean flow through the Øresund over 2008 – 2017 is estimated at 144 km^3/year (the corresponding model result for 2008-2017 was not reported[3]).

The exchange of salt has not been addressed in [2]. But from [10], referenced in [9], we understand that the distribution of salt transport over the Straits can be different from the

[3] In [9] DHI reports a 31% higher net flow of 189 km^3/year for the period 2002-2019. The origin of this value and the reason for the difference is not known at present.

ratios provided for the flows. E.g. for small Major Baltic Inflow (MBI) events the part of the salt transport through the Øresund can be much larger than 25-30% of the total transport. However, in the comparison of the time-series of measured and modelled salinity the long-term fit over 10 years is stable. Although this is still less than the residence time of about 30 years, it suggests that the total salt exchange through the Danish Straits is modelled reasonably well.

The accuracy of water and salt exchange though the Øresund in the DKBS2 model has not been addressed in [2], but since the water levels are further calibrated and salinity is further verified in the Øresund model this is less relevant for the present study.

5.1.5 Conclusion

Considering the large space and time scales of the simulations with the DKBS2 model, the general quality of the results over the period 2008 – 2017 is reasonably good. By definition, the model lacks finesse in and near Øresund, and the accuracy of the parameters used for nesting of the Øresund model has not been addressed. Comparison to values from literature suggest an accuracy in the order of 10% for the total net flow through all Danish Straits. For the salt exchange such information was not available. However, the stable long-term results for the salt dynamics in the Baltic Sea suggests that the total salt exchange through the Danish Straits is modelled reasonably well.

The DKBS2 model has been used to provide boundary conditions and initial conditions for the Øresund model in the year 2018. However, the application of the DKBS2 model to 2018 has not been presented or discussed.

The limited accuracy information and the lack of data on the general performance in 2018 does not have to be a major problem, since certain model aspects have been subject to further calibration (water level boundary condition) or verification (salinity) in the Øresund model, see Section 5.2.

5.2 Results of Øresund model verification

In Annex A of the Øresund report the results of the calibrated model have been verified with measured water levels and salinities for the year 2018 (see [4]). The results for currents and temperatures were not verified. The results of (integrated) flow and salt transport for the reference situation (without Lynetteholm) are presented in Par 6.1.6 of the Øresund report.

5.2.1 Water levels

In Annex A.1 of [4] the time-series of measured and modelled water levels in the 11 water level stations used for calibration are presented for the entire year 2018. 6 stations are located on the Danish shore and 5 on the Swedish shore of the Øresund. Additionally, scatterplots and frequency of occurrence plots of measured and modelled water levels are presented. These plots also include a numerical evaluation, but this is not discussed in [4]. From these results we conclude that due to the calibration of the water level boundaries of the Øresund model the fit of the time-series is good, with an average root-mean-square error (RMSE) of 0.06 m.

In view of the water level gradient driven part of the flow through Øresund, a comparison of the difference in water levels between stations near the northern boundary and the southern boundary for the model and the measurements would be of interest. Probably this error is only slightly larger.

5.2.2 Currents

Comparison of modelled and measured currents in transects or fixed points on Drogden Sill would provide a strong verification of the Øresund model. This is especially relevant since the transport through the Øresund determined by the DKBS2 model was changed by the calibration of the water levels. However, no verification of currents is available in the Øresund report, nor is it explained that current measurements are not available in the Øresund in 2018, or alternatively in other periods. The verification of the flow therefore depends on the assessment of the accumulated flow in general terms, see Section 5.2.4.

5.2.3 Salinity and temperature

In Annex A.2 of [4] modelled and measured salinity profiles have been compared for 22 moments distributed over the year in the stations P2 and P4 located about 30 km north and 25 km southwest of Drogden Sill in respectively 35 and 14 m deep water. These results are not discussed in [4] and therefore a short discussion is included here. Inspection of the profiles shows that the salinity near the bed in station P2 is on average roughly 4 psu too low compared to the measured profiles. The measurements also show a (much) stronger stratification than the model. In station P2 the surface salinity increases during the MBI event in September 2018 in both model and measurements. This resulted in station P4 also in a significant increase (between 10 - 15 psu) in salinity over the entire water depth in September in both model and measurements (salinity values exceeding 17 psu). In the shallower station P4 the difference between the salinity at the surface and the bed is generally small or even negligible.

During the inflow event of December 2018, no increase of salinity is noted in the stations P2 and P4. This is perhaps (partly) due to the large interval between the measured profiles (26 November – 20 December 2018).

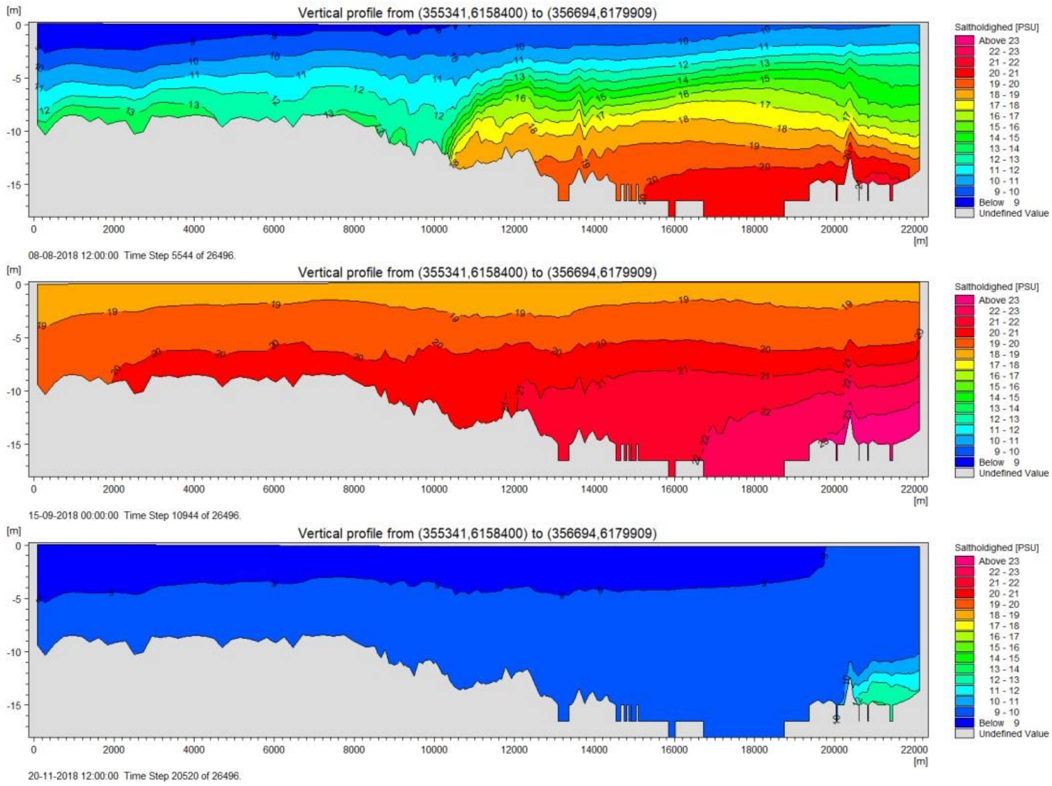

Figure 5.1 Vertical section of salinity during various stages of exchange flow along Drogden Channel and Hollænderdybet computed for the reference situation: (top) after a more or less stable period on 8 August 2018 (middle) during a period of saltwater intrusion on 15 September 2018 and (bottom) after a longer period of low salinity outflow on 20 November 2018 (Source: Figure 6-152 to Figure 6-154 in [4]).

The salinity distributions in various stages of exchange flow have been illustrated in [4] by the computed salinity distributions in a vertical section along Drogden Channel and Hollænderdybet, see Figure 5.1. From top to bottom the plots show the longitudinal section after a more or less stable period on 8 August 2018, during a period of saltwater intrusion on 15 September 2018 during the MBI event, and after a longer period of low salinity outflow. The stages can be verified from the plot of the accumulated salt transport in Figure 5.2. In all stages a vertical density gradient is present at Drogden Sill. Note that in areas with a water depth of less than 15 m in the vertical section 'sigma-effects' can be found at places where the isohalines follow the variation of the sea bed.

It is recommended to add time-series of modelled surface and near bed salinity and their measured values, to verify the high variability of surface salinities noted in DKBS2 model. In addition, it is recommended to add time-series and profiles of modelled and measured water temperature to the verification.

5.2.4 Water and salt exchange through Øresund

The water and salt transport computed by the model for 2018 cannot be compared to measurements. We can compare the net transport and the exchange flow of water and salt to the characteristic values given in Table 2.1, however. For the MBI events present in the simulation, we have used estimates from literature for comparison.

In Par 6.1.6.2 of [3] the net and the accumulated flow through the Øresund is discussed amongst others for the reference or baseline situation. From Table 6-5 in [3] it follows that the net flow through the Øresund in the model is 175 km^3/year over 2018. This is 35% higher than the average flow through the Øresund of about 130 km^3/year derived from literature by taking 27% of 480 km^3/year for all Danish Straits, see also Section 5.1.4.

An estimate of the mean water exchange per year through the Øresund can be obtained by taking half of the mean absolute flow of 29 652 m^3/s (see Table 6.1), or 467.6 km^3/year and correct this with half of the net flow, or 87.5 km^3/year. This leads to a mean water inflow of about 319 km^3/year and a mean water outflow of 555 km^3/year through the Øresund in 2018. This is respectively 19% and 24 % higher than the estimated mean values of 319 and 448 km^3/year that one would get for the Øresund by taking 27% of the global values given in Table 2.1 for all Danish Straits.

The largest inflow events are estimated from the plot of the accumulated flow for the Øresund cross-section at Santholm, see Figure 6-128 in [3], at ~50 km^3 in September and ~40 km^3 in December 2018. These were identified as small/medium size MBI events in [9]. Mohrholz estimates the water transport through the Øresund at 35 km^3 during the September event and 42 km^3 during the December event at a different ratio of 22% (compared to 27% above) of the total water exchange during the events, see [10] and the link given in [9] . Despite the differences found, this confirms that the transport of water during the MBI events is in the right order of magnitude taking into account the different nature of the model results and the estimate by Mohrholz.

In Par. 6.1.6.5 and Par. 6.1.6.6 of [3] the net and the accumulated salt transport though the Øresund is discussed for the reference or baseline situation, amongst others. The instantaneous salt transport has a range of approximate -2 000 000 kg/s to +1 000 000 kg/s (positive is north going), see Figure 6-143 in [3], while the long-term net transport would almost be zero, see Table 2.1. The range of the accumulated salt transport through the Øresund is between +900 and -400 M ton salt, see Figure 5.2. At the end of the year 2018 the annual net salt transport for the Øresund is not necessarily zero due to inter annual variations. In this case it is small and slightly negative with -100 M ton salt. This is roughly in

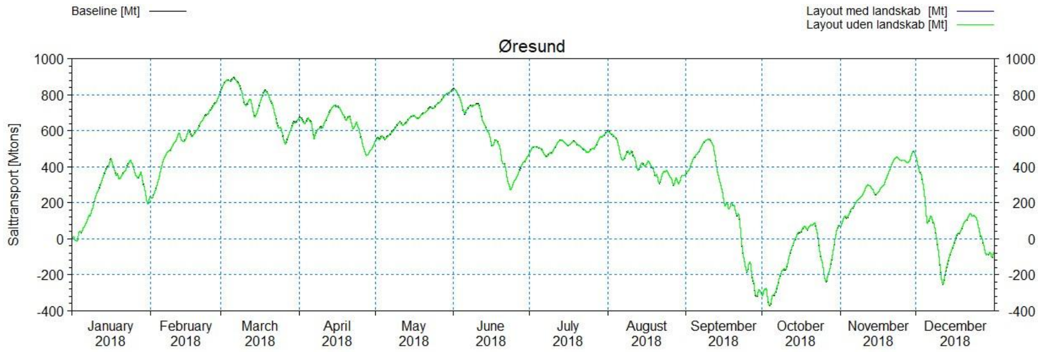

Figure 5.2 Accumulated transport of salt in the cross-section through the Øresund with the existing conditions (black curve), reclamation without landscape (green curve) and reclamation with landscape (blue curve). Source: Figure 6-148 in [4][3].

agreement with the balance in the salt transport shown in Table 2.1 as it is only 0.3% of the total salt exchange of 30 G ton/year for all Danish Straits.

A fair estimate of the mean salt exchange per year through the Øresund can be obtained by taking half of the mean absolute salt transport of 350 000 kg/s given in Table 6.2. This leads to a salt exchange of about 11 G ton/year through the Øresund in 2018 or 37% of the 30 G ton/year through all Danish Straits mentioned in literature, see Table 2.1.

Regarding the two small/medium size MBI events identified in [9], the inflow of salt can be estimated from the accumulated salt transport through the Øresund in Figure 5.2. In the event of September 2018, the accumulated salt transport changes from about +560 to -370 M ton, so during the event about 930 M ton or 0.93 G ton of salt flowed into the Baltic Sea. In a similar way an inflow of about 0.74 G ton salt is estimated for the event of the beginning of December 2018. In the reference and link given in [9], Mohrholz estimates the salt transport for the Øresund at 0.65 G ton during the September event and 0.75 G ton during the December event at ratios of 57% and 52% of the total salt exchange during the events. Despite the differences, this also confirms that the transport of salt during the MBI events is in the right order of magnitude.

