FEHMARNBELT MARINE BIOLOGY
FEHMARNBELT HYDROGRAPHY

Final Report

FEHMARNBELT FIXED LINK
MARINE BIOLOGY SERVICES (FEMA)
HYDROGRAPHIC SERVICES (FEHY)

Lolland reclamation lagoons, flushing and water quality for new layout of the Pocket Beach Lagoon and Canal

E2TR0045

Supplementary Note to:

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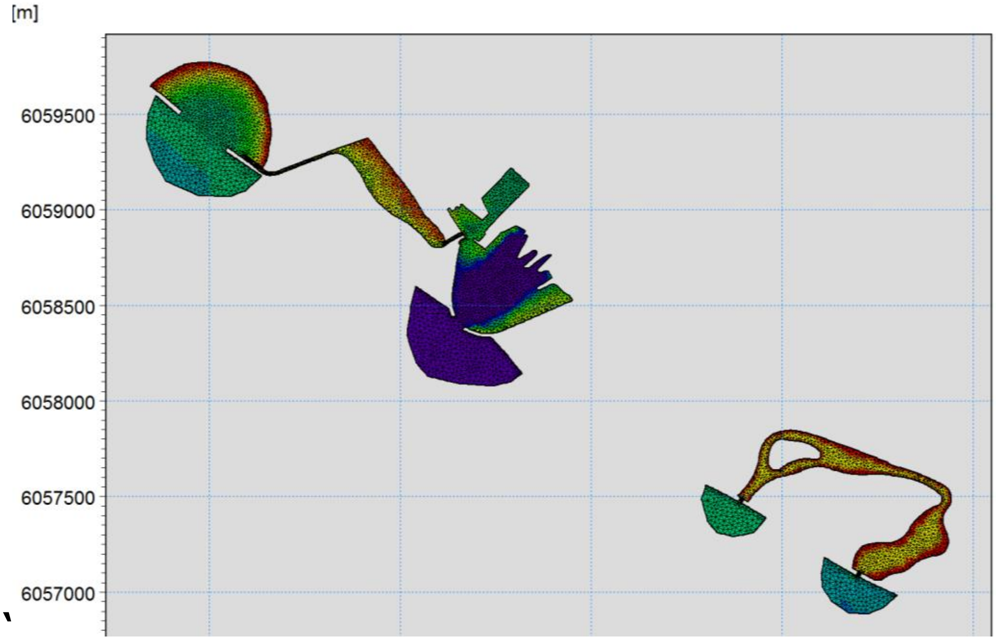

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Lolland reclamation lagoons, flushing and water quality for new layout of the Pocket Beach Lagoon and Canal

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Lists of figures and tables are included as the final pages.

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

Since the original EIA assessment a new design of the Pocket Beach Lagoon has been suggested. The new Pocket Beach Lagoon has been shifted 400 m towards NW along the perimeter of the land reclamation and the canal connecting the Pocket Beach Lagoon with the Inner Lagoon has been extended and the outlet of the canal has been shifted to the SE-ern corner of the Pocket Beach Lagoon.

The purpose of the supplementary report is to document if changes in environmental impacts of the relocated Pocket Beach Lagoon are in compliance with the EIA results.

The assessment of the environmental conditions in the western lagoon system consisting of Rødbyhavn, Inner Lagoon and the new Pocket Beach Lagoon has concluded the following as listed below. However, please note that items where there are changes are presented in *Italic,* items with no changes are repeated with normal text and items related to the Nature Lagoon are not repeated here because there are no changes in this lagoon relative to the conclusions in the FEMA-FEHY (2013) report.

- *The water exchange in the western lagoon system in general will with the new design have an average flushing time (T_{50}) of 1-5 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 flushing water from the harbour canal in 56% of the time. Any contamination levels inside the western recreational harbour basin during these westward flow situations will consequently result in similar concentrations in the Inner Lagoon. In the remaining time, where eastward flow dominates, the Inner Lagoon will generally receive "clean" Fehmarnbelt water through the Pocket Beach Lagoon.

- High TBT concentrations in mussels have 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 and the harbour canal the flushing of the western harbour basin 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.

- 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 between 15,000 and 20,000 m^3/year after 30 years, whereupon 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 accumulated sedimentation of fine suspended sediments over a 50- and 100-year period for the Inner Lagoon has been evaluated. The resulting sedimentation layer thickness after 50 and 100 years is 15 cm and 25 cm, re-*

spectively, for the Inner Lagoon. It is concluded that the computed sedimentation rates are so low that maintenance dredging will not be required the first 50 years for the Inner 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 new Pocket Beach in the Pocket Beach Lagoon between the west end and Rødbyhavn and the Paddling Beach along the the NE perimeter of the Inner Lagoon. The Inner Lagoon is connected to the west to the Pocket Beach Lagoon and to the east to the eastern part of Rødbyhavn harbour (at the recreational harbour basin). 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.

- Neither with the original nor the new design of the western lagoons the relocation of the outfall from 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.

- 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 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.

- Only the West Beach is finalized relatively early in 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 in the present coastal waters.

- 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 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.

None of the above few changes compared to the assessment for the EIA version of the western lagoons are thus found to be of importance to the environmental conditions.

2 INTRODUCTION

The present note is a supplementary note to the report:

FEMA-FEHY (2013). Fehmarnbelt Fixed Link EIA.
Lolland reclamation lagoons, water quality and flushing
Report No. E2TR0030
Report: 61 pages
May 2013

The purpose of the supplementary note is to document the possible changes in environmental impacts of the relocated Pocket Beach Lagoon. The lagoon has been shifted 400 m towards NW along the perimeter of the land reclamation and the canal connecting the Pocket Beach Lagoon with the Inner Lagoon has been extended and the outlet of the canal has been shifted to the SE-ern corner of the Pocket Beach Lagoon. The original layout of the lagoon and the canal as well as the new layout are presented in Figure 2-1.

The methodology use in the present study is in principle a repetition of the previous computations for flushing etc. but with the new layout of the Pocket Beach Lagoon as explained above. For technical reasons it was not possible to exactly repeat the earlier used simulation methodology wherefore a slightly refined simulation methodology has been applied. The new methodology was tested against the original methodology by repeating the flushing simulations for the old layout with the new methodology and comparing the results. These comparisons showed only minor differences and it was concluded that the new simulation methodology was capable of reproducing the previous results satisfactorily.

The present note documents the flushing results for the system consisting of Rødbyhavn Harbour, Inner Lagoon and the new Pocket Beach Lagoon. The simulations did also include the Nature Lagoon but no changes were detected for this, as expected. Consequently, the results for the nature lagoon have generally not been reported in the present supplementary note.

The composition of the present note is in principle identical to the one used in the FEMA-FEHY (2013) report, which means that all the same section headings are included, but where there are no changes this has been noted and the original text has not been repeated.

