FEHMARNBELT MARINE BIOLOGY

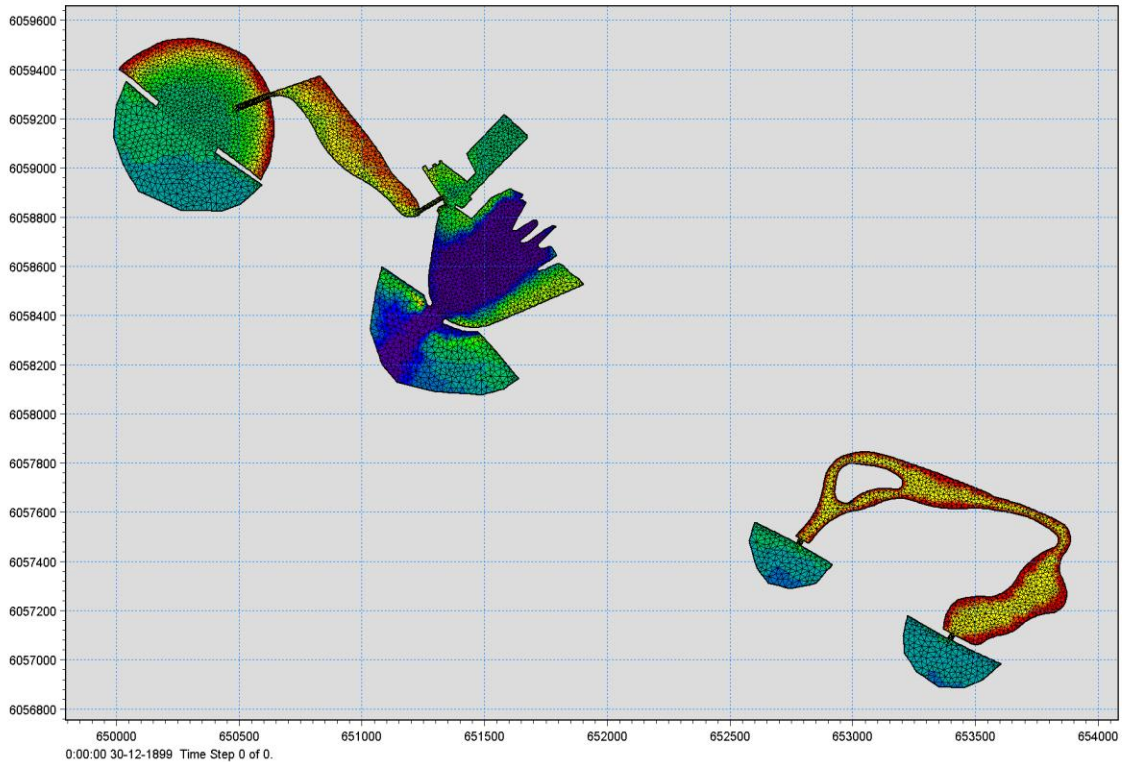
FEHMARNBELT HYDROGRAPHY

Final Report

FEHMARNBELT FIXED LINK
Marine Biology Services (FEMA)
Hydrographic Services (FEHY)

Lolland reclamation lagoons, flushing and water quality

E2TR0030



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Note to the reader:

In this report the time for start of construction is artificially set to 1 October 2014 for the tunnel and 1 January 2015 for the bridge alternative. In the Danish EIA (VVM) and the German EIA (UVS/LBP) absolute year references are not used. Instead the time references are relative to start of construction works. In the VVM the same time reference is used for tunnel and bridge, i.e. year 0 corresponds to 2014/start of tunnel construction; year 1 corresponds to 2015/start of bridge construction etc. In the UVS/LBP individual time references are used for tunnel and bridge, i.e. for tunnel construction year 1 is equivalent to 2014 (construction starts 1 October in year 1) and for bridge construction year 1 is equivalent to 2015 (construction starts 1st January).

1 EXECUTIVE SUMMARY

The assessment of the environmental conditions inside the new lagoons on the Lolland reclamations has concluded the following for the provided layout with the developed depth specifications:

- The water exchange will in general be sufficient with average flushing times (T_{50}) of 1-4 days. These flushing times are considered satisfying for the recreational use of the bathing water beaches and for development of a diverse nature.

- The recreational Inner Lagoon with a paddling beach will receive much of the water exchange via the harbour canal, and concentrations in the Inner Lagoon will therefore be almost similar to any contamination levels inside the western (recreational) harbour basin.

- High TBT concentrations in mussels has been detected in the western harbour basin near the planned connection between the harbour and the Inner Lagoon. This is due to leaching from TBT polluted sediments and a very long residence time allowing TBT in water to build-up concentrations that are 10-20 times above environmentally safe concentrations (Environmental Quality Standards). After establishment of the Inner Lagoon the flushing of the recreational harbour basin through the harbour canal will be increased by at least a 10-factor. It is evaluated that the increased dilution would be sufficient to ensure TBT levels will not degrade the recreational potential of the Inner Lagoon.

- A decoupling of the water quality inside the Inner Lagoon and in the harbour may be achieved by a one-way sluice in the opening between the harbour basin and the Inner Lagoon, only allowing flow from the lagoon into the harbour.

- Prognosis of the sedimentation of sand in the opening to the Pocket Beach Lagoon predicts that it will start about 15 years after the construction of the reclamation and increase to about 15,000 to 20,000 m^3/year after 30 years, whereafter the sedimentation rate in the lagoon opening will stabilise at about 20,000 m^3/year. Furthermore, it is evaluated that no maintenance dredging in the lagoon will be required until after 30 to 45 years after construction.

- The entrances to the Nature Lagoon are assessed to be exposed to negligible sedimentation of sand. The very minor sedimentation of sand in the entrances will be concentrated very near the openings as there will be neither enough currents nor waves to transport sand into the lagoon proper.

- The thickness of accumulated sedimentation of fine suspended sediments over a 50- and 100-year period for the Inner Lagoon and for Nature Lagoon has been evaluated. The resulting sedimentation layer thickness after 50 and 100 years is 20 cm and 33 cm for the Lagoon and 4 cm and 6 cm for the Nature Lagoon, respectively. It is concluded that the computed sedimentation rates are so low that maintenance dredging will not be required the

first 30-45 years for the Lagoon and will never be required for the Nature Lagoon.

- Three new beaches are included in the design of the future landscape of the land reclamation: the West Beach at the western end of the reclamation, the Pocket Beach between the west end and Rødbyhavn and the Paddling Beach on the NE coast of the Inner Lagoon. Considering the slope and wave exposure as well as the current, the beaches are foreseen to be attractive for recreational purposes; the Paddling Beach will however experience sedimentation of fine sediments on the lower part of the shoreface.

- The necessary relocation of the outfall of Rødbyhavn wastewater treatment plant is not foreseen to cause hygienic problems leading to non-compliance with the legal standards for good-excellent bathing water quality at the new recreational beaches.

- The new location of the marine outlet is not foreseen to cause deterioration of the quality of the existing bathing waters.

- Some accumulation of detached floating eelgrass leaves and macroalgae will occur in the lagoons and at the beaches, but the impact is predicted to be smaller than at the existing beaches (where it is not considered a problem). For the Pocket Beach Lagoon it is estimated that accumulation will amount to about 30% of the present accumulation along the beach west of Rødbyhavn. For the Inner Lagoon the amount will be considerably smaller. At the Nature Lagoon only minor amounts of floating and suspended seaweed are expected to penetrate into the lagoon.

- Only the West Beach is finalized during the construction period and it may be exposed to sediment spill from the earth works. As the beach is opened in the third year after start of construction the spill will be low and fine sediments will not settle on the beach due to the wave action. The spill is not considered to become a nuisance to the bathers. There are no legal standards regarding the clearness of the bathing water.

- Considering the flushing times the water quality will most probably be determined by the conditions in Fehmarnbelt although some internal nutrient exchange between sediment and water is expected as the lagoons mature and develop bottom flora and fauna. It cannot be excluded that algal blooms will occur – as is also the case at the present beaches.

- Cyanobacteria will be a natural part of the phytoplankton of the lagoons and may form blooms during late summer as such blooms occur in Fehmarnbelt. The present blooming in Fehmarnbelt is not considered to be an impediment to the existing beaches.

- The natural benthic flora and fauna of Fehmarnbelt are expected to colonize the seabed of the lagoons. Eelgrass and other flowering plants can colonize the sandy bottom, and macroalgae will grow on stones. Also fauna as gastropods feeding on benthic microalgae, burrowing polychaetes such as the lugworm and filtering infauna species such as soft clams and cockles can be expected to inhabit the new environment. With time some accumulation of fine material will occur in some areas making the seabed less sandy and thus less suitable for eelgrass and flowering plants. Considering the estimated currents, retention times and the seabed structure a natural shallow water ecosystem with a diverse marine flora and fauna is expected to develop in the lagoons. This is supported by the development at e.g. Køge Bugt Strandpark.

- Along the gently sloping shores of the Inner Lagoon and the Nature Lagoon accumulation of fine material is predicted. Based on this and the current conditions and the minimal wave exposure it is assessed that reed will slowly invade the SW perimeter of the Inner Lagoon whereas no reed growth is expected along the other perimeter sections of this lagoon. It is also evaluated that reed will slowly invade into the Nature Lagoon where it will grow along all the gently sloping perimeters. With time the Nature Lagoon will probably develop into a wetland with reed and limited water exchange.

2 INTRODUCTION

In the process of excavating the trench for the proposed Fehmarnbelt immersed tunnel there will be a surplus volume of excavated soil in the order of magnitude of 18.8 million m^3. Femern A/S and RAT JV have proposed to utilize this surplus volume of soil for creating new coastal landscapes along the Danish coast, and to a minor extent also on the German side. The present study only covers the land reclamation at Lolland.

The interior marine parts within the Lolland reclamation component of the Fixed Link project should be included in the EIA with the purpose of completion of the EIA documentation. For this purpose Femern A/S ENV requires an environmental assessment of the new lagoons and the Lolland reclamation. The following was the basis of the investigations:

1. The Pocket Beach Lagoon and the Inner Lagoon west of Rødbyhavn will be for recreational use, and the Nature Lagoon east of Rødbyhavn will be designed with focus on nature.

2. The quality of the lagoons will be addressed by analysing:

    - the depths and slopes in the lagoons in order to assess if water exchange is sufficient, but also to assess the growth conditions for vegetation at the banks and the seabed of the lagoons

    - water exchange in the lagoons (calculation by modelling)

    - the risk of trapping of floating seaweed (modelling)

    - the risk of sedimentation of lagoons

    - the water quality in the lagoons, involving

        i. influence of the new location of the outlet of the sewage plant taking the upgrading of treatment processes and capacity into consideration
        ii. influence of Rødbyhavn harbour

The overall objective of the investigation was:

- To investigate whether it is plausible that the water exchange and the water quality of lagoons will be suitable for the various objectives of the different lagoons

To investigate whether the lagoons will develop as planned as recreational and nature elements, respectively, in relation to growth of reed, seagrasses and macroalgae

To investigate the nature and magnitude of trapping of floating seaweed and sedimentation in the lagoons

3 DESCRIPTION OF THE LAYOUT OF THE LOLLAND LAND RECLAMATION

The history of the coastal landscape in the area of the land reclamation is reported in detail in the Coastal Morphology Baseline Report (FEHY 2013b). The main events in the development of this coastal stretch are the following:

- The entire coastal hinterland along the southeastern part of Lolland was heavily flooded during the extreme storm in November 1872. A dike running all along the Lolland coastline was constructed the following years as a consequence of this event in which connection a series of coastal lagoons including Rødby Fjord were reclaimed.

- The construction of the first Rødbyhavn at the beginning of the 19^{th} century caused trapping of the SE-ward littoral transport along this coastline which resulted in the complete erosion of the sandy beaches at a stretch of more than 3 km SE of the harbour

- Erosion along other sections of the dike protecting the SE coast of Lolland has caused the disappearance of the beaches along many other sections of the dike.

The main purpose of the landscaping is as mentioned to utilize the surplus material for the land reclamation considering the possibilities of environmental and recreational rehabilitation of the area which, according to the above described history and condition of the coast adjacent to Rødbyhavn, is heavily required. The additional requirements for rehabilitation of the coastal stretches have been interpreted as follows:

Creation of a smooth connection between the tunnel portal and the adjacent coastal stretches thereby minimising the visual impact of the portal buildings.

Adding new coastal landscape features to the land reclamation for enhancement of environmental and recreational conditions.

These requirements have been made operational by introducing artificial beaches and lagoons in the reclamation as listed in the following and as illustrated in Figure 3-1:

- The West Beach
- The Pocket Beach Lagoon between Lalandia and Rødbyhavn
- The Inner Lagoon immediately west of Rødbyhavn with a Padding Beach
- The Nature Lagoon with wetlands east of the portal

An Active Cliff along the easternmost part of the reclamation

The Pocket Beach Lagoon and the Inner Lagoon are connected with each other and the Inner Lagoon is also connected to the marina basin of Rødbyhavn in order to enhance flushing of the lagoon system. The Nature Lagoon is equipped with two fixed openings in order to sustain flushing of the lagoon.

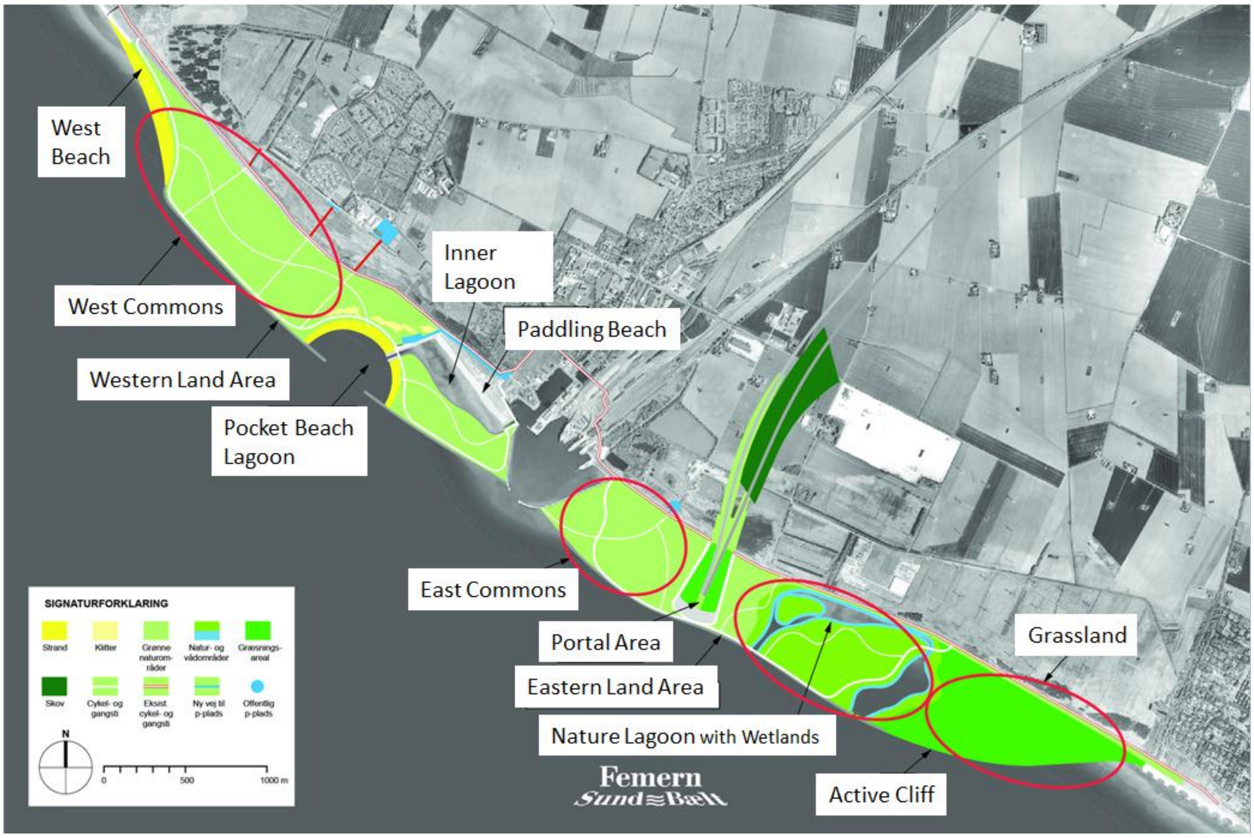

Figure 3-1 Lolland land reclamation with (preliminary) naming of landscape elements

Only the proposed option as described above has been investigated. Environmental impacts during construction will not be covered in the present report, as they are described in other background reports. Only conditions related to the marine and coastal environment in the operational phase will be analysed. The analyses are based on the design conditions received from Femern A/S. Investigations related to the detailed layout of the lagoons are not part of the present investigations. The detailed layout will be handled by the technical department in Femern A/S.

4 BASELINE DESCRIPTION OF PRESENT CONDITIONS

The baseline description of the coastal stretches has been performed in the Coastal Morphology Baseline Report (FEHY 2013b). This description will not be repeated here.

4.1 Description of bathymetry in the lagoons

The bathymetry in the lagoons has been developed by the RAT JV and used as basis for the numerical simulations of the lagoons. The bathymetries have been developed according to the following principles.

Pocket Beach Lagoon

The beach in the pocket beach lagoon is semi exposed to waves. The concept behind the beach is that it will be shaped by the incoming waves. When the waves enter the lagoon they will be diffracted around the heads of the protecting breakwaters whereby the wave fronts will form a near circular shape. The beach in the lagoon will adjust to this equilibrium shape and the coastal profile in the active zone will adjust to an equilibrium profile with a depth (d) vs. distance (x) relation of the form:

$$d = A\ x^{0.67}$$

where d is the depth in the distance x (both in meters) and A is a constant dependent of the mean grain size of the sediments. With d_{50} = 0.3 mm the value of A will be: A = 0.103.

This is in principle the shape of the beach profile introduced in the Pocket Beach Lagoon down to a water depth of about 3.0 m, below which the slope of the coastal profile has been set to 1:10 until the sand profile reaches the natural seabed.

Beach profile in the Inner Lagoon

The coastal profiles in the Inner Lagoon will not be exposed to any waves, apart from locally wind generated waves which will be very small. The bathymetry in this area has been taken as the existing bathymetry. The SW perimeter in the inner lagoon will be constructed with a gentle slope and will be left for natural development into a green slope.

Canals between the Pocket Beach Lagoon and the Inner Lagoon and between the Inner Lagoon and the Harbour

The depth in the canal between the Pocket Beach Lagoon and the Inner Lagoon has in the numerical simulations been set at 2.0 m and the depth in the canal between the Inner Lagoon and the Harbour has been set at 2.5 m. This is a compromise between the requirement for higher water exchange and for safety for swimmers.

Nature Lagoon with Wetlands

The depth profiles of the Nature Lagoon have been constructed with gentle slopes along the perimeters and with a fairway in the middle of the lagoon canals with a depth of 2.0 m. The depth in the entrances to the Nature Lagoon has been set at 2.0 m with a steep slope towards the sea.

General comment on the bathymetry

The depths developed for the lagoon systems for the purpose of numerical simulations are somewhat simplified. The detailed layouts of the lagoons including depths will be fine-tuned during the refinement of the layouts of the lagoons.

The bathymetry used for the numerical simulation is presented in Figure 4-1.

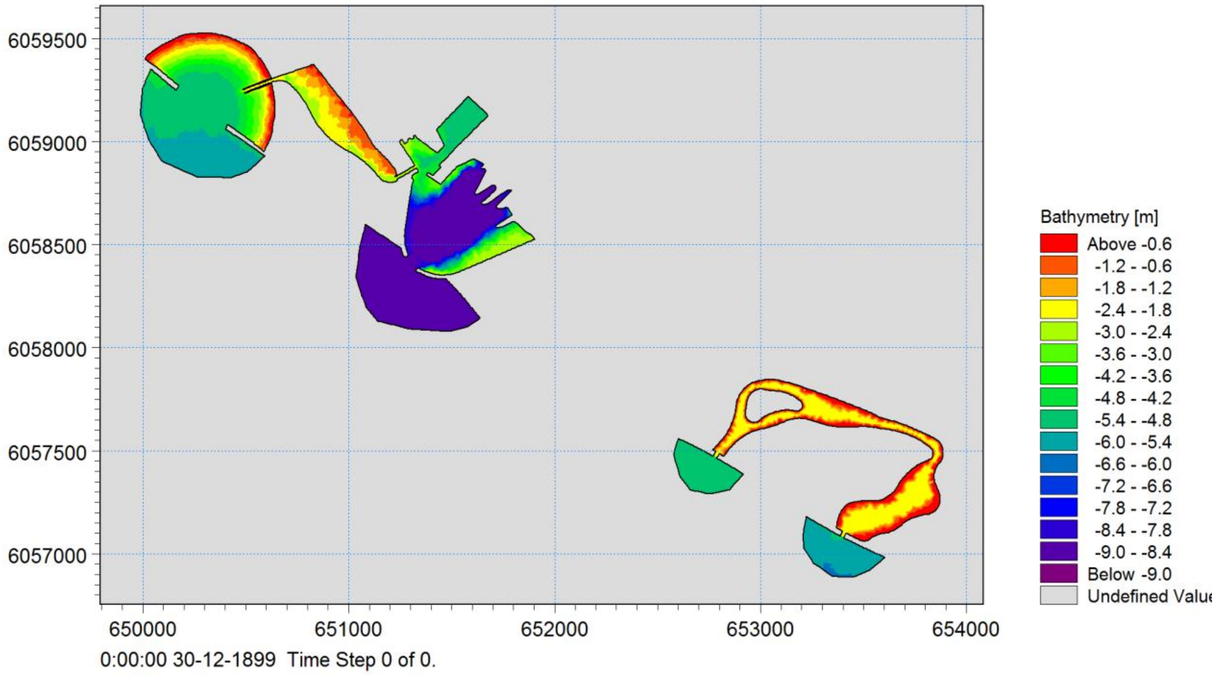

Figure 4-1 Bathymetry of the lagoon systems as used in the numerical 2D simulations. The lagoon model is explained in the text

4.2 *Hydrodynamics of the lagoons*

The objectives of the hydrodynamic simulations of the lagoon system are to provide the basis for the consequent simulation of the following items:

To assess the flushing times of the individual parts of the lagoons

To assess the amount of water spreading from Rødbyhavn into the Inner Lagoon

To provide a basis for discussion of the risk for trapping of floating seaweed on the beach in the Pocket Beach Lagoon

The hydrodynamic model used as the basis for simulation of the water quality in the waters along the reclamation after relocation of the dewatering and wastewater outlet is a different model (see section 7.1.1).