De total salt transports estimated by Mohrholz for the September and December events is 1.16 and 1.45 G ton. These are somewhat lower than the 1.6 G ton of salt transport that corresponds to a MBI occurring on average once per year, based on the exponential curve in Figure 5.3.

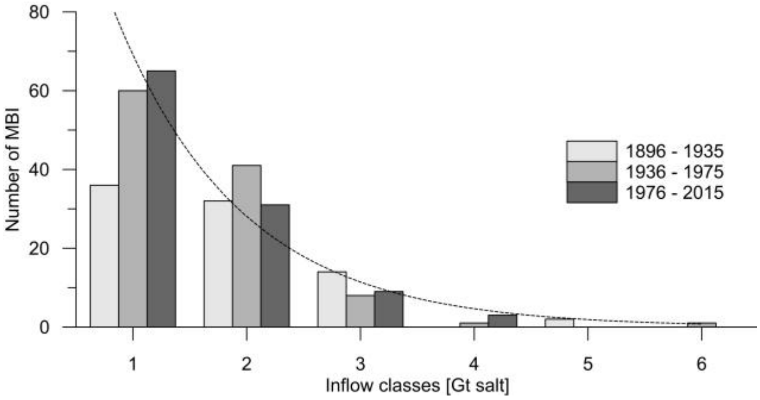

Figure 5.3 Total frequency of inflow classes in the time series DS0 for the three subsequent 40-year periods 1896-1935, 1936-1975 and 1976-2015 (source: https://www.io-warnemuende.de/major-baltic-inflow-statistics-7274.html)

In summary:

- The net flow through the Øresund in the model is 175 km^3/year over 2018, 35% higher than estimated on the basis of global numbers in Table 2.1.
- The net salt exchange is very small, as expected.
- The water exchange in the model is estimated from the results at about 319 km^3/year inflow and about 555 km^3/year outflow through the Øresund in 2018, respectively 19% and 24 % higher than estimated on the basis of average numbers in Table 2.1.
- The salt exchange in the model is estimated from the results at about 11 G ton/year through the Øresund in 2018 (inflow and outflow), or 37% of the average salt exchange through all Danish Straits mentioned in Table 2.1.
- During two small/medium size MBI events the inflow thought the Øresund in the model is about 35 km^3 in September and about 42 km^3 in December. The corresponding inflow of salt into the Baltic Sea is estimated at 0.93 G ton and 0.74 G ton. Both the inflow of water and salt during these MBI events seem in the right order of magnitude for MBI events occurring more than once per year on average.

Although the modelled flow and salt transport though the Øresund could not be verified with measurements of 2018, we conclude from a comparison with published characteristic values that the modelled flow and salt transport in 2018 is possibly somewhat stronger than average but realistic in magnitude. The year also contains two small/medium size MBI events and therefore the simulation of 2018 might be sufficiently representative for the investigation of the effect of Lynetteholm on the water and salt exchange through the Øresund, provided that the blocking effect is not sensitive for the occurrence of these events (see Section 6.2).

5.2.5 Conclusion

The performance of the Øresund model was verified for time-series of water-levels and profiles of salinity measured in 2018. Unfortunately, no verification of currents and water temperature has been provided. Since the adjustment of the water levels prescribed at the open boundaries (originally derived from the DKBS2 model by nesting) may have changed the transport through the Øresund , it is necessary to verify the transport of water and salt at least in some way. Therefore, we compared the transport of water and salt and the two small/medium size MBI events identified in [9] to values published in literature. From this we conclude that the flow and salt exchange computed by the model for 2018 is possibly somewhat stronger than average but realistic in magnitude. Therefore, we consider the simulation of 2018 sufficiently representative for the present purpose, to estimate the effect of Lynetteholm on the water and salt exchange through the Øresund by comparing model results of a simulation including Lynetteholm with the reference situation without Lynetteholm provided that the blocking effect is not sensitive for the occurrence of MBI events (see Section 6.2). Concrete data on the model accuracy has not been provided, except for the water levels. The accuracy of the water and salt exchange will be discussed the next section in terms of the accuracy band of the blocking effect.

6 Evaluation of the impact of Lynetteholm on water and salt exchange

In the Hydrodynamic Study, the impact of Lynetteholm on the water and salt exchange through the Øresund has been determined by applying the Øresund model to Main Proposal 1 and 2 of Lynetteholm and comparing the results with those obtained for the reference situation. In the Øresund report the comparison presented for the cross-sections Øresund (an east – west section across Santholm) and Peberholm East and Peberholm West are the most interesting ones. Several parameters on the water and salt exchange are presented, notably:

- the instantaneous flow, the mean absolute flow (Par. 6.1.6.1),
- the accumulated flow and the annual net flow (Par. 6.1.6.2),
- the blocking effect for flow (Par. 6.1.6.3).
- the momentary salt transport (Par. 6.1.6.5),
- the accumulated salt transport and the annual net salt transport (Par. 6.1.6.6),
- the blocking effect for salt transport (Par. 6.1.6.7),

see [3] and [4].

The key parameter in this comparison is the blocking effect for water flow and salt transport, as described in Section 3.3. The conclusions presented in the Øresund report are based on the cross-section Øresund. In principle it is better to evaluate the blocking effect at the smallest and shallowest cross-section, Drogden Sill, however. Therefore, we will make also use of the additional blocking analyses in [8], where the blocking effect has been evaluated by combining the sections of Peberholm East and Peberholm West, located close to Drogden Sill.

6.1 Blocking effect for water exchange

In Table 6.1 the mean absolute flow over 2018 of the reference situation (baseline) and two Lynetteholm variants (Main Proposal 1 and Main Proposal 2) is shown for the most relevant cross-sections, together with the percentage of change, based on [8]. Compared to [8] we have adjusted the sign of the percentage of change, to let it correspond with the definition of the blocking effect for the entire year. The values for the cross-section Total Drogden Sill (red text and numbers) were simply obtained by combining the mean absolute flow of Peberholm East and Peberholm West and deriving the blocking effect/change percentage from that. This introduces minor errors in the estimate, however. Therefore, in [8] a new estimate for Total Drogden Sill (black numbers) was provided by analyzing the combined discharges Peberholm East and Peberholm West (first determining the total discharge, and then the mean absolute values). The resulting blocking effect for 2018 for the flow at Drogden Sill (East & West Peberholm combined) is -0.186% and -0.244% for Main Proposal 1 and 2, respectively. This is similar to the blocking effect originally computed for the Øresund section. The blocking for Main Proposal 2 (-0.244%) is somewhat stronger than for Main Proposal 1 (-0.186%) due to the coastal landscape in Main Proposal 2.

The accuracy of the calculation of the blocking effect is discussed in [9]. It is argued in [9] that it is reasonable to accept the 95% confidence range of ±0.25% of the blocking effect established for the Øresund Link modelling as an estimate of the accuracy for the present modelling of the blocking effect in the Øresund. Although this is not explicitly stated, we assume the confidence range holds both for flow and for salt. We can imagine that the confidence range is within the given range of ±0.25% due to improvements in the modelling approach such as higher resolution models and longer simulations compared to that applied for Øresund Link. However, we do not agree to reduce the confidence range with 50% because the initial blocking of Lynetteholm is about 50% of the initial blocking effect of the Øresund Link, as suggested in [9].

We conclude therefore that for the flow through the Øresund the blocking effect is -0.186% and -0.244% for Main Proposal 1 and 2, respectively, with 95% confidence range within ±0.25%.

Furthermore, it is relevant to check if the blocking effect is sensitive for the occurrence of the small/medium MBIs described in Section 5.2.4. Inspecting the time-series of the blocking effect for flow derived for the Øresund cross-section (Figure 6-133 in [3]) we do not see notable effects in the periods of the MBIs (September, beginning of December).

Table 6.1 Mean absolute flow over 2018 (Annual mean gross water flow - calculated without sign) from [8]. Change percentage is equal to the computed blocking effect over 2018.

Cross-section	Baseline	Main Proposal 1	Main Proposal 2	Main Proposal 1	Main Proposal 2
	m3/s	m3/s	m3/s	Change %	Change %
West Peberholm	10897.87492	10800.71993	10767.86938	-0.892%	-1.193%
East Peberholm	18789.44222	18829.02629	18844.63364	0.211%	0.294%
Total Drogden Sill	29687.31715	29629.74622	29612.50302	-0.194%	-0.252%
Total Drogden Sill	29651.52822	29596.23035	29579.10229	-0.186%	-0.244%
Oresund (across Saltholm)	29568	29513	29496	-0.186%	-0.244%

6.2 Blocking effect for salt transport

In Table 6.2 the mean absolute salt transport over 2018 of the reference situation (baseline) and two Lynetteholm variants (Main Proposal 1 and Main Proposal 2) is presented for the most relevant cross-sections, together with the percentage of change, in a similar way as was done for the flow in Table 6.1. In this case the new estimate for the blocking effect for 2018 for salt transport at Drogden Sill (East & West Peberholm combined) in [8] provides with -0.191% and -0.241% for Main Proposal 1 and 2, numbers that show a slightly stronger effect than computed for the Øresund section across Santholm. Note that the new values are very close to the values obtained for the blocking effect for the flow.

We conclude that for the salt transport through the Øresund the blocking effect is -0.191% and -0.241% for Main Proposal 1 and 2, respectively, with a similar 95% confidence range within ±0.25%, as for the flow.

Furthermore, we checked the sensitivity of the blocking effect on the occurrence of the small/medium MBIs described in Section 5.2.4. Inspecting the time-series of the blocking effect for salt derived for the Øresund cross-section (Figure 6-157 in [3]) the effects in the periods of the MBIs (September, beginning of December) are very small for Main Proposal 1 and slightly larger for main Proposal 2, but not more than -0.01%. Therefore 2018 is considered sufficient representative for the analysis of the impact of Lynetteholm on the exchange of water and salt.

Table 6.2 Mean absolute salt transport over 2018 (Annual mean salt transport - calculated without sign) from [8]. Change percentage is equal to the computed blocking effect over 2018.

Cross-section	Baseline	Main Proposal 1	Main Proposal 2	Main Proposal 1	Main Proposal 2
	kg/s	kg/s	kg/s	Change %	Change %
West Peberholm	136252.4264	134829.9941	134438.3022	-1.044%	-1.331%
East Peberholm	214002.6852	214718.4694	214933.8328	0.334%	0.435%
Total Drogden Sill	350255.1116	349548.4635	349372.135	-0.202%	-0.252%
Total Drogden Sill	349824.0955	349156.339	348981.0446	-0.191%	-0.241%
Oresund (across Saltholm)	362226.0053	361584.2347	361414.9652	-0.177%	-0.224%

6.3 Results in perspective

In summary, in the Hydrodynamic Studies, the blocking effect for water and salt at Drogden Sill is estimated at -0.19% and -0.24% for Main Proposal 1 and 2 respectively, with a 95% confidence range within ±0.25%. This indicates that a small reduction of the exchange of water and salt through the Øresund is likely. Whether these ranges are acceptable or not, is outside the scope of this review.

In an attempt to put this result into perspective, DHI compared it to the blocking criteria for the Øresund Link (Par. 6.1.6.3) and to a rough estimate of the effect of the expected sea level rise (Par. 6.1.6.4 and Par. 6.1.6.8 in [3] and [4]).

In [3] the blockage effect estimated for Lynetteholm was compared to the blocking criteria that were applied for the Øresund Link. Citation: "*In connection with the Øresund Link, a zero solution was required, where by compensation excavations an attempt was made to produce conditions resulting in a zero-blocking factor for both water and salt. In these calculations, the blocking requirement was set at less than 0.1% with an uncertainty spread estimated at +/- 0.25% within an uncertainty limited to a 95% confidence interval, Ref. /1/[4]. The uncertainty accepted by the zero solution is thus higher than the estimated blockage than the Lynetteholm reclamation for salt transport through Øresund."* For a correct interpretation we would like to add that this needs to be expressed in terms of an X% chance that the blocking effect of Lynetteholm Main Proposal 2 is better (less negative) than the Zero Solution (-0.1 ±0.25%), and a Y% chance that the blocking effect is worse (more negative)[5]. Where X and Y need to be determined from the two probability distributions.

In [3] the blockage effect estimated for Lynetteholm was also compared to the estimated effects of Sea Level Rise (SLR) on the blockage in an attempt to relate the blocking effect for water and salt transport due to Lynetteholm to other (autonomous) physical processes. The approach was to increase the water levels in the model by 2 cm and determine the effect on blocking after half a year (January – June 2018). This slightly increased the thickness of the top (sigma-) layers in the model. Other parameters from the initial conditions and boundary conditions were not changed. Other effects of climate change than SLR (river runoff, precipitation, evaporation, wind) were ignored without discussion. The effect of 2 cm SLR on the blocking effect of flow in the Øresund cross-section of both Main Proposals was +0.030 %, see Figure 6-148 in [3]. Assuming a rate of SLR of 1.55 mm/year this suggests that a period of about 8 years is required to balance the effect of Main Proposal 1 and 10 years for Main Proposal 2.

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[4] See reference [6]. This reference has not been made available.
[5] In [9] a requirement for the blockage effect of 0% ±0.25% is mentioned for the Zero Solution of the Øresund Link instead of -0.1% ±0.25%. When this is correct the probability statement should be adjusted accordingly.

For salt transport a similar approach is followed in [3]. The effect of 2 cm SLR on the blocking effect of salt in the Øresund cross-section of both Main Proposals was +0.024 %, see Figure 6-162 in [3]. Assuming a rate of SLR of 1.55 mm/year this suggests that a period of about 10 years is required to balance the effect of Main Proposal 1 and 12 years[6] for Main Proposal 2.

Although it was stressed by DHI that the effect of the SLR scenario (with all limitations) was intended for comparison and not as a mitigating measure, the result can also be interpreted in the sense that Lynetteholm absorbs about 10 years of (autonomous) improvement of exchange of water and salt due to climate change, assuming the estimate is correct. Note that this statement holds only for the transport through the Øresund (about 27% of the total flow, but the percentage can be much larger for salt transport) and not for the transports through the Little and Great Belt (about 73% for flow).

[6] The Øresund report mentions 25 years, which we believe is not correct.

7 Synthesis of findings

The review will be closed with a discussion of the most important restrictions and uncertainties in the reviewed studies. Next, the final conclusions of the review of the Hydrodynamic Studies with reference to the exchange flows through the Øresund will be given, together with some recommendations.

7.1 Discussion of impact of Lynetteholm

In the discussion of the impact of Lynetteholm on the exchange of water and salt we address three important restrictions and uncertainties in the Hydrodynamic Studies.

The first restriction is that the approach based on the Øresund model, with identical boundary conditions for the reference situation and the Main Proposals for Lynetteholm, is in principle only valid when the blocking effect due to Lynetteholm is negligible. The degree to which a non-negligible blocking effect estimated on the basis of the Øresund model with fixed boundary conditions is conservative or not would be useful information for the interpretation of the results. The reports of the Hydrodynamic Studies provided no insight in this; however, it may have been addressed in previous studies or in literature. Otherwise it can be investigated in a sensitivity study with the DKBS2 model.

The second subject is the improvement of the model set-up, calibration and the verification of the Øresund model and the DKBS2 model.
Partly the improvement could be directed at the reporting of model set-up, calibration and verification. Note that an assessment of the original input and output files of the applied numerical models cannot replace such documentation as the report should contain the substantiation of the choices that were made. A better reporting should help to provide more confidence in the quality of the models.
Another matter is the verification of the transports in the Øresund model. Assuming that no current or transport measurements were available for 2018, perhaps the application of the same methodology in another year in which such measurements are available could provide confidence in the model performance, e.g. by showing that calibration on water levels and water level gradients and certain aspects of salinity is sufficient to obtain correct water and salt transports.

Thirdly, the results of the Hydrodynamic Studies regarding the impact of Lynetteholm on the exchange of water and salt might also benefit of an improved (and possibly reduced) estimate of the 95% confidence range. This can perhaps be achieved in a qualitative approach, by regarding the original Monte Carlo approach for the Øresund Link modelling and estimate the effect of e.g. a more detailed model and longer simulation periods. Or alternatively, by repeating the Monte Carlo approach.

When required, several options exist to provide more confidence in the results. However, we cannot estimate whether the efforts involved will be proportional to the improvement of the results. That also depends on the magnitude of the blocking effect that will be considered acceptable and/or negligible by the Swedish and Danish authorities.

7.2 End conclusion

In this review of the Hydrodynamic Studies on the impact of Lynetteholm on the exchange of water and salt through the Øresund, the report of the Hydrodynamic Studies carried out by DHI and additional material provided in response to questions to By & Havn and DHI have been evaluated considering the methodology, the set-up and verification of the modelling, the interpretation of the model results and the conclusions with respect to the exchange of water and salt through Øresund.

The *key results of the Hydrodynamic Studies* on the impact of Lynetteholm on the exchange of water and salt through the Øresund are the estimate of the blocking effect for flow and salt at Drogden Sill of -0.19% and -0.24% for Main Proposal 1 and 2, respectively, with a 95% confidence range of ±0.12% for Lynetteholm. These results are based on a relative approach in which the Main Proposals 1 and 2 of Lynetteholm are compared to the reference situation using a 3D numerical model of the Øresund and the conditions of 2018. The 95% confidence range of ±0.12% for Lynetteholm is half of the ±0.25% confidence range established in the Øresund Link modelling.
Note that this result differs slightly from the reduction reported in the EIA of 0.23-0.25% for the total flow through the Øresund and 0.21-0.23% for the salt transport for Main Proposal 1 and 2, respectively, because these values were based on a different cross-section.

The *main findings of the review* are the following:

- The blocking effect defined in the Hydrodynamic Studies is an appropriate measure for changes in the exchange of water and salt through the Øresund. Note that the blocking effect becomes negative when the exchange is weakening, and positive when the exchange increases.
- The approach based on the Øresund model, with identical boundary conditions for the reference situation and the Main Proposals for Lynetteholm, is valid as long as Lynetteholm does not affect the hydrodynamic conditions at the locations of the open boundaries.
- The set-up and calibration of the models is not well documented, but the resolution, the modelled processes and the type of forcing are appropriate for the purpose.
- The verification of the models is not complete, particularly a verification of currents or transports trough the Øresund is missing in the Øresund model. The additional comparison during the review of the computed exchange of water and salt trough the Øresund to global numbers from literature supports that the model and the selected conditions based on 2018 are appropriate for the evaluation of the blocking effect of Lynetteholm.
- Based on the foregoing, the blocking effect of -0.19% and -0.24% for Main Proposal 1 and 2 at Drogden Sill found in the Hydrodynamic Studies is considered a realistic result. Based on the review we find a 95% confidence range of ±0.25% more reasonable.

It is outside the scope of the review to evaluate whether the blocking effects found are acceptable and/or negligible or not.

In case the above estimates of the blocking effect and confidence range are considered not fully acceptable and/or negligible, further substantiation might be needed. For this the following suggestions can be made.

- It would be useful to learn to which degree the approach based on the Øresund model with fixed boundary conditions is conservative or not, either from previous studies or literature, or from a sensitivity study with the DKBS2 model.
- It could be useful to improve the reporting of model set-up, calibration and verification. This could help to provide more confidence in the quality of the models. Particularly, the verification of the transports in the Øresund model should be considered. Such a verification for 2018 or for another year could enhance the confidence in the model performance, e.g. by showing that calibration on water levels and water level gradients and certain aspects of salinity is sufficient to obtain correct water and salt transports.

- A 95% confidence range smaller than ±0.25% is perhaps achievable but would require further substantiation.

In addition to the estimates of the blocking effect for water and salt, the *Hydrodynamic Studies* presented two ways to put the blocking effect for water and salt due to Lynetteholm into *perspective*: a comparison with the 'Zero Solution' of the Øresund Link, and a comparison with the effects of sea level rise.

In the first way, the *Hydrodynamic Studies* compared the estimated blocking effect for Lynetteholm to the blocking requirement applied in the Zero Solution of the Øresund Link. At the time the requirement was that the blocking was less than 0.1% with a 95% confidence interval ±0.25%. This is interpreted as the blocking effect such as defined in the present study is higher than -0.1% ±0.25%. The Hydrodynamic Studies concluded that the uncertainty accepted by the Zero Solution is thus higher than the estimated blocking effect for Lynetteholm.

In the *review* the following remarks are made:

- We think that such a comparison can be of use, if it can be confirmed that the requirements of that time are still valid, e.g. by later long-term monitoring (from 2000 – present) of the effects of the Øresund Link.
- Given the blocking effect of Main Proposal 1 of -0.19% with a 95% confidence interval of ±0.25% or the blocking effect of Main Proposal 2 of -0.24% ±0.25% a probability statement would be more appropriate for comparison with the requirement of the Zero Solution of better than -0.1 ±0.25% than to state that the uncertainty accepted by the Zero Solution is higher than the estimated blocking effect for Lynetteholm.
- NB. a blockage requirement of 0% ±0.25% has also been mentioned for the Zero Solution [9].

In the second way, the *Hydrodynamic Studies* presented a comparison with the estimated effects of sea level rise on the exchange of water and salt through the Øresund. Simulations were performed for the existing situation and the two Main Proposals with the Øresund model in which all water levels were increased by 2 cm. Assuming a rate of sea level rise of 1.55 mm/year, the blocking effect due to Lynetteholm was expected to be equalized after a 10-year period. For salt the blocking effect was expected to be equalized after a 25-year period. It was stressed that the sea level rise scenario was intended for comparison of the order of magnitude and not as a mitigating measure.

In the *review* the following remarks are made:

- We have doubts about the approach since sea level rise is only one aspect of climate change. Other aspects like North Sea conditions, wind climate, precipitation, river run-off, and even water quality and ecological processes may also change, and lead to different results.
- Using the same data, we estimate that for flow ~8 and 10 years are required to balance the effect of Main Proposal 1 and 2, resp. and for salt ~10 and 12 years are required to balance the effect of Main Proposal 1 and 2 resp.
- Assuming that these estimates are correct, it could be interpreted as Lynetteholm absorbing about 10 years of (autonomous) improvement of the exchange of water and salt through Øresund due to climate change.
- However, given the doubts about the approach the present conclusions based on sea level rise scenarios are not convincing and should not be used without further substantiation.

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Lynetteholm Turbidity Management Hindcast Rapport

Hindcast periode: 2022-01-03 – 2022-02-06

Til:	Lynetteholm Turbidity Management Group
Att.:	By & Havn og MST
Cc:	Michael Lundgaard (By & Havn), Finn Jensen (By & Havn), Anders Vedel (MST)
Fra:	DHI (BBC, SIS)
DHI ref.:	11823523-017
BDC ref.:	83087
Projekt	Lynetteholm
Dato:	2022-03-01
Emne:	Turbidity Management Hindcast
Revision:	0

1 Resumé

Der er udført hindcast modellering med henblik på at dokumentere spredningen af de udførte klapninger. Denne hindcast rapport dækker perioden 3. januar 2022 til 6.februar 2022 og omfatter dermed kun klapning af materialer fra Svælget syd for Middelgrunden.

Klapning af materiale startede op den 6. januar 2022, og der er frem til den 6. februar i alt klappet 58.080 m^3 svarende til ca. 77.400 tons på klapplads Kb.

Alt klapmaterialer i denne periode stammer fra uddybning af sejlrenden ved Svælget. Det opgravede materiale indeholder mange sten og er generelt groft graderet. Generelt er vurderingen, at cirka halvdelen af materialet udgøres af partikler grovere end sand. I den udførte modellering er der anvendt en materialesammensætning som antager at 0,6 % af materialet er ler-partikler, 1,5 % er fin silt, 2,1 % medium silt og 95,8 % er sand eller grovere partikler.

I de udførte forecast dækkende nærværende hindcast periode, gav de 7 opstillede kriterier for klapning ikke anledning til dage med klapforbud.

2 Oversigt af klapmængder

Gravearbejdet i hindcast perioden blev udført med:

- Ajax R (Spandkædemaskine) med 24 timer drift

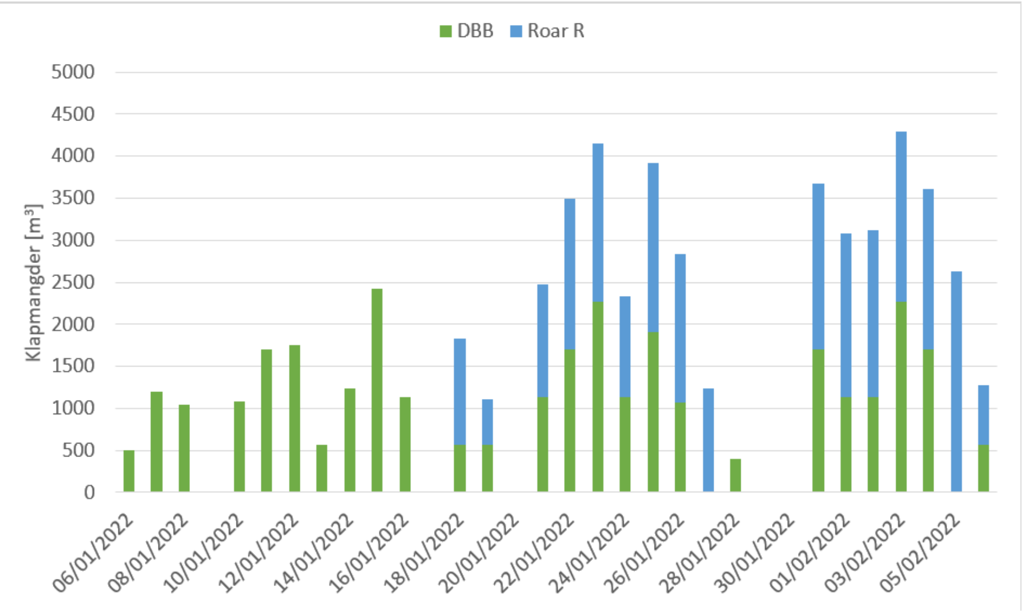
Klapning:

- DBB splitpram 01 med 700 m^3 lastkapacitet
- DBB splitpram 02 med 700 m^3 lastkapacitet
- Rohde Nielsen Roar splitpram med 950 m^3 lastkapacitet

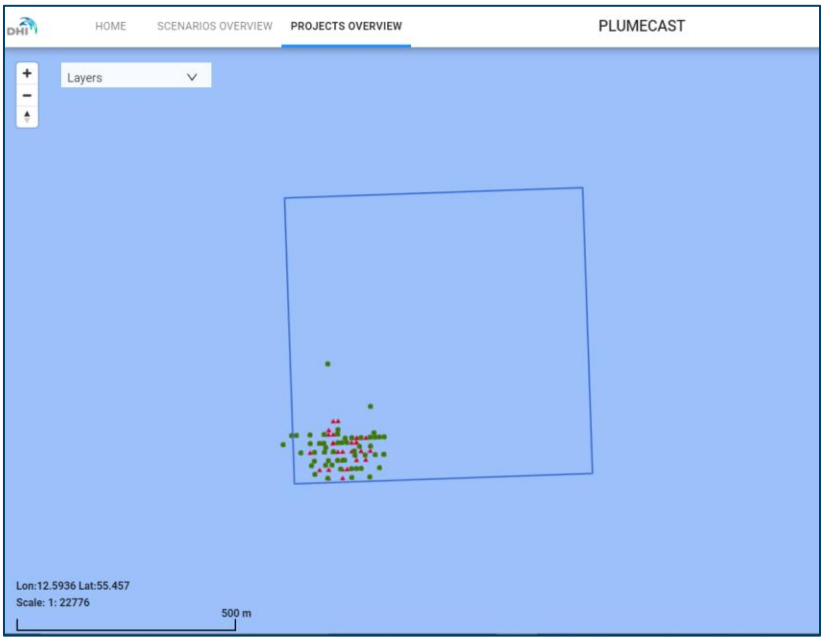
Generelt lastes prammene med en mindre last end den ovenfor opgivne kapacitet.

I Figur 1 er de samlede daglige klapmængder fra de to DBB-splitpramme og splitpram Roar R vist. Alt materiale har sit ophav fra uddybningen af sejlrenden ved Svælget syd for Middelgrunden.

Figur 2 viser de aktuelle klapningspositioner i hindcast perioden. Grønne markører er for DBB splitprammene og de røde markører er for Roar R. Ifølge de opgivne koordinater er en af klapningerne foretaget lige udenfor det definerede klappladsområde, mens en anden er foretaget på grænsen. Alle klapninger er foretaget i klappladsens sydvestlige sektor. At en klapning er angivet som værende udenfor klappladsområdet, kan skyldes at fartøjet driver mens der klappes og at positionen først er registreret efter at klapmaterialet er tømt.



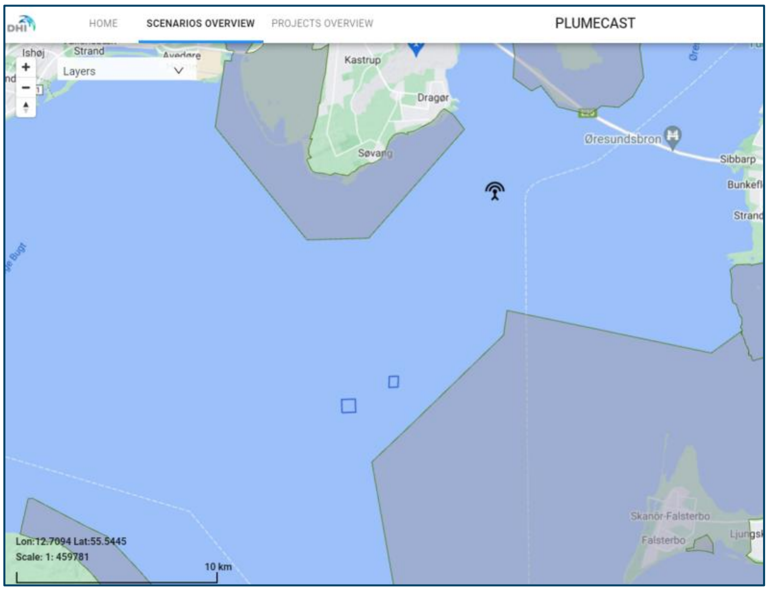
Figur 1 Oversigt over daglige klapmængder i hindcast perioden.



Figur 2 Aktuelle klapplaceringer i hindcast periode. Grøn: DBB, Rød: Roar R

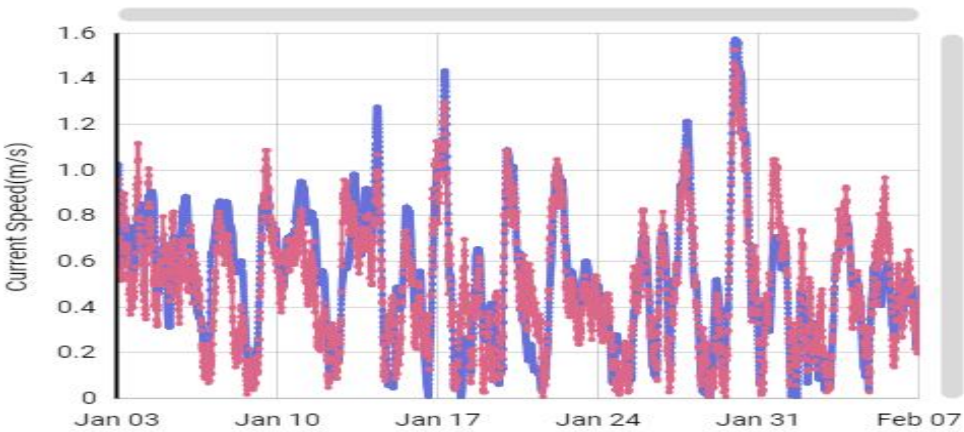
2.1 HD-model evaluering

En forudsætning for at sedimentspredningen kan beskrives kvalitativt korrekt, er at strømforholdene ved klappladsområdet er godt beskrevet. Til evaluering af modellens strømbeskrivelse, er der anvendt data fra Forsvarets strømbøje ved Drogden Fyr. Bøjen er beliggende på 10,8 meter vanddybde og indikeret med en sort signalmarkør i Figur 3 nedenfor.

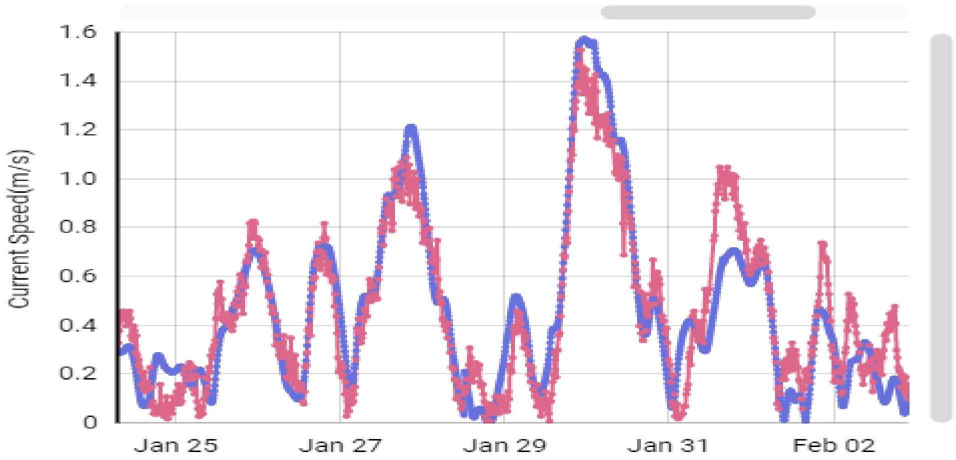


Figur 3 Positionen af strømbøjen ved Drogden Fyr (sort markør).

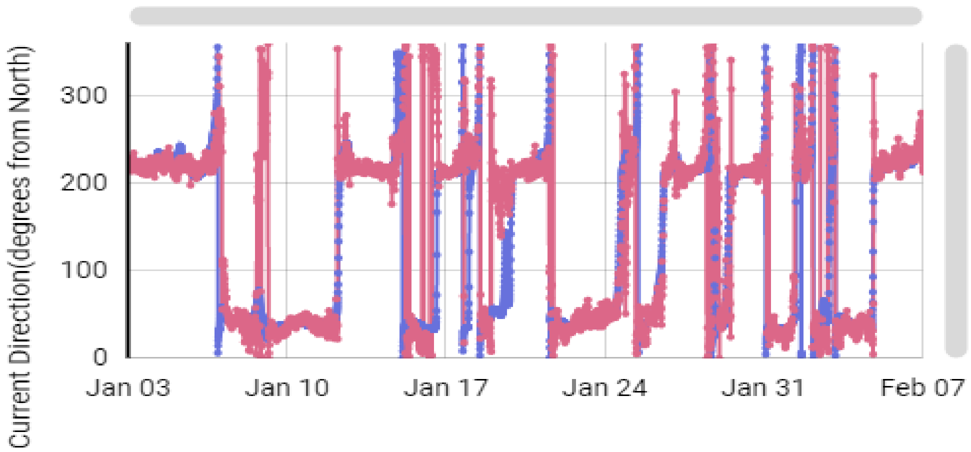
En sammenligning af målte og modellerede strømhastigheder tæt på vandoverfladen i hele hindcast perioden (3. januar – 6. februar) er vist i Figur 4. Den fuldt optrukne blå kurve viser den modellerede strøm, mens den stiplede røde kurve viser den målte strøm. Figur 5 viser et udsnit af Figur 4 i den uge, hvor de højeste strømhastigheder forekommer. Det ses, at der er en meget fin overensstemmelse mellem målte og modellerede strømhastigheder på den givne lokalitet. Figur 6 viser en sammenligning mellem målte og modellerede strømretninger tæt på vandoverfladen. Som for strømhastigheder, ses der at være en fin overensstemmelse mellem målinger og model.



Figur 4 Strømhastighed tæt på havvandoverfladen ved Drogden Fyr. Blå: Model, Rød: Målinger.

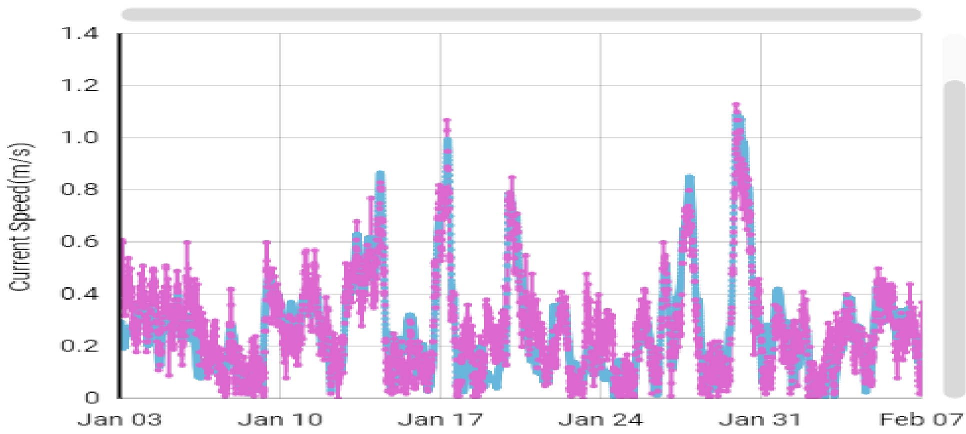


Figur 5 Strømhastighed tæt på havoverfladen ved Drogden Fyr. Blå: Model, Rød: Målinger – eksempel periode 25. januar – 2.februar.

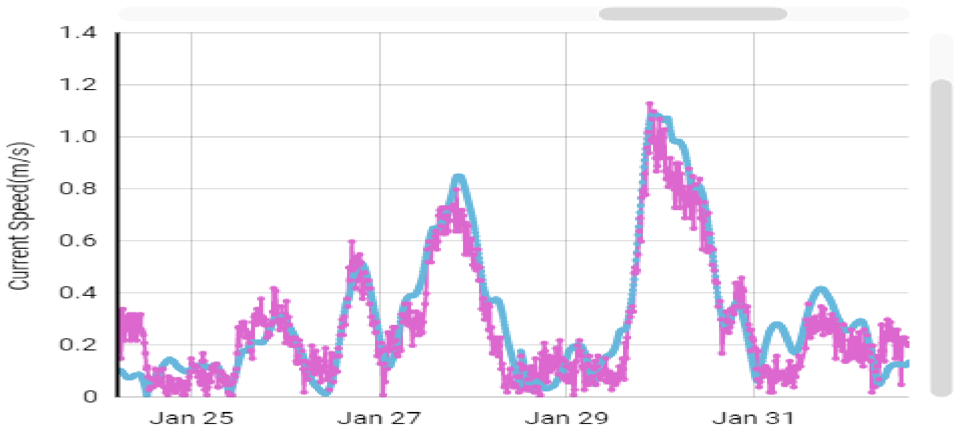


Figur 6 Strømretninger tæt på havoverfladen ved Drogden Fyr. Blå: Model, Rød: Målinger.