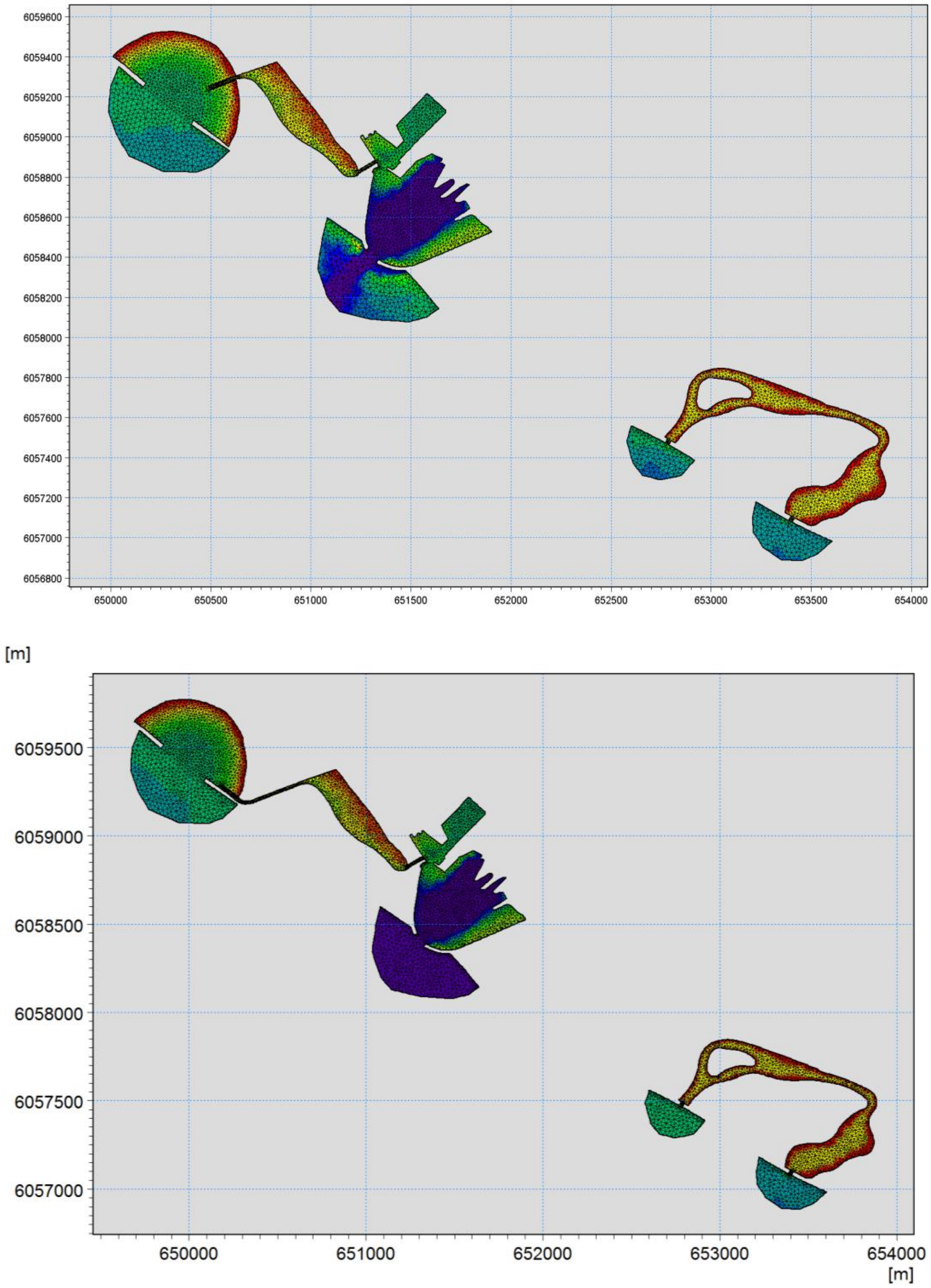

Figure 2-1 Upper: The original layout from the May 2013 report. Lower: The new layout where the Pocket Beach Lagoon has been shifted 400 m towards NW along the reclamation perimeter and where the alignment of the canal linking to the Inner Lagoon has been changed.

3 DESCRIPTION OF THE LAYOUT OF THE LOLLAND LAND RECLAMATION

The only change in this section is the new location of the Pocket Beach Lagoon and the canal connecting the Inner Lagoon with the Pocket Beach Lagoon. The new layout is presented in Figure 3-1.

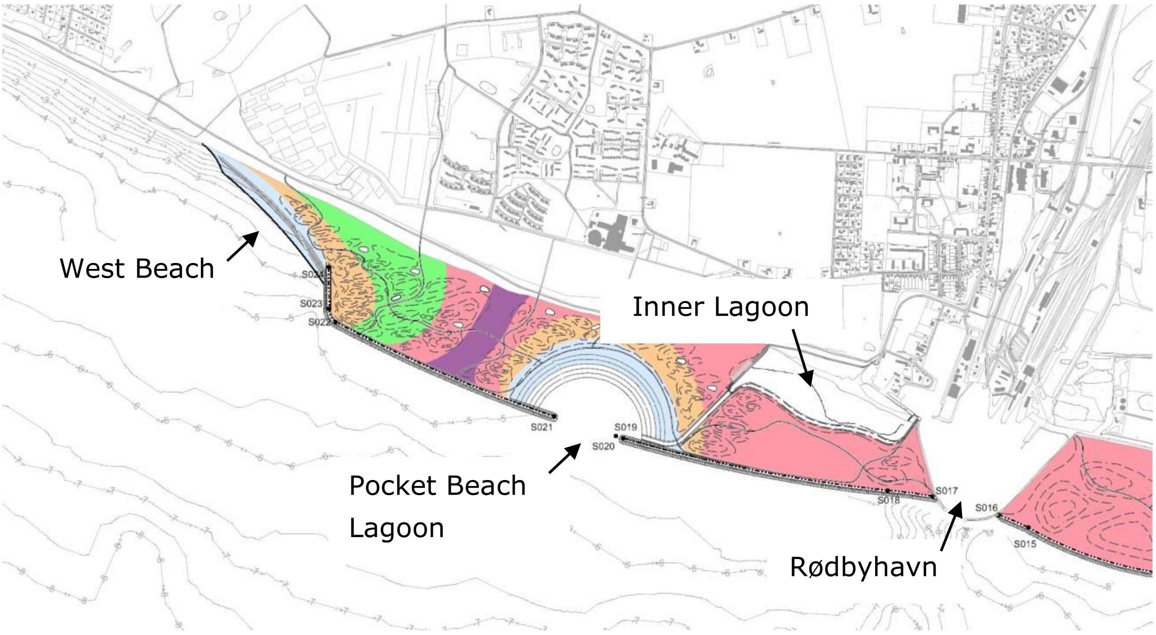

Figure 3-1 New layout of Pocket Beach Lagoon and of canal connection to the Inner Lagoon.

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 layout of the new Pocket Beach Lagoon is identical to the original lagoon, it has just been shifted 400 m towards NW along the perimeter of the reclamation. The depth in the canal between the Pocket Beach Lagoon and the Inner Lagoon has in the numerical simulations been maintained at 2.0 m and the depth in the canal between the Inner Lagoon and the Harbour has been maintained at 2.5 m.

The bathymetry in the new lagoon system in presented in Figure 4-1.

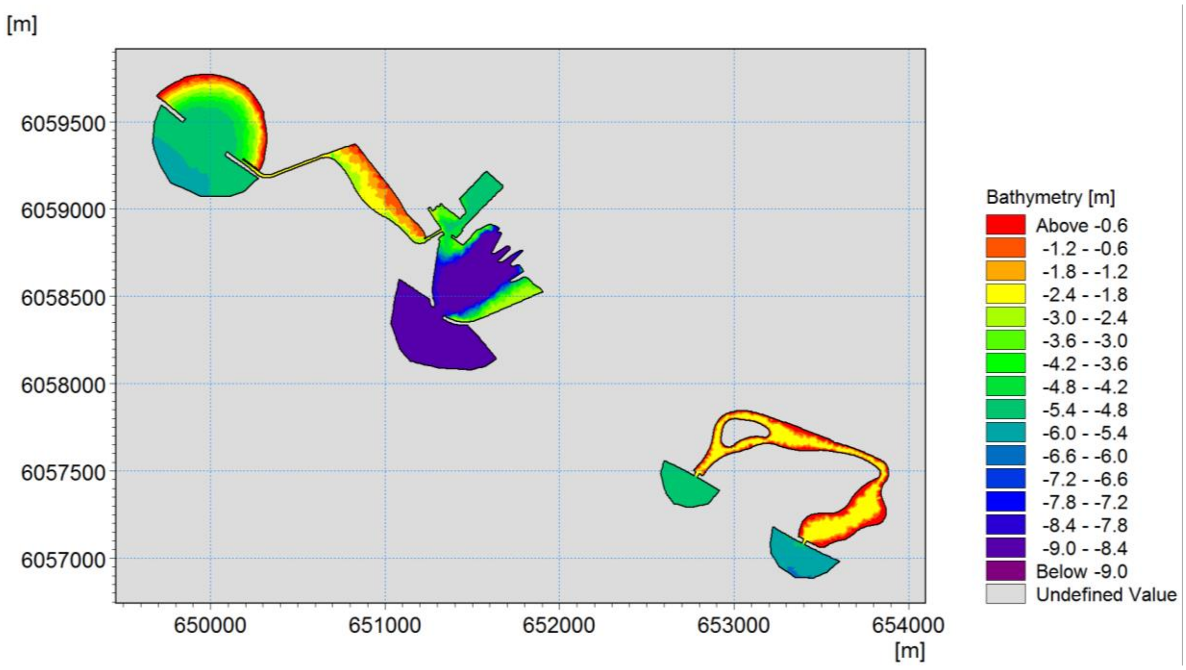

Figure 4-1 Bathymetry of the new Pocket Beach Lagoon and associated canal used in the numerical 2D simulations. There are no changes to the Nature Lagoon.

4.2 Hydrodynamics of the lagoons

No changes relative to the FEMA-FEHY (2013) report.

Currents in the lagoons

Characteristic flow velocities in the new Pocket Beach Lagoon – Inner Lagoon system have been extracted with the purpose of providing an impression of the characteristic flow conditions, see Figure 4-2 and Figure 4-3, 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.

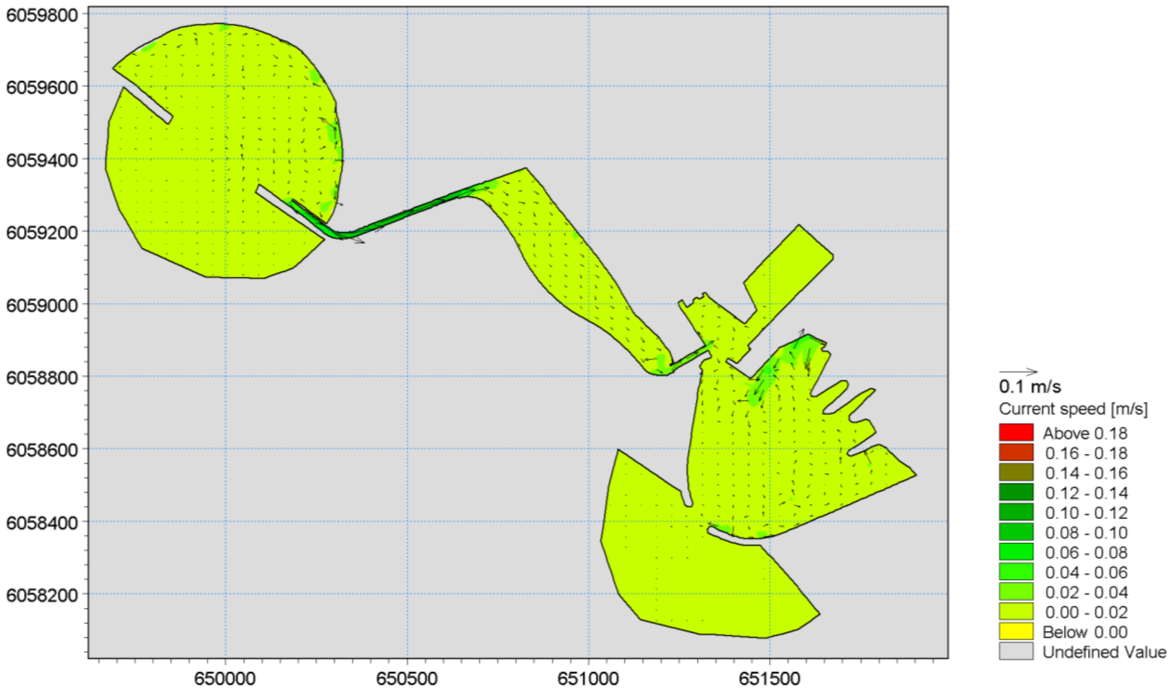

Figure 4-2 Current pattern for the new Pocket Beach Lagoon – Inner Lagoon system for characteristic SE-ward flow situation in Fehmarnbelt

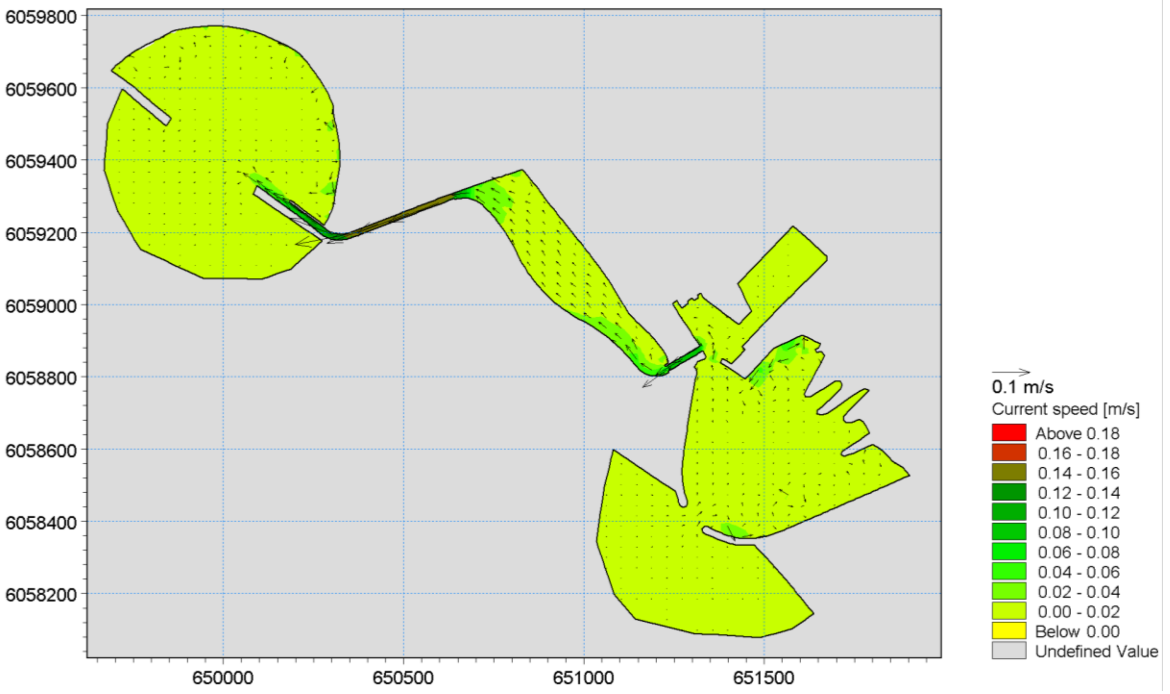

Figure 4-3 Current pattern for the new Pocket Beach Lagoon – Inner Lagoon system for characteristic NW-ward flow situation in Fehmarnbelt

Current speeds have been extracted and analysed in the various canal sections, and currents statistics have been developed, see Figure 4-4. Generally the current speeds in the new 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.

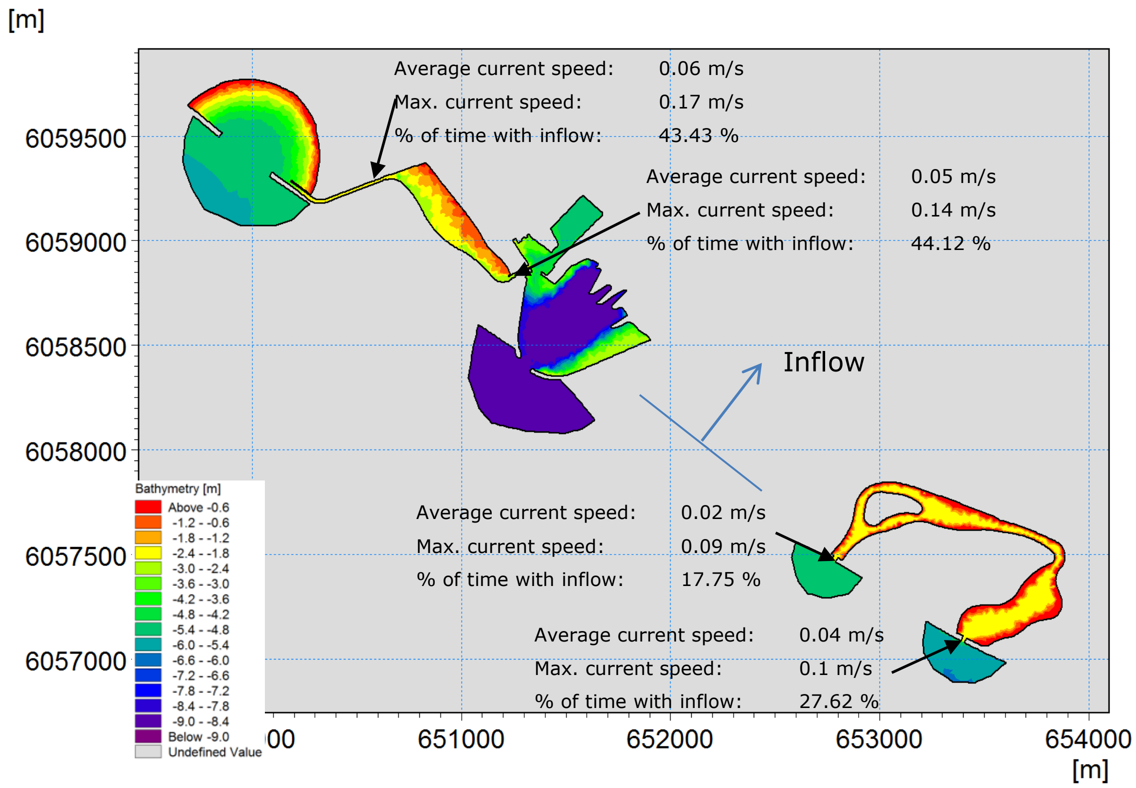

Figure 4-4 Current statistics in canal section of the lagoon systems for the new Pocket Beach, results for the Nature Lagoon are identical to those presented in the FEMA-FEHY (2013) report.

The model predicts that the flow direction in the Inner Lagoon is from west to east about 44% of the time and consequently from the harbour basin towards the lagoon about 56% 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. The corresponding percentages for the original layout were 34% and 66%, respectively.

The characteristic flow velocities in the Nature Lagoon have not changed and are not presented again.

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 new Pocket Beach Lagoon and the eastern entrance to the Nature Lagoon is shown.

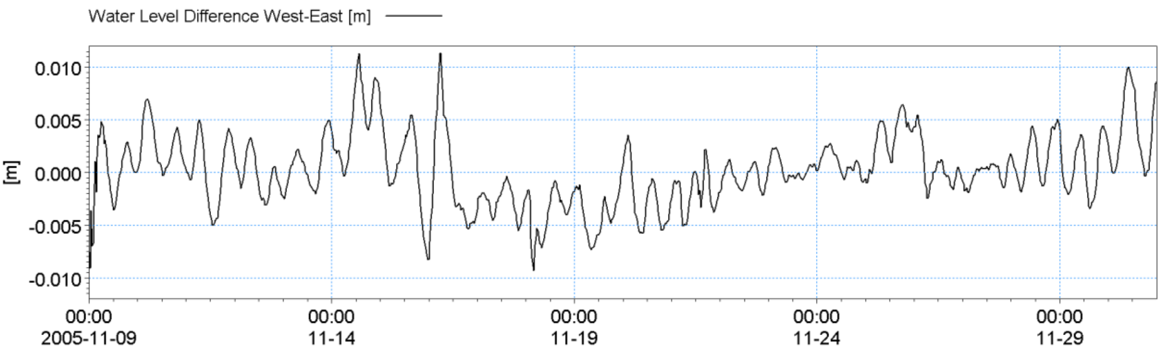

Figure 5-1 Water level difference from western entrance (new Pocket Beach Lagoon) to eastern entrance (near the Active Cliff)

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 flow
- Period 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.

The results shown in this supplementary note are achieved by using updated boundary conditions as shown in Figure 5-1. The flushing times are calculated for the former lagoon layout and the new layout introduced in Chapter 3. Table 5-1 to Table 5-3 include the results from the former FEMA-FEHY (2013) report and the results for the new layout.

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 new Pocket Beach Lagoon and the right plots show the flushing of Rødbyhavn. Flushing results for the Nature Lagoon have not been shown. The separate flushing for the new Pocket Beach Lagoon, for the Inner Lagoon and for the Inner Lagoon including the new Pocket Beach has also been simulated.

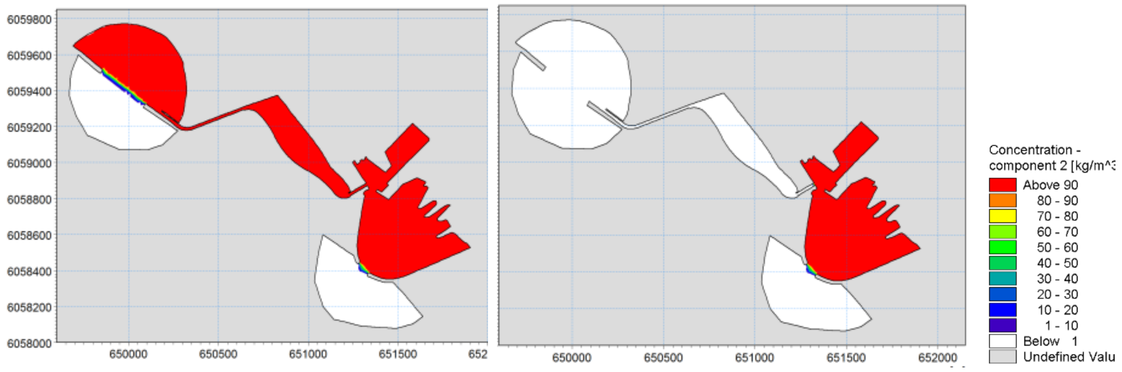

Figure 5-2 Flushing results for Period 1, new Pocket Beach Lagoon. Initial distribution of conservative matter

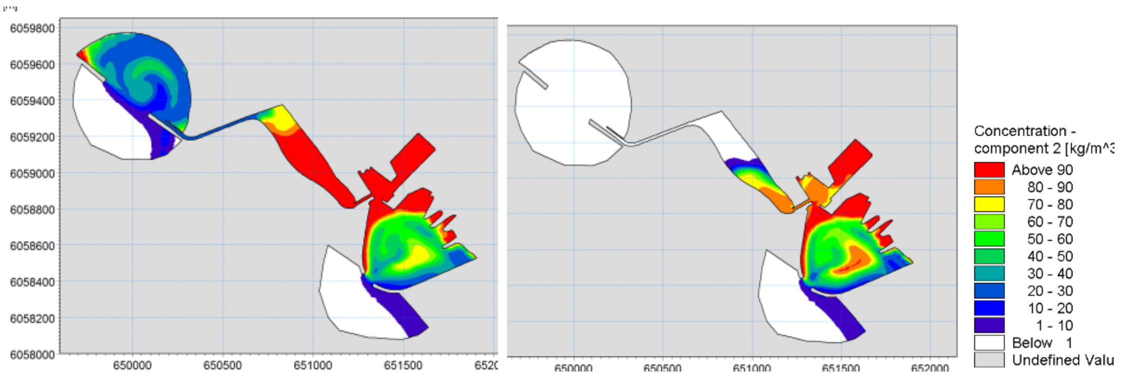

Figure 5-3 Flushing results for Period 1, new Pocket Beach Lagoon. Conservative matter after 5 days

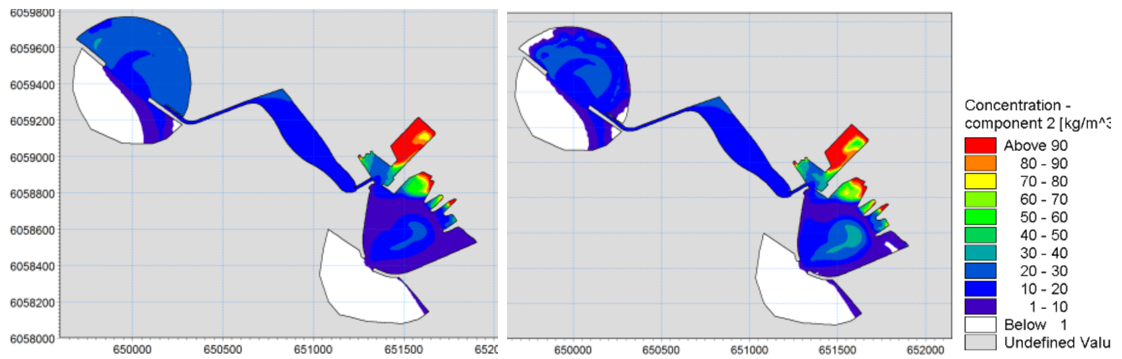

Figure 5-4 Flushing results for Period 1, new Pocket Beach Lagoon. Conservative matter after 10 days

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 1.8 and 6.5 days. The longest flushing time is estimated for Rødbyhavn and the shortest for the Inner Lagoon.

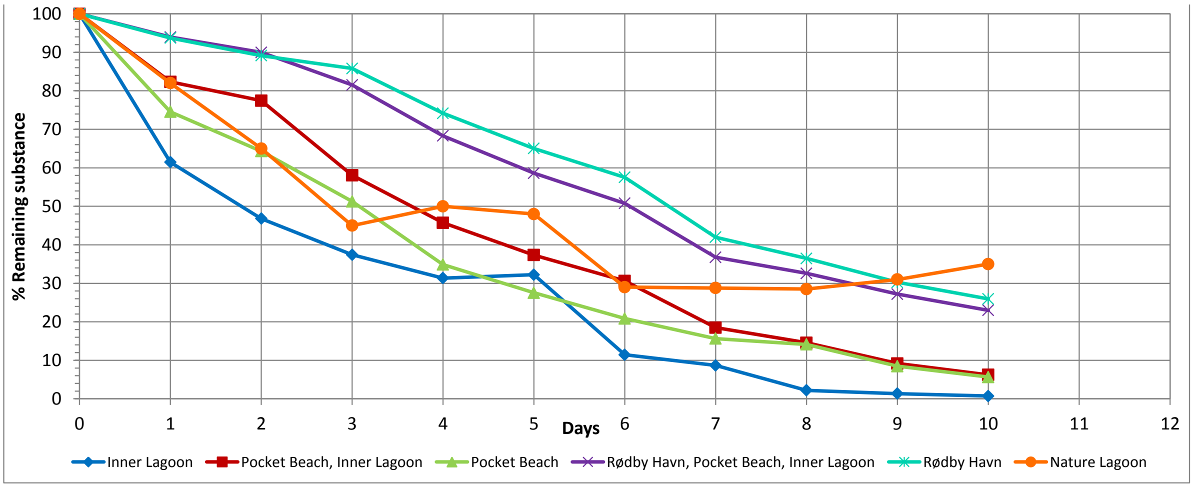

Figure 5-5 Period 1. Overall flushing in six areas

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

Location	T_{50} (days) Original layout	T_{50} (days) New layout	Change (%)
Inner Lagoon	1.3	1.8	+38%
New Pocket Beach Lagoon	3.4	3.1	-9%
Inner Lagoon and new Pocket Beach Lagoon	3.9	3.6	-8%
Rødbyhavn	5.6	6.5	+16%
Rødbyhavn, new Pocket Beach Lagoon and Inner Lagoon	5.9	6.1	+3%

Flushing in Period 2: 14 – 24 November 2005

In the following results of 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 new Pocket Beach Lagoon and right plot covers the flushing in Rødbyhavn. Flushing results for the Nature Lagoon have not been shown. The separate flushing for the new Pocket Beach Lagoon, for the Inner Lagoon and for the Inner Lagoon including the new Pocket Beach Lagoon has also been simulated.