General approach

The local Fehmarnbelt model established by FEHY has been used as basis for the modelling (see report on hydrodynamics of Fehmarnbelt, FEHY 2013d). The domain of this model is given in Figure 4-2.

During the previous Fehmarnbelt studies a 21-day period with hydrographic conditions representative of the average conditions has been selected as basis for simulations of water exchange. From this model period boundary conditions (water levels) are extracted for a smaller local 2D model of the lagoons.

The domain of the lagoon model is shown in Figure 4-3. This model is set up for the purpose of simulating the flushing through the lagoon systems and it does not represent the flow conditions along the reclamation perimeter, i.e. in the Fehmarnbelt, correctly. The impact of the wind on the level and flow conditions is included in the 3D model, which provides boundary data for the lagoon model, but the lagoon model has been run without wind impact on the lagoon waters. This is normal practice for flushing simulations as this gives conservative estimates of the flushing.

Currents in the lagoons

Characteristic flow velocities in the Pocket Beach Lagoon – Inner Lagoon system have been extracted with the purpose of providing an impression of the characteristic flow conditions, see Figure 4-4 and Figure 4-5, which show characteristic "strong" flow situations towards SE and NW in the lagoon systems, respectively. The flow pattern in the Inner Lagoon is in most cases a "clean" flow one or the other way driven by gradients in the water level between the two openings.

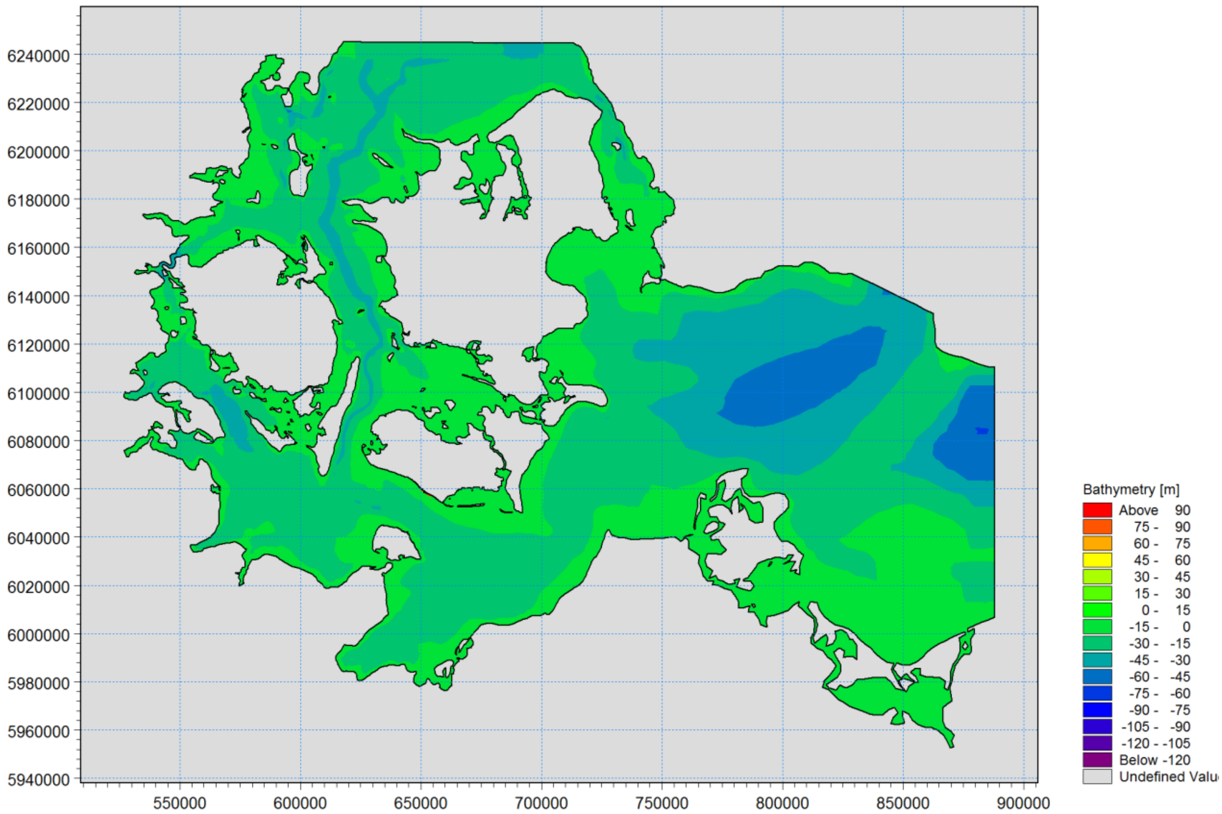

Figure 4-2 The domain of the Fehmarnbelt local model (FEHY 2013d)

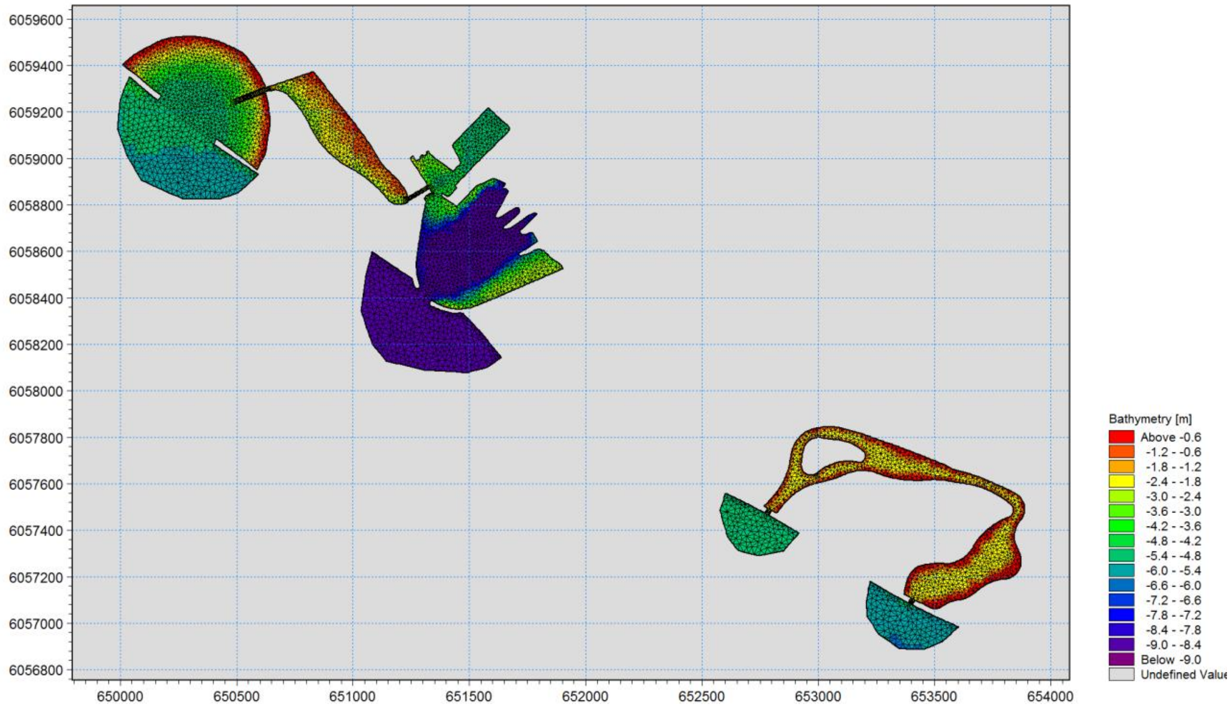

Figure 4-3 Local lagoon model domain with computational mesh

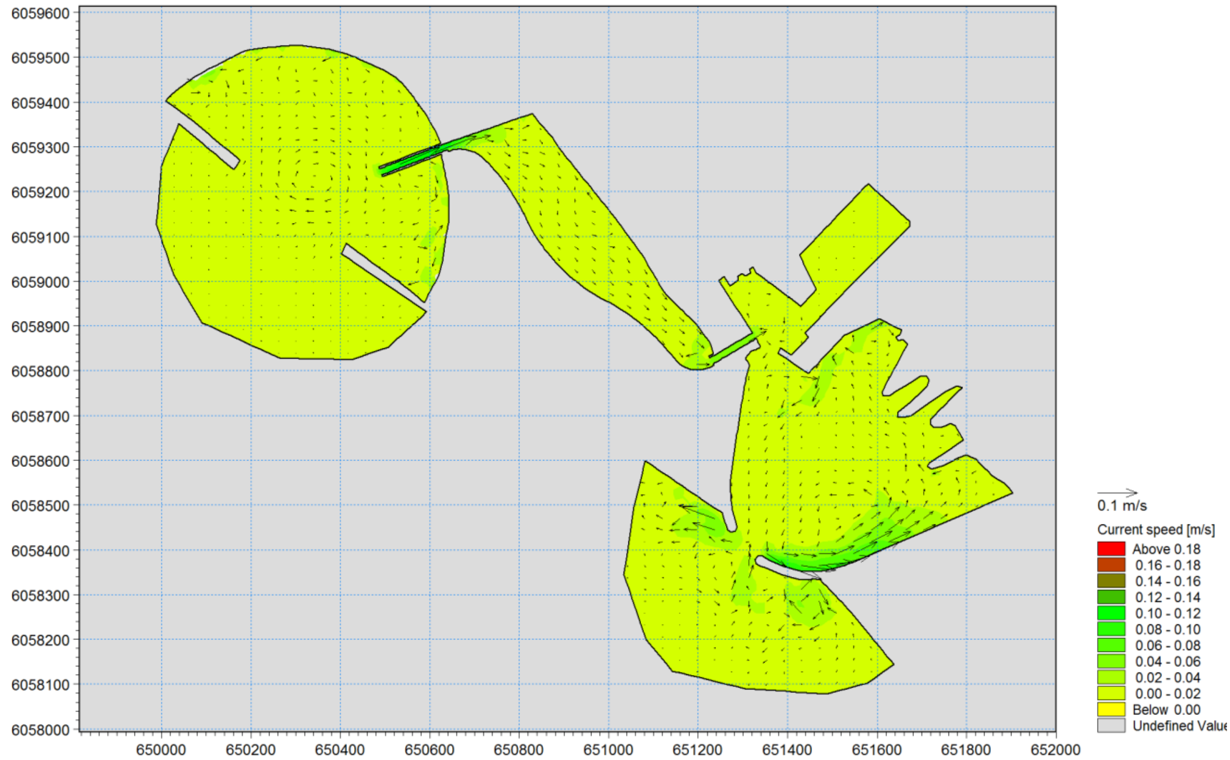

Figure 4-4 Current pattern for the Pocket Beach Lagoon – Inner Lagoon system for characteristic SE-ward flow situation in Fehmarnbelt

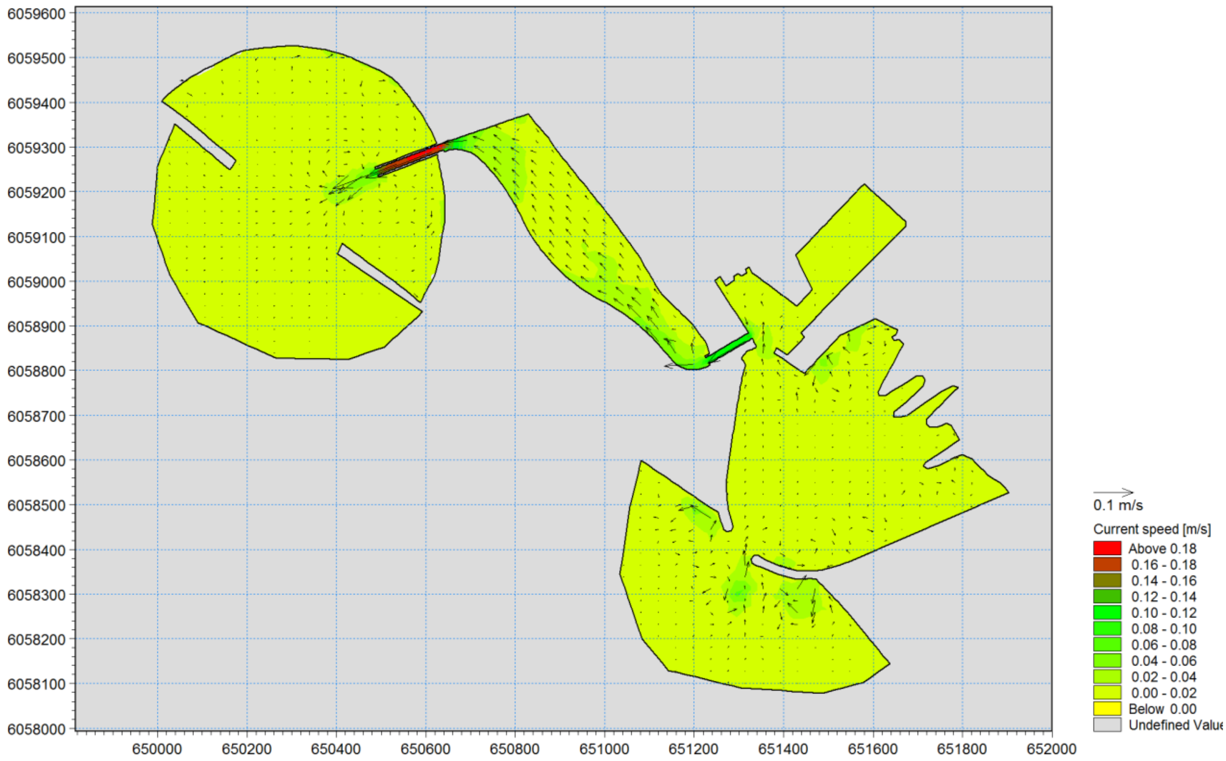

Figure 4-5 Current pattern for the Pocket Beach Lagoon – Inner Lagoon system for characteristic NW-ward flow situation in Fehmarnbelt

Current speeds have been extracted and analysed in the various canal sections, and currents statistics have been developed, see Figure 4-6. Generally the current speeds in the Pocket Beach Lagoon and in the Inner Lagoon are very low. The highest current speeds are seen in the canal sections connecting the Inner Lagoon to adjacent water bodies where current speeds may reach 0.2 m/s. The currents off the harbour entrance and off the entrances to the lagoons will follow the ambient currents in the waters off the reclamation. These currents are not correctly simulated in the lagoon model as mentioned above, but in the full 3D model.

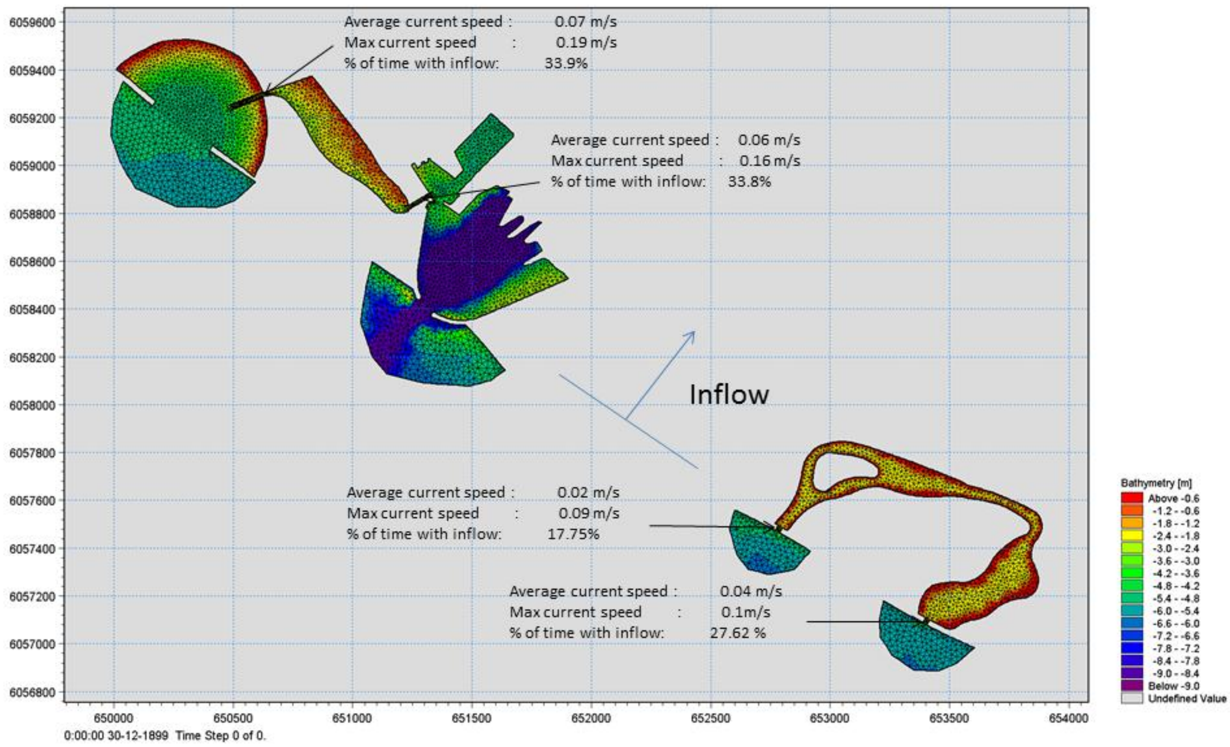

Figure 4-6 Current statistics in canal section of the lagoon systems

The model predicts that the flow direction in the Inner Lagoon is from west to east about 34% of the time and consequently from the harbour basin towards the lagoon about 66% of the time. This implies that suspended or dissolved matter, which may be present in the harbour basin, will tend to be transported into the Inner Lagoon.

Characteristic flow velocities in the Nature Lagoon have also been extracted with the purpose of providing an impression of the characteristic flow conditions in the lagoon, see Figure 4-7 and Figure 4-8, which show characteristic flow situations towards SE and NW in the lagoon systems, respectively.

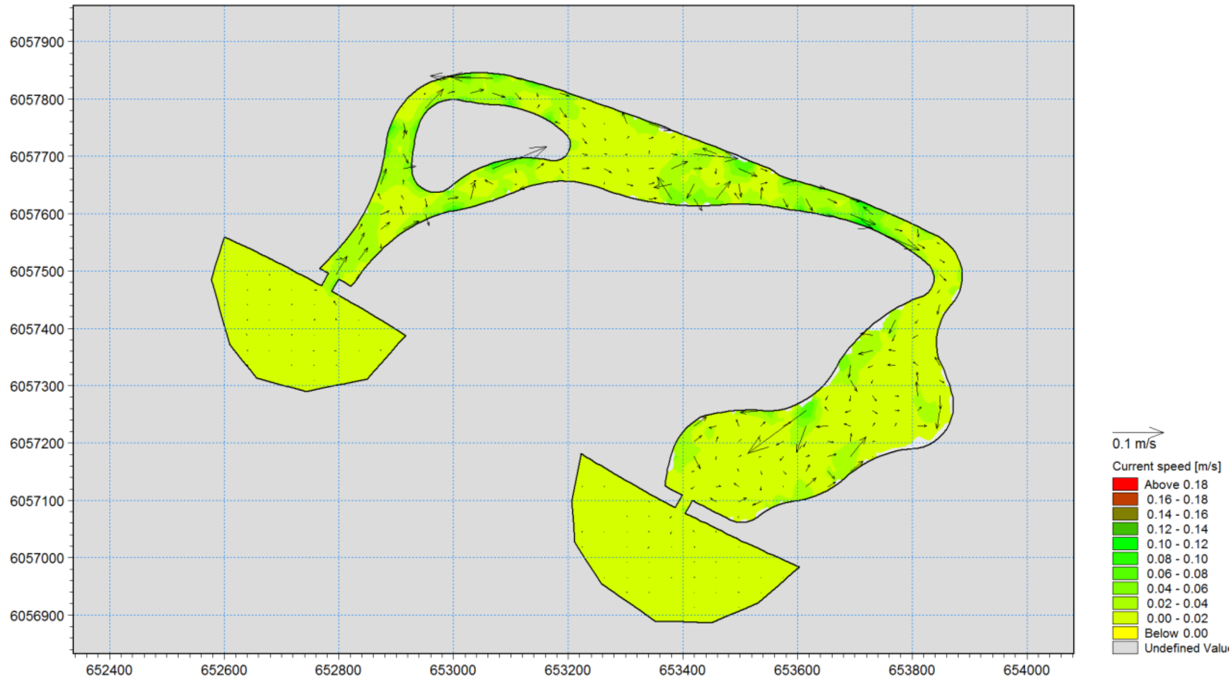

Figure 4-7 Current pattern for the Nature Lagoon for characteristic SE-ward flow situation in Fehmarnbelt

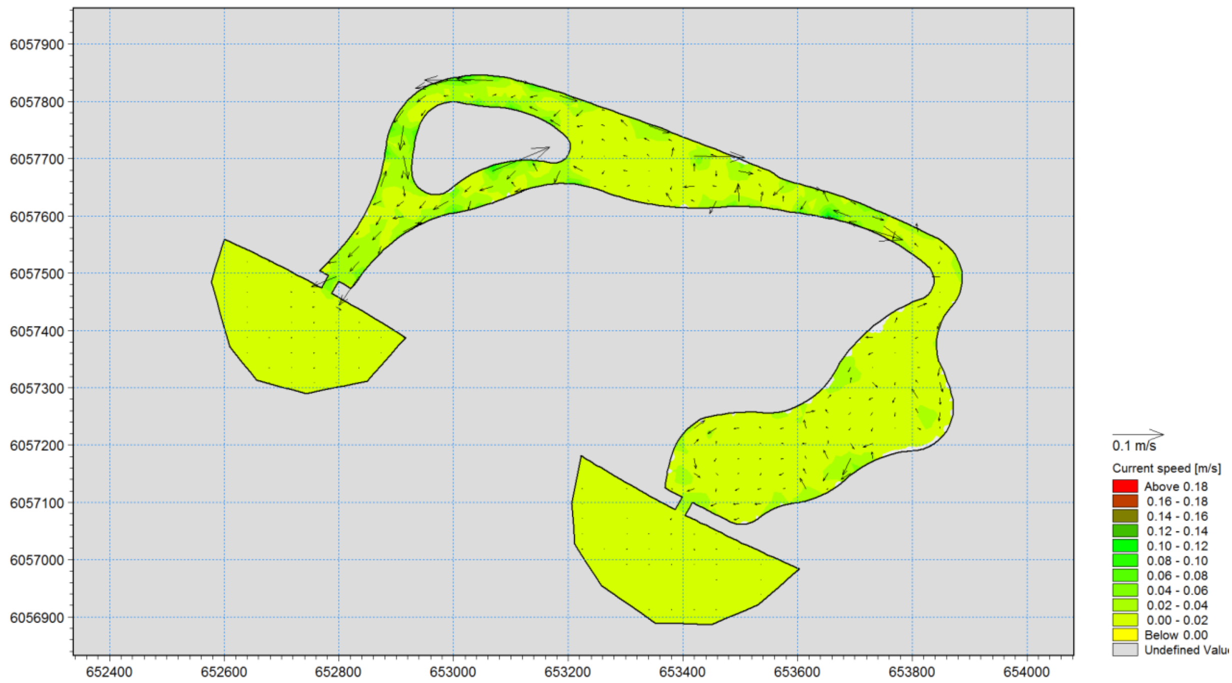

Figure 4-8 Current pattern for the Nature Lagoon for characteristic NW-ward flow situation in Fehmarnbelt

The flow pattern in the Nature Lagoon is often relatively chaotic and not with clear through-flow patterns. There is often tidal inflow in both inlets at the same time and tidal outflow at the same time in the two inlets. This is due to the relatively short distance between the two openings, which makes the difference in water level between the openings very small. The flow in the Nature Lagoon is therefore mostly driven by the tidal exchange effect, which means that water is flowing into the lagoon through both inlets at rising tides and flowing out of the lagoon through both inlets at falling tides. This makes the flushing of the lagoon less effective than for the Inner Lagoon.