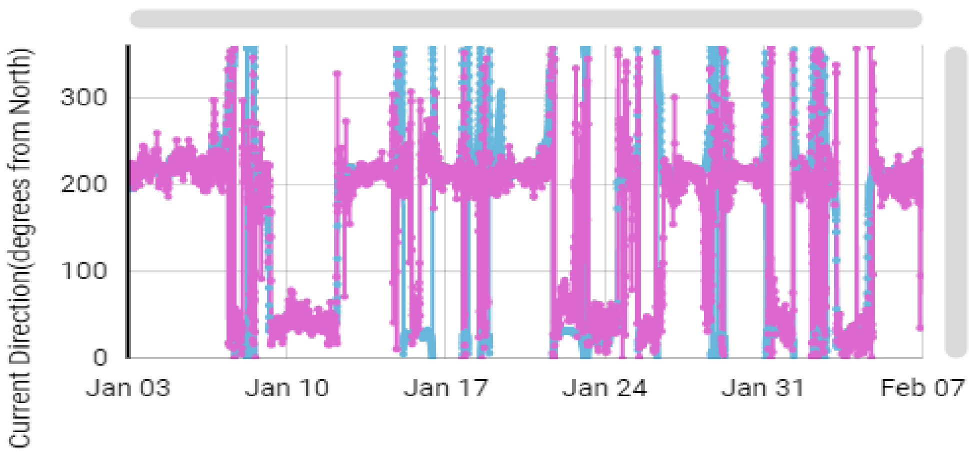
En tilsvarende sammenligning af målte og modellerede strømhastigheder tæt på havbunden i hele hindcast perioden er vist i Figur 7. Den fuldt optrukne lyseblå kurve viser den modellerede strøm, mens den stiplede lyserøde kurve viser den målte strøm. Figur 8 viser et udsnit af Figur 7 i den uge i løbet af hindcast perioden, hvor de højeste strømhastigheder forekommer. Det ses, ligesom for overfladestrømmen, at der er en meget fin overensstemmelse mellem målte og modellerede strømhastigheder på den givne lokalitet. Figur 9 viser en sammenligning mellem målte og modellerede strømretninger tæt på havbunden igennem hele hindcast perioden. Som for strømhastigheder, ses der at være en fin overensstemmelse mellem målinger og model. Der er derfor god grund til at tro, at modellens beskrivelse af de lokale strømforhold ved klappladsområdet også er ganske god.



Figur 7 Strømhastighed tæt på havbunden ved Drogden Fyr. Blå: Model, Lyserød: Målinger.



Figur 8 Strømhastighed tæt på havbunden ved Drogden Fyr. Blå: Model, Lyserød: Målinger – eksempel periode 25. januar – 02.februar.



Figur 9 Strømretninger tæt på havbunden ved Drogden Fyr. Blå: Model, Lyserød: Målinger.

3 Hindcast resultater

I dette afsnit er den modellerede påvirkning af de faktisk udførte klapninger vurderet. Ligeledes er bundstrømforholdene ved klappladsen analyseret, da denne har betydning for spredningen i forbindelse med klapning og endnu vigtigere, betydning for en eventuel re-suspension af klapmaterialet. Evalueringen af påvirkningen forholder sig til skyggevirkningseffekter med udgangspunkt i kumuleret varighed af dybdemidlede sedimentkoncentrationer større end henholdsvis 2 mg/l og 5 mg/l. Ligeledes estimeres tabet af klapmateriale til vandområderne Østersøen, Øresund nord for Drogden tærsklen og Køge Bugt. Tabet opgøres i tons og som procent af den samlede klapmængde. Endelig vises der aflejringskort.

3.1 Bundstrømmen ved klapplads

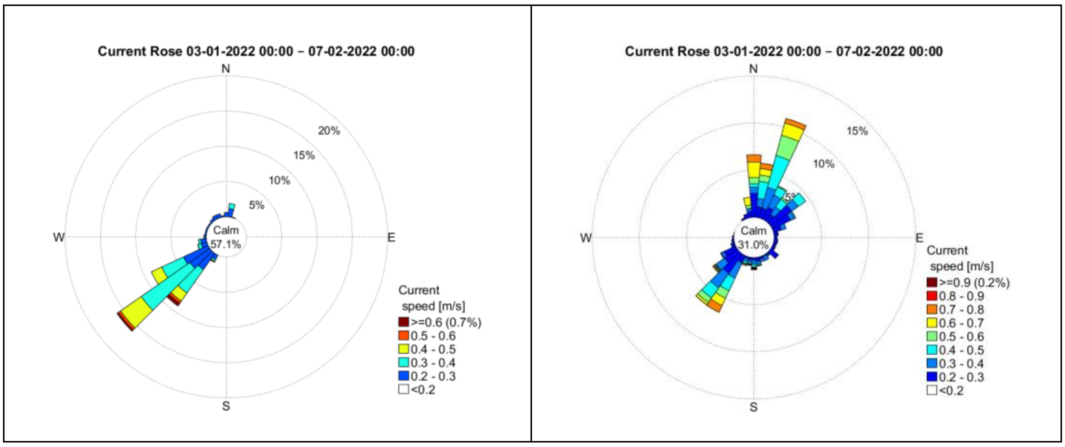
Strømforholdene nær ved havbunden har betydning for hvordan materialet i de enkelte klapninger spredes, men i endnu højere grad betydning for, hvornår tidligere klappet materiale vil blive re-suspenderet og potentielt blive spredt væk fra klappladsområdet. Hvis klapmaterialet er af samme beskaffenhed som den eksisterende havbund, vil klapmaterialet ikke føre til ændringer i den naturlige baggrundskoncentration. Er klapmaterialet mere løst aflejret og lettere at re-suspendere, vil det give sig udslag i at sedimentkoncentrationen øges i forhold til den naturlige baggrundskoncentration i situationer, hvor bundstrømmen er stærk. Mængden som re-suspenderes vil afhænge af, hvor stor en pulje løst aflejret sediment, der er blevet klappet, samt over hvor stort et område det er blevet spredt i forbindelse med de foretagne klapninger.

Klapmaterialet fra uddybningen af sejlrenden ved Svælget er af nogenlunde samme beskaffenhed, som den eksisterende havbund. Klapmaterialet fra Svælget forventes derfor ikke at påvirke de eksisterende forhold nævneværdigt.

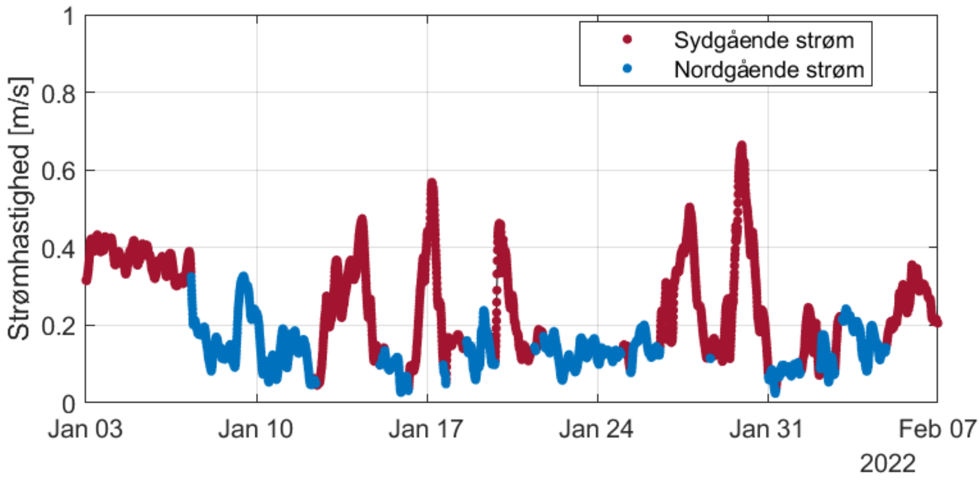
Strømforhold ved klappladsen:

Strømforholdene ved klappladsen varierer over tid. Nær ved havbunden er der to hovedstrømretninger; sydvest og nordnordøst. De kraftigste bundstrømme er sydvestgående og ligeledes er det også sydvestgående bundstrøm der optræder mest hyppigt. I hindcast perioden er hyppigheden af sydvestgående bundstrøm noget større end hvad der ville forventes set over et helt år. Ved havoverfladen er overfladestrømmen domineret af nordgående strømme, som følge af nettoafstrømningen af brakvand fra Østersøen. Vindens påvirkning indebærer at overfladestrømmens retning varierer mere end bundstrømmen, der primært er styret af rendernes topografi. I Figur 11 er der vist strømroser ved klappladsen 2 meter over havbundsniveau og ved havoverfladen. Det ses, at høje bundstrømhastigheder primært optræder i forbindelse med sydgående strøm. Re-suspensionshændelser vil derfor primært føre til en spredning i retning mod Østersøen. Ved overfladen optræder der i perioder høje strømhastigheder i både nordgående retning (nord-nordnordøst) og i sydgående retning (sydsydvest). Bemærk at der er anvendt forskellig skala i de to strømroseplot.

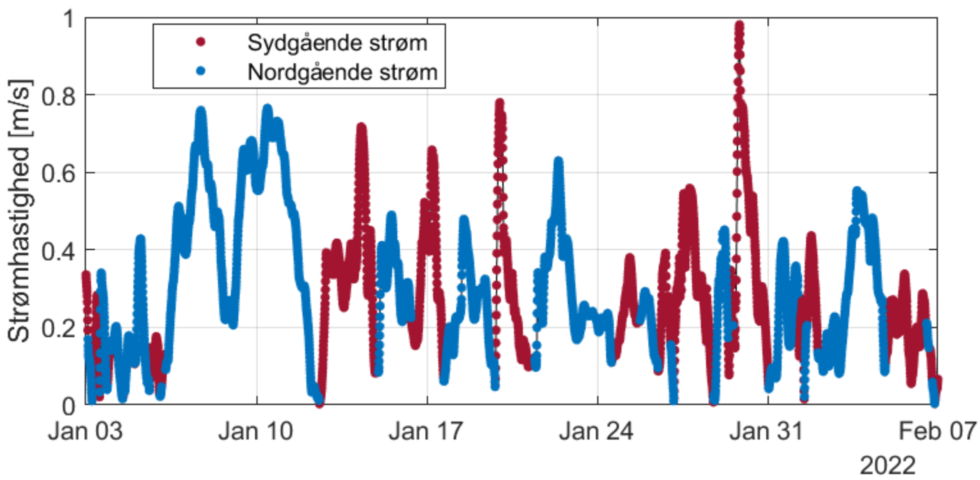
I Figur 11 og Figur 12 er der vist strømhastigheder 2 meter over havbundsniveau og ved vandoverfladen. Det ses, at der i perioder med lagdelt strømning er modsat rettet strømning ved havbund og vandoverflade. Den røde del af kurven indikerer forhold med sydgående strøm, mens den blå kurve indikerer forhold med nordgående strøm. Tilhørende strømretninger i de to niveauer er vist i Figur 13 og Figur 14. En strømretning på 0° er udtryk for at strømmen er rettet mod nord, mens en strømretning på 90° er rettet mod øst og 180° er rettet mod syd, etc.



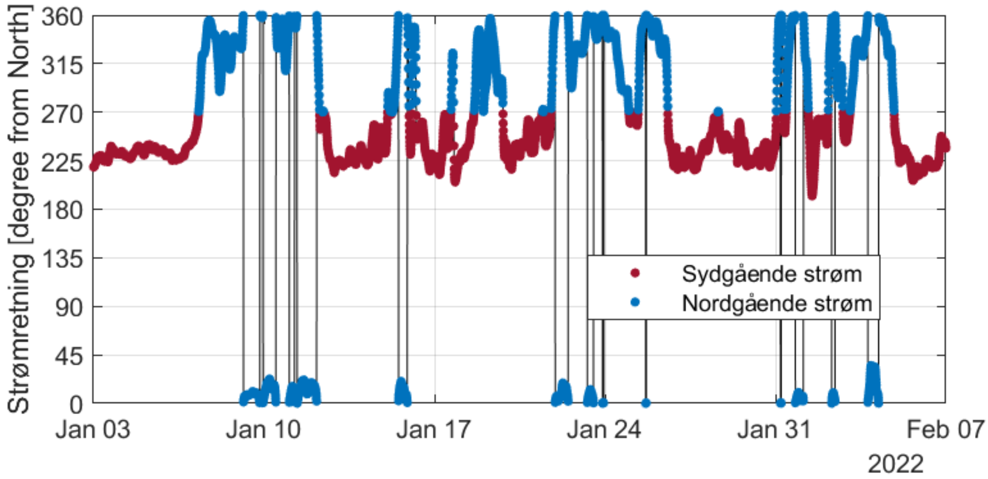
Figur 10 Venstre: Rose plot for bundstrøm 2 meter over havbund ved klapplads. Højre: Rose plot for overfladestrøm ved klapplads.