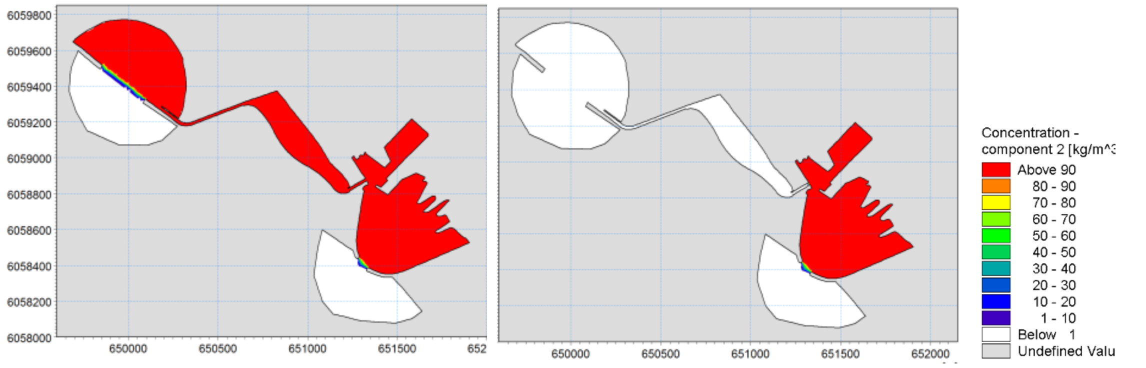

Figure 5-6 Flushing results for Period 2, new Pocket Beach Lagoon2. Initial distribution of conservative matter.

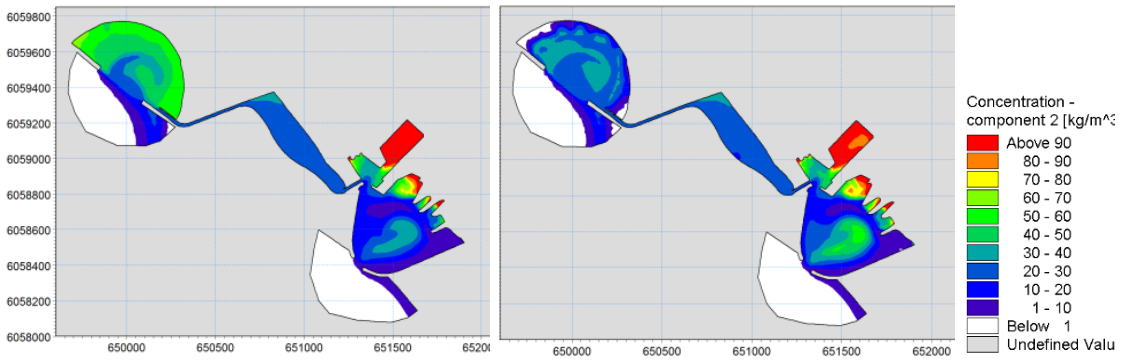

Figure 5-7 Flushing results for Period 2, new Pocket Beach Lagoon. Conservative matter after 5 days.

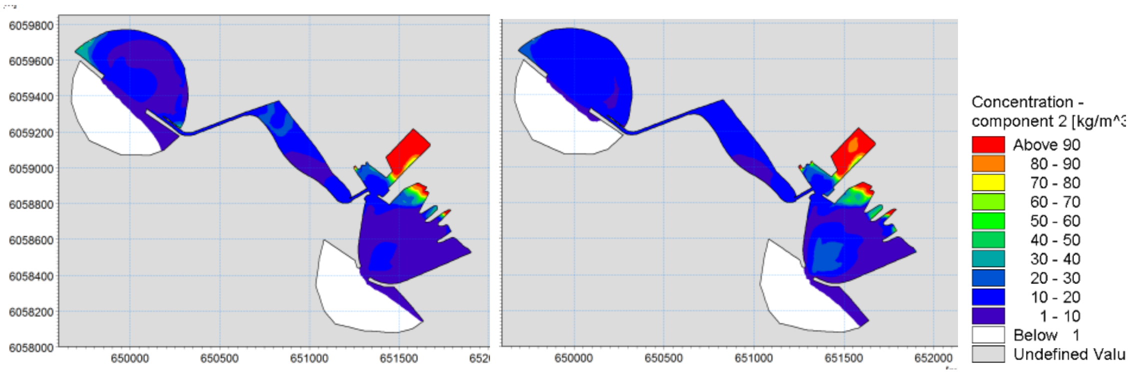

Figure 5-8 Flushing results for Period 2, new Pocket Beach Lagoon. Conservative matter after 10 days

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

Results show flushing times between 1.4 and 3.0 days, longest for Rødbyhavn-new Pocket Beach Lagoon - Inner Lagoon system and shortest for Inner Lagoon assessed separately.

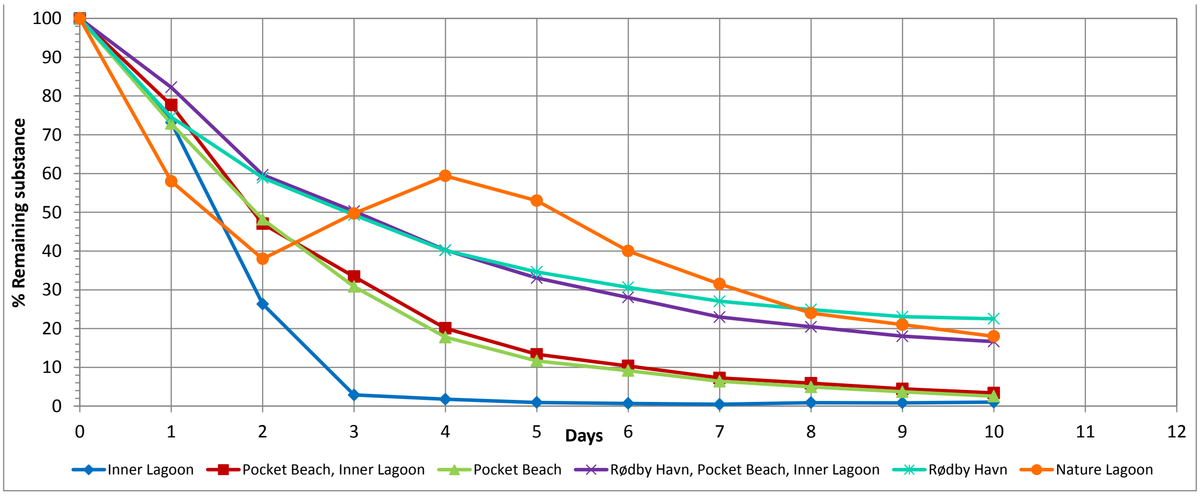

Figure 5-9 Period 2. Overall flushing times for six areas

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

Location	T_{50} (days) Original layout	T_{50} (days) New lay-out	Change (%)
Inner Lagoon	0.75	1.4	+87%
New Pocket Beach Lagoon	0.9	1.9	+111%
Inner Lagoon and new Pocket Beach Lagoon	0.8	1.9	+137%
Rødbyhavn	3.6	2.9	-19%
Rødbyhavn, new Pocket Beach Lagoon and Inner Lagoon	4.2	3.0	-29%

Flushing in Period 3: 17 -27 November 2005

In the following results of 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 new Pocket Beach Lagoon and the right plots covers the flushing in Rødbyhavn. No results are presented for the Nature Lagoon. The separate flushing for the new Pocket Beach, for the Inner Lagoon and for the Inner Lagoon including the Pocket Beach has also been simulated.

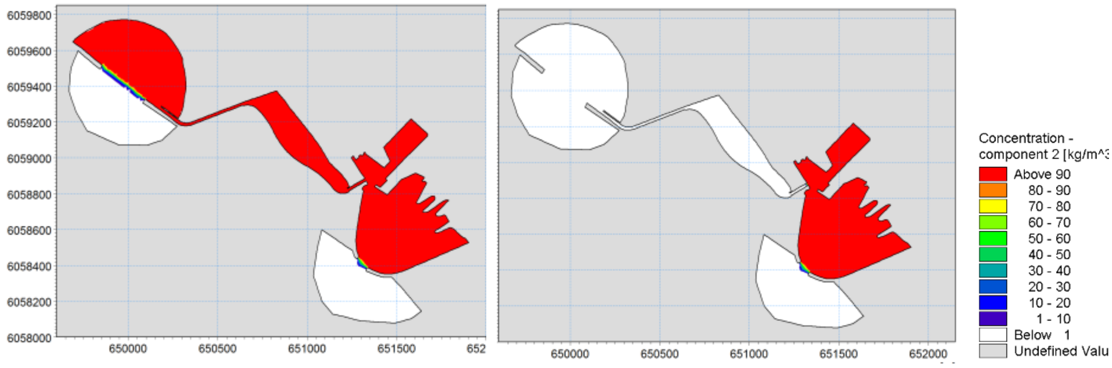

Figure 5-10 Flushing results for Period 3, new Pocket Beach Lagoon. Initial distribution of conservative matter

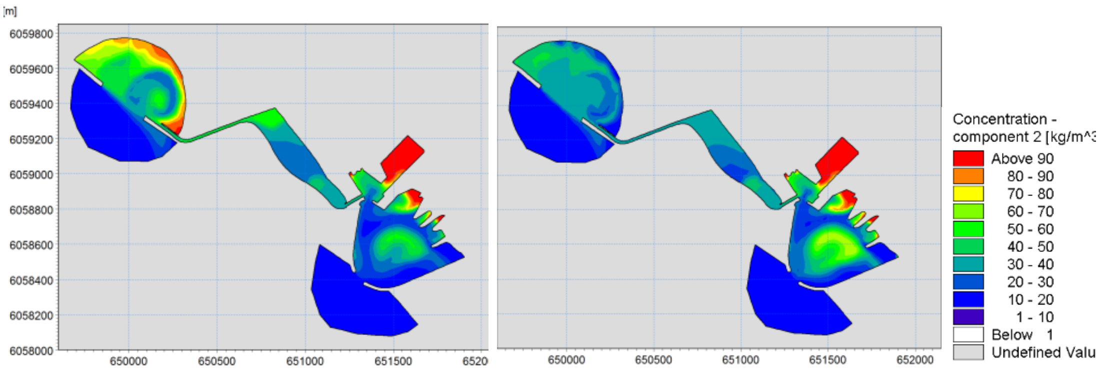

Figure 5-11 Flushing results for Period 3, new Pocket Beach Lagoon3. Conservative matter after 5 days

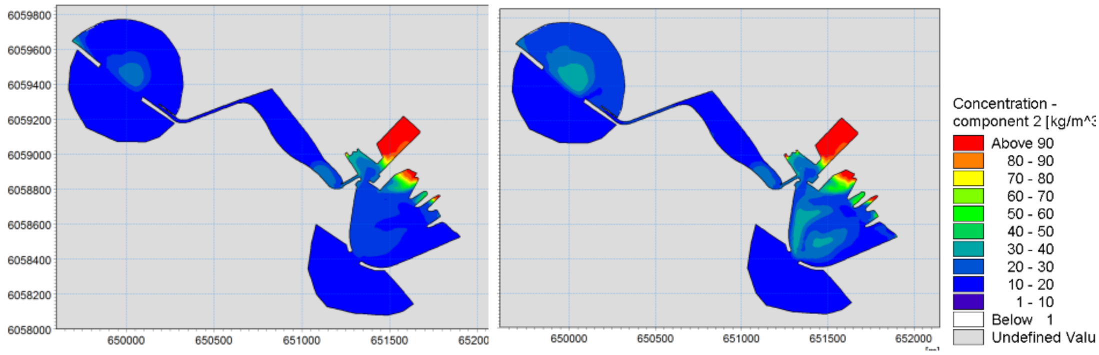

Figure 5-12 Flushing results for Period 3, new Pocket Beach Lagoon. Conservative matter after 10 days

The overall flushing as function of time is given in Figure 5-13 and Table 5-3. Results show flushing times between 0.6 and 3.4 days. The longest flushing time is estimated for Rødbyhavn and the shortest for Inner Lagoon.

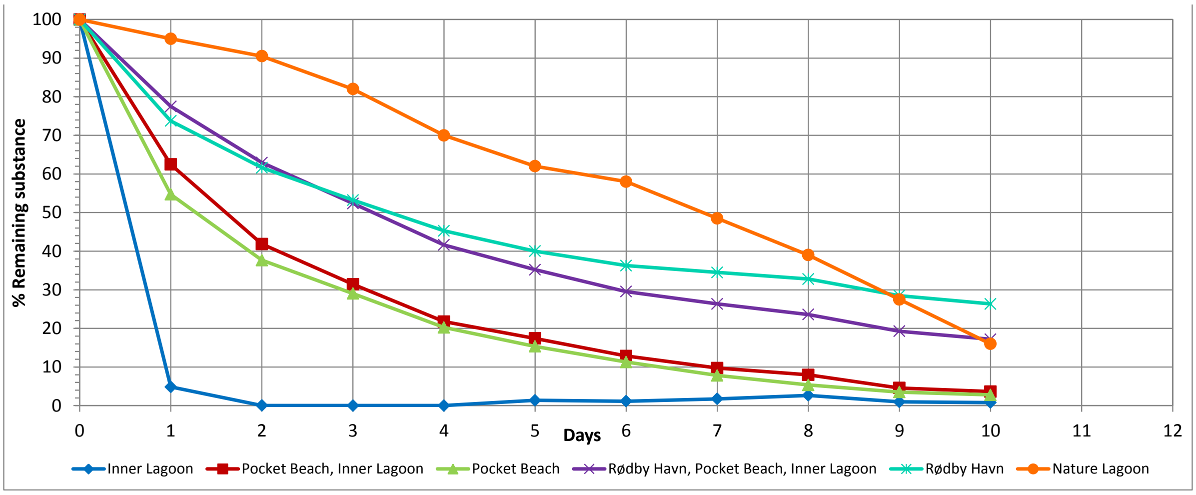

Figure 5-13 Period 3. Overall flushing times

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

Location	T_{50} (days) Original layout	T_{50} (days) New layout	Change (%)
Inner Lagoon	0.5	0.6	+20%
Pocket Beach	1.8	1.3	-28%
Inner Lagoon and Pocket Beach	1.6	1.6	0%
Rødbyhavn	2.9	3.4	+17%
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	3.4	3.2	-6%

Overview of flushing times and comparison between original and new layout of Pocket Beach Lagoon

In Table 5-4 an overview of the flushing times for all three scenarios is given for the original layout as well as for the new layout of the Pocket Beach Lagoon.

Table 5-4 Overview of flushing times (T_{50} in days) for the three periods for the original and new layout

Location	Original Layout		New Layout	
	T_{50} (days)	Average T_{50} (days)	T_{50} (days)	Average T_{50} (days)
Inner Lagoon	0.5 – 1.3	0.9	0.6 – 1.8	1.3
Pocket Beach Lagoon	0.9 – 3.4	2.0	1.3 – 3.1	2.1
Inner Lagoon and Pocket Beach Lagoon	0.8 – 3.9	2.1	1.6 – 3.6	2.4
Rødbyhavn	2.9 – 5.6	4.3	2.9 – 6.5	4.7
Rødbyhavn, Pocket Beach Lagoon and Inner Lagoon	3.4 – 5.9	4.7	3.0 – 6.1	4.6

It is generally seen that the flushing times in all lagoon systems can be characterised as small to moderate with average flushing times in the range of 1-5 days for the original layout as well as for the new Pocket Beach Lagoon. This indicates good flushing conditions in all parts of the lagoon systems. The flushing time for the Inner Lagoon is the lowest indicating very good flushing conditions for this lagoon, however there is a slight increase in the flushing time for the Inner Lagoon as a result of the new position of the Pocket Beach Lagoon and especially due to the longer canal but the flushing conditions for the new layout of the Pocket Beach Lagoon are still considered as being good.

Sensitivity tests with a slightly deepened canal (half a meter increased depth, i.e. a depth of 2.5 m), shows that this will result in slightly reduced flushing times, but also the position of the canal outlet into the Pocket Beach has some implications for the flushing time.

5.3 Inflow of water into the Inner Lagoon

The sum of the inflows of water through the two openings to the Inner Lagoon over the entire simulation period of 21 days has been re-calculated for the western lagoon system with the new layout of the Pocket Beach Lagoon. This is 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 Inner Lagoon for the original layout as well as for the new layout, average inflow and average flushing time

Inner 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})
Original layout	21	4,000,000	190,000	170,000	0.9
New layout	21	2,800,000	131,000	170,000	1.3

It is seen that the introduction of the new layout increases the inflow to the Inner Lagoon.

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 new Pocket Beach Lagoon, this sand will theoretically build up along the ~1,000 m (~1,400 for the original layout) section of reclamation from the west 'corner' to the lagoon opening of the reclamation and reach the lagoon opening in another approximately 4-8 years (5-10 years for the original layout). 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 14 to 28 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, where after 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 new 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

No changes relative to the original layout. It can therefore be concluded that the entrances to the Nature Lagoon will only be exposed to negligible sedimentation. The conditions for sedimentation in the entrances to the Nature Lagoon are**.**

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 with the new layout of the Pocket Beach Lagoon will be evaluated on basis of the flushing characteristics of the lagoon 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.

The conditions in the Nature Lagoon will not change and is consequently not repeated here.

Assessment of amounts of water brought into the Inner 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 Inner Lagoon and the average residence time for the lagoon are presented in Table 6-1.

Table 6-1 Inflow of water into the Inner Lagoon with the new layout of the Pocket Beach Lagoon, 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	131,000	$48{\cdot}10^6$	1.3

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

There are no changes to this section relative to the FEMA-FEHY (2013) report. The main result is that the concentration of suspended sediments (CCS) in the waters of the Fehmarnbelt has a yearly average value of about 15 g/m^3 and 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, 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 1.3 days for the Inner Lagoon it can be concluded that all suspended sediments brought into the lagoons will settle on the seabed.

Assessment of sedimentation in the Inner Lagoon due to the settling of suspended sediments

The average inflow of water into the Inner Lagoon and the average concentrations of suspended sediments in the water flowing into the lagoon 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. The average amounts of sediments brought into the Inner Lagoon 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 consolidate, but the initial value has been used in the present assessment.

Table 6-2 Average yearly inflow of water and sediments into the Inner Lagoon and sedimentation in the lagoon.

Inner Lagoon 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
Original Layout	$69{\cdot}10^6$	15	$1{,}035{\cdot}10^3$	310,000	3.3	1.1
New Layout	$48{\cdot}10^6$	15	$720{\cdot}10^3$	310,000	2.3	0.8

It is seen that less sedimentation in the Inner Lagoon can be expected for the new layout of the Pocket Beach Lagoon.

It must be mentioned that it has been assumed that the sediments settle evenly distributed over the seabed of the entire lagoon. 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

Inner Lagoon	Sedimentation after 50 years	Sedimentation after 100 years
Original layout	20 cm	33 cm
New layout	15 cm	25 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.

7 IMPACT OF WASTEWATER ON THE WATER QUALITY

The impact of wastewater on the water quality at the new location of the Pocket Beach Lagoon has been evaluated on basis of the earlier simulation results. The only difference is that the Pocket Beach Lagoon is now located 400 m further away from the discharge point of sewage water.

The model setup includes 3 different outlet positions:

- 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 7-1 the different discharge points are illustrated.

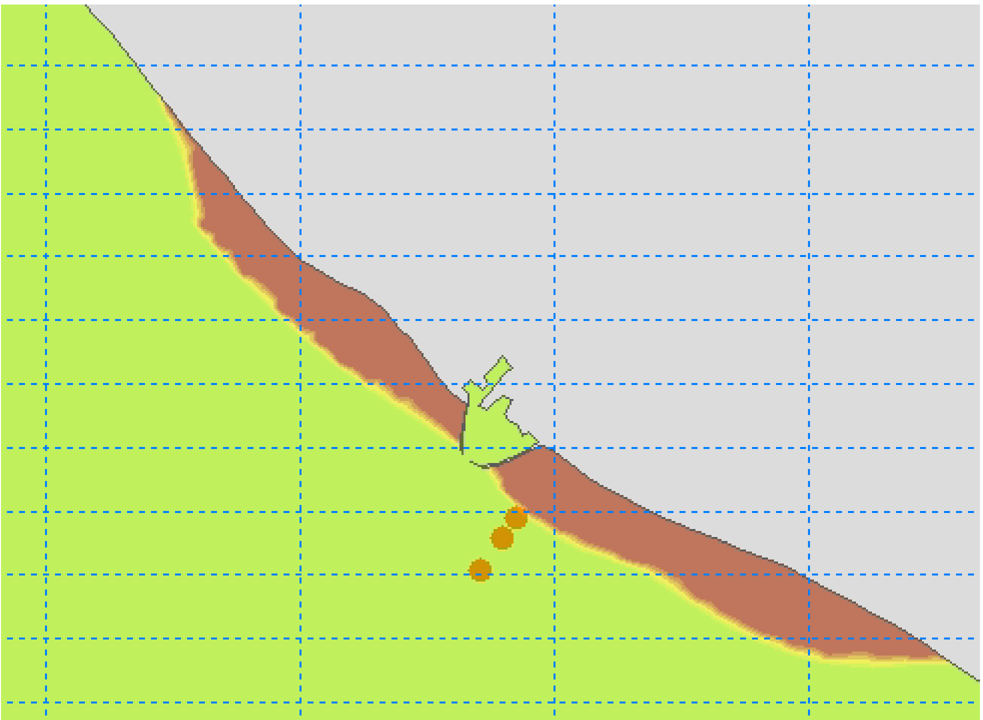

Figure 7-1 The location of the different discharge points included in the model evaluation

7.1 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 7-2, corresponding to the beach at Holeby/Hyldtofte Østersøbad, a point just outside the original Pocket Beach Lagoon, and finally a point at the NW end of the new landfill close to West Beach, see Figure 7-2. 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.

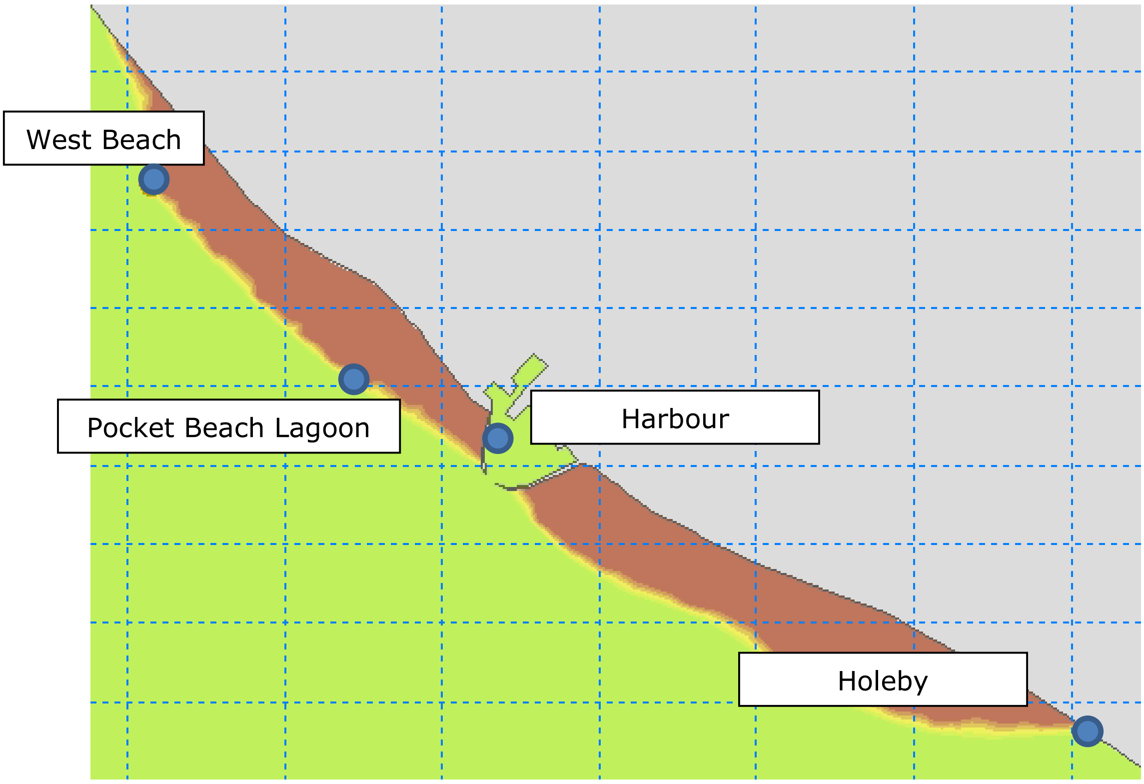

Figure 7-2 Location of the four points used for evaluating the bathing water quality at the beaches Holeby Østersøbad, original Pocket Beach Lagoon and West Beach, as well as in the harbour

Impact of treated wastewater during operation phase

It was found for the original layout that all concentrations are well below the criteria for 'Good Quality' even for the used coastal position of the discharge. This will also be valid for the new layout of the Pocket Beach Lagoon.

Impact of by-pass

The conclusion from the simulation with the original layout was that 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. It is evaluated that this will also be the case for with the new layout of the Pocket Beach Lagoon.

The effect of the *by-pass* water outside the Pocket Beach Lagoon and at the other beaches is also illustrated in Figure 7-3. 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. It is seen that the conditions at the original location and at the now location of the Pocket Beach Lagoon will not differ much in such an event.

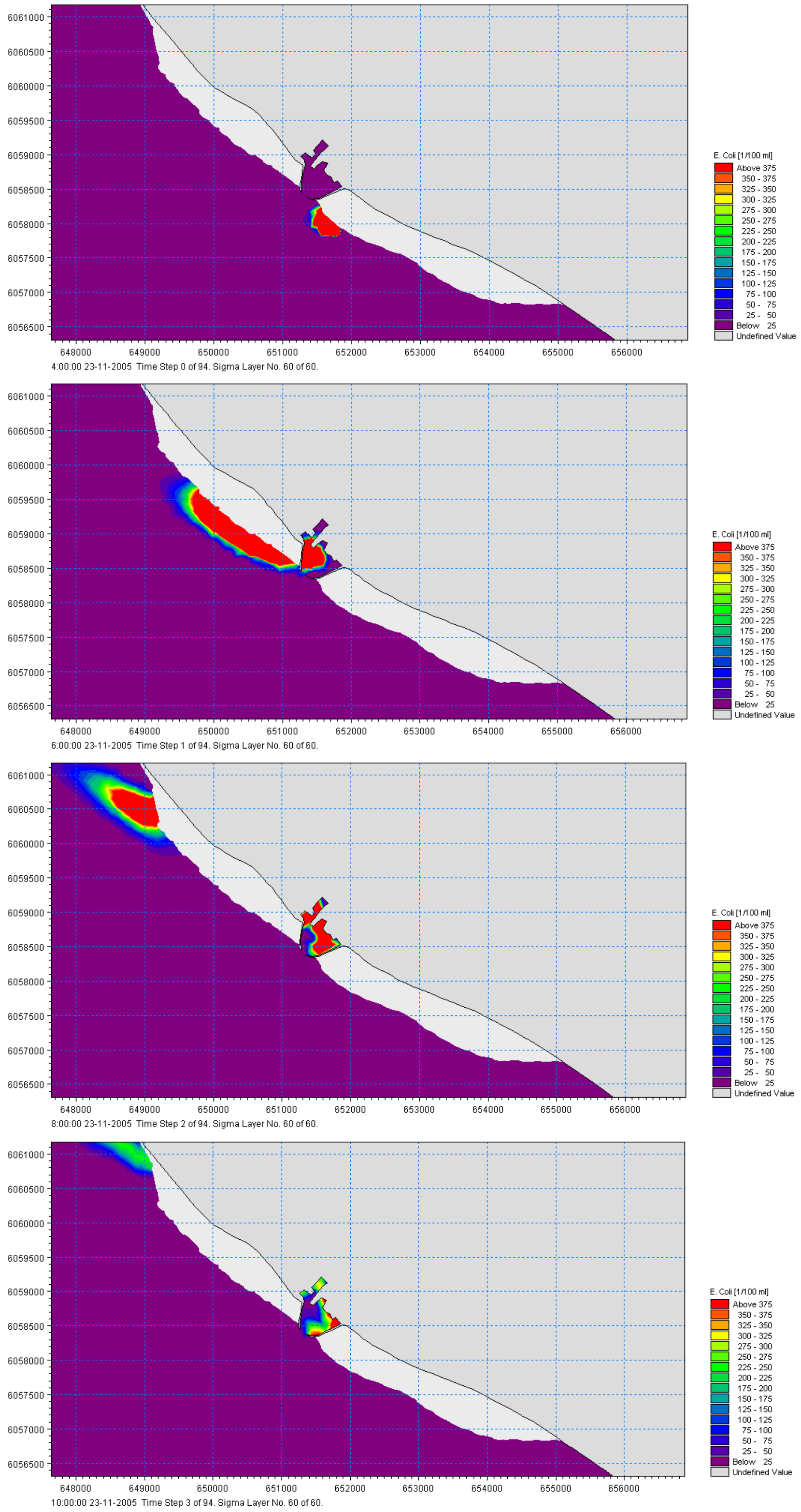

Figure 7-3 *Modelled* E.coli *concentrations after a* by-pass under conditions dominated by west-going current*. The situations origin from the 23 November 2005, and between the four images the time step is 2 hours. Note that the highest range is >375 counts per 100 ml, i.e. it does not indicate exceedance of the quality criteria*

Impact of wastewater from the project during the construction phase

It is concluded that concentration patterns are equal and much lower than the criteria for 'Good Quality' for this situation. This is also valid for the new location of the Pocket Beach Lagoon.

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 beach in 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.

These conclusions are valid for the original location as well as for the new location of the Pocket Beach Lagoon.

7.2 Nutrient discharges

It was concluded in the FEMA-FEHY (2013) report that the contribution and effects of nutrient discharge from the Rødbyhavn treatment plant at present and during construction and operational phase are insignificant compared to the natural flux of nutrients in the area. This conclusion will not be affected by the new location of the Pocket Beach Lagoon.

7.3 Discharge of toxic substances

No changes relative to the FEMA-FEHY (2013) report.

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.

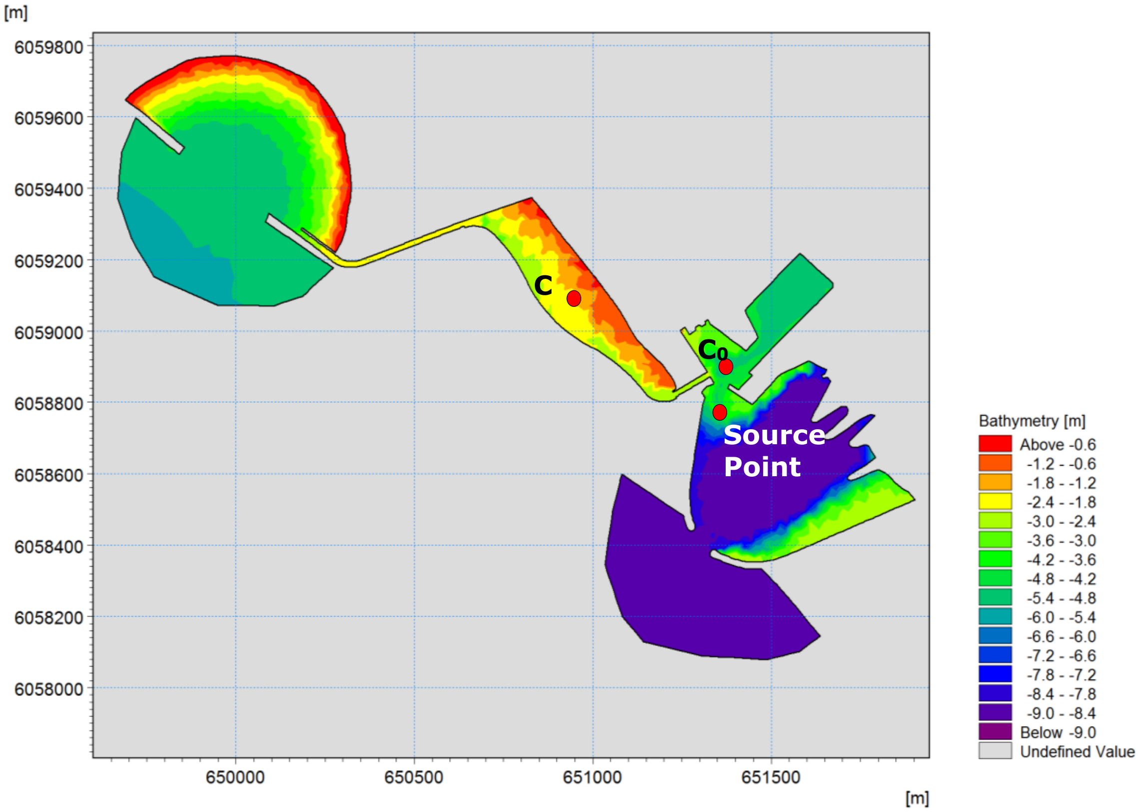

Figure 8-1 Location of the two points where concentration have been extracted and where the source is located (modelling with new layout)

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, for the original situation as well as for the situation with the new layout of the Pocket Beach Lagoon and the canal.

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, for the original situation and for the situation with the new layout of the Pocket Beach Lagoon and the canal.

Period	$\frac{\bar{c}}{\bar{c}_0}$	
	Original layout	New layout
Period 1	0.9	0.5
Period 2	1.0	1.0
Period 3	0.9	0.8

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. This is valid for the original situation as well as for the situation with the new layout of the Pocket Beach Lagoon.

The possible pollution of the harbour basins is further discussed in the following sections.

8.2 Harbour concentrations of hygienic pollutants

It is evaluated that there are no significant changes to the concentrations of hygienic pollutants in the harbour and their spreading to the Inner Lagoon as a result of the new layout of the Pocket Beach Lagoon.

8.3 Harbour concentrations of toxic pollutants and risk assessment of TBT in the Inner Lagoon

8.3.1 Harbour concentrations of toxic pollutants

There are no changes in the assessment of the presence of toxic pollutants in the harbour basin as a result of the new layout of the Pocket Beach Lagoon.

8.3.2 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 canal, 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 criterion (EAC) developed for TBT in mussels, 2) relation between TBT concentrations in mussels and water (so-called bio-concentration factors – BCF), 3) Environmental Quality Standards (EQS) set by EU for TBT and, 4) estimated flushing rates of the Inner Lagoon.

It is evaluated that there are no significant changes in the assessment of the risk that TBT can be carried from the harbour to the Lagoon by water exchange as a result of the new layout of the Pocket Beach Lagoon.

9 RISK OF TRAPPING FLOATING 'SEAWEED' ON THE BEACHES

Generally there are no changes in risk related to trapping of seaweed in the Pocket Beach relative to the FEMA-FEHY (2013) report. However, the new location of the opening of the canal in the Pocket Beach Lagoon will further minimize the risk of seaweed being transported from the Pocket Beach Lagoon into the Inner Lagoon. This is because the opening is located at a more protected location relative to prevailing SWerly waves.

10 ECOLOGICAL STATUS OF THE LAGOONS

There are no changes regarding ecological status of the lagoons relative to the FEMA-FEHY (2013) report.

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