Current speeds have also been extracted and analysed in the inlets to the Nature Lagoon, and currents statistics have been developed, see Figure 4-6. Overall, the current speeds in the Nature Lagoons are very small. The highest current speeds are seen in the inlet sections connecting the Nature Lagoon to Fehmarnbelt where current speeds may reach 0.1 m/s.

Inflow and outflow conditions in the Nature Lagoon are generally occurring simultaneously as explained above. Inflow is occurring in about 20 – 30% of the time and outflow or calm conditions in the remaining time.

5 FLUSHING OF THE LAGOONS

5.1 Methodologies

Study methodology for flushing

The flushing of the lagoons is investigated by adding a conservative substance to different water volumes inside the lagoons including Rødbyhavn and simulating the dilution (flushing) of the substance. The flushing characteristics of the lagoons are expressed as the time (in days) required for flushing of 50% of the initial amount of substance. This is the so-called flushing time T_{50}. Three periods of ten days are simulated. The periods are chosen based on different regimes in the boundary conditions. In Figure 5-1 the water level difference in the regional model between the entrance to the Pocket Beach Lagoon and the eastern entrance to the Nature Lagoon is shown.

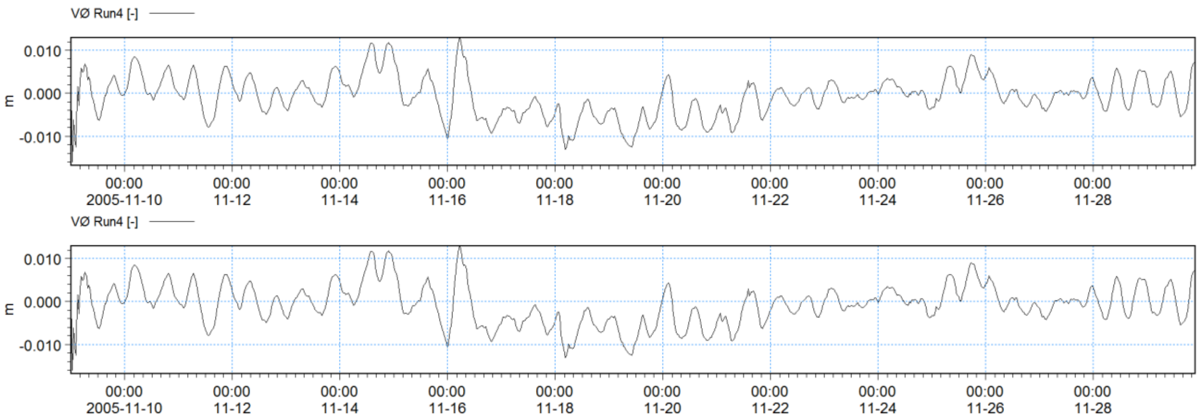

Figure 5-1 Water level difference from western entrance (Pocket Beach) to eastern entrance (near the Active Cliff)

The three selected periods for simulation are the following:

- Period 1: 9 -19 November 2005. Starting with varying flow directions and finalizing with westward flow
- Period 2: 14 – 24 November 2005. Starting with varying to eastward flow and finalizing with westward flowPeriod 3: 17 – 27 November 2005. Starting with westward flow and finalizing with eastward to varying flow

Study methodology for spreading from source in Rødbyhavn

Another study methodology has also been used in order to investigate the spreading of a diluted substance from a source in Rødbyhavn main harbour basin into the Inner Lagoon. A source of conservative matter is placed in the western part of Rødbyhavn and the spreading of this matter is simulated. The source has a concentration of 100 units/s. The approach is to compare the equilibrium conditions in Rødbyhavn harbour with the equilibrium conditions in the Inner Lagoon to obtain a measure of correlation between the concentration levels in the harbour and the concentration levels in the Inner Lagoon.

5.2 Estimated flushings

Flushing in period 1: 9 – 19 November 2005

In the following results of the flushing simulations from the period 9 – 19 November 2005 are presented. Figure 5-2 shows the initial concentrations at time step 0, while Figure 5-3 and Figure 5-4 show the amount of remaining substance after 5 and 10 days, respectively. Left plots show flushing in Rødbyhavn, Inner Lagoon and the Pocket Beach Lagoon, middle plots show the flushing of Rødbyhavn, and right plots show flushing in the Nature Lagoon. The flushing at the Pocket Beach, the Inner Lagoon and the Inner Lagoon including the Pocket Beach has also been simulated.

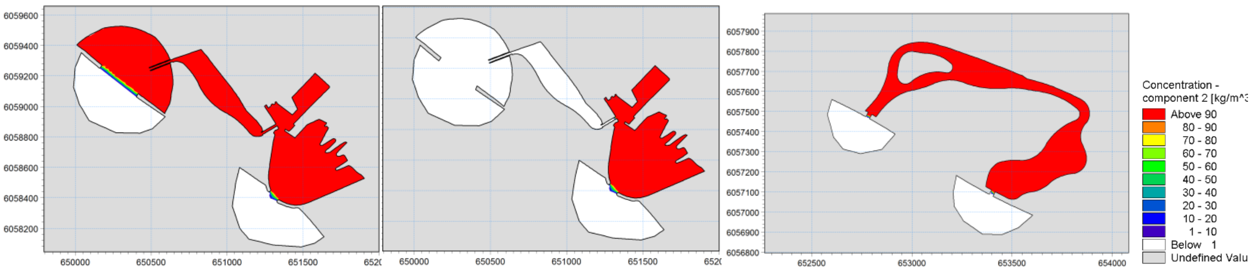

Figure 5-2 Period 1. Initial distribution of conservative matter

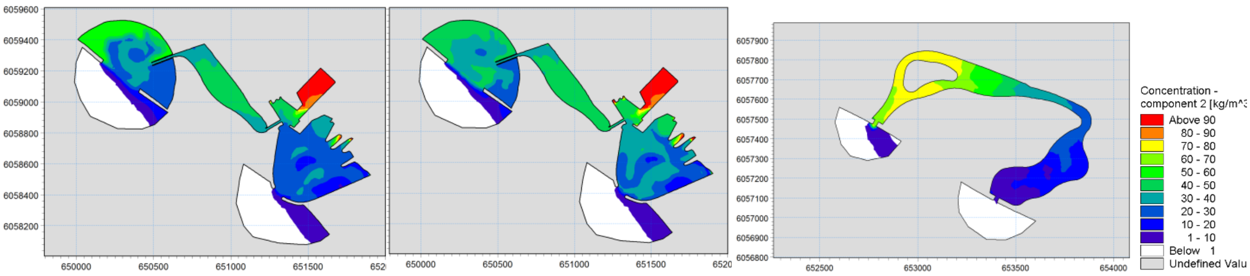

Figure 5-3 Period 1. Conservative matter after 5 days

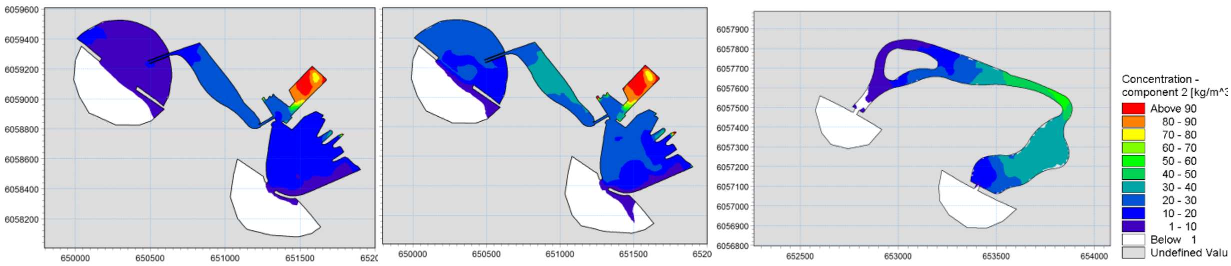

Figure 5-4 Period 1. Conservative matter after 10 days

The overall flushing as a function of time is shown in Figure 5-5 and Table 5-1. Results show T_{50} flushing times between 1.3 and 5.9 days. The longest flushing time is estimated for the Rødbyhavn-Pocket Beach - Inner Lagoon system and the shortest for the Inner Lagoon.

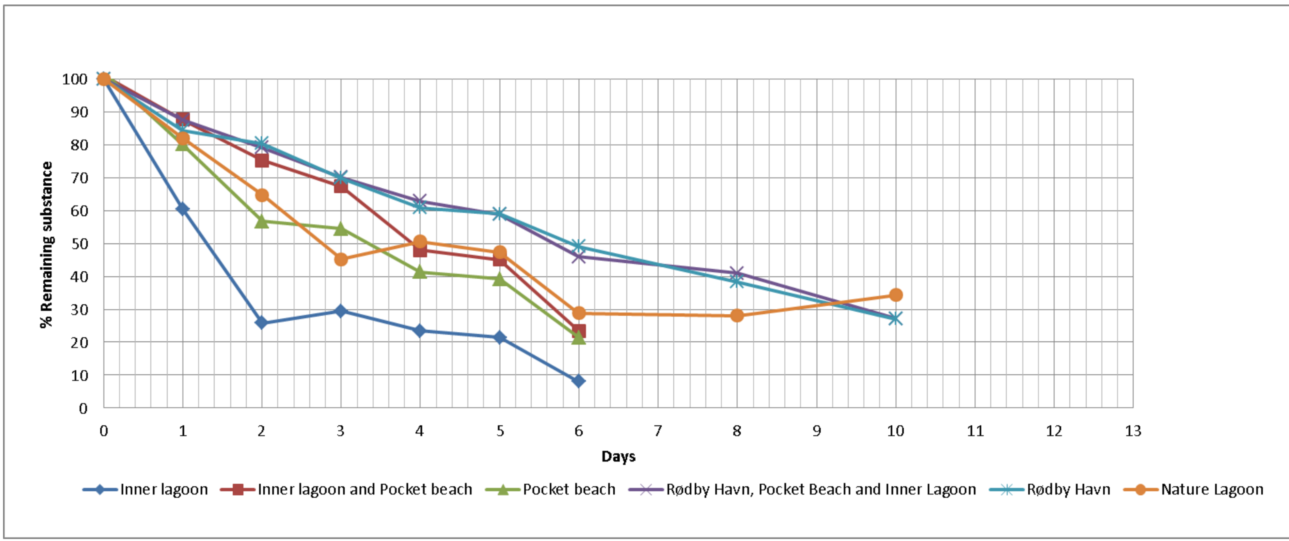

Figure 5-5 Period 1. Overall flushing in six areas

Table 5-1 Period 1. Overview of flushing times T_{50}

Location	T_{50} (days)
Inner Lagoon	1.3
Pocket Beach	3.4
Inner Lagoon and Pocket Beach	3.9
Rødbyhavn	5.6
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	5.9
Nature Lagoon	2.8

Flushing in period 2: 14 – 24 November 2005

In the following results the flushing calculations from the 14 – 24 November 2005 are presented. Figure 5-6 shows the initial concentrations at time step 0. Figure 5-7 and Figure 5-8 show the amount of remaining substance after 5 and 10 days. Left plot covers flushing in Rødbyhavn, Inner Lagoon and the Pocket Beach. Middle plot covers the flushing in Rødbyhavn. Right plot covers flushing in the Nature Lagoon. The flushing at the Pocket Beach, the Inner Lagoon and the Inner Lagoon including the Pocket Beach has also been simulated.

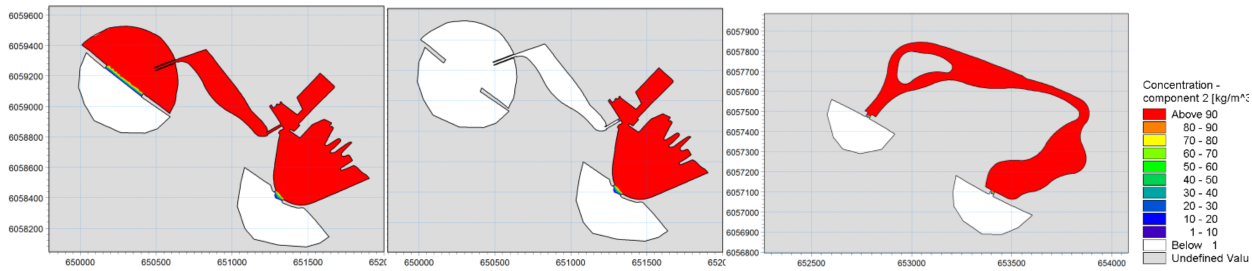

Figure 5-6 Period 2. Initial distribution of conservative matter.

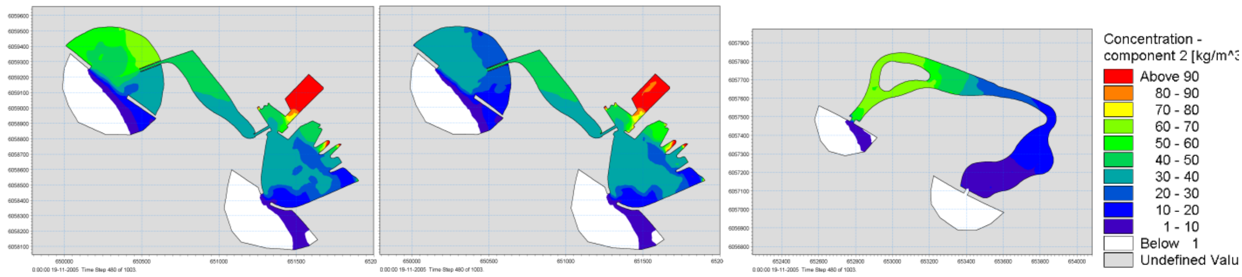

Figure 5-7 Period 2. Conservative matter after 5 days.

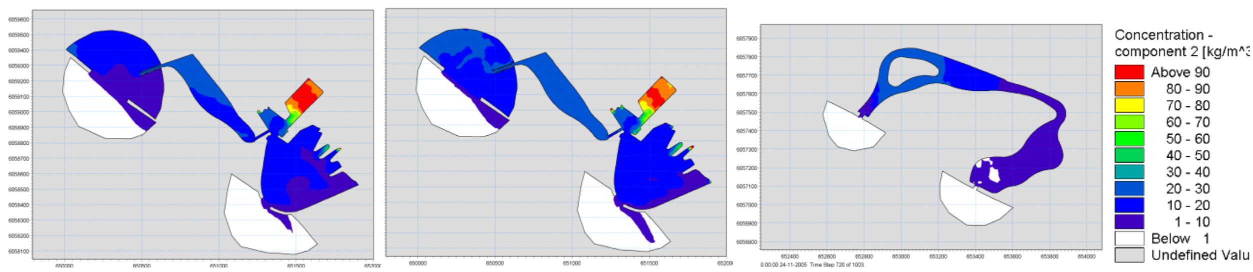

Figure 5-8 Period 2. Conservative matter after 10 days

The overall flushing as a function of time is given in Figure 5-9 and Table 5-2.

Results show flushing times between 0.75 and 4.2 days. Longest for Rødbyhavn-Pocket Beach - Inner Lagoon system and shortest for Inner Lagoon.

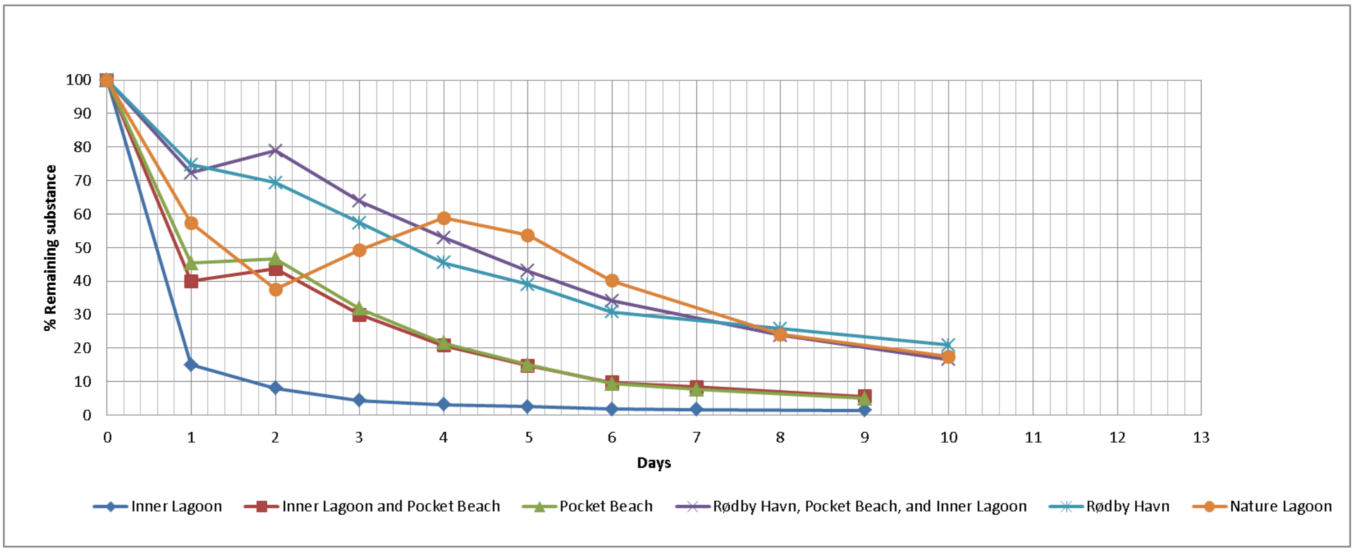

Figure 5-9 Period 2. Overall flushing times for six areas

Table 5-2 Period 2. Overview of flushing times T_{50}

Location	T_{50}
Inner Lagoon	0.75
Pocket Beach	0.9
Inner Lagoon and Pocket Beach	0.8
Rødbyhavn	3.6
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	4.2
Nature Lagoon	1.3

Flushing in period 3: 17 -27 November 2005

In the following results the flushing calculations from the period 17 – 27 November 2005 are presented. Figure 5-10 shows the initial concentrations at time step 0. Figure 5-11 and Figure 5-12 show amount of remaining substance after 5 and 10 days. Left plot covers flushing in Rødbyhavn, Inner Lagoon and the Pocket Beach Lagoon. Middle plot covers the flushing in Rødbyhavn. Right plot covers flushing in the Nature Lagoon. The flushing at the Pocket beach, the inner lagoon and the Inner Lagoon and the Pocket Beach has also been simulated.

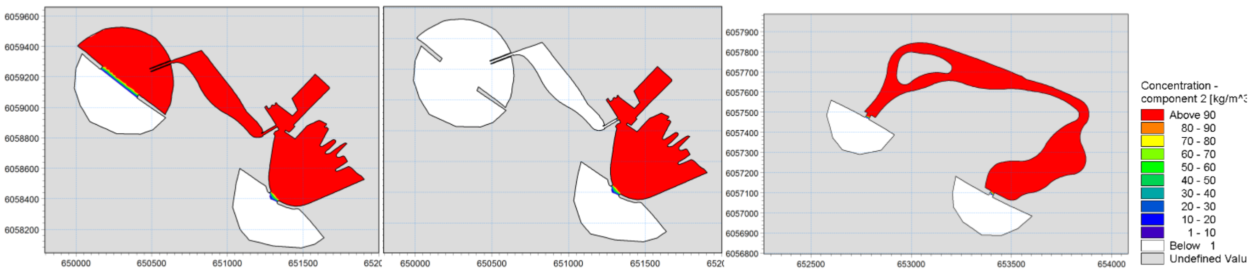

Figure 5-10 Period 3. Initial distribution of conservative matter

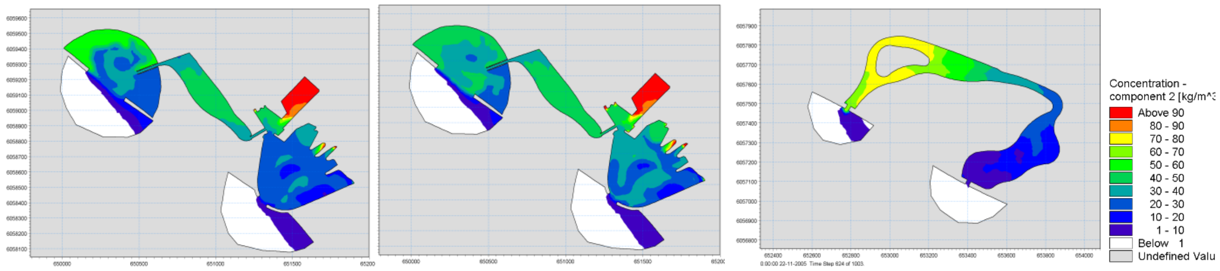

Figure 5-11 Period 3. Conservative matter after 5 days

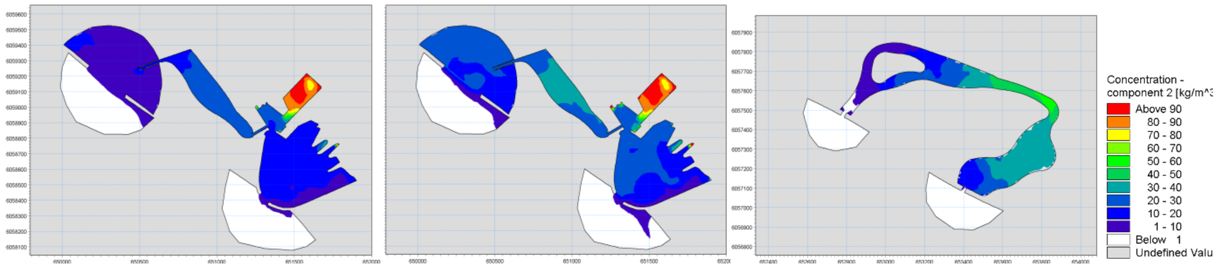

Figure 5-12 Period 3. Conservative matter after 10 days

The overall flushing as function of time is given in Figure 5-13 and Table 5-3. Results show flushing times between 0.5 and 6.6 days. The longest flushing time is estimated for Nature Lagoon and the shortest for Inner Lagoon.

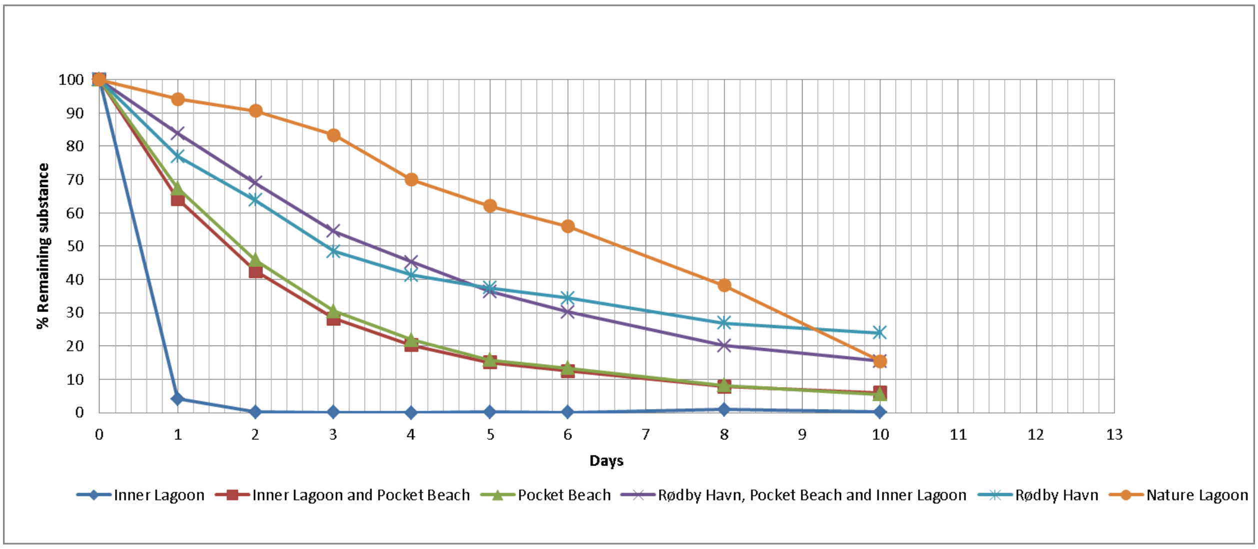

Figure 5-13 Period 3. Overall flushing times

Table 5-3 Period 3. Overview of flushing times T_{50}

Location	T_{50} (days)
Inner Lagoon	0.5
Pocket Beach	1.8
Inner Lagoon and Pocket Beach	1.6
Rødbyhavn	2.9
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	3.4
Nature Lagoon	6.6

Overview of flushing times

In Table 5-4 an overview of the flushing times for all three scenarios is given.

Table 5-4 Overview of flushing times (T_{50} in days) for the three period

Location	T_{50} (days)	Average T_{50} (days)
Inner Lagoon	0.5 – 1.3	0.9
Pocket Beach	0.9 – 3.4	2.0
Inner Lagoon and Pocket Beach	0.8 – 3.9	2.1
Rødbyhavn	2.9 – 5.6	4.3
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	3.4 – 5.9	4.7
Nature Lagoons	1.3 - 6.6	4.0

It is generally seen that the flushing times in all lagoon systems can be characterised as rather high with average flushing times in the range of 1-5 days.

5.3 Inflow of water into the lagoons

The sum of the inflows of water through the two openings over the entire simulation period of 21 days has been calculated for both lagoons. This will be used as basis for the evaluation of sedimentation in the lagoons due to import of suspended sediments contained in the water entering the lagoons from Fehmarnbelt. The results of these computations are presented in Table 5-5.

Table 5-5 Inflow of water into the lagoons, average inflow and average flushing time

Lagoon	Simulation time in days	Total inflow in m^3	Average inflow per day in m^3/day	Volume of lagoon in m^3	Average flushing time in days (T_{50})
Inner Lagoon	21	4,000,000	190,000	170,000	0.9
Nature Lagoon	21	1,400,000	67,000	270,000	4.0

6 RISK OF SEDIMENTATION IN THE LAGOONS

There are two types of potential sedimentation in the lagoons. The risk of these types of sedimentation will be described in two sub-tasks:

- Sub-task 4.5.1: Risk of sedimentation of sand in the entrances to the lagoons
- Sub-task 4.5.2: Risk of sedimentation of suspended sediments in the lagoons

6.1 Risk of sedimentation of sand at the entrances to the lagoons

Sand is transported along the original shorelines as littoral transport. The natural littoral transport along the Lolland coast has been described in the Baseline Morphological Report (FEHY 2013b). It is evident from this report that the natural net littoral transport in the area west of Rødbyhavn is between 31,500 and 21,500 m^3/year towards SE. The transport takes place out to a water depth of 3 – 4 m, the so-called closure depth, dl, which is consequently dl ~3.5 m west of Rødbyhavn. The similar data at the stretch SE of Rødbyhavn to Holeby/Hyldtofte Østersøbad is a net SE-ward transport of 1,500 m^3/year immediately SE of the harbour increasing to 20,000 m^3/year at Holeby/Hyldtofte Østersøbad. The closure depth in this area is dl ~2.5 m.

The depth at the entrances to the Pocket Beach Lagoon and to the Nature Lagoon, respectively, is about 5 to 6 m, which is well beyond the respective closure depths. This means that initially there will be hardly any transport of sand along the outer perimeter of the reclamation towards the lagoon openings, indicating that initially there will be negligible sedimentation in the openings to the lagoons.

The risk of sedimentation in the two lagoons will develop with time as described in the following.

Risk of sedimentation at the entrance of the Pocket Beach Lagoon

The impact of the reclamation on sediment transport and the shoreline development in the area adjacent to the reclamation are described in the Impact Assessment report on Coastal Morphology (FEHY 2013c).

The reclamation will block the net supply of sediment from the west. The sediment will accumulate along the 1,100 m new beach at the western termination of the reclamation. The accumulation will build up and fill the 'corner' between the reclamation and the existing coastline as a sand fillet starting from the western part of the new beach. Calculations show that 31,500 m^3/year will deposit along the new beach and that the beach width will initially (first 1-2 years) increase by up to 20 m/year and reduce to about 8-12 m/year near the reclamation after 5 years.

With time deposition will occur along a longer stretch and the rate of the shoreline will advance as well as the progression rate towards the northwest will decrease. In the period 5-30 years after the end of construction, the shoreline is predicted to advance and increase the width of the beach by about 3-9 m/year and progress towards the northwest by a rate of 100 m/year after 5 years, decreasing to about 40-50 m/year after 30 years. Thirty years after the construction of the reclamation, the accumulation zone is expected to reach the coastline between Bredfjed and Skarholm, see Figure 6-1.

As the shoreline advances along the western part of the reclamation, the water depth decreases at the offshore western 'corner' of the reclamation to a depth where sand can start by-passing and a sand bar can build up along the offshore part of the reclamation. The time period before by-pass starts may be (a few) decades. The accumulation of sand west of the reclamation is predicted to continue within the lifetime of the project similarly to the situation at the beach west of Rødbyhavn in the baseline situation.

Figure 6-1 Predicted development of the shoreline west of the Lolland reclamation 0-30 years after end of construction. Aerial photo from 2009 (©COWI Orthophoto April 2009)

The water depth at the offshore part of the reclamation (approximately 6 m DVR90) is initially too large to facilitate a significant transport of sediment around the offshore western 'corner' of the reclamation and further along the offshore part of the reclamation.

As described above a sand bar will start to build up along the offshore perimeter of the reclamation after 10-20 years. The sand bar will build up along the reclamation with a layer thickness of 2-3 m reducing the water depth to an active depth for sediment transport to occur. It is assumed that the deposition will have a width of about 50 m and that 50-100% of the sediment supply from west will by-pass the reclamation. For sedimentation to occur at the opening to the Pocket Beach Lagoon, this sand will theoretically build up along the ~1,400 m section of reclamation from the west 'corner' to the lagoon opening of the reclamation and reach the lagoon opening in another approximately 5-10 years. This is similar to the situation at Rødbyhavn in the baseline situation.

In summary, the lagoon opening will not be exposed to sedimentation until about 15 to 30 years from the construction of the tunnel project. It is consequently evaluated that the sedimentation in the opening to the Pocket Beach Lagoon will start about 15 years after the construction of the reclamation and increase to about 15,000 to 20,000 m^3/year after 30 years, whereafter the sedimentation rate in the lagoon opening will stabilise at about 20,000 m^3/year.

It has not been investigated in detail how the sedimentation in the Pocket Beach Lagoon will take place. However, it is evaluated that the sedimentation will start at the entrance to the lagoon and gradually develop into the entire lagoon due to the wave exposure. Furthermore, it is evaluated that the lagoon can absorb about 150,000 - 250,000 m^3 of sand until it is becoming so shallow that maintenance dredging will be required. It is consequently estimated that it will take additionally about 15 years before maintenance dredging will be required, which means that no maintenance dredging in the lagoon will be required until after 30 to 45 years after construction.

Risk of sedimentation at the entrance to the Nature Lagoon

The conditions for sedimentation in the entrances to the Nature Lagoon are somewhat different as explained in the following.

The sand which will be transported along the western part of the reclamation, i.e. west of Rødbyhavn, will never reach the entrances to the Nature Lagoon because the outer parts of the breakwaters at Rødbyhavn and the deepened access channel will act as a complete blockage for the SE-ward transport along the perimeter of the reclamation. This is under the assumption that Rødbyhavn is maintained with the present access channel. This means that now sand will accumulate along the perimeter structure SE of Rødbyhavn. Consequently, there will be hardly any sediment transport along the perimeter of the reclamation SE of Rødbyhavn. It is furthermore evaluated that there will be no build-up of sand from SE along the perimeter east of the eastern entrance to the Nature Lagoon because this is opposite the direction of the net transport. It can therefore be concluded that the entrances to the Nature Lagoon will only be exposed to negligible sedimentation. The very minor sedimentation of sand in the entrances will be concentrated very near the openings as there will be neither enough currents nor waves to transport sand into the lagoon proper.

6.2 Risk of sedimentation of suspended sediments in the lagoons

When water is flushed into the lagoons any substance suspended in the water will also be brought into the lagoon where it may subsequently cause sedimentation.

The methodology for estimation of sedimentation of fines in the lagoons is described in the following.

The concentrations of fines in the nearshore area are varying drastically with mainly the wave conditions. Most of the fines carried into the lagoons will settle on the seabed due to the relatively calm conditions in the lagoons, both with respect to waves and to currents. This is valid for the Inner Lagoon and for the Nature Lagoon, which are both protected against wave penetration.

However, the Pocket Beach Lagoon is relatively open for wave penetration which means that most of the suspended fine sediments brought into this lagoon will stay in suspension. Of special importance is that the fines will not settle on the beach in the Pocket Beach Lagoon due to the wave exposure, which is the reason why a recreational beach of high quality can be maintained in this lagoon.

The amount of suspended sediments brought into the Inner Lagoon and the Nature Lagoon will be evaluated on basis of the flushing characteristics of the lagoons under different weather conditions, as established in Task 4.2 and as further specified in the following, combined with data on the concentration of fines in the ambient waters, which are reported in (FEHY 2013d). Finally, the sedimentation will be discussed by assessing the percentage of the suspended sediments brought into the lagoons which will settle on the bottom of the lagoon.

Assessment of amounts of water brought into the Inner Lagoon and into the Nature Lagoon

The average inflow of water flowing into the lagoons during the simulation period was calculated in Table 5-5. The average daily and yearly inflow of water into the lagoons and the average residence time for the two lagoons are presented in Table 6-1.

Table 6-1 Inflow of water into the lagoons, average inflow and average flushing time (T_{50})

Lagoon	Average inflow per day in m^3/day	Average inflow per year in m^3/year	Average flushing time in days
Inner Lagoon	190,000	$69 \cdot 10^6$	0.9
Nature Lagoon	67,000	$24 \cdot 10^6$	4.0

Assessment of the suspended sediments concentrations in the coastal waters of the Fehmarnbelt

Suspended sediment concentrations (SSC) in the waters of Fehmarnbelt have been monitored during a survey campaign performed during the period February 2009 through May 2011. This monitoring campaign has been reported in (FEHY 2013d).

Turbidity and concentration of suspended sediments have been measured at the stations presented in Figure 6-2.

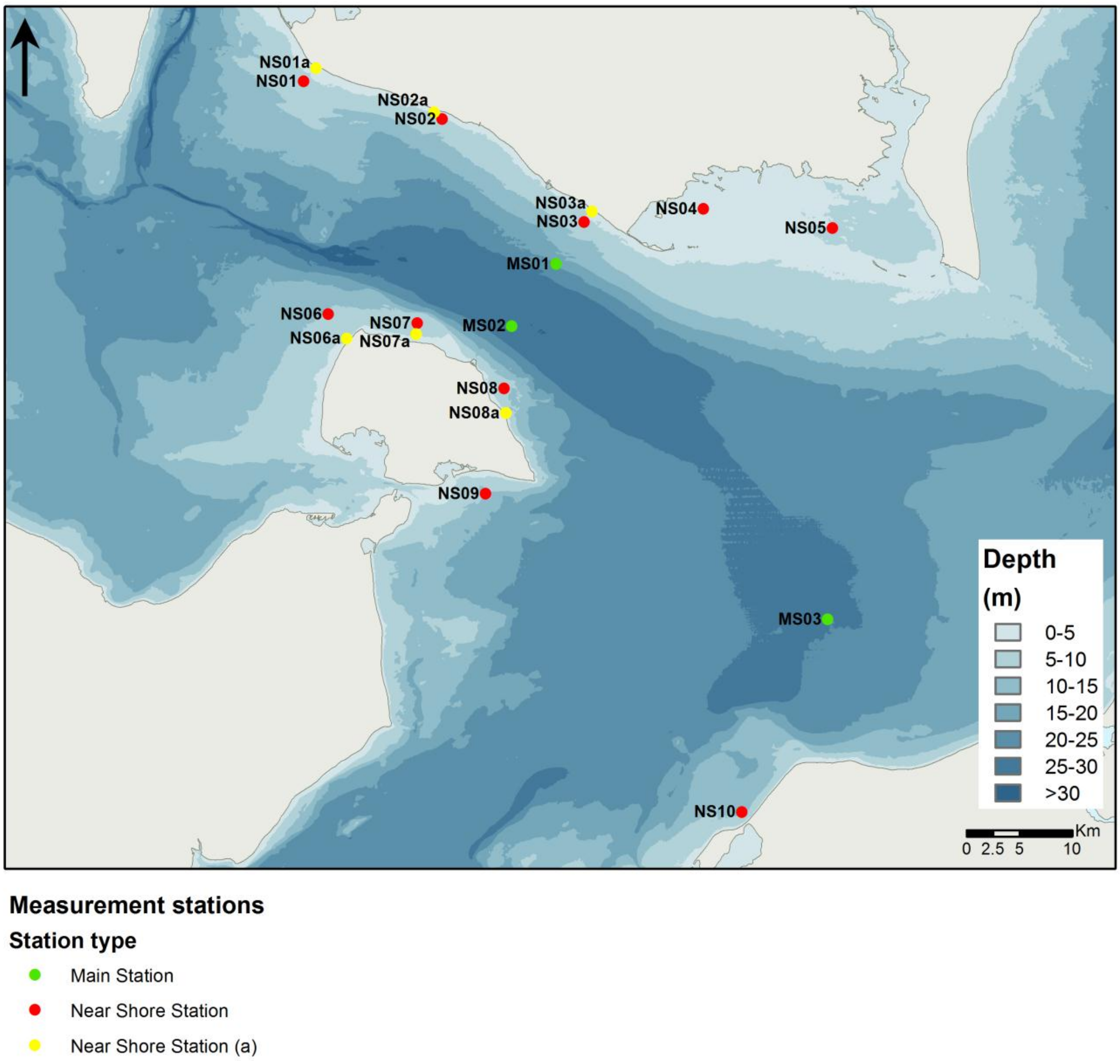

Figure 6-2 Fixed measurement stations from the Fehmarnbelt Fixed Link monitoring programme from February 2009 to May 2011, from (FEHY 2013d)

Furthermore, monthly campaigns have been performed during the period from February 2009 to December 2010 at a large number of stations.

The results of the statistical analysis of the SSC are summarised in Figure 6-3.

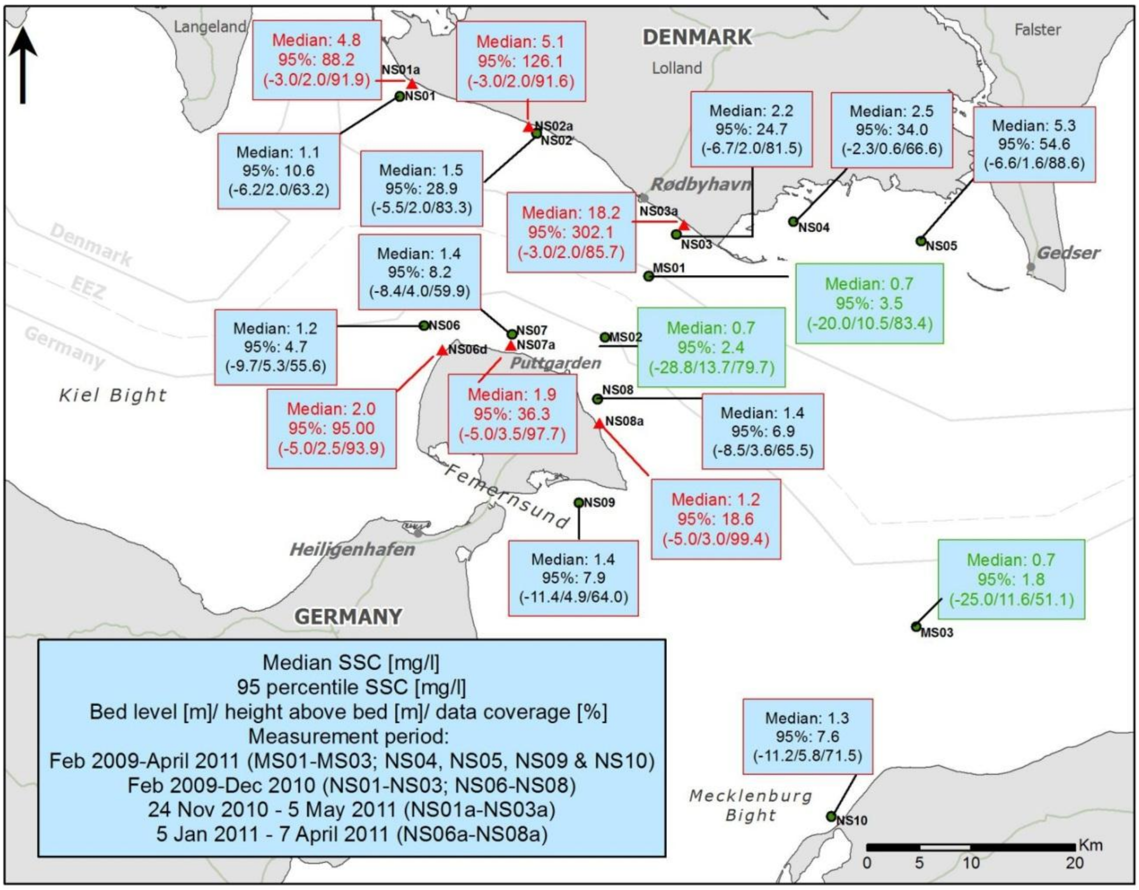

Figure 6-3 Overall statistics for the suspended sediment concentration at the nearshore stations and the main stations. 'Median' is the value which is exceeded in 50% of the observations. The values presented at the main stations are from the mid water measurements

The SSC near the lagoon openings will be based on the results of the measurements at the nearshore stations NS02, NS02a, NS03 and NS03a. It is seen that the median SSC in the nearshore waters near the Lolland coast is relatively small under normal calm conditions; according to Figure 6-3 they are varying between 1.5 and 18.2 mg/l with an estimated average of the medians of about 5 mg/l (5 g/m^3). However, the SSC in the nearshore waters may reach relatively high values during storm conditions, where high waves and relatively strong currents bring bottom sediments into suspension. These conditions are represented by the 95 percentile of SSC; according to Figure 6-3 these 95 percentiles vary between 24.7 and 302.1 mg/l in the above mentioned nearshore stations with an estimated average of the 95 percentiles of about 100 mg/l (100 g/m^3). Assuming that the average value is representative for 90% of the time and that the 95 percentile is representative for 10% of the time *a yearly average value of about 15 g/m^3 is obtained*. This yearly average value will be used in the following estimates of sedimentation in the lagoons.

Settling velocities of the various types of suspended sediments have been investigated in (FEHY 2013e). The settling velocities vary considerable depending on the type of material being suspended. The main type of seabed substrate along the south coast of Lolland is coarse sediments/boulders, which is the result of washing out of the fines of the Upper till/Late glacial clay, which is the dominant type of geological formation along the south coast of Lolland, see Figure 6-4.

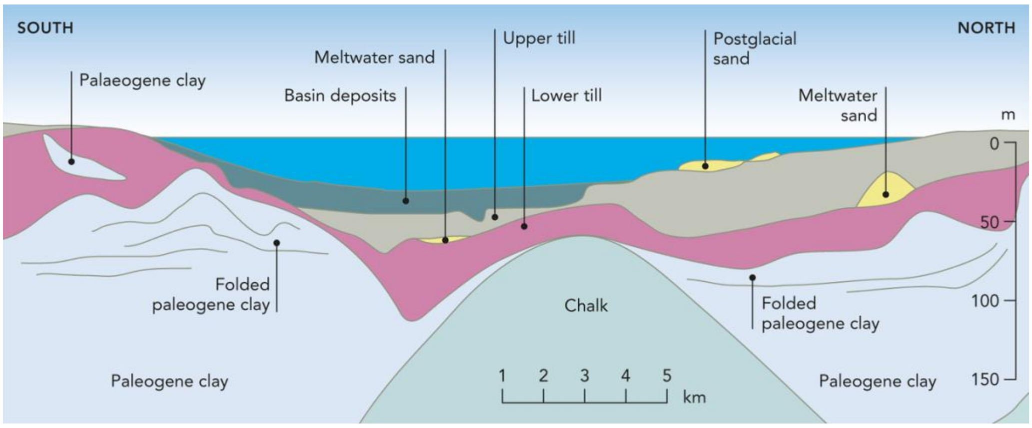

Figure 6-4 Overview of the geology in the Fehmarnbelt, from (FEHY 2013d)

The average settling velocity for spilled material originating from Late glacial clay has in (FEHY 2013e) been estimated at 0.07 mm/s. Assuming that the suspended sediments in the nearshore waters are of the same nature, the settling velocity for these suspended sediments is assumed to be w_s = 0.07 mm/s.

With a maximum water depth of 2.0 m in the Inner Lagoon and in the Nature Lagoon, it is seen that it requires about 8 hours for all suspended sediments brought into the lagoon to settle at the seabed. With average retention times of 0.9 and 4.0 days for the Inner Lagoon and for the Nature Lagoon, respectively, it can be concluded that all suspended sediments brought into the lagoons will settle on the seabed.

Assessment of sedimentation in the lagoons due to the settling of suspended sediments

The average inflow of water into the lagoons and the average concentrations of suspended sediments in the water flowing into the lagoons have been assessed in the above sub-sections. These assessments will be used to calculate the annual amounts of sediments brought into the lagoons and the corresponding annual sedimentation layer thickness.

The Inner Lagoon receives its inflow via the Pocket Beach Lagoon and via the Harbour basin, where some of the suspended sediments contained in the waters from the Fehmarnbelt will settle. This potential reduction in the SSC in the water flowing into the Inner Lagoon has not been taken into account in the assessment of the sedimentation. There is no similar reduction in the SSC of the water flowing into the Nature Lagoon. The average amounts of sediments brought into the two lagoons based on these assumptions are presented in Table 6-2.

The thickness of the annual sedimentation layer has been calculated using a density of the settled sediments of ρ = 300 kg/m^3. This is the value obtained from the test pit investigations reported in (FEHY 2012f). This density is valid for newly settled material and it is assumed that the density will increase with time when the sediments consolidates, but the initial value has been used in the present assessment.

Table 6-2 Average yearly inflow of water and sediments into the lagoons and sedimentation in the lagoons

Lagoon	Average inflow of water per year in m^3/year	Yearly average SSC in g/m^3	Yearly import of fine sediments in kg/year	Area of lagoon seabed in m^2	Yearly sedimentation in $kg/m^2/y$	Initial yearly average thickness of sedimentation in cm/year
Inner Lagoon	$69 \cdot 10^6$	15	$1{,}035 \cdot 10^3$	310,000	3.3	1.1
Nature Lagoon	$24 \cdot 10^6$	15	$360 \cdot 10^3$	720,000	0.5	0.2

It must be mentioned that it has been assumed that the sediments settle evenly distributed over the seabeds of the entire lagoons. In reality, the coarse fractions will settle close to the lagoon openings and the fine sediments will settle in the central parts of the lagoons.

The computed sedimentation rates are considered as being very conservative because they are based on the initial very small density of the settled sediments. Following the settling of the sediments a consolidation process will start. The consolidation process will reduce the accumulated thickness of the sedimentation layer for specific period of years relative to the initial rate multiplied by the number of years in the considered period.

The thickness of the accumulated sedimentation over a 50-year and a 100-year period taking the consolidation process into account has been evaluated assuming a long term density of 1200 Kg/m^3 being obtained after 10 years. The resulting sedimentation layer thickness after 50 and 100 years is presented in Table 6-3.

Table 6-3 Sedimentation thickness after 50 years including impact of consolidation to 1200 kg/m^3 after 10 years

Lagoon	Sedimentation after 50 years	Sedimentation after 100 years
Inner Lagoon	20 cm	33 cm
Nature Lagoon	4 cm	6 cm

It is concluded that the computed sedimentation rates are so small that mitigation measures in form of maintenance dredging will not be required the first 50 years for the Inner Lagoon and will never be required for the Nature Lagoon.

7 IMPACT OF WASTEWATER ON THE WATER QUALITY

Today Rødbyhavn wastewater treatment plant discharges treated water just southeast of Rødbyhavn close to the coastline. Furthermore, stormwater overflow is discharged through the same pipeline in situations with major precipitation where the sewage plant cannot treat all the combined sewage water (waste and rain water). The discharge takes place through one of the the pumping stations draining the lowlying hinterland.

Before construction of the land reclamation, the location of the outlet has to be moved further offshore, and the treatment plant will be upgraded to increase the capacity of the plant (ensuring larger treatment and storage capacity). In the operation phase, the new outlet may potentially affect the bathing water quality of adjacent waters, including near-by beaches and nearby lagoons. Moreover, during the construction of the link and the reclamation the amount of discharged treated wastewater will increase due to the major workforce involved in the construction works.

The aim of this assessment is to evaluate the possible impact on the bathing water quality at the nearby beaches, including the new beaches of the land reclamation, of discharged treated wastewater and by-passed mixed sewage and storm water in the operation phase as well as the possible impact of the increased amount of treated wastewater expected during the construction phase of the Fehmarnbelt Link.

The data used to analyse the influence of the Fehmarnbelt project on the hygienic water quality are based on communication with several stakeholders: Femern A/S technical department (Jørgen Andresen, Niels Erik Mortensen), Lolland Wastewater Treatment Plant (Peder L. Sørensen, Henrik Sløk Hansen (also including a note prepared by Krüger A/S)), Lolland Municipality (Hanne Jønsson), and local Rødbyhavn stakeholders (Torben Christiansen, Stig Rasmussen).

The marine pipeline and discharge

Today, the treatment plant discharges treated water into the Fehmarnbelt via a pumping station just outside the treatment plant south of the harbour. The water from the pumping station is led through a short pipe and discharged at the coastline, about 10m from the coastline. In addition, a stormwater overflow basin is located at the treatment plant. This by-pass basin is activated during heavy rainfall when the treatment capacity is exceeded. The by-pass is also discharged through the pumping station.

During the construction period the project will lead to extra discharge of domestic wastewater due to a temporary increase in the population. This is considered to be the only project related contribution to the hygienic quality of the beaches.

In addition to treated wastewater and the stormwater from the treatment plant, the pumping station discharges drain water and surface runoff from the hinterland. We have not been able to get any data on the total amount of water (water flow) discharged via the pumping station. And no data exists (to our knowledge) on concentrations of pollutants in the discharged drainage water. Drainage and surface runoff usually contain relatively low concentrations of faecal bacteria. Consequently, the discharge of drainage water is not included in the following analyses.

If the discharge is large, it may affect the hydrodynamic (and thus also the estimates of spreading of bacteria discharged in the marine waters). However, presently the maximum capacity is about 1340 l/s and this is not considered important to the hydrodynamics. The pump is expected to have a larger capacity in future but it is unknown what the new capacity will be.

It may be discussed if the project also contributes to stormwater discharge, i.e. increases the amount of water discharged during heavy rainfalls. However, as the quantity of discharged water from sealed areas is unknown, such contribution is not considered in this study. Furthermore, as mentioned above the concentration of faecal bacteria in surface run off is relatively low and therefore not considered significant.

The new pipeline will be an extention of the present one but with the outlet moved seawardly to a location off the new coastline. The position of the new outlet is not yet decided upon. Therefore more positions are being studied. Thus, the study will give guidance as to how far out the outlet should be located to avoid risks of unsatisfactory bathing water quality.

The westerly pumping station which is foreseen to be moved to the new coastline between the tunnel portal and the new Nature Lagoon will not discharge wastewater and is therefore not considered a source of faecal pollution.

At present some companies around Rødbyhavn discharge untreated domestic wastewater into the harbour basin. Such pollution could influence the water quality in the recreational lagoon system. The municipality has however stated that these discharges will stop before 2015. Other pollutions (heavy metals and toxic substances) accumulated in the bottom sediments in the harbour may however pose a risk for the quality of the lagoon water. This issue is discussed in Chapter 8.

7.1 Hygienic bathing water quality

The existing public beaches that could be affected by faecal pollution from the wastewater treatment plant are Lalandia, Rødbyhavn at the Søpavillon and Holeby/Hyldtofte Østersøbad. The Lalandia and Søpavillon beaches will be closed early in the construction phase as they are located within the land reclamation area. The beaches will be replaced by the West Beach at the western end of the land reclamation and the Pocket and Paddling Beach located between Rødbyhavn and the West Beach (see Figure 4-1). The West Beach will be opened in the third year of the construction phase while the Pocket and Paddling Beach are expected to be useable by the end of the construction phase. The existing Holeby/Hyldtofte Østersøbad located just east of the land reclamation will be maintained.

The assessment of impact of discharge of faecal bacteria is based on modelling of discharge, spreading and degradation of the two indicator bacteria *E. coli* and enterococci. These two organisms are the standard organisms used in evaluations of bathing water quality. Table 7-1 gives the EU standards used in assessment of bathing water quality.

Table 7-1 EU standards for assessment of bathing water quality. Thresholds for the concentration of the faecal bacteria E. coli *and enterococci (counts per 100 ml) for the 4 bathing water classes*

Bacteria	**Criteria for the four classes of bathing water quality**			
	Excellent	Good	Sufficient	Poor
E. coli	<250*	<500*	<500**	>500**
Enterococci	<100*	<200*	<185**	>185**

*) in 95 pct. of the time, **) in 90 pct. of the time.

It should be noted that the concentrations given in Table 7-1 are thresholds values applied for classification based on statistics on measurements (at least 16) for a 4 year period. It is however common practice in Denmark to use these values for assessment of individual events too.

7.1.1 Methodology

Wastewater data

Three sources of faecal pollution are evaluated: The treated water from the wastewater treatment plant without the Fehmarnbelt project, the untreated water from the by-pass basin and finally the expected additional wastewater due to the increased population during the constructing period of the link.

Future wastewater treatment plant

Today, the treatment plant discharges 5540 m^3/day of treated water. This water is a mixture of sewage water including industrial waste water[1] and water that leaks into the pipe. The treatment plant receives domestic sewage water corresponding to 8000 PE, and with an estimated water use per PE of 200 l/day[2], this corresponds to 1600 m^3/day which then leaves an excess of 3940 m^3/day.

For the future, the treatment plant estimates a growth in PE of 1500, independent of the Fixed Link construction works, why the future amount of treated wastewater is calculated as (8000 PE + 1500 PE) x 0.2 m^3/PE/day + 3940 m^3/day = 6420 m^3/day, or 0.07 m^3/sec.

The concentrations of the two indicator bacteria *E. coli* and enterococci in treated and untreated wastewater vary significantly. In Table 7-2 some examples of estimated concentrations used for bathing water forecasts by DHI are included.

Table 7-2 Varying concentrations of E.coli and enterococci in discharges from different treatment plants around Denmark (source: DHI bathing water forecast)

Numbers per 100ml water	Lynetten (Damhus)	Avedøre	Egå	Marselisborg
E.coli	75,000	92,000	20,000	100,000
Enterococci	14,800	33,500	1,000	10,000

As a conservative estimate the following values have been used in the assessment:

- *E. coli*: 90.000 per 100ml; and
- Enterococci: 15.000 per 100ml

These values also correspond to Erichsen et al. (2006).

[1] According to note from Krüger there are very few industries connected to the treatment plant

[2] Today a more correct water use would probably be closer to 150 l/PE/day, but for this study we have applied the 200 l/PE/day which then is a conservative estimate.

By-pass

According to the official bathing water profiles a certain risk of combined sewer outfalls exists in situations when more water is led to the treatment plant than the plant capacity[3].

According to the discharge permit the *by-pass* is allowed to discharge 7 times a year with a total of 4950 m^3/year. Hence, during each event an average of 707 m^3 will be discharged corresponding to 0.39 m^3/sec assuming that each of the *by-passes* lasts 30 min. In the model (see below), *by-pass* has been introduced every second day, and hence 10 *by-passes* are included in this study.

In the *by-pass* water the concentrations of *E. coli* and enterococci are set at 1.000.000 *E. coli* per 100 ml and 170.000 enterococci per 100 ml. These values are similar to concentrations used in *by-pass* water and combined sewage overflows in the bathing water forecasts run by DHI.

Additional wastewater during the construction phase

As part of the increase in the temporary workforce during the construction of the Fehmarnbelt Link, additional wastewater is assumed to be led to the wastewater treatment plant. An increase of 4.400 persons is expected. It is assumed that each person contributes with 1 PE. This is probably an overestimation. The estimated increase amounts to 4.400 PE, corresponding to an additional wastewater discharge of 0.01 m^3/s.

Location and concentrations are similar to the treated water described above.

Model setup

Model

For evaluating the hygienic water quality the Fehmarnbelt the hydrodynamic local model (3D model, MIKE 3 FM) is applied. The model domain includes a large part of the Western Baltic Sea as well as the Danish Straits and a part of Kattegat, see Figure 7-1. For further details see (FEHY 2013a).

[3] The capacity will be increased but since we do not know the future condition we have based our assumption on the present discharge permit.

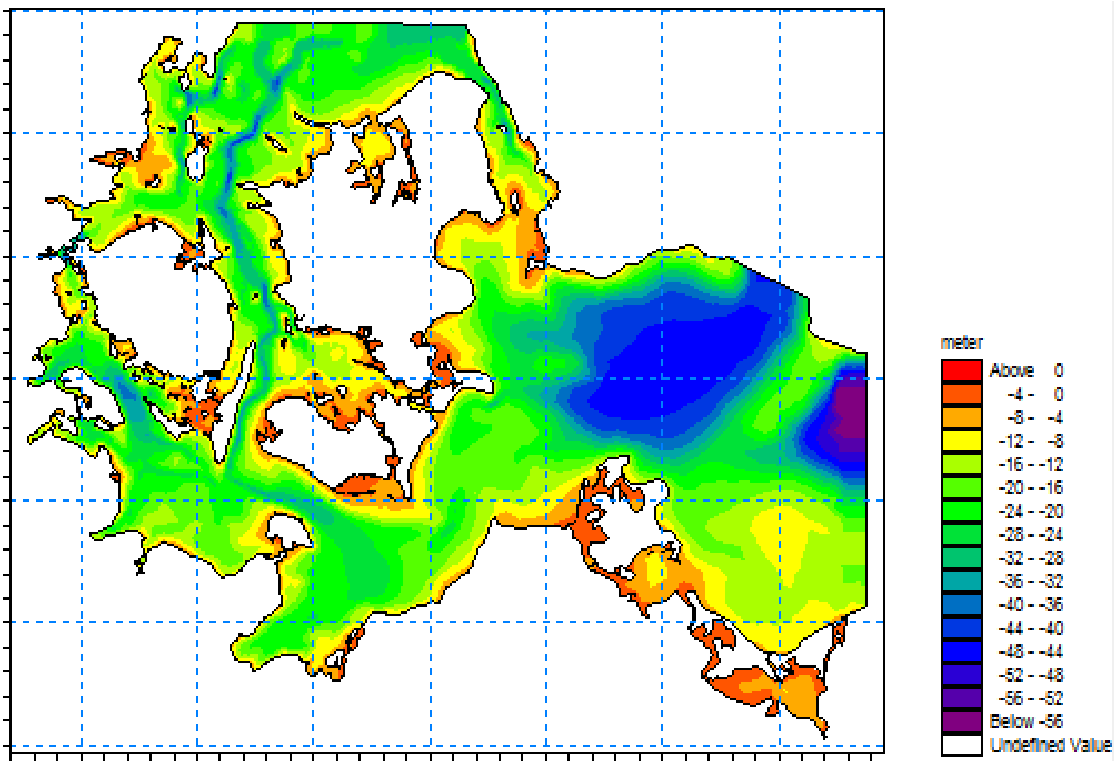

Figure 7-1 Model domain and bathymetry for the MIKE 3 local model

Bacteria

On top of the hydrodynamic model an ECO Lab model is applied describing the fate of the two indicator bacteria *E. coli* and enterococci. This ECO Lab module is described in more detail in Erichsen et al. (2006). The main driving factors determining the fate of both bacteria are solar radiation and temperature. Increasing temperature and solar radiation increase the decay rate of the bacteria.

Time period

The model is executed for 20 days covering the period 9-30 November 2005. November is not regarded as part of the bathing season, but as both light and temperature will be lower in November compared to August, this is not regarded a problem as bacteria die faster at higher temperatures and light intensities. Hence, using November is regarded conservative.

Position of the marine outlet

The model setup includes 3 different outlet position:

- Scenario 1 is at the new coastline
- Scenario 2 is 200m from the new coastline
- Scenario 3 is 500m from the new coastline

In Figure 7-2 the different discharge points are illustrated.

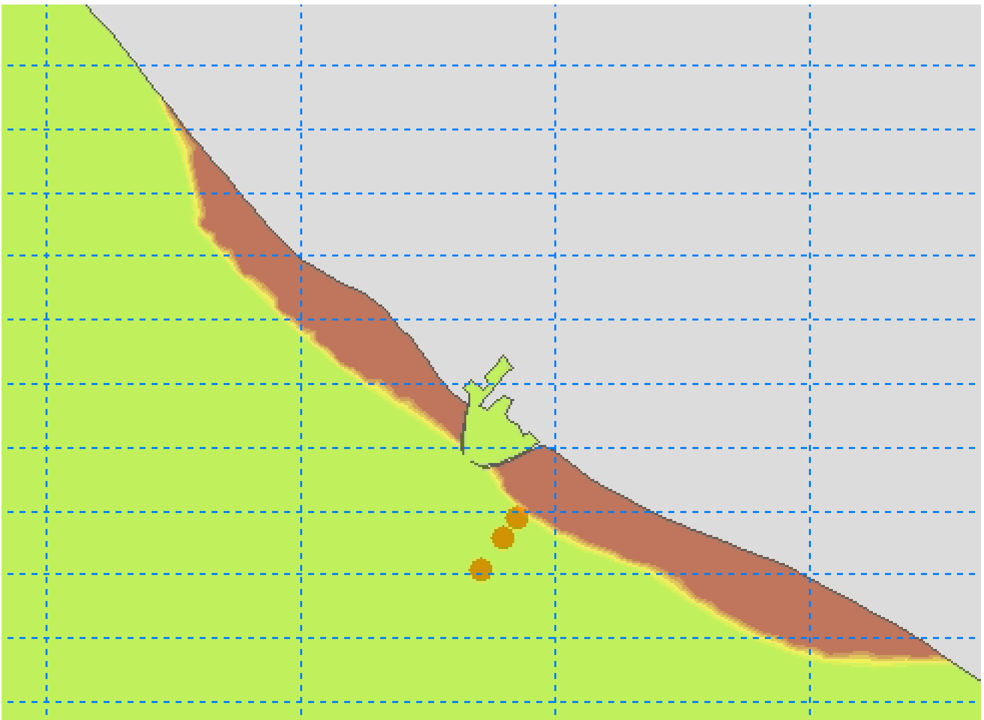

Figure 7-2 The location of the different discharge points included in the model evaluation

Evaluation criteria

The bathing water quality is evaluated against the bathing water directive (EU 2006). The bathing water criteria used are for good quality (see Table 7-1): concentrations above 500 *E. coli* per 100 ml and 200 enterococci per 100 ml, respectively, mean that the bathing water quality is not satisfying. These criteria have to be met for minimum 95% of the bathing season.

7.1.2 Impact of discharges

The results are split into the three different kinds of sources: treated water from the wastewater plant, the *by-pass* and the additional temporary wastewater load from the construction camps. Finally, the sum of the different sources is also evaluated.

The evaluation is carried out at three beach positions, see Figure 7-3, corresponding to the beach at Holeby/Hyldtofte Østersøbad, a point just outside the Pocket Beach Lagoon, and finally a point at the NW end of the new landfill close to West Beach, see Figure 3-1 and Figure 7-3. Furthermore, one point inside the harbour is included (the results for this position are presented and discussed in Chapter 8). Model results have been extracted at 0.5 m depth.

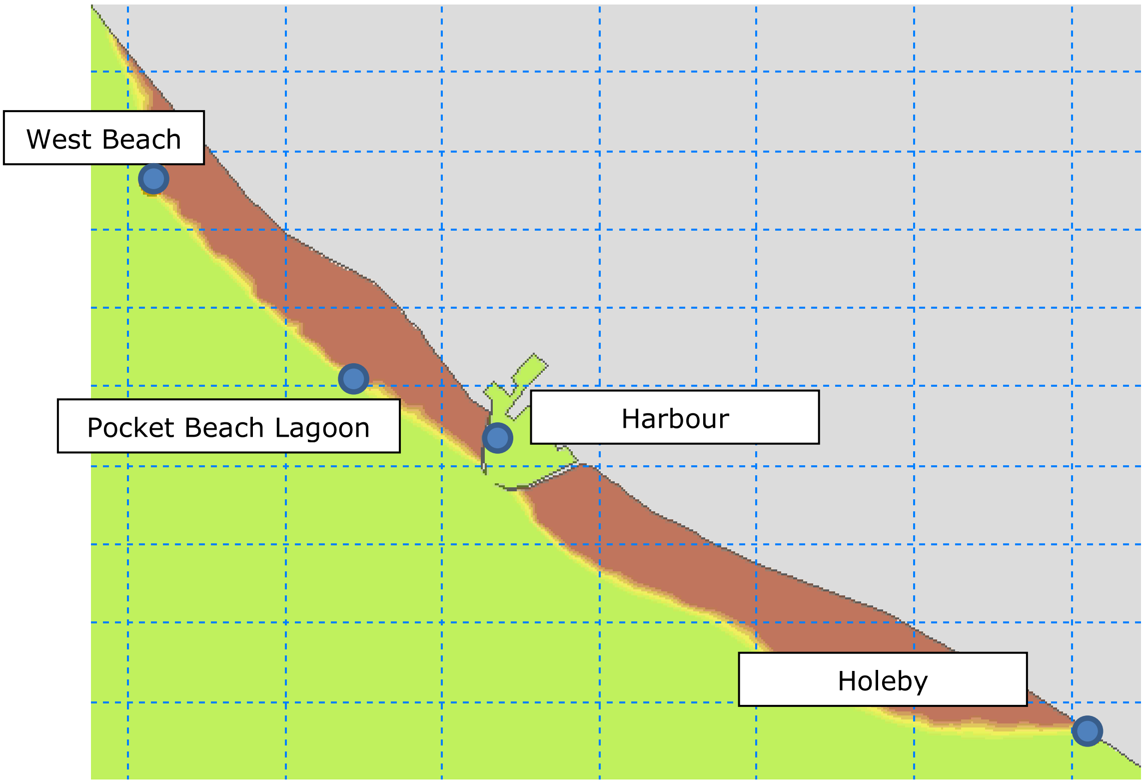

Figure 7-3 *Location of the four points used for evaluating the bathing water quality at the beaches Holeby Østersøbad, Pocket Beach Lagoon and West Beach, as well as in the harbour*

Impact of treated wastewater during operation phase

In Figure 7-4 the model results from the future wastewater treatment plant load are shown (i.e. in the operation phase with general population increase but without the additional wastewater from the construction phase workforce). The results originate from the outlet point at the new coastline. As can be seen from Figure 7-4, elevated concentrations of *E.coli* and enterococci are modelled, and especially Holeby Østersøbad has one incidence when the modelled concentrations are high compared to the rest of the period. However, all concentrations are well below the criteria for 'Good Quality' even for this coastal position of the discharge.

Impact of by-pass

Usually the major problem with bathing water quality is not the regular discharge of treated wastewater but the infrequent combined overflow of untreated wastewater and rain water as the highest concentrations are associated with *by-pass*. Both flows and concentrations are larger compared to the treated water flows and concentrations.

During the 10 *by-pass* events included in this study, one event results in modelled concentrations above the quality criteria for 'Good Quality' with respect to both *E. coli* and enterococci and only at the position outside the Pocket Beach Lagoon. The exceedance occurs both when the outlet is located at the new coastline and 200 m from the coast. As can be seen from Figure 7-6, no real differences are modelled discharging 200 m from the coast compared to at the coast.

Assuming the outlet position 200 m from the new coastline, the same event will lead to exceedance of the enterococci threshold at the West Beach. The *E. coli* concentration is also high but not exceeding the threshold.

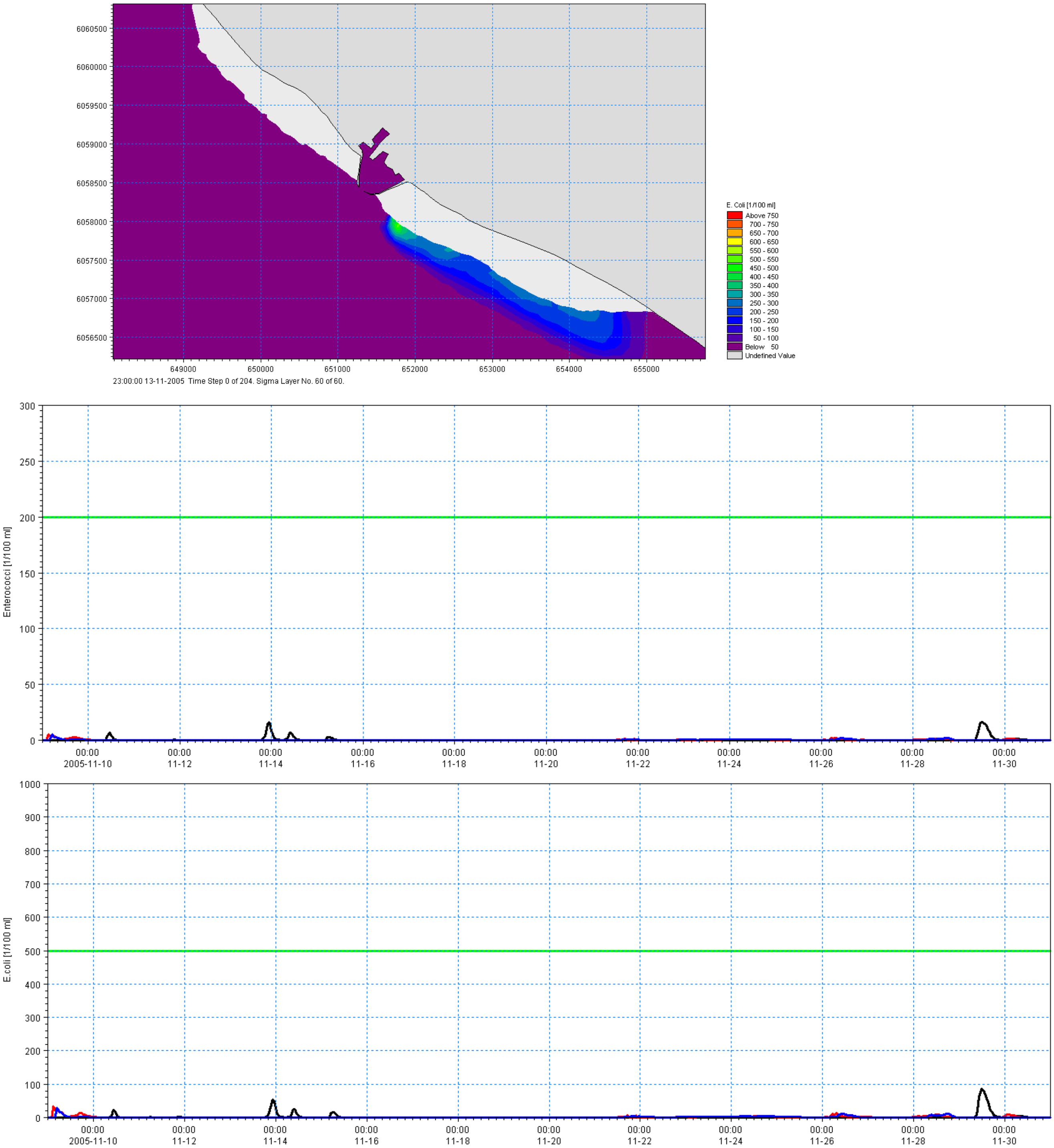

Figure 7-4 *Top figure is an example from the 13 November 2005 23:00 on modelled concentrations of indicator bacteria* for the regular operation (without by-pass) in the situation with 9500 PE and an outlet at the coastline (Scenario 1). *Middle and bottom figures are modelled* E. coli *(middle figure) and enterococci (bottom figure) concentrations resulting from the wastewater treatment plant during the 21 days discharging at the coast. Black line is the concentrations at Holeby Østersøbad, red line is at the Pocket Beach Lagoon and the blue line is at West Beach. Green lines are the criteria for 'Good Quality'*

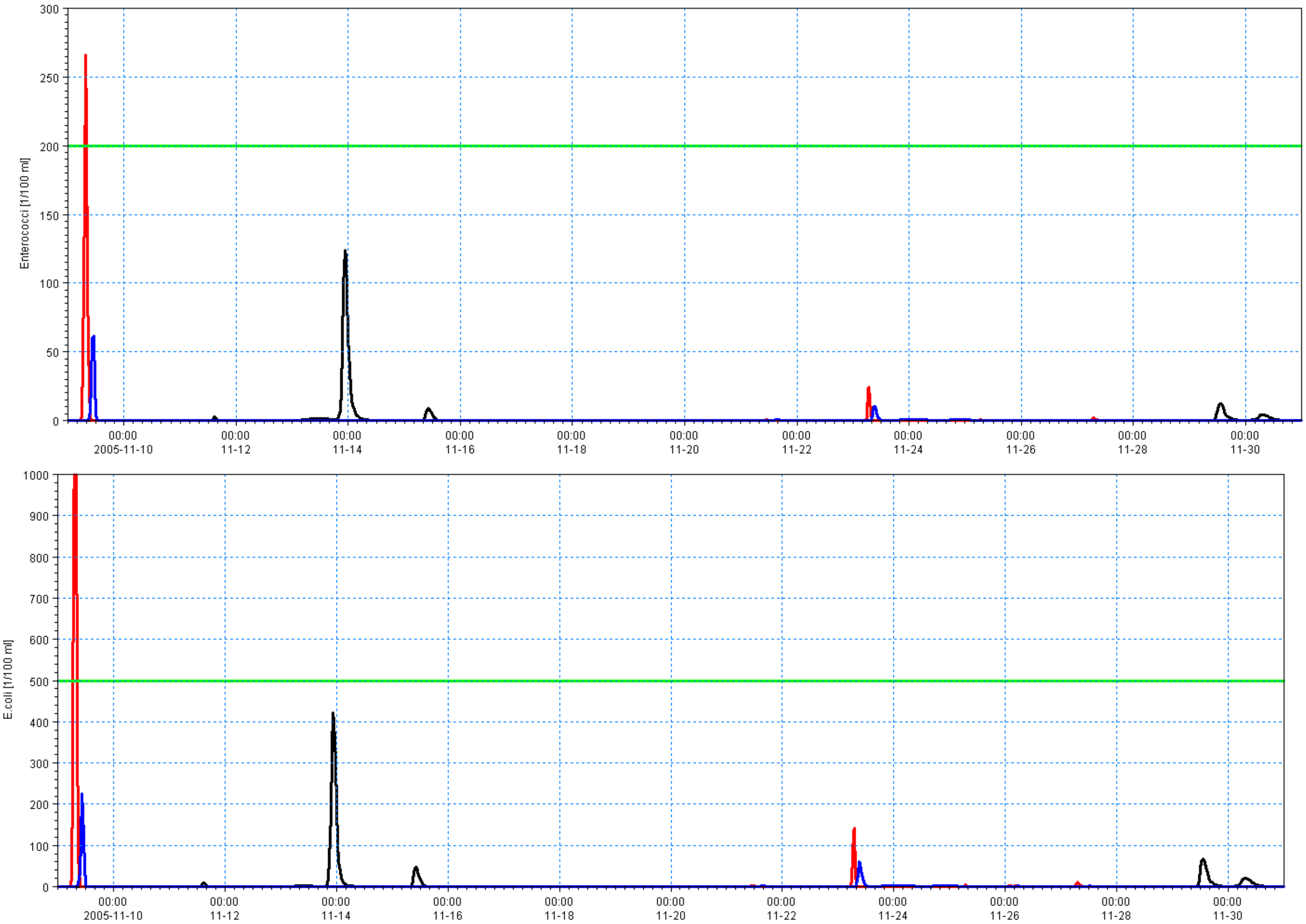

Figure 7-5 *Modelled* E.coli *(top figure) and enterococci (bottom figure) concentrations resulting from* by-pass *during the 21 days discharging close to the coast (Scenario 1). Black line is the concentrations at Holeby Østersøbad, red line is at the Pocket Beach Lagoon and the blue line is at West Beach. Green lines are the criteria for 'Good Quality'*

Only when discharging 500 m from the coast all modelled concentrations are below – or very close to – the criteria for 'Good Quality' in all cases.

At Holeby/Hyldtofte Østersøbad more events lead to elevated bactial concentration but concentrations do not exceed the threshold values irrespective of the position of the outlet. During one event the concentrations are close to critical levels for outlet positions at the new coastline and 200 m off the coast.

The difference between occurrence of elevated concentrations at the beaches west and east of the discharge point is due to different prevalent current directions.

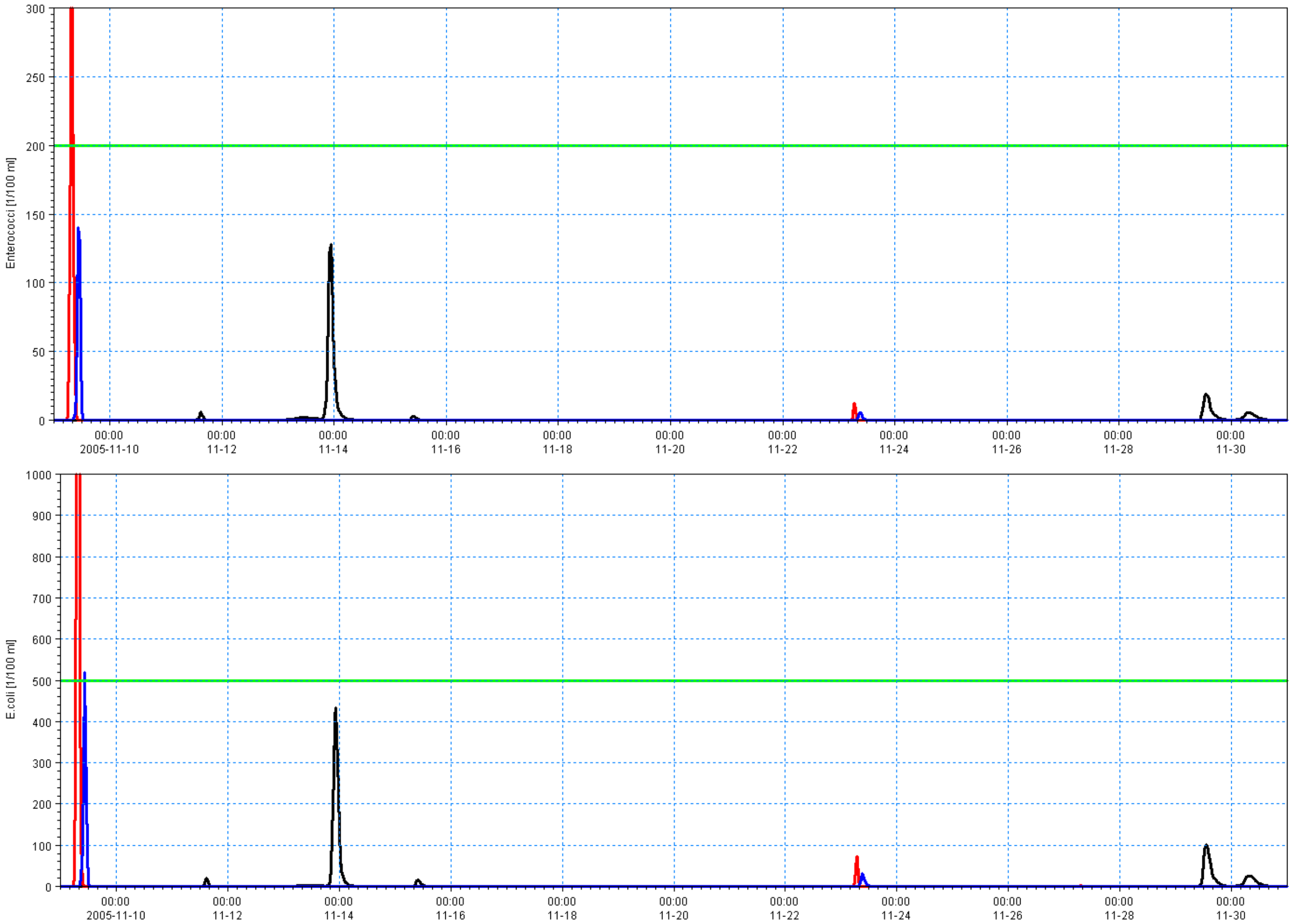

Figure 7-6 *Modelled* E.coli *(top figure) and enterococci (bottom figure) concentrations resulting from* by-pass *during the 21 days discharging 200 m from the coast (Scenario 2). Black line is the concentrations at Holeby Østersøbad, red line is at the Pocket Beach Lagoon and the blue line is at West Beach. Green lines are the criteria for 'Good Quality'*

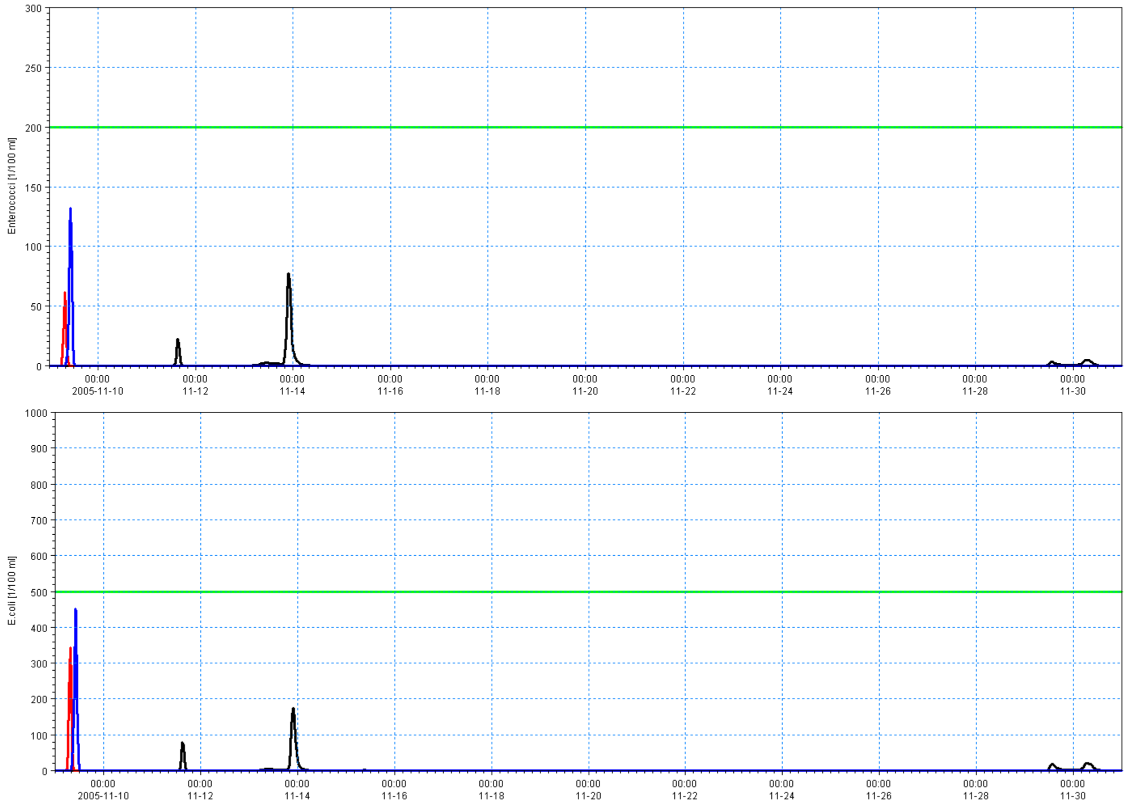

Figure 7-7 *Modelled* E.coli *(top figure) and enterococci (bottom figure) concentrations resulting from* by-pass *during the 21 days discharging 500 m from the coast (Scenario 3). Black line is the concentrations at Holeby Østersøbad, red line is at the Pocket Beach Lagoon and the blue line is at West Beach. Green line is the criteria for 'Good Quality'*

The effect of the *by-pass* water outside the Pocket Beach Lagoon and at the other beaches is also illustrated in Figure 7-8. A by-pass on the 23 November 2005 increases the bacterial concentrations near the outlet point. Hereafter the bacteria bloom moves westwards and in this situation impacts the conditions in the harbour as well as the concentrations outside the Pocket Beach Lagoon before it continues to the West Beach.

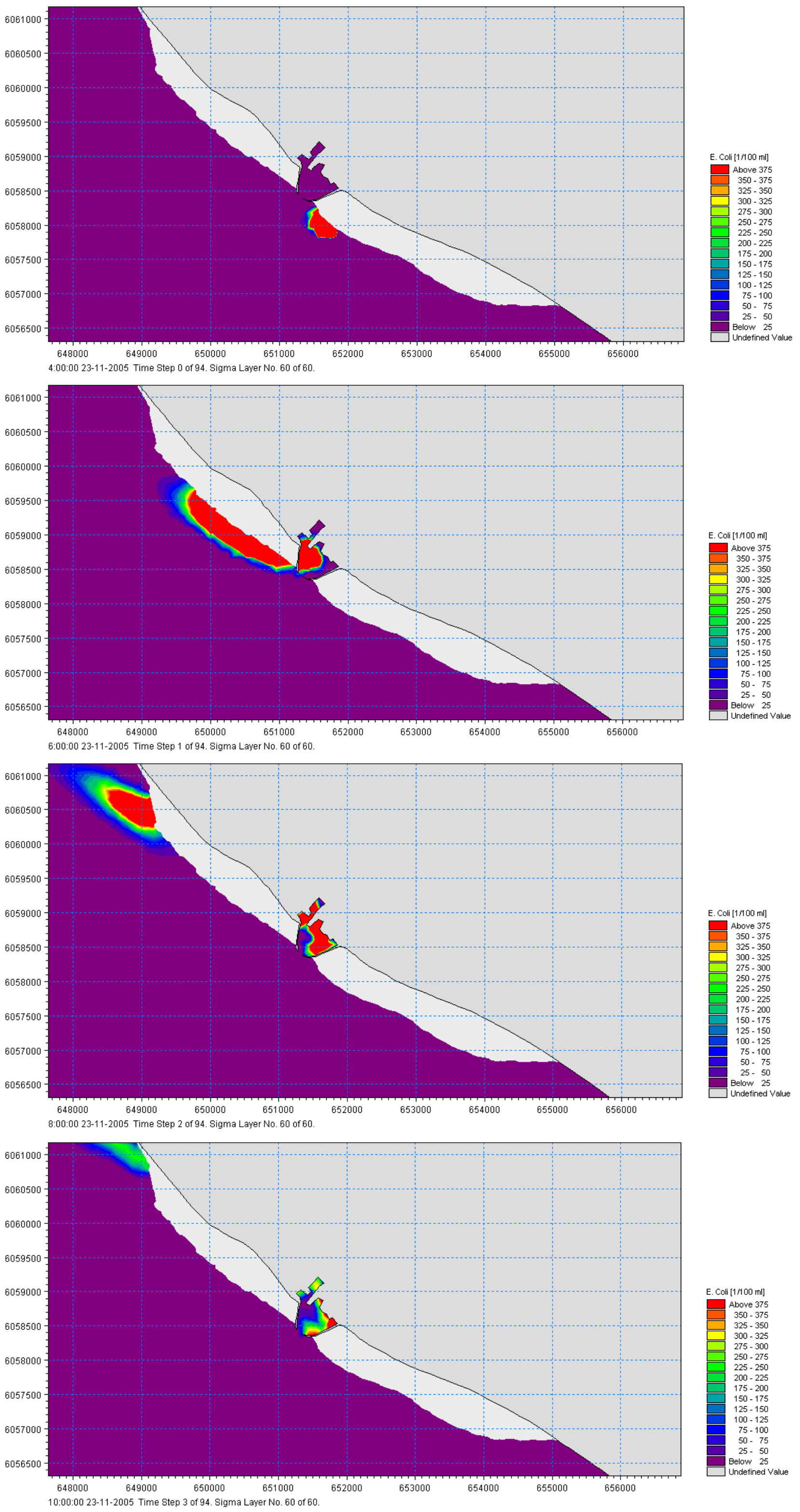

Figure 7-8 *Modelled* E.coli *concentrations after a* by-pass under conditions dominated by west-going current. *The situations origin from the 23 November 2005, and between the four images the time step is 2 hours. Note that the highest range is >375 counts per 100 ml, i.e. it does not indicate exceedance of the quality criteria*

Impact of wastewater from the project during the construction phase

The distribution of concentrations when evaluating the additional 4,400 PE's is very similar to the modelled concentrations of the ordinary treated wastewater with 9500 PE's, see Figure 7-9. Patterns are equal and much lower than the criteria for 'Good Quality'.

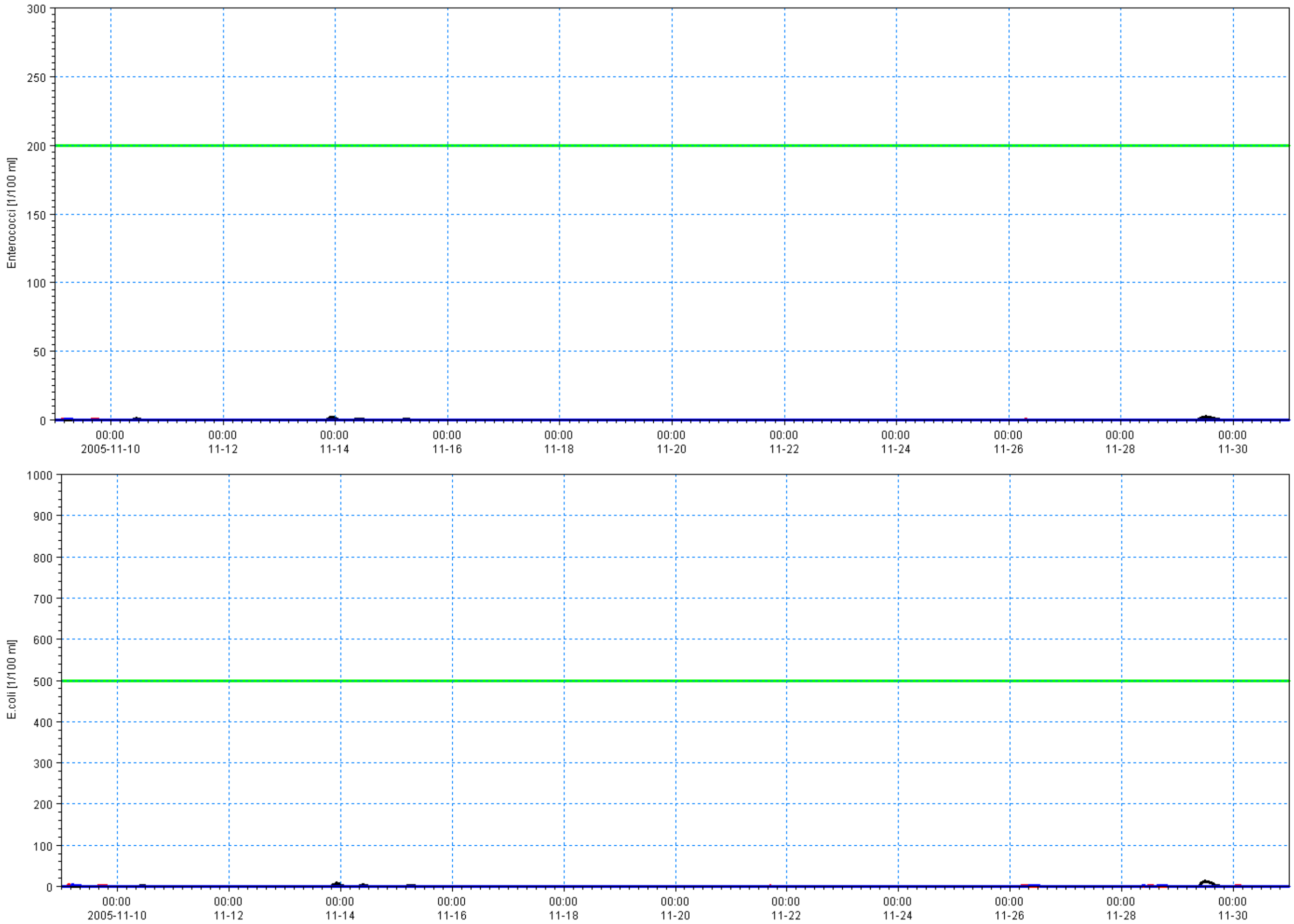

Figure 7-9 Modelled E.coli *(top figure) and enterococci (bottom figure) concentrations resulting from the additional wastewater alone (4400 PE) during the 21 days discharging at the coast. Black line is the concentrations at Holeby Østersøbad, red line is at the Pocket Beach Lagoon and the green line is at West Beach*

Combined impacts during construction and operation phases

The modelled concentrations of the sum of the three different discharges do not change the picture from the single evaluation.

The results of the modelling study indicate that discharge of treated wastewater close to the coast will most likely not affect any of the three beaches: Holeby Østersøbad, The Pocket Beach Lagoon and West Beach. This is the case with the future treated amount of water and also if including additional wastewater due to an increase in PE during the construction of the Fixed Link.

The critical situations arise when the by-pass is added to the regular discharge of treated wastewater. The modelling results show that *by-pass* events of stormwater could have a negative impact in some situations on the water quality in the Pocket

Beach Lagoon for the coastal discharge and that there is a risk of situations with critical concentrations at the West Beach and Holeby/Hyldtofte Østersøbad.

The concentrations are not modelled inside the Pocket Beach Lagoon but if concentrations are elevated just outside the lagoon opening it is likely that the concentration just inside could be similarly affected.

Furthermore, the water quality inside the harbour is impacted due to *by-pass* discharges at the coastal position. It has been shown that any concentration of pollutants inside the harbour basin will quickly spread into the Inner Lagoon. Consequently, in can be concluded that situations with violations of the bathing water criteria in the harbour basin will also apply to the Inner Lagoon.

If the design criteria are that the bathing quality should be respected in all conditions, the discharge position should be further out than 200m off the new coastline, probably nearly 500m off the new coastline.

7.2 Nutrient discharges

Measurements in the outflow from Rødbyhavn treatment plant in 2011 show concentrations of total nitrogen and phosphorus at 5.6 mg N/l and 0.4 mg P/l, compared to the present permit concentrations of 8 mg N/l and 1.5 mg P/l (see Table 7-3). Estimates using the measured concentration give a present yearly load of 11 tons N/year and 0.8 tons P/year. During the construction this load will temporarily increase to 15 tons N/year and 1 tons P/year.

The net surface westward flow from the western Baltic Sea through the Fehmarnbelt is around 850 km^3 per year and with average concentrations of nitrogen and phosphorus of 250 mg N/m^3 and 35 mg P/m^3 there is a background surface transport of more than 200,000 tons of nitrogen and about 30,000 tons of phosphorus. In comparison, the contribution and effects of nutrient discharge from the Rødbyhavn treatment plant at present and during construction and operational phase are insignificant.

Table 7-3 Rødbyhavn treatment plant discharge concentrations in 2011 and permit thresholds

	Unit	Discharge concentrations	Permit threshold
BOD	mg/l	2.5	15
COD	mg/l	33	75
SS	mg/l	4	25
Total N	mg/l	5.6	8
Total P	mg/l	0.4	1.5

7.3 Discharge of toxic substances

The wastewater may also contain toxic substances. However, according to the note from Krüger presently very few industries are connected to the treatment plant. Previously, pollution with toxic substances was not an issue considered in the discharge permission. According to Femern's project description (the one delivered to L2 spring 2012) it is not foreseen that the project will cause discharge of toxic substances.

8 RISK OF HARBOUR WATER POLLUTING THE INNER LAGOON

8.1 Spreading of water from Rødbyhavn into the Inner Lagoon

The purpose of this exercise is to determine to which extent a source of polluted water in Rødbyhavn harbour will penetrate into the Inner Lagoon. A source has been located in the western part of the ferry harbour basin, and spreading of the substance from this source into the inner harbour basin and further into the Inner Lagoon has been simulated for the three periods, and average concentrations in the two points C and C0 have been computed for the three periods. The locations of the source and of the points where the concentrations are extracted are shown in Figure 8-1.

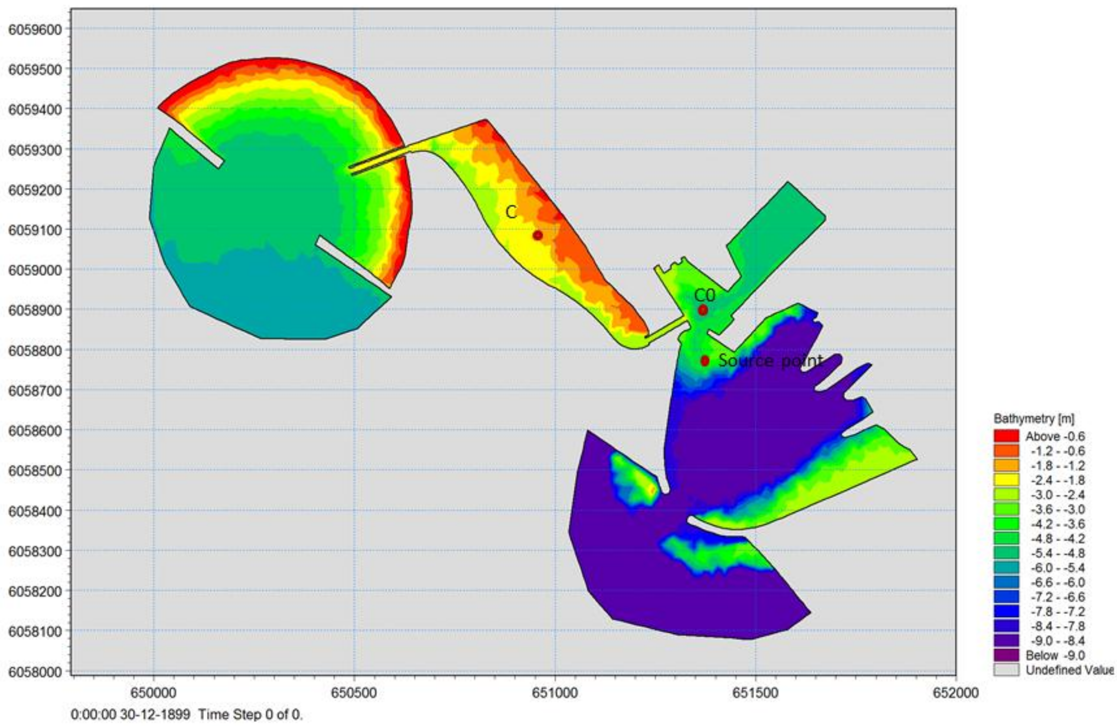

Figure 8-1 Location of the two points where concentration have been extracted and where the source is located

The ratio between the average concentration at point C and the average concentration at point C0 has hereafter been calculated as a measure of the spreading of the pollution into the inner harbour basin relative to the spreading of the pollution in the Inner Lagoon. The results are presented in Table 8-1.

Table 8-1 Ratio between mean concentrations in the Inner Lagoon and in the basin of Rødbyhavn next to the entrance to the Inner Lagoon

Period	$\frac{\bar{c}}{\bar{c}_0}$
Period 1	0.9
Period 2	1.0
Period 3	0.9

The comparison shows that the water quality of the Inner Lagoon is very dependent on the quality of the water in the harbour basin. This means that any pollution present in the ferry harbour will quickly spread into the Inner Lagoon. The possible pollution of the harbour basins is further discussed in the following sections.

8.2 Harbour concentrations of hygienic pollutants

The bathing water quality has also been evaluated inside the harbour. As can be seen in Figure 8-1 the Inner Lagoon is connected to the harbour and to the Pocket Beach Lagoon. This connection will help exchange water inside the Inner Lagoon; the exchange is partly originating from the Pocket Beach Lagoon and partly from the harbour. Based on the dominance of exchange with the harbour, the risk of spreading of faecal bacteria through the harbour to the Inner Lagoon has been assessed. With regard to the position of the outlet, an extra position 100 m off the coast is included in this part of the study.

E.coli concentrations inside the harbour for the normal flow conditions and after *by-pass* are presented in Figure 8-2. Similar to the previous results, the treated wastewater does not create conflicts with the bathing water criteria. Similarly the additional wastewater due to the project will not add any problems (data not shown). Only *by-pass* situations lead to exceedance of the bathing water criteria. The events causing the exceedance do only partly coincide with the ones having impacts on the beaches (results shown in Figure 7-5 and Figure 7-6) and all positions except 500 m off the coast result in events with short exceedance of the bathing water criteria.

In periods with east-going currents in the Inner Lagoon, it may be impacted by bacterial pollutions from the Pocket Beach Lagoon. As shown in Chapter 7 the frequency of events with exceedance is predicted to be low. Thus pollutions from the harbour are the most critical.

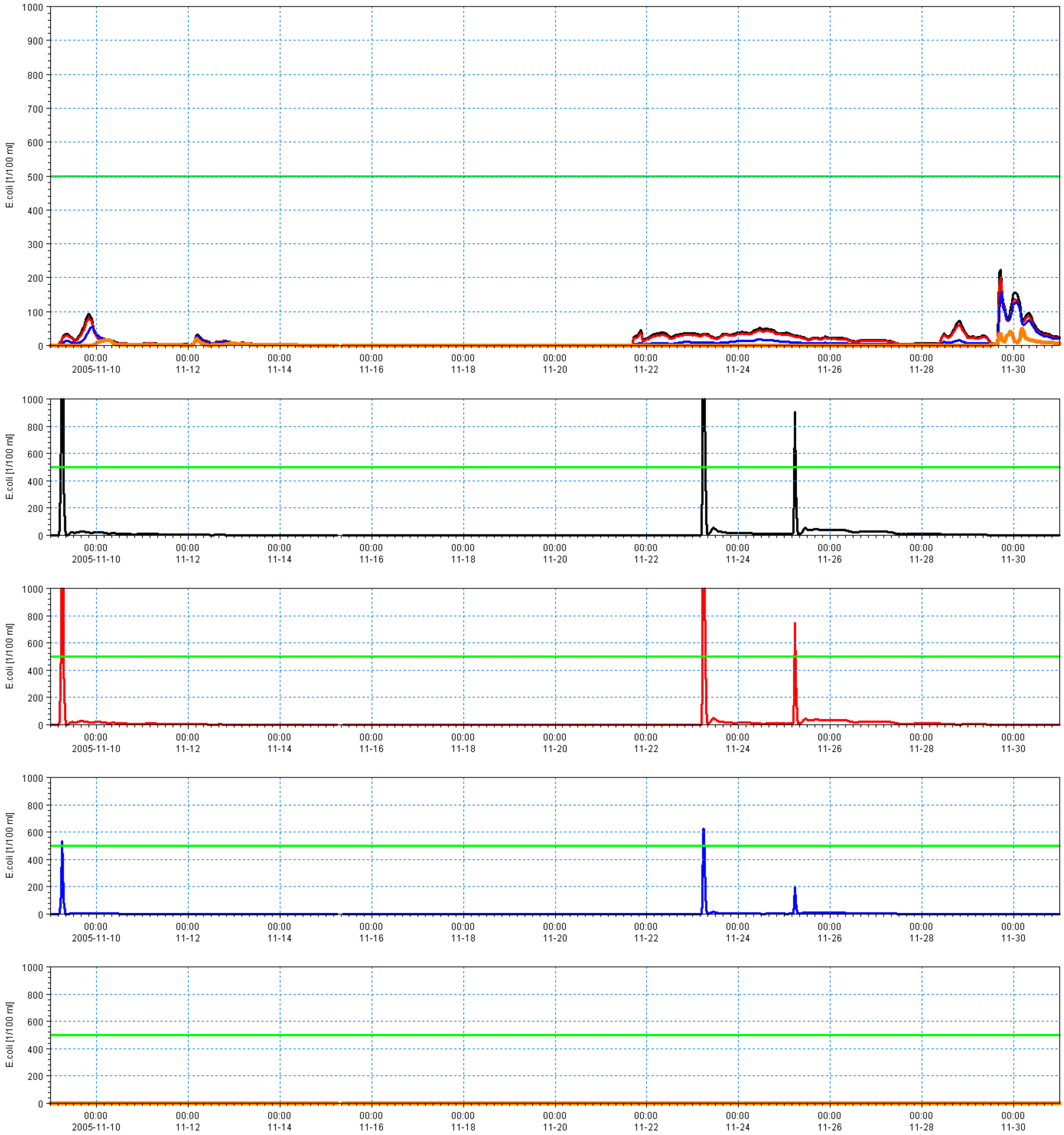

Figure 8-2 *Top figure shows modelled E.coli concentrations inside the harbour resulting from treated wastewater discharged at a point at the coast (black line), 100 m from the coast (red line), 200 m from the coast (blue line) and 500 m from the coast (orange line). Bottom figures show modelled E.coli concentrations inside the harbour resulting from by-pass discharged at a point at the coast (black line), 100 m from the coast (red line), 200 m from the coast (blue line) and 500 m from the coast (orange line). Green lines are the criteria for 'Good Quality'*

8.3 Harbour concentrations of toxic pollutants

If toxic pollutants are present in the harbour water, they may pose a risk to the water quality of the Inner Lagoon. As shown earlier the flushing (T_{50}) of the Inner Lagoon is 0.5-1.3 days with a mean at 0.9 days. Furthermore, the connection to the western harbour basin implies that the quality of water entering the lagoons will to a large extent be identical with the water quality in the harbour basin.

Pollution of the harbour water could occur if the harbour sediment contains critical concentrations of pollutants and if such pollutants are released to the above-laying water either by diffusion or during resuspension of the sediment; e.g. during manoeuvring of the ferries and other large vessels.

Measurements made in connection with the permit to deepen the harbour basin (data from 2010 and 2011, NST (2012)) show that sediments in the western harbour basin are contaminated with TBT; locally with concentrations exceeding the upper action level (200 µg Sn/kg dry weight) set by the Danish Environmental Authorities for regulating dredging and disposal options for marine sediment (BLST 2008).

Concentrations of other analysed contaminants (heavy metals) did not exceed the lower action level, and they are therefor not considered to constitute a problem.

Dissolved TBT is very toxic to aquatic organisms and besides, TBT also shows hormonal effect in various molluscs, in which male characteristics are imposed on females (imposex). For that reason the use of TBT on large commercial vessels have been banned in EU since 2008 and on recreational boats since 2003, but due to the large pool of organotins in the sediments, the compounds are still present in comparable high concentrations in the marine environment (Strand et al. 2006, Dahl et al. 2007). At present, the most important source of TBT in the aquatic environments are polluted sediments in harbours and shipping lanes.

There are conflicting information on mobility and bioavailability of sediment-associated TBT to invertebrates and fish in the scientific literature, probably due to differences in environmental conditions such as pH and salinity in the different studies (Rüdel 2003, Hamer & Karius 2005, Pynaert & Speleers 2006). However, accumulation of TBT in bivalves such as mussels at sites with high sediment concentrations has been documented in several studies (Kim et al. 2008, Devier et al 2005, Guéguen et al. 2011). Therefore, to clarify the situation blue mussels were sampled in spring 2013 from quay walls in the different harbour basins and analysed for TBT, its degradation products (dibutyltin - DBT, monobutyltin - MBT) and triphenyltin (TPhT) (see Figure 8-3) in order to document levels in the Rødby Harbour. For reference, two comparable samples (in terms of shell length and numbers) of mussel collected in 2011 in the Fehmarnbelt at 9 m depths were also analysed for TBT's.

The concentrations of organotins (TBT, DBT, MBT and TPhT) were highest at station RH-1 with decreasing concentration along the gradient out of the recreational harbour (RH-1, RH-2 and RH-4). In the fishery harbour the concentrations were highest at RH-5 (Figure 8-4).

At station RH-1 the concentration of TBT was 187.4 µg Sn/kg DW and approximately 13 times higher than at the reference stations (RH-6 and RH-7) in Fehmarnbelt, where the average concentration of TBT was 14.5 µg Sn/kg DW. TPhT was only measurable at station RH-1.

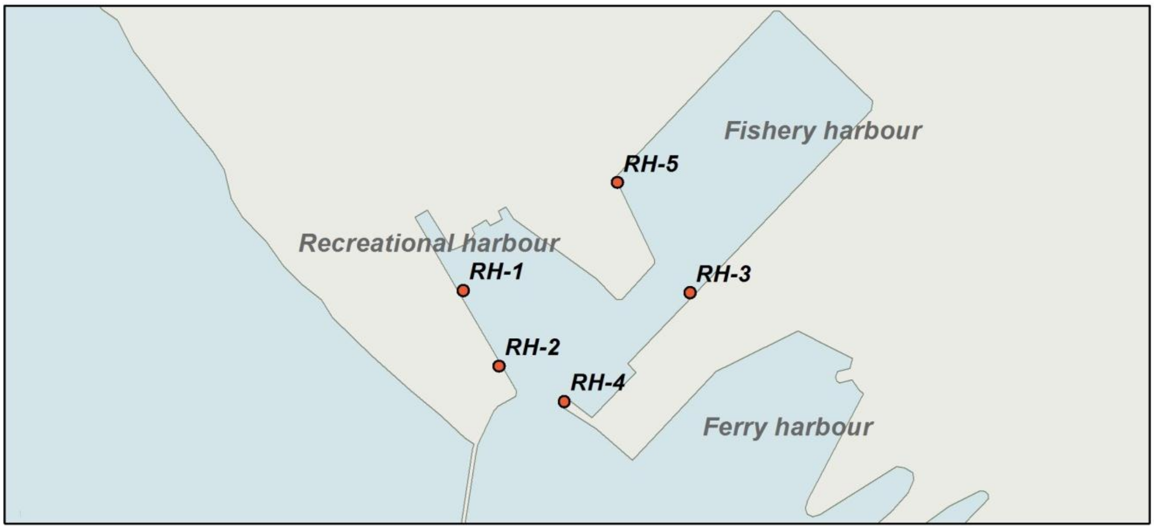

Figure 8-3 Positions in Rødby Harbour where mussels were sampled in spring 2013. The Recreational harbour is a synonym for the "western harbour".

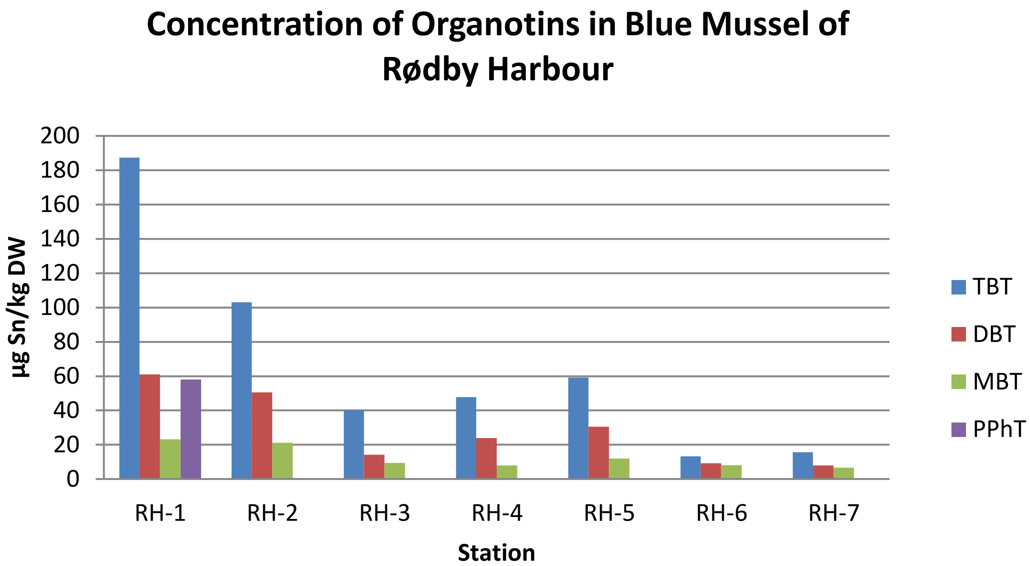

Figure 8-4 Concentration of organotins in blue mussels from Rødby Harbour (RH-1 to RH-5) and in Fehmarnbelt (RH-6 and RH-7).

8.3.1 Risk assessment of TBT in Inner Lagoon

In the future scenario the Inner Lagoon will be connected to the western (recreational) harbour basin through a channel, and there is a potential risk that TBT can be carried from the harbour to the Lagoon by water exchange. To this end, a risk assessment were carried out building on 1) environmental assessment criterium (EAC) developed for TBT in mussels, 2) relation between TBT concentrations in mussels and water (socalled bioconcentration factors – BCF), 3) Environmental Quality Standards (EQS) set by EU for TBT and, 4) estimated flushing rates of the Inner Lagoon (see above).

Environmental assessment criteria

Concentration of toxic compounds such as TBT in biota can assist in risk assessment in particular environments (Strand 2009). The Oslo-Paris Commission has developed a set of environmental assessment criteria (EAC) that represent the contaminant concentration in mussels below which chronic effects are not expected to occur in marine species, including the most sensitive species in the water body (OSPAR 2010). For TBT in mussels the EAC value is 12 µg Sn/kg DW and thus comparable to concentration in mussels collected in the Fehmarnbelt at 14.5 µg Sn/kg DW. All samples from Rødby harbour exceeded the EAC value and especially the samples from the western harbour basin (RH-1, RH-2) exceeded the EAC by a large margin, i.e. concentration of TBT in mussels from this basin is 12 times higher than EAC. The high concentration of organotins in the mussels indicates that the pool of TBT in the harbour sediments becomes available for the mussels either by re-suspension of sediments or by passive release from the sediments to the water column.

Exceedance of EAC for TBT occurs widespread in inner Danish waters, e.g., in the Danish monitoring programme more than 70% of mussel samples collected in 2007 exceeded the EAC (Dahl et al. 2007) and 34% and 95% of the samples collected in 2009 and 2010, respectively exceeded EAC (Gustavson et al. 2012). Still, the two samples from the recreational harbour are among the highest concentrations measured in mussels from Danish waters, including harbours.

TBT assessment in western harbour basin

Direct and reliable measurements of TBT in water is few, because of analytical difficulties at realistic and low environmental concentrations. Instead, TBT contrntrations in mussels can be used as a proxy for water concentrations provided that a simple relation between TBT in mussels and water exists. Such a relation is called a Bio-Concentration-Factor (BCF) for TBT and expressed by the ratio of the concentration of a TBT in an organism to the concentration of the TBT in water. Further, it is assumed that BCF is independent of the concentration (Polikarpov 1960, Kim et al. 2008).

Using data from decadal monitoring of TBT in shellfish production areas, Guéguen et al. (2011) estimated BCF for TBT in mussels at $2.8*10^5$ to $1.3*10^6$. In comparison, Kim et al. (2008) estimated an average BCF value about an order of magnitude lower at $5*10^4$ using transplanted blue mussels in a harbour area. "Low" BCF values in the range $1*10^4$ - $6*10^4$ were published in an earlier study (Salazar & Salazar 1996). Back-calculations from concentration of TBT in mussels from RH-1 and RH-2 in Rødby Harbour indicates that the average (and approximate) concentration of TBT in the water matches the EQS value at 0.0002 µg Sn/l using the BCF Guéguen et al. (2011) data or, TBT in water is 10-20 times higher at 0.003 – 0.004 µg Sn/l, if the BCF's calculated by Kim et al. (2008) and Salazar & Salazar (1996) are used. Because both EAC (= 12 µg Sn/kg DW) and EQS (= 0.0002 µg Sn/l) for TBT are set to protect the aquatic environments, the ratio EAC/EQS (= $6*10^4$ L/kg DW) can be seen as an independent estimate of BCF for TBT. With this in mind, it is most likely that both the Environmental Assessment Criterium, EAC (in mussels) and the Environmental Quality Standard (water concentration) for TBT is exceeded 10-20 times in the recreational harbour which indicate a degraded quality of the local environment (Table 8-2).

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Table 8-2 Assessment concentrations of TBT in the recreational harbour and assessment criteria for TBT in mussels (EAC) and in water (EQS). Assessment criteria from OSPAR (2010) and EC (2008). BCF for TBT in mussels is used to estimate TBT concentrations in recreational harbour. Exceedance denote the number times the TBT concentration in mussels exceed the EAC and the number of times the estimated water concentration exceeds the EQS.

	TBT in Mussels		BCF in mussels	TBT in water	
	Recreational Harbour (RH-1, RH-2)	EAC in mussels		Recreational Harbour (estimated)	EQS
Unit	*µg Sn/kg DW*		*L/kg DW*	*µg/l*	
TBT	145.2	12	$6*10^4$	0.003-0.004	0.0002
Exceedance	12 times			15-20 times	

TBT assessment in Inner Lagoon

At present, the maximum flushing time of Rødby Harbour (T_{50}) can be estimated from the tidal prism (10-20 cm) and the water depth of the harbour (~8.5 m) to T_{50}=12 days, but in reality the flushing time will vary from few days at the outer ferry basin to weeks in the sheltered inner parts of the western and fishery harbours. Hence, a long flushing time in the western harbour is the reason for build up of high TBT concentration in water and in mussels.

After establishing the lagoons the flushing time of the harbour as a whole will be reduced by a factor of 3, and because the western harbour basin directly is in the loop connecting the Inner Lagoon with the Fehmarnbelt, it is evaluated that the flushing time of the western harbour basin will be reduced by at least a 10-factor, i.e. from weeks to days (see Table 5-4). In effect, the dilution of TBT leaching from the enriched sediments in the western harbour will increase accordingly and TBT concentrations in the recreational harbour and in the Inner Lagoon will approach concentrations in Fehmarnbelt.

The evaluation is based on the assumption that TBT leaching from sediments in the recreational harbour remains unchanged after the flushing rate is markedly increased. Increased flushing will improve oxygen conditions in sediments and probably lead to increases in pH which would tend to increase the release of TBT from sediment particles (Pynaert & Speleers 2006). Improved oxygen condition may also via higher rates of bioturbation expose subsurface TBT-rich sediments to water and thereby lead to increase in TBT leachacing. But quantatively, these processes are evaluated to be of minor importance compared to the increased dilution because of increased flushing.

Uncertainty of assessment

There are several issues where lack of knowledge will contribute to uncertainty of assessment. In ranked order of importance they include: 1) local flushing time in the western harbour under present conditions 2) changes in TBT mobilisation rate from sediments as result of changed flushing rate, 3) resuspension of TBT-contaminated sediments in the western harbour and advective transport of contaminated sediments to the Inner Lagoon.

The estimates of local flushing time under present conditions (i.e. "weeks", i.e. centered at 3 weeks) was based on judgement by a DHI expert. It is evaluated that bias in this judgement could contribute to 25% uncertainty in assessment.

There are few, but consistent studies showing that TBT mobilisation from sediments are increased, when pH increases from 6-7 to 8. Based on this information release of TBT from western harbour sediments could increase up to 30%, if the increased flushing will raise pH in sediments to 8.

Advection of TBT-contaminated sediments from the western harbour to the Inner Lagoon will only be possible under high current conditions with strong easterly winds acting on the harbour and lagoon waters and giving rise to resuspension of contaminated sediments. The dominating circulation driven by gradients in the water level between the two openings only gives rise to currents in 1-2 cm/s range and will not contribute to transport od sediments. Without detailed modelling of resuspension potential of western harbour sediments it is impossible to predict the contribution.

9 RISK OF TRAPPING FLOATING 'SEAWEED' ON THE BEACHES

Beaches along the coasts in the Fehmarnbelt, and along beaches in the inner Danish waters in general, are exposed to accumulation of floating and suspended loose 'seaweed'. In this connection the floating/suspended 'seaweed' covers several types of marine benthic flora:

- Rejected or torn off leaves of eelgrass, which float in the surface
- Various types of macroalgae, including the so-called 'fedtemøg', which are mainly carried suspended in the water

The loose types of algae follow the flow of the water whereas the floating eelgrass leaves float in the surface and are therefore also under the impact of the wind and the wind induced surface current.

9.1 Present conditions and general comments

Accumulation of different types of seaweed is presently known in the area, especially on the beach west of Rødbyhavn and in the local bays between the detached breakwaters at Holeby/Hyldtofte Østersøbad (see the description in FEHY 2013b). Accumulation of seaweed on a natural beach is normally not a problem as the seaweed is pushed up on the beach by the waves, where it forms seaweed berms as on the beach west of Rødbyhavn, see Figure 9-1. However, such seaweed berms can relatively easily be mechanically cleaned up if they turn out to be a problem for the recreational use of the beach.

Figure 9-1 Seawed accumulations at the beach west of Rødbyhavn

These seaweed berms dry relatively quickly following the storm event which caused the deposition of the berms. The semi dry seaweed berms do not normally cause severe stink or unpleasant odeur and they are normally washed offshore atlater events with high water level and winds blowing offshore. However, excessive amounts of seaweed accumulation can happen under certain conditions, typically in sheltered corners between coasts and coastal structures, such as in the segmented breakwater at Holeby/Hyldtofte Østersøbad, see Figure 9-2.

The harbour master in Rødbyhavn has reported that seaweed is accumulating in the harbour basins during summer time. The plants are flushed out during late summer-autumn.

Figure 9-2 Massive seaweed accumulation in the segmented breakwater at Holeby/Hyldtofte Østersøbad

Accumulation of algae in sheltered bays with shallow water may start a putrefaction process causing anoxic conditions and unpleasant odour and unaestetic conditions in general. The layout of the Pocket Beach Lagoon and of the Inner Lagoon has consequently been optimised with respect to minimising the risk of trapping floating seaweed; this is discussed further in the following.

9.2 Discussion of future risk of trapping of floating seaweed

Future mechanisms at the West Beach

Floating seaweed is deposited on the beach mainly during conditions with winds from westerly directions combined with eastward current in the Fehmarnbelt. The maximum amounts of torn-off eelgrass leaves occur in the late summer while 'fedtemøg' is more common in early summer. They are transported with the current along the coast and pushed towards the shore by the onshore component of the surface current generated by the wind stress. The amount of seaweed accumulated on the West Beach will be similar to the existing beaches west of Rødbyhavn.

Future mechanisms at the Pocket Beach Lagoon

To a certain extent floating seaweed will be transported into the Pocket Beach Lagoon where some of it will accumulate on the new beach. The opening to the Pocket Beach Lagoon is restricted by the width of the opening between the controlling breakwaters, which is 300 m. The length of the circular pocket beach is about 950m. The amount of seaweed carried into the lagoon is proportional with the width of the opening. It is very difficult to quantify how big amounts of seaweed will be carried into the lagoons. We can define the amount of 1 unit/m. The amount of seaweed carried into the lagoon is thus 1 unit/m x 300 m = 300 units. This number of units is hereafter distributed along the 950 m long circular beach amounting to 0.3 unit/m. This means that the relative density of seaweed accumulated on the circular beach is about 30% of the density of seaweed on the existing beach.

This assessment is made under the following assumptions:

- The flow through the lagoon system does not influence the amount of seaweed carried into the lagoon. This is a fair assumption taking into consideration that the flow at the entrance to the lagoon is dominated by the flow in the open water off the reclamation rather than the comparable weak flow in and out of the lagoon
- The transport will mainly take place from east towards west following the dominant current direction
- Some of the seaweed floating along the coast will already be trapped at the West Beach, which means that less seaweed will be carried to the opening of the Pocket Beach Lagoon

Future transport of seaweed into the Inner Lagoon

A fraction of the seaweed transported into the Pocket Beach Lagoon will be transported further into the Inner Lagoon. However, the amount of seaweed transported into the Inner Lagoon will be very small as the flow velocity into the Inner Lagoon is so small that the flow will not "suck" the floating seaweed into the lagoon. The seaweed transported into the lagoon is rather the seaweed 'hitting' the 20m wide opening from the Pocket Beach Lagoon to the Inner Lagoon.

Some of the seaweed transported into the harbour basin may also be transported further into the Inner Lagoon, but it is evaluated that this will also be a very small amount because most of the seaweed transported into the harbour will be trapped in the corners of the outer basin. Consequently, only very small amounts of seaweed will be transported from the harbour basin into the Inner Lagoon.

Future transport of seaweed into Nature Lagoon

It is evaluated that only minor amounts of floating and suspended seaweed will penetrate into the Nature Lagoon. The reason for this is that the openings to the Nature Lagoon are relatively narrow and that there is only weak inward flow through the openings. The minor amounts of seaweed that will be carried into the

Nature Lagoon will settle on the seabed and along the perimeters of the lagoon where they will contribute to building up a “natural” coastal lagoon environment.

10 ECOLOGICAL STATUS OF THE LAGOONS

The present task covers the following issues:

- Growth conditions for reed in the various lagoons
- Growth conditions for eelgrass in the various lagoons
- Growth conditions for macroalgae in the various lagoons

The growth of reed is considered as a natural and wanted type of vegetation in part of the Inner Lagoon and in the Nature Lagoon whereas it is unwanted in the Pocket Beach Lagoon.

Reed requires the following conditions to grow:

- Protection against wave impact
- Shallow water, e.g. in the form of a gently sloping bank
- Nutrient-rich and soft seabed
- Sufficient nutrients in the water

The growth of eelgrass is considered as a natural and wanted type of vegetation in in the Nature Lagoon and will be acceptable in the Inner Lagoon and the Pocket Beach Lagoon. Though not deemed necessary in the latter two lagoons, it may also here contribute to a diverse natural environment.

Eelgras and other flowering plants require the following conditions to grow:

- Protection against high wave exposure
- Sufficient light availability, i.e. good water quality
- Sandy seabed

The growth of perennial macroalgae will be an attractive element in the Nature Lagoon and will be acceptable in the Inner Lagoon and the Pocket Beach Lagoon. Though not deemed necessary in the latter two lagoons, it may also here contribute to a diverse natural environment.

Macroalgae require the following conditions to grow:

- Sufficient light availability, i.e. good water quality
- Solid substrates such as stones and boulders

10.1 The Pocket Beach Lagoon

The conditions in the Inner Lagoon can be described as follows:

- Relatively open for wave penetration but exposure will be less than on the open Fehmarnbelt coast
- Fines will not sediment along the perimeter but with time an accumulation will probably occur in the central part of the lagoon
- The flushing will be relatively high ensuring short residence time and brackish conditions as in Fehmarnbelt
- The nutrient level in the water will be as in the Fehmarnbelt

The wave exposure in the lagoon and low accumulation of fines along the perimeter will prevent the development of reeds along the bank.

Conditions are less exposed in the lagoon than along the Fehmarnbelt coast and this together with a sandy seabed and flushing rates indicate sufficient water quality and light conditions at the seabed to facilitate growth of eelgrass and other flowering plants. In general, it is however difficult to predict colonisation of eelgrass. Years of nutrient reduction has not yet resulted in the expected re-establishment of eelgras populations. We lack a detailed understanding of the importance and interaction of multiple factors such as nutrients, sediments, climate effects (temperature rise) as well as physical and ecological factors. If stones are left on the seabed they may be colonised by macroalgae and epifauna such as gastropods. Soft clams, cockles and various polychaetes including the lugworm are likely to dominate the infauna community. Seabed vegetation will contribute to the accumulation of seaweed on the beach but is not expected to be a nuisance to the visitors (see Chapter 9).

Based on the close connection to Fehmarnbelt and the high flushing time, the nutrient levels will largely be determined by the conditions in the Fehmarnbelt. The frequency of major blooms in Fehmarnbelt is however limited but during periods of plankton blooms in Fehmarnbelt planktonalgae will probably also be transported into the Pocket Beach Lagoon. The risk is highest in late summer when the concentration of cyanobacteria increases throughout the Westernwestern Baltic.

10.2 The Inner Lagoon

The conditions in the Inner Lagoon can be described as follows:

- Protected against wave impact apart from locally generated small wind waves especially at the beach facing SW
- The NE-perimeter, i.e. the present beach, consists of sand and is relatively steep
- The SW-perimeter will be constructed with a gentle slope
- The flushing will be relative high ensuring short residence time and brakish conditions as in Fehmarnbelt
- The nutrient level in the water will be determined by the levels in the Pocket Beach lagune and in the harbour. With time accumulation of fines and development seabed flora and fauna will probably increase the nutrient level
- Suspended sediments will settle on the seabed at an initial rate of about 1 cm/year

The NE perimeter is designed as a paddling beach. The seabed in the lagoon will in general suffer from settling of suspended sediments, but it is evaluated that the paddling beach will be able to keep itself free of sedimentation of suspended sediment out to a water depth of about 30 – 40 cm. This is because the beach is steep, consists of clean sand, and is exposed to small locally generated waves as well as to paddling activities. Under these conditions it is evaluated that reed will not grow along this perimeter section of the Inner Lagoon.

The SW perimeter will be built with a gentle slope of unsorted reclamation material, which contains a certain fraction of fine materials. The seabed will be exposed to sedimentation of suspended fine materials, which will by large cover the entire bank slope as there will be hardly any wave impact and no paddling activities. These conditions will promote the growth of reed, which will slowly invade the area by natural means.

The western end of the Inner Lagoon will be built with rubble slopes. These slopes will not promote growth of reed.

Based on water depth (about 1.5 to 2 m in a large part of the lagoon), flushing rates and expected seabed conditions (sandy), it is possible that flowering plants eventually colonize the slightly deeper areas. Sedimentation may, however, over time cause accumulation of fines making the seabed unsuitable for flowering plants. Stones on the seabed are expected to be colonised by macroalgae and epifauna such as gastropods. Soft clams, cockles and various polychaetes including the lug-worm are likely to dominate the infauna community.

Based on the flushing time and thus close connection to Fehmarnbelt, although through the Pocket Beach Lagoon and the harbour, the nutrient levels will largely be determined by conditions in the Fehmarnbelt. With time as the flora and fauna of the lagoon develop some natural eutrophication may occur. It is not foreseen that this will impact the recreational value of the lagoon.

During periods of plankton blooms in the Fehmarnbelt planktonalgae will probably also be transported into the Inner Lagoon. The risk is highest in late summer when the concentration of cyanobacteria increases throughout the Western Baltic. The frequency of major blooms in Fehmarnbelt is however limited. Local blooms may occur during calm periods but they will quickly be washed out due to the flushing time of the lagoon.

10.3 The Nature Lagoon

The conditions in the Nature Lagoon can be described as follows:

- Protected against waves as hardly any waves will penetrate through the openings and as practically no locally generated wind waves will be formed in the lagoon
- All the banks in the lagoon will be constructed with gentle slopes
- The flushing will be moderate; in some areas restricted
- The nutrient level and salinity of the water will be as in the Fehmarnbelt, which can be characterised as a low nutrient level. With time accumulation of fines and development of seabed flora and fauna will probably increase the nutrient level
- Suspended sediments will settle on the seabed at a rate of about 0.2 cm/year

All perimeter banks will be built with gentle slopes of unsorted reclamation material, which contains a certain fraction of fine materials. The seabed will be exposed to sedimentation of fine materials, which will cover practically the entire bank slope as there will be hardly any wave impact and no other activities which can prevent the sedimentation. These conditions will promote the growth of reed, which will slowly invade the area. Similar developments are seen in coastal areas in Køge Bay Beach Park.

The purpose of the natural lagoon is to create a natural lagoon, where some parts are open to the public whereas other parts will be designated as protected areas. The seabed in Nature Lagoon will be constructed of mixed material mainly consisting of till. Consequently colonization of eelgrass and other aquatic flowering plants is not likely except in smaller areas with sufficient current and seabed of sand and gravel suitable for the bottom vegetation. With time the nature will probably develop into a wetland with reed and relatively low water exchange.

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