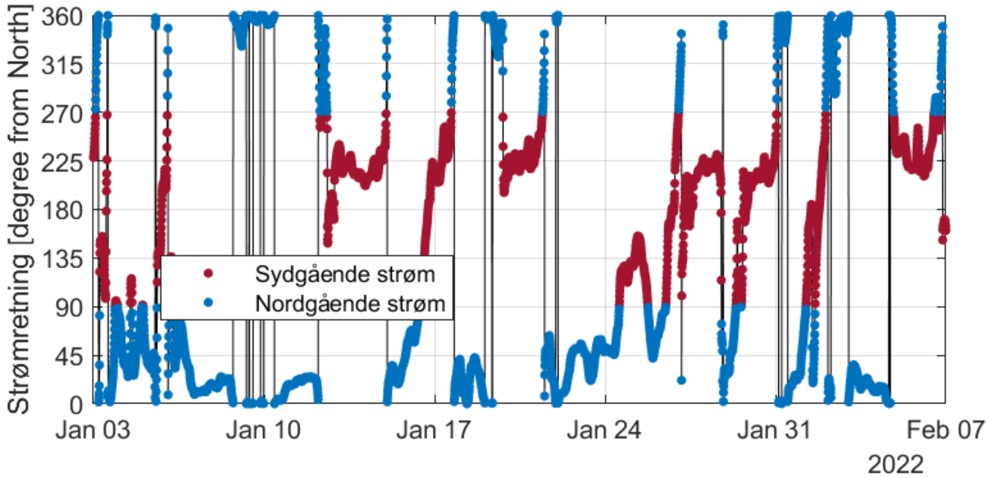
Figur 11 Bundstrømhastigheder 2 meter over havbund ved klapplads.



Figur 12 Overfladestrømhastigheder ved klapplads.



Figur 13 Bundstrømretninger 2 meter over havbund ved klapplads.



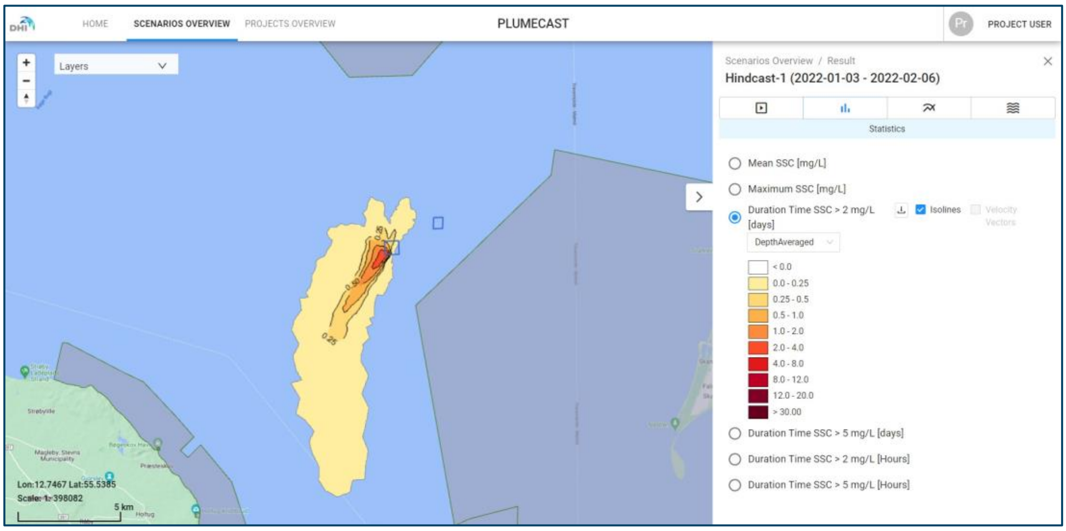
Figur 14 Overfaldestrømretninger ved klapplads.

3.2 Skyggevirkning fremkaldt af klapskyer og re-suspenderet klapmateriale

Klapskyerne kan potentielt påvirke de omkringliggende Natura 2000 områder, som følge af aflejring eller skyggevirkningseffekter. Til vurdering af skyggevirkningseffekter, ses der typisk på i hvor lang tid en række dybdemidlede sedimentkoncentrationsniveauer er overskredet. Grænsen for en synlig sedimentfane går typisk et sted mellem 2-5 mg/l.

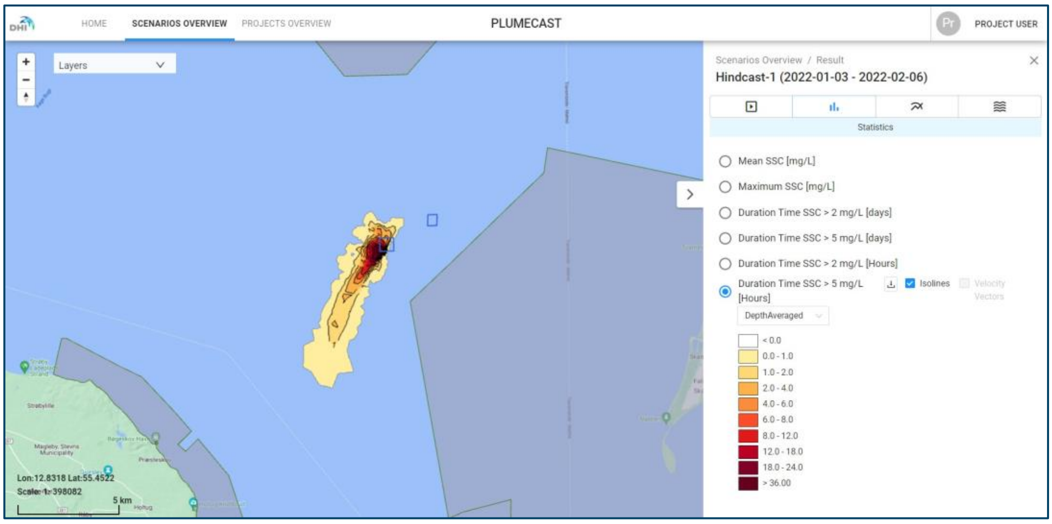
På baggrund af de udførte klapninger frem til den 6. februar, er den akkumulerede overskridelsesvarighed af en dybdemidlet koncentration på 2 mg/l beregnet. De beregnede koncentrationer indeholder ikke et bidrag fra den naturlige baggrundskoncentration og er dermed udelukkende relateret til effekten fra klapningerne.

Figur 15 viser det område, hvor dybdemidlet SSC samlet set overstiger 2 mg/l i mere end 6 timer og derover. Det ses af figuren, at ingen af de omkringliggende Natura 2000 områder er influeret af klapfanerne.



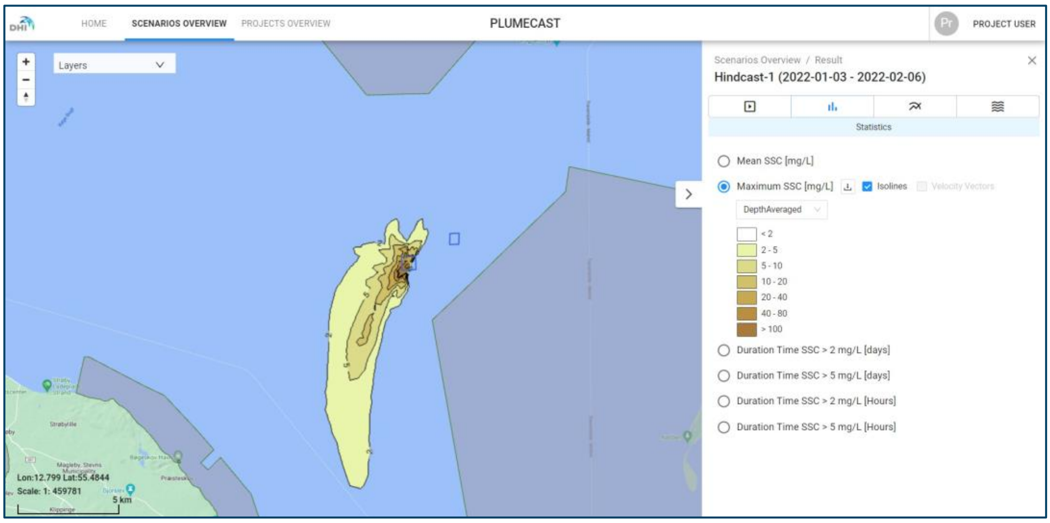
Figur 15 Akkumuleret overskridelsesvarighed af dybdemidlet SSC på 2 mg/l.

En tilsvarende analyse er udført for overskridelse af 5 mg/l. Figur 16 viser de områder, hvor dybdemidlet SSC overstiger 5 mg/l i mere end 1 time og derover. Som det fremgår af figuren, kan der ikke identificeres nogen påvirkning af de omkringliggende Natura2000-områder.



Figur 16 Akkumuleret overskridelsesvarighed af dybdemidlet SSC på 5 mg/l.

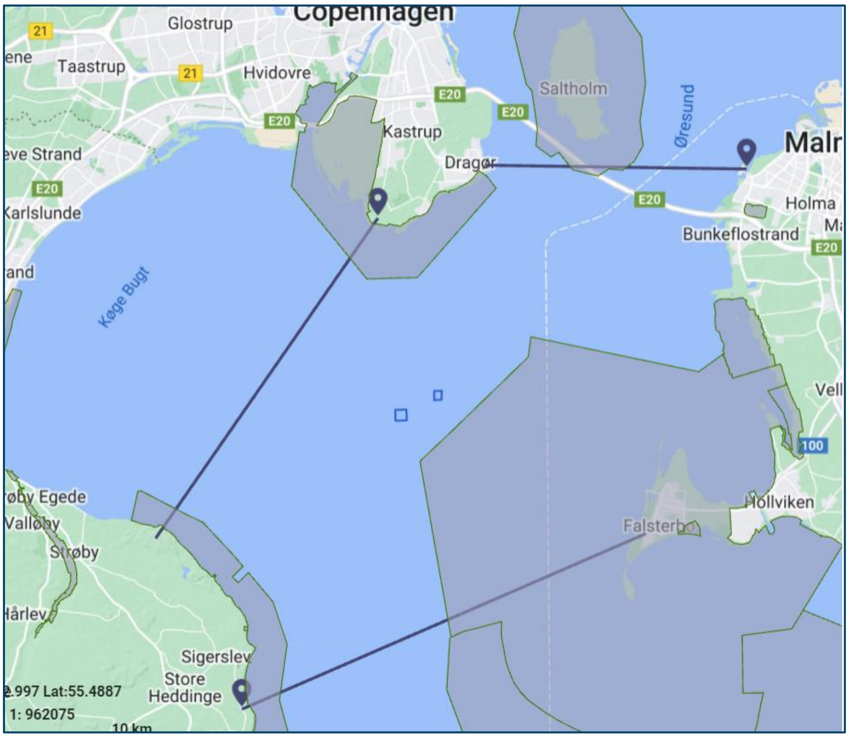
Til illustration af det maksimale påvirkningsområde relateret til klapning af materiale og en efterfølgende re-suspension, er der i Figur 17 vist dybdemidlet maksimum sediment-koncentration i hindcast perioden løbende fra den 3. januar 2022 til og med den 6. februar 2022. Det fremgår at spredningen primært er i sydgående retning og at der ikke har fundet nogen påvirkning af Natura 2000 områderne sted.



Figur 17 Maksimum dybdemidlet sedimentkoncentration i hindcast perioden.

3.3 Spredning af klapmateriale til omkringliggende vandområder

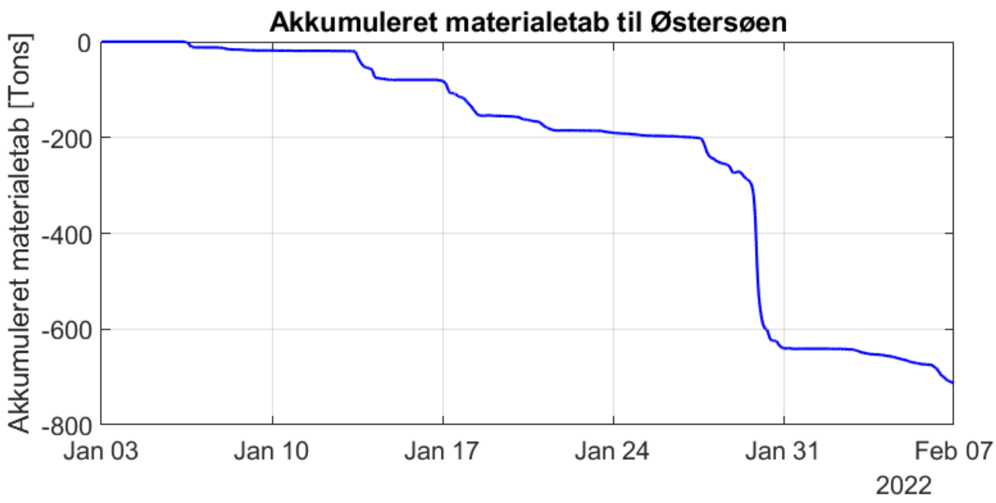
Afhængig af klapmaterialets karakter vil der være risiko for spredning af materiale til de omkringliggende vandområder, som følge af selve klapningen, men potentielt i endnu grad som følge af re-suspension af klappet materiale. Tabet af klapmateriale beregnes som den sedimentflux, der passerer de tre sorte linjer indikeret i Figur 18



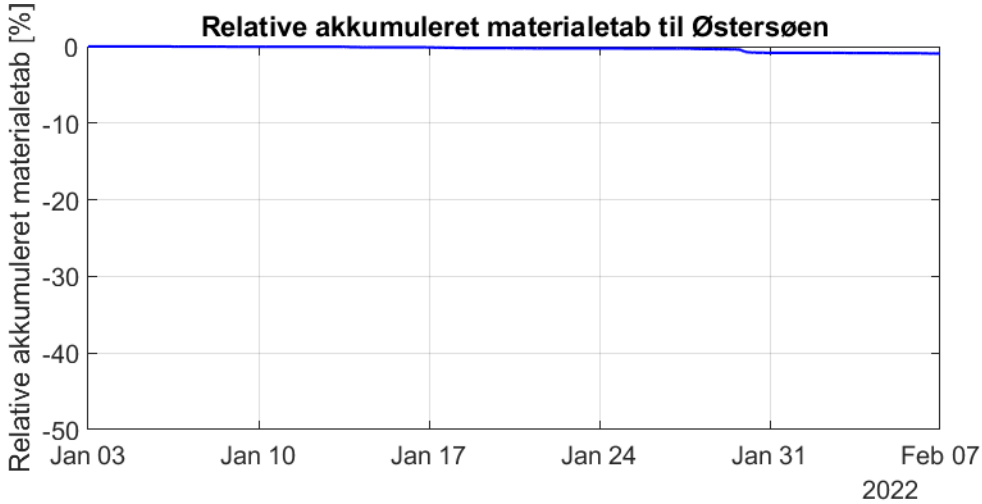
Figur 18 Placering af de tre tværsnit (Østersøen, Nordlige Øresund og Køge Bugt), hvorover sedimentfluxen beregnes.

Bundstrømmen ved klappladsen er hovedsagelig rettet mod sydvest. Der vil derfor være en overvejende tendens til, at klapmaterialet kan spredes mod sydvest og videre ned i det dybereliggende bassin i Østersøen.

Det akkumulerede sedimenttab til Østersøen igennem hindcast perioden er vist i Figur 19 i form af en tidsserie. Det ses, at der typisk vil kunne udløses et større materialetab i forbindelse med stormflodshændelser og saltvandsindbrud, jf. dynamikken d. 30. januar. Den samlede masse af sedimenter som forlader modelområde i retning mod syd, er beregnet til 713 tons, som svarer til cirka. 0,92% af klapmængden over hindcast perioden. I Figur 20 er klaptabet angivet som det relative tab i procent af den samlede klapmængde i hindcast perioden. Det ses, at tabet er ganske beskedent.



Figur 19 Akkumuleret materialetab til Østersøen.

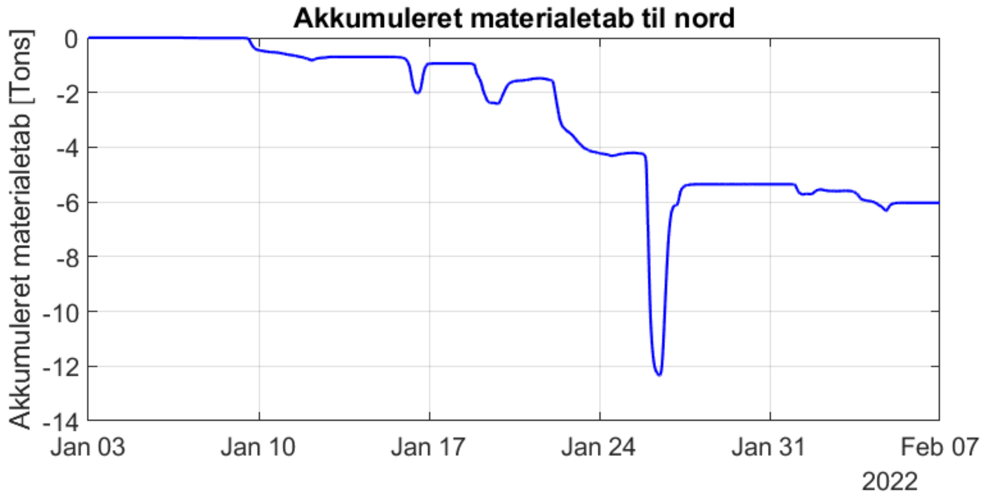


Figur 20 Relativt akkumuleret materialetab til Østersøen.

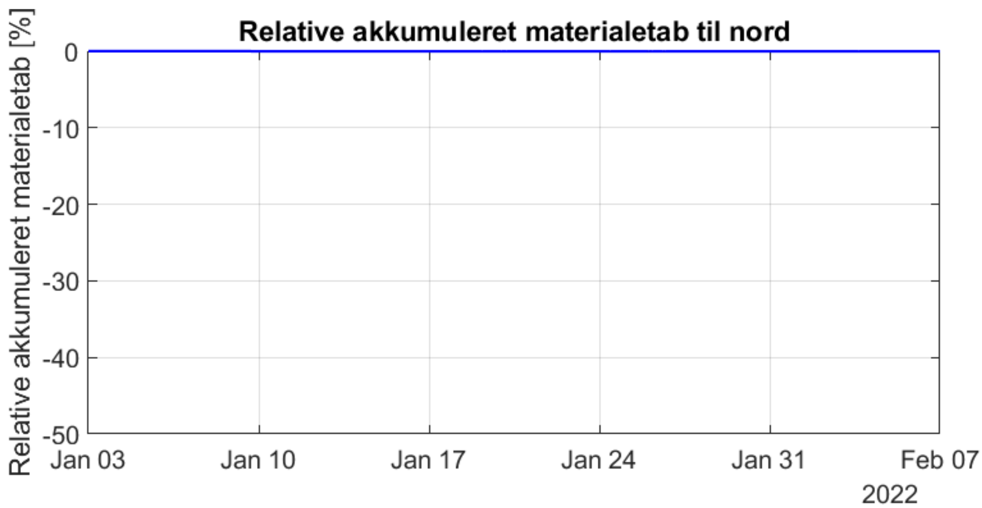
Hele hindcast perioden har overvejende været domineret af forhold med sydvestgående bundstrøm. Det akkumulerede sedimenttab til vandområdet beliggende nord for Drogden tærsklen (Øresund), er derfor ganske beskedent. Dels som følge af strømforholdene, men også som følge af at klapmaterialet i hindcast perioden har et lavt indhold af finkornet sediment.

Det akkumulerede sedimenttab til nord (Øresund) igennem hindcast perioden er vist i Figur 21 i form af en tidsserie. I nogle situationer vil dele af materialet kunne trækkes tilbage til vandområdet med klappladserne, som det eksempelvis sker i perioden omkring den 27.

januar. Den samlede masse af sedimenter som forlader området i retning mod nord, er 6 tons, hvilket er ca. 0,008% af klapmængden i hindcast perioden. I Figur 22 er klaptabet angivet som det relative tab i procent af den samlede klapmængde i hindcast perioden. Det ses, at der nærmest ikke er et tab.

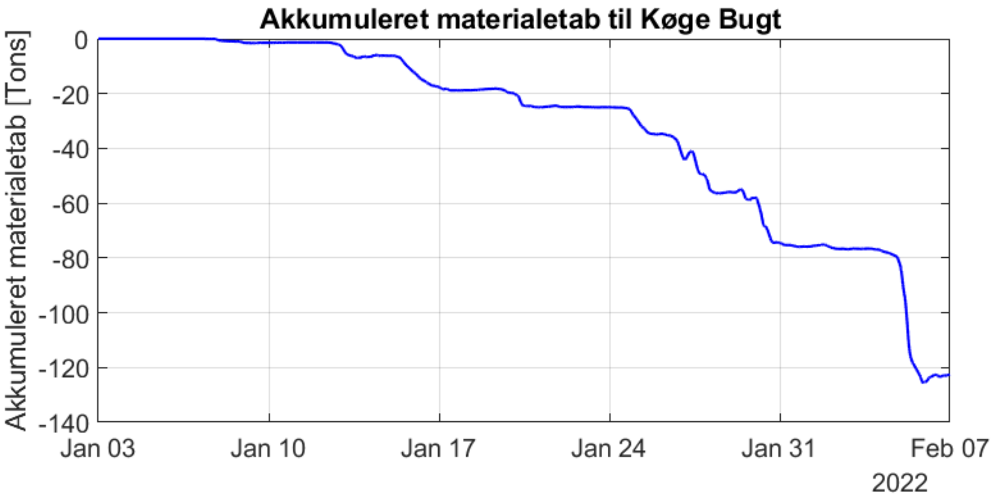


Figur 21 Akkumuleret materialetab til vandområdet nord for Drogdentærsklen.



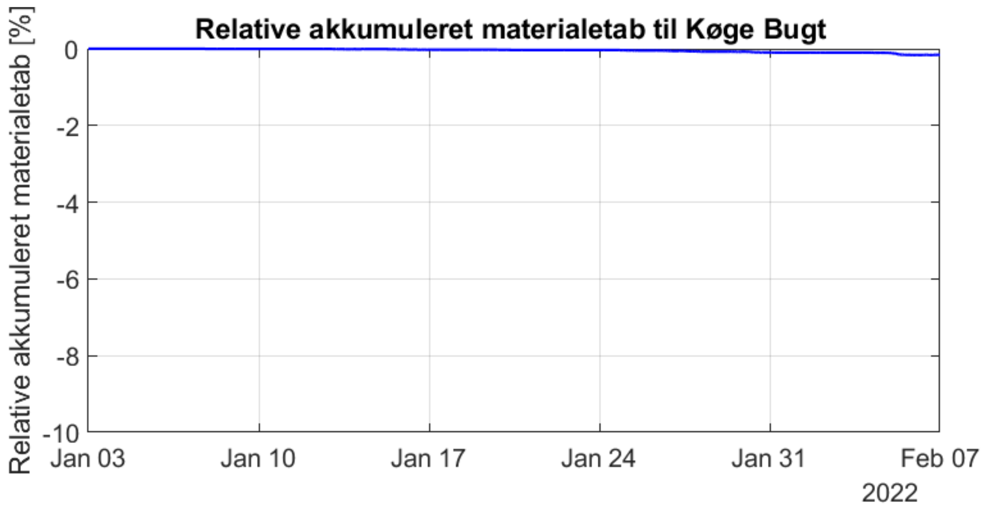
Figur 22 Relativt akkumuleret materialetab til vandområdet nord for Drogdentærsklen.

Det akkumulerede sedimenttab til Køge Bugt igennem hindcast perioden er vist i Figur 23 i form af en tidsserie. Det ses, at der i hindcast perioden er meget beskeden spredning af klapmateriale til Køge bugt. Den samlede masse af sedimenter som forlader modelområde i retning mod Køge Bugt, er estimeret til 123 tons, hvilket er ca. 0,16% af klapmængden i hindcast perioden, jf. Figur 24.



Figur 23 Akkumuleret materialetab til Køge Bugt

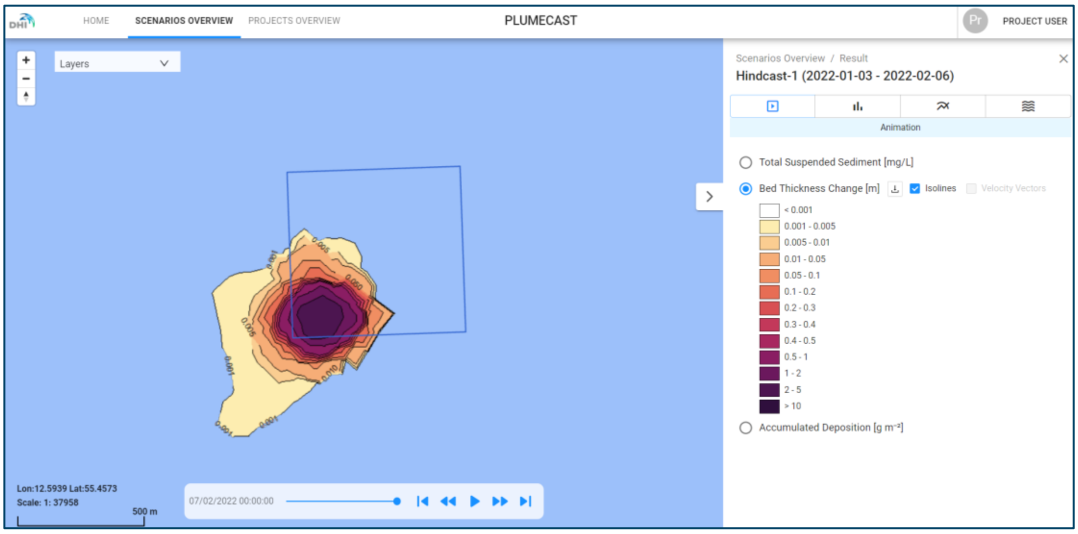
Samlet set er der fundet en ganske beskeden spredning af klapmateriale til de omkringliggende vandområder (1,09%), hvilket hænger sammen med at der i hindcast perioden kun er klappet materiale fra uddybningen af sejlrenden ved Svælget syd for Middelgrunden. Spredningen vil øges i takt med at der klappes materiale fra Lynetteholm perimeteren.



Figur 24 Relativt akkumuleret materialetab til Køge Bugt.

3.4 Deposition

I hindcast perioden frem til den 6. februar er der klappet 77.400 ton, hvoraf de 66.404 ton er aflejret indenfor det med blå ramme markerede klappladsområde. Langt størstedelen af klapmaterialet (~86%) er aflejret i selv klapområdet, som følge af at klapmaterialet fra Svælget er relativt groft. Figur 25 viser et aflejringskort for det klappede materiale. Mindste viste aflejringstykkelse på kortet er 0,1 mm. Aflejringstykkelser er beregnet med antagelse om en tørdensitet på 600 kg/m^3. Det ses, at der er en svag spredning væk fra klappladsen i retning mod sydvest, der er forårsaget af bundstrømmens fremherskende hovedretning. Hovedparten af de 14% som ikke er aflejret indenfor klappladsområdet er som det fremgår af Figur 25 aflejret i umiddelbar nærhed af klappladsen. Spredningen af materiale til øvrige vandområder; Østersøen, Øresund nord for Drogdentærsklen og idvandszonen Køge Bugt er yderst beskeden, jf. afsnit 3.3.



Figur 25 Aflejringskort for materialet klappet i hindcast perioden.

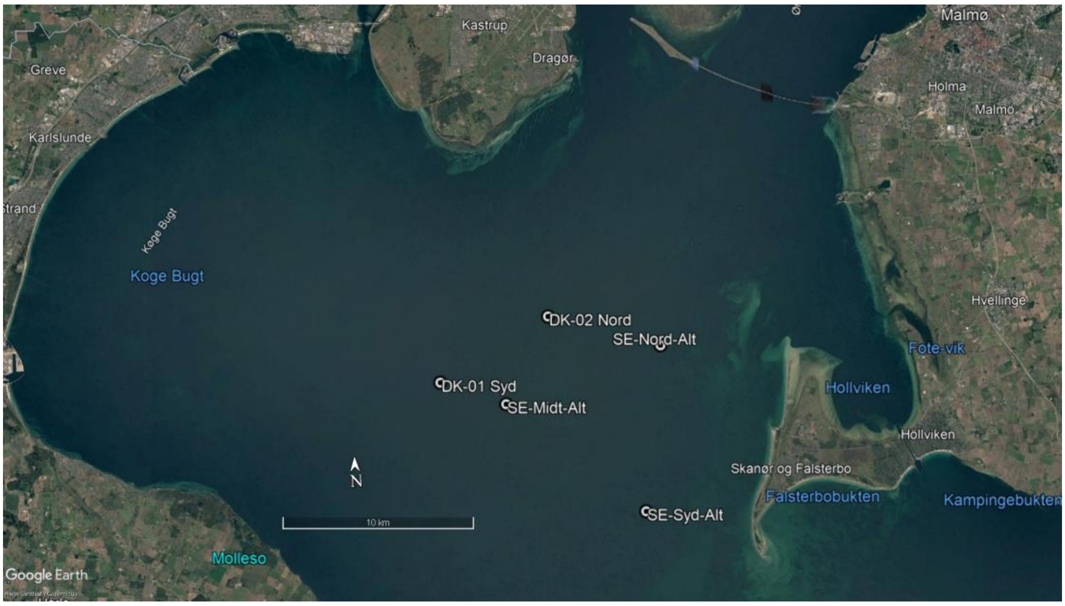
4 Turbiditetsmålinger

Det hårde vejr med gentagne lavtrykspassager uge efter uge, har gjort det vanskeligt at finde egnede tidsvinduer, hvor turbiditetsstationerne har kunnet løftes sikkert op til havoverfladen og tømmes for data. I weekenden 26-27. februar lykkedes det at bjærge de 5 stationer og tappe dem for data. De 5 stationer er beliggende på de i Tabel 1 angivne positioner og vanddybder. Turbiditetsmålerne er placeret en meter over havbundsniveau.

Tabel 1 Turbiditetsstationer.

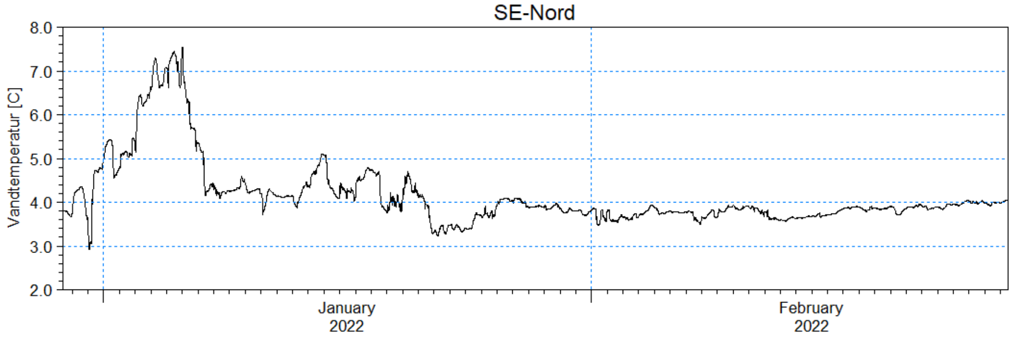
Stationsnavn	Længdegrad	Breddegrad	Vanddybde [m]
DK-01 Syd	12,55638	55,44524	15
DK-02 Nord	12,64769	55,47391	11
SE-Nord-Alt	12,739474	55,458061	10,5
SE-Syd-Alt	12,721424	55,380833	10,4
SE-Midt-Alt	12,60995	55,43382	11

Figur 26 viser hvor i det sydlige Øresund at de fem turbiditetsstationer er placeret.

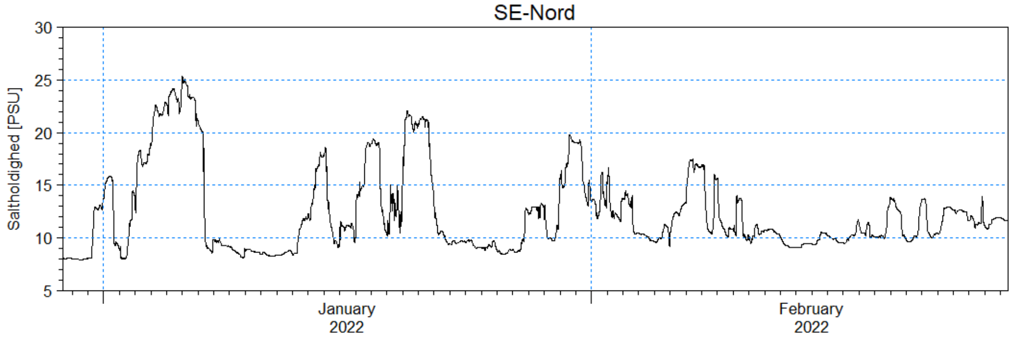


Figur 26 Oversigtskort visende de 5 turbiditetsstationers placeringer.

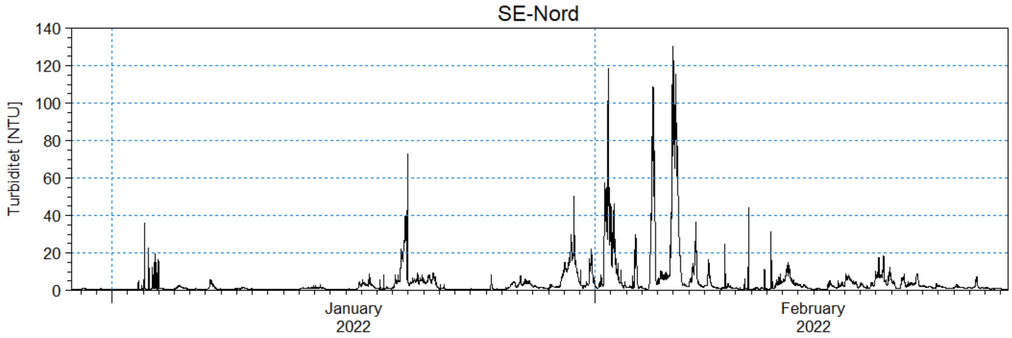
Turbiditetsmålingerne er endnu ikke blevet færdiganalyseret og kvalitetssikret, men forventes indeholdt i en opdateret version af denne hindcast rapport, som vil blive delt i forbindelse med TMG-mødet d. 9. marts. Nedenfor er der dog vist nogle foreløbige data af vandtemperatur, saltholdighed og turbiditet fra SE-Nord stationen.



Figur 27 Målt vandtemperatur 1 meter over havbund ved SE-Nord.

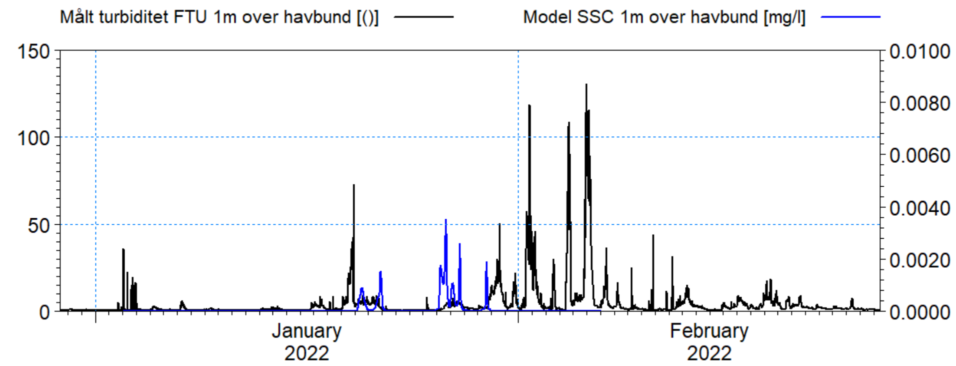


Figur 28 Målt saltholdighed 1 meter over havbund ved SE-Nord.



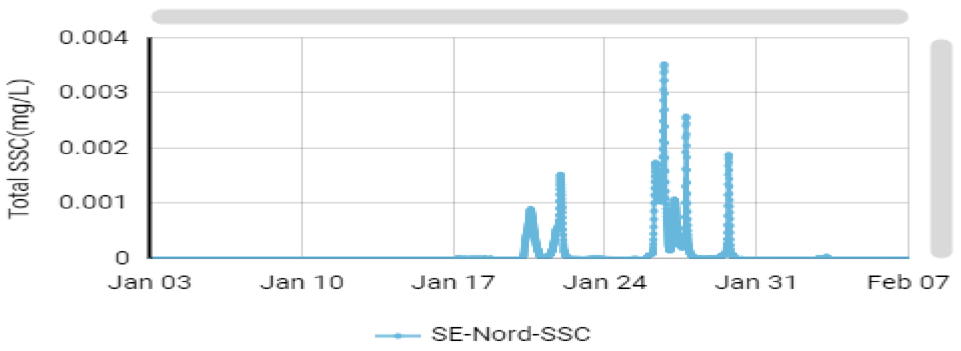
Figur 29 Målt turbiditet 1 meter over havbund ved Se-Nord.

Omsætningsfaktoren for omregning af turbiditet til sedimentkoncentration kendes ikke pt, men det ses, at der er en dynamik i den første del af februar. Den målte turbiditet på SE-Nord stationen er sammenholdt med den modellerede sedimentkoncentration udløst af klapningsaktiviteter, jf. Figur 30. Umiddelbart kan den målte dynamik ikke relateres til de i udførte klapninger. Udslagene i turbiditet kan muligvis relatere til skibsinduceret re-suspension i kombination med de lokale strømforhold.



Figur 30 Målt turbiditet (FTU), og model SSC (mg/l) 1 meter over havbund ved SE-Nord.

I Figur 31 er sedimentkoncentrationen (udover baggrund) 1 meter over havbund på positionen for SE-Nord vist. Det ses, at der ikke optræder identificerbare bidrag fra klapningerne, da alle værdier er mindre end 0,005 mg/l.



Figur 31 Model SSC (mg/l) 1 meter over havbund ved SE-Nord.

5 Øvrige aktiviteter

Klappladsen har i hindcast perioden været benyttet af andre end By & Havn. Avedøre Havn har tilladelse til at klappe materiale stammende fra oprensning af havneområdet. I klaptilladelsen er der angivet, at der er et forventet behov i år (2022) på at klappe 10.500 m^3, svarende til cirka 8.160 tons tørstof. Klapning og oprensning må ifølge tilladelsen kun finde sted i perioderne 1. januar – 28. februar og 1. juni – 31. juli. Det er uklart hvordan mængden vil blive fordelt i de to perioder, men der er konstateret klapaktiviteter i hindcast perioden. Da klapmaterialet stammer fra oprensning af centrale dele af havnen og området langs den sydvestlige dækmole, må materialet antages at være meget siltholdigt og mere mobilt end klapmaterialet fra Svælget. Klapmængderne fra Avedøre Hav er dog beskedne i forhold til klapmængderne fra uddybningen af sejlrenden og bundudskiftningen ved Lynetteholm.