Final Report

FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES (FEHY)

Marine Soil - Impact Assessment

Coastal Morphology along Fehmarn and Lolland

E1TR0059 – Volume III

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Please cite as:

FEHY (2013). Fehmarnbelt Fixed Link EIA.
Marine Soil - Impact Assessment.
Coastal Morphology along Fehmarn and Lolland.
Report No. E1TR0059 - Volume III

Report: 211 pages - Appendix included: 11 pages

May 2013

ISBN 978-87-92416-37-7

Maps:
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Model software geographic plots: Also data from Farvandsvæsenet and Bundesamt für Seeschifffahrt und Hydrographie

Photos:
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Co-financed by the European Union
Trans-European Transport Network (TEN-T)

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Appendix A: Wave Modelling using WAMIT

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).

0 EXTENDED SUMMARY

The impact assessments of the tunnel and the bridge alternatives are carried out for conceptual designs of the tunnel and bridge projects with a number of mitigation measures included in the assessed designs of the projects. Following the impact assessment, additional mitigation measures have been included.

The consequences of the additional mitigation measures are commented where relevant throughout this report.

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)..

0.1 Environmental theme and assessed components

The topic of this report is the impact on the so-called "Coastal Morphology" in the Fehmarnbelt. Coastal morphology covers in the present report from the dunes, dikes, coastal cliffs, or other structures, which back the present coastline, to the 6 m DVR90 depth contour.

The character of the natural coastal zone is to a large extent determined by the geology in the area and the exposure to waves. If the coast consists of loose sediments, mud, sand or gravel, the coastal profiles will adjust to the exposure from the predominant waves. If the predominant waves approach the coast under an angle the wave breaking process will result in currents in the surf zone and high turbulence levels which for periods keep the sand in suspension and transport it along the coast. This longshore sediment transport, the so-called littoral drift, is the process which leads to shoreline advance updrift of coastal structures blocking the transport zone, and shoreline and sea bed erosion on the downdrift side, as presently seen on the west and east side of Rødbyhavn, respectively.

Any longshore variation in the longshore transport – also for other reasons than structures - leads to either shoreline advance or retreat. The coastal zone both on the Fehmarn and Lolland side is dominated by narrow sandy beaches in front of dikes on long stretches at low-lying areas. The coastal morphology is generally under development along the coasts of the Fehmarnbelt. The present report deals with the influence of the tunnel and bridge projects on this on-going development of the coastal morphology.

The sub-components listed in Table 0.1 are addressed in the impact assessment of the component Coastal Morphology.

Table 0.1 Component Coastal Morphology with sub-components

Component	Sub-components
Coastal Morphology	Beaches and other unprotected sections of the coastline
	Coastal protection
	Individual coastal structures
	Special morphological features

0.2 Assessment of impacts of tunnel alternative

Impacts on the coastal morphology from the tunnel alternative E-ME/August 2011 were assessed. Impacts are caused by the permanent reclamations, the protection reefs and the access channel to the production facilities (the latter only on Lolland). The reclamations extend 3,720 m east and 3,750 m west of Rødbyhavn on the Danish side and 700 m east of Puttgarden on the German side.

The impacts on the coastlines of Lolland and Fehmarn were quantified by analysis of the results from numerical modelling of waves, longshore sediment transport and shoreline evolution. These modelling tools were calibrated and applied in the evaluation of the baseline conditions (FEHY 2013a).

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more than 25-30 years.

The impacts on the coastal morphology from the tunnel project as well as the bridge project develop with time. All impacts on coastal morphology are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the temporary work harbours. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The mitigation measures included in the assessed design of the tunnel project and the additional mitigating are supplied in Table 0.2.

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Table 0.2 Mitigation and compensation measures at Lolland

Project	Mitigation and compensation measures included in the conceptual assessed design	Additional mitigation and compensation measures
Tunnel project	Erodible cliff at the eastern part of the reclamation on Lolland Two beach sections in the reclamation on Lolland A new beach section in the reclamation on Fehmarn	Nourishment of approximately 14,000 m^3/year at the coast east of the reclamation to keep the baseline situation New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of Rødbyhavn Measures to establish a new and adequate waste water outlet at Rødbyhavn Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk

0.2.1 Impacts – Lolland

A total stretch of 11,500 m of the Lolland coast were assessed to be impacted by the assessed design of the tunnel project. The 11,500 m are composed of 7,470 m of lost coastline and 4,030 m of impaired coastline. Seven individual structures were assessed to be impacted (2 lost and 5 impaired). A summary is provided in Table 0.3. The impacts on the coast are primarily caused by the reclamation occupying part of the original coastline and by blocking of the sediment transport caused by the reclamation. To a minor degree, the impacts are caused by changes to the wave field. The blocking of sediment transport is to some degree compensated by an erodible cliff at the eastern part of the reclamation.

The impacts on the coastline comprise of loss and impairments of unprotected sections (including beaches) as well as sections with coastal protection such as revetments and breakwaters as indicated in Figure 0.1. The impacted individual structures are also shown in the figure. The Hyllekrog/Rødsand barrier system, which is categorised as a 'special morphological feature' was found not to be impacted by the tunnel project.

West of Rødbyhavn, only the coastline occupied by the new reclamation is classified as 'loss' and no impairment of the coastline is considered. It is noted, however, that accumulation of sand west of the reclamation is expected to cause an increase in the widths of the beaches by up to 160 m, starting from the end of the reclamation and extending to Skarholm over 30 years. However, this new beach is not considered as a (negative) impairment, except that one structure, Dragsminde Sluice at Sandholm west of Rødbyhavn, will be impaired as this sedimentation blocks the water outflow. It should be mentioned that the plans for the reclamation is to include new beach areas to compensate for the loss of existing beaches west of Rødbyhavn.

East of Rødbyhavn, the coastline is impacted by the assessed design of the tunnel project between Rødbyhavn and Brunddragene. The lost present coast due to the reclamation covers a length of 3,750 m. Increased erosion is expected to cause loss of beaches and failure of structures within 5-10 years after construction for the coastal section 0-1,100 m east of the reclamation. The predicted impacts include failure of the breakwater scheme protecting the beach in front of the summerhouse area, Hyldtofte Østersøbad, and a risk of erosion in the dike in this area. Further east, increased erosion caused by the tunnel project is also expected but on a longer time scale. Increased erosional pressure due to the assessed design of the tunnel project is predicted to extend to Brunddragene.

The problem of erosion along this coastline is as such a problem, which is expected even without the tunnel project. The Rødbyhavn breakwaters cause similar impacts on the coast east of the harbour; however, the impacts at Hyldtofte Østersøbad are predicted to occur earlier in time with the assessed design of the tunnel project (about 15-25 years). The wind farm, Rødsand 2, located offshore of Hyllekrog, causes slight erosion along this section too. The present impacts/erosion from especially the section nearest the reclamation will be enhanced by the tunnel project. The problems can, however, be resolved with available and efficient methods of mitigation such as nourishment at a relatively low cost.

Two individual structures (one water outlet and a waste water outlet east of Rødbyhavn) will be lost and four structures (older groynes west of Hyldtofte Østersøbad) are impaired.

The recreational value of the coastal landscape of the new reclamation is assessed to improve or at least balance the loss of the part of the Lolland coastline, which will be integrated into the new reclamation.

Project including additional mitigation measures
On Lolland the additional mitigation measures for the tunnel project include nourishment of approximately 14,000 m^3 each year to the coast east of the reclamation and two new/improved outlet structures at Dragsminde Sluice and east of Rødbyhavn, respectively. A new and adequate waste water outlet at Rødbyhavn is also included as a planned mitigation measure.

Nourishment of about 14,000 m^3each year initiated at the beginning of the project is assessed to prevent the erosion-problems (maintain the baseline conditions) caused by the blocking of the land reclamation along the coastline east of the reclamation.

With the implementation of these mitigating measures, the residual impacts are insignificant.

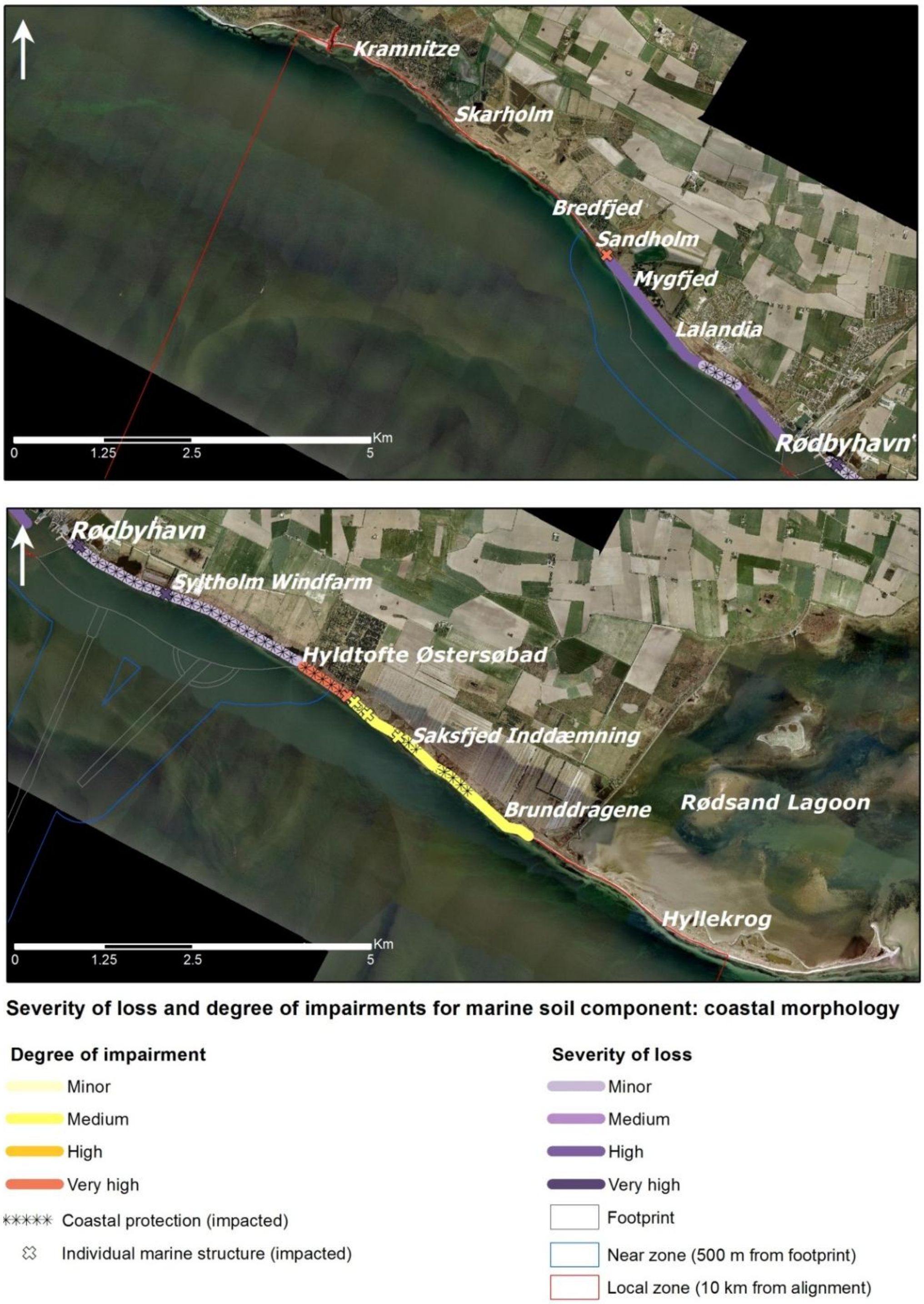

Figure 0.1 *Degree of impairment and severity of loss assigned to sections of the coast due to the pressure from reclamation, protection reef and access channel on the Lolland side. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the severity of loss of and degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast east of the projects, the outlet at Sandholm (Dragsminde Sluice) and an outlet as well as a waste water outlet east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 0.3 Summary of impacts on the coastal morphology on Lolland from tunnel project (E-ME/August 2011). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent

Summary of impacts	Total m	Individual structures (No.)	Special morphological features (No.)
Severity of loss			
Very high severity	0	2[2]	0
High severity	3,180[1]	0	0
Medium severity	0	0	0
Minor severity	4,290	0	0
Total	**7,470[1]**	**2[2]**	**0**
Degree of impairments			
Very high impairment	750[2,3]	2[2]	0
High impairment	0	0	0
Medium impairment	3,280[2]	3[2]	0
Minor impairment	0	0	0
Total	**4,030[2,3]**	**5[2]**	**0**

[1]includes 3,180 m of loss of beach west of Rødbyhavn, which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [2]Impacts, which will not to be effectuated following additionally planned mitigation measures, please refer to the text

0.2.2 *Impacts – Fehmarn*

The tunnel project has been assessed to cause impacts on a total of 1,070 m of the coastline southeast of Puttgarden on Fehmarn. The 1,070 m are composed of 700 m of lost coastline and 370 m of impaired coastline, see summary in Table 0.4. The impacts on the coast are caused by the reclamation occupying part of the original coastline and the changes in the sediment transport as a result of changes to the waves. Six groynes are impacted of which one is considered 'lost' since the new reclamation will extend beyond this groyne.

Impacts on the coast of Fehmarn from the tunnel project are restricted to the coastline southeast of the reclamation east of Puttgarden shown in Figure 0.2. No impacts are predicted west of Puttgarden, i.e. no changes are predicted for Grüner Brink, which is classified as a 'special morphological feature' and protected Natura 2000 area as well as Naturschutzgebiete.

700 m of the existing beach east of Puttgarden will be directly affected by the reclamation for the tunnel portal. The new reclamation is planned to have a beach of about the same length facing an east-southeastern direction. The loss of original beach east of the eastern breakwater of Puttgarden due to the occupancy of the reclamation is therefore compensated by a new beach.

The erosional pressure on the groynes and the seawall protecting the Ohlenborgs Huk from erosion is predicted to increase with the tunnel project.

The overview of affected areas by the assessed design tunnel project is shown in Table 0.4.

Project including additional mitigation measures

On Fehmarn regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion around coastal structures at Ohlenborgs

Huk are planned for as an additional mitigation measure. The impacts on this part of the coastline are hence considered insignificant.

In conclusion, the impacts from the tunnel project on the coastline of Fehmarn are assessed as insignificant with the included additional mitigation measures.

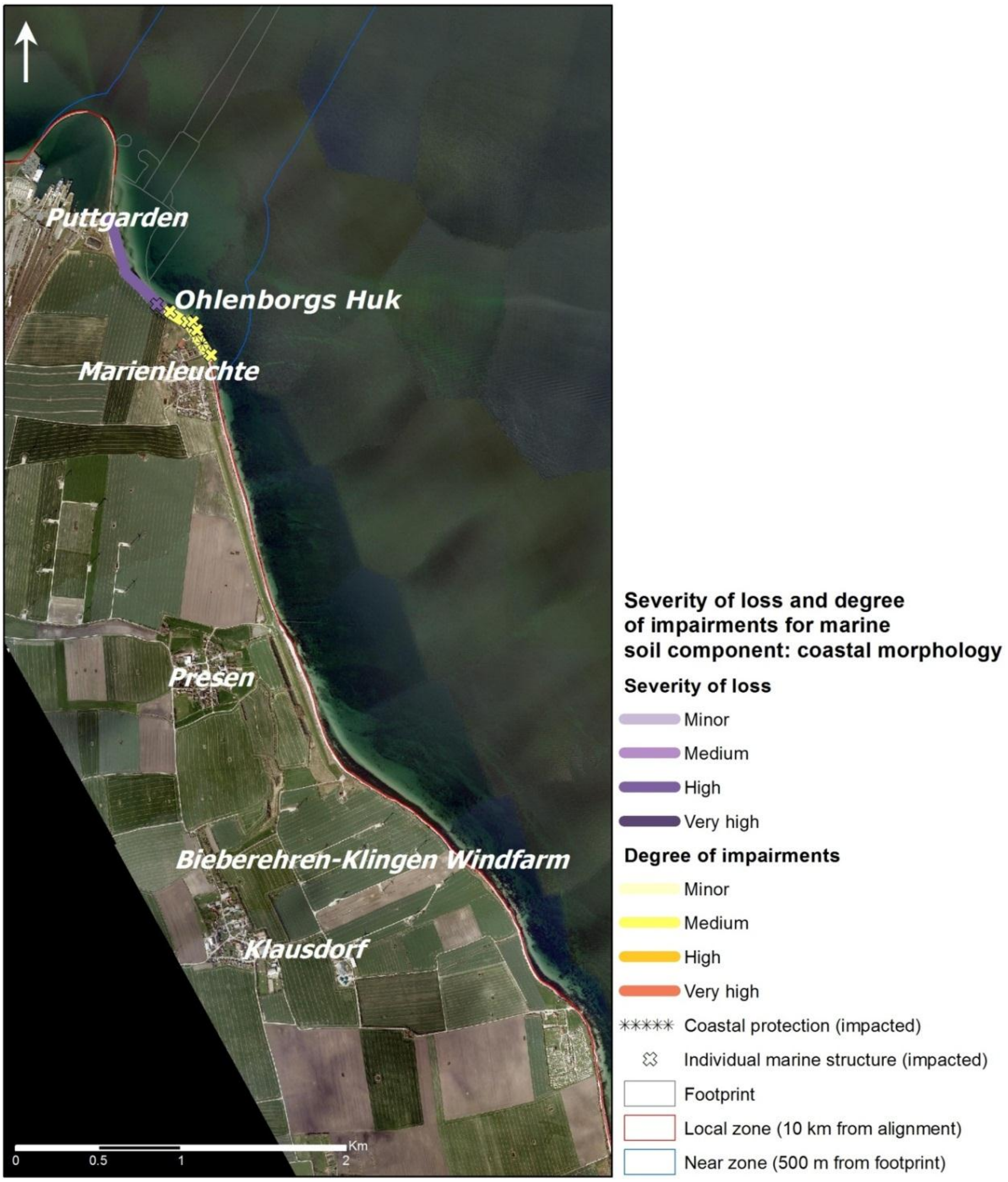

Figure 0.2 *Degree of impairments and severity of loss assigned to sections of the coast of Fehmarn southeast of Puttgarden due to the pressure from the tunnel project. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the severity of loss and the degree of impairment for such structures. Note: following this assessment additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast at Ohlenborgs Huk/Marienleucte, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

Table 0.4 *Summary of impacts on the coastal morphology on Fehmarn from tunnel project (E-ME/August 2011). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent*

Summary of impacts	**Total m**	**Individual structures (No.)**	**Special morph. features (No.)**
Severity of loss			
Very high severity	0	0	0
High severity	700[1]	1	0
Medium severity	0	0	0
Minor severity	0	0	0
Total	**700[1]**	**1**	**0**
Degree of impairments			
Very high impairment	0	0	0
High impairment	0	0	0
Medium impairment	370[2]	5[2]	0
Minor impairment	0	0	0
Total	**370[2]**	**5[2]**	**0**

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclattion, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text.

0.3 Assessment of impacts of bridge alternative

Impacts on the coastal morphology from the bridge alternative Var. 2 B E-E/October 2010 were assessed. Impacts are caused by project pressure from the marine ramps including reclamations and new beaches (Lolland and Fehmarn) and the piers/pylons. The marine ramps are located east of respectively Rødbyhavn and Puttgarden.

The impacts on the coastlines of Lolland and Fehmarn were quantified by analysis of results from numerical modelling of waves, longshore sediment transport and shoreline evolution.

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more than 25-30 years.

The impacts on the coastal morphology from the bridge project develop with time. All impacts on coastal morphology are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the temporary work harbours. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The mitigation measures included in the assessed design of the bridge project and the additional mitigating measures are supplied in Table 0.5.

Table 0.5 Mitigation and compensation measures

Project	Mitigation and compensation measures included in the conceptual assessed design	Additional mitigation and compensation measures
Bridge project	Beaches east and west of the marine ramp on Lolland New beach section included in the marine ramp on Fehmarn	Nourishment of costal sections exposed to erosion on Lolland by the bridge project (approximately 1,500 m^3/year at Bredfjed 10,000-12,000 m^3/year east of the marine ramp) to keep the baseline situation New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of the eastern breakwater at Rødbyhavn) Measures to establish a new and adequate waste water outlet at Rødbyhavn Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk, Fehmarn Nourishment of costal sections on the coast southeast of Puttgarden(approximately 2,000 m^3/year between Marienleuchte and Presen on Fehmarn) Regular monitoring of the outlet from Blankenwisch west of Puttgarden and improved/new structure, if required Regular monitoring of the beach in front of Marienleuchte and new/improved structures, if required, to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte, Fehmarn

0.3.1 Impacts - Lolland

A total stretch of the Lolland coast of about 3,400 m is either lost (1,300 m) or impaired (2,100 m) by the assessed design of the bridge project. The impacts on the coast are caused by the marine ramp including the planned beaches occupying part of the original coastline, by the blocking of the sediment transport caused by the marine ramp and changes to the sediment transport due to changes in the near-shore wave field.

The impacts on the coastline comprise of a minor degree of impairment of a section of beach west of Rødbyhavn and loss/impairment of sections of coast with coastal protection east of Rødbyhavn as indicated in Figure 0.3 and summarised in Table 0.6. Three individual structures (outlet at Dragsminde at Sandholm, a waste water outlet and a water outlet east of Rødbyhavn) are impaired with a minor degree of impairment due to increase in sedimentation or erosion. The special morphological feature, the easternmost part of the spit of Hyllekrog located within a Natura 2000 area, is impaired with to minor degree.

West of Rødbyhavn, the impairment of the beach in front of Bredfjed is caused by a relatively weak increase in erosion is predicted.

East of Rødbyhavn, blocking of the sediment supply to the coastline 0-1,100 m east of the marine ramp may potentially cause a risk of failure of the revetment since enhanced erosion along this section is expected. Erosion in front of this revetment and also further east than 1,100 m from the ramp was to be expected even without the bridge project since the Rødbyhavn breakwaters cause similar impacts on the coastline; however, not to the degree of impact as assessed for the bridge project.

Only a short section of the coastline at Lolland is lost. The ramp with the two beaches to the east and west occupies about 1,300 m of the original coastline. The two new beaches – a total of about 1.3 km new beach - provide a new section of coast with recreational value near Rødby.

The impacts on Hyllekrog are assessed to be an issue of minor extent with a weakly reduced migration of the spit on a longer time scale. Mitigation of this type of impact is not possible. The impacted spit of Hyllekrog is considered a morphological element belonging to conservation objectives within Natura 2000. It is noted that the offshore wind farm Rødsand 2 was evaluated to cause a weak additional erosional pressure (DHI 2007c) along the western one third of Hyllekrog. This includes the stretch where the barrier has the smallest width. The impacts from the bridge project are assessed to have the opposite effect, i.e. reduce the erosion. The order of magnitude of the two effects is about the same but in both cases evaluated to be insignificant. Furthermore, the reduction in the migration of the eastern spit caused by Rødsand 2 was assessed to be <5%. The reduction in the migration rate of this spit caused by the bridge project is in the order of 10-15%. The cumulative impact is a reduction of 15-20%. The significance of the impacts on the overall morphological development of Hyllekrog is considered minor. The bridge project is assessed not to have impacts on the littoral transport and hence on the barriers further to the east, the West and the East Rødsand.

In conclusion, it is assessed that the impairments from the assessed design of the bridge project consist of sections of the coast with potentially significant impacts.

Project including additional mitigation measures

On Lolland the additional mitigation measures include nourishment of approximately 1,500 m^3/year at Bredfjed and 10,000-12,000 m^3/year to the coast east of the ramp. With this nourishment is assessed that erosion from the beach at Bredfjed and from coastal profiles in front of the coastal protection east of the ramp due to the bridge project can be prevented. Impacted outlet structures on the coast of Lolland are mitigated by the additional mitigation measures including new/improved outlet structure at Dragsminde Sluice at Sandholm, new/improved outlet east of Rødbyhavn, as well as measures to establish a new and adequate waste water outlet at Rødbyhavn.

Conclusion

In conclusion, it is assessed that the impacts from the bridge project in the conceptual design when including the additional mitigation measures are restricted to the insignificant loss of original coastline in the area of the marine ramp. The bridge project imposes a minor impact on the special morphology feature, Hyllekrog, which will not change the overall coastal morphology of the barrier. The impact is hence assessed as insignificant.

With the implementation of these mitigating measures, the residual impacts are insignificant.

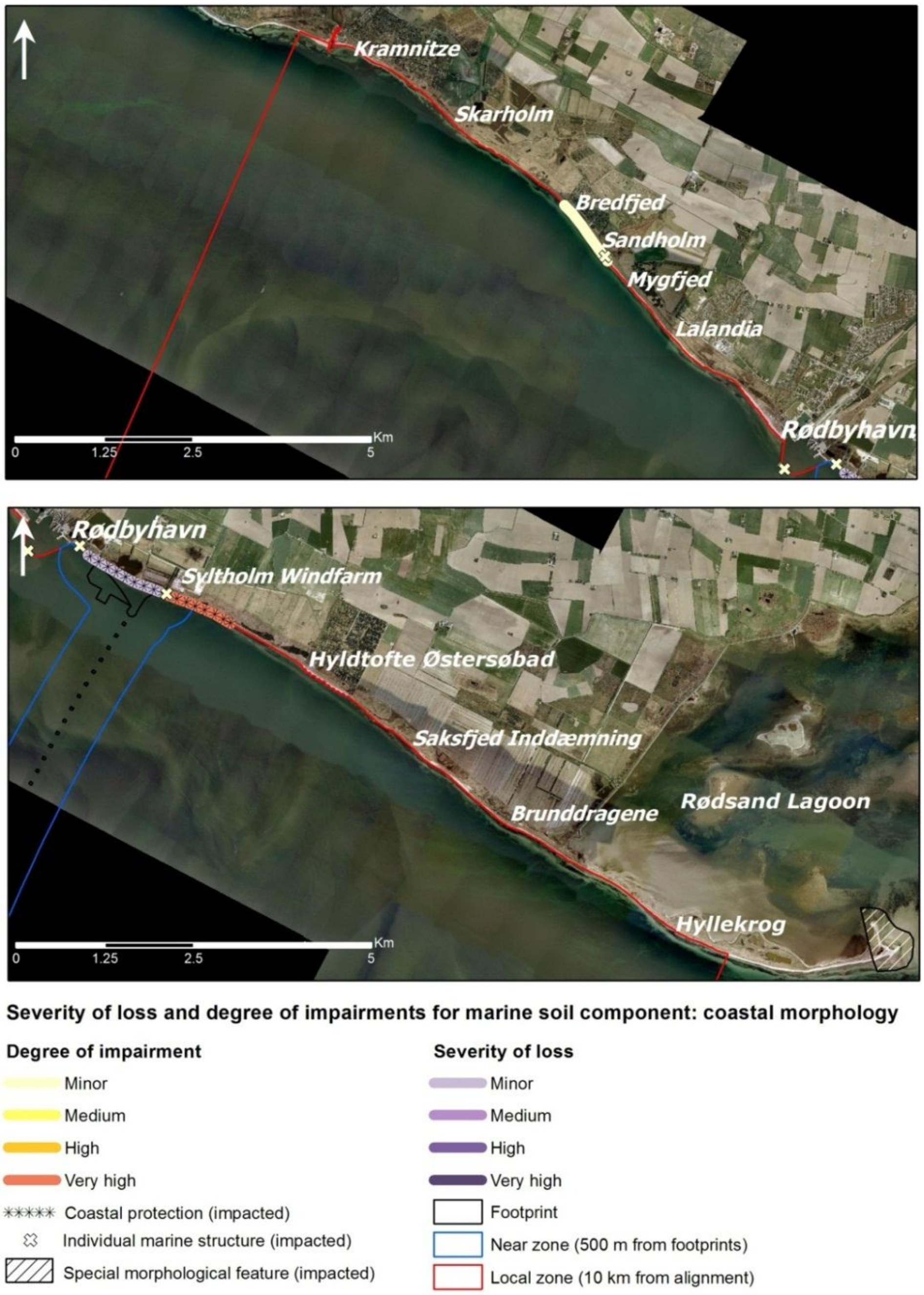

Figure 0.3 *Degree of impairment and severity of loss assigned to sections of the coast due to the pressure from permanent structures of the bridge, the marine ramp on the Lolland side and the piers/pylons. Var. 2 B E-E/October 2010. Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the loss and impairment of such structures/features. Note: following this assessment additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast west and east of Rødbyhavn, and the impairments to the three outlets (two water outlets and one waste water outlet, individual structures) west and east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 0.6 Summary of impacts on the coastal morphology on Lolland from bridge project (Var. 2 B E-E/October 2010). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent

Summary of impacts	**Total** **m**	**Individual structures (No.)**	**Special morpholog-ical features (No.)**
Severity of loss			
Very high severity	0	0	0
High severity	0	0	0
Medium severity	0	0	0
Minor severity	1,300[1]	0	0
Total	**1,300**[1]	**0**	**0**
Degree of impairments			
Very high impairment	1,100[2]	0	0
High impairment	0	0	0
Medium impairment	0	0	0
Minor impairment	1,000[2]	3[3]	1[4]
Total	**2,100**[2]	**3**[3]	**1**[4]

[1]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [2]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text, [3]new/improved structures included as additional mitigation structures will prevent impairments to these structures, please refer to text, [4]outside local + near zone

0.3.2 Impacts - Fehmarn

A total of about 3,235 m of the coastline of Fehmarn (of which 700 m are loss and 2,535 m are impaired), nine individual structures and the special morphological feature of Grüner Brink will be impacted to some extent by the bridge solution, see summary of impacts in Table 0.7 and in Figure 0.4-Figure 0.5 for the coastline west and southeast of Puttgarden, respectively. The impacts on the coast are caused by the ramp, piers and pylons and reclamation and the changes to the sediment transport as a result of changes to the waves.

700 m of the existing beach east of Puttgarden is directly affected by the reclamation for the marine ramp. The reclamation with the marine ramp is planned to be implemented with a beach east of the ramp. The loss of original beach east of the eastern breakwater of Puttgarden due to the occupancy of the reclamation is therefore compensated by a new beach.

The erosional pressure on the groynes and the seawall protecting the Ohlenborgs Huk from erosion is predicted to increase. Possible erosion at this section can be effectively prevented by strengthening the existing protection scheme.

The erosion along the beach southeast of Marienleuchte can effectively be prevented by nourishment.

Nine individual structures (six groynes around Ohlenborgs Huk, two outlets – from Blankenwisch and in front of Presen, respectively – and the bathing bridge at Marienleuchte) are predicted to be impaired/lost caused by the bridge project.

Grüner Brink is impaired to a minor degree of impairment. The area is a highly dynamic feature and the effects are assessed not to influence the character of the feature and how it develops, but only slightly increases the rate of development. Mitigation of this type of impact is not possible.

Project including additional mitigation measures
Following the assessment, additional mitigation measures have been planned for.

On Fehmarn regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion around the coastal structures at Ohlenborgs Huk are planned for as an additional mitigation. Nourishment of about 2,000 m^3/year on the coast between Marienleuchte and Presen and regular monitoring as well as new/improved structures (bathing bridge at Marienleuchte and water outlet at Presen), if required, are also planned for. The residual impacts on the coastline southeast of Putgarden are with these mitigation measures considered insignificant.

Regular monitoring and new/improved structure, if required, to secure the water outlet from Blankenwisch west of Puttgarden is similarly included as additional mitigation and the impairment to this outlet is hence also considered insignificant.

Conclusion
In conclusion, the impacts from the bridge project on the coastline of Fehmarn are assessed as insignificant with the included additional mitigation measures.

The residual impacts include loss in the marine ramp area and a slight increase in the rate of development of the Grüner Brink. The residual impacts are considered insignificant.

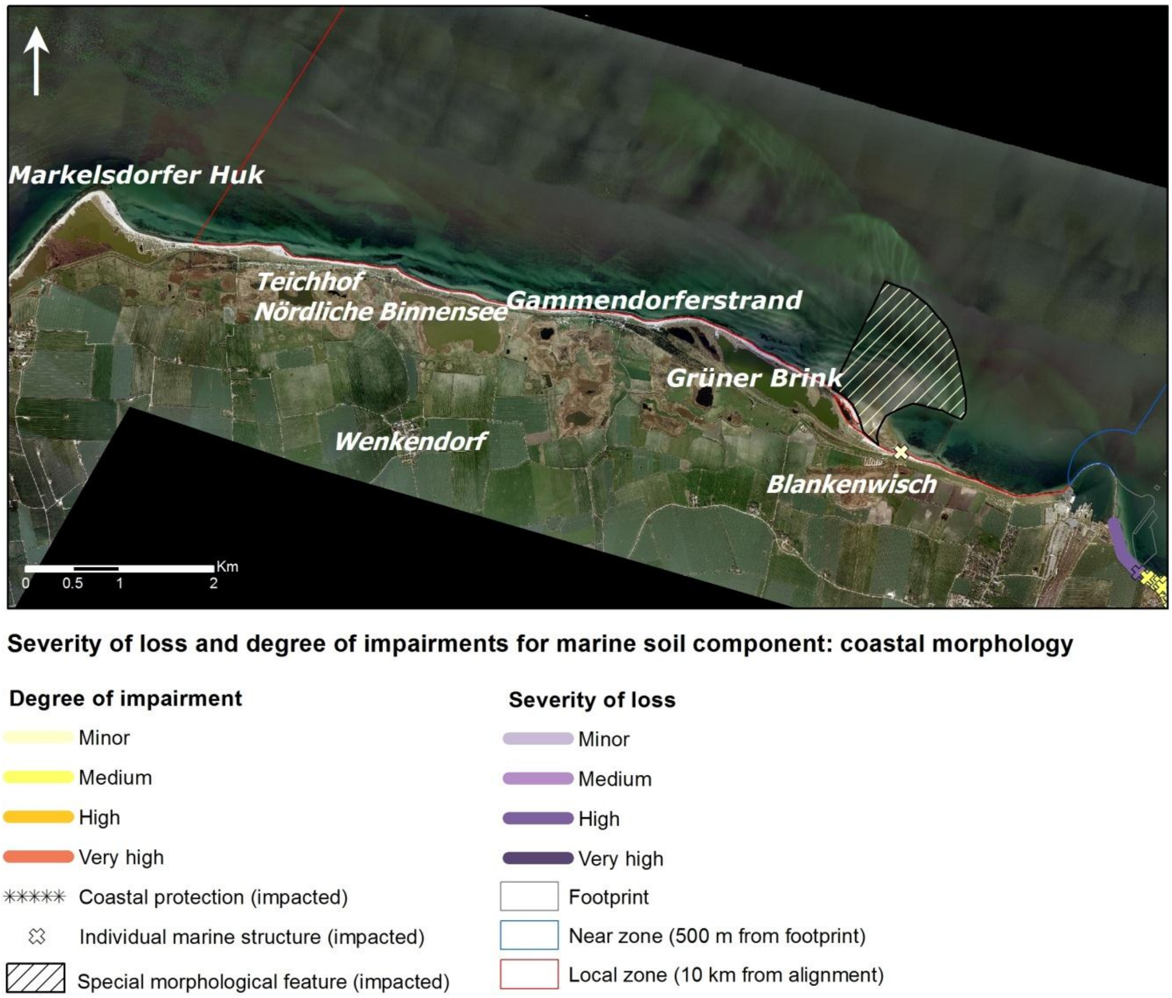

Figure 0.4 *Degree of impairment and severity of loss assigned to sections of the coast of Fehmarn west of Puttgarden due to the pressure from the bridge project. Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the loss and impairment of such structures/features. Note: following this assessment additional planned mitigation measures have been included. The impairments to the outlet from Blankenwisch (individual structure) west of Puttgarden will not become effectuated, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Figure 0.5 *Degree of impairment and severity of loss assigned to sections of the coast of Fehmarn southeast of Puttgarden due to the pressure from the bridge project. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signs for loss/impairment. These indicate hence the loss of and degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been included. The impairments to coastline southeast of Puttgarden will hence not become effectuated, please refer to the text Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

Table 0.7 Summary of impacts on the coastal morphology on Fehmarn from bridge project (Var. 2 B E-E/ October 2010). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent

Summary of impacts	**Total m**	**Individual structures (No.)**	**Special morph. features (No.)**
Severity of loss			
Very high severity	0	0	0
High severity	700[1]	1	0
Medium severity	0	0	0
Minor severity	0	0	0
Total	**700**[1]	**1**	**0**
Degree of impairments			
Very high impairment	0	0	0
High impairment	0	0	0
Medium impairment	370[2]	5[2]	0
Minor impairment	2,165[2]	3[2]	1
Total	**2,535**[2]	8[2]	**1**

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

0.4 Comparison of bridge and tunnel

The impacts from the tunnel and the bridge alternatives are compared below. The impact assessments of the tunnel and the bridge alternatives are based on a number of mitigation measures included in the assessed designs of the projects.

In the comparison below, the projects are compared based on the assessed design of the projects. The consequences of the additional mitigation measures and a comparison of the residual effects for the two projects are commented on further below.

Comparison of impacts from assessed designs of the projects
<u>Lolland</u>

A comparison of the impacts from the tunnel and the bridge projects on the Lolland coastline are provided in Table 0.8. A larger part of the coastline of Lolland will become impacted by the tunnel project compared with the bridge project due to the relatively large reclamation area on the Danish side, which is a part of the tunnel project.

Furthermore, the tunnel project has more impacts classified with a very high, high or medium degree of impact (severity of loss or degree of impairment) than the bridge project, which only has impacts classified with a medium and minor degree of impact to the coastline of Lolland.

Both projects impose impacts within the Natura 2000 area SCI DK 006X238. The tunnel project impacts the protected coastal landscape along the shoreline east of the reclamation. The bridge project imposes an impact on the special morphology feature, Hyllekrog, further east. Mitigation of the impact on Hyllekrog is not possible.

The overall evaluation of the impacts from the assessed design of the tunnel project on the coastline of Lolland is that a) the assessed impairments to the Lolland coastline and structures can be mitigated effectively and at a relatively low cost and b) the added value of the new reclamation with respect to coastal landscape compensates the loss of original coastline.

The impact from the bridge on Hyllekrog is assessed to be of a minor impact, which will not change the overall coastal morphology of the barrier.

Fehmarn

Table 0.9 provides the comparison of the assessed tunnel and the bridge alternative of the impacts on the coastline of Fehmarn. The assessed design of the bridge project causes larger impacts on the Fehmarn side, which is contrary to the situation on Lolland, where the tunnel project impacts a larger part of the coastline.

The main difference between the impacts on the Fehmarn coastline caused by the bridge and the tunnel project is the impacts from the bridge on a) Grüner Brink and b) the mild increase in erosion along the coastline between Marienleuchte and Presen caused by the impact on the waves caused by the piers/pylons.

The bridge is assessed to increase the rate of the morphological development of Grüner Brink. No mitigation methods can be recommended. Grüner Brink is part of the Natura 2000 area SCI DE 1532-391 and Naturschützgebiete 'Grüner Brink'; however, the effects are assessed not to influence the character of the feature. The impact is therefore assessed to be insignificant. The mild increase in erosion along the coast between Marienleuchte and Presen can be mitigated effectively and at a relatively low cost and is also evaluated as insignificant.

Conclusion based on assessed designs

In conclusion, the main difference between the assessed bridge and tunnel project for the marine soil component coastal morphology is the relatively large new reclamation along the coast of Lolland, which is a part of the tunnel project. The reclamation is, however, also considered to add value to the area with respect to recreational value and coastal landscape and to compensate the loss of original coastline.

The impacts on the remaining sections of the coastlines of Fehmarn and Lolland from the tunnel as well as the bridge project are assessed to be insignificant, if mitigated where possible. Effective mitigation is possible for all significant impacts at a relatively low cost for the bridge as well as the tunnel project.

The differences in the impacted areas as well as the differences in the character of the impacts from the assessed designs of the projects do not lead to one or the other project being the preferred option based on the impacts on coastal morphology.

Projects including additional mitigation measures
Following the assessment, additional mitigation measures have been planned for as described above.

Lolland

The residual impacts after including the effects of the additional mitigation measures are the loss of coastline in the areas where the projects occupy the existing coastline due to reclamations/ramps. The bridge project imposes a minor impact on the special morphology feature, Hyllekrog, which will not change the overall coastal morphology of the barrier.

Coastal sections exposed to increased erosion caused by either of the projects are with the additional mitigation measures mitigated by nourishment and effects to structures such as outlet structures are handled by including regular monitoring and, if required, new/improved structures to ensure their functionality.

The main difference between the bridge and the tunnel project is therefore also with the additional mitigating measures included in the project designs the relatively large new reclamation on Lolland.

The differences in the loss of coastline as well as the minor impact to Hyllekrog from the bridge solution, do not lead to one or the other project being the preferred option based on the impacts on coastal morphology on Lolland.

Fehmarn

The residual impacts after including the effects of the additional mitigation measures are for both projects the loss of the same part of the coastline east of Puttgarden in the area, where the projects occupy the existing coastline due to reclamation (tunnel) or marine ramp (bridge). The bridge project imposes a minor impact on the special morphological feature, Grüner Brink, which will not change the overall coastal morphology of the formation.

Coastal sections exposed to increased erosion from the projects are planned to be mitigated by nourishment and effects to structures such as water outlets are handled by including regular monitoring and if required new/improved structures to ensure their functionality.

The only difference between the two projects is therefore the minor impact to Grüner Brink from the bridge project. This impact is insignificant, since the effects from the bridge are assessed not to influence the character of the feature.

The impact to Grüner Brink from the bridge solution, do hence not lead to one or the other project being the preferred option based on the impacts on coastal morphology.

Conclusion

In conclusion, the main difference between the bridge and the tunnel project for the marine soil component coastal morphology is the relatively large new reclamation along the coast of Lolland, which is a part of the tunnel project. The reclamation is, however, also considered to add value to the area with respect to recreational value and coastal landscape and to compensate the loss of original coastline.

The impacts on the remaining sections of the coastlines of Fehmarn and Lolland are assessed to be insignificant with the additional mitigation measures.

The differences in the loss of coastline as well as the differences in the character of the residual impacts from the projects including the additional mitigation measures do not lead to one or the other project being the preferred option based on the impacts on coastal morphology. Table 0.10 summarises the comparison of the immersed tunnel and cable stayed bridge.

Table 0.8 Comparison of impacts on Lolland for the assessed immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridge (main alternative Var. 2 B E-E/October 2010)

Component:	**Coastal morphology, Lolland**					
	Immersed tunnel E-ME/August 2011			**Cable stayed bridge Var. 2 B E-E/October 2010**		
	Total coastline (m)	**Individual structures**	**Spec. Morph. features**	**Total coastline (m)**	**Individual structures**	**Spec. Morph. features**
Severity of loss						
Very high severity	0	2[4]	0	0	0	0
High severity	3,180[2]	0	0	0	0	0
Medium severity	0	0	0	0	0	0
Minor severity	4,290	0	0	1,300[3]	0	0
Total	**7,470[2]**	**2**[4]	**0**	1,300[3]	0	0
Part of coastline (%)[1]	37.3[2]	-	-	6.5[3]	-	-
Degree of impairments						
Very high impairment	750[4]	2[4]	0	1,100[4]	0	0
High impairment	0	0	0	0	0	0
Medium impairment	3,280[4]	3[4]	0	0		0
Minor impairment	0	0	0	1,000[4]	3[4]	0
Total	**4,030**[4]	**5**[4]	**0**	**2,100[4]**	**3**[4]	**0**
Part of coastline (%)[1]	20.1[4]	-	-	10.5[4]	-	-
Reference (m)	20,035			20,035		

[1] Refers to part of coastline (%) within the near zone + local 10-km zone, [2]includes 3,180 m of loss of beach west of Rødbyhavn which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [3]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [4]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

Table 0.9 Comparison of impacts on Fehmarn for the assessed immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridge (main alternative Var. 2 B E-E/October 2010)

Component:	**Coastal morphology, Fehmarn**					
	Immersed tunnel E-ME/August 2011			**Cable stayed bridge Var. 2 B E-E/October 2010**		
	Total coastline (m)	**Individual structures**	**Spec. Morph. features**	**Total coastline (m)**	**Individual structures**	**Spec. Morph. features**
Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	700[2]	1	0	700[2]	1	0
Medium severity	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0
Total	**700**[2]	**1**	**0**	**700**[2]	**1**	**0**
Part of coastline (%)[1]	3.1	-	-	3.1	-	-
Degree of impairments						
Very high impairment	0	0	0	0	0	0
High impairment	0	0	0	0	0	0
Medium impairment	370[3]	5[3]	0	370[3]	5[3]	0
Minor impairment	0	0	1	2,165[3]	3[3]	1
Total	**370**[3]	**5**[3]	**1**	**2,535**[3]	8[3]	**1**
Part of coastline (%)[1]	1.6	-	-	11.2	-	-
Reference (m)	22,680			22,680		

[1]refers to part of coastline (%) within the near zone+ local 10-km zone, [2] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach, [3]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

Table 0.10 Comparison matrix of impacts from Immersed tunnel and Cable stayed bridge including additional mitigating measures. For each factor, the relatively environmentally best alternative is identified. 0: No difference; (+) Small environmental benefit; + Environmental benefit; ++ Large environmental benefit. Note that even an alternative is evaluated less environmental beneficial, this does not imply that there are significant impacts on the environment

Component	**Sea bed morphology**			
Assessed sub-components	**Immersed tunnel** **E-ME/August 2011**		**Cable stayed bridge** **Variant 2 B E-E/October 2010**	
Beaches / unprotected coastline	Loss of beaches compensated by new beaches (Fehmarn and Lolland) and new coastal landscape (Lolland).	0	Insignificant loss of beach (at Fehmarn), compensation by new beach. Loss of beach/unprotected coastline smaller than for tunnel project.	0
Coastal protection	No impairments on the coastal protection on Lolland and Fehmarn (with additional mitigation measures planned by Femern A/S). Insignificant loss of coastal protection (covered by the Lolland land reclamation)	0	No impairments on the coastal protection on Lolland and Fehmarn (with additional mitigation measures planned by Femern A/S). Insignificant loss of coastal protection (covered by the marine ramp)	0
Individual structures	No significant effects on the individual structures on Lolland and Fehmarn	0	No significant effects on the individual structures on Lolland and Fehmarn	0
Special morphological features	No effects	0	Insignificant minor impact to Hyllekrog but no morphological effects on the barrier. Insignificant minor impact to Grüner Brink, but no changes to character of formation	0
Total – coastal morphology	No significant impacts on the coastline of Lolland. Loss of beaches compensated by new beaches and new coastal landscape. Femern: no significant impacts.	0	No significant impacts on the coastline of Lolland. Loss of coastline significantly smaller than for tunnel project. New beaches included in project design. Femern: no significant impacts.	0

1 INTRODUCTION

1.1 Environmental theme

The topic of this report is the impact on the so-called "Coastal Morphology" in the Fehmarnbelt. Coastal morphology is the topography (above mean sea level) and bathymetry (below mean sea level) in the coastal zone covering from dunes, dikes, coastal cliffs, or other structures which back the present coastline, to the active depth of the nearshore zone. "Active depth" is the water depth within which the wave action is strong enough to agitate any loose bed material. The morphology within the 6 m DVR90 depth contour is dealt with in the present report.

The character of the natural coastal zone is to a large extent determined by the geology in the area and the exposure to waves. If the coast consists of loose sediments, mud, sand or gravel, the coastal profiles will adjust to the exposure from the predominant waves. If the predominant waves approach the coast under an angle the wave breaking process will result in currents in the surf zone and high turbulence levels which keep the sand in suspension and transport it along the coast. This longshore sediment transport, the so-called littoral drift, is the process which lead to shoreline advance updrift of coastal structures, which block the transport zone, and erosion on the downdrift side, as presently seen on the west and east side of Rødbyhavn, respectively. Any longshore variation in the longshore transport leads to either shoreline advance or retreat. The coastal zone both on the Lolland and the Fehmarn side is dominated by narrow sandy beaches, which are backed by dikes on long stretches at low-lying areas. The coastal morphology is generally under development along the coasts of the Fehmarnbelt. The present report deals with the influence of the tunnel and bridge projects on this on-going development of the coastal morphology.

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)..

1.2 Environmental components assessed

Coastal Morphology is one out of three components under the Sub-factor Marine Soil, see Table 1.1.

The sub-components listed in Table 1.2 are addressed in the impact assessment of the component Coastal Morphology. These include beaches/unprotected sections of the coast as well as coastal protection along the coast. Coastal protection refers to structures parallel to the coast such as revetments, dikes and wave breakers. The total length of sections of the coastlines of Fehmarn and Lolland with beaches/unprotected sections as well as coastal protection are listed in Table 1.3 and Table 1.4, respectively. Individual coastal structures refer to point-structures on the coast, such as groynes, outlet structures or the harbour breakwaters/piers of Rødbyhavn and Puttgarden. Special morphological features such as spits, barrier islands and beach lagoons occurring at the Hyllekrog/Rødsand barriers and at Grüner Brink are assessed as a separate sub-component.

The coastline and the coastal morphology closer to the coast than the 6 m DVR90 depth contour are assessed in the present impact assessment. The sea bed morphology offshore the 6 m DVR90 depth contour are assessed in (FEHY 2013b) related to Sea Bed Morphology.

The influence of deposition of spill of fine sediments from the dredging activities on the bathing water is treated in (FEHY 2013c).

Table 1.1 Marine area Factor Soil with Sub-factors and components. Coastal Morphology is one out of three components under the Marine area Factor Soil and Sub-factor Marine Soil

Factor	Sub-factor	Components
Soil	Marine Soil (including marine landscape)	Sea Bed morphology Coastal Morphology Sea Bed Chemistry

Table 1.2 Component Coastal Morphology with sub-components

Component	Sub-components
Coastal Morphology	Beaches and other unprotected sections of the coastline Coastal protection Individual coastal structures Special morphological features

Table 1.3 Sections of the coastline with the sub- components beaches and other un-protected stretches and coastal protection along the Fehmarn coast within the 10-km zone

Beaches and other unprotected sections (m)	Coastal protection (m)	Total (m)
20,925	1,755	22,680

Table 1.4 Sections of the coastline with the sub-components along the Lolland coast within the 10-km zone

Beaches and other unprotected sections (m)	Coastal protection (m)	Total (m)
12,020	8,415	20,035[1]

[1] The length of the coastline (total of 20.035 m) deviates by 400 m from the sum of Beaches and Coastal protection due to overlapping of beach and coastal protection at Hyldtofte Østersøbad, where a beach section of 750 m is fronted by 10 shore-parallel breakwaters of each 40 m

2 THE FEHMARNBELT FIXED LINK PROJECT

The impact assessments of the tunnel and the bridge alternatives are carried out for conceptual designs of the tunnel and bridge projects with a number of **mitigation measures included in the assessed designs of the projects**.

Following the impact assessment below, **additional mitigation measures**. have been planned for.

In Table 2.1, the mitigation measures included in the assessed designs of the projects as well as the additional mitigation measures are tabulated.

The consequences of the additional mitigation measures are commented on where relevant.

Table 2.1 Mitigation and compensation measures

Project	**Mitigation and compensation measures included in the conceptual assessed design**	**Additional mitigation and compensation measures**
Tunnel project	Erodible cliff at the eastern part of the reclamation on Lolland Two beach sections in the reclamation on Lolland A new beach section in the reclamation on Fehmarn	Nourishment of in average 14,000 m^3/year to the coast east of the reclamation New structures to replace the present outlets at Dragsminde Sluice and the two outlets east of Rødbyhavn Regular monitoring of potential erosion at Ohlenborgs Huk
Bridge project	Beaches east and west of the marine ramp on Lolland New beach section included in the marine ramp on Fehmarn	Nourishment of costal sections exposed to erosion on Lolland by the bridge project (approximately 1,500 m^3/year at Bredfjed, 10,000-12,000 m^3/year east of the marine ramp) Monitoring of sedimentation and improved/new outlet structure for Dragsminde Sluice at Sandholm (Lolland) Monitoring of sedimentation and new/improved structures to ensure the functionality of the present two outlets east of the eastern breakwater of Rødbyhavn on Lolland Nourishment of costal sections exposed to erosion by the bridge project (approximately 2,000 m^3/year) between Marienleuchte and Presen on Fehmarn Monitoring of sedimentation and improved/new structure if required for water outlet from Blankenwish on Fehmarn Monitoring of erosion and new/improved structures if required to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte, Fehmarn

2.1 General description of the project

The Impact assessment is undertaken for two fixed link solutions:

- Immersed tunnel E-ME (August 2011)
- Cable Stayed Bridge Variant 2 B-EE (October 2010)

2.1.1 The Immersed Tunnel (E-ME August 2011)

The alignment for the immersed tunnel passes east of Puttgarden, crosses the Fehmarnbelt in a soft curve and reaches Lolland east of Rødbyhavn as shown in Figure 2.1ure 2.1 along with near-by NATURA2000 sites.

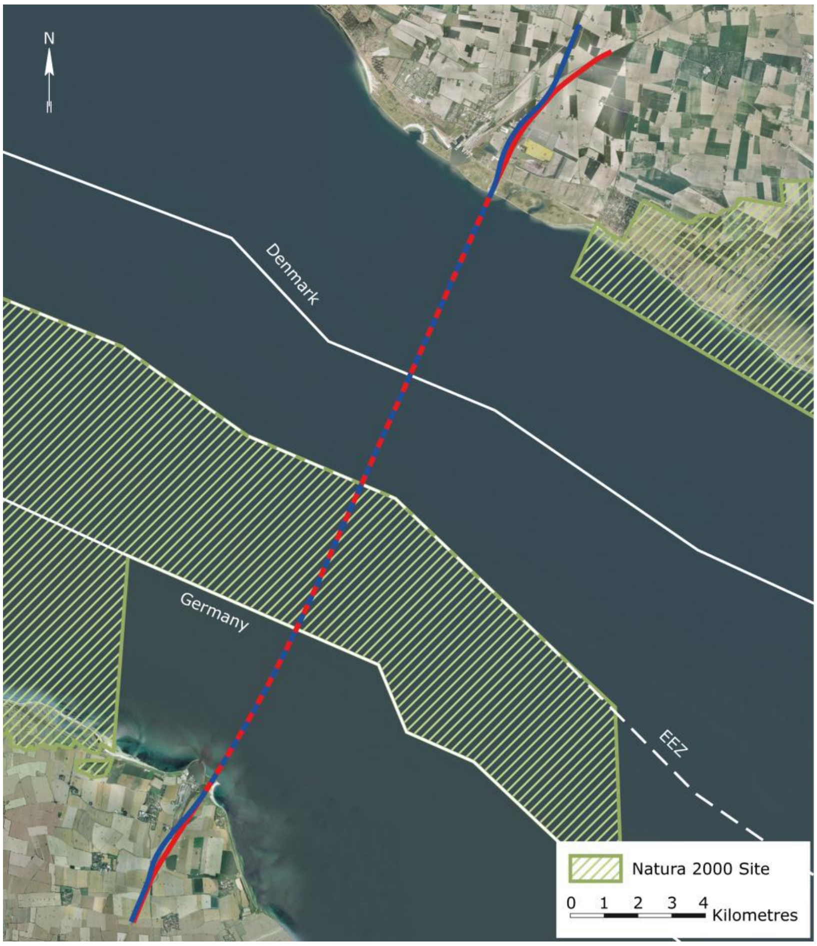

Figure 2.1 Proposed alignment for immersed tunnel E-ME (August 2011)

Tunnel trench

The immersed tunnel is constructed by placing tunnel elements in a trench dredged in the seabed, see Fig. 2.2. The proposed methodology for trench dredging comprises mechanical dredging using Backhoe Dredgers (BHD) up to 25m water depth and Grab Dredgers (GD) in deeper waters. A Trailing Suction Hopper Dredger (TSHD) will be used to rip the clay before dredging with GD. The material will be loaded into barges and transported to the near-shore reclamation areas where the soil will be unloaded from the barges by small BHDs. A volume of approx. 14.5 mio. m^3 sediment is handled.

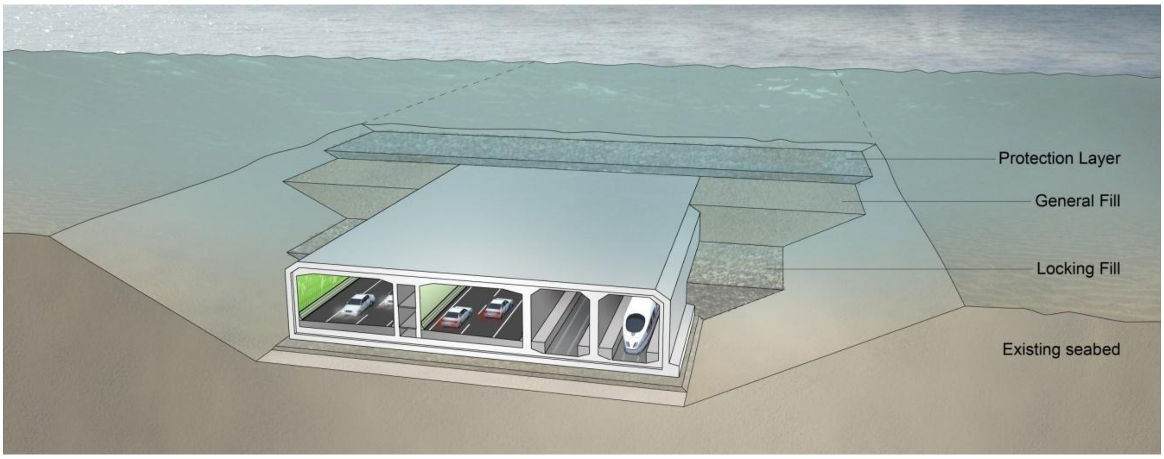

Figure 2.2 Cross section of dredged trench with tunnel element and backfilling

A bedding layer of gravel forms the foundation for the elements. The element is initially kept in place by placing locking fill followed by general fill, while on top there is a stone layer protecting against damage from grounded ships or dragging anchors. The protection layer and the top of the structure are below the existing seabed level except near the shore. At these locations, the seabed is locally raised to incorporate the protection layer over a distance of approximately 500-700m from the proposed coastline. Here the protection layer is thinner and made from concrete and a rock layer.

Tunnel elements

There are two types of tunnel elements: standard elements and special elements. There are 79 standard elements, see Fig. 2.3. Each standard element is approximately 217 m long, 42m wide and 9m tall. Special elements are located approximately every 1.8 km providing additional space for technical installations and maintenance access. There are 10 special elements. Each special element is approximately 46m long, 45m wide and 13m tall. After placement of the elements, the tunnel trench will be backfilled with marine material, potentially partly from Kriegers Flak.

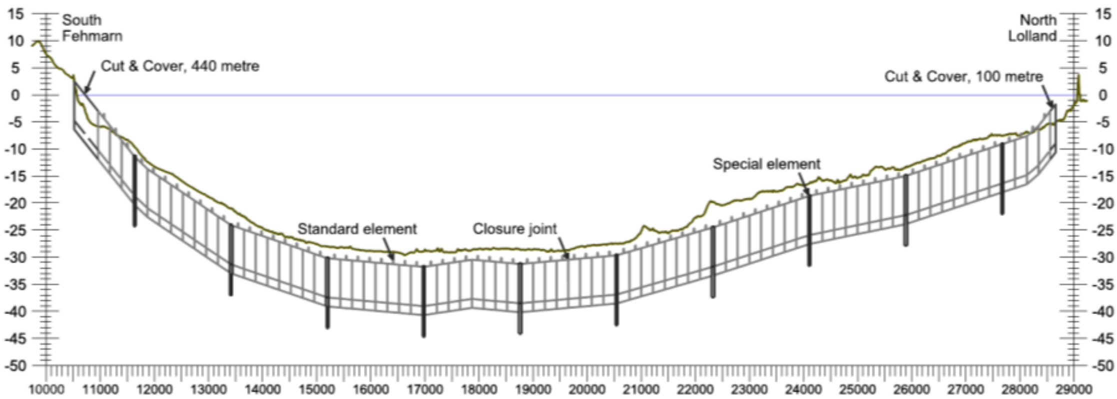

Figure 2.3 Vertical tunnel alignment showing depth below sea level

The cut and cover tunnel section beyond the light screens is approximately 440m long on Lolland and 100m long on Fehmarn. The foundation, walls, and roof are constructed from cast in-situ reinforced concrete.

Tunnel drainage
The tunnel drainage system will remove rainwater and water used for cleaning the tunnel. Rainwater entering the tunnel will be limited by drainage systems on the approach ramps. Fire fighting water can be collected and contained by the system for subsequent handling. A series of pumping stations and sump tanks will transport the water from the tunnel to the portals where it will be treated as required by environmental regulations before being discharged into the Fehmarnbelt.

Reclamation areas
Reclamation areas are planned along both the German and Danish coastlines to accommodate the dredged material from the excavation of the tunnel trench. The size of the reclamation area on the German coastline has been minimized. Two larger reclamations are planned on the Danish coastline. Before the reclamation takes place, containment dikes are to be constructed some 500m out from the coastline.

The landfall of the immersed tunnel passes through the shoreline reclamation areas on both the Danish and German sides

Fehmarn reclamation areas
The proposed reclamation at the Fehmarn coast does not extend towards north beyond the existing ferry harbour outer breakwater at Puttgarden. The extent of the Fehmarn reclamation is shown in Fig. 2.4. The reclamation area is designed as an extension of the existing terrain with the natural hill turning into a plateau behind a coastal protection dike 3.5m high. The shape of the dike is designed to accommodate a new beach close to the settlement of Marienleuchte.

Figure 2.4 Proposed reclamation area at Fehmarn

The reclaimed land behind the dike will be landscaped to create an enclosed pasture and grassland habitat. New public paths will be provided through this area leading to a vantage point at the top of the hill, offering views towards the coastline and the sea.

The Fehmarn tunnel portal is located behind the existing coastline. The portal building on Fehmarn houses a limited number of facilities associated with essential equipment for operation and maintenance of the tunnel and is situated below ground level west of the tunnel.

A new dual carriageway is to be constructed on Fehmarn for approximately 3.5km south of the tunnel portal. This new highway rises out of the tunnel and passes onto an embankment next to the existing harbour railway. The remainder of the route of the highway is approximately at level. A new electrified twin track railway is to be constructed on Fehmarn for approximately 3.5km south of the tunnel portal. A lay-by is provided on both sides of the proposed highway for use by German customs officials.

Lolland reclamation area

There are two reclamation areas on Lolland, located either side of the existing harbour. The reclamation areas extend approximately 3.7km east and 3.4km west of the harbour and project approximately 500m beyond the existing coastline into the Fehmarnbelt. The proposed reclamation areas at the Lolland coast do not extend beyond the existing ferry harbour outer breakwaters at Rødbyhavn.

The sea dike along the existing coastline will be retained or reconstructed, if temporarily removed. A new dike to a level of +3m protects the reclamation areas against the sea. To the eastern end of the reclamation, this dike rises as a till cliff to a level of +7m. Two new beaches will be established within the reclamations. There will also be a lagoon with two openings towards Fehmarnbelt, and revetments at the openings. In its final form the reclamation area will appear as three types of landscapes: recreation area, wetland, and grassland - each with different natural features and use.

The Lolland tunnel portal is located within the reclamation area and contained within protective dikes, see Fig. 2.5. The main control centre for the operation and maintenance of the Fehmarnbelt Fixed Link tunnel is housed in a building located over the Danish portal. The areas at the top of the perimeter wall, and above the portal building itself, are covered with large stones as part of the landscape design. A path is provided on the sea-side of the proposed dike to serve as recreation access within the reclamation area.

Figure 2.5 Proposed design of tunnel portal area at Lolland

A new dual carriageway is to be constructed on Lolland for approximately 4.5km north of the tunnel portal. This new motorway rises out of the tunnel and passes onto an embankment. The remainder of the route of the motorway is approximately at level. A new electrified twin track railway is to be constructed on Lolland for approximately 4.5km north of the tunnel portal. A lay-by is provided in each direction off the landside highway on the approach to the tunnel for use by Danish customs officials. A facility for motorway toll collection will be provided on the Danish landside.

Marine construction works
The temporary works comprises the construction of two temporary work harbours, the dredging of the portal area and the construction of the containment dikes. For the harbor on Lolland an access channel is also provided. These harbours will be integrated into the planned reclamation areas and upon completion of the tunnel construction works, they will be dismantled/removed and backfilled.

Production site
The current design envisages the tunnel element production site to be located in the Lolland east area in Denmark. Fig. 2.6 shows one production facility consisting of two production lines. For the construction of the standard tunnel elements for the Fehmarn tunnel four facilities with in total eight production lines are anticipated.

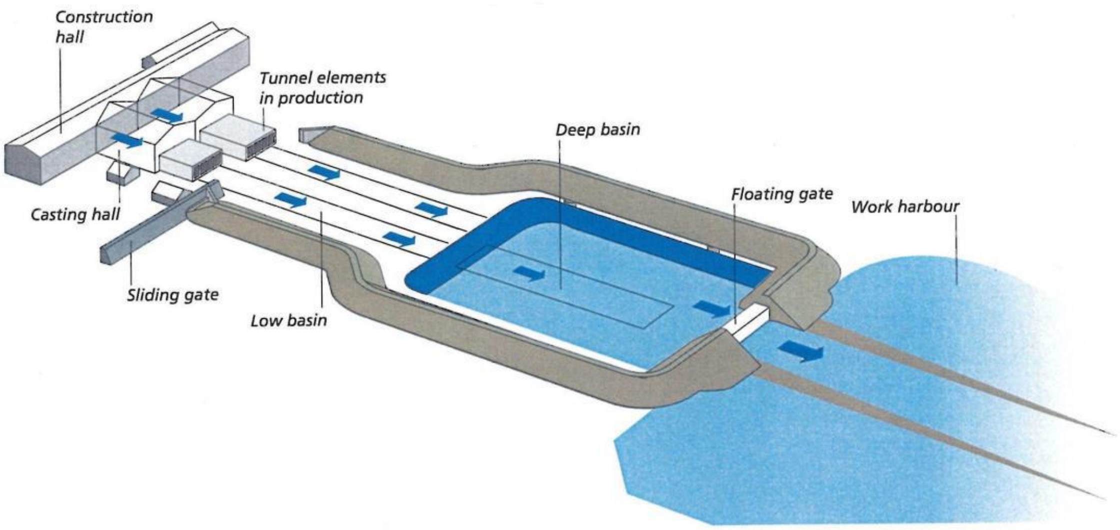

Figure 2.6 Production facility with two production lines

In the construction hall, which is located behind the casting and curing hall, the reinforcement is handled and put together to a complete reinforcement cage for one tunnel segment. The casting of the concrete for the segments is taking place at a fixed location in the casting and curing hall. After the concrete of the segments is cast and hardened enough the formwork is taken down and the segment is pushed forward to make space for the next segment to be cast. This process continues until one complete tunnel element is cast. After that, the tunnel element is pushed into the launching basin. The launching basin consists of an upper basin, which is located at ground level and a deep basin where the tunnel elements can float. In the upper basin the marine outfitting for the subsequent towing and immersion of the element takes place. When the element is outfitted, the sliding gate and floating gate are closed and sea water is pumped into the launching basin until the elements are floating. When the elements are floating they are transferred from the low basin to the deep basin. Finally the water level is lowered to normal sea level, the floating gate opened and the element towed to sea. The proposed lay-out of the production site is shown in Fig. 2.7.

Dredging of approx. 4 million m^3 soil is required to create sufficient depth for temporary harbours, access channels and production site basins.

Figure 2.7 Proposed lay-out of the production site east of Rødbyhavn

2.1.2 *The Cable Stayed Bridge (Variant 2 B-EE, October 2010)*

The alignment for the marine section passes east of Puttgarden harbour, crosses the belt in a soft S-curve and reaches Lolland east of Rødbyhavn, see Fig. 2.8.

Bridge concept

The main bridge is a twin cable stayed bridge with three pylons and two main spans of 724m each. The superstructure of the cable stayed bridge consists of a double deck girder with the dual carriageway road traffic running on the upper deck and the dual track railway traffic running on the lower deck. The pylons have a height of 272m above sea level and are V-shaped in transverse direction. The main bridge girders are made up of 20m long sections with a weight of 500 to 600t. The standard approach bridge girders are 200m long and their weight is estimated to ~ 8,000t.

Caissons provide the foundation for the pylons and piers of the bridge. Caissons are prefabricated placed 4m below the seabed. If necessary, soils are improved with 15m long bored concrete piles. The caissons in their final positions end 4m above sea level. Prefabricated pier shafts are placed on top of the approach bridge caissons. The pylons are cast in situ on top of the pylon caissons. Protection Works are prefabricated and installed around the pylons and around two piers on both sides of the pylons. These works protrudes above the water surface. The main bridge is connected to the coasts by two approach bridges. The southern approach bridge is 5,748m long and consists of 29 spans and 28 piers. The northern approach bridge is 9,412m long and has 47 spans and 46 piers.

Figure 2.8 Proposed main bridge part of the cable stayed bridge

Land works
A peninsula is constructed both at Fehmarn and at Lolland to use the shallow waters east of the ferry harbours breakwater to shorten the Fixed Link Bridge between its abutments. The peninsulas consist partly of a quarry run bund and partly of dredged material and are protected towards the sea by revetments of armour stones.

Fehmarn
The peninsula on Fehmarn is approximately 580m long, measured from the coastline, see Fig. 2.9. The gallery structure on Fehmarn is 320m long and enables a separation of the road and railway alignments. A 400m long ramp viaduct bridge connects the road from the end of the gallery section to the motorway embankment. The embankments for the motorway are 490m long. The motorway passes over the existing railway tracks to Puttgarden Harbour on a bridge. The profile of the railway and motorway then descend to the existing terrain surface.

Lolland
The peninsula on Lolland is approximately 480m long, measured from the coastline. The gallery structure on Lolland is 320m long. The existing railway tracks to Rødbyhavn will be decommissioned, so no overpass will be required. The viaduct bridge for the road is 400m long, the embankments for the motorway are 465m long and for the railway 680m long. The profile of the railway and motorway descends to the natural terrain surface.

Figure 2.9 Proposed peninsula at Fehmarn east of Puttgarden

Drainage on main and approach bridges
On the approach bridges the roadway deck is furnished with gullies leading the drain water down to combined oil separators and sand traps located inside the pier head before discharge into the sea.

On the main bridge the roadway deck is furnished with gullies with sand traps. The drain water passes an oil separator before it is discharged into the sea through the railway deck.

Marine construction work
The marine works comprises soil improvement with bored concrete piles, excavation for and the placing of backfill around caissons, grouting as well as scour protection. The marine works also include the placing of crushed stone filling below and inside the Protection Works at the main bridge.

Soil improvement will be required for the foundations for the main bridge and for most of the foundations for the Fehmarn approach bridge. A steel pile or reinforcement cage could be placed in the bored holes and thereafter filled with concrete.

The dredging works are one of the most important construction operations with respect to the environment, due to the spill of fine sediments. It is recommended that a grab hopper dredger with a hydraulic grab be employed to excavate for the caissons both for practical reasons and because such a dredger minimises the sediment spill. If the dredged soil cannot be backfilled, it must be relocated or disposed of.

Production sites

The temporary works comprises the construction of two temporary work harbours with access channels. A work yard will be established in the immediate vicinity of the harbours, with facilities such as concrete mixing plant, stockpile of materials, storage of equipment, preassembly areas, work shops, offices and labour camps.

The proposed lay-out of the production site is shown in Fig. 2.10.

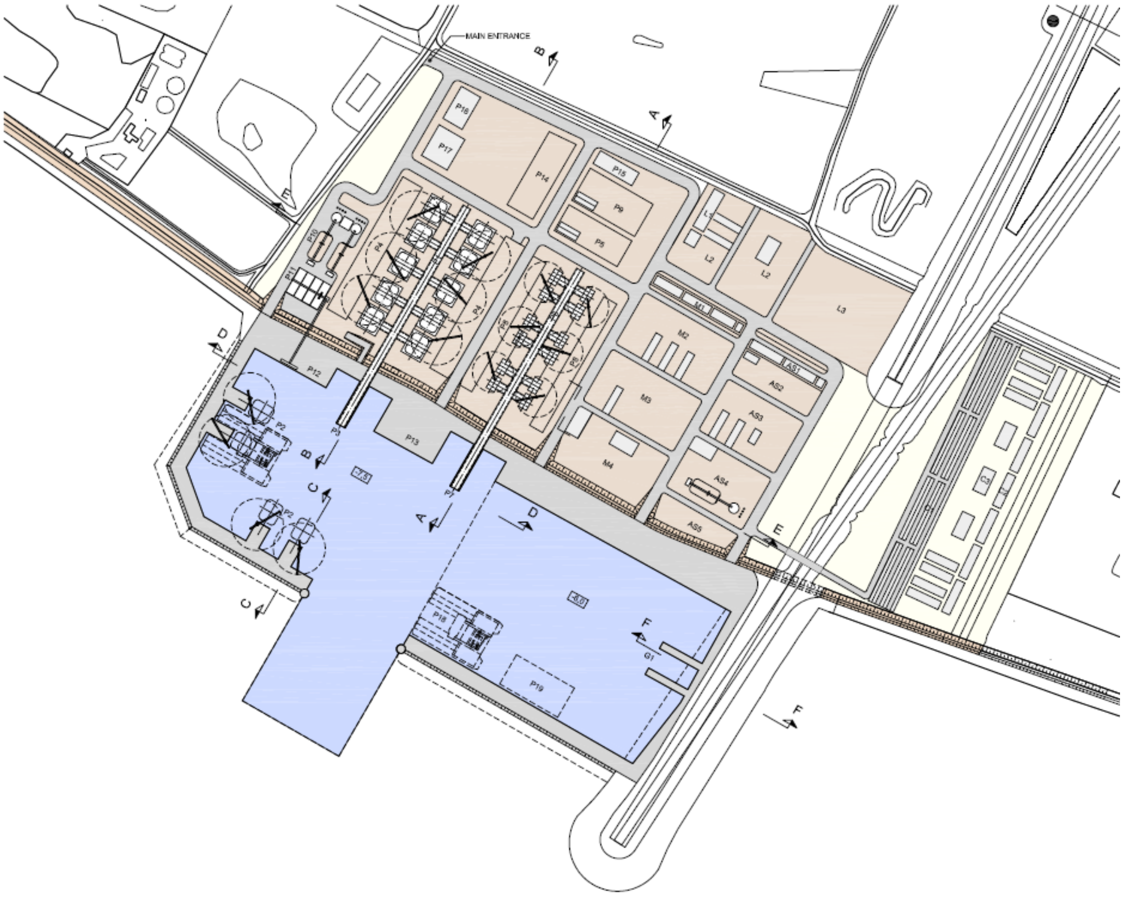

Figure 2.10 Proposed lay-out of the production site at Lolland east of Rødbyhavn

2.2 Relevant project pressures

Impacts on the coastlines of Fehmarn and Lolland are caused by the permanent structures. The relevant project pressures and potential impacts are described below for the tunnel as well as the bridge alternative.

Temporary structures such as the temporary work harbours and temporary work areas occupying part of the coast and potentially influencing the transport pattern along the coast on a short time-scale are not considered to cause any significant impacts on the coastlines of Fehmarn and Lolland compared to the effects caused by the permanent structures, which impact the coastlines throughout the lifetime of the project.

The impacts on the coastal morphology from the tunnel or bridge project develop and extend further in time than the 25-30 years, which is used as the differentiator between temporary and permanent effects. All impacts from the tunnel project are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures mentioned above. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The ferry operation is not expected to have any significant impacts on the sediment budget for the coastlines of Fehmarn and Lolland. The assessment carried out for the situation with continued ferry operation is therefore expected to cover the situation without continued ferry operation, which is hence not assessed further.

2.2.1 Project pressures for the tunnel alternative

Impacts on the coastlines of Fehmarn and Lolland are caused by the permanent structures, the reclamations and the protection reefs, and by the access channel to the production facilities on Lolland. The pressures and potential impacts are listed in Table 2.2.

The impacts on the coast are caused by the reclamations including new beaches occupying part of the original coastline and blocking the natural transport of sediment along the coast. The reclamations and protection reefs, but also the access channel to the production facilities on Lolland will cause changes to the nearshore wave field and thereby changes to the sediment transport along the coasts.

Table 2.2 Project pressures for component Coastal Morphology in the case of the main alternative of the tunnel

Project Features	Environmental pressure	Potential impacts
Permanent structures	**Pressure 1:** Reclamations and protection reefs of Lolland and Fehmarn Access channel to production facility on Lolland	Increased erosion/accretion along beaches/unprotected sections of the coastline Increased erosion in front of structures/ failure of structures Changes to special morphological features

2.2.2 Project pressures for the bridge alternative

Impacts on the coastlines of Fehmarn and Lolland are caused by the permanent structures in the bridge project: the marine ramps with the attached beaches and the piers and pylons of the bridge. The pressures and potential impacts are listed in Table 2.3.

The impacts on the coast are caused by the marine ramps including beaches/reclamations occupying part of the original coastline, blocking the natural transport of sediment along the coast and the changes to the sediment transport as a result of changes to the nearshore wave field.

Table 2.3 Project pressures for component Coastal Morphology in the case of the main alternative of the bridge

Project features	Environmental pressure	Potential impacts
Permanent structures	**Pressure 1:** Permanent structures comprising piers/pylons and marine ramps with beaches	Increased erosion/accretion along beaches/unprotected sections of the coastline Increased erosion in front of structures/ failure of structures Changes to special morphological features

3 DATA AND METHODS

3.1 Areas of investigation

The Fehmarnbelt is part of a narrow transition area between the North Sea/Kattegat and the Baltic Sea, connecting the southern part of the Great Belt and the Kiel Bight with the Mecklenburg Bight and further over the shallow Darss Sill into the Arkona Basin of the Baltic Sea, see Figure 3.1.

This report focuses on the coastal areas near the alignment within which potential impacts from the project may occur, see Figure 3.2. These coastal areas cover the coastal stretch between Kramnitze and the barrier formation Hyllekrog on Lolland and the coastal stretch between Markelsdorfer Huk and the coast off the village of Klausdorf on Fehmarn. These stretches are shown in more detail in Figure 3.3 and Figure 3.4. A description of the baseline conditions can be found in (FEHY 2013a).

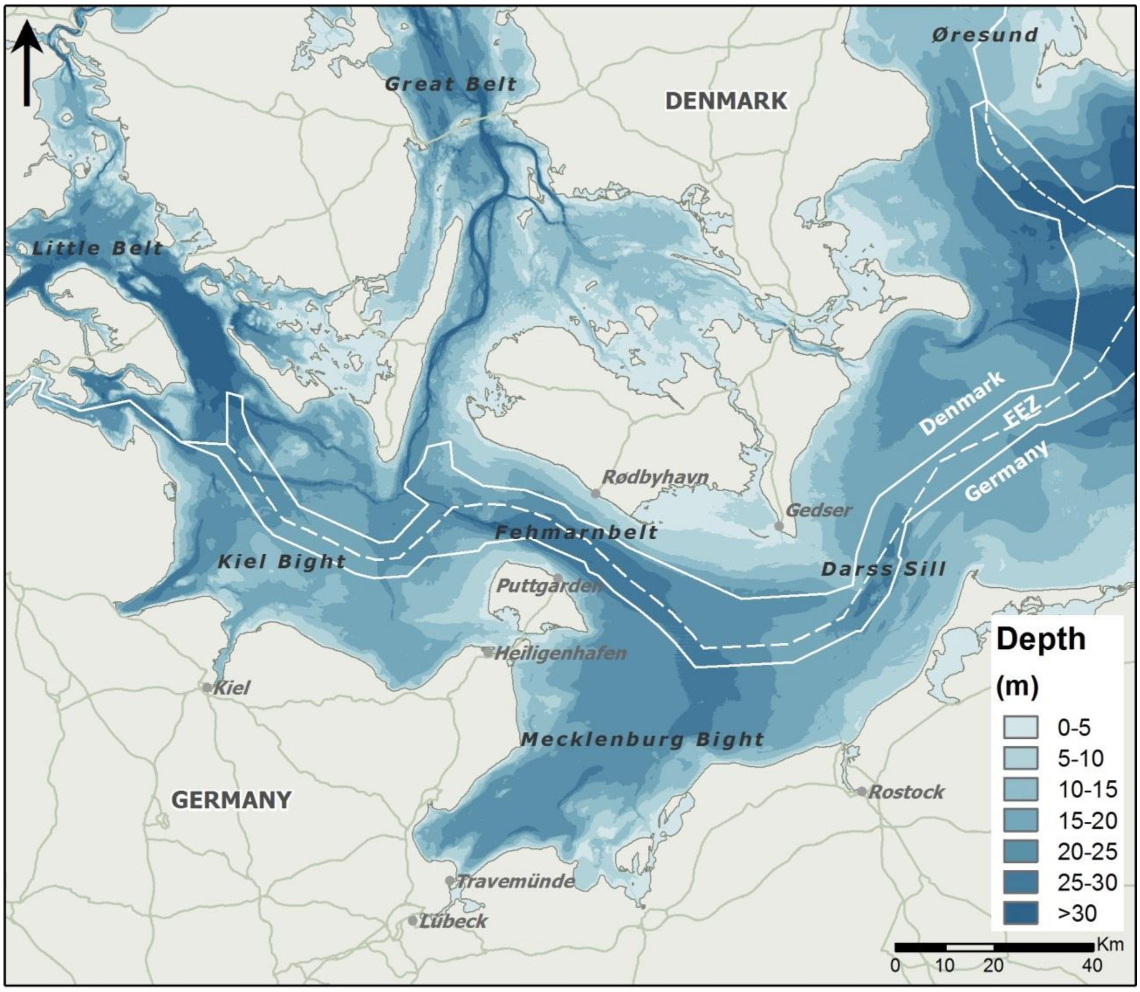

Figure 3.1 Bathymetry of the Fehmarnbelt region

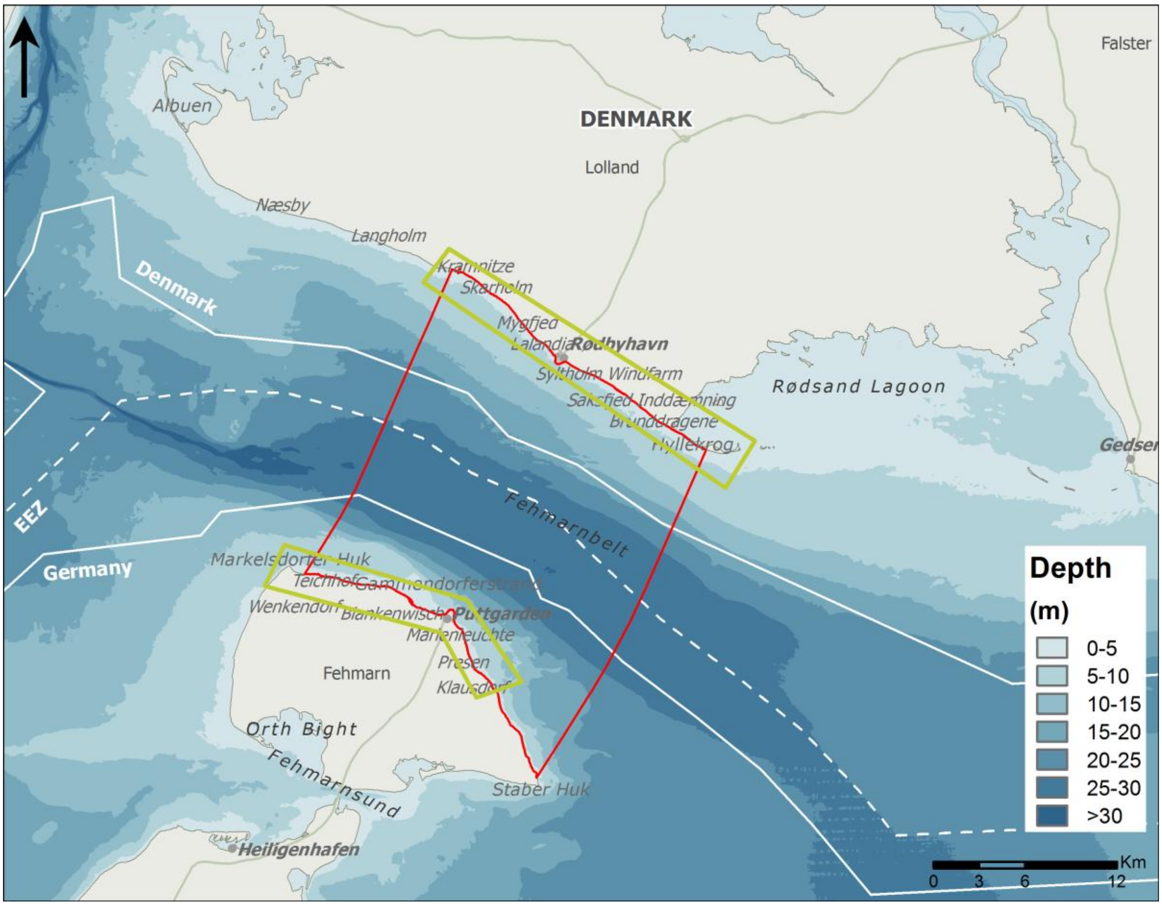

Figure 3.2 Investigation areas on Fehmarn and Lolland. Green boxes indicate the coastlines assessed. Area marked by the red curve is the 'local 10-km zone', which is the area of the Fehmarnbelt within a distance of 10 km from the planned alignment of a fixed link. Note: the local zone excludes a near zone, which is defined as a zone of 500 m around the tunnel or bridge project, respectively

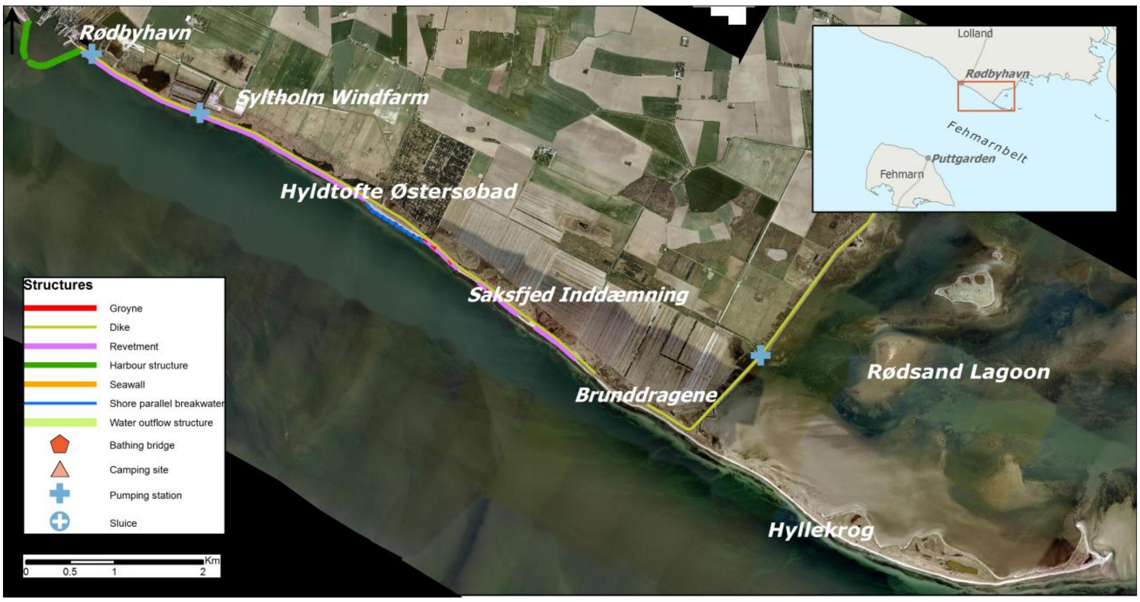

Figure 3.3 Coastal area on Lolland between Kramnitze and Rødbyhavn (upper figure) and between Rødbyhavn and Hyllekrog (lower figure). Aerial photo from 2009 (©COWI Orthophoto April 2009)

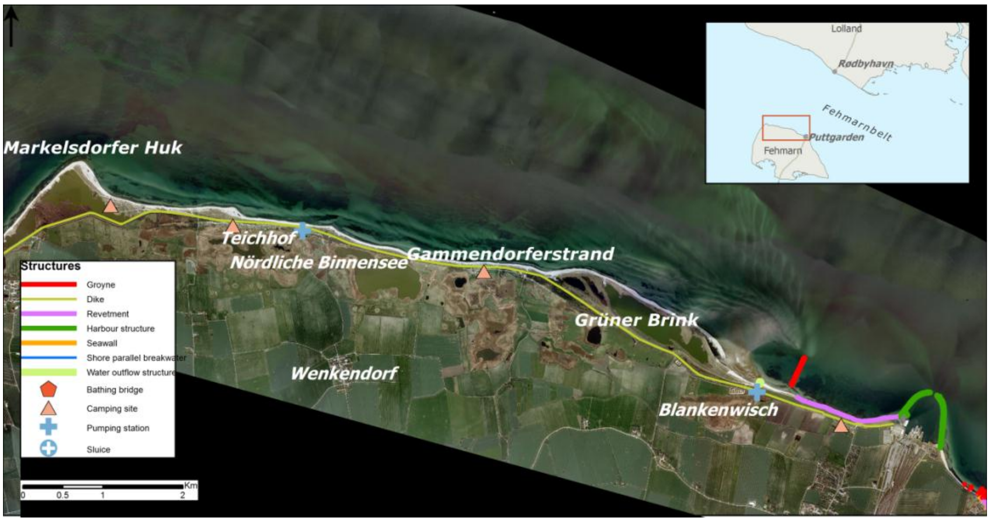

Figure 3.4 Coastal areas on Fehmarn between Markelsdorfer Huk and Puttgarden (upper figure) and between Puttgarden and Klausdorf (lower figure). Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

3.2 The Assessment Methodology

To ensure a uniform and transparent basis for the EIA, a general impact assessment methodology for the assessment of predictable impacts of the Fixed Link Project on the environmental factors (see box 3.1) has been prepared. The methodology is defined by the impact forecast methods described in the scoping report (Femern and LBV-SH-Lübeck 2010, section 6.4.2). In order to give more guidance and thereby support comparability, the forecast method has been further specified.

As the impact assessments cover a wide range of environs (terrestrial and marine) and environmental factors, the general methodology is further specified and in some cases modified for the assessment of the individual environmental factors (e.g. the optimal analyses for migrating birds and relatively stationary marine bottom fauna are not identical). These necessary modifications are explained in Section 3.2.2. The specification of methods and tools used in the present report are given in the following sections of Chapter 3.

3.2.1 Overview of terminology

To assist reading the background report as documentation for the German UVS/LPB and the Danish VVM, the Danish and German terms are given in the columns to the right.

Term	Explanation	Term DK	Term DE
Environmental factors	The environmental factors are defined in the EU EIA Directive (EU 1985) and comprise: Human beings, Fauna and flora, Soil, Water, Air, Climate, Landscape, Material assets and cultural heritage. In the sections below only the term environmental factor is used; covering all levels (factors, sub-factors, etc.; see below). The relevant level depends on the analysis.	Miljøforhold/-faktor	Schutzgut
Sub-factors	As the Fixed Link Project covers both terrestrial and marine sections, each environmental factor has been divided into three sub-factor: Marine areas, Lolland and Fehmarn (e.g. Marine waters, Water on Lolland, and Water on Fehmarn)	Sub-faktor	Teil-Schutzgut
Components and sub-components	To assess the impacts on the sub-factors, a number of components and sub-components are identified. Examples of components are e.g. Surface waters on Fehmarn, Groundwater on Fehmarn; both belonging to the sub-factor Water on Fehmarn. The sub-components are the specific indicators selected as best suitable for assessing the impacts of the Project. They may represent different characteristics of the environmental system; from specific species to biological communities or specific themes (e.g. trawl fishery, marine tourism).	Component/sub-komponent	Komponente
Construction phase	The period when the Project is constructed; including permanent and provisional structures. The construction is planned for 6½ years.	Anlægsfase	Bauphase
Structures	Constructions that are either a permanent elements of the Project (e.g. bridge pillar for bridge alternative and land reclamation at Lolland for tunnel alternative), or provisional structures such as work har-	Anlæg	Anlage

Term	Explanation	Term DK	Term DE
	bours and the tunnel trench.		
Operation phase	The period from end of construction phase until decommissioning.	Driftsfase	Betriebsphase
Permanent	Pressure and impacts lasting for the life time of the Project (until decommissioning).	Permanent	Permanent
Provisional (temporary)	Pressure and impacts predicted to be recovered within the life time of the project. The recovery time is assessed as precise as possible and is in addition related to Project phases.	Midlertidig	Temporär
Pressures	A pressure is understood as all influences deriving from the Fixed Link Project; both influences deriving from Project activities and influences originating from interactions between the environmental factors. The type of the pressure describes its relation to construction, structures or operation.	Belastning	Wirkfaktoren
Magnitude of pressure	The magnitude of pressure is described by the intensity, duration and range of the pressure. Different methods may be used to arrive at the magnitude; dependent on the type of pressure and the environmental factor to be assessed.	Belastningsstørrelse	Wirkintensität
Footprint	The footprint of the Project comprises the areas occupied by structures. It comprises two types of footprint; the permanent footprint deriving from permanent confiscation of areas to structures, land reclamation etc., and provisional footprint which are areas recovered after decommissioning of provisional structures. The recovery may be due to natural processes or Project aided re-establishment of the area.	Arealinddragelse	Flächeninanspruchnahme
Assessment criteria and Grading	Assessment criteria are applied to grade the components of the assessment schemes. Grading is done according to a four grade scale: very high, high, medium, minor or a two grade scale: special, general. In some cases grading is not doable. Grading of magnitude of pressure and sensitivity is method dependent. Grading of importance and impairment is as far as possible done for all factors.	Vurderingskriterier og graduering	Bewertungskriterien und Einstufung
Importance	The importance is defined as the functional values to the natural environment and the landscape.	Betydning	Bedeutung
Sensitivity	The sensitivity describes the environmental factors capability to resist a pressure. Dependent on the subject assessed, the description of the sensitivity may involve intolerance, recovery and importance.	Følsomhed/ Sårbarhed	Empfindlichkeit
Impacts	The impacts of the Project are the effects on the environmental factors. Impacts are divided into Loss and Impairment.	Virkninger	Auswirkung
Loss	Loss of environmental factors is caused by permanent and provisional loss of area due to the footprint of the Project; meaning that loss may be permanent or provisional. The degree of loss is described by the intensity, the duration and if feasible, the range.	Tab af areal	Flächenverlust
Severity of loss	Severity of loss expresses the consequences of occupation of land (seabed). It is analysed by combining magnitude of the Project's footprint with importance of the environmental factor lost due to the footprint.	Omfang af tab	Schwere der Auswirkungen bei Flächenverlust

Term	Explanation	Term DK	Term DE
Impairment	An impairment is a change in the function of an environmental factor.	Forringelse	Funktionsbeeinträchtigung
Degree of impairment	The degree of impairments is assessed by combining magnitude of pressure and sensitivity. Different methods may be used to arrive at the degree. The degree of impairment is described by the intensity, the duration and if feasible, the range.	Omfang/grad af forringelser	Schwere der Funktionsbeeinträchtigung
Severity of impairment	Severity of impairment expresses the consequences of the Project taking the importance of the environmental factor into consideration; i.e. by combining the degree impairment with importance.	Virkningens væsentlighed	Erheblichkeit
Significance	The significance is the concluding evaluation of the impacts from the Project on the environmental factors and the ecosystem. It is an expert judgment based on the results of all analyses.	Virkningens væsentlighed	Erheblichkeit

It should be noted that in the sections below only the term environmental factor is used; covering all levels of the receptors of the pressures of the Project (factors, sub-factors, component, sub-components). The relevant level depends on the analysis and will be explained in the following methodology sections (section 3.2.3 and onwards).

3.2.2 The Impact Assessment Scheme

The overall goal of the assessment is to arrive at the severity of impact where impact is divided into two parts; loss and impairment (see explanation above). As stated in the scoping report, the path to arrive at the severity is different for loss and impairments. For assessment of the *severity of loss* the footprint of the project (the areas occupied) and the *importance* of the environmental factors are taken into consideration. On the other hand, the assessment of severity of impairment comprises two steps; first the *degree of impairment* considering the magnitude of pressure and the sensitivity. Subsequently the severity is assessed by combining the degree of impairment and the importance of the environmental factor. The assessment schemes are shown in Figure 3.5 - Figure 3.7. More details on the concepts and steps of the schemes are given below. As mentioned above, modification are required for some environmental factors and the exact assessment process and the tools applied vary dependent on both the type of pressure and the environmental factor analysed. As far as possible the impacts are assessed quantitatively; accompanied by a qualitative argumentation.

3.2.3 Assessment Tools

For the impact assessment the assessment matrices described in the scoping report have been key tools. Two sets of matrices are defined; one for the assessment of loss and one for assessment of impairment.

The matrices applied for assessments of severity of loss and degree of impairment are given in the scoping report (Table 6.4 and Table 6.5) and are shown below in Table 3.1 and Table 3.2, respectively.

Table 3.1 *The matrix used for assessment of the severity of loss. The magnitude of pressure = the footprint of the Project is always considered to be very high*

Magnitude of the predicted pressure (footprint)	Importance of the environmental factors			
	Very high	High	Medium	Minor
Very High	**Very High**	**High**	**Medium**	**Minor**

The approach and thus the tools applied for assessment of the degree of impairment varies with the environmental factor and the pressure. For each assessment the most optimal state-of-the-art tools have been applied, involving e.g. deterministic and statistical models as well as GIS based analyses. In cases where direct analysis of causal-relationship is not feasible, the matrix based approach has been applied using one of the matrices in Table 3.2 (Table 6.5 of the scoping report) combining the grades of magnitude of pressure and grades of sensitivity. This method gives a direct grading of the degree of impairment. Using other tools to arrive at the degree of impairment, the results are subsequently graded using the impairment criteria. The specific tools applied are described in the following sections of Chapter 3.

Table 3.2 *The matrices used for the matrix based assessment of the degree of impairment with two and four grade scaling, respectively*

Magnitude of the predicted pressure	Sensitivity of the environmental factors			
	Very high	High	Medium	Minor
Very high	**General loss of function, must be substantiated for specific instances**			
High	**Very High**	**High**	**High**	**Medium**
Medium	**High**	**High**	**Medium**	**Low**
Low	**Medium**	**Medium**	**Low**	**Low**

Magnitude of the predicted pressure	Sensitivity of the environmental factors	
	Special	General
Very high	**General loss of function, must be substantiated for specific instances**	
High	**Very High**	**High**
Medium	**High**	**Medium**
Low	**Medium**	**Low**

To reach severity of impairment one additional matrix has been prepared, as this was not included in the scoping report. This matrix is shown in Table 3.3.

Table 3.3 The matrix used for assessment of the severity of impairment

Degree of impairment	Importance of the environmental factors			
	Very high	High	Medium	Minor
Very High	**Very High**	**High**	**Medium**	**Minor**
High	**High**	**High**	**Medium**	**Minor**
Medium	**Medium**	**Medium**	**Medium**	**Minor**
Low	**Minor**	**Minor**	**Minor**	**Negligible**

Degree of impairment	Importance of the environmental factors	
	Special	General
Very high	**Very High**	**Medium**
High	**High**	**Medium**
Medium	**Medium**	**Medium**
Low	**Minor**	**Minor**

3.2.4 Assessment Criteria and Grading

For the environmental assessment two sets of key criteria have been defined: Importance criteria and the Impairment criteria. The importance criteria is applied for grading the importance of an environmental factor, and the impairment criteria form the basis for grading of the impairments caused by the project. The criteria have been discussed with the authorities during the preparation of the EIA.

The impairment criteria integrate pressure, sensitivity and effect. For the impact assessment using the matrix approach, individual criteria are furthermore defined for pressures and sensitivity. The criteria were defined as part of the impact analyses (severity of loss and degree of impairment). Specific assessment criteria are developed for land and marine areas and for each environmental factor. The specific criteria applied in the present impact assessment are described in the following sections of Chapter 3 and as part of the description of the impact assessment.

The purpose of the assessment criteria is to grade according to the defined grading scales. The defined grading scales have four (very; high, Medium; minor) or two (special; general) grades. Grading of magnitude of pressure and sensitivity is method dependent, while grading of importance and impairment is as far as possible done for all factors.

3.2.5 Identifying and quantifying the pressures from the Project

The pressures deriving from the Project are comprehensively analysed in the scoping report; including determination of the pressures which are important to the individual environmental sub-factors (Femern and LBV SH Lübeck 2010, chapter 4 and 7). For the assessments the magnitude of the pressures is estimated.

The magnitudes of the pressures are characterised by their type, intensity, duration and range. The *type* distinguishes between pressures induced during construction, pressures from the physical structures (footprints) and pressures during operation. The pressures during construction and from provisional structures have varying duration while pressures from staying physical structure (e.g. bridge piers) and from the operation phase are permanent. Distinctions are also made between direct and indirect pressures where direct pressures are those imposed directly by the Project activities on the environmental factors while the indirect pressures are the consequences of those impacts on other environmental factors and thus express the interactions between the environmental factors.

The *intensity* evaluates the force of the pressure and is as far as possible estimated quantitatively. The *duration* determines the time span of the pressure. It is stated as relevant for the given pressure and environmental factor. Some pressures (like footprint) are permanent and do not have a finite duration. Some pressures occur in events of different duration. The *range* of the pressure defines the spatial extent. Outside of the range, the pressure is regarded as non-existing or negligible.

The magnitude of pressure is described by pressure indicators. The indicators are based on the modes of action on the environmental factor in order to achieve most optimal descriptions of pressure for the individual factors; e.g. mm deposited sediment within a certain period. As far as possible the magnitude is worked out quantitatively. The method of quantification depends on the pressure (spill from dredging, noise, vibration, etc.) and on the environmental factor to be assessed (calling for different aggregations of intensity, duration and range).

3.2.6 Importance of the Environmental Factors

The importance of the environmental factor is assessed for each environmental sub-factor. Some sub-factors are assessed as one unity, but in most cases the importance assessment has been broken down into components and/or sub-components to conduct a proper environmental impact assessment. Considerations about standing stocks and spatial distribution are important for some sub-factors such as birds and are in these cases incorporate in the assessment.

The assessment is based on *importance criteria* defined by the functional value of the environmental sub-factor and the legal status given by EU directives, national laws, etc. the criteria applied for the environmental sub-factor(s) treated in the present report are given in a later section.

The importance criteria are grading the importance into two or four grades (see section 3.2.4). The two grade scale is used when the four grade scale is not applicable. In a few cases such as climate, grading does not make sense. As far as possible the spatial distribution of the importance classes is shown on maps.

3.2.7 Sensitivity

The optimal way to describe the sensitivity to a certain pressure varies between the environmental factors. To assess the sensitivity more issues may be taken into consideration such as the intolerance to the pressure and the capability to recover after impairment or a provisional loss. When deterministic models are used to assess the impairments, the sensitivity is an integrated functionality of the model.

3.2.8 Severity of loss

Severity of loss is assessed by combining information on magnitude of footprint, i.e. the areas occupied by the Project with the importance of the environmental factor (Figure 3.5. Loss of area is always considered to be a very high magnitude of pressure and therefore the grading of the severity of loss is determined by the importance (see Table 3.1).

The loss is estimated as hectares of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

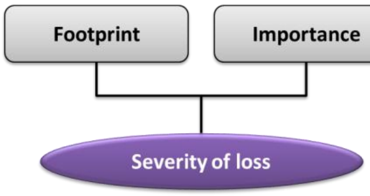

Figure 3.5 The assessment scheme for severity of loss

3.2.9 *Degree of impairment*

The degree of impairment is assessed based on the magnitude of pressure (involving intensity, duration and range) and the sensitivity of the given environmental factor (Figure 3.6). In worst case, the impairment may be so intensive that the function of the environmental factor is lost. It is then considered as loss like loss due to structures, etc.

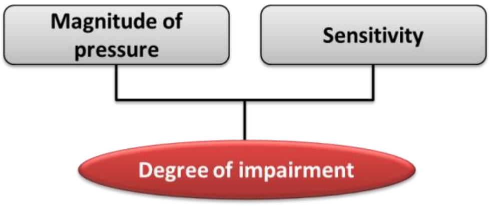

Figure 3.6 The assessment scheme for degree of impairment

As far as possible the degree is worked out quantitatively. As mentioned earlier the method of quantification depends on the environmental factor and the pressure to be assessed, and of the state-of-the-art tools available for the assessment.

No matter how the analyses of the impairment are conducted, the goal is to grade the degree of impairment using one of the defined grading scales (two or four grades). Deviations occur when it is not possible to grade the degree of impairment. The spatial distribution of the different grades of the degree of impairment is shown on maps.

3.2.10 *Severity of Impairment*

Severity of impairment is assessed from the grading's of degree of impairment and of importance of the environmental factor (Figure 3.7) using the matrix in Table 3.3.

Table 3.3 If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

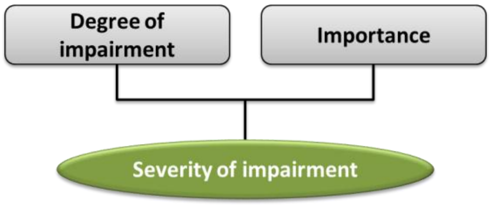

Figure 3.7 The assessment scheme for severity of impairment

In the UVS and the VVM, the results of the assessment of severity of impairment support the significance assessment. The UVS and VVM do not present the results as such.

3.2.11 Range of impacts

Besides illustrating the impacts on maps, the extent of the marine impacts is assessed by quantifying the areas impacted in predefined zones. The zones are shown in Figure 3.8. In addition the size of the impacted areas located in the German national waters and the German EEZ zone, respectively, as well as in the Danish national plus EEZ waters (no differentiation) are calculated. If relevant the area of transboundary impacts are also estimated.

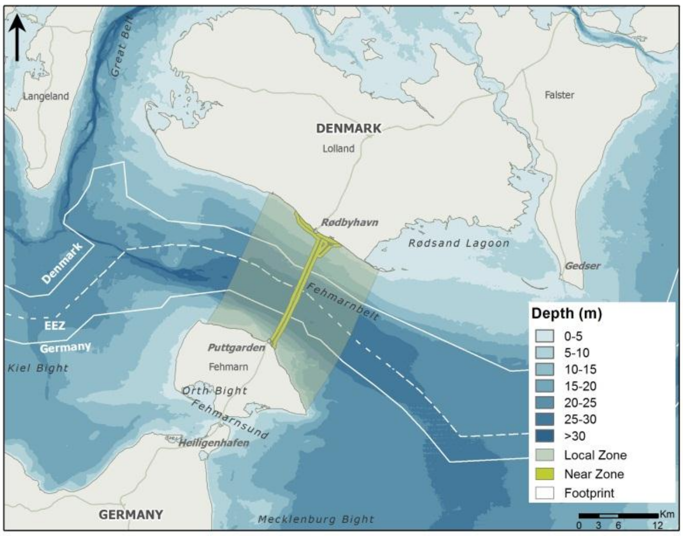

Figure 3.8 The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders are approximately 10 km from the centre of the alignment

3.2.12 Duration of impacts

Duration of impacts (provisional loss and impairments) is assessed based on recovery time (restitution time). The recovery time is given as precise as possible; stating the expected time frame from conclusion of the pressure until pre-project conditions is restored. The recovery is also related to the phases of the project using Table 3.4 as a framework.

Table 3.4 Framework applied to relate recovery of environmental factors to the consecutive phases of the Project

Impact recovered within:	In wording
Construction phase+	recovered within 2 year after end of construction
Operation phase A	recovered within 10 years after end of construction
Operation phase B	recovered within 24 years after end of construction
Operation phase C	recovery takes longer or is permanent

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)..

3.2.13 Significance

The impact assessment is finalised with an overall assessment stating the significance of the predicted impacts. This assessment of significance is based on expert judgement. The reasoning for the conclusion on the significance is explained. Aspects such as degree and severity of impairment/severity of loss, recovery time and the importance of the environmental factor are taken into consideration.

3.2.14 Comparison of environmental impacts from project alternatives

Femern A/S will prepare a final recommendation of the project alternative, which from a technical, financial and environmental point of view can meet the goal of a Fehmarnbelt Fixed Link from Denmark to Germany. As an important input to the background for this recommendation, the consortia have been requested to compare the two alternatives, immersed tunnel and cable-stayed bridge, with the aim to identify the alternative having the least environmental impacts on the environment. The bored tunnel alternative is discussed in a separate report. In order to make the comparison as uniform as possible the ranking is done using a ranking system comprising the ranks: 0 meaning that it is not possible to rank the alternatives, + meaning that the alternative compared to the other alternative has a minor environmental advantage and ++ meaning that the alternative has a noticeable advantage. The ranking is made for the environmental factor or sub-factor included in the individual report (e.g. for the marine area: hydrography, benthic fauna, birds, etc.). To support the overall assessment similar analyses are sometimes made for individual pressures or components/subcomponents. It should be noticed that the ranking addresses only the differences/similarities between the two alternatives and not the degree of impacts.

3.2.15 Cumulative impacts

The aim of the assessment of cumulative impacts is to evaluate the extent of the environmental impact of the project in terms of intensity and geographic extent compared with the other projects in the area and the vulnerability of the area. The assessment of the cumulative conditions does not only take into account existing conditions, but also land use and activities associated with existing utilized and unutilized permits or approved plans for projects in the pipe.

When more projects within the same region affect the same environmental conditions at the same time, they are defined to have cumulative impacts. A project is relevant to include, if the project meets one or more of the following requirements:

- The project and its impacts are within the same geographical area as the fixed link
- The project affects some of the same or related environmental conditions as the fixed link
- The project results in new environmental impacts during the period from the environmental baseline studies for the fixed link were completed, which thus not is included in the baseline description
- The project has permanent impacts in its operation phase interfering with impacts from the fixed link

Based on the criteria above the following projects at sea are considered relevant to include in the assessment of cumulative impacts on different environmental conditions. All of them are offshore wind farms:

Project	**Placement**	**Present Phase**	**Possible interactions**
Arkona-Becken Südost	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
EnBW Windpark Baltic 2	South east off Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, , barrier effect
Wikinger	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, , barrier effect
Kriegers Flak II	Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
GEOFReE	Lübeck Bay	Construction	Sediment spill, habitat displacement, collision risk
Rødsand II	In front of Lolland's southern coast	Operation	Coastal morphology, collision risk, barrier risk

Rødsand II is included, as this project went into operation while the baseline investigations for the Fixed Link were conducted, for which reason in principle a cumulative impact cannot be excluded.

On land, the following projects are considered relevant to include:

Project	**Placement**	**Phase**	**Possible cumulative impact**
Extension of railway	Orehoved to Holeby	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect
Construction of emergency	Guldborgsund to Rødbyhavn	Construction	Area loss, noise and dust

Project	Placement	Phase	Possible cumulative impact
lane		Operation	Landscape, barrier effect
Extension of railway	Puttgarden to Lübeck	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect
Upgrading of road to highway	Oldenburg to Puttgarden	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect

The increased traffic and resultant environmental impacts are taken into account for the environmental assessment of the fixed link in the operational phase and is thus not included in the cumulative impacts. In the event that one or more of the included projects are delayed, the environmental impact will be less than the environmental assessment shows.

For each environmental subject it has been considered if cumulative impact with the projects above is relevant.

3.2.16 Impacts related to climate change

The following themes are addressed in the EIA for the fixed link across Fehmarnbelt:

- Assessment of the project impact on the climate, defined with the emission of greenhouse gasses (GHG) during construction and operation
- Assessment of expected climate change impact on the project
- Assessment of the expected climate changes impact on the baseline conditions
- Assessment of cumulative effect between expected climate changes and possible project impacts on the environment
- Assessment of climate change impacts on nature which have to be compensated and on the compensated nature.

Changes in the global climate can be driven by natural variability and as a response to anthropogenic forcing. The most important anthropogenic force is proposed to be the emission of greenhouse gases, and hence an increasing of the concentration of greenhouse gases in the atmosphere.

Even though the lack of regulations on this issue has made the process of incorporating the climate change into the EIA difficult, Femern A/S has defined the following framework for assessment of importance of climate change to the environmental assessments made:

- The importance of climate change is considered in relation to possible impacts caused by the permanent physical structures and by the operation of the fixed link.
- The assessment of project related impacts on the marine hydrodynamics, including the water flow through the Fehmarnbelt and thus the water exchange

of the Baltic Sea, is based on numerical model simulations, for baseline and the project case, combined with general model results for the Baltic Sea and climate change.

- Possible consequences of climate change for water birds are analysed through climatic niche models. A large-scale statistical modelling approach is applied using available data on the climatic and environmental factors determining the non-breeding distributions at sea of the relevant waterbirds in Northern European waters.

- The possible implications of climate change for marine benthic flora and fauna, fish, marine mammals, terrestrial and freshwater flora and fauna, coastal morphology and surface and ground water are addressed in a more qualitative manner based on literature and the outcome of the hydrodynamic and ecological modelling.

- Concerning human beings, soil (apart from coastal morphology), air, landscape, material assets and the cultural heritage, the implications of climate changes for the project related impacts are considered less relevant and are therefore not specifically addressed in the EIA.

The specific issues have been addressed in the relevant background reports.

3.2.17 How to handle mitigation and compensation issues

A significant part of the purpose of an EIA is to optimize the environmental aspects of the project applied for, within the legal, technical and economic framework. The optimization occurs even before the environmental assessment has been finalized and the project, which forms the basis for the present environmental assessment, is improved environmentally compared to the original design. The environmental impacts, which are assessed in the final environmental assessment, are therefore the residual environmental impacts that have already been substantially reduced.

Similarly, a statement of the compensation measures that will be needed to compensate for the loss and degradation of nature that cannot be averted shall be prepared. Compensating measures shall not be described in the impact assessment of the individual components and are therefore not treated in the background reports, but will be clarified in the Danish EIA and the German LBP (Landschaftspflegerischer Begleitplan), respectively.

In the background reports, the most important remediation measures which are included in the final project and are of relevance to the assessed subject are mentioned. In addition additional proposals that are simple to implement are presented.

3.3 Modelling tools and methodologies

The present section gives a brief overview of modelling tools and applied methods including references to relevant reports.

3.3.1 Wave modelling

Information on the nearshore waves in the situation after the construction of the tunnel or the bridge is obtained by numerical modelling.

The nearshore wave conditions are predicted by simulations of the wave fields applying the numerical wave model, MIKE 21 SW, developed by DHI. MIKE 21 Spectral Wave Model is a third generation spectral wind-wave model. The model simulates the growth, decay and transformation of wind generated waves and swells in offshore and coastal areas. More detailed information about the model can be found in (DHI 2011a).

This modelling tool was also applied in the evaluation of the baseline conditions (FEHY 2013a) and wave modelling for the impact assessment follows the same procedures as the wave modelling performed for the baseline situation, refer to (FEHY 2013a) for a description of the wave model setup.

Calculations of the wave conditions (wave heights, wave directions and wave periods) are carried out for a time period of 21 years (1989-2010) with hourly values. The calculations are performed in a fine grid of calculation points (mesh points).

In the impact assessment, the effects of the structures involved in the projects are included in the wave modelling, see the following sections.

It should be noted that in the baseline study it was found necessary to adjust the nearshore waves, since some deviations were found between measured and modelled waves. The deviations have their origin in the wind field applied as forcing for the waves and vary with the directions from which the waves approach. A thorough description is included in (FEHY 2013a). The adjustments of the nearshore waves in the baseline situation are applied also to the modelled nearshore waves for the situations with the tunnel project and the bridge project, respectively.

Wave modelling for the tunnel project

- In the tunnel project, the structures, which have an impact on the wave fields, are included in the calculation mesh. These include:The reclamations on the Lolland and Fehmarn side. These are included as additional land areas in the calculations

- The protection layers in the areas where the tunnel approaches the reclamations

- The access channel to the production facilities on Lolland

- The new beaches are included as additional land areas in the calculation mesh. Offshore from the waterline, the water depths have been decreased to have a beach slope in the order of 1:30. This corresponds to infill with sand with a grain diameter about 0.3 mm (Mangor 2004)

The tunnel trench itself will not influence the wave field, since the natural water depths are maintained above the tunnel trench. Also the lagoon and the bay in the reclamation area on the Lolland side are not included.

The calculation mesh including the structures at the Lolland and Fehmarn side, respectively, are shown in Figure 3.9.

The impacts on the waves from the tunnel are discussed in Sections 5.1.2 and 5.1.5.

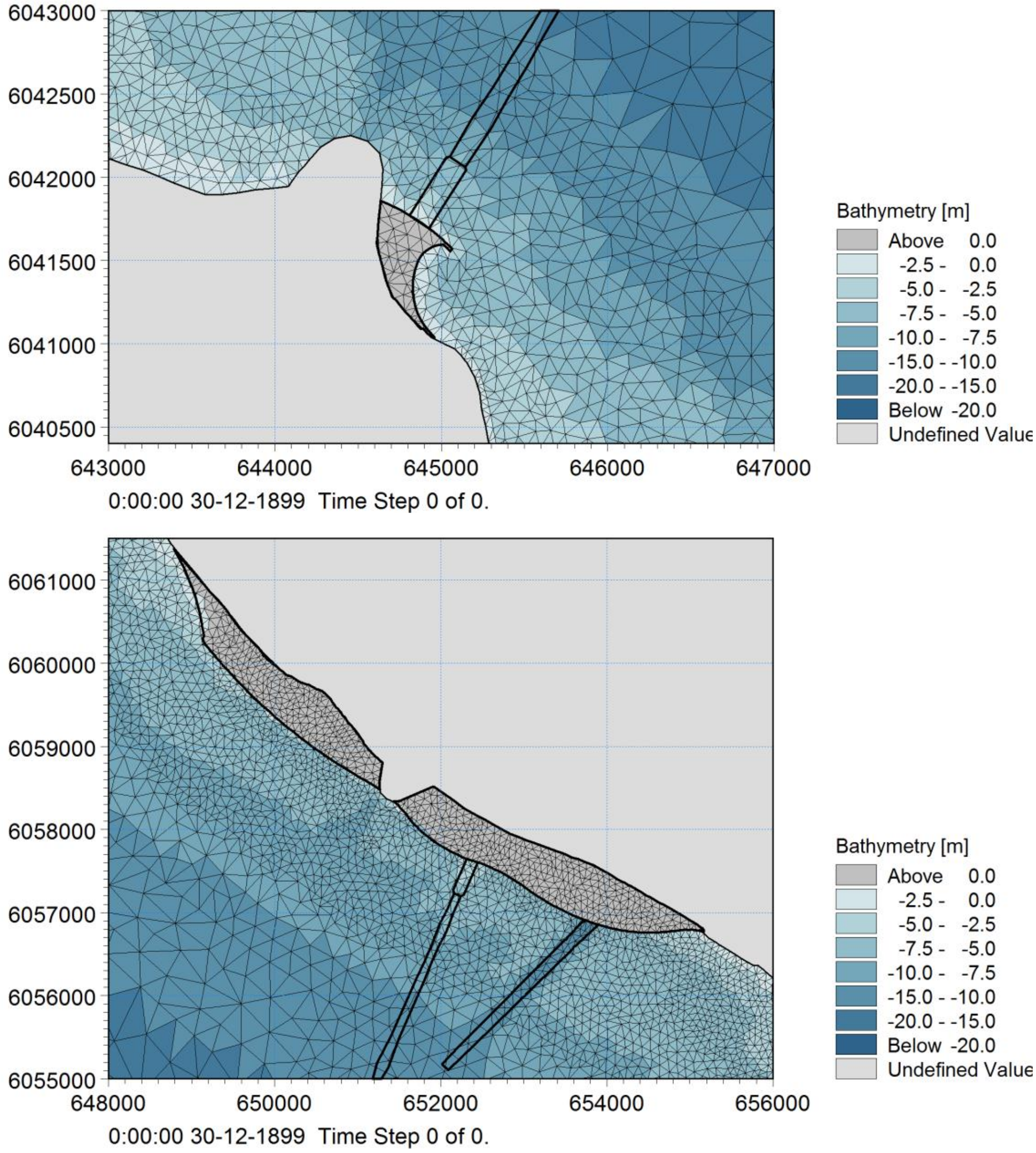

Figure 3.9 Inclusion of structures for the tunnel project in the wave model calculation mesh. Upper figure: Fehmarn. Lower figure: Lolland

Wave modelling for the bridge project

In the wave simulations for the bridge project, the man-made structures which have an impact on the wave fields are included in the following way:

- Marine ramps at the Lolland and Fehmarn side are included as additional land areas in the calculations
- The new beaches are included as additional land areas in the calculation mesh. Offshore from the waterline, the water depths have been decreased to have a beach slope in the order of 1:30. This corresponds to infill with sand with a grain diameter about 0.3 mm (Mangor 2004)
- The effect of the bridge piers and pylons is included by altering the transmission of wave energy at the locations of the structures. This is described in further details below and in Appendix A. It is assumed that the energy is reflected 180

degrees and no energy loss is assumed. The effect of wave reflection on the wave field is therefore considered conservative

The calculation mesh including the structures at the Lolland and Fehmarn side and the locations of the piers/pylons, respectively, are shown in Figure 3.10.

The temporal work harbours are not included as they will be demolished and have no permanent effects.

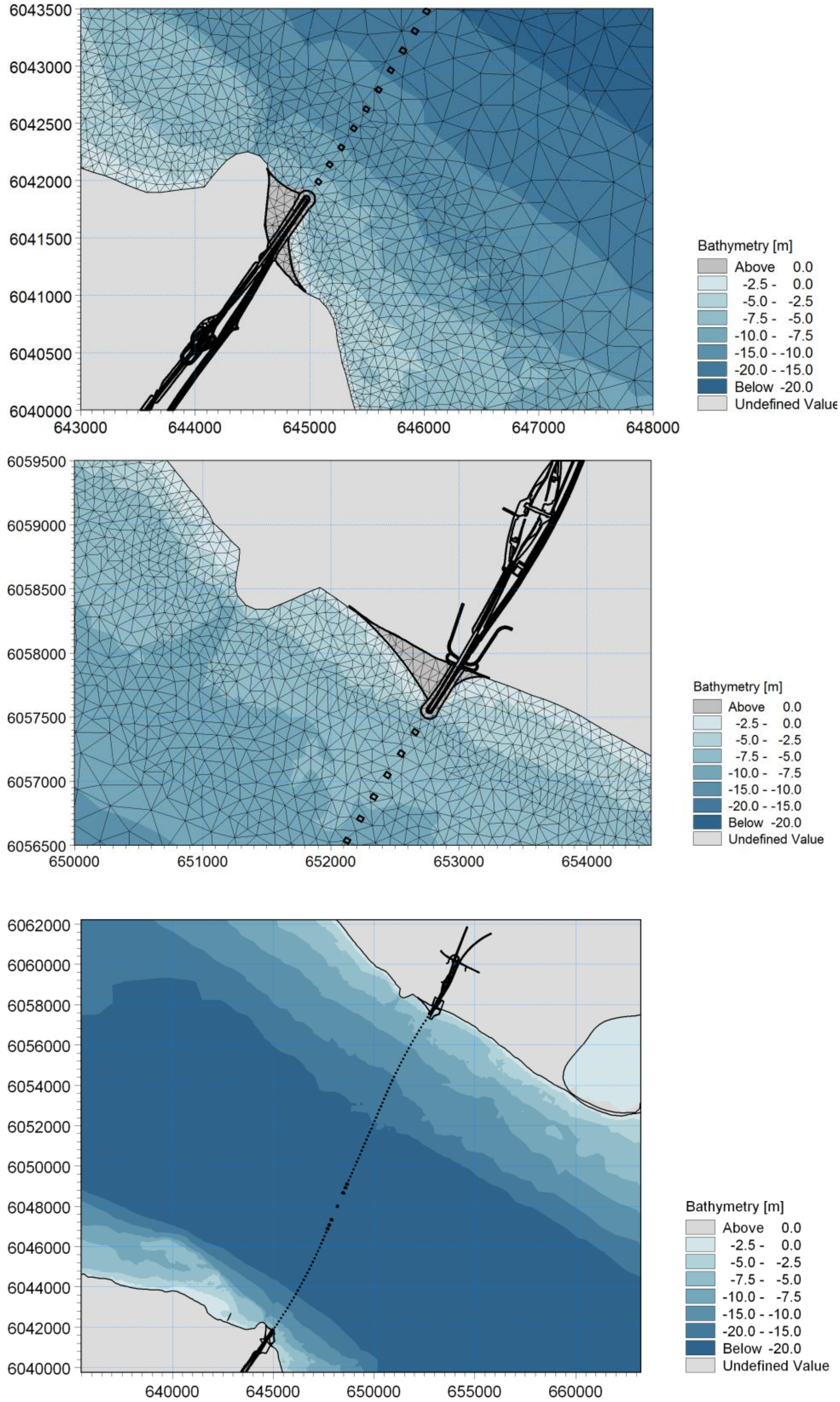

Figure 3.10 Inclusion of structures for the bridge project in the wave model calculation mesh. Upper figure: Fehmarn. Central figure: Lolland. Lower figure: location of bridge piers/pylons

Effect of bridge piers/pylons in the wave model

When waves interact with bridge pier/pylon foundations, spreading of the wave energy takes place.

The main cause for the spreading of wave energy in the area of bridge piers/pylons is reflection and diffraction of the waves caused by the structures. Diffraction is the process by which wave energy is transmitted around the structure. The physical processes of reflection and diffraction are well known and happen around all off-shore structures, such as bridge piers, offshore platforms, and breakwaters. Other mechanisms as friction and separation also reduce the wave energy. Separation is the process, where the flow very near the surface/foundation detaches from the surface and creates lee-side vortices. Based on experience, however, friction and separation are known to be insignificant compared to the other effects.

The wave energy flux is proportional with the square of the wave height. The change of the wave height and hence the energy flux due to reflection/diffraction effects depends on:

- water depth
- wave period for the incoming waves
- the shape and size of the pier/pylon-foundation
- the number of piers/pylons and the distance between them

In order to quantify the wave height changes a three-step procedure has been used:

1. Detailed calculations of the wave climate around a single foundation: calculations are performed for a selection of bridge piers/pylons using a separate modelling tool, WAMIT. An example of how the foundations of the piers/pylons are represented in WAMIT is shown in Figure 3.11

2. The results are parameterised to the *Equivalent Blocking Widths*. Equivalent Width corresponds to the width of the structure, which allows no energy to pass

3. Wave modelling including bridge piers/pylons: the change in wave climate from all the bridge piers/pylons is calculated with the numerical wave model, MIKE 21 SW, now modified to include these blocking widths so that the transmitted and reflected wave energy is altered at each position of a bridge-pier/pylon

The 3 steps are described in more details in Appendix A.

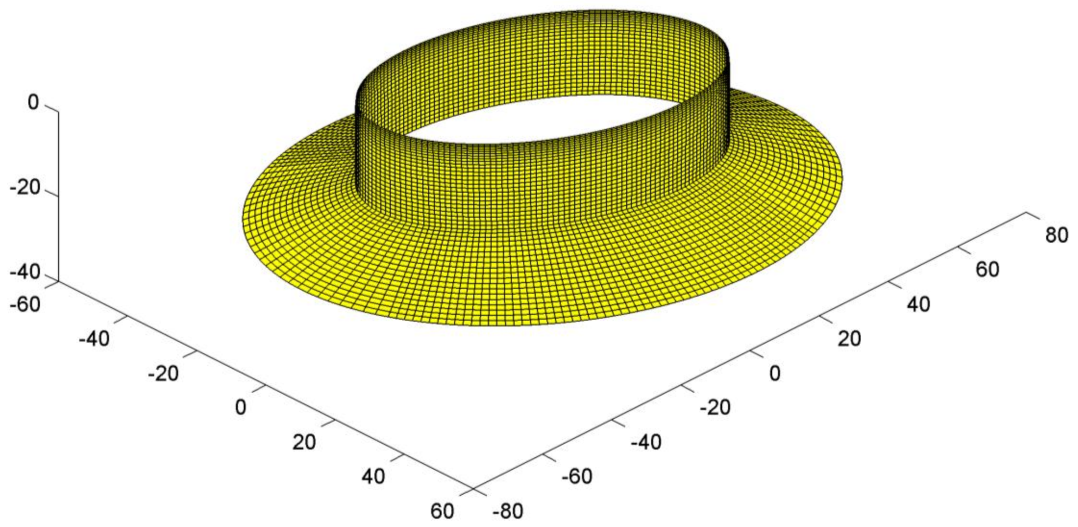

Figure 3.11 Example of how the foundation is included in WAMIT: here the pier/pylon is placed in a caisson from the seabed level (here -28.7 m) up to +4 m. The caisson is 80 m long and 50 m wide. From the seabed level up to -20 m the caisson is sur-rounded by a protection lay-er

3.3.2 Littoral drift modelling and shoreline changes

The littoral drift calculations are carried out using LITDRIFT in DHI's LITPACK modelling system. It simulates the cross-shore distribution of wave height, set-up and set down, longshore current and sediment transport for an arbitrary coastal profile.

Littoral drift calculations from LITDRIFT at selected locations along the coasts are used to calculate a continuous variation of the littoral drift rates along the coastline. The variation in the wave conditions and changes in the coastline orientation or the coastal profile are therefore integrated into the results.

A description of LITDRIFT can be found in (DHI 1998).

This modelling tool was calibrated and applied in the evaluation of the baseline conditions (FEHY 2013a).

The littoral budgets for the projects are compared to the similar budget for the baseline situations. The same procedures in calculating the budgets are followed.

The variability in the littoral transport rates along the coasts causes erosion or accumulation at the beach due to an increase or a decrease in the transport rates along the coast. This makes the shoreline retreat or advance with time.

The impact assessments on the shoreline are carried out based on a comparison of the calculations of the changes to the littoral budget due to the projects.

The following results are presented in Section 5:

- **Littoral drift rates:** net transport, gross transport and east- and westgoing transport components of the sediment transport along the coast in the littoral zone in the situation without and with the tunnel or bridge projects

- **Shoreline evolution. Shoreline advance and retreat:** the calculated tendencies for the shoreline to retreat and advance are compared with results for the baseline situation as evaluated in (FEHY 2013a)

- **Equilibrium beach orientations**: the equilibrium beach orientation is the beach orientation (defined as the normal to the depth contours at the beach) that gives a net annual littoral drift of zero. Along a shoreline with a dominant incident wave direction, the equilibrium orientation is reached when the coastline is facing this direction. If a new beach is designed such that it faces the equilibrium orientation, the average net transport is zero leading to a stable shoreline

A brief description of the methodology in the littoral transport calculations is provided below.

Littoral drift calculations
A two-step approach is applied to calculate the littoral transport rates along the coasts:

- **Step 1:** establishment of the overall sediment budget

- **Step 2:** refined calculation of the variability along the coast

Step 1: establishment of the overall sediment budget

Sediment transport computations have been performed at selected profiles with about 1 km distance along coastal stretches. The sediment transport computations are based on nearshore wave climates extracted from the wave models at a water depth of approximately 4 m DVR90. The locations of the coastal cross sections, for which the nearshore wave climates and/or the littoral drift rates are evaluated, are shown in Figure 3.12 and Figure 3.13. Littoral drift calculations are carried out for coastal cross sections, where the fixed link projects impose changes to the nearshore wave climates, which may change the sediment budget. Sediment budgets are hence established between D6 and D17 on the Lolland coast and between G1 and G14 on the Fehmarn coast.

Another output from the Step 1 calculations is the 'q-alpha' relations. The 'q-alpha'-curves define at a given location the relationship between the net littoral drift and the beach orientation at the location. For the actual beach orientation, this curve gives the net littoral transport rate at this location.

The calculations are based on specification of physical parameters (specified wave conditions, coastal profile and sea bed conditions etc) and model parameters. The zone of movable beach sand is restricted due to hard sea bed or revetments. These levels within which the littoral transport takes place are listed in Table 3.5 together with other key parameters. Further details can be found in (FEHY 2013a).

The littoral drift rates give input to the overall sediment budget for the coastal stretches and are the basis for analysis of the overall tendency for the sediment budget to change due to the fixed link project.

Step 2: refined calculation

The small-scale variability within these locations is not captured in Step 1. In Step 2, the littoral drift rates between the locations where the transport rates are calculated in Step 1 are estimated by interpolation in the transport rates for the adjacent locations, both of which computed with the actual beach orientation at the point where the transport rate is interpolated to. The active depth is the water depth where waves and wave driven currents generate littoral drift. Insignificant transport rates were found offshore at about 3-4 m water depth in the baseline study (FEHY 2013a). The resulting shoreline evolution, the shoreline advance or retreat, is calculated from the gradient of the transport rates.

Details in the calculations in Step 1 and Step 2 and the comparison with observed shoreline changes/maintenance dredging rates are described for the baseline situation in (FEHY 2013a).

The calculation methodology described above has as a precondition that the alongshore variations in the coastal profile, wave and sea bed conditions should be limited and slowly varying. This is not the case along the stretch west of Puttgarden due to the presence of Grüner Brink and the long groyne, which are so large and within a short stretch of the coast that they result in a large variability of the nearshore bathymetry. The littoral drift rates and the changes to the rates due to the projects have therefore been calculated in selected cross sections only where the conditions are approximately fulfilled.

The quantification of the changes to the coastlines and the erosion in front of the structures are estimated to be correct within the factor of two which is the general uncertainty in the estimation of sediment transport.

Figure 3.12 D1-D22: locations of coastal cross sections for analysis of nearshore wave cli-mate. D6-D17: coastal cross sections where littoral drift has been calculated. Lolland coast. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Figure 3.13 C1-C14: locations of coastal cross sections for analysis of nearshore wave climate and calculation of littoral drift. Fehmarn coast. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Table 3.5 *Sea bed characteristics applied in the littoral transport model. The cut-off levels indicate the limits for the littoral zone; note not all locations are relevant for the tunnel project*

Loca-tion	Grain size, d_{50} [mm]	Geometrical standard devia-tion [-]	Nearshore cut-off level for transport [m DVR90]	Offshore cut-off level for transport [m DVR90]
D6	0.25	1.4	-0.4	-2
D7	0.25	1.4	-	-2
D8	0.25	1.4	-	-4.5
D9	0.25	1.4	-	-2
D9B	0.25	1.4	-	-2
D10	0.2	1.3	-	-5
D11	0.3	1.5	-1	-2
D12	0.3	1.5	-1	-2
D13	0.25	1.3	-0.2	-2.5
D14	0.25	1.4	-1	-2.5
D15	0.25	1.3	-0.75	-2.5
D16	0.25	1.3	-	-2.5
D17	0.25	1.3	-	-2.5
G1	0.25	1.35	-	-3.5
G2	-	-	-	-
G3	0.2	1.35	-	-
G4	0.25	1.3	-	-
G5	0.2	1.3	-	-3.2
G6	0.2	1.3	-	-0.6
G7	0.25	1.4	-	-1.5
G8	0.2	1.4	-1	-2.5
G10	0.25	1.5	-1.5	-2.5
G11	0.2	1.55	-	-0.6
G12	0.25	1.65	-	-1
G13	0.25	1.5	1	-2
G14	0.25	1.5	-1.5	-1.8

3.3.3 Hydrodynamic modelling

Nearshore current conditions are obtained from a local 3D flow model carried out by FEHY for Femern A/S (FEHY 2013d).

The model is operated for the baseline situation. The (small) effects of changes to the currents from the structures are therefore not included. The model results are from the year 2005 only and the current conditions for this year are therefore assumed representative for the average current conditions in the 21-year period, 1989-2011, required for the littoral drift calculations. The applied methodology follows the procedure in the baseline assessment in (FEHY 2013a).

3.4 Assessment of magnitude of pressures

The magnitude of the pressure for the tunnel alternative is summarised in Table 3.6 and for the bridge alternative in Table 3.7.

The assessment of pressure for the bridge alternative is based on results calculated with a previous bridge alternative; bridge alternative B E-E/April 2010. However, the differences between the two layouts are such that the differences in the effects on waves along the adjacent coasts, which are the driving force for the sediment transport in the coastal zone, are judged to be small.

The pressure indicators are mainly the changes to the near shore wave and current conditions (wave heights and directions, current speeds) and the blocking of the littoral transport by the structures in the littoral zone. The potential impacts are shoreline advance/retreat due to the projects on the sandy coasts and the possible additional erosion or deposition in front of coastal structures along protected stretches and around marine structures.

The magnitude of pressure is evaluated within the modelling complex described in Section 3.3 above.

Table 3.6 Methods for assessment of magnitude of pressures for the tunnel alternative

Environmental pressure	Assessment of magnitude of pressure
• Reclamations and protection reefs	Extent of structures along the coastline (GIS analysis)
• Access channel production facility on Lolland	Quantification of effects on waves, currents and sediment transport

Table 3.7 Methods for assessment of magnitude of pressures for the bridge alternative

Environmental pressure	Assessment of magnitude of pressure
• Piers and pylons • Embankments	Quantification of effects on waves, currents and sediment transport

3.5 Assessment of sensitivity

The sensitivity of shoreline advance/retreat and of the erosion/deposition in front of marine structures along the adjacent coastlines to the projects is quantified. The shoreline retreat/advance and the coastal erosion/deposition are mainly determined by the wave action and the sediment characteristics in the coastal zone. The sensitivity is therefore quantified first by modelling of the longshore sediment transport, the so-called littoral drift, in the baseline situation and with the projects in place. The corresponding changes in shoreline retreat/advance and coastal erosion/deposition measured in [m/year] and [m^3/m/year] respectively are calculated. The quantification of the sensitivity is described in Section 5.

3.6 Assessment criteria

The impairments of the subcomponents have been assessed based on the criteria summarised in Table 3.8.

Table 3.8 Criteria for assessment of changes to the coastal morphology and assignment of degrees of impairments

Factor **Sub-factor component**	**Impact by project**	**Criteria for assessment of changes (short description)**	**Duration**	**Degree of impairment**
Soil Marine soil Coastal morphology	Blocking of sediment, changed sediment budget and erosion/accretion along the coastline, changes of areal use due to structures related to project	• Loss of beaches due to severe erosion • Permanent loss of functionality of special morphological features such as Hyllekrog/Rødsand and Grüner Brink • Failure of coastal structures	Permanent	Very high
		• Increased erosion of beach material/sea bed material of more than an average of 5 m^3/m/year or • More than 5 m^3/m/year extra accretion adjacent to harbours and intakes/outlets, both of which for average year wave conditions • Temporary loss of functionality of special morphological features such as Hyllekrog/Rødsand and Grüner Brink	Permanent/ temporary	High
		• Increased erosion of beach material/sea bed material at an average of 2.5-5 m^3/m/year or • 2.5-5 m^3/m/year extra accretion adjacent to harbours and intakes/outlets, both of which for average year wave conditions • Changes in functionality of special morphological features such as Hyllekrog/Rødsand and Grüner Brink	Permanent	Medium
		• Increased erosion of beach material/sea bed material at an average of 0.5-2.5 m^3/m/year • 0.5-2.5 m^3/m/year extra accretion adjacent to harbours and intakes/outlets, both of which for average year wave conditions • Changes in morphological elements of special morphological features such as Hyllekrog/Rødsand and Grüner Brink	Permanent	Minor

Increased erosion/accretion of beach and in front of coastal structures
A very high impact on a coast is typically related to a situation where the coast loses its function. The coast provides recreational areas, typically the beaches, but also natural protection to the facilities built in the coastal hinterland. The "coast" is defined as: "the topography (above mean sea level) and bathymetry (below mean sea level) in the coastal zone covering from dunes, dikes, coastal cliffs, or other structures which back the present coastline, to the active depth of the nearshore zone. The morphology within the 6 m depth contour is dealt with in the present report. This means that a Very High impact on a coast could be complete erosion of the coastal features or failure of coastal structures within a specified time horizon whereby it would be required to mitigate with beach nourishment to maintain a beach or perform coast protection in order to safeguard the coastal structures built

against the retreat of the coastline. A very high impact is related to the situation, where the coast or coastal structures lose their functionality within 5 years after construction. How much that is in terms of erosion per year depends on the width of the coastal land and the structures.

A high impact is related to the impact which on a longer time scale causes severe changes of function to the coast/beaches or risk of failure of the structures. Mitigating measures (coast protection) to prevent such future severe impairments to fixed coastal installations or existing beaches, will to some degree interfere with the natural and existing coastal landscape and mitigationg measures should consequently only be allowed when there is a real need for protection of valuable installations or recreational areas. Such mitigation measures are by expert judgement assessed to be acceptable only when severe impairments are expected within 25 years after the end of construction of the project. The width of the coast, typically the dunes, along the coast of Fehmarn and of Lolland is varying quite a lot, but a natural width is typically in the order of 30 m. It is actually less at many locations although at many of them the coast is in consequence thereof protected by revetments in front of the dikes. Combined with the time horizon of 25-30 years this gives a critical erosion rate of 1 m/year in average corresponding to 5 m3/m per year for the Fehmarnbelt area, where the active height of the coastal profile is in the order of 5 m. In front of structures with no beach, the erosion will take place from the sea bed in front of the structures.

An accumulation of sand along a coast and thereby accretion of the coastline is not critical in the same way as the coastline retreat. Accretion of coastlines can be divided in accretion of sand spits and accretion of long strait coastlines. Examples of naturally accreting sand spits in the area are the sand spit east of Grüner Brink, which accretes about 20 m/year and the Hyllekrog sand spit, which accretes about 25 m/year. These are special morphological cases and not relevant to include in a general classification. An accretion along a natural coastline is not considered critical and is therefore not included in the general classification for impacts, which will cause a risk to the coastal environment. The only cases where an accretion along a coast causes a damaging impact are accretions adjacent to harbours, intakes and outlets from pumping stations etc., where the accretion may impact negatively on the function of these installations. One example of an accreting coastline is the coastline immediately west of Rødbyhavn, which accretes about 4 m/year. This accretion causes bypass of sand to the entrance of Rødbyhavn and is therefore beyond the critical rate. Consequently, it is recommended to use an accretion rate of 1 m/yr (corresponding to about 5 m^3/m per year) as being critical in relation to action to be taken. This is used as the criteria for a high impact.

Factors of 0.5 have been applied to go from High to Medium and from Medium to Minor. Erosion/accumulation of sand of less than 0.5 m^3/m/year is applied as the lower limit for when the shoreline is assessed with an impact. 0.5 m^3/m/year corresponds to a shoreline retreat or accretion of about 0.1 m/year. This effect is very small and also within the uncertainty for prediction of shoreline changes.

Special morphological features

The barrier islands/spits of Hyllekrog/Rødsand and the migrating formation of Grüner Brink are special morphological features in the Fehmarnbelt. Hyllekrog/Rødsand protects the hinterland against wave action and the lengths of the spits/barriers are determining factors in the water exchange between the Fehmarnbelt and the shallow estuary Rødsand Lagoon. Grüner Brink is an area of coastal lagoons enclosed by the sea along the entire perimeter by barriers. It is a dynamic feature, which is created and continuously developing by spit-formation fed by a net transport of sediment from the west. The sediment deposits partly in front of the sub-surface spit and partly at the submerged front west of the long groyne west of Puttgarden.

A very high degree of impact is denoted the situation, where the features lose their functionality permanently. This refers to a situation where Hyllekrog/Rødsand would lose functionality in protecting against the wave action and where the water exchange would change drastically. For Grüner Brink, severe erosion of the protecting barrier or a drastic change of the sediment transport regime would also cause loss of functionality. A high impact refers to a situation where the loss of function is temporary.

A medium degree of impairment is assigned in the situation where the morphological functionality changes and a minor degree of impairment is assigned where changes occur only to the morphological elements of the special features.

3.7 Assessment of loss

Loss does for all sub-components under Coastal Morphology take place only where the projects' **permanent footprints** occupy parts of the coastline. No other pressures cause loss of the sub-components under Coastal Morphology.

3.7.1 Method of assessment

The magnitude of loss is evaluated as a section of the coast of the given sub-components, which is occupied by the permanent structures. The sections are found by combining maps of the permanent footprints with maps of the coastline including mapped structures from FEHY (2013a) in GIS analysis.

3.8 Assessment of degree of impairment

3.8.1 Methods of assessment

Impairment covers all impacts, where the function of the environmental sub-component is reduced or changed compared to the state in the 0-alternative.

The impairments are considered permanent because the present coastal dynamics and rates of coastal development are changed. Only pressures from the permanent structures/operation period are considered of relevance for coastal morphology, refer to discussion in Section 2.2.

The degree of impairment is defined from the magnitude of the impairment and the assessment criteria in Table 3.8. The impairment is for all sub-components under Coastal Morphology evaluated as sections of the coast or coastal protection (in metres) or the numbers of coastal structures, which are impaired.

In general, the impaired sections/structures of the coast and the degrees (very high, high, medium or minor) of impairment are determined from a combination of numerical modelling results of the response of the shoreline evolution to the project pressures and sensitivity of the sediment budget and as well as an expert evaluation of the results. The present state as well as recent and historical development of the coasts are also considered in this evaluation.

The impaired sections of the coast are compared to the sections of each sub-component within the 10-km zone from the alignment. The 10-km zone is shown in Section 3.1.

The data and model results described in Section 3.2 are applied.

3.9 Assessment of severity

The severity of the impact is assessed by combining loss and degree of impairment along sections of the Fehmarn and Lolland coasts with importance levels assigned to these areas.

3.9.1 Importance levels

The importance of the coastal sections within the investigation area has been assessed based on the conservation objectives of the Natura 2000 areas occurring within the area of investigation, coastal sections which are protected under German legislation as Naturschutzgebiete and the key functional importance of these areas.

The assignment of importance levels for the Marine Soil component coastal morphology to sections of the coastlines of Fehmarn and Lolland is described in (FEHY 2013a). Maps of the importance levels for relevant sections of the Fehmarn and Lolland coastlines are presented in Figure 3.14 and Figure 3.15 for Fehmarn and in Figure 3.16 for Lolland, respectively.

Table 3.9 Importance levels for the Marine Soil component: Coastal morphology

Importance level	Description
Very high	Coastal areas (including coastal protection structures along these) within Natura 2000 areas, where coastal morphological elements are part of the conservation objectives. Coastal sections, which are protected under German legislation as NGS areas. Individual marine structures (not coastal protection)
High	Coastal stretches (including coastal protection structures along these) with sandy beaches and cusp areas (cuspate foreland) including coastal lagoons, not included under the 'Very high' category.
Medium	All other coastal stretches (including coastal protection structures along these), which are not heavily influenced by anthropogenic activities as mentioned under the "Minor" category
Minor	Coastal stretches under heavy influence of anthropogenic activities

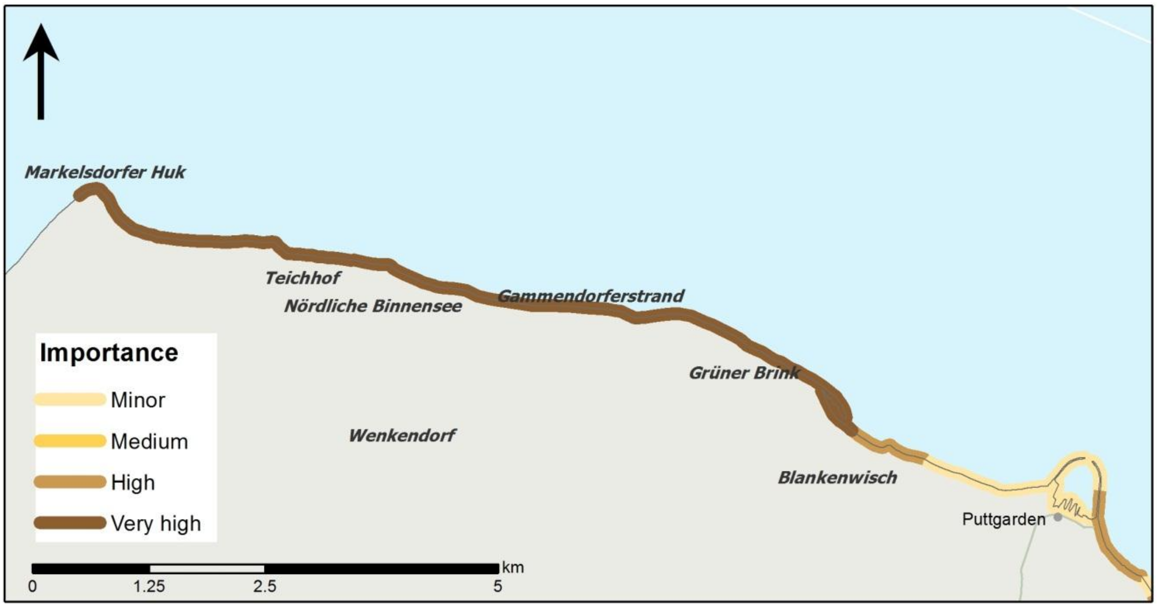

Figure 3.14 Importance levels for relevant sections of the northern shoreline of Fehmarn

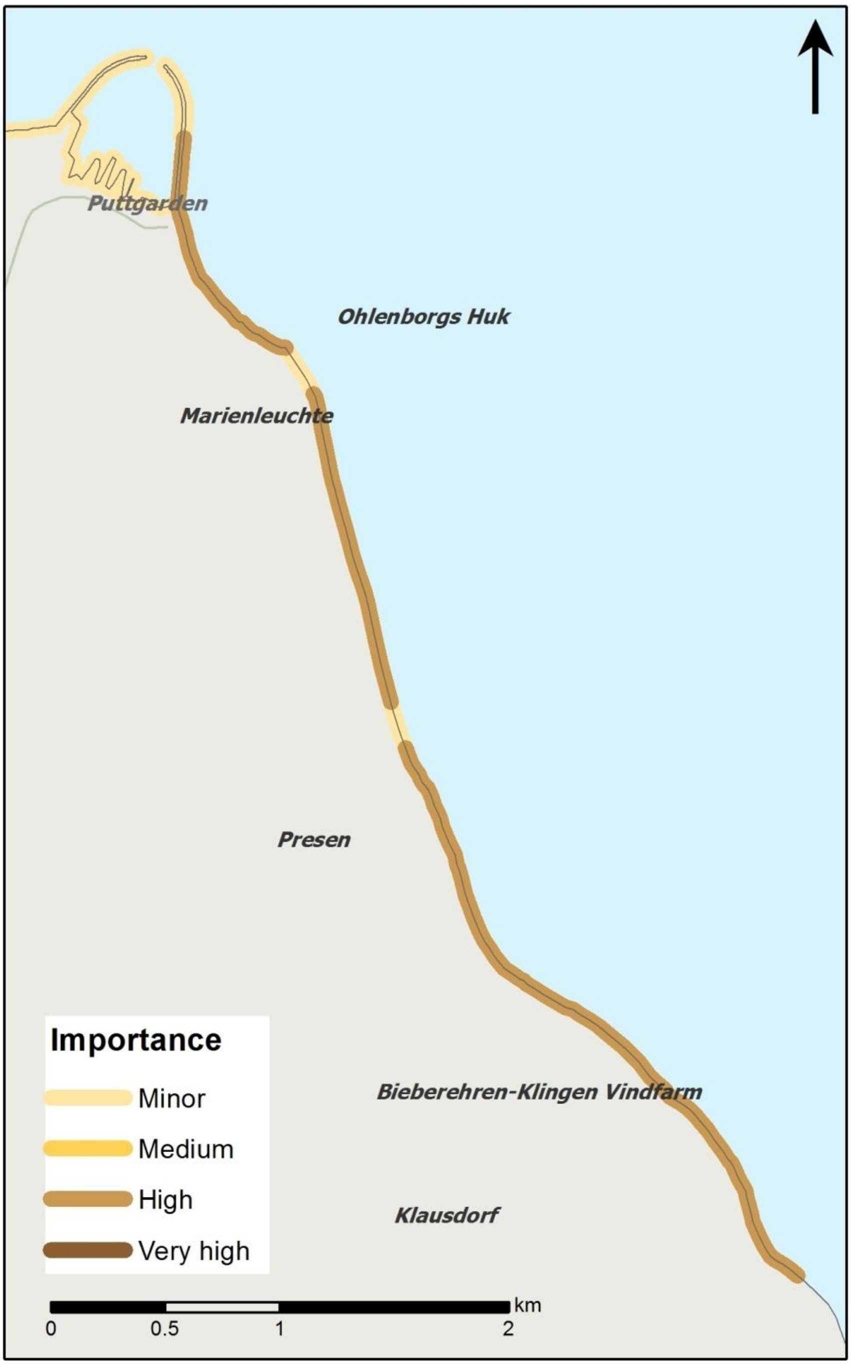

Figure 3.15 Importance levels for relevant sections of the northeastern shoreline of Fehmarn. Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

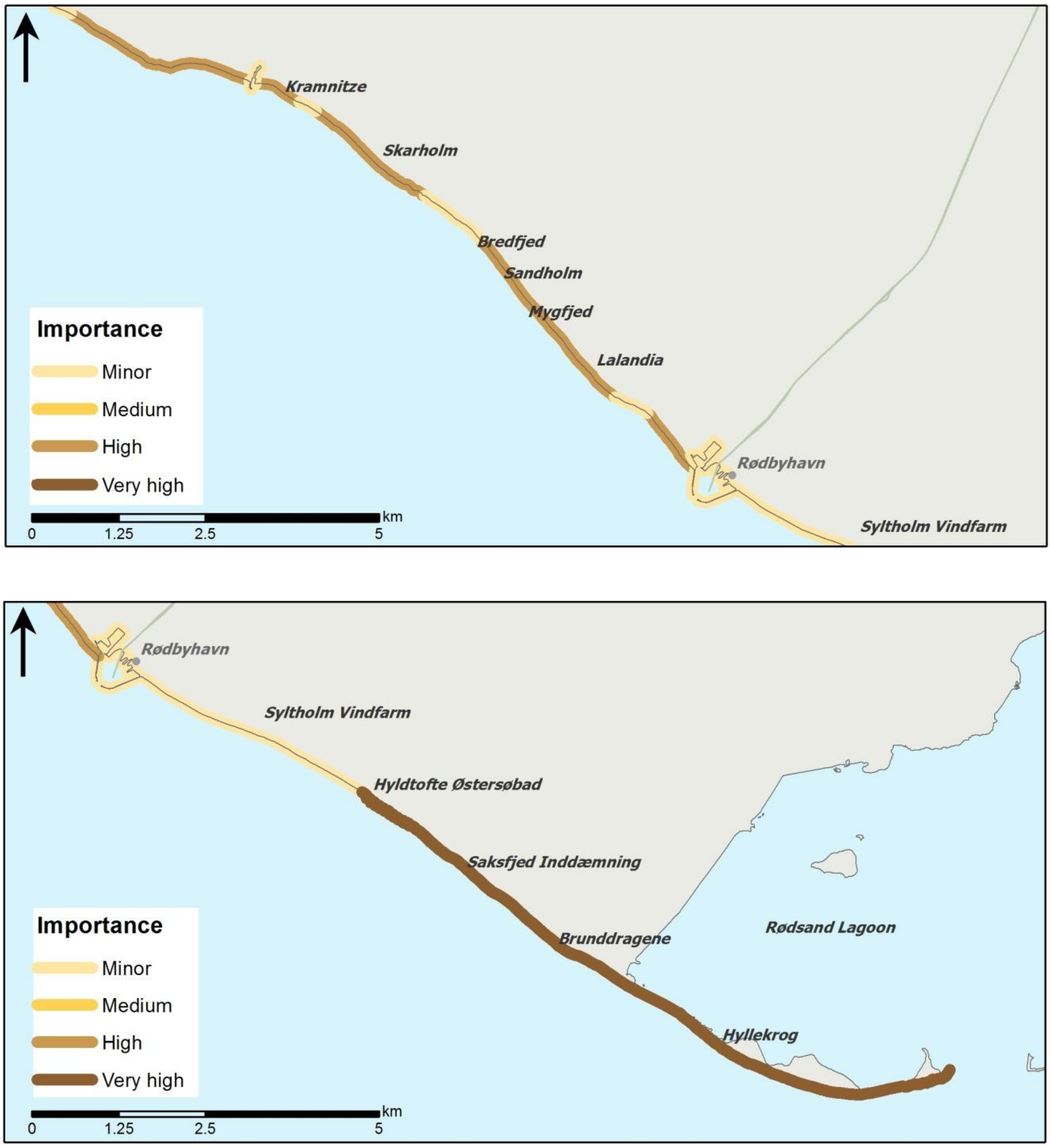

Figure 3.16 Importance levels for relevant sections of the southern shorelines of Lolland

3.9.2 *Degree of severity*

The degree of severity of the impacts is derived from a combination of the loss or degree of impairment and the importance levels described above. The degree of severity obtained by the combination of degree of impairment and the importance levels is given in Table 3.10. The degree of severity follows the four-level scale: very high, high, medium and minor. As an example an impact, which has been classified as a medium degree of impairment within a high importance level section of the coast, is evaluated to be of medium severity. This classification is used for sections of the coast with beaches/unprotected coastlines and for coastal protection structures such as revetments/breakwaters/sea walls. Individual groynes are treated similarly. It is noted that an impact, classified as a minor impairment within a minor importance level part of the coast, is assigned "negligible severity".

Individual marine structures such as water outlets and sluices are not related to the coastal area in the same way – they often have a functionality connected to the hinterland. They are assigned a degree of severity of impairment/loss matching the assigned degree of impairment or - in case of loss - a very high degree of severity loss.

Coastal stretches with loss are assigned a degree of severity matching the assigned importance level for the area, see Table 3.11.

Sections of the coast/number of structures or features impacted by a certain degree of severity are quantified by GIS-analysis applying the mapping of each of the four sub-components (beaches/unprotected sections, costal protection, individual marine structures, special morphological features) from the baseline study (FEHY 2013a).

Table 3.10 Matrix by which the degree of severity is assigned. The degree of severity is based on the combination of the degree of impairment (vertical axis) and the importance level (horisontal axis)

Degree of impairment	**Importance of the environmental factor, sub-factor or component**			
	Very high	High	Medium	Minor
Very high (loss of function)	**Very high ••••**	**High •••**	**Medium ••**	**Minor •**
High	**High •••**	**High •••**	**Medium ••**	**Minor •**
Medium	**Medium ••**	**Medium ••**	**Medium ••**	**Minor •**
Minor	**Minor •**	**Minor •**	**Minor •**	**(Negligible) 0**

Table 3.11 Degree of severity for areas with loss. The degree of severity is based on the combination of the magnitude of pressure (vertical axis) and the importance level (horisontal axis)

Magnitude of pressure	**Importance** of the environmental factor, sub-factor or component (four levels)			
	Very high	High	Medium	Minor
Very high (caused by footprint)	**Very high ••••**	**High •••**	**Medium ••**	**Minor •**

3.10 Assessment of significance

Assessment of significance is based on expert judgement. The assessment of significance is primarily based on an overall evaluation of impacts on the coastlines compared with the loss/impairment of the recreational values/functionalities/conservation objectives. The possibilities for effective mitigation/compensation methods at a low cost and the state of the coastlines in the 0-alternative are taken into account and commented on.

4 ASSESSMENT OF 0-ALTERNATIVE

All impacts on coastal morphology are compared to the existing conditions (2009/2010).

Given the present knowledge on the coastal morphology of the Fehmarnbelt, it is a reasonable assumption that the conditions in 2025 without the fixed link project will remain unchanged compared to the situation in 2009/2010.

5 SENSITIVITY ANALYSIS

The sensitivity of the beaches, coastal structures as revetments and breakwaters, other coastal structures as inlets, outfalls and groynes, and special morphological features, to the pressures from the tunnel alternative and bridge alternative is presented in this section.

The sensitivity of these components are related to changes in the nearshore wave conditions due to new structures, such as dampening or shelter in the lee of structures, which in turn changes the sediment transport in the coastal zone and blockage of the littoral drift by structures. These changes lead to coastal erosion or accretion. On open sandy coasts these changes correspond to shoreline retreat or advance. On coastlines, which are protected by structures such as revetments, groynes or shore parallel breakwaters, erosion in front of these structures may lead to failure of the structures. In this chapter the sensitivity of the littoral drift and shoreline evolution to the tunnel and the bridge projects is described.

It is noted that the sensitivity analysis is carried out for **the assessed designs of the projects**. The **additional mitigation measures** mentioned in the beginning of Chapter 2 are not part of the sensitivity analysis.

5.1 The Tunnel Alternative

5.1.1 The Permanent Structures along the Lolland Coast

An overview of the planned structures along the Lolland coast is provided in Figure 5.1 and Figure 5.2 together with the present structures. Note that the access channel to the production facilities is classified as a "permanent structure" in this context. This access channel will be left for natural backfilling. The time scale for backfilling is more than 30 years, see (FEHY 2013b), and the channel is therefore included as a pressure on the coastal morphology.

The present day coastline in the area, where the new structures/reclamations are planned, is described briefly below. A further description of the baseline conditions can be found in (FEHY 2013a).

Bredfjed to Sandholm

This stretch has a sandy beach with some gravel. Low dunes are found along this section. The western end of the reclamation area - a curved beach - extends to the section in front of Sandholm, see Figure 5.1.

Lalandia

West of Rødbyhavn is Lalandia, a holiday resort. The present beach in front of Lalandia is sandy with dunes in front of the dike, see Figure 5.3. During the period 1999-2009 the area has experienced accumulation of sand causing the shoreline to move forward by about 5-10 m in the period.

Lalandia to Rødbyhavn

Along the shoreline between Lalandia and Rødbyhavn, the area is filled up and the new shoreline at this location is the rock protection in the reclamation about 500 m from the present shoreline. Except for a small part presently protected by a revetment, the present day shoreline in this area consists of a sandy beach as the area is an accumulation zone for littoral transport from the west.

Rødbyhavn to Hyldtofte Østersøbad
The planned reclamation extends to 3.8 km east of Rødbyhavn to the western end of Hyldtofte Østersøbad. Hyldtofte Østersøbad is a summerhouse area. The present coastline along this section is a continuous revetment in front of the dike. There is no beach in front of the revetment. The new reclamation will extend to about 500-800 m from the existing shoreline.

Hyldtofte Østersøbad
The reclamation is planned to terminate just west of the breakwater scheme at Hyldtofte Østersøbad, see Figure 5.4. The coastal shore-parallel breakwaters were constructed in 1999 to keep sand in the area and prevent erosion of the beach. The scheme consists of 10 breakwaters covering a stretch of 800 m. The small sections of beaches suspended between the breakwaters have in general eroded since 1999. The erosion occurred primarily in the first period after construction, 1999-2004, while the beaches have stabilised since 2004 (FEHY 2013a).

Figure 5.1 New permanent structures along the Lolland coast in the tunnel project – west of Rødby-havn. For enlarged version of this figure, refer to Figure 6.1. Aerial photo from 2009 (©COWI Orthophoto April 2009)

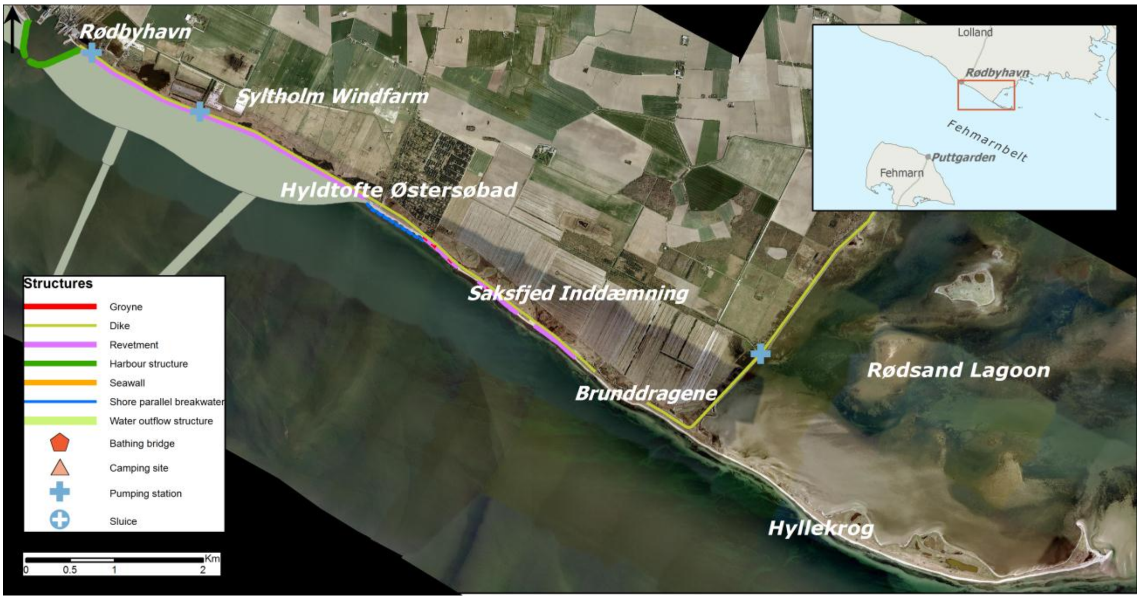

Figure 5.2 New permanent structures along the Lolland coast in the tunnel project and the tunnel alignment – east of Rødbyhavn. For enlarged version of this figure, refer to Figure 6.2. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Figure 5.3 Sandy beach off Lalandia with dunes in front of the dike, steel piles for bathing bridge in the foreground

Figure 5.4 Hyldtofte Østersøbad. Aerial photo from 2009 (©COWI Orthophoto April 2009)

5.1.2 Impacts on nearshore waves along the Lolland coast

Quantification of the changes in the nearshore waves due to the tunnel project is input to the assessment of changes to the sediment budget on the Lolland coast. The waves are the primary driving force in transporting loose sea bed material along the coast (littoral transport). The waves act by enforcing an alongshore current and by introducing an additional stirring mechanism, which helps mobilising the sediment.

The changes in the nearshore waves are assessed by comparing nearshore waves calculated by numerical models for a 21-year period (1989-2010) for a) the baseline situation and b) the situation after the tunnel project. The simulations of the wave fields are carried out for the situation with the permanent structures as described in Section 3.3.1.

West of Rødbyhavn

A snapshot illustrating the changes to the wave field west of Rødbyhavn is shown in Figure 5.5. The shown instant in time is representative for situations with high waves from east (see upper panel).

Wave heights are shown as so-called 'significant wave heights', which is a measure for the average wave height for the highest one third of the waves in an irregular wave field. Wave directions are shown with arrows indicating the travelling directions.

The planned reclamation for the tunnel project is seen to cause a lee-zone just west of the reclamation. The lee zone stretches for the shown instance about 1.5 km west of the curved beach at the western end of the reclamation. The coastal section west of Sandholm will therefore experience small reductions up to the order of 5%

of the wave heights in the baseline situation (central panel) along the original coastline when the waves come from eastern directions. The changes to the wave directions (lower panel) for the same situation are shown in the lower figure. West of the reclamations the waves change to have a slightly more clockwise mean wave direction since the reclamation primarily shadows for the eastern wave components.

The slight change in directions is due to the protection layer and the access channel, both of which change the refraction slightly. Further, the illustration shows the effect of the steep slope on the wave heights and directions along the revetment.

In case of waves from western directions, the reclamation in the tunnel project will not influence the nearshore waves.

Changes in the relative wave heights and wave directions further away from the coast are due to changes in the spreading of wave energy caused by the combination of the reclamation and the access channel. Note that the waves are small in this area (~0.4 m) for the shown point in time and the absolute changes in the wave height are therefore very small.

East of Rødbyhavn

A situation with waves from west-northwestern direction is shown in Figure 5.6. The figure illustrates the influence of the tunnel project to the wave field east of the reclamation.

The reclamation extends offshore to a maximum of about 700-800 m from the original coastline east of Rødbyhavn, but the gently curving shape towards the east reduces the impacts of the reclamations to the waves. The lee zone east of the reclamation is seen to extend about 1 km east. Wave heights from the western directions will be decreased at the coastal stretch in front of Hyldtofte Østersøbad towards Saksfjed Inddæmning.

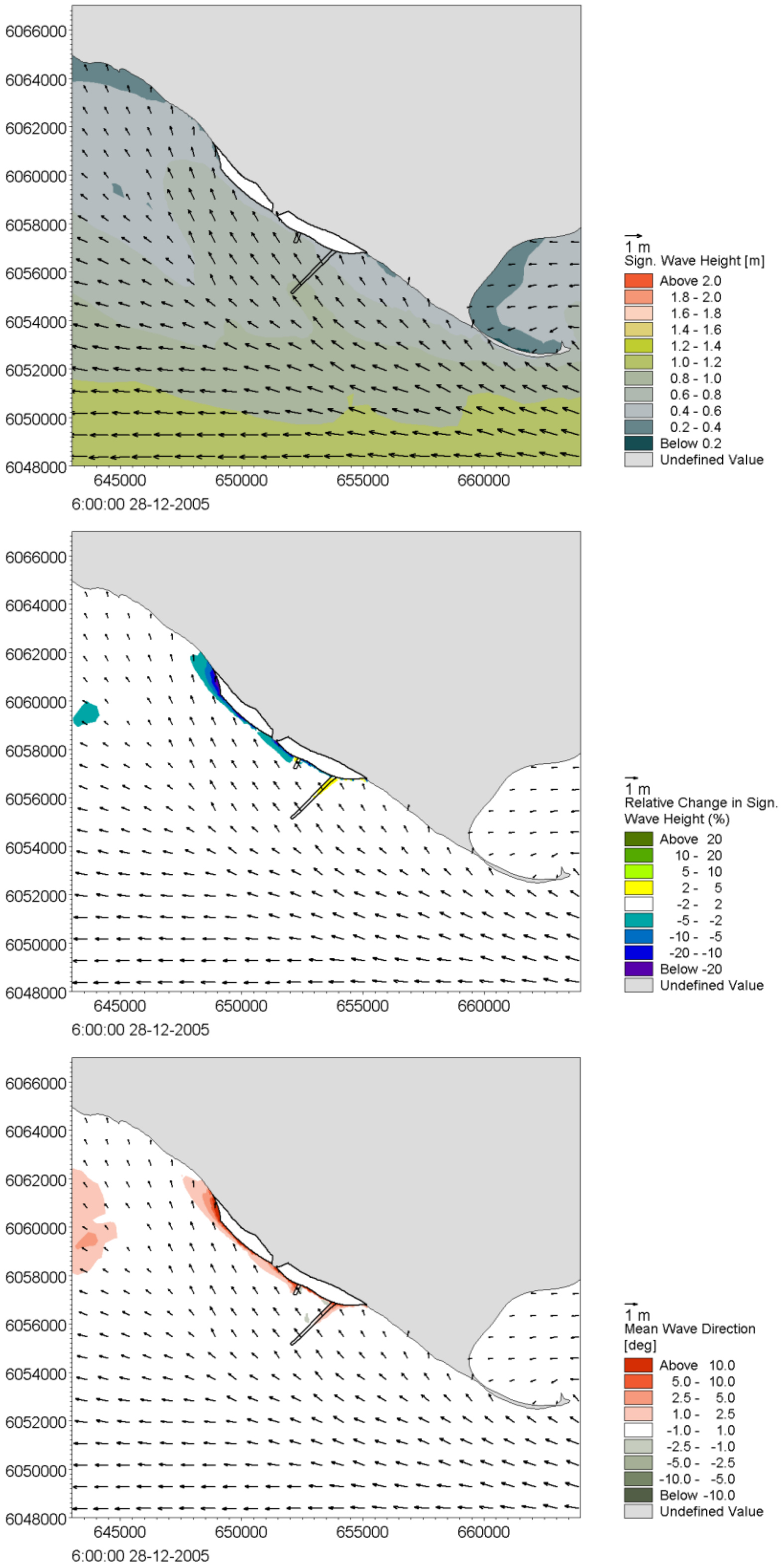

Figure 5.5 Changes to the wave field along the Lolland coast from Kramnitze in the west to Hyllekrog in the east. Typical situation (Date: 28-12-2005, 6:00 AM) with waves from east. Upper figure: wave field for the situation with the tunnel project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)

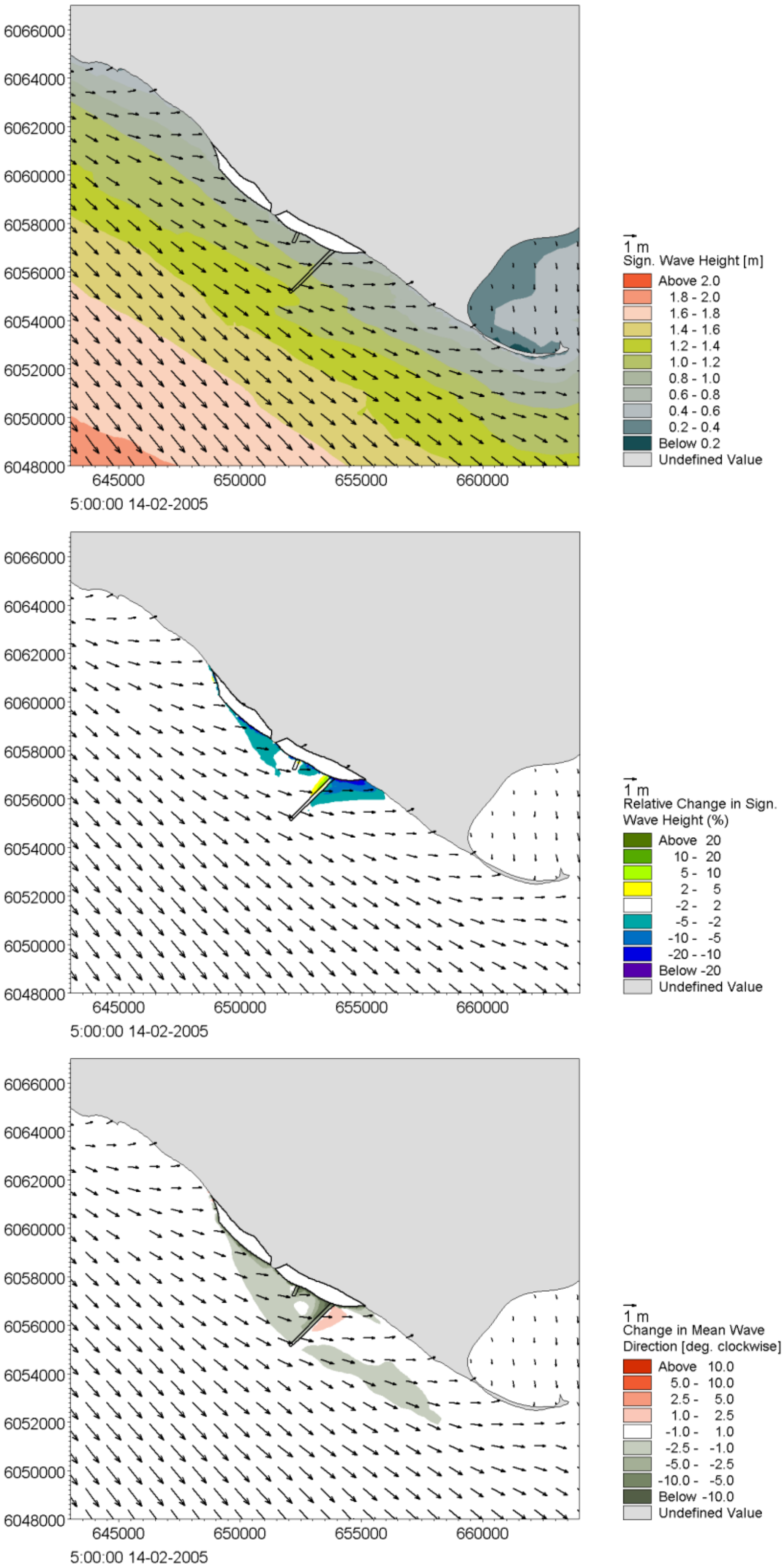

Figure 5.6 *Changes to the wave field along the Lolland coast from Kramnitze in the west to Hyllekrog in the east. Typical situation (Date: 14-02-2005, 5:00 AM) with waves from west. Upper figure: wave field for the situation with the tunnel project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)*

5.1.3 *Changes to the sediment budgets and shoreline evolution, Lolland Coast*

The littoral drift budget has been established along the south coast of Lolland for the situation after the construction of the tunnel project. The littoral drift budgets are calculated for coastal stretches west (Bredfjed to Sandholm) and east (Hyldtofte Østersøbad to Brunddragene) of the planned reclamation on the Lolland side.

Littoral drift budget and shoreline evolution west of the reclamation

The littoral drift budget for the coast west of the reclamation has been calculated using the average wave conditions (1989-2010), see Figure 5.7. The littoral drift rates are compared to the transport conditions in the baseline situation. The net and gross littoral drift rates in the situation with the tunnel project and the changes compared with the baseline case are tabulated in Table 5.1. The annual shoreline advance or retreat for the average year (1989-2010) evaluated from the littoral drift rates is shown in Figure 5.8 and compared to the simulated shoreline evolution for the baseline situation.

The net eastwards transport rate of 20,000-30,000 m^3/year along this section found in the baseline situation is in general seen to maintain the same order of magnitude. Only within about 1 km from the western termination of the reclamation the transport and shore evolution pattern do change.

The reclamation blocks the littoral drift and the sediment will hence build up west of the reclamation. In this regard the reclamation has the same effect as Rødbyhavn has in the baseline situation, where the sediment is accumulated west of the western breakwater. In the situation with the tunnel project, the accumulation area is shifted towards west to the area in front of Sandholm. No transport will by-pass the reclamation initially as the water depth in front of the reclamation is too large to facilitate transport as described above.

The changes of the sediment transport and the shoreline evolution along the coastal sections west of the reclamation are described below:

<u>West of Bredfjed</u>

The coast west of Bredfjed does not experience any changes related to the tunnel project in the initial situation.

<u>Bredfjed to Sandholm</u>

Along the coastal section in front of Sandholm, the net eastward sediment transport will remain the same. The small changes to the wave conditions from east at this section (as described in Section 5.1.2) lead to insignificant modifications to the transport rates along the existing coast just west of the new beach (D8). The reason is a combination of two opposing effects: a small reduction in wave heights acting to reduce the westward transport and a slight clockwise turning of the wave directions (from a very perpendicular angle) acting to increase the westward transport. The two effects have about the same order of magnitude for the existing beach orientation. The westward transport and thereby the net eastward transport rate are therefore practically unchanged.

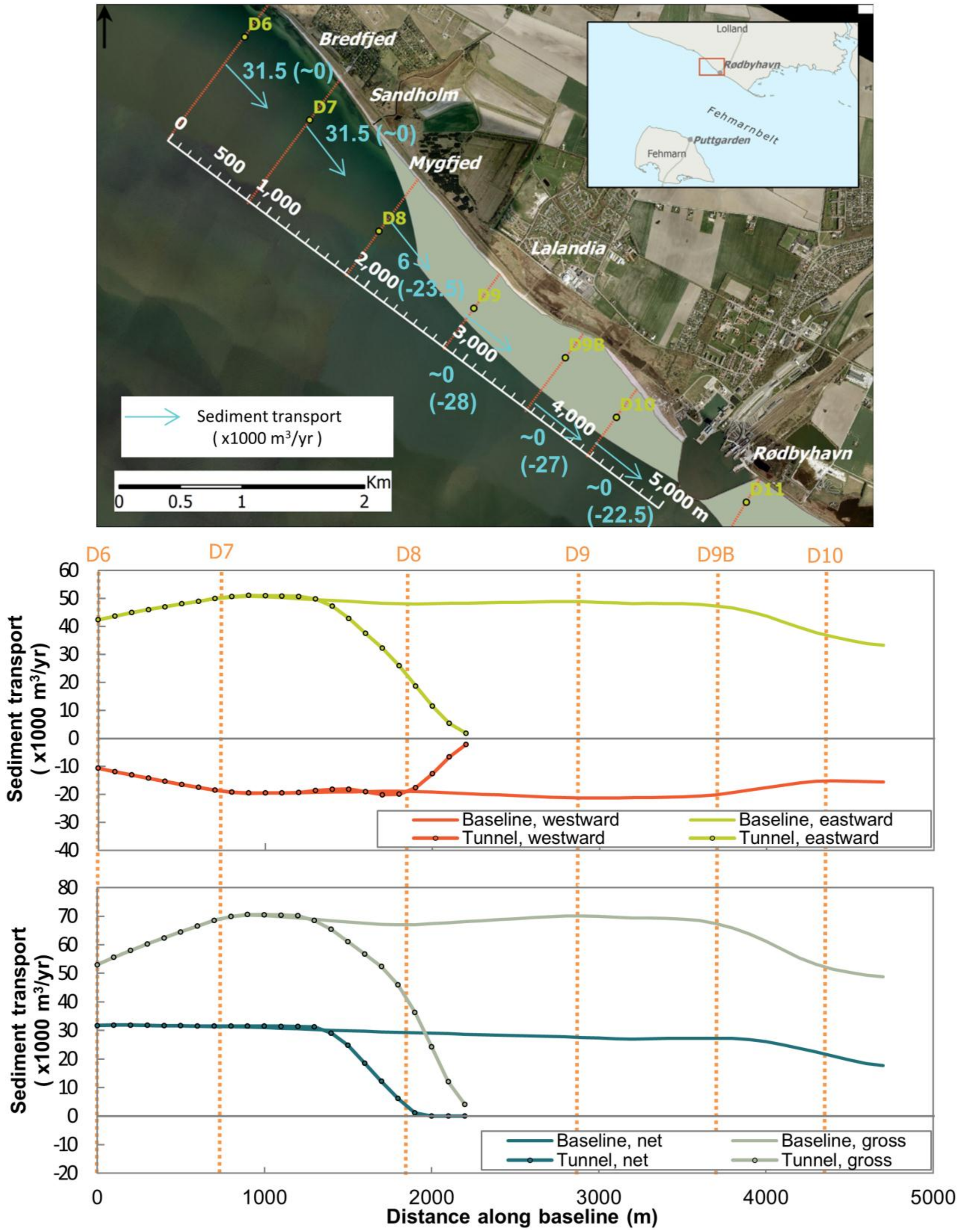

Figure 5.7 *Average littoral drift rates west of the reclamation for the situation with the tunnel project and change from the baseline situation (in brackets). Upper figure: net littoral drift rates and changes to transport rates due to the tunnel project in brackets (x1000 m^3/yr). Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Positive net transport rates towards the east. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 5.1 Average net and gross littoral transport rates west of Rødbyhavn for the tunnel project and the differences compared with the baseline situation (in brackets). Positive net transport rates towards the east

Location	Net littoral transport rate (m^3/year)	Gross littoral transport rate (m^3/year)
D6	31,500 (~0)	53,000 (~0)
D7	31,500 (~0)	68,500 (~0)
D8	6,000 (-23,500)	41,000 (-26,000)
Western termination	0 (-28,000)	0 (-68,500)
Point of reclamation		

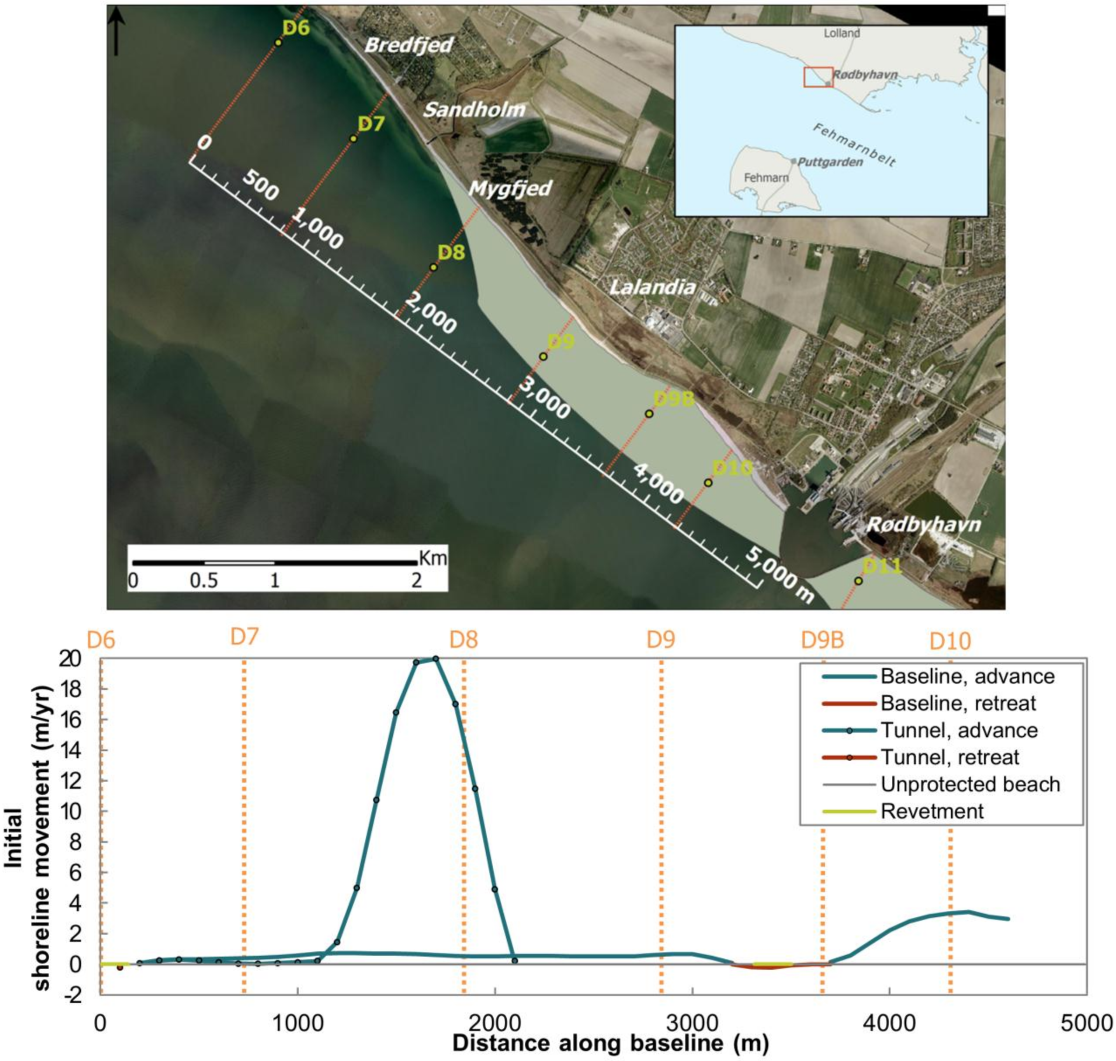

Figure 5.8 Predicted initial annual shoreline evolution for the situation with the tunnel project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Positive shoreline movement indicates accretion and negative indicates erosion. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Sandholm/new beach

As described above, the reclamation will block the littoral drift.

The beach at the western end of the reclamation is planned to terminate in front of Sandholm. The new beach curves around to a have a more westerly orientation (about 242 degr. N) than the original beach (about 230 degr. N). This orientation of the beach facilitates a smaller net littoral drift rate (see the socalled 'q-alpha' relation for point D8 in Figure 5.9) as the angle between the dominant wave direction and the beach orientation decreases. The gradual decrease in the transport of littoral sediments towards the southeast along the new beach causes the deposition of sediment.

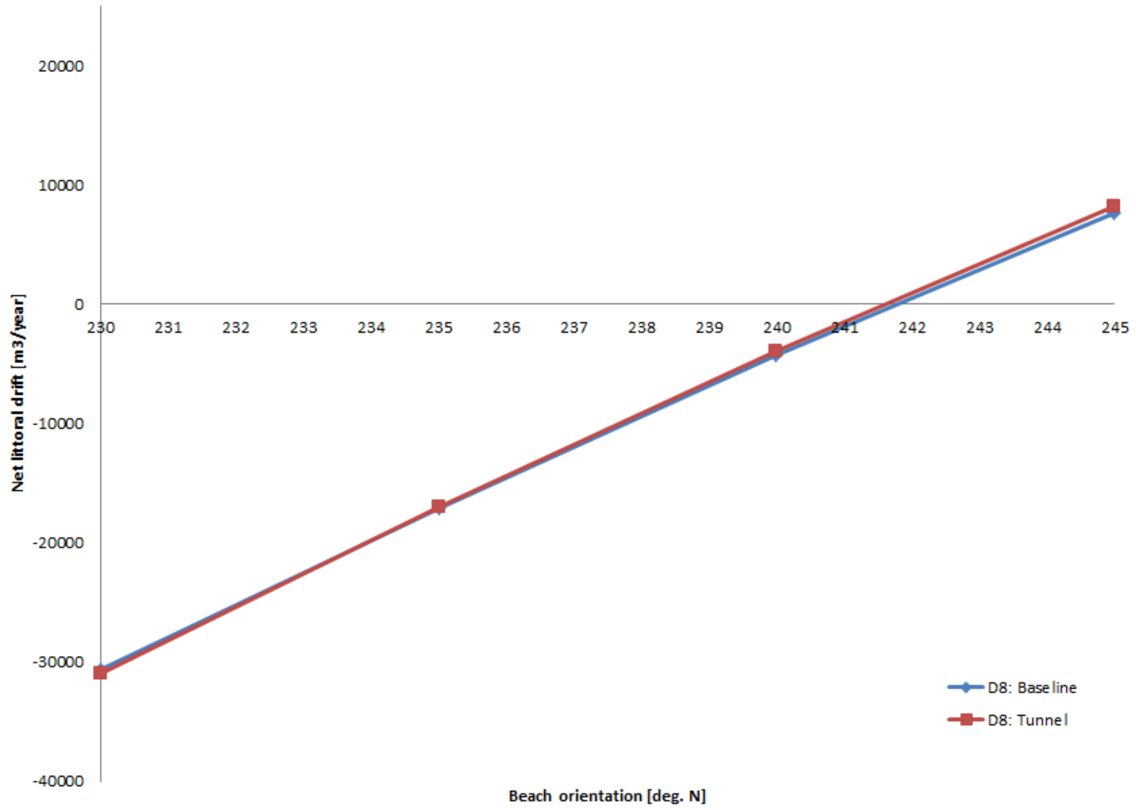

Figure 5.9 "Q-alpha" relation (relation between littoral drift and shoreline orientation) for D8

Littoral drift budget and shoreline evolution east of the reclamation
The littoral drift budget for the coast east of the reclamation has been calculated using the average wave conditions (1989-2010), see Figure 5.10. The net and gross littoral drift rates in the situation with the tunnel project and the changes compared with the baseline case are tabulated in Table 5.2.

The annual shoreline advance or retreat for the average conditions is evaluated from the littoral drift rates. The average shoreline evolution is shown in Figure 5.11 and compared to the simulated shoreline evolution for the baseline situation.

The reclamation blocks the littoral drift from west in the same way as Rødbyhavn does in the baseline situation. The reclamation also causes a weak shadow zone where the wave heights reduce and slightly change orientation in the anticlockwise direction for waves from west. The effect on the waves extends only about 1 km east of the reclamation.

The eastern part of the reclamation is planned to consist of an artificial and erodible cliff formed by the dredged excess material (clay till) from the dredging operation. This eroded sand from the cliff will feed sediment into the coastal system to help stabilise the coasts east of the reclamation.

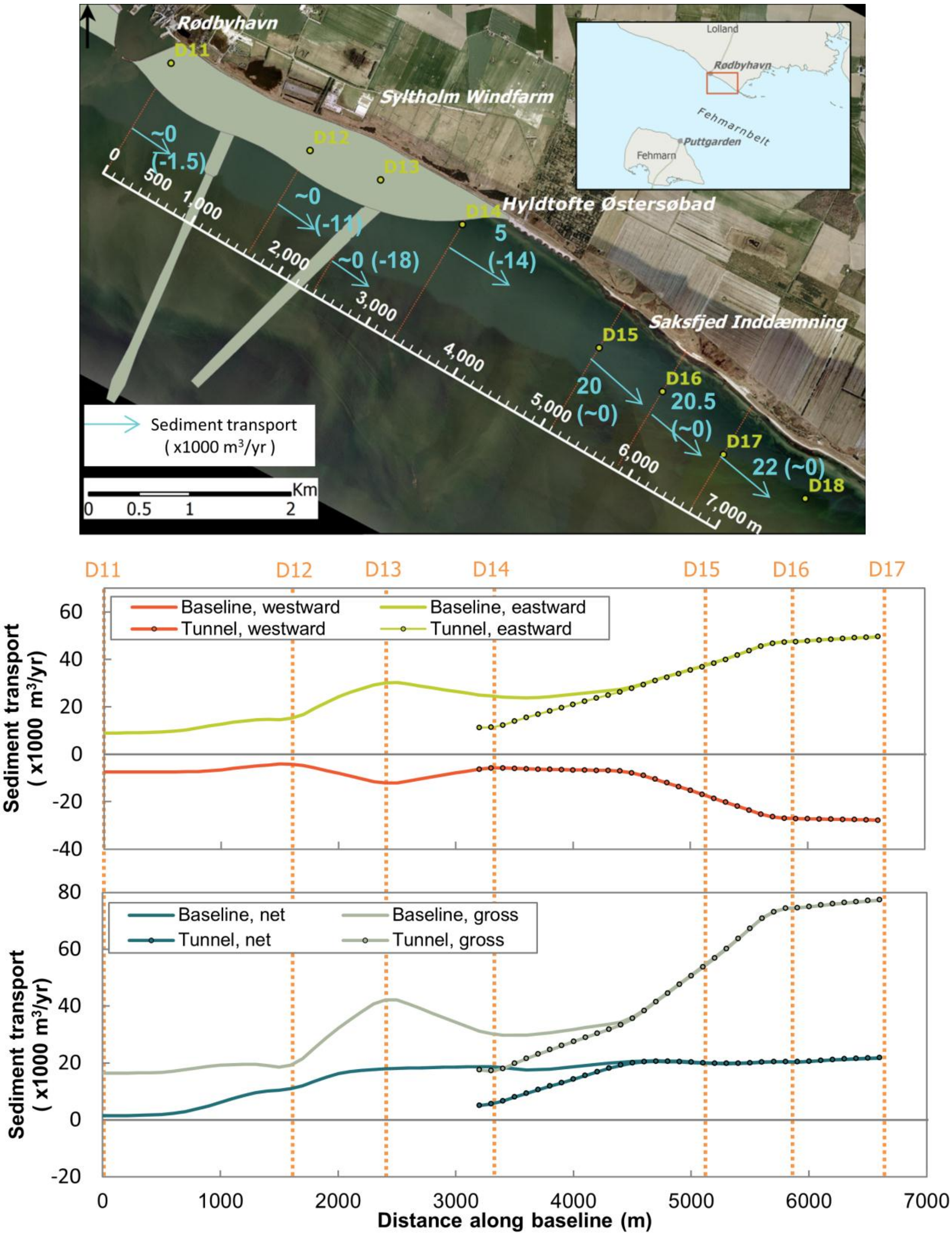

Figure 5.10 Average littoral drift rates east of the reclamation for the initial situation with the tunnel project and changes from the baseline situation (in brackets). Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Positive net transport rates towards the east. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Table 5.2 *Average net and gross littoral transport rates east of Rødbyhavn for the tunnel project and the differences compared with the baseline situation (in brackets). Positive net transport rates towards the east*

Location	Net littoral transport rate (m^3/year)	Gross littoral transport rate (m^3/year)
D14 (eastern termination point of reclamation	5,000 (-14,000)	17,500 (-12,500)
D15	20,000 (~0)	54,000 (~0)
D16	20,500 (~0)	74,500 (~0)
D17	22,000 (~0)	77,500 (~0)

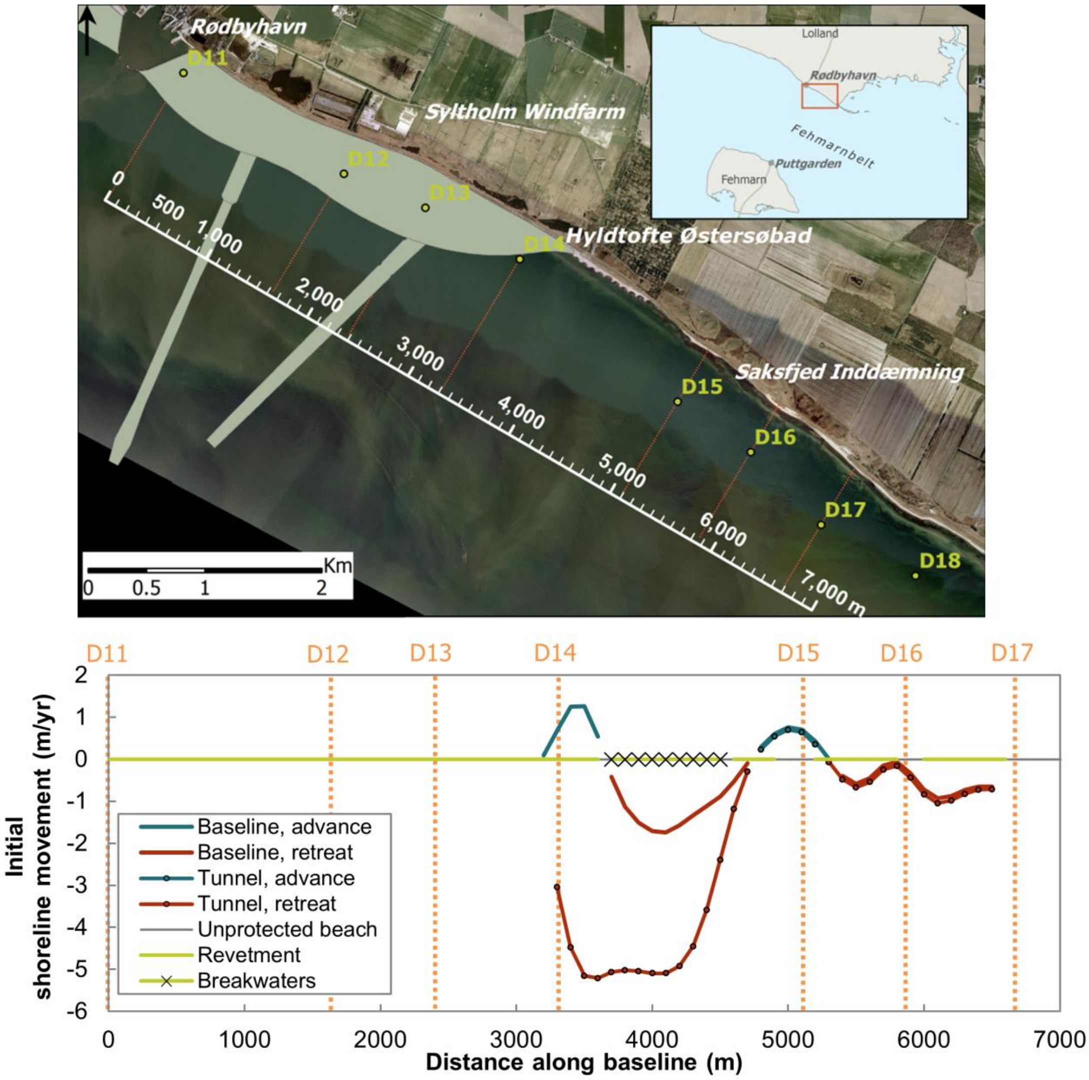

Figure 5.11 *Predicted initial annual shoreline evolution for the situation with the tunnel project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Positive shoreline movement indicates accretion and negative indicates erosion. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Contribution from artificial cliff

The contribution to the littoral drift budget from the erodible cliff and the littoral drift budget along the coast east of the reclamation has been estimated as follows:

- The littoral drift rate (of sand) at the eastern termination point of the reclamation (immediately west of Hyldtofte Østersøbad) is ~5000 m^3/year. This assumes that the cliff erodes an average of 1 m/year, the erodible length is 1,500 m, the height of the eroded cliff is 6 m and the sand content in the cliff is 50%

The sand content in the dredged clay till has been estimated to about 50% in (FEHY 2013c). The erosion rate of the cliff is difficult to predict and will vary from year to year and along the stretch. An erosion rate of 1 m/year is within the range of erosion from natural cliffs, but in the upper end. The erosion of natural cliffs depends on the wave exposure, soil material, consolidation, vegetation and water content. Wave action acts to erode from the foot of the cliff and 'undermines' the cliff such that land-slides take place. Examples of natural cliffs are shown in Figure 5.12.

From the foot of the cliff, the material will be degraded and the finer material (clay, silt) will be carried along the beach by the waves and wave driven currents. The annual release of such finer material from the cliff is about the same volume as the sand, i.e. about 4,000-5,000 m^3/year.

It is difficult to estimate accurately how this contribution compares with the supply of fines from erosion of the sea bed in the area of the reclamation in the 0-alternative. The erosion of sand, which contributes to the sediment budget at D14 has been found to 19,000 m^3/year by calibration (FEHY 2013a). An estimated 20-30% of this volume corresponding to 4-5,500 m^3/year is eroded material from the sea bed in the area. The sub sea bed material is till with a content of sand material of approx. 30-40%, and approx. 60% fines. Erosion leading to a release of 4-6,000 m^3/year of sand, therefore also releases about 7-9,500 m^3/year of fines. Another part of the contribution of sand to the sediment budget at D14 comes from erosion of the sandy parts of the profiles, primarily nearest Hyldtofte Østersøbad. This erosion will typically release only a few per cent (2-5%) of fines. The remaining erosion corresponding to about 13,500-15,000 m^3/year of sand will hence cause additional release of fines of approx. 300-800 m^3/year. In summary it is estimated that the coastal area of the reclamation in the 0-alternative releases an annual volume of 7,500-10,000 m^3/year. The expected annual release of fines from the artificial cliff is hence expected to be slightly less than in the 0-alternative.

The fines will primarily be released to the water phase during storm events, and will be transported along the coast. This is unchanged from the present situation. The source of fines will be more concentrated when eroded from the (relatively short) cliff than from the sea bed in the area of the reclamation in the 0-alternative. However, mixing by the waves during situations of the primary release will quickly even out the concentrations of fines in the water phase to be comparable to concentrations in the 0-alternative.

The potential for transporting the material along the coast in front of the cliff and towards the east is estimated to about 40,000 m^3/year. The estimate is based on the q-alpha relation at D14 for the baseline situation (FEHY 2013a) for the planned orientation of the cliff (about 180 degr. N, defined as the normal to the depth contours of the beach).

Figure 5.12 Examples of natural till cliffs. Upper figure: erosion of till cliff during rough weather at Gedser Odde, about 40 km east of Rødbyhavn. Lower figure: till cliff with accumulation of stones from the eroded cliff. From Karrebæksminde Strand about 60 km north-northeast of Rødbyhavn (south-coast of Zealand facing Smålandsfarvandet between Lolland and Zealand)

Coarser materials in the clay till (pebbles, stones) will be left at the beach. With time, when the cliff has retreated due to erosion, the coarser materials can cover a longer stretch of the beach and can possibly reduce or prevent further erosion. With time, the cliff will become (more or less) stable. Other processes than wave action causing erosion are for instance frost, rain and groundwater seepage.

Only the sand fraction from the erosion of the artificial cliff will contribute to the sediment budget east of the reclamation. The changes of the sediment transport and the shoreline evolution along the coastal sections east of the reclamation are described below.

Hyldtofte Østersøbad

No by-pass around the reclamation from the coast west of Rødbyhavn will take place.

The erodible cliff contributes 5,000 m^3/year of sand to the coast: the deficit in the net input of sediment to the stretch east of the reclamation is reduced to 14,000 m^3/year (19,000-5,000 m^3/year).

At D15 east of Hyldtofte Østersøbad, the effect of the reclamation on the net transport has diminished. Between D14 and D15, the reduction in the net (eastward) transport is caused by the changes to the waves from western directions.

Assuming that the material is eroding only from the shoreline, the annual initial shoreline retreat due to the tunnel project is estimated to about 4-6 m along the stretch as shown in Figure 5.11. The shoreline retreat is estimated assuming that the active height of the profile is 2.5 m (the same as in the calibrated model applied in the baseline situation).

Saksfjed Inddæmning til Brunddragene

In front of Saxfjed Inddæmning and Brunddragene (D16-D17), insignificant effects on the littoral drift rates due to the tunnel project are predicted at the initial stage (first few years). This is expected to be the situation with or without the erodible cliff.

Hyllekrog

No impacts on the Hyllekrog barrier island/spit (see Figure 5.2) are predicted from the tunnel project.

5.1.4 The Permanent Structures along the Fehmarn Coast

An overview of the planned structures along the Fehmarn coast is provided in Figure 5.13 and Figure 5.14 together with the present structures.

A reclamation is planned east of the eastern breakwater of Puttgarden (see Figure 5.13). The reclamation extends approximately 500 m towards the east with a landfill protected by a dike and a revetment facing the north-northeast. A curved beach facing a south-easterly direction is suspended between a breakwater terminating the above-mentioned revetment and the original coastline.

The new beach attaches to the original coastline west of Ohlensborgs Huk. Ohlensborgs Huk is protected by a number of small groynes and the new beach terminates just west of these as seen in Figure 5.13.

The present day coastline in the area is further described in (FEHY 2013a).

Figure 5.13 *New permanent structures along the Fehmarn coast in the tunnel project – east of Puttgarden. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

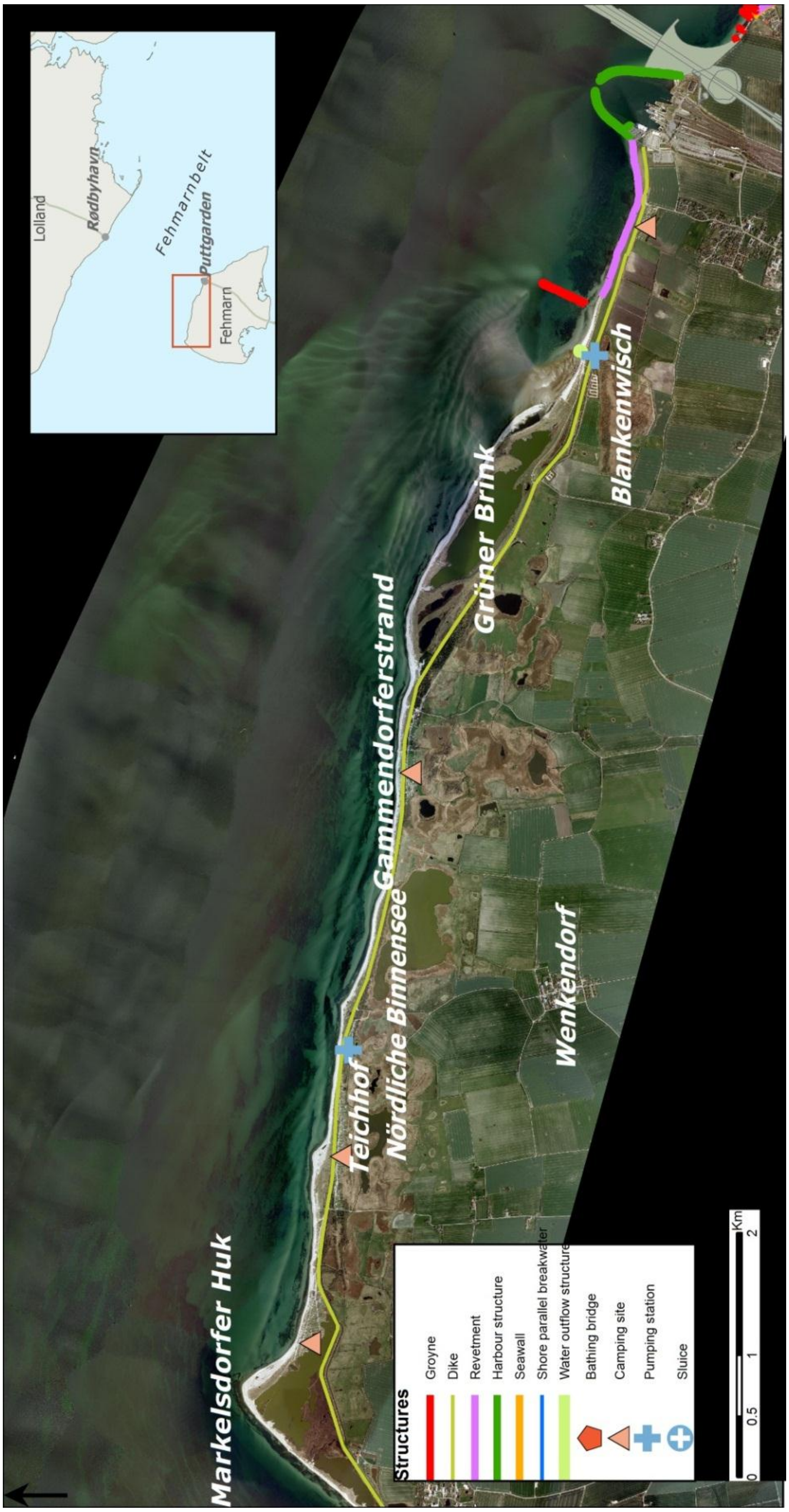

Figure 5.14 No permanent structures are planned west of Puttgarden. The planned reclamation east of Puttgarden is visible in the right side of the figure. Aerial photo from 2009 (©COWI Ortho-photo April 2009)

5.1.5 Impacts on nearshore waves on the Fehmarn Coast

Quantification of the changes in the nearshore waves due to the tunnel project is input to the assessment of changes to the sediment budget on the Fehmarn coast.

The waves are the primary driving force in transporting loose sea bed material along the coast (littoral transport). The waves act by enforcing an alongshore current and by introducing an additional stirring mechanism, which helps mobilising the sediment.

The changes in the nearshore waves are assessed by comparing nearshore waves calculated by numerical models for a 21-year period (1989-2010) for a) the baseline situation and b) the situation after the tunnel project. The simulations of the wave fields are carried out for the situation with the permanent structures as described in Section 3.2.

East of Puttgarden
A situation with waves from a westerly direction is shown in Figure 5.15. The figure illustrates the influence of the tunnel project to the wave field east of the reclamation. The shown instant in time is representative for situations with high waves.

Wave heights are shown as so-called 'significant wave heights', which is a measure for the average wave height for the highest one third of the waves in an irregular wave field. Wave directions are shown with arrows indicating the travelling directions.

The planned reclamation for the tunnel project is seen to cause a lee-zone just east of the reclamation. The wave heights are reduced most in front of the new beach. This is due to the spreading of the wave energy as the waves propagate around the eastern part of the revetment/breakwater. Also the slope of the beach with reduced water depths causes a reduction of the wave heights. However, the lee zone stretches for the shown instance about 5 km along the coast southeast of the planned reclamation east of Puttgarden. The waves from westerly directions propagate around the harbour and the reclamation and refract towards the coast. Refraction is the process by which the waves turn when the waves propagate with an oblique angle to the depth contours. The waves will turn towards the normal to the depth contours, when they propagate towards shallower depths. For this reason these waves turn and arrive at the coast from northern directions. The reclamation has the impact of turning the wave directions for these waves slightly clockwise. In case of waves from easterly directions, the reclamation in the tunnel project will not influence the nearshore waves, except for at the new beach.

West of Puttgarden
A snapshot in time illustrating the changes to the wave field west of Puttgarden is shown in Figure 5.16.

Waves from south-easterly directions east of the planned reclamation propagate around the reclamation and Puttgarden and result in insignificant changes to the wave field west of Puttgarden. In this area these waves approach the coast from northerly directions.

In case of waves from western directions, the reclamation in the tunnel project will not influence the nearshore waves.

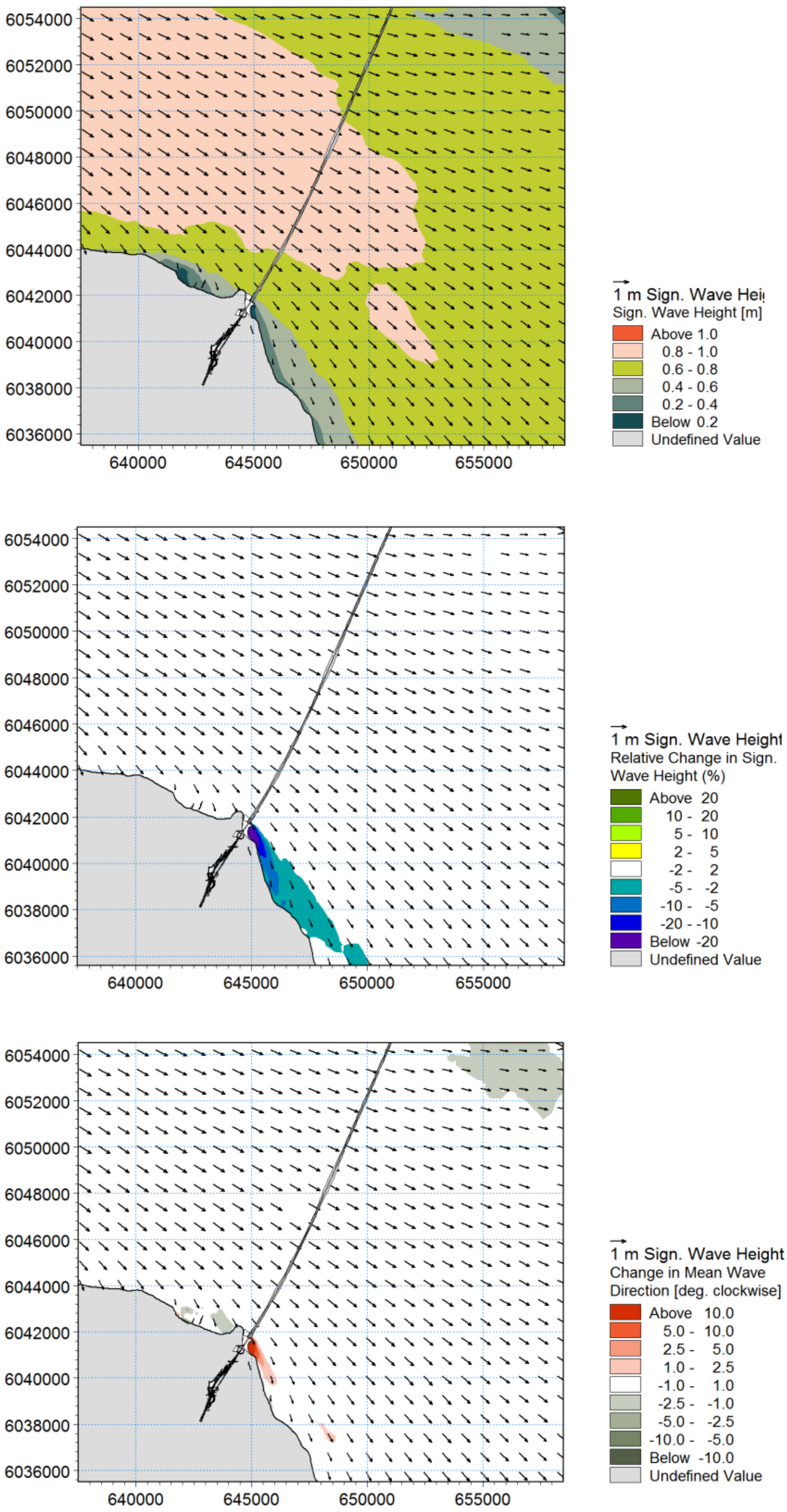

Figure 5.15 Changes to the wave field east around Puttgarden for a typical situation with waves from northwest (Date: 08-05-2005 00:00). Upper figure: wave field for the tunnel project. Middle figure: relative change in significant wave heights due to the tunnel project. Lower figure: change in wave direction due to the tunnel project

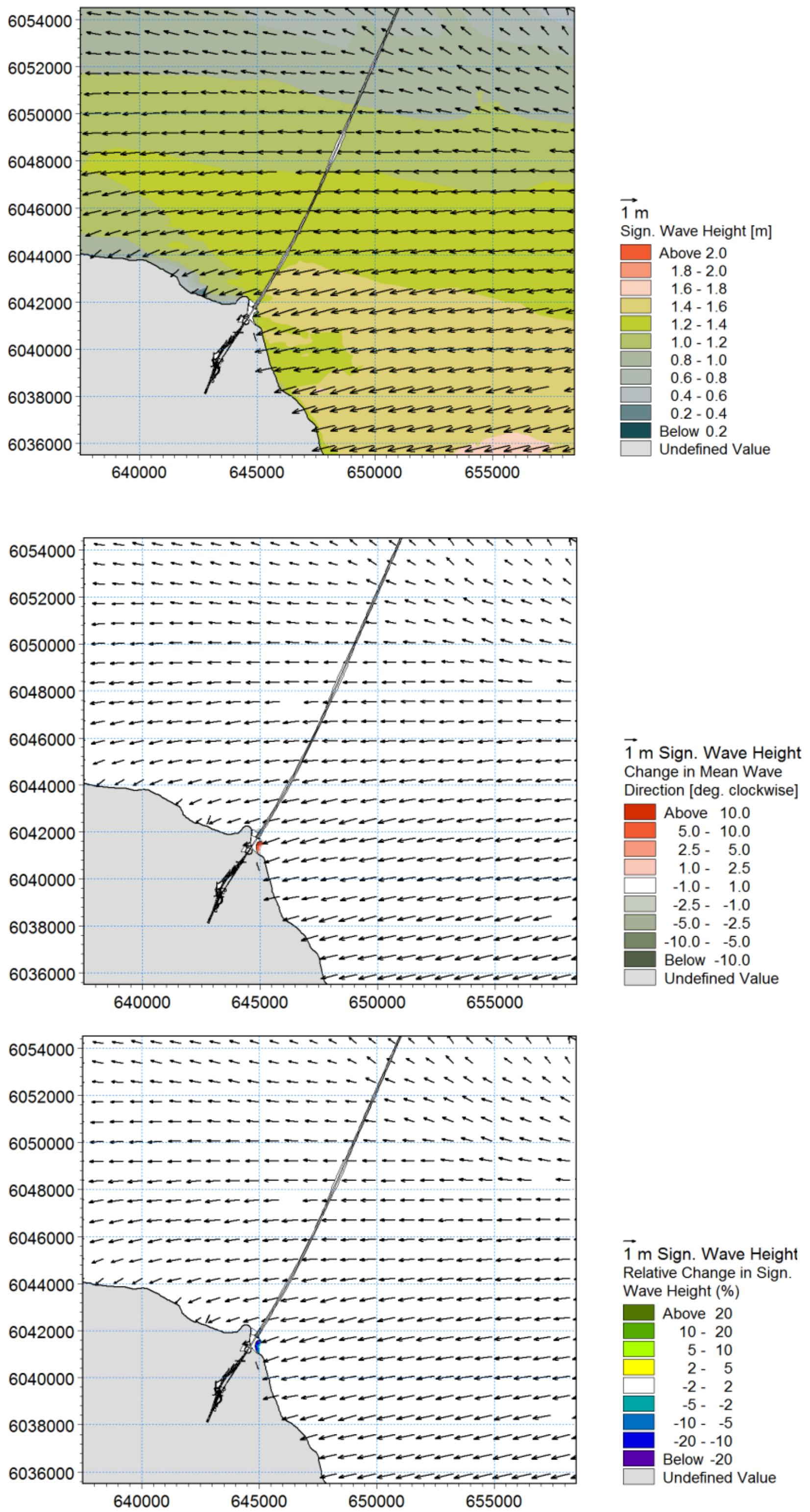

Figure 5.16 Changes to the wave field around Puttgarden for a typical situation with waves from southeast (Date: 28-12-2005 06:00). Upper figure: wave field for the tunnel project. Middle figure: relative change in significant wave heights due to the tunnel project. Lower figure: change in wave direction due to the tunnel project

5.1.6 *Changes to the sediment budgets and shoreline evolution, Fehmarn coast*

The littoral drift budget has been established along the coast of Fehmarn for the situation after the construction of the tunnel project. The littoral drift budgets are calculated for coastal stretches about 5-6 km east and west of Puttgarden (Gammendorferstrand to the coast south of Presen) at the Fehmarn side.

Littoral drift budget and shoreline evolution west of Puttgarden
The littoral drift budget for the coast west of Puttgarden has been calculated using the average wave conditions (1989-2010), see Figure 5.17. The annual drift rates have been calculated by Step 1 for calculation points G1-G8. The refined method, Step 2, is not appropriate along this section, refer to discussion above. The net and gross rates as well as the west- and eastwards components are presented in Table 5.3.

The changes to the transport rates (in differences compared to the baseline littoral drift rates) due to the tunnel project are given in brackets. The changes are seen to be insignificant at all calculation points west of Puttgarden.

<u>Grüner Brink</u>

The small reclamation east of Puttgarden does not extend beyond the breakwaters of Puttgarden and has no impacts on the waves from eastern directions arriving at Grüner Brink. The littoral drift budget is therefore considered unchanged by the tunnel project.

<u>Long groyne to Puttgarden</u>

The tunnel project has no impact on the sediment budget and shoreline along this section. A small impact on the waves from eastern directions can be identified just west of Puttgarden (refer to Section 5.1.5), where the reclamation changes the propagation of waves from southeast around Puttgarden very slightly. The change to the (very limited) net littoral drift at this location is insignificant as the east- as well as westgoing component is changed slightly. The westerly waves are unchanged. The impacts on the transport conditions west of Puttgarden are therefore insignificant.

<u>Puttgarden</u>

The harbour experiences presently no sedimentation in the harbour basin and access channel. The situation is expected to be unchanged after construction of the tunnel project.

Table 5.3 *Average net, gross and eastward/westward littoral transport rates west of Puttgarden for the tunnel project and differences compared with the baseline situation (in brackets). Positive net transport rates towards the east*

Location	Net littoral transport rate (m^3/yr)	Gross littoral transport rate (m^3/yr)	Westward transport rate ($10^3 m^3$/yr)	Eastward transport rate (m^3/yr)
G1	~41,000 (~0)	65,000 (~0)	12,000 (~0)	53,000 (~0)
G3	~20,000 (~0)	70,000 (~0)	~25,000 (~0)	~45,000 (~0)
G4	11,000-15,000 (~0)	40,000-45,000 (~0)	15,000 (~0)	26,000-30,000 (~0)
G5	-1,000 (~0)	7,000 (~0)	4,000 (~0)	3,000 (~0)
G6	<-5,000 (~0)	~10,000 (~0)	5,000-10,000 (~0)	0-5,000 (~0)
G7	<-5,000 (~0)	~25,000 (~0)	10,000-15,000 (~0)	10,000-15,000 (~0)
G8	~0 (~0)	~10,000 (-1000)	~5,000 (<-500)	~5,000 (<-500)

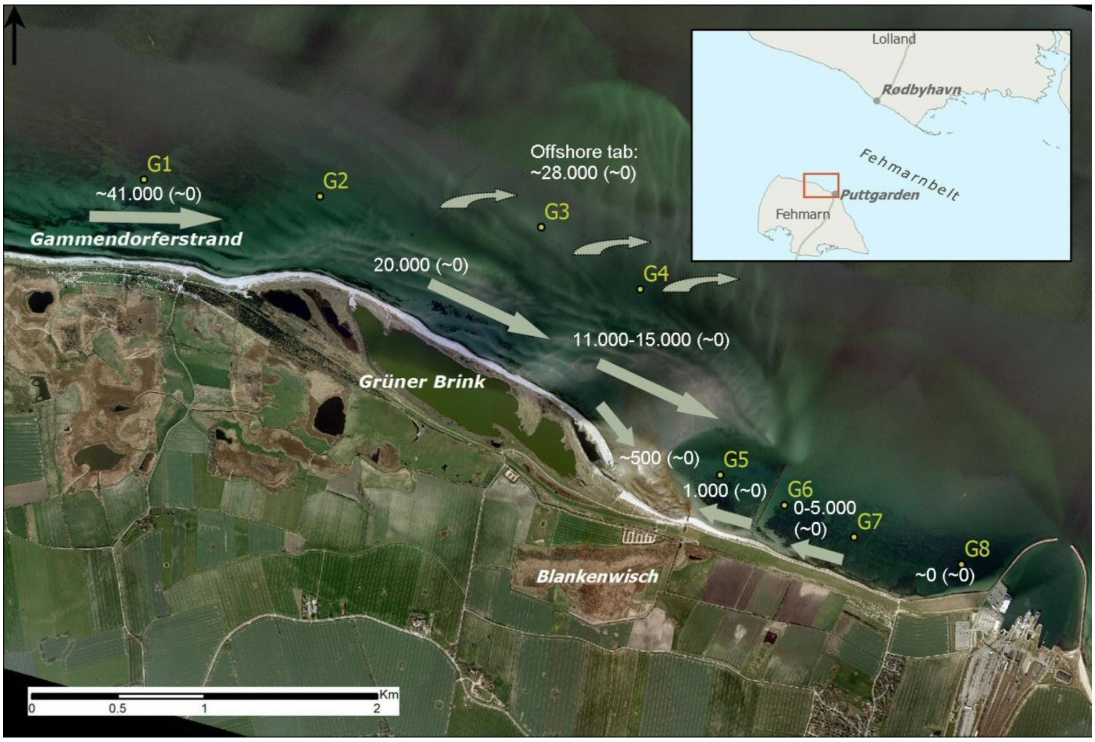

Figure 5.17 *Littoral drift budget (m3/year) along the coast west of Puttgarden for the situation with the tunnel project. The changes to the transport rates due to the tunnel project are given in brackets. No changes are expected west of Puttgarden.. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Littoral drift budget and shoreline evolution east of Puttgarden and the reclamation

The littoral drift budget for the coast east of the reclamation has been calculated using the average wave conditions (1989-2010), see Figure 5.18. The net and gross littoral drift rates are tabulated in Table 5.4.

The littoral drift rates are compared to the transport conditions in the baseline situation. The annual shoreline advance or retreat for the average year (1989-2010) evaluated from the littoral drift rates are shown in Figure 5.19 and compared to the simulated shoreline evolution for the baseline situation.

The littoral budget along this section shows only small changes due to the tunnel project, except for a small coastal stretch between the new beach and Ohlenborgs Huk, which is in the lee zone behind the new reclamation.

The effect of the reclamation is to increase the net transport rates towards the northwest. The reason is that the reclamation has the effect of decreasing the transport component towards the southeast. The decrease in transport rates towards the southeast is a balance by two opposing effects, both of which are related to the waves: a slight dampening of the wave heights for waves from northwesterly directions has the effect of reducing the transport towards the southeast. A small clockwise rotation of the wave directions from north caused by the reclamation decreases the angle between the incoming waves and the beach orientation. The changes in the directions act to increase the transport towards the southeast, but the (small) changes to the wave heights dominate. The changes to the waves are illustrated in Figure 5.15.

The changes of the sediment transport and the shoreline evolution along the coastal sections are described below.

<u>New beach northwest of Ohlenborgs Huk</u>

The *potential* net transport rate north of Ohlensborgs Huk towards the northwest is about 30-35,000 m^3/year, which is an increase of about 8,000 m^3/year. The transport capacity at G10 will not be effectuated due to small groynes and the seawall protecting the Ohlenborgs Huk from erosion and lack of loose sediment.

<u>Marienleuchte to Presen</u>

The changes to the shoreline evolution caused by the tunnel project are very small. The changes are less than +/-0.1 m/year everywhere.

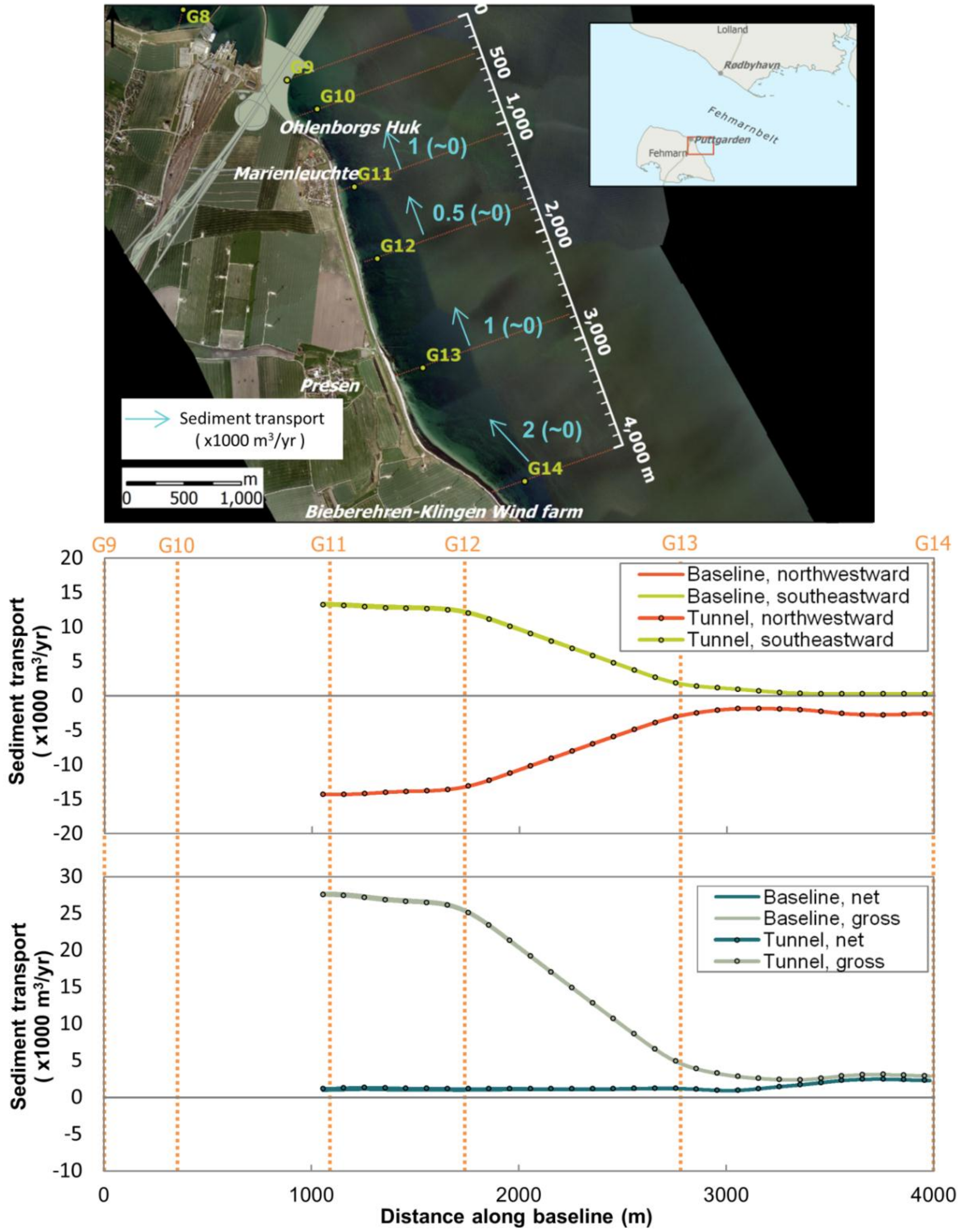

Figure 5.18 Average littoral drift rates east of the reclamation for the situation with the tunnel project and changes from the baseline situation (in brackets). Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Positive net transport rates towards the east. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen Wind farm is not the correct name of the wind farm south of Presen

Table 5.4 Average net, gross and eastward/westward littoral transport rates east of Puttgarden for the tunnel project and differences compared with the baseline situation (in brackets). Positive net transport rates towards the southeast. (1)indicate that these transport rates are not effectuated

Location	Net littoral transport rate (m^3/yr)	Gross littoral transport rate (m^3/yr)	Northwestward transport rate (m^3/yr)	Southeastward transport rate (m^3/yr)
	Reclamation			
G10[2]	~-30-35,000[1] (-8,000)	~35-40,000[1] (-8000)	34,000[1] (~0)	1,000-4,000[1] (-8,000)
G11	-1000 (<-500)	27,500 (<-500)	14,500 (~0)	13,500 (<-500)
G12	-500 (<-500)	26,000 (<-500)	13,000 (~0)	12,500
G13	-1,000 (~0)	4,500 (~0)	3,000 (~0)	1,500 (~0)
G14	-2,000 (~0)	2,500 (~0)	2,500 (~0)	<500 (~0)

[1]Potential transport capacity not effectuated. [2]With present orientation of the coastline

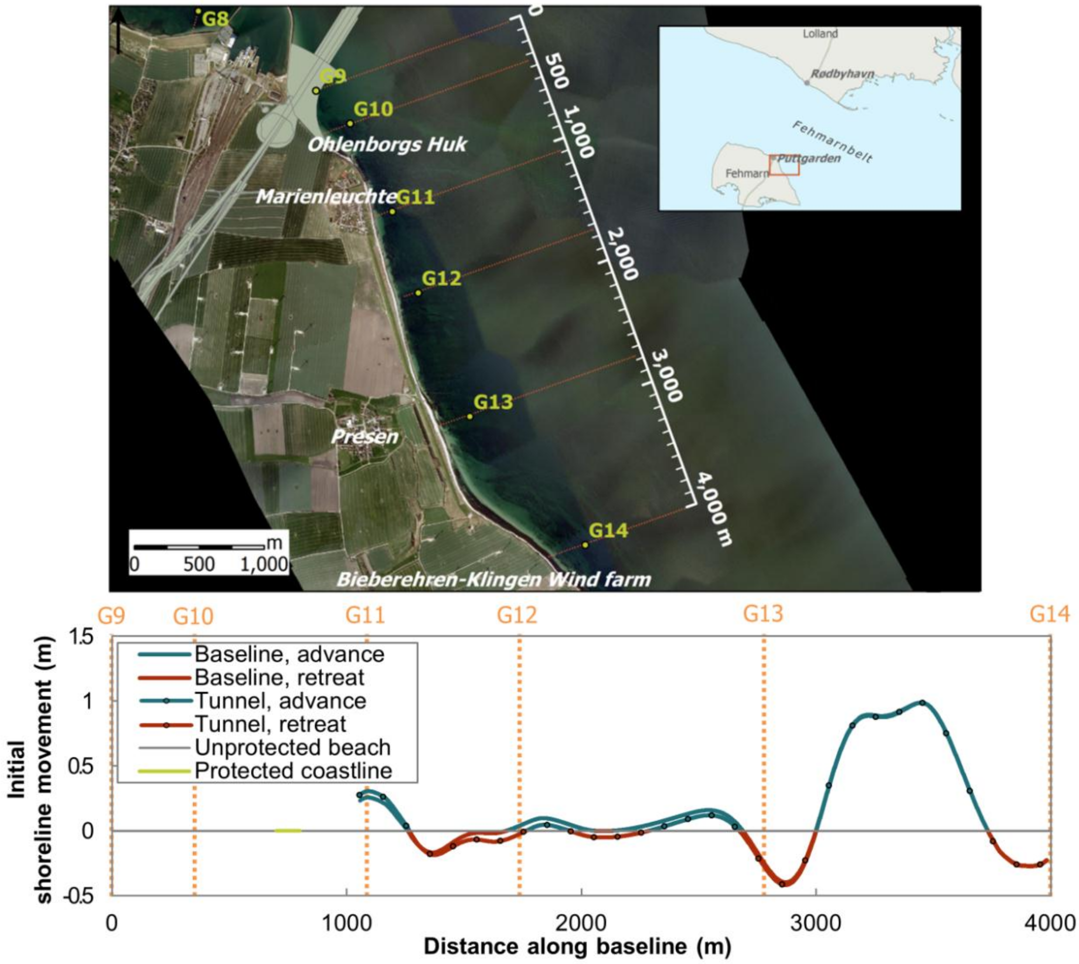

Figure 5.19 Predicted annual shoreline evolution for the situation with the tunnel project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Positive shoreline movement indicates accretion and negative indicates erosion. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

5.2 The bridge alternative

5.2.1 The permanent structures along the Lolland coast

The planned marine ramp east of Rødbyhavn is shown in Figure 5.20 together with the existing structures along the coast between Rødbyhavn and Hyllekrog. No new structures are planned west of Rødbyhavn. The existing structures along the coastal section between Rødbyhavn and Kramnitze are shown in Figure 5.21. The present day coastline is described in detail in (FEHY 2013a).

The marine ramps for the landfall of the bridge are planned between Rødbyhavn and Syltholm Wind Farm. The present coastline along this section is a revetment in front of the dike, see Figure 5.22.

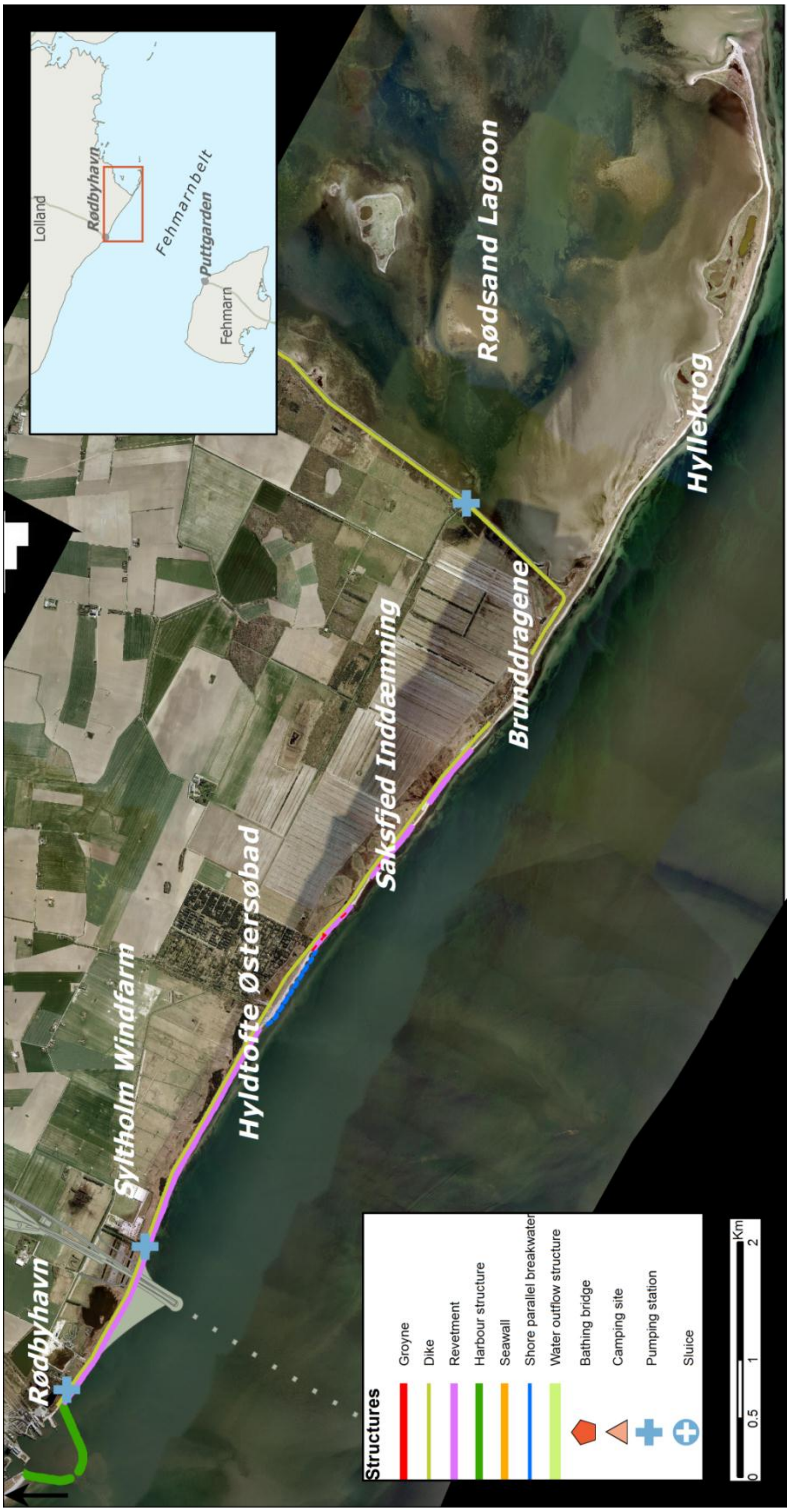

Figure 5.20 New permanent structures along the Lolland coast in the bridge project and existing structures – east of Rødbyhavn. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Figure 5.21 Existing structures west of Rødbyhavn. No permanent structures are planned west of Rødbyhavn as a part of the bridge project. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Figure 5.22 Existing revetment along the coast where the marine ramp and beaches are planned

5.2.2 Impacts on nearshore waves along the Lolland coast

Quantification of the changes in the nearshore waves due to the bridge project is input to the assessment of changes to the sediment budget on the Lolland coast. The waves are the primary driving force in transporting loose sea bed material along the coast (littoral transport). The waves act by enforcing an alongshore current and by introducing an additional stirring mechanism, which helps mobilising the sediment.

The changes in the nearshore waves are assessed by comparing nearshore waves calculated by numerical models for a 21-year period (1989-2010) for a) the baseline situation and b) the situation after the bridge project. The simulations of the wave fields are carried out for the situation with the permanent structures.

Waves from west

A snapshot illustrating the changes to the wave field due to the bridge for a situation with high waves from west (see upper panel) is shown in Figure 5.23. Westerly waves are dominating the wave field in the Fehmarnbelt. Waves from these directions are more frequent and typically higher than waves from easterly directions.

Wave heights are shown as so-called 'significant wave heights', which is a measure for the average wave height for the highest one third of the waves in an irregular wave field. Wave directions are shown with arrows indicating the travelling directions.

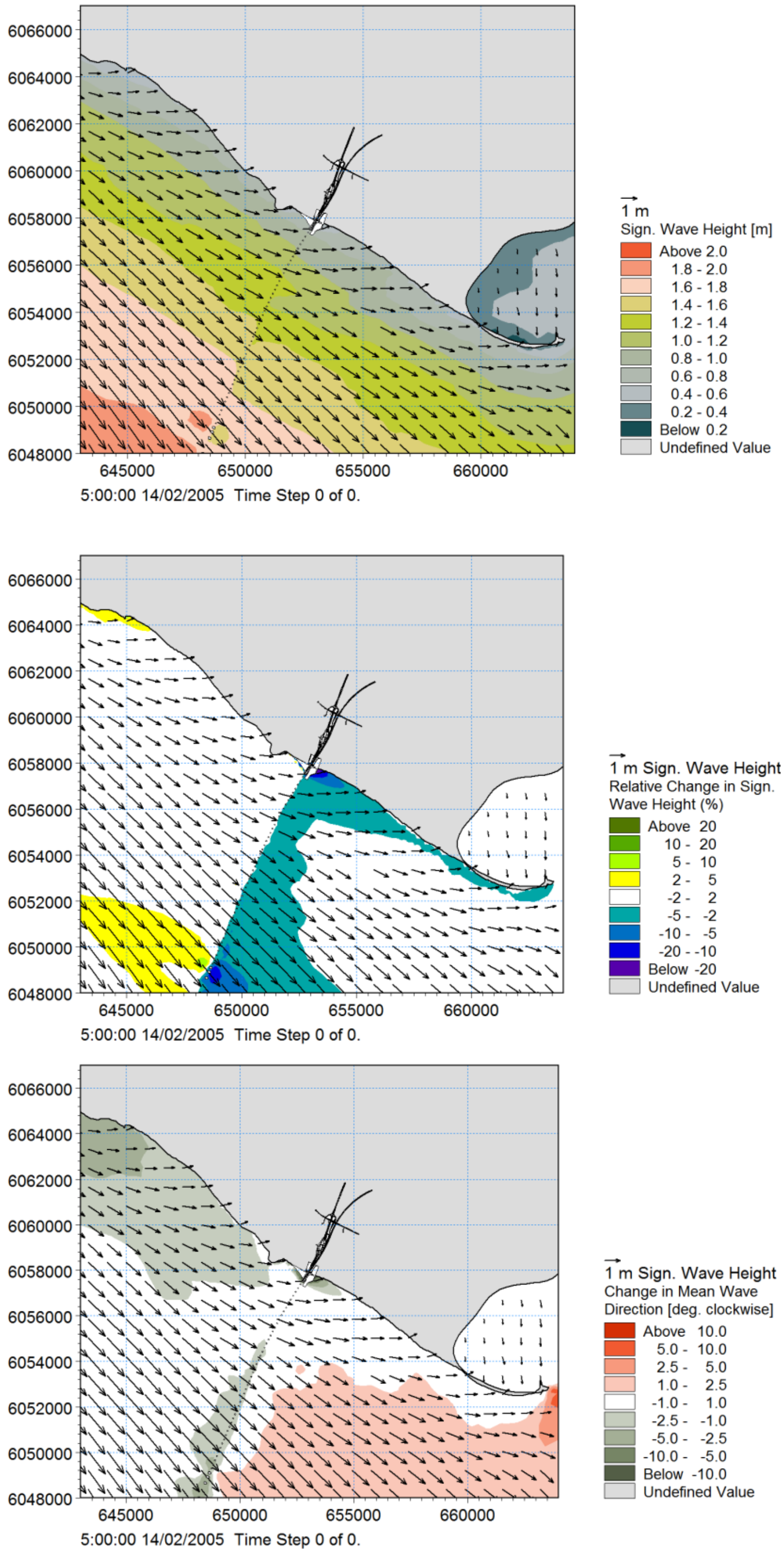

Figure 5.23 Changes to the wave field along the Lolland coast from Kramnitze in the west to Hyllekrog in the east. Typical situation (Date: 14-02-2005, 5:00 AM) with waves from west. Upper figure: wave field for the situation with the bridge project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)

The bridge project is seen to dampen the waves east of the alignment 'downstream' of the bridge piers and the marine ramp. The wave heights are dampened due to blocking of wave energy from west of the bridge alignment. The marine ramp has the influence of reducing the wave heights by 5-20% for about 1 km east of the ramp in the shown situation. Further east the wave heights are reduced by 2-5% along the remaining coastline between the marine ramp and the barrier island to the west, Hyllekrog.

Small changes to the wave direction on the downstream side of the bridge alignment can also be seen due to the increased spreading of the wave energy. The bridge piers have also a slight filtering effect as the waves with the longer wave lengths pass unchanged through the bridge alignment to the 'downstream' side to a higher degree than waves with a shorter wave length.

Only small effects of the reflection are seen on the wave heights west of the alignment. The wave heights increase slightly near Kramnitze about 8 km west of Rødbyhavn. The (vector) mean wave directions change slightly anti-clockwise along the coast west of the alignment as the wave energy from the reflected wave components (which have a south-easterly direction) is superposed with the incoming waves from west/northwest. For other directions more important for the littoral drift, the effects of reflection along the coast are smaller as the waves reflect towards the offshore. It should be noted that the modelled effects of reflection are considered conservative as mentioned in Section 3.3.1.

Waves from east

In case of waves from eastern directions (Figure 5.24), similar tendencies are seen. Waves from this direction are less frequent than waves from western directions and wave heights are typically smaller.

The bridge project is seen to reduce the wave heights west of the alignment where the structures block the wave energy and increase the wave heights 'upstream' of the bridge (as the blocked wave energy is reflected by the structures). Changes to the wave conditions for waves from east are most pronounced in the area just west of the land fall in the area between the marine ramp including the new beach and Rødbyhavn. The changes to the wave heights at the Lolland coast are for some sections of the coast for the shown instance in the order of 2-5% on both sides of the alignment. It should be noticed that the wave heights along the coast are relatively small for this angle of the incoming waves (i.e. the absolute changes are small, in particular in the westernmost part of the figure).

The directional changes are up to about 5 degr. at the coast east of the marine ramp in the area where the waves reflect to. This specific wave direction and the alignment of the coast cause a relatively strong effect of reflection east of the ramp around D15-D19, see locations on Figure 5.27. For most other wave directions (more important for sediment transport), the waves will primarily reflect towards the open sea and have an insignificant impact on the nearshore waves. It is noted that the modelled effects of reflection are considered conservative as mentioned in Section 3.3.1.

The marine ramp causes a lee-zone along the coast west of the ramp where the wave heights are dampened. In the lee zone the wave directions are turned clockwise since they propagate around the marine ramp and refract towards the new beach.

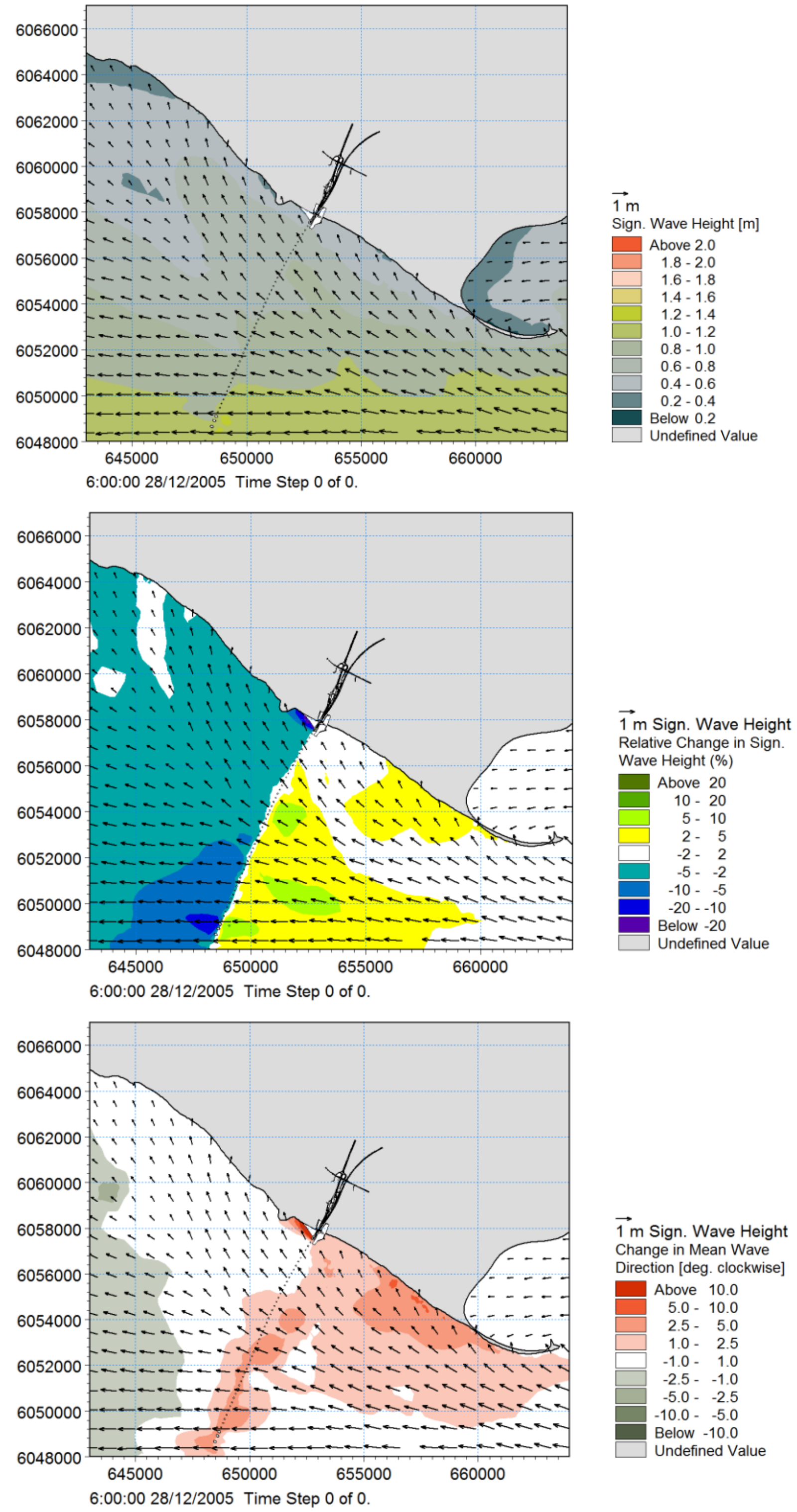

Figure 5.24 Changes to the wave field along the Lolland coast from Kramnitze in the west to Hyllekrog in the east. Typical situation (Date: 28-12-2005, 6:00 AM) with waves from east. Upper figure: wave field for the situation with the bridge project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)

5.2.3 Changes to the sediment budgets and shoreline evolution

The littoral drift budget has been established along the south coast of Lolland for the situation after the construction of the bridge project. The littoral drift budgets are calculated for coastal stretches about 3 km west (Bredfjed to Lalandia) and 3 km east (Hyldtofte Østersøbad to Brunddragene) of the planned reclamation on the Lolland side.

Littoral drift budget and shoreline evolution west of Rødbyhavn
The littoral drift budget for the coast west of Rødbyhavn has been calculated using the average wave conditions (1989-2010) applying the situation with the bridge project. The littoral drift rates are compared to the transport conditions in the baseline situation. The net and gross littoral drift rates in the situation with the bridge project and the changes compared with the baseline case are tabulated in Table 5.5. The annual shoreline advance or retreat for the average year (1989-2010) evaluated from the littoral drift rates is shown in Figure 5.28 and compared to the simulated shoreline evolution for the baseline situation.

The net eastwards transport rate of 20,000-30,000 m^3/year along this section found in the baseline situation is found to increase by about 1000-1500 m^3/year. The reason is a reduction in the westward transport component caused by the dampening of waves from eastern directions, see Figure 5.25. The eastward transport component is found to be unchanged along the coast. The small effects on the waves travelling from east caused by reflection from the bridge piers, see Section 5.2.2, do not impact the littoral transport.

The changes of the sediment transport and the initial shoreline evolution along the coastal sections west of the harbour and to Rødbyhavn are described below.

<u>Rødbyhavn</u>

The net eastward transport rates are estimated to increase slightly by about 1,500 m^3/year along the beach (accumulation area) just west of the harbour.

As the net transport increases with about the same rate along the beach west of Rødbyhavn (the accumulation area), the gradient in the alongshore littoral drift is unchanged.

The sedimentation in the access channel and harbour basins of Rødbyhavn is expected to increase by about 1,500 m^3/year.

<u>Lalandia to Sandholm</u>

The net eastward transport rates are estimated to increase by about 1500 m^3/year along this coastal section. The shoreline advance is practically unchanged at about 0.5 m/year.

<u>Sandholm to Bredfjed</u>

At D6, the increase in the net transport is about 1000 m^3/year, i.e. a slightly smaller increase in the net transport than further east caused by the partly immobile profile at this location due to a revetment that occupies some of the coastal profile (the revetment extends to a water depth of approximately 0.4 m DVR90 (see FEHY 2013a).

<u>West of Bredfjed</u>

The impact of the bridge project on the waves is seen to remain the same along the coast further west (Section 5.2.2). The wave heights for the easterly waves are dampened by about 2-3% all along the coast.

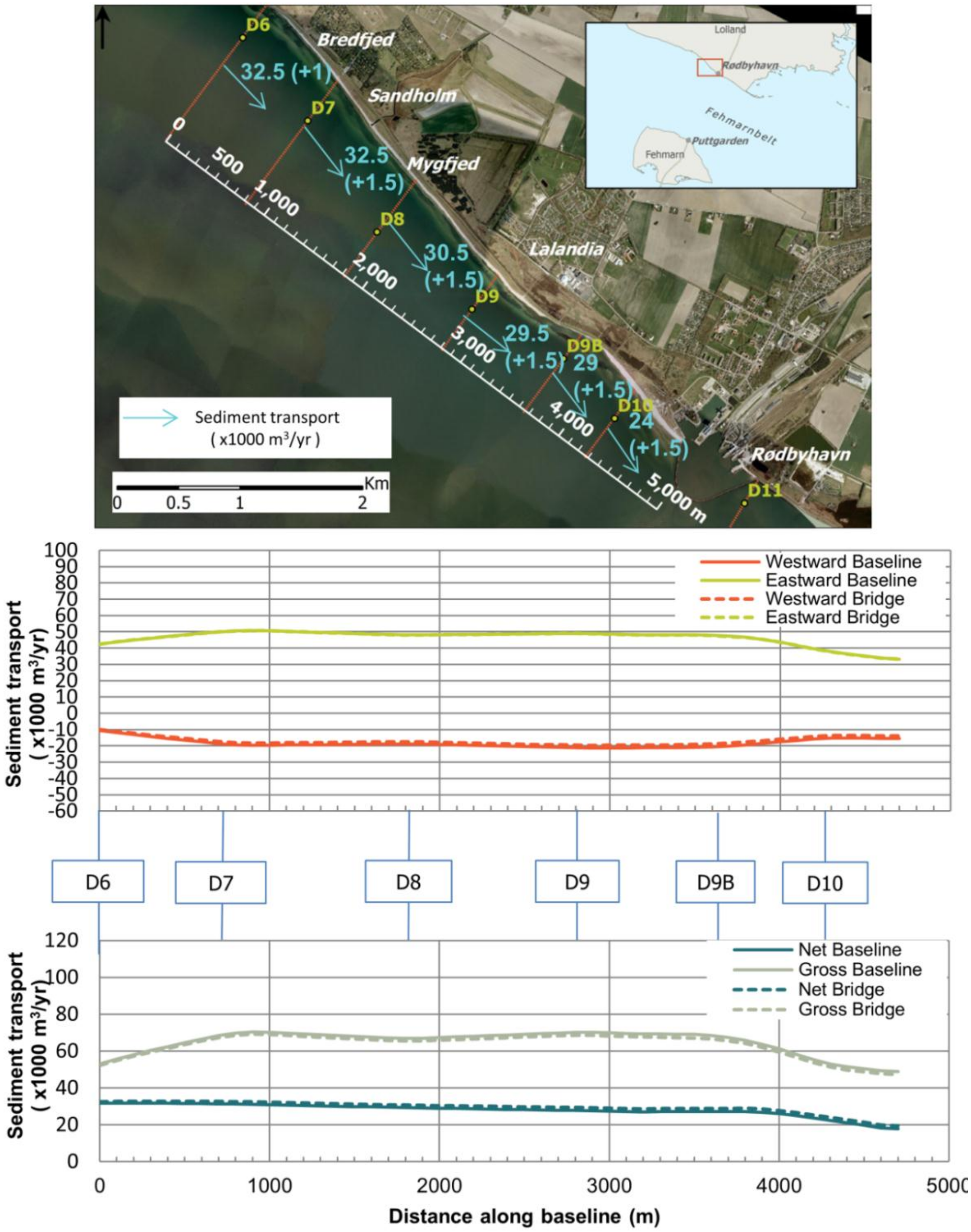

Figure 5.25 Average littoral drift rates west of Rødbyhavn for the situation with the bridge project and the baseline situation. Upper figure: net littoral drift rates and changes to transport rates due to the bridge project in brackets (x1000 m3/yr). Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Table 5.5 *Average net and gross littoral transport rates west of Rødbyhavn for the bridge project and the differences compared with the baseline situation (in brackets). Positive net transport rates towards the east*

Location	Net littoral transport rate (m^3/year)	Gross littoral transport rate (m^3/year)
D6	32,500 (+1,000)	54,000 (+1,000)
D7	32,500 (+1,500)	70,000 (+1,500)
D8	30,500 (+1,500)	68,500 (+1,500)
D9	29,500 (+1,500)	71,500 (+1,500)
D9B	29,000 (+1,500)	70,000 (+1,500)
D10	24,000 (+1,500)	54,500 (+1,500)

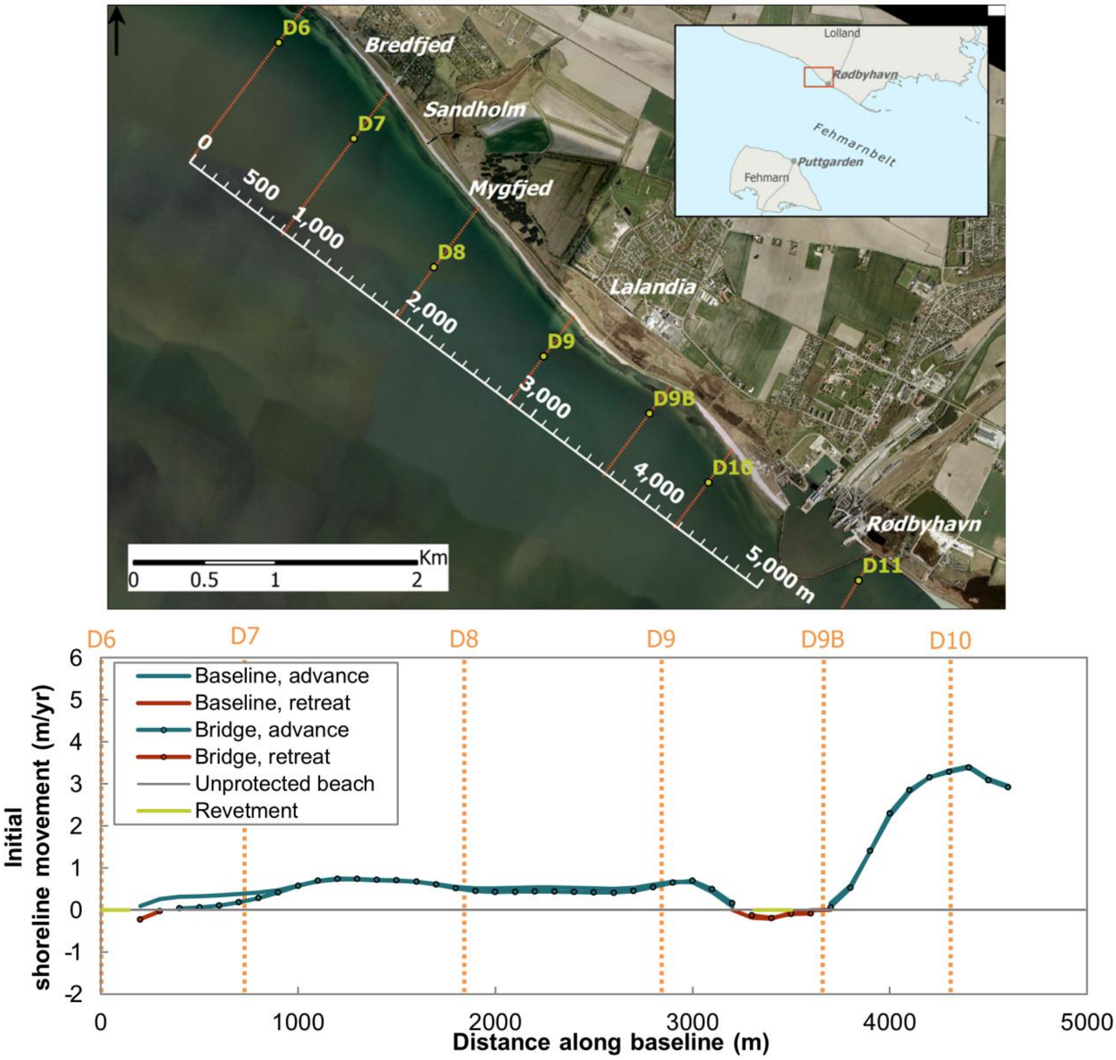

Figure 5.26 *Predicted initial annual shoreline evolution west of Rødbyhavn for the situation with the bridge project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Positive shoreline movement indicates accretion and negative indicates erosion. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Littoral drift budget and shoreline evolution east of Rødbyhavn

The littoral drift budget for the coast east of Rødbyhavn has been calculated using the average wave conditions (1989-2010), see Figure 5.27. The net and gross littoral drift rates in the situation with the bridge project and the changes compared with the baseline case are tabulated in Table 5.6. The annual shoreline advance or retreat for the average conditions is evaluated from the littoral drift rates. The average shoreline evolution is shown in Figure 5.28 and compared to the simulated shoreline evolution for the baseline situation.

The marine ramp with beaches has the impact of blocking the littoral drift along the coast. The effect of the bridge piers and pylons on dampening the waves from west further reduces the net littoral transport along the coast.

Rødbyhavn blocks the transport from west as in the baseline situation. Between Rødbyhavn and the marine ramp, the net littoral drift begins to pick up, but the short distance to the new beach and the ramp as well as the reorientation of part of the shoreline due to the new beach means that the transport along this section is limited.

No by-pass around the marine ramp takes place. East of the marine ramp, the net littoral drift is zero and gradually increases as the lee effect of the ramp on the westerly waves weakens. From approximately 400-500 m east of the ramp (around Syltholm Wind Farm at D12) and further east towards Saxfjed Inddæmning, the net littoral drift is reduced by 1,500-3,000 m^3/year corresponding to about 11-16% of the net transport in the baseline situation. The reduction is caused by the dampening of the westerly waves due to the bridge piers/pylons, which has the impact of reducing the eastward transport component. The westward component is unchanged, i.e. the influence on reflecting waves on the littoral transport is insignificant. The reduction in the wave heights by about 2-3% continues along the entire stretch and also further along Hyllekrog, see Section 5.2.2.

The reduction in the littoral transport is seen to have same order of magnitude in all calculation points (D12-D17) with small variations. The differences are primarily due to a) variations in the availability of loose sea bed material in the coastal profiles or b) longshore variation in the approach angle of the waves from west to the beach orientation. The availability of loose sediments along the coast was taken into account in the calculations as described in Section 3.3.2. In coastal profiles with more mobility (i.e. where revetments do no occupy part of the profile and the sea bed is less hard) the changes due to the bridge project on the waves has a larger impact on the net transport rate. The angle between the approaching waves from west and the beach orientation determines the importance of the waves from west on the littoral drift transport and therefore the influence of the bridge project.

The changes of the sediment transport and the shoreline evolution along the coastal sections east of the bridge are described below.

<u>Rødbyhavn and new beach west of the marine ramp</u>

An increase in the limited net eastward transport just east of the eastern breakwater of Rødbyhavn is predicted and this will slightly increase the erosional west of the ramp.

<u>Marine ramp to Hyldtofte Østersøbad</u>

A short section of beach is planned in the corner between the ramp and the existing coast east of the ramp. The beach shall be designed to be aligned with the equilibrium orientation for the waves from east.

The coastal section between the marine ramp and Hyldtofte Østersøbad has in the baseline situation a net deficit of sand due to the lack of input from east caused by Rødbyhavn. The shoreline is protected by a revetment, but the coastal profiles experience an erosional pressure due to the increase in the net transport towards the east.

Near Hyldtofte Østersøbad

At Hyldtofte Østersøbad ten coast-parallel breakwaters were built in 1999 to stabilise the beach and have sections of beaches in front of the summerhouses.

The net transport increases slightly along this section as the coast gets more exposed to waves from west and northwest. As these waves become more important for the net transport, the impact of the bridge on the littoral transport after construction increases. The gradient in the net transport along this stretch thereby reduces due to the bridge project and the tendency for erosion decreases slightly.

Just east of the breakwater scheme, the shoreline orientation is turned slightly clockwise causing a small accumulation area. The clockwise turn in the beach orientation causes the waves to have a relatively smaller influence on the littoral drift than in front of the summerhouses.

Saksfjed Inddæmning to Brunddragene

In front of Saxfjed Inddæmning (D16-D17) the shoreline retreat decreases slightly due to the increasing eastward transport rate and the increase in the mobility of the coastal profile. Both of these processes act to increase the impact of the bridge project and reduce the gradient in the net littoral drift.

Hyllekrog

The impact of the bridge project on the waves is seen to remain the same along the coast further east (Section 5.2.2). The wave heights for the westerly waves are dampened by about 2-3% all along the coast towards Hyllekrog. The net littoral drift transport is expected to reduce with an order of about 3000 m^3/year corresponding to 10-15%.

The Q-alpha relation between the beach orientation and the transport rates (net, eastward and westward components) are seen in Figure 5.30, calculated for the average wave conditions at D20 and applying the coastal profile and sea bed conditions similar to D17.

The bridge project reduces the larger littoral transport rates the most. The gradient in the transport rate is thereby reduced.

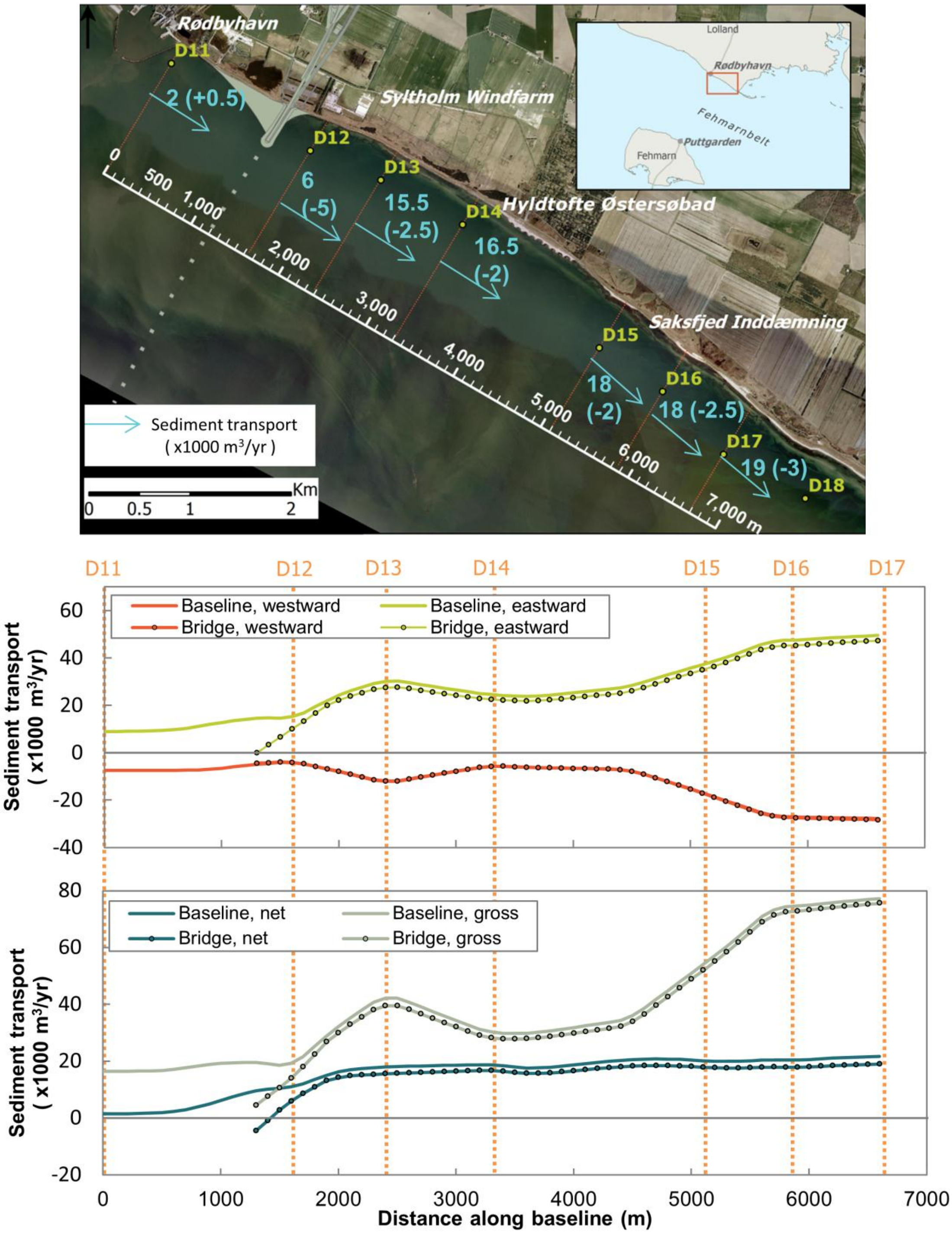

Figure 5.27 Average littoral drift rates east of Rødbyhavn for the situation with the bridge project and the baseline situation. Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Table 5.6 Average net and gross littoral transport rates east of Rødbyhavn for the bridge project and the differences compared with the baseline situation (in brackets). Positive net transport rates towards the east

Location	Net littoral transport rate (m^3/year)	Gross littoral transport rate (m^3/year)
D11	2000 (+500)	17,000 (+500)
D12	9,500 (-1,500)	18,000 (-1,500)
D13	15,000 (-2,500)	39,500 (-2,500)
D14	16,500 (-2,000)	28,500 (-2,000)
D15	18,000 (-2,000)	52,000 (-2,000)
D16	18,000 (-2,500)	72,000 (-2,500)
D17	19,000 (-3,000)	74,500 (-3,000)

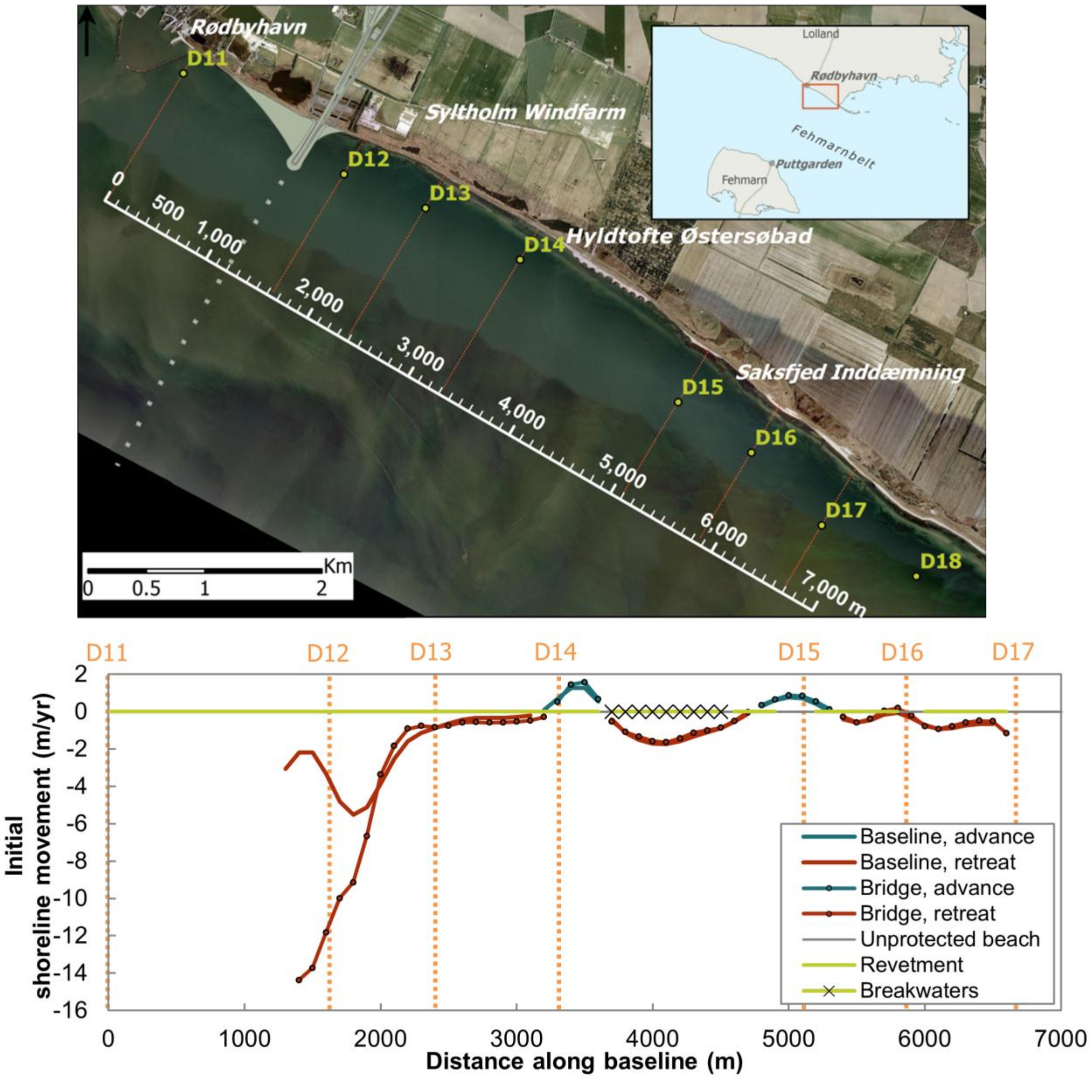

Figure 5.28 Predicted initial annual shoreline evolution east of Rødbyhavn for the situation with the bridge project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Aerial photo from 2009 (©COWI Orthophoto April 2009)

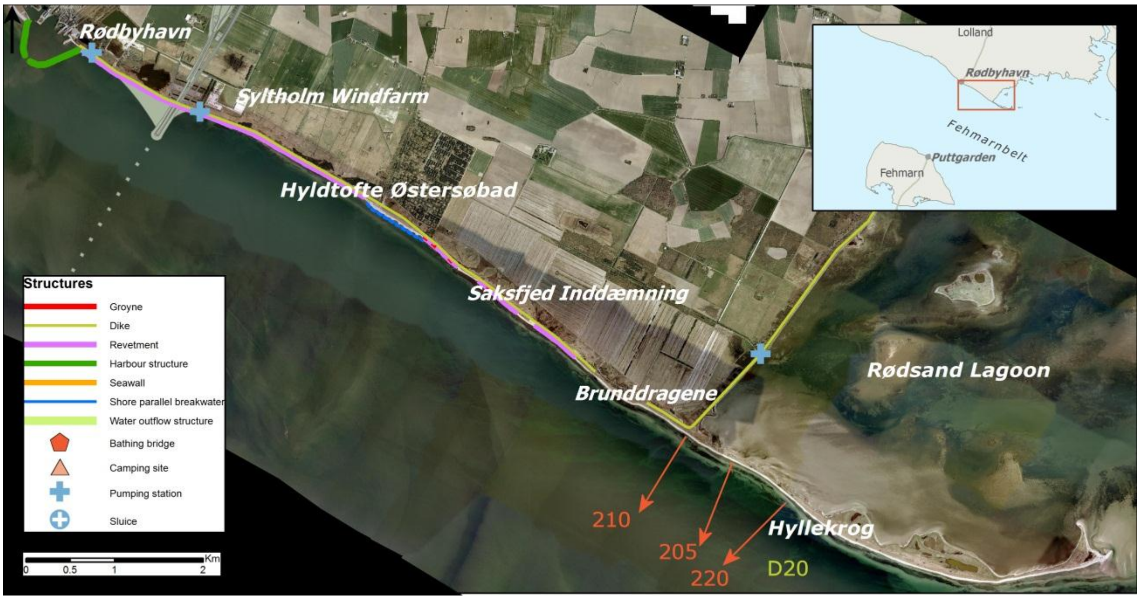

Figure 5.29 Change of beach orientation along Hyllekrog near the connection point to Lolland. Aerial photo from 2009 (©COWI Orthophoto April 2009)

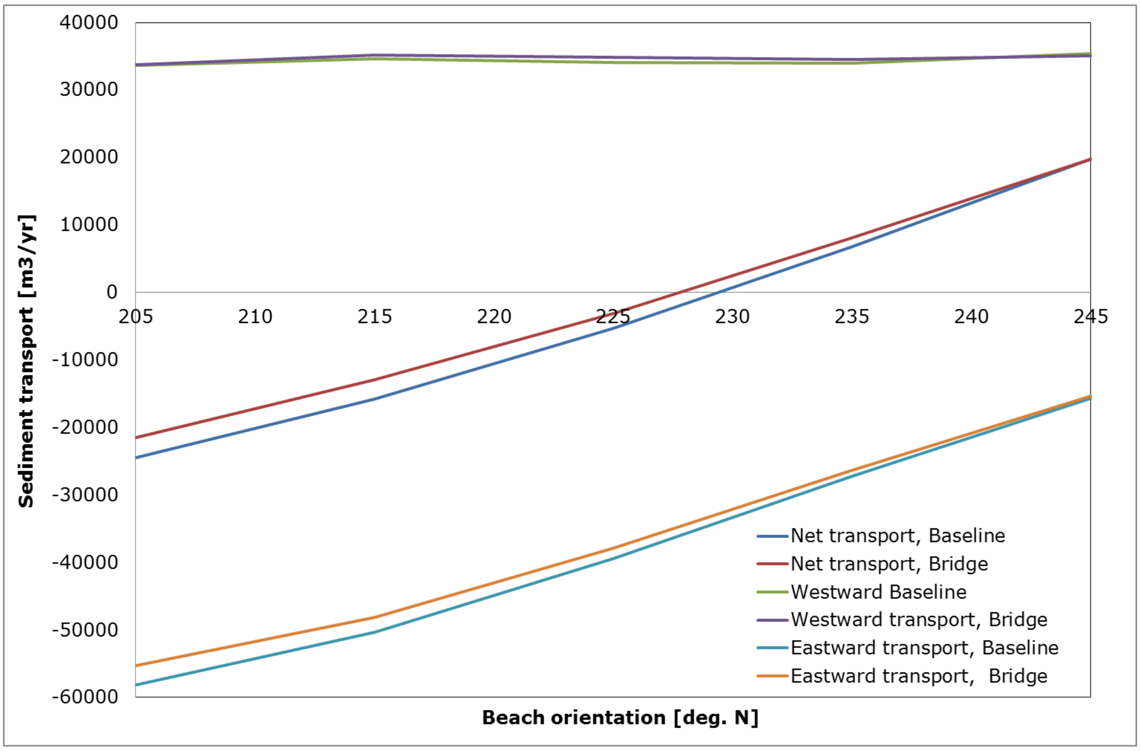

Figure 5.30 "Q-alpha" relation (relation between littoral drift and beach orientation) for D20

5.2.4 *The Permanent Structures along the Fehmarn Coast*

An overview of the planned structures along the Fehmarn coast is provided in Figure 5.31 and Figure 5.32 together with the present structures.

The bridge attaches to land with a ramp east of the eastern breakwater of Puttgarden (see Figure 5.31). The marine ramp extends approximately 700 m towards the northeast with a landfill east of the ramp. A curved beach facing a south-easterly direction is suspended between the offshore protection/breakwater and the original coastline.

The present shoreline in this area consists of the eastern breakwater of Puttgarden and a small accumulation of sand in the transition between the harbour and the coast.

The new beach attaches to the original coastline west of Ohlensborgs Huk. Ohlensborgs Huk is protected by a number of small groynes and the new beach terminates just west of these as seen in Figure 5.31.

No new structures are planned west of Puttgarden as a part of the bridge project.

The present day coastline in the area is further described in (FEHY 2013a).

Figure 5.31 *New permanent structures along the Fehmarn coast in the bridge project – east of Puttgarden. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

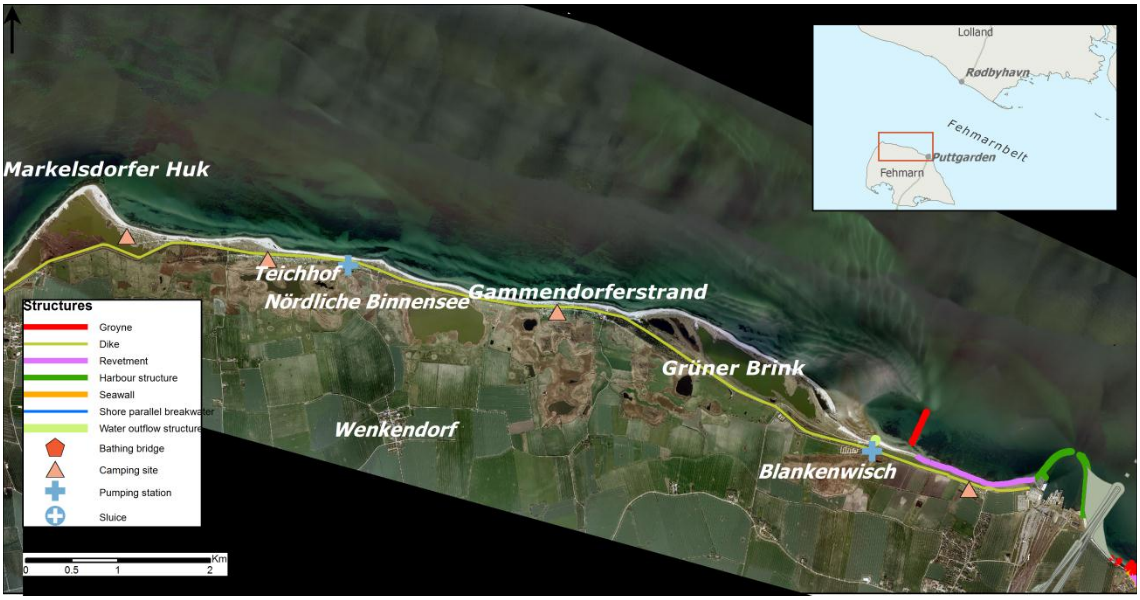

Figure 5.32 No permanent structures are planned west of Puttgarden. The planned reclamation with marine ramp and beach east of Puttgarden is visible in the right side of the figure. Aerial photo from 2009 (©COWI Orthophoto April 2009)

5.2.5 Impacts on nearshore waves along the Fehmarn coast

Quantification of the changes in the nearshore waves due to the bridge project is input to the assessment of changes to the sediment budget on the Fehmarn coast. The waves are the primary driving force in transporting loose sea bed material along the coast (littoral transport). The waves act by enforcing an alongshore current and by introducing an additional stirring mechanism, which helps mobilising the sediment.

The changes in the nearshore waves are assessed by comparing nearshore waves calculated by numerical models for a 21-year period (1989-2010) for a) the baseline situation and b) the situation after the bridge project. The simulations of the wave fields are carried out for the situation with the permanent structures.

Waves from west

A snapshot illustrating the changes to the wave field due to the bridge project in a situation with high waves from west (see upper panel) is shown in Figure 5.33 and Figure 5.34. Westerly waves are dominating the wave field in the Fehmarnbelt. Waves from these directions are more frequent and typically higher than waves from easterly directions.

Wave heights are shown as so-called ‘significant wave heights’, which is a measure for the average wave height for the highest one third of the waves in an irregular wave field. Wave directions are shown with arrows indicating the travelling directions.

The bridge project is seen to dampen the waves east of the alignment ’downstream’ of the bridge alignment, especially in the lee zone behind the pylons in the central part of the Fehmarnbelt and to a smaller degree ‘downstream’ of the smaller bridge piers.

Small changes to the wave direction on the downstream side of the bridge alignment can also be seen due to the increased spreading of the wave energy. The bridge piers have also a slight filtering effect as the waves with the longer wave lengths pass unchanged through the bridge alignment to the ‘downstream’ side to a higher degree than waves with a shorter wave length.

The reclamation with the marine ramp east of Puttgarden dampens the wave heights of the waves that propagate around the reclamation and refract towards the coast southeast of the reclamation. Refraction is the process by which the waves turn when the waves propagate with an oblique angle to the depth contours. The waves will turn towards the normal to the depth contours, when they propagate towards shallower depths. For this reason these waves turn and arrive at the coast from northern directions. The impact is visible and changes the wave heights by 2-5% in the area. The reclamation has the impact of reducing the wave heights by 5-20% up to about 5 km from the reclamation and a smaller effect (change of 2-5% of the wave heights) are seen further south. The reclamation also has the impact of turning the wave directions for these waves slightly clockwise. The effect extends approximately 5 km further south to the coast east of Staberhuk (see Figure 3.2), however the wave heights from these directions are small along the coast, so that the absolute changes are small, and the wave directions nearly parallel to the coast, causing these changes to be insignificant for the littoral drift as shown in the following sections.

The effects of reflection are seen on the wave heights west of the alignment. The wave heights increase ‘upstream’ of especially the bridge pylons but also slightly west of the piers. Small changes to the wave heights and directions can be seen along the coast west of Puttgarden. As mentioned above these changes are estimated to have the correct order of magnitude, but the effects are probably slightly too large.

The (vector) mean wave directions change slightly clockwise along the coast west of the alignment as the wave energy from the reflected wave components (which have easterly directions) is superposed with the incoming waves from westerly directions.

Waves from east
In case of waves from eastern directions (Figure 5.34), similar tendencies are seen. Waves from this direction are less frequent than waves from western directions but are important for the sediment transport conditions along the coast east of Puttgarden.

The bridge project is seen to dampen the waves west of the alignment and also along the coast west of Puttgarden. The wave heights are reduced by 2-5% west of the harbour and also in the Grüner Brink area, where the littoral drift zone extends about 1 km from the coastline due to the shallow water depths, see Figure 3.13. No changes are seen in the wave directions. Reflection increases the wave heights east of the bridge alignment, but no changes to wave heights and directions are seen along the coast southeast of the reclamation east of Puttgarden.

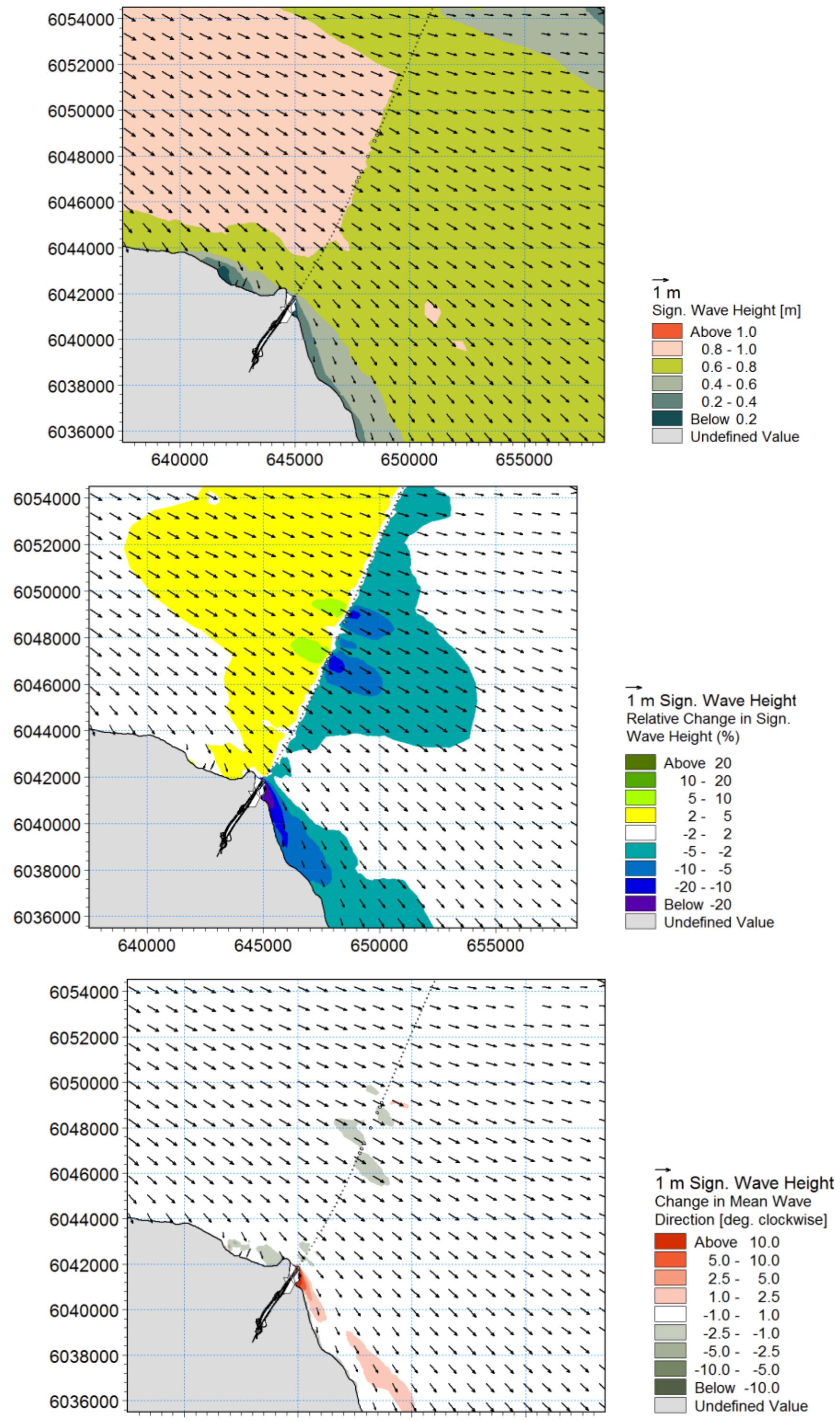

Figure 5.33 Changes to the wave field in case of waves from west along the Fehmarn coast from Gammensdorfer Strand in the west to Klausdorf in the southeast. Typical situation (Date: 08-05-2005, 0:00 AM) with waves from west. Upper figure: wave field for the situation with the bridge project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)

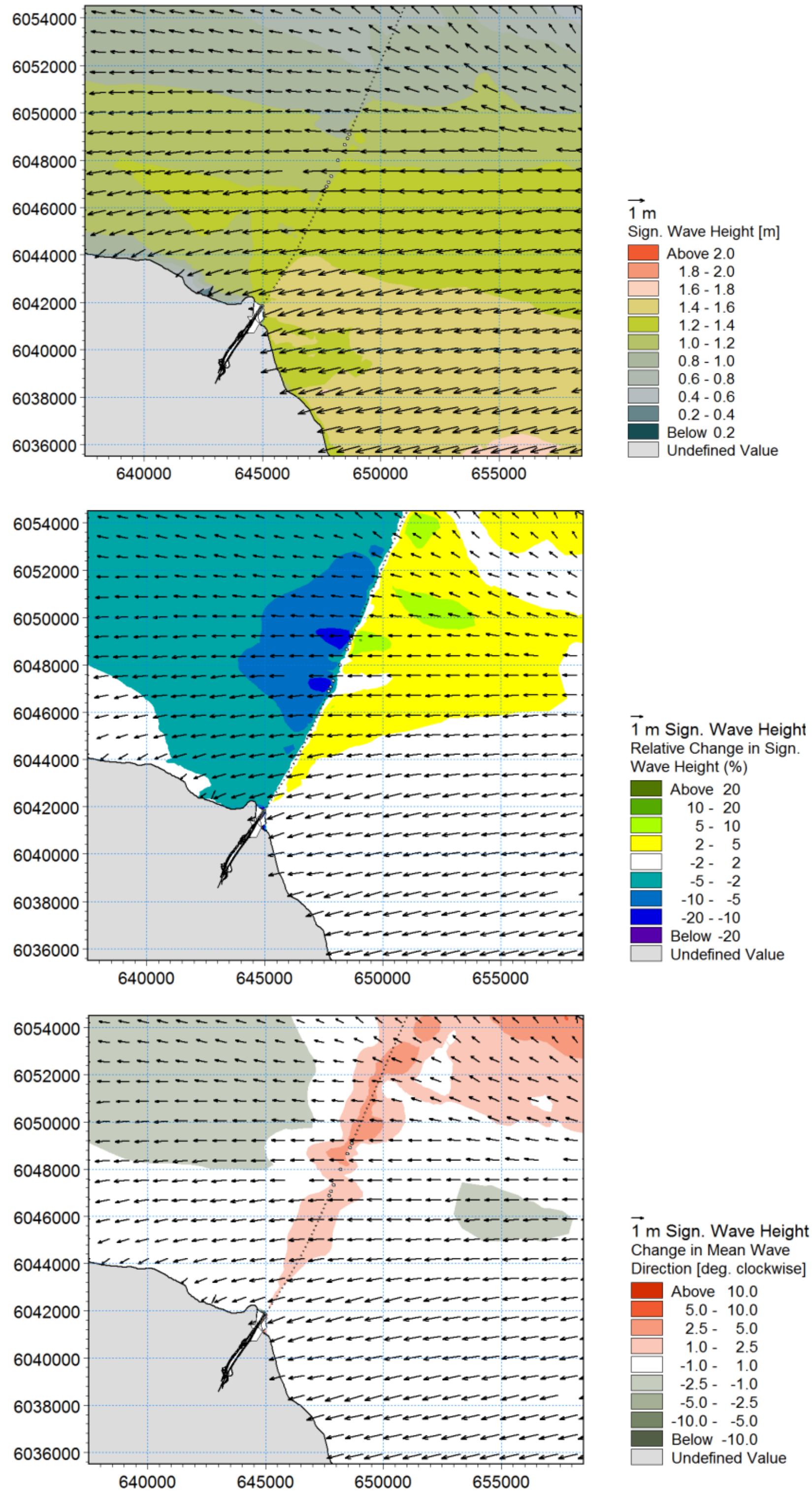

Figure 5.34 Changes to the wave field in case of waves from east along the Fehmarn coast from Gammensdorfer Strand in the west to Klausdorf in the southeast. Typical situation (Date: 28-12-2005, 6:00 AM) with waves from east. Upper figure: wave field for the situation with the bridge project. Middle figure: relative changes in wave heights (% of wave height in the baseline situation). Lower figure: change in wave directions (degr. clockwise)

5.2.6 Changes to the sediment budgets and shoreline evolution, Fehmarn coast

The littoral drift budget has been established along the south coast of Fehmarn for the situation after the construction of the bridge project. The littoral drift budgets are calculated for coastal stretches about 5-6 km east and west of Puttgarden (Gammendorferstrand to the coast south of Presen) at the Fehmarn side.

Littoral drift budget and shoreline evolution west of Puttgarden
The littoral drift budget for the coast west of Puttgarden has been calculated using the average wave conditions (1989-2010), see Figure 5.35. The annual drift rates have been calculated by Step 1 for calculation points G1-G8. The refined method, Step 2, is not appropriate along this section, refer to discussion above. The net and gross rates as well as the west- and eastwards components are presented in Table 5.7.

The changes to the transport rates (in differences compared to the baseline littoral drift rates) due to the bridge project are given in brackets.

The net eastward littoral drift increases with up to 20% due to the bridge project. The changes from the bridge to the wave field in case of waves from west as well as from east contribute to the increase in net eastward transport. The reduced wave heights for waves from east reduce the westward components. The effects of reflection on the wave heights (increase) and wave direction (clockwise rotation) increase the eastward components.

The changes vary along the coast and the impacts on the sediment budget are described below.

<u>Grüner Brink</u>

The net eastward transport along the Grüner Brink formation increases due to the combined impacts on the eastward as well as the westward components. The westward component decreases since the piers/pylons block the wave energy for waves travelling from east and thereby reduce the wave heights for the waves from east. The eastward transport component increases since the waves travelling from west are subject to reflection at the bridge piers and pylons and this causes an increase of the nearshore wave heights and a clockwise change in the wave direction; both of which act to increase the eastward component due to the very oblique approach angle of the waves along the Grüner Brink perimeter. The effect on the eastward component is estimated to be somewhat conservative as the effect on the waves due to reflection is estimated to be on the high side.

The impact of the bridge increases the net transport about 2000-5000 m^3/year corresponding to about 15-20% at G3-G4.

The impact of the bridge on the net transport is larger in terms of the absolute transport at G3 (~+5000 m^3/year) than at G1 (~ +1000 m^3/year) and G4 (~ +2000 m3/year). The reasons are a stronger impact on the waves at G3 compared to G1 and a steeper profile facilitating more transport at G3 than at G4. This is expected to lead to an unchanged or slightly reduced offshore transport of sediment to the sand wave field offshore of Grüner Brink (also visible in Figure 5.35).

<u>Long groyne to Puttgarden</u>

The bridge project has a small impact on the transport rates between the long detached groyne and Puttgarden. The net transport towards west (G6-G7) decreases with the order of 500 m^3/year. The impacts on the littoral transport caused by the reduced wave heights for waves from east are larger than the impacts on the reflected waves in case of waves from west. At G8 the net transport is expected to increase from about zero to about 500 towards the east.

Table 5.7 Average net, gross and eastward/westward littoral transport rates west of Puttgarden for the tunnel project and differences compared with the baseline situation (in brackets). Positive net transport rates towards the east

Location	Net littoral transport rate (m^3/yr)	Gross littoral transport rate (m^3/yr)	Westward transport rate ($10^3 m^3$/yr)	Eastward transport rate (m^3/yr)
G1	42,000 (+1,000)	65,000 (~0)	11,500 (-500)	53,500 (+500)
G3	~25,000 (+5,000)	70,000 (~0)	~23,000 (-2,000)	~47,000 (+2,000)
G4	13,000-17,000 (+2,000)	40,000-45,000 (~0)	13,500 (-1,500)	27,000-30,000 (+500)
G5	-750 (-250)	6,500 (-500)	3,500 (-500)	3,000 (<500)
G6	<-5,000 (+500)	~10,000 (-500)	5,000-10,000 (-500)	0-5,000 (~0)
G7	<-5,000 (+500)	~25,000 (-1,500)	10,000-15,000 (-1,000)	10,000-15,000 (-500)
G8	~+500 (+500)	~10,000 (-2,000)	~4,000 (-1,500)	~4,000 (-1,000)

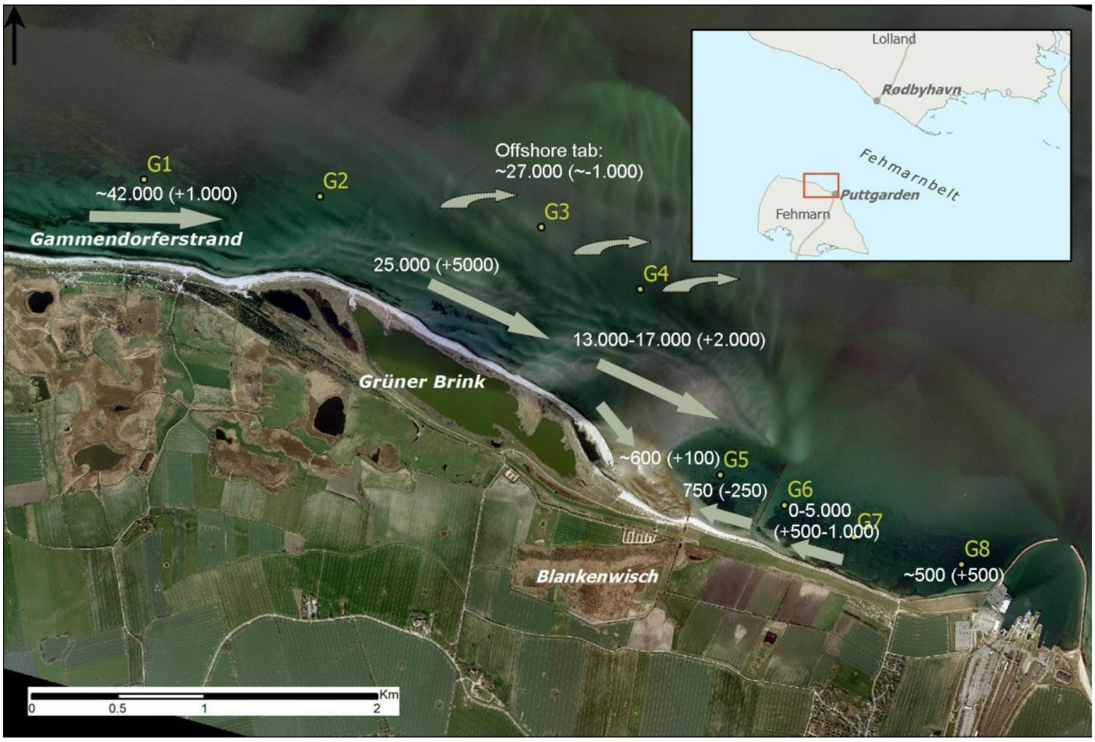

Figure 5.35 Littoral drift budget (m3/year) along the coast west of Puttgarden for the situation with the bridge project. The changes to the transport rates due to the bridge project are given in brackets. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Littoral drift budget and shoreline evolution east of Puttgarden

The littoral drift budget for the coast southeast of Puttgarden has been calculated using the average wave conditions (1989-2010), see Figure 5.36. The net and gross littoral drift rates in the situation with the bridge project and the changes compared with the baseline case are tabulated in Table 5.8.

The annual shoreline advance or retreat for the average conditions is evaluated from the littoral drift rates. The average shoreline evolution is shown in Figure 5.37 and compared to the simulated shoreline evolution for the baseline situation.

The reclamation east of Puttgarden harbour creates a lee area southeast of the reclamation for waves from western directions which propagate around the marine reclamation and arrive from northern directions at the coast. The effect of the bridge piers and pylons is mainly to block wave energy for waves from west and thereby reduce the wave heights for these waves. Both of these effects act to reduce the southeastern component of the transport and thereby increase the net northwestward transport of littoral drift. The effect of the bridge piers and pylons to reflect wave energy, does not impact the littoral drift along the coast southeast of Puttgarden since the reflected wave components travel to this coast to a very minor degree.

The changes of the sediment transport and the shoreline evolution along the coastal sections east of the reclamation are described below.

<u>New beach northwest of Ohlenborgs Huk</u>

The *potential* net transport rate north of Ohlensborgs Huk towards the northwest is about 30-35,000 m^3/year, which is an increase of about 8,000 m^3/year. The transport capacity at G10 will not be effectuated due to small groynes and the seawall protecting the Ohlenborgs Huk from erosion and lack of loose sediment.

<u>Marienleuchte to Presen</u>

The bridge project will increase the gradient of the net northward littoral drift along the coastal section between Marienleuchte and Presen. The increase in the net transport is highest nearest the bridge structures and decreases with the distance from the alignment.

The equilibrium beach orientation changes by approximately 1 degree clockwise, see Figure 5.38, which is indicating that the erosional pressure will be highest in the southernmost part of the section.

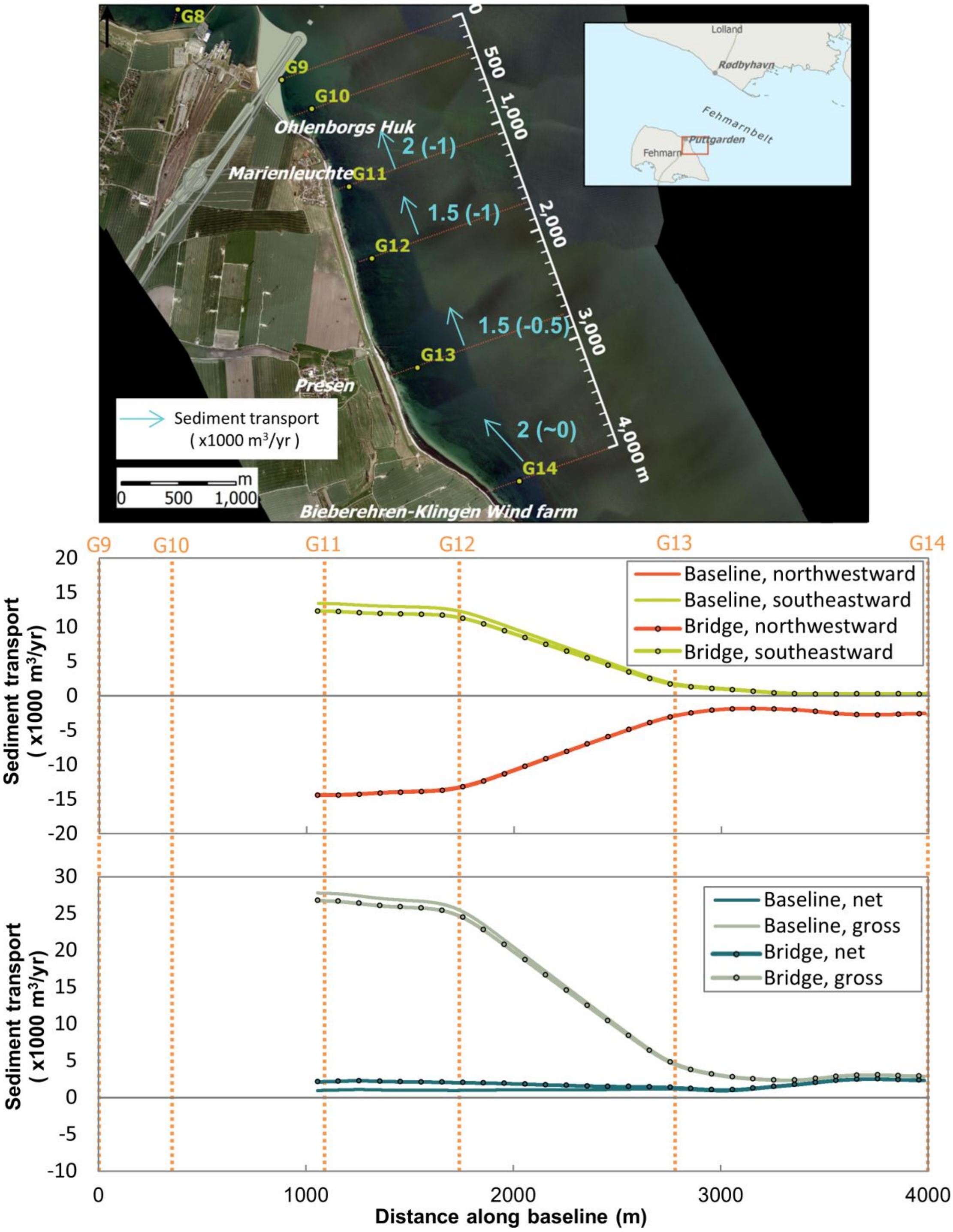

Figure 5.36 Average littoral drift rates southeast of Puttgarden for the situation with the bridge project and the baseline situation. Middle figure: west- and eastgoing transport components. Lower figure: net and gross transport rates. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

Table 5.8 *Average net and gross littoral transport rates southeast of Puttgarden for the bridge project and the differences compared with the baseline situation (in brackets). Positive net transport rates towards the east*

Location	Net littoral transport rate (m^3/yr)	Gross littoral transport rate (m^3/yr)	Northwestward transport rate (m^3/yr)	Southeastward transport rate (m^3/yr)
	Reclamation/marine ramp			
G10	~-30-35,000[1] (-8,000)	~35-40,000[1] (-8,000)	34,000[1] (~0)	1,000-4,000[1] (-8,000)
G11	-2000 (<-1,000)	27,000 (-1,000)	14,500 (~0)	12,500 (-1,000)
G12	-1,500 (-1,000)	25,000 (-1,000)	13,000 (~0)	11,500 (-1,000)
G13	-1,500 (<-500)	4,500 (<-500)	3,000 (~0)	1,500 (<-500)
G14	-2,000 (~0)	2,500 (~0)	2,500 (~0)	<500 (~0)

[1]Potential transport capacity not effectuated

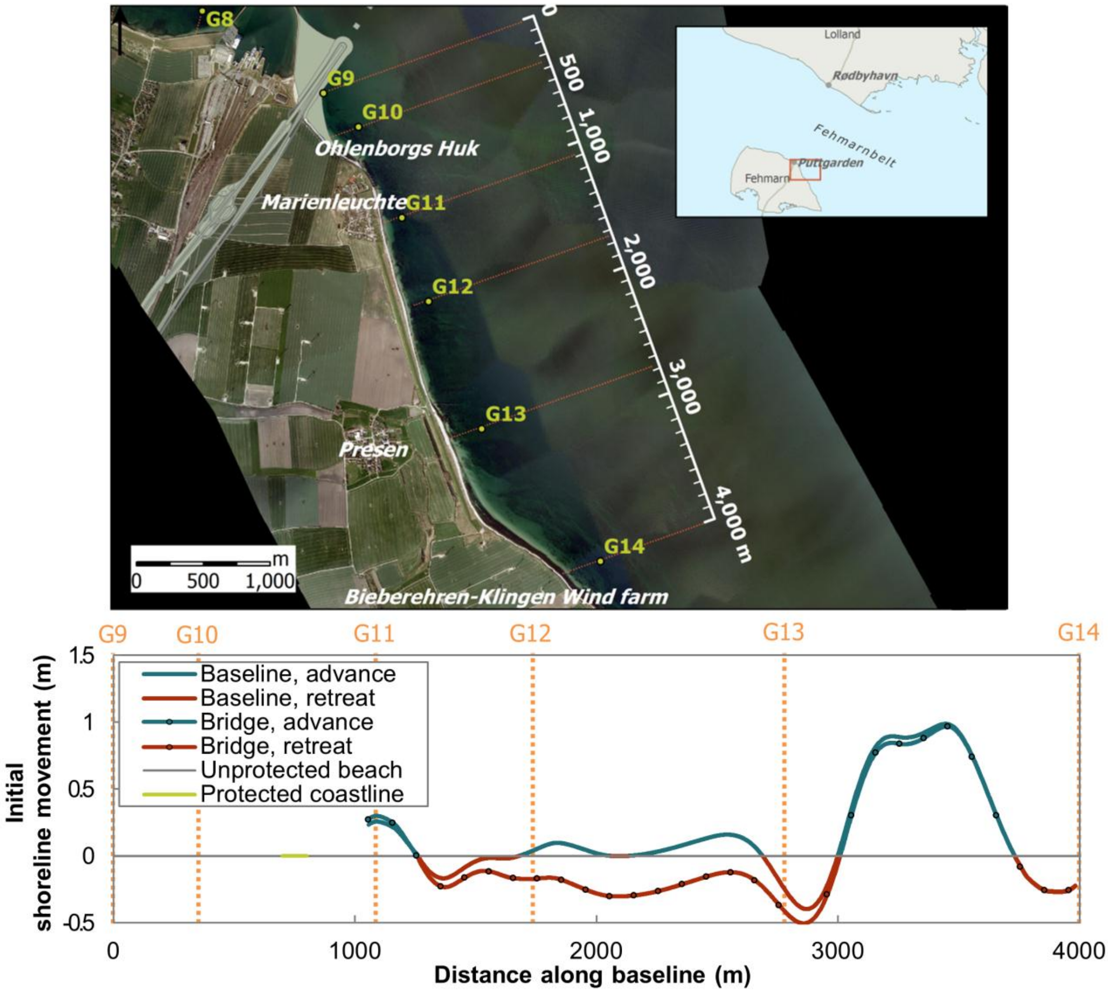

Figure 5.37 *Predicted initial annual shoreline evolution southeast of Puttgarden for the situation with the bridge project using long term averaged wave climate, 1989-2010, compared with the baseline situation. Positive shoreline movement indicates accretion and negative indicates erosion. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

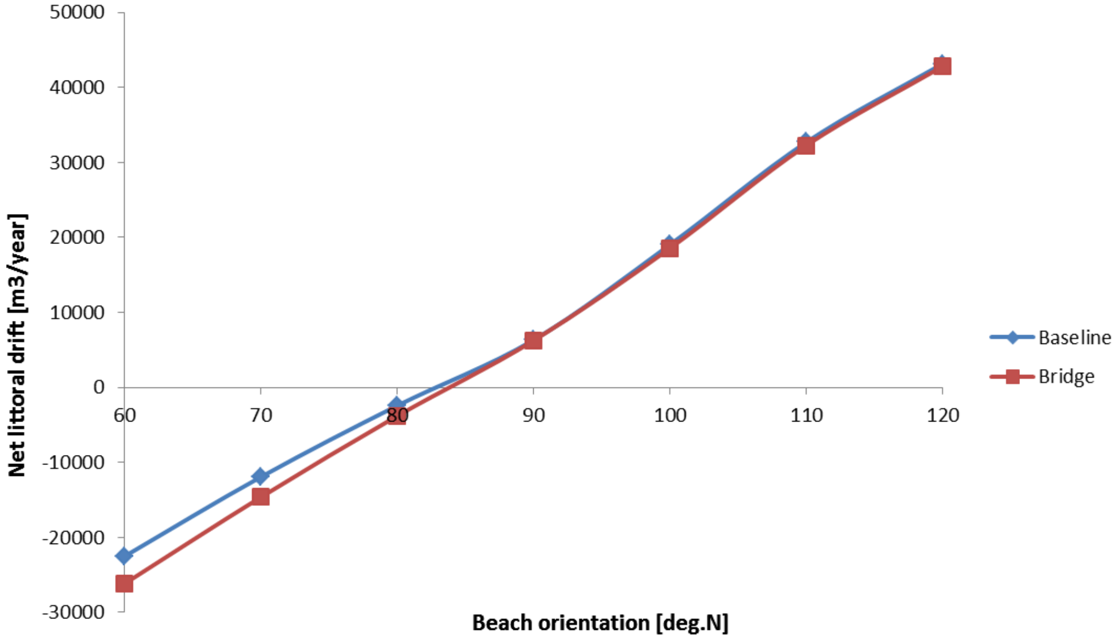

Figure 5.38 "Q-alpha" relation (relation between littoral drift and shoreline orientation) for G11. Present beach orientation is about 82 degrees

6 ASSESSMENT OF IMPACTS OF TUNNEL ALTERNATIVE

The impacts from the tunnel alternative E-ME/August 2011 are described below. The impacted sections of the coast (loss and impairments) are derived based on the magnitudes of the pressure from the tunnel project and the sensitivity to the pressure of the sub-components of the Marine Soil Component Coastal Morphology.

The impacts from the tunnel project on the Lolland and the Fehmarn coasts are treated separately.

The comparison of the baseline-situation and the situation with the tunnel project is carried out for the 'with ferry' situation only. The 'no ferry' scenario is not assessed. There is a negligible effect from the ferry to the sub-components and the assessment for the 'no ferry scenario' will therefore be identical to the assessment below for the situation with the ferry.

It is noted that the assessment is based on the following **mitigation measures included in the assessed design of the tunnel project**:

- The eastern 1.5 km of the land reclamation at Lolland is planned as an erodible cliff. The erosion from this section will release sand, which will partly compensate the blocking of the sediment transport caused by the reclamation.

- Two new sections of beach are included as part of the design of the land reclamation on Lolland to compensate for existing beaches which will be lost due the reclamation.

- A new beach section is included as part of the design of the land reclamation on Fehmarn to compensate for the existing beach east of Puttgarden, which will be lost due the reclamation on Fehmarn.

Following the impact assessment below, **additional mitigation measures**, have been planned for:

- Nourishment of approximately 14,000 m^3 each year at the coast east of the reclamation to keep the baseline situation

- New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of Rødbyhavn

- Measures to establish a new and adequate waste water outlet at Rødbyhavn

- Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk

Comments on the effects of the additional mitigation measures on the assessed impacts are provided, where relevant.

6.1 Lolland

6.1.1 Magnitude of pressure 1: reclamation, protection reef and access channel

The only impacts on the Lolland coastline are caused by the reclamation, protection reef and access channel to the production facilities on the Lolland side.

A total length of 7,470 m of the baseline coastline is integrated into the planned reclaimed area along the southern coastline of Lolland (see Figure 5.1 and Figure 5.2). The reclamation west of Rødbyhavn extends approximately 3,720 m from Rødbyhavn to Sandholm. East of Rødbyhavn, the reclamation extends to the western termination of the breakwater scheme at Hyldtofte Østersøbad 3,750 m from Rødbyhavn.

The magnitudes of the pressure to the coastal sections east and west of the reclamations are related to the effects, these structures have on the sediment budget along the coast. The impacts on the sediment budget from the structures and the access channel on the Lolland side were described in the previous Section 5.1. The impacts on the sediment budget were analysed based on the average year hydrodynamic conditions.

Figure 6.1 *New reclamation west of Rødbyhavn - indicated in grey - along the Lolland coast in the tunnel project. Baseline coastal and marine structures included. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

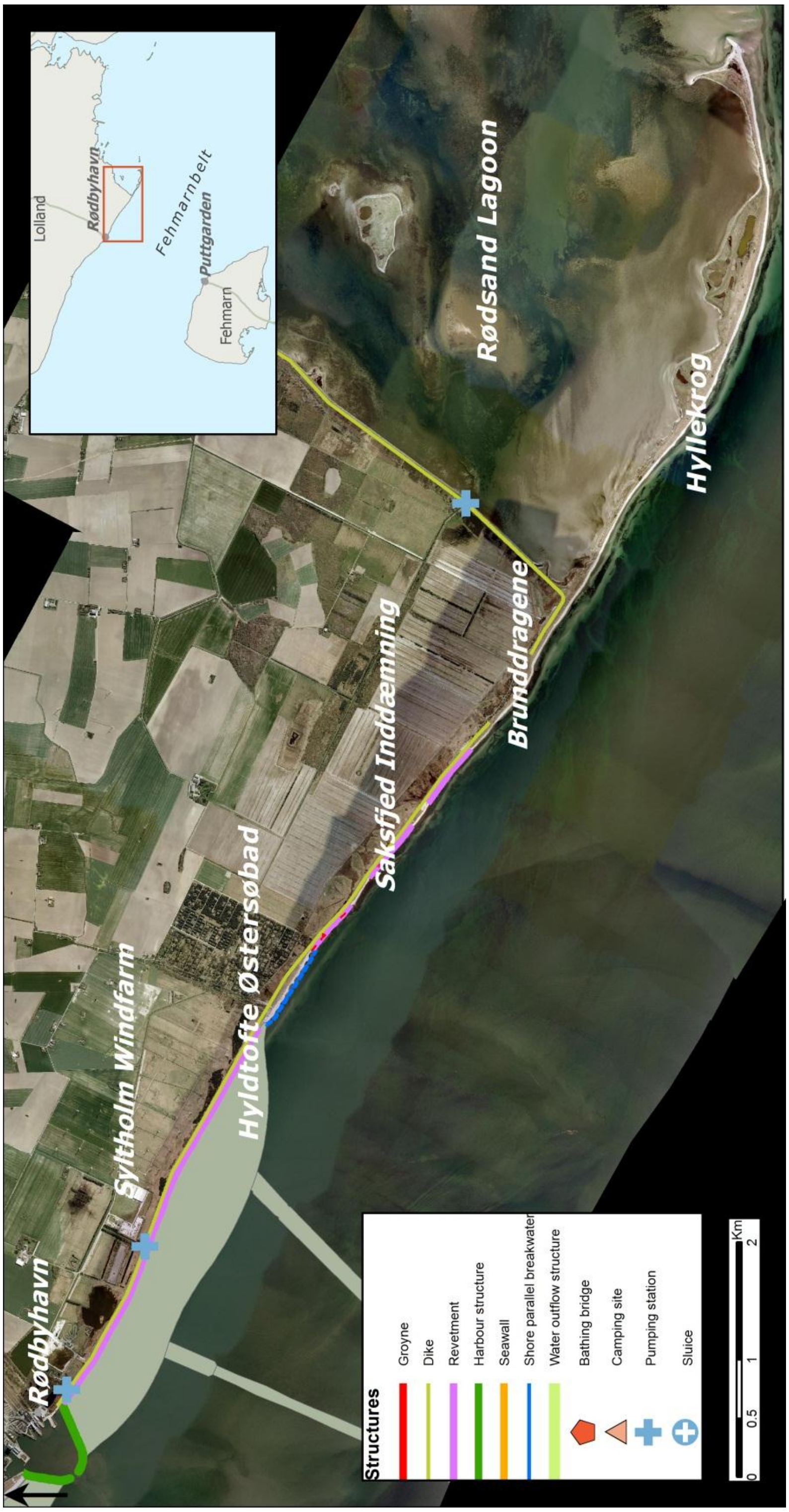

Figure 6.2 New permanent structures (reclamation and protection reef),access channel to production facilities on Lolland and tunnel trench indicated. East of Rødbyhavn. Baseline coastal and marine structures included. Aerial photo from 2009 (©COWI Orthophoto April 2009)

6.1.2 Severity of loss and degree of impairments

The impacts on the coastline are analysed based on the modelling of changes to the transport of sediment (sediment budget) and of the initial shoreline evolution along the Lolland coast caused by the tunnel project.

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more 25-30 years The permanent effects are evaluated for the lifetime of the project up to 120 years.

The impacts on the coastal morphology from the tunnel develop with time and the coast does not recover from the impacts. All impacts from the tunnel project are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the temporary work harbour. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The impacts for sections of the coast are described below. The impacts are assessed with the four level scales for severity of loss and degree of impairment described in Section 3.7 and Section 3.8, respectively.

Severity of loss is assigned based on the importance levels given in the previous Section 3.9 (Figure 3.16), whereas the degrees of impairment are assigned based on the assessment criteria for impairments, Table 3.8.

The impacts are summarised in Figure 6.6 Table 6.1.

Skarholm to Sandholm/new beach. Dragsminde Sluice at Sandholm
The reclamation will block the net supply of sediment from west. The sediment will accumulate along the 1,100 m new beach at the western termination of the reclamation. The present coastline at the termination point is seen in Figure 6.3. The accumulation will build up and fill in the 'corner' between the reclamation and the existing coastline as a sand fillet starting from the western part of the new beach. Calculations in Section 5 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 for the average year conditions.

Within the first 5 years, the accumulation of sand (the sand fillet) is predicted to progress rapidly towards the northwest in the order of 100 m/year. The accumulation will cause increasing beach widths from Sandholm and along the eastern part of the beach in front of Bredfjed summerhouse area, see Figure 6.4. The shoreline will initially advance by up to about 8-12 m/year near the reclamation. The rate of shoreline advance decreases towards the northwest.

With time deposition will occur along a longer stretch and the rate of the shoreline advance as well as the progression rate towards the northwest 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. The beach width at Bredfjed summerhouses will begin to increase approximately 5-10 years after end of construction of the reclamation west of Rødbyhavn. Thirty years after the construction of the reclamation, the accumulation zone is expected to fill up about 32 ha and to reach the coastline between Bredfjed and Skarholm, see Figure 6.4. The build-up of the sand accumulation with time is estimated by an analytical solution (method by Pelnard and Considére, see e.g. Deigaard and Fredsøe 1992).

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. Initiation of by-pass around the reclamation and the long stretch where deposition occurs will reduce the rate of shoreline advance and progression towards the west.

The advance of the shoreline west of Rødbyhavn is not assessed as an impairment of the coast except at the outlet at Dragsminde Sluice located off Sandholm. The accumulation of sand in front of the outlet will block the outflow of water draining from the low-lying land behind the dike. An alternative solution for the outflow should be sought. The accumulation of sand in front of Dragsminde Sluice is estimated to cause an advance of the shoreline in the order of 160 m within the first 30 years. The functionality of the present structure is hence considered lost and the structure is classified with a very high degree of impairment according to the criteria in Section 3.6.

Note: Following the impact assessment, a new/improved outlet structure at Dragsminde Sluice is included in the assessed design as a planned mitigation measure. The ‘very high degree of impairment’ for the outlet from Dragsminde Sluice will therefore not be effectuated.

Figure 6.3 Sandy beach with gravel at the outlet from Dragsminde Sluice - the location for the western termination of the reclamation

Figure 6.4 Predicted development of shoreline west of the Lolland reclamation 0-30 years after end of construction. Aerial photo from 2009 (©COWI Orthophoto April 2009)

Rødbyhavn to Sandholm

The impacts on the coast between the western breakwater of Rødbyhavn and Sandholm are restricted to the occupancy of the original coastline by the reclamation. The impacts in this area are considered 'loss' as the original coastline is occupied by the reclamation. The original coastline is in the baseline situation composed of approximately 3.2 km of beach and 500 m of revetment. Beaches are assigned with a 'high importance level' (Section 3.9.1) and the loss of beach is hence according to the assessment method assessed with a 'high degree of severity'. Sections with coastal protection is assigned with a 'minor importance level' and is correspondingly assessed with a 'minor degree of severity'. The conceptual design of the reclamation includes a section of 1,100 m new beach at the western part of the reclamation.

Rødbyhavn

The sedimentation of sand in the harbour basins and the access channel to Rødbyhavn was estimated to be in the order of 15,000-20,000 m^3/year during the period 1999-2009 (FEHY 2013a). The sedimentation occurs primarily because of by-pass around the western breakwater.

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. For sedimentation to occur in the harbour and access channel, this sand will theoretically build up along the ~2,800 m section of the reclamation and reach the access channel to Rødbyhavn in another approximately 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. This is similar to the situation at Rødbyhavn in the baseline situation. Depending on the detailed design of the reclamation west of Rødbyhavn, parts of this sediment may deposit in the beach lagoon west of Rødbyhavn, which might become part of the final design.

In summary, Rødbyhavn will benefit from the construction of the tunnel project for some decades. The costs for maintenance in the harbour basins and access channel are expected to decrease drastically for at least the first 30-40 years after the construction of the reclamation in the tunnel project.

Only negative impacts are classified in the assessment. Rødbyhavn is hence classified with 'no impact' caused by the tunnel project.

Rødbyhavn to Hyldtofte Østersøbad

The new reclamation occupies 3,750 m of the coastline with revetment between Rødbyhavn and Hyldtofte Østersøbad, which is assigned as 'loss'. This section is assigned with a 'minor importance level' and therefore the loss is classified with a 'minor degree of severity' according to the impact methodology.

A small outlet (pipeline) and a waste water outlet east of Rødbyhavn from wetland areas behind the dike will be lost. They are indicated with a very high degree of severity of loss in Figure 6.6.

Note: Based on the impact assessment, it has been decided to include a new/improved outlet as well as measures to establish a new and adequate waste water outlet as planned mitigation measures as a part of the assessed project. The loss of these two outlets will hence not become effectuated.

Hyldtofte Østersøbad to Brunddragene

The reclamation blocks the sediment supply from west. The erosion from the artificial cliff at the eastern part of the reclamation is estimated to supply a an input of sand to the shoreline east of the cliff in the order of 5000 m^3/year. In the baseline conditions, the net sediment supply to the coast east of the eastern termination of the reclamation is estimated at 19,000 m^3/year for the average year conditions. The tunnel project therefore causes a lack of sediment supply in the order of 14,000 m^3/year (see Section 5.1.3).

Short term, <20 years after end of construction, 0-1,030 m east of the reclamation

Initially erosion will take place from the coastal section nearest the reclamation, the beach in front of the summerhouse area Hyldtofte Østersøbad and just east of here. The coastline retreats in front of Hyldtofte Østersøbad also in the baseline situation and has since 1999 been protected by a breakwater scheme consisting of 10 coast-parallel breakwaters, see Figure 5.4.

The deficit of sediment input of about 14,000 m^3/year to the coast east of the reclamation has been calculated to cause a retreat of the shoreline/coastal profile by up to 5 m/year compared to the present retreat of 0-2 m/year, both of which for the average year conditions (Figure 5.11). The retreat extends initially along Hyldtofte Østersøbad to nearly 300 m east of the breakwater scheme. The retreat corresponds to an additional erosional pressure caused by the tunnel project of 8-12 m^3/m/year on this coastal section. Further east, the short term impact is insignificant.

The erosional pressure will cause the shoreline to retreat between the shoreparallel breakwaters in the Hyldtofte Østerbad breakwater scheme (750 m) and from the coastal profiles in front of the 280 m long revetment east of here. Along the protected sections (breakwaters and revetment), the erosion will take place from the coastal profiles by lowering the sea bed level and increasing the steepness of the profiles.

The increased steepness of the coastal profiles in front of the breakwaters/revetment and a small groyne east of the breakwater scheme are expected to cause a severe risk of failure of the present structures within 5-10 years after the end of construction. With no mitigation carried out, also the dike located 20-50 m from the shoreline will be at risk within this time frame. The structures are therefore categorized with a very high degree of impairment corresponding to loss of functionality according to the assessment criteria. The width of the present beach to the vegetation line is about 10-20 m in the bays between the breakwaters. The retreat of the shoreline/failure of structures described above will reduce the beach widths to a degree, where they also loose functionality. The beaches are therefore also considered impaired with a very high degree of impairment.

Note: The above impairments are mapped in Figure 6.6. Following the impact assessment, beach nourishment of about 14,000 m^3each year has been included as a planned mitigation measure in addition to the construction of the cliff, which also feeds sediment to the coast east of the reclamation. Design of a beach nourishment scheme will be part of the detailed design of the tunnel project. The supply of sediment from beach nourishment is together with the sediment supply from the cliff predicted to compensate for the lack of sediment supply from the coastal section occupied by the land reclamation. With these mitigation measures, the development of the coast is expected to maintain the situation for the existing conditions. The above-mentioned impairments from the tunnel project to the coast 0-1,030 m east of the reclamation will therefore not become effectuated.

Long term, 20-120 years after end of construction, 0-4,030 m east of the reclamation

As the coastal section nearest the reclamation (0-1,030 m) becomes starved from sediment (due to lack of sediment supply from the coastal section occupied by the reclamation as described above; without beach nourishment), the net littoral sediment transport along this section will decrease and the sediment input to the coastal sections further east will drop. The erosion will thereby spread to coastal sections further east.

The eastward spreading of erosion from the coastal profiles is estimated based on the following: The present Rødbyhavn was constructed in 1962-63 and has blocked the transport of sediment along the coast in the same way as the new reclamation will do. Analysis of mapping of surface sediments in front of the revetment east of Rødbyhavn in 2009 (FEHY 2013a) shows that the coast is starved from finer sediments extending to about 2,500-3,000 m from the eastern breakwater of Rødbyhavn. The erosion of sediment from the coastal profile has therefore progressed eastwards by a rate of about 53 m/year in average between 1962 and 2009[1]. The net supply of sediment from west within the coastal zone is about 25,000-30,000 m^3/year along the coast corresponding to erosion of about 470 m^3 per metre of the coastline from the coastal profile[2].

Assuming that the coastal profiles along the coast east of the reclamation have a volume of 470 m^3/m erodible sea bed material, the lack of sediment input of annu-

[1] The first Rødbyhavn was constructed in 1900-02. The erosion caused by this harbour is assumed to have caused erosion and retreat of the shoreline primarily within the area where the extended harbour was built in 1962/63.

[2] The order of magnitude corresponds to an average of about 1.2 m lowering of the sea bed within a zone of about 400 m from the shoreline. Analysis of measured coastal profiles east of Rødbyhavn shows a great variation in the profiles, and verification of this magnitude is hence difficult.

ally 14,000 m^3/year is predicted to cause the erosion to progress eastwards by a rate of 30 m/year. This progression is expected to continue east on a long-term basis since the blocking of the supply of sediment from west to the coastline east of Rødbyhavn continues for the entire lifetime of the project.

The coastline further east than the coastal section 0-1,030 m from the reclamation is expected to start after approximately 20-25 years. After 20-25 years, the profiles along the section 0-1,030 m east of the reclamation have been starved from 160-300 m^3/m (applying the above mentioned erosion rate of 8-12 m^3/m/year) corresponding to about half of the available volume of erodible sediment in the profiles. The erosion rate from this section can be expected to gradually decrease as the coarser sea bed material (gravels, pebbles) will remain at the sea bed and reduce erosion. This will decrease the sediment supply to the coastal section further east and initiate the erosion from this coastline.

Within the next 100 years of the project, the erosion is expected to extend approximately 3,000 m further east (100 years of 30 m/year), i.e. to 4,030 m east of the reclamation to Brunddragene 120 years after end of construction.

The impact on the coastline will reduce somewhat as the erosion will diminish with the distance from the reclamation. The erosion will with time take place along a longer stretch and smooth out the erosional pressure and a small input of sediment from the offshore will also occur. If the offshore input is assumed negligible, the annual deficit of 14,000 m^3/m along the 4,030 m corresponds to an estimated average erosional pressure of about 3.5 m^3/m for the 20-120 year period after the end of construction.

The small sections of unprotected beach along this section will retreat with 0.5-1 m/year for the average conditions and the functionality and risk of failure of the coastal protection (revetments and two small groynes) will need regular monitoring.

According to the assessment criteria this corresponds to a medium degree of impairment for the unprotected as well as the protected sections of the coast, as shown in Figure 6.6.

Note: As described above, nourishment of approximately 14,000 m^3 each year have been included as a planned mitigation measure following this assessment. Nourishment initiated at the beginning of the project will prevent the above-mentioned erosion to initiate from the coastal profiles and the coastline immediately east of the reclamation (0-1,030 m). This coastal section will hence maintain the availability of erodible sea bed material and will continuously provide the coastal sections further east (1,030-4,030 m) with sediment. Beach nourishment of approximately 14,000 m^3each year will maintain the coastal development (erosion/deposition) expected for the existing conditions without the tunnel project.

Figure 6.5 Hyldtofte Østersøbad

West of Brunddragene and Hyllekrog/Rødsand
No impacts are predicted from the tunnel project within 120 years after the construction of the tunnel project. Aerial photo from 2009 (©COWI Orthophoto April 2009).

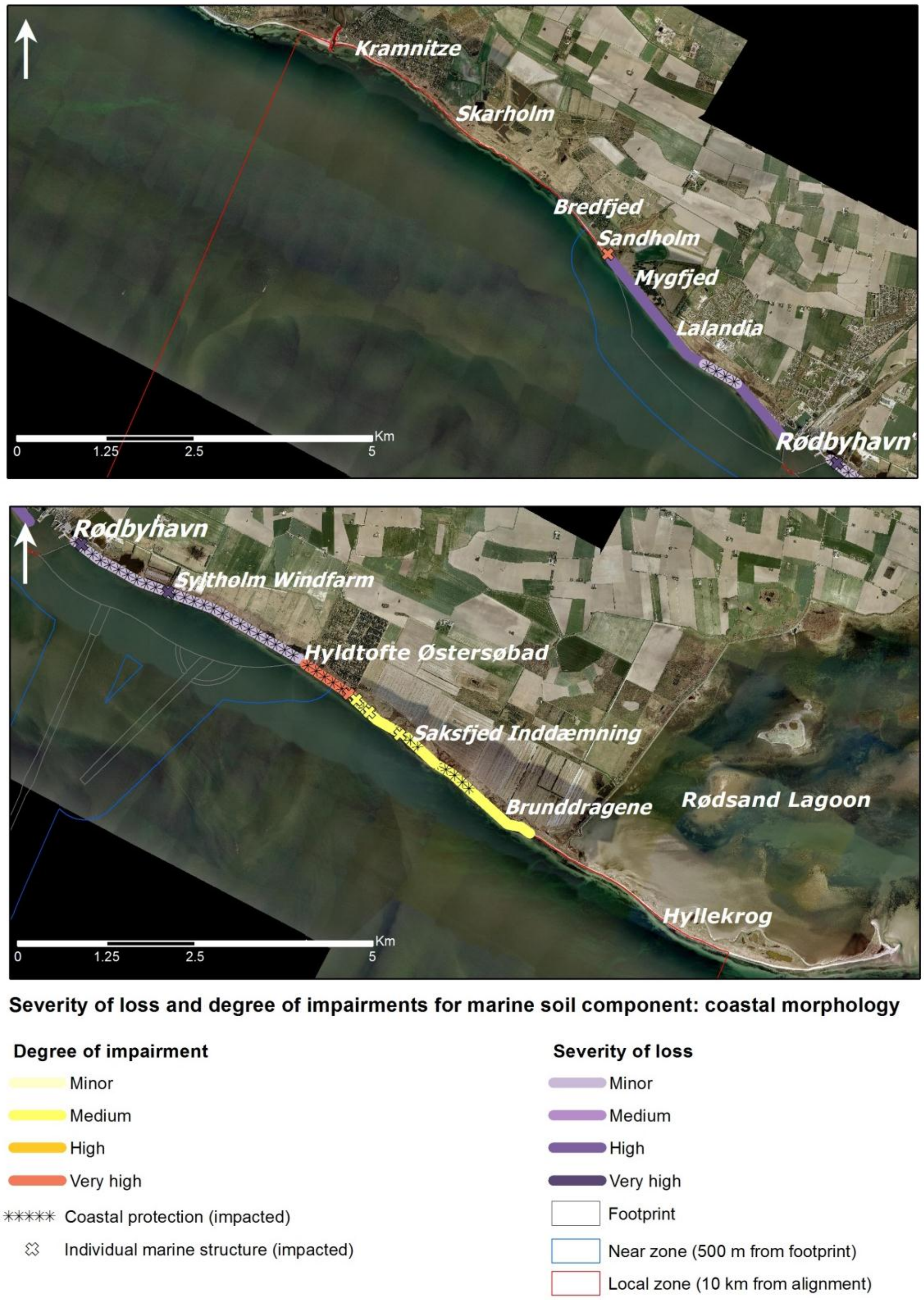

Figure 6.6 *Degree of impairment and severity of loss assigned to sections of the coast due to the pressure from reclamation, protection reef and access channel on the Lolland side. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the severity of loss of and degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast east of the projects, the outlet at Sandholm (Dragsminde Sluice) and the loss of two outlets east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 6.1 Summary of impacts on the coastal morphology on Lolland from tunnel project (E-ME/August 2011). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.

Summary of impacts	**Total m**	**Individual structures (No.)**	**Special morphological features (No.)**
Severity of loss			
Very high severity	0	2[2]	0
High severity	3,180[1]	0	0
Medium severity	0	0	0
Minor severity	4,290	0	0
Total	**7,470[1]**	**2[2]**	**0**
Degree of impairments			
Very high impairment	750[2,3]	2[2]	0
High impairment	0	0	0
Medium impairment	3,280[2]	3[2]	0
Minor impairment	0	0	0
Total	**4,030[2,3]**	**5[2]**	**0**

[1]includes 3,180 m of loss of beach west of Rødbyhavn, which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [2]Impacts, which will not to be effectuated following additionally planned mitigation measures, please refer to text.

6.1.3 *Severity of impairments*

Impairments of sections of the Fehmarn coastline with/without structures and of individual structures are assigned severity levels as given in Table 3.10 for combinations of the assigned degrees of impairment (Figure 6.6) and the importance levels for the respective areas of impact (Figure 3.16). The results are shown in Figure 6.7 and summarised in Table 6.2. Severity levels for loss are also shown in the figure.

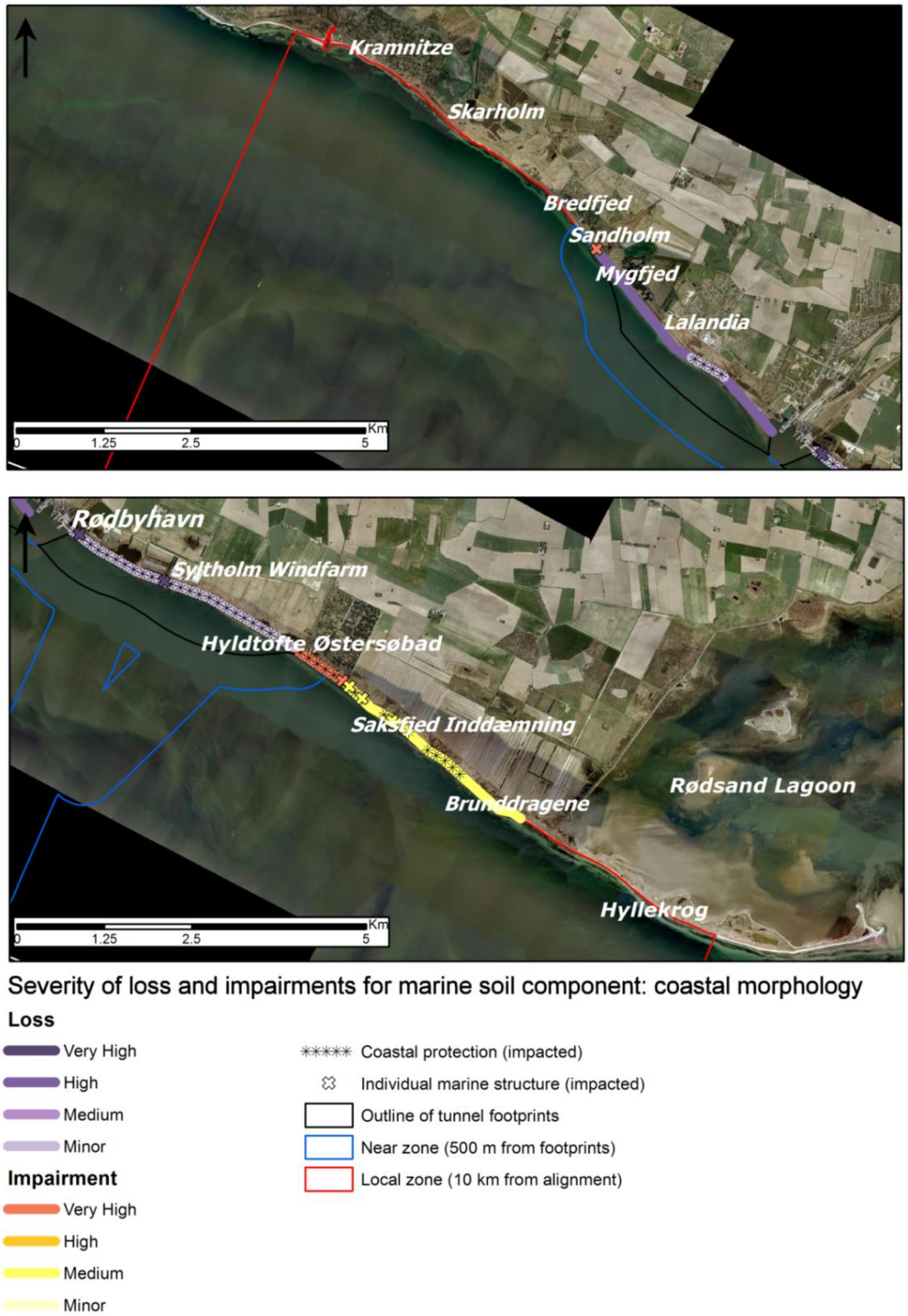

Figure 6.7 *Severity of loss and severity of impairments along the Lolland coastline for the tunnel project (E-ME/August 2011). Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the loss of and degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been planned for. These are assessed to mitigate the impairments to the coast east of the projects, the outlet at Sandholm (Dragsminde Sluice) and the loss of two outlets east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 6.2 Summary of severity of impairments on the coastal morphology on Lolland from tunnel project (E-ME/August 2011). Impairments on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.

Severity of impairments	Total m	Individual structures (No.)	Special morphological features (No.)
Very high severity	750[1]	2[1]	0
High severity	0	0	0
Medium severity	3,280[1]	3[1]	0
Minor severity	0	0	0
Total	**4,030[1]**	**5[1]**	**0**

[1]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text.

6.1.4 Summary of impacts

A total stretch of the Lolland coast of 11,500 m is impacted by the tunnel project. This stretch comprises 7,470 m of loss and 4,030 m of impaired coastline (Table 6.1).

3,930 m of the coast are lost/impaired with a very high or high impact level (severity of loss and degree of impairment). The remaining impacts on the coastline are categorised as medium or minor impacts.

Two individual structures (two outlets east of Rødbyhavn) will be lost. They are assigned a very high degree of severity of loss. Two individual structures (Dragsminde Sluice at Sandholm and one older groyne at Hyldtofte Østersøbad) are impaired with a very high degree of impairment. Three structures (older groynes west of Hyldtofte Østersøbad) are impaired with a medium degree of impairment.

Note: Following the above assessment, additional mitigation measures have been planned as described in the above section. The impairments to the coastal section east of the reclamation will hence not be effectuated. Also the loss/impairment of the three outlets (one water outlet east of Rødbyhavn, the outlet structure from Dragsminde Sluice and the waste water outlet at Rødbyhavn) will be prevented by new/improved structures and measures to establish a new and adequate waste water outlet.

Sub-components

The impacts are evaluated for each of the three sub-components (increased erosion/accretion, increased erosion in front of revetments/breakwaters and special morphological features) to distinguish between the impacts on different functionalities of coastline.

A table providing the impacted stretches of the individual sub-components is given below (Table 6.3). The impacts are divided based on the four levels scales for severity of loss and degree of impairment described in Section 3.7 and Section 3.8, respectively.

The impacts are given in lengths of the coastal sections occupied by the given sub-component and in parts (%) of the total length the given sub-component occupies along the Lolland coast within the near zone + the local 10-km zone. These are shown in Figure 6.6.

5,570 m of the beaches/unprotected coastline is impacted (3,180 m loss and 2,390 m impaired). 3,180 m of these are integrated into the new reclamation.

2,040 m coastal protection (breakwaters and revetments) are impaired. These structures may need mitigation. 400 m of these are classified with a very high degree of impairment.

Note: following the above assessment, nourishment of the coastal section east of the land reclamation by approximately 14,000 m^3/year has been included as a planned mitigation measure to maintain the baseline conditions. The described impairments to the coast described above will therefore not be effectuated.

Table 6.3 Summary of impacts at Lolland from the tunnel project (E-ME/August 2011) divided on sub-components. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline with the given sub-component (reference) within the near zone + local 10 km zone.

Impacts on coastal morphology	**Coastal sub-components**							
	Total		Beaches/ unprotected coastline		Coastal protection		Individu-al struc-tures	Special morph feat.
	m	**%**	**m**	%	m	%	No	No
Severity of loss								
Very high severity	0	0	0	0	0	0	2[2]	0
High severity	3,180[1]	15.9	3,180[1]	26.5	0	0	0	0
Medium severity	0	0	0	0	0	0	0	0
Minor severity	4,290	21.4	0	0	4,290	51.0	0	
Total loss	**7,470**[1]	**37.3**	**3,180**[1]	**26.5**	**4,290**	**51.0**	**2**[2]	**0**
Degree of impairment								
Very high impairment	750[2,3]	3.7[2]	750[2,3]	6.2[2]	400[2,3]	4.8[2]	2[2]	0
High impairment	0		0	0	0	0	0	0
Medium impairment	3,280[2]	16.4[2]	1,640[2]	13.6[2]	1,640[2]	19.5[2]	3[2]	0
Minor impairment	0	0	0	0	0	0	0	0
Total	**4,030**[2,3]	**20.1**[2]	**2,390**[2]	**19.9**[2]	**2,040**[2]	**24.2**[2]	**5**[2]	**0**
Reference (m)	**20.035**[3]		**12,020**		**8,415**			

[1]includes 3,180 m of loss of beach west of Rødbyhavn, which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [2]impacts, which will not to be effectuated following additionally planned mitigation measures, please refer to text, [3] The 750 m of very high impairments to the coastline at Hyldtofte Østersøbad consists of 750 m of impaired beach fronted by 10 times 40 m of shore-parallel breakwaters (400 m impaired coastal protection). In the 'Total' for impairments, this section is counted as only 750 m of very high impaired coastline due to the overlapping of beach and coastal protection. The length of the reference coastline (total of 20.035 m) deviates due to the overlapping of beach and coastal protection also by 400 m from the sum of beaches and coastal protection, respectively.

Total impact for specific areas

The impacted areas of the component coastal morphology are divided on sub-parts of the Lolland coastline in Table 6.4. All impacts are considered permanent.

The loss of coastline takes place only within the near zone of 500 m around the project during construction. A total of 7,470 m of the coastline will be lost; the lost section is all within the near zone.

The provided impairments to the coast in Table 6.4 will not be effectuated, since nourishment of the coastal section east of the land reclamation has been included as a planned mitigation measure to maintain the baseline conditions.

Table 6.4 Summary of impacts at Lolland from the tunnel project (E-ME/August 2011) divided on sub-parts of the Lolland coastline. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline (reference) within the sub-part.

Impacts on coastal morphology	**Impacts divided on sub-parts of the coastline of Lolland**						
	Total		**Near zone**		**Local 10 km zone**		**Denmark National**
	m	**%**	**m**	**%**	**m**	**%**	**m**
Severity of loss							
Very high severity	0	0	0	0	0	0	0
High severity	3,180[1]	15.9	3,180[1]	34.6	0	0	3,180[1]
Medium severity	0	0	0	0	0	0	0
Minor severity	4,290[1]	21.4	4,290[1]	46.7	0	0	4,290[1]
Total	**7,470[1]**	**37.3**	**7,470[1]**	**81.3**	**0**	**0**	**7,470[1]**
Degree of impairments							
Very high impairment	750[2]	3.7[2]	500[2]	5.4[2]	250[2]	2.3[2]	750[2]
High impairment	0	0	0	0	0	0	0
Medium impairment	3,280[2]	16.4[2]	0	0	3,280[2]	30.2[2]	3,280[2]
Minor impairment	0	0	0	0	0	0	0
Total	**4,030[2]**	**20.1[2]**	**500[2]**	**5.4[2]**	**3,530[2]**	**32.5[2]**	**4,030[2]**
Reference (m)	**20,035**		**9,190**		**10,845**		

[1]includes 3,180 m of loss of beach west of Rødbyhavn which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [2]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text.

6.1.5 Impact significance

Assessed design of the project

The assessed tunnel project has been assessed to cause loss (7,470 m) or impairments (4,030 m) on a total of 11,500 m of the Lolland coastline. Further, impacts (not included as loss or impairments) will be present west of the project, where the shoreline is predicted to advance by up to 160 m within 30 years after the construction. The impacts are on a permanent time scale.

7,470 m of the original coastline is integrated into the reclamation. This may be considered a significant impact on the coastline, but a new coastline along the perimeter of the reclamation will be created and compensate for the lost sections of coast. East of Rødbyhavn, the relevant stretch of shoreline is heavily protected with large stones and west of Rødbyhavn – except for the beach west of the western breakwater of the harbour - the coastline is primarily narrow beaches of mixed quality.

The final design of the reclamation has not been carried out, but it is expected that the new shoreline will consist of hard protection along the offshore part, but also 1,100 m of new beach at the western end of the reclamation and a smaller beach in the eastern part. Inshore of the outer perimeter, landscape types such as lagoons with inlets connected to the Belt and a semi-natural cliff are planned to be created from the surplus dredged material. The recreational value of the coastal landscape of the new reclamation compensates the loss of the part of the Lolland coastline, which will be integrated into the new reclamation. Sections of the dike, which will be impacted by the tunnel project, are replaced such that the dike maintains the present protection of the land.

To which degree, the new landscape and the new beaches compensate for the loss of coastal landscape in the area of the reclamation, is a subjective matter. The variety of the coastal landscape will increase with the reclamation. On the other hand, the new beach will be located several kilometres west of the present main beach between Rødbyhavn and Lalandia.

The impairment of the coastline east of the reclamation is considered severe for the assessed design of the tunnel project. The problem of erosion along this coastline is as such a problem, which is expected along this section even without the tunnel project, since Rødbyhavn will cause similar impacts on the coastline once the coastal profiles all along the coast to Hyldtofte Østersøbad are starved of erodible sea bed material. The impairment of the beaches and structures will occur earlier in time due to the tunnel project (with about 15-25 years; the estimated time before the starvation of the sea bed reaches Hyldtofte Østersøbad without the tunnel project) and the impacts/erosion from especially the section nearest the reclamation will be enhanced.

The impacts on the coastline east of the reclamation are considered significant for sections of the coast, which have been classified with a very high or medium degree of impairments as shown in the impact map in Figure 6.6.

The impacts on three outlets are evaluated as significant.

4,030 m of the impacted coastline (the stretch east of the reclamation) is within Nature 2000, however, no morphological elements belonging to conservation objectives are predicted impacted.

Project including additional mitigation measures
Following the assessment, additional mitigation measures have been planned for. These are mentioned in the beginning of Chapter 6.

On Lolland the additional mitigation measures include nourishment of approximately 14,000 m^3each year, two new/improved outlet structures at Dragsminde Sluice and Rødbyhavn, respectively and measures to secure an adequate waste water outlet at Rødbyhavn.

Nourishment of about 14,000 m^3/year initiated at the beginning of the project is assessed to prevent the erosion-problems (maintain the baseline conditions) caused by the blocking of the land reclamation along the coastline east of the reclamation.

Conclusion
In conclusion, it is assessed that the impacts from the present tunnel project in the conceptual design when including the additional mitigation measures are restricted to the loss of original coastline in the area of the reclamation and the shoreline advance (not included as loss or impairment) west of the land reclamation.

Overall it is assessed that the planned reclamation is expected to increase the value of the coastal landscape in the area of the reclamation and as such can become a benefit for the area.

The project is therefore concluded to have no significant impacts on Lolland with the additional mitigation measures.

6.1.6 Cumulative impacts

Rødsand 1 and 2 Offshore Wind Farms are not included in the wave modelling for the coastal morphology impact assessment. The wind farms have only negligible influence on the wave conditions near the Link and along the coastline of Lolland except for in the immediate vicinity of the wind farms. It is furthermore noted that the lifetime of the Wind Mill Park is "only" 30 years while the tunnel and bridge project have a project lifetime of 120 years. Consequently, it was decided to exclude Rødsand 1 and 2 Offshore Wind Farms from the wave modelling.

The morphological impacts on the Rødsand barriers (Hyllekrog, Eastern and Western Rødsand) from the offshore wind farms were evaluated in (DHI 2001), (DHI 2007b) and (DHI 2007c). The findings are summarised below and the cumulative impacts on the barriers from the tunnel project are assessed.

Summary of morphological impacts from Rødsand 1+2

Rødsand 1 wind farm consists of 72 wind turbines of 2.3 MW. It was finalised in December 2003. Rødsand 2 wind farm consists of 90 wind turbines of 2.3 MW. It was finalised in 2010. The location of the two wind farms are seen in Figure 6.8.

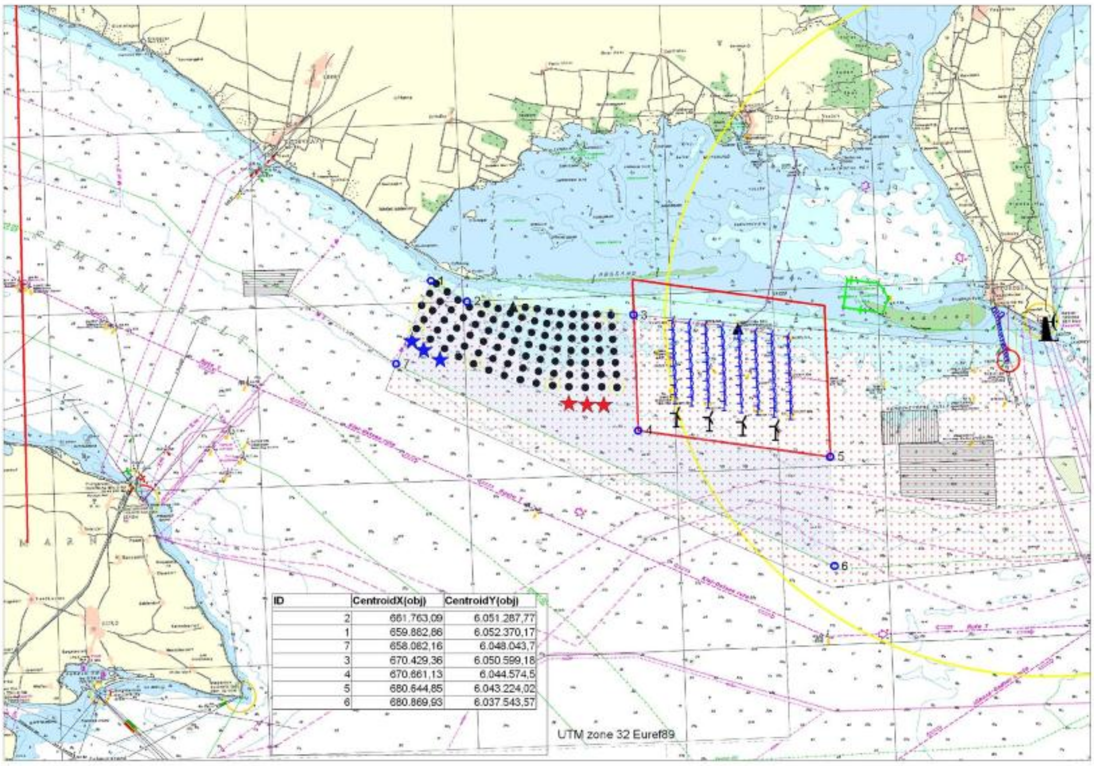

Figure 6.8 Map showing the location of the Rødsand 2 wind farm (black dots). The existing Rødsand 1 wind farm is framed by a red line. (From DHI 2007b).

There are two Rødsand barrier formations, the West Rødsand and the East Rødsand. West Rødsand is a submerged sand barrier formation, which in the west end is connected to Hyllekrog spit formation. The seabed off the Rødsand formations is a residual seabed consisting of till material with scattered stones and only scarse sand patches. The East Rødsand is an isolated emerged sand barrier formation with low dune formations to a level of 1 to 2 m. The Rødsand barrier formations are different from normal barrier formations because they are located on a till seabed, which can only supply very little material to the build-up of the barriers, and because they are bordered by relatively deep water in the Rødsand Lagoon, which means that the barriers are losing material to deep water when they travel towards N.

The two Rødsand formations are active morphological elements which are illustrated by the following development patterns:

- The east tip of the West Rødsand has moved 1,500 m towards east over the last 55 years corresponding to a rate of about 25 m/year and the south limit of the formation has moved 200 to 300 m northward

- The west tip of the East Rødsand formation has during the period 1945 to 1998 moved about 1.3 km eastward also corresponding to a rate of 25 m/year, the south coast has moved about 250 m northward and the east tip of the island has moved about 350 m towards east

- The opening between the East Rødsand and the West Rødsand formations called Østre Mærker, thus also moves at a rate of 25 m/year towards east

The historical development of Hyllekrog is described in (FEHY 2013a).

The morphological impact of the Rødsand 1 wind farm on Hyllekrog and on the Rødsand formations was assessed as follows (DHI 2001):

- The Rødsand 1 wind farm shelters somewhat for the waves causing a reduced wave impact on the Rødsand formations and thereby a reduction of the rate of the morphological development described above. The eastward movements of the Rødsand formations and of the Østre Mærker over a 30-year period are consequently assessed to be reduced from 750 m to 500 m

- No impacts on Hyllekrog

The morphological impact of the combined Rødsand 1 and 2 wind farms on the Rødsand formations was assessed by computing the transport in the profiles presented in Figure 6.9. The impacts by introducing Rødsand 2 compared to the impacts of only Rødsand 1 are assessed in (DHI 2007c) as follows:

- The overall sediment transport pattern was not changed along the Rødsand formations, neither relative to the natural situation nor relative to the Rødsand 1 situation. However, some changes in the magnitude of the transports were computed

- The coastal section between profile B and A, i.e. the stretch east of Rødbyhavn towards the western one third of Hyllekrog, experiences a marginally increased erosional pressure by the introduction of Rødsand 2. This includes the section of the Hyllekrog barrier, where the barrier has the smallest width in the baseline situation. The erosion rate due to Rødsand 2 is in the order of 0.1 m/year

- The remaining part of the Hyllekrog barrier will experience a slight tendency or either reduction of the on-going erosion or a slight advance of the coastline due to the introduction of Rødsand 2.This is because more sediment is transported into the area from west and less is transported further towards east

- The growth rate of the eastern tip of West Rødsand was assessed to be further reduced as compared to the situation with only Rødsand 1

- The introduction of the Rødsand 2 wind farm introduces only insignificant additional changes in the East Rødsand area

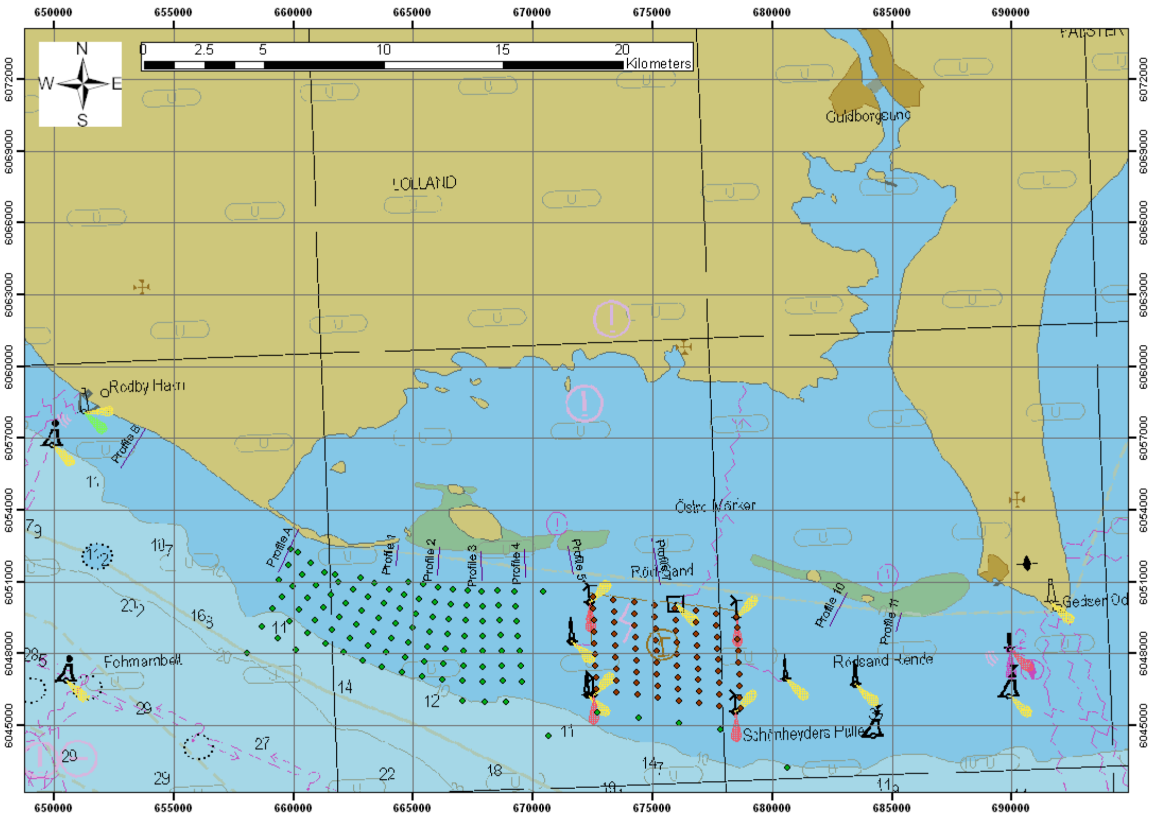

Figure 6.9 Computation profiles for littoral transport. Profiles A and B west of Rødsand 2, are only assessed for Rødsand 2. From DHI(2007b)

Cumulative impacts
The cumulative impacts for the Rødsand 1+2 offshore wind farms are assessed as follows.

<u>Rødbyhavn to Brunddragene:</u> along the stretch Rødbyhavn to Hyllekrog, the impact on the shoreline from Rødsand 2 was in (DHI 2007c) assessed to cause a very weak additional erosional pressure. The increased erosion was estimated to about 0.1 m/year and assessed to be insignificant.

The predicted erosion caused by the wind farm adds to the predicted erosion of the coastal profile and shoreline caused by the tunnel project due to the blocking of sediment supply from west. On a short time scale (<20 years after the end of construction), the predicted erosion from the wind farm will be insignificant compared to the predicted erosion at the section 0-1,100 m east of the reclamation. On a longer time scale (20-120 years), the predicted shoreline retreat of 0.5-1 m/year extending to Brunddragene will be increased by the erosion caused by the wind farm of about 0.1 m/year.

The cumulative effect from the wind farm and the tunnel project, however, does not change the degree of severity of impact along this section of the coast and the conclusion of the assessment of the tunnel project in Section 6.1.5 is not changed due to these cumulative impacts.

East of Brunddragene, Hyllekrog: no impacts from the tunnel project are predicted east of Brunddragene. There are therefore no cumulative impacts from the wind farms and the tunnel project.

It is noted that with the additional mitigation measures mentioned in the beginning of Chapter 6, no cumulative effects will be present between the tunnel project and the Rødsand 1+2 offshore wind farms.

6.1.7 Transboundary impacts

Transboundary impacts are not relevant for coastal morphology.

6.1.8 Climate change

The climate changes up to year 2080-2100 have been evaluated at a workshop at the start of the Fehmarnbelt workshop, see (FEHY 2009). The outcome was the following main predictions:

- Air temperature will increase up to 4°C in the area
- The extreme wind speed (50 year return period) may increase by 3 m/s or 10%. Preliminary results suggest a small increase of moderate to strong wind speeds (15-35 m/s)
- A sea level rise up to 1 m

The parameters of importance for the coastal morphology are normally occurring wave conditions and sea level rise. The future wave conditions have not been studied until now, but the change in normally occurring wave heights follows the trend for the moderate to strong wind speeds, which indicated only a small increase in wave heights. A possible change in the wave directions may also impact the coastal morphology. Also the possible change in wind and wave directions has not been investigated. From the present knowledge it is not possible to conclude how the changes in the wind and wave climate will affect the morphological stability of the Lolland coastline. Even relatively small changes in the wave directions may change the pattern and rates of erosion and deposition, especially for longer sections of unprotected shoreline. Sediment transport may increase or decrease depending on the change in wave direction.

The predicted sea level rise of 1 m will have the following general impacts on the coastal morphology:

- The Lolland coastal area is in general low-lying and a sea level rise of 1 m will reduce the protection of the hinterland by the present dike and other coastal structures. Furthermore, the present coastal structures will at many locations not be sufficient to protect the dike against erosion.
- Many of the small-scale coastal structures (revetments, groynes) will become submerged or partly submerged. They will still offer some protection of the

coastline and reduce the transport of sediment along the coast as they will occupy a part of the coastal profile

Based on the above it is likely that means for protecting the southcoast of Lollands against coastal flooding (with or without the tunnel project) will be effectuated. It is concluded:

- Climate change may change the rate of erosion east of the tunnel reclamation. The impact of climate change of changing the wave directions and/or wave heights can cause the erosion to spread faster or slower towards the east depending on the impact on the net sediment transport

- Due to sea level rise and the following reduced beach widths in front of revetments and dikes -and less effective coastal structures (unless strengthened), the predicted erosion by the tunnel project may put the coastline at a higher risk than evaluated for the 0-alternative

- The tunnel project is not expected to change the effects of climate change on the southcoast of Lolland significantly

6.1.9 Mitigation and compensation measures

Mitigation measures at Lolland are tabulated in Table 6.5. The mitigation measures include measures included in the assessed design of the tunnel project and additional mitigation measures, which have been included in the project following the present impact assessment.

The assessed design of the assessed tunnel project includes an erodible cliff at the eastern part of the reclamation on the Lolland side. The cliff compensates to some extent for the blocking of sediment supply by feeding sediment to the coastline in front of Hyldtofte Østersøbad and further east. It is assessed that the compensation from the cliff in the conceptual design is not sufficient to prevent severe erosion from the coastline east of the reclamation. Following the assessment, nourishment of 14,000 m^3 each year to the coast east of the reclamation has been included as additional planned mitigation measures.

The cliff is presently designed as an almost vertical cliff formed by the dredged excess material (clay till) from the dredging operation with an estimated sand content of 50%. It is assessed that the cliff releases approximately 5,000 m^3/year of sand to the downstream coast.

Together with the nourishment of 14,000 m^3 each year it is assessed that erosion from the beaches and in front of the breakwaters and revetments east of the reclamation due to the tunnel project can be prevented. Beach nourishment is used as coastal protection along several sections of the Danish west coast since the solution maintains the beaches, the access to the water and a natural look of the coastline.

The annual nourishment of 14,000 m^3 is comparable to the lack of sediment supply caused by the tunnel project in the conceptual design. The required need for nourishment to maintain the baseline conditions is hence 14,000 m^3 per year. It is noted that nourishment with 14,000 m^3 per year does not prevent erosion from the shoreline that already takes place in the baseline situation.

Further east towards Brunddragene and Hyllekrog, the longshore sediment transport rate for the 0-alternative situation increases to 22,000-25,000 m^3/year. Between Hyldtofte Østersøbad and Hyllekrog there is hence in the existing situation a sediment deficit of about 8,000-11,000 m^3/year and this situation will remain the same with the planned mitigation measures.

Distribution of the nourishment along the coast may be required. Further analysis is required to map how the longshore sediment transport and the pattern of erosion/accretion along the coast will respond to the nourishment.

It has been further decided to include new structures/means to replace the functionality of the two outlet structures along the Lolland coast as planned mitigation measures: Dragsminde Sluice and the one outlet structures from the wetland areas east of Rødbyhavn. Furthermore, measures to secure the waste water outlet east of Rødbyhavn are included as a planned mitigation measure. These three outlets are otherwise predicted to lose their functionality due to the tunnel project.

Two new beach sections in the western part of the land reclamation on Lolland compensate for the loss of beach west of Rødbyhavn.

The mitigation and compensation measures are tabulated in Table 6.5. No further mitigation measures are recommended.

Table 6.5 Mitigation and compensation measures

Mitigation and compensation measures included in the conceptual assessed design	Additional mitigation and compensation measures
Erodible cliff at the eastern part of the reclamation on Lolland Two beach sections in the reclamation on Lolland	Nourishment of approximately 14,000 m^3/year at the coast east of the reclamation to keep the baseline situation New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of Rødbyhavn Measures to establish a new and adequate waste water outlet at Rødbyhavn

Further, in case the shoreline advance west of the western reclamation is undesirable, sand from the accumulation zone can dredged and eventually be by-passed to the sections east of the project as nourishment.

6.1.10 Decommissioning

Decommissioning is foreseen to take place in the year 2140, when the fixed link has been in operation for the design lifetime of 120 years.

The decommissioning will leave the reclaimed areas untouched. The shoreline evolution of the coastline is therefore considered to continue as in the situation with the tunnel project, i.e. the erosional pressure on the coast east of the reclamation is expected to continue unless mitigated as described in the sections above. No changes are expected due to the decommissioning process.

6.2 Fehmarn

6.2.1 Magnitude of pressure 1: Reclamation and protection reefs on Fehmarn

The only potential impacts on the Fehmarn coastline from the tunnel project are caused by the reclamation and protection reef on the Fehmarn side.

An overview of the planned structures along the Fehmarn coast is provided in Figure 6.10 and Figure 6.11 together with the present structures.

A land reclamation is planned east of the eastern breakwater of Puttgarden (see Figure 5.13). A total length of 700 m of the coastline is integrated into the planned reclamation, which consist of a landfill protected by a dike and a revetment facing the north-northeast. A curved beach facing a southeasterly direction is suspended between a breakwater terminating the above-mentioned revetment and the original coastline.

The magnitudes of the pressure to the coastal sections outside of the area integrated into the reclamation caused by the tunnel project are related to the effects, the reclamation and the protection reef have on the sediment budget southeast of Puttgarden. These impacts on the sediment budget were described in the previous 5.1.6 on the sensitivity of the sub-components of coastal morphology to the project pressures. The impacts on the sediment budget were analysed based on the average year hydrodynamic conditions.

Figure 6.10 New permanent structures along the Fehmarn coast in the tunnel project – east of Puttgarden. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

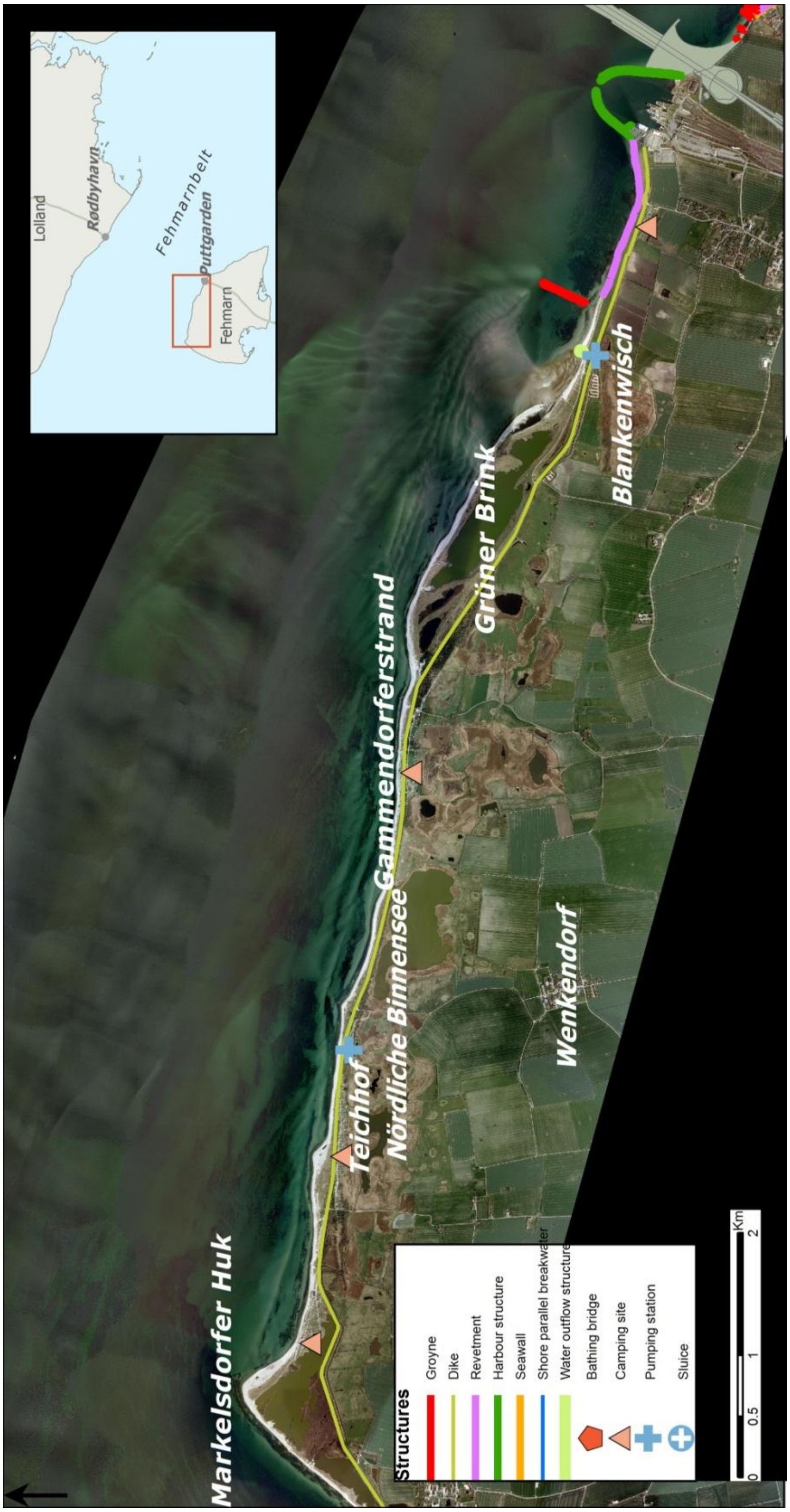

Figure 6.11 No permanent structures are planned west of Puttgarden. The planned reclamation east of Puttgarden is visible in the right side of the figure. Aerial photo from 2009 (©COWI Orthophoto April 2009)

6.2.2 *Severity of loss and degree of impairments*

The impacts on the coastline are analysed based on the modelling of changes in the transport of sediment (sediment budget) and of the initial shoreline evolution along the Fehmarn coast caused by the tunnel project.

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more than 25-30 years. The permanent effects are evaluated for the lifetime of the project, up to 120 years.

The impacts on the coastal morphology from the tunnel develop with time and the coast does not recover from the impacts. All impacts from the tunnel project are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the temporary work harbour. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The impacts and the loss/degree of impairment for sections of the coast are described below.

Severity of loss are assigned based on the importance levels given in the previous Section 3.9 (Figure 3.14 and Figure 3.15), whereas the degrees of impairment are assigned based on the assessment criteria for impairments Table 3.8.

Markelsdorfer Huk to Grüner Brink

The littoral drift budget and the shoreline evolution for this section are unchanged and no impacts are predicted. The morphological development and migration of the special morphological feature of Grüner Brink is therefore also considered unchanged by the tunnel project.

Long groyne to Puttgarden

The tunnel project has negligible impact on the sediment budget and shoreline along this section. The very small changes to the waves from eastern directions caused by the reclamation and protection reef, which are identified just west of Puttgarden (refer to Section 5.1.6), are assessed to cause negligible impacts on the coastal morphology.

Puttgarden

The harbour experiences presently no sedimentation in the harbour basin. The situation is expected to be unchanged after construction of the tunnel project and no impacts are predicted for Puttgarden.

Puttgarden to Ohlensborgs Huk

The impacts on the coast between the eastern breakwater of Puttgarden and Ohlenborgs Huk are occupancy of the original coastline by the reclamation. The present shoreline in this area consists of the eastern breakwater of Puttgarden and a small accumulation of sand in the transition between the harbour and the coast. The impacts in this area are considered 'loss'. Beaches are assigned with a 'high importance level' (Section 3.9.1) and the loss of beach is hence according to the assessment method assessed with a 'high degree of severity'.

The new beach of approximately 700 m attaches to the original coastline west of Ohlensborgs Huk. Ohlensborgs Huk is protected by a number of small groynes and the new beach terminates just west of these as seen in Figure 5.13. Very little sediment is expected to bypass Ohlensborg Huk from the southeast, so the accumulation of sand at the new beach is expected to be very limited.

Ohlenborgs Huk/Marienleuchte
The erosional pressure on the groynes and the seawall protecting the Ohlenborgs Huk from erosion will increase as described in Section 5.1.6 due to the potential increase of about 8,000 m^3/year in the transport towards the northwest.

The additional *potential* erosion caused by the tunnel project is about 8 m^3/m/year (increase of 8000 m^3/year along a section of about 1000 m). This is an estimated increase of about 20-35%. The erosion is expected to be effectuated only to a smaller degree due to the already existing coastal protection (sea wall, glacier and groynes). Erosion of much of the finer sea bed material (assumed to be available in the calculations) has been removed by years of erosion from this section already. However, some lowering of the sea bed and increased erosion from the shoreline/beach in between the groynes can take place. The magnitude is difficult to predict. Monitoring of the structures are recommended and strengthening of the structures/new structures may be required with time (within 5-10 years after construction). The coastal section is classified with a medium degree of impairment.

Note: Following the above assessment, which is mapped in Figure 6.12, regular monitoring and strengthening of coastal protection structures, if required, to prevent erosion at Ohlensborgs Huk have been included as additional mitigation measures. The impairments are assessed as negligible with these mitigating measures and possible strengthening of structures, if required.

Marienleuchte to Presen
The changes to the shoreline evolution caused by the tunnel alternative are very small south of the protected stretch at Ohlensborgs Huk. The changes due to the tunnel project are less than +/-0.1 m/year everywhere. The coast is presently nearly stable at this section with shoreline changes of less than 0.5 m/year in average and this is not expected to change.

The marine structures (a bathing bridge in front of Marienleuchte and a pumping station/water outlet at the coast in front of Presen, see Figure 5.13) will not be affected.

The coastline and the marine structures are classified with no impairment.

South east of Presen
The coast southeast of Presen is not expected to experience any impacts related to the tunnel project within the 120 years after end of construction of the project.

Figure 6.12 Degree of impairments and severity of loss assigned to sections of the coast of Fehmarn southeast of Puttgarden due to the pressure from the tunnel project. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the severity of loss of and the degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been include. These are assessed to mitigate the impairments to the coast at Ohlenborgs Huk/Marienleucte, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009) . Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

Table 6.6 Summary of impacts on the coastal morphology on Fehmarn from tunnel project (E-ME/August 2011). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.

Severity of impacts	**Total** **m**	**Individual structures (No.)**	**Special morph. features (No.)**
Severity of loss			
Very high severity	0	0	0
High severity	700[1]	1	0
Medium severity	0	0	0
Minor severity	0	0	0
Total	**700[1]**	**1**	**0**
Degree of impairments			
Very high impairment	0	0	0
High impairment	0	0	0
Medium impairment	370[2]	5[2]	0
Minor impairment	0	0	0
Total	**370[2]**	**5[2]**	**0**

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text.

6.2.3 *Severity of impairments*

Impairments of sections of the Fehmarn coastline with/without structures and of individual structures are assigned severity levels as given in Table 3.10 for combinations of the assigned degrees of impairment (Figure 6.12) and the importance levels for the respective areas of impact. The importance levels for the relevant sections of the Fehmarn coastline were shown in the previous Section 3.9 (Figure 3.14 and Figure 3.15).

The results are shown in Figure 6.13 and summarised in Table 6.7.

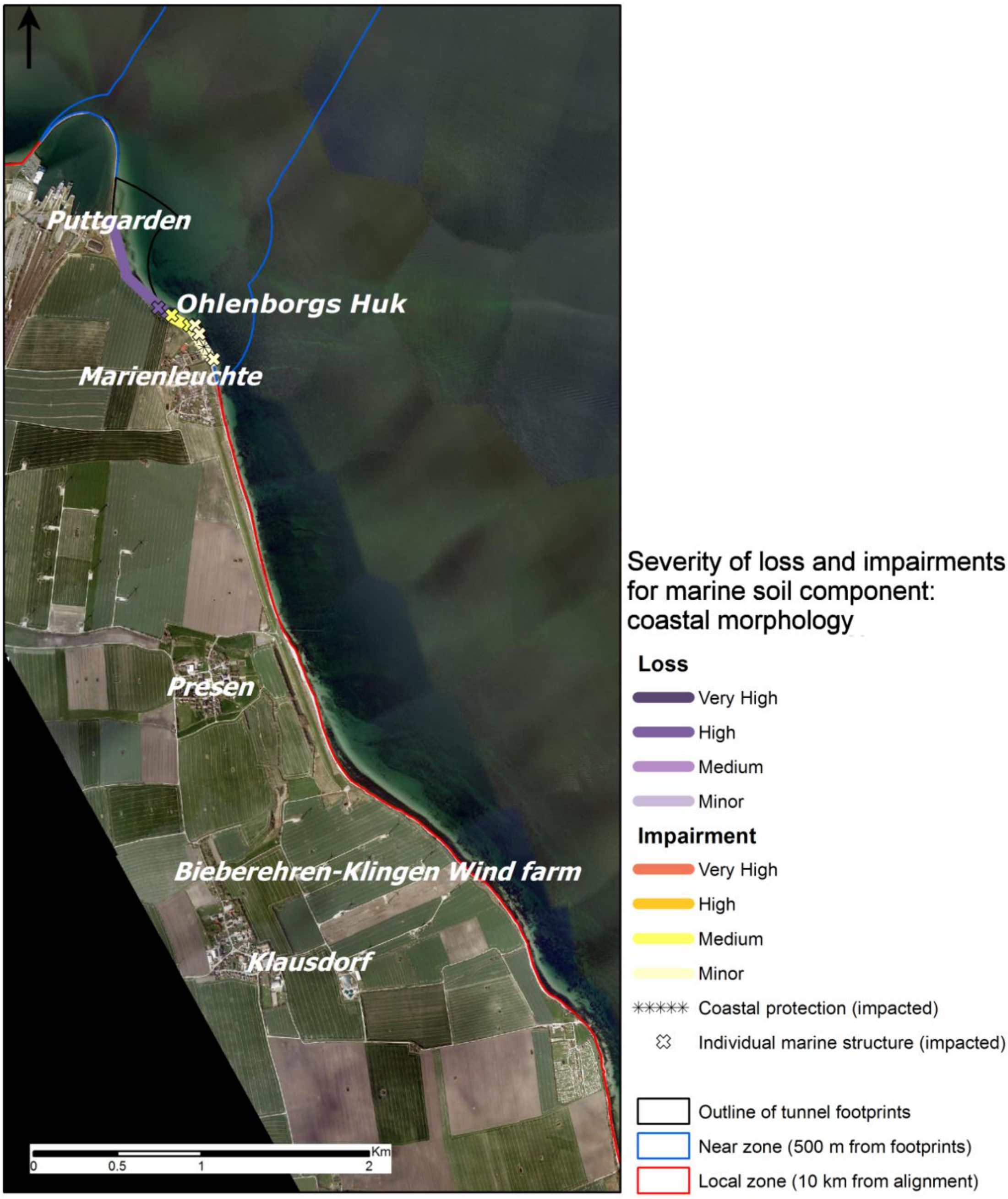

Figure 6.13 Severity of loss and severity of impairments southeast of Puttgarden. Tunnel alternative E-ME/August 2011. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signatures for loss/impairment. These indicate hence the severity of loss and impairment for such structures. Note: following this assessment, additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast at Ohlenborgs Huk/Marienleucte, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009) . Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

Table 6.7 Summary of severity of impacts on the coastal morphology on Fehmarn from tunnel project (E-ME/August 2011). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.

Severity of impacts	**Total** **m**	**Individual structures (No.)**	**Special morph. features (No.)**
Very high severity	0	0	0
High severity	0	0	0
Medium severity	135[2]	2[2]	0
Minor severity	235[2]	3[2]	0
Total	**370**[2]	**5**[2]	**0**

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text.

6.2.4 *Summary of impacts*

A total stretch of the Fehmarn coast of 1,070 m is impacted by the tunnel project. These accounts for a section of 700 m of 'lost' coastline, which is included in the reclamation and 370 m of coastline, which is impaired and classified with a medium degree of impairment. A total of 6 groynes (individual structures) are impacted.

It is noted that regular monitoring of the potential impaired section of the coast (including 5 groynes) around Ohlenborgs Huk and Marienleuchte has been included as an additional mitigation measure following this impact assessment. With this monitoring and possible strengthening of the coastal protection is required, no impairments are assessed on this part of the coastline.

Sub-components

The impacts distributed on sub-components are provided in Table 6.8 and for sub-areas of the Fehmarnbelt in Table 6.9. The impacts are shown in Figure 6.12 above.

135 m of beach between the groynes north of Ohlenborgs Huk and 235 m of coastal protection at Ohlenborgs Huk are impaired with a medium degree.

Five of the six smaller groynes protecting Ohlenborgs Huk are impaired with a medium degree of impairment. One groyne will be integrated into the reclamation or removed (i.e. lost).

A total of 700 m is characterised as lost with a high degree of severity.

Note comments about effects of additional mitigation impacts in the beginning of this section and in the footnote to the table below.

Table 6.8 *Summary of impacts at Fehmarn from the tunnel project (E-ME/August 2011) divided on sub-components. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline with the given sub-component (reference) within the near zone + local 10 km zone.*

Impacts on coastal morphology	**Coastal sub-components**							
	Total coastline		Beaches/ unprotected coastline		Coastal protection		Individu-al struc-tures	Special morph feat.
	m	**%**	**m**	%	m	%	No	No
Severity of loss								
Very high severity	0	0	0	0	0	0		0
High severity	700[1]	3.1	700[1]	3.3	0	0	1	0
Medium severity	0	0	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0	0	0
Total loss	**700[1]**	**3.1**	**700[1]**	**3.3**	**0**	**0**	**1**	**0**
Degree of impairment								
Very high impairment	0	0	0	0	0	0	0	0
High impairment	0	0	0	0	0	0	0	0
Medium impairment	370[2]	1.6[2]	135[2]	0.6[2]	235[2]	13.4[2]	5[2]	0
Minor impairment	0	0	0	0	0	0	0	0
Total	**370[2]**	**1.6**[2]	**135**[2]	**13.4**[2]	**235**[2]	**13.4**[2]	**5**[2]	**0**
Reference	**22,680**		**20,925**		**1,755**	**-**		

[1] Includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text.

Total impact for specific areas

The impacted areas of the component coastal morphology are divided on sub-parts of the Fehmarn coastline in Table 6.9. The entire impacted coastline on Fehmarn is within the near zone of 500 m around the project during construction.

Note comments about effects of additional mitigation impacts in the beginning of this section and in the footnote to the table below.

Table 6.9 Summary of impacts at Fehmarn from the tunnel project (E-ME/August 2011) divided on sub-parts of the Fehmarncoastline. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline (reference) within the sub-part

Impacts on coastal morphology	**Impacts divided on sub-parts of the coastline of Fehmarn**						
	Total		**Near zone**		**Local 10 km zone**		**German National**
	m	**%**	**m**	**%**	**m**	**%**	**m**
Severity of loss							
Very high severity	0	0	0	0	0	0	0
High severity	700[1]	3.1	700[1]	58.3	0	0	700[1]
Medium severity	0	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0	0
Total	**700[1]**	**3.1**	**700[1]**	**58.3**	**0**	**0**	**700[1]**
Degree of impairments							
Very high impairment	0	0	0	0	0	0	0
High impairment	0	0	0	0	0	0	0
Medium impairment	370	1.6	370	30.8	0	0	370
Minor impairment	0	0	0	0	0	0	0
Total	**370**	**1.6**	**370**	**30.8**	**0**	**0**	**370**
Reference (m)	**20,680**		**1,200**		**21,480**		

[1] Includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text.

6.2.5 Impact significance

Assessed design of the project

The tunnel project has been assessed to cause impacts on a total of 1,070 m of the coastline southeast of Puttgarden on Fehmarn. The impacts are on a permanent time scale.

700 m of the beach east of Puttgarden is integrated into the reclamation. The planned reclamation is planned to have a beach of about the same length facing an east-southeastern direction. The significance of the loss of original beach east of the eastern breakwater of Puttgarden due to the occupancy of the reclamation is therefore considered insignificant.

Monitoring of the potential erosion around the coastal protection structures east of the reclamation at Ohlenborg Huk is recommended. Possible erosion at this section can be effectively presented by strengthening the protection scheme without changing the recreational or natural value of the site. However, the potential impacts on the structures/coastline are considered significant for the assessed design of the project.

Project including additional mitigation measures

Following the assessment, additional mitigation measures have been planned for. These are mentioned in the beginning of Chapter 6.

On Fehmarn regular monitoring and strengthening of coastal protection, if required, to prevent potential erosion around coastal structures at Ohlenborgs Huk are planned for. The impacts on this part of the coastline are hence considered insignificant.

Conclusion
In conclusion, the impacts from the tunnel project on the coastline of Fehmarn are assessed as insignificant with the included additional mitigation measures.

6.2.6 Cumulative impacts
At present there are no plans for new nearby major constructions that will have a cumulative impact in the future. No cumulative impacts are therefore assessed for the coastal morphology along Fehmarn.

6.2.7 Transboundary impacts
Transboundary impacts are not relevant for coastal morphology.

6.2.8 Climate change
The climate changes up to year 2080-2100 have been evaluated at a workshop at the start of the Fehmarnbelt workshop, see (FEHY 2009). The outcome was the following main predictions:

- Air temperature will increase up to 4°C in the area
- The extreme wind speed (50-year return period) may increase by 3 m/s or 10%. Preliminary results suggest a small increase of moderate to strong wind speeds (15-35 m/s)
- A sea level rise up to 1 m

The parameters of importance for the coastal morphology are normally occurring wave conditions and sea level rise. The future wave conditions have not been studied until now, but the change in normally occurring wave heights follows the trend for the moderate to strong wind speeds, which indicated only a small increase in wave heights. A possible change in the wave directions may also impact the coastal morphology. The possible change in wind and wave directions has also not been investigated. From the present knowledge it is not possible to conclude how the changes in the wind and wave climate will affect the morphological stability of the Fehmarn coastline. Even relatively small changes in the wave directions may change the pattern and rates of erosion and deposition, especially for longer sections of unprotected shoreline. Sediment transport may increase or decrease depending on the change in wave direction.

The predicted sea level rise of 1 m will have the following general impacts on the coastal morphology on Fehmarn:

- The Fehmarn coastal area is in general very low-lying and a sea level rise of 1 m will drastically reduce the protection of the hinterland by the present dike and other coastal structures. Furthermore, the present coastal structures will at many locations not be sufficient to protect the dike against erosion
- The small-scale coastal structures (revetments, groynes) will become submerged or partly submerged. They will still offer some protection of the coastline and reduce the transport of sediment along the coast as they will occupy a part of the coastal profile

Based on the above it is likely that means for protecting the coastal area of Fehmarn from sea level rise (with or without the tunnel project) will be effectuated. However, it is concluded:

- The gradients in the sediment transport are not expected to change significantly due to changes in wave directions or wave heights caused by climate change. The effect of the tunnel project of increasing the erosional pressure at Ohlenborgs Huk/Marienleuchte is therefore not expected to change significantly from the assessment of the 0-alternative above. However, due to sea level rise and the reduced beach widths and less effective coastal structures (unless strengthened), the predicted erosion by the tunnel project may put the coastline at a higher risk than evaluated for the 0-alternative

- It is not expected that climate change will change the effect of the tunnel project west of Puttgarden

- The tunnel project is not expected to change the effects of climate change on the Fehmarn north coast significantly

6.2.9 Mitigation and compensation measures

Mitigation measures at Fehmarn are tabulated below. The mitigation measures include measures included in the assessed design of the tunnel project and additional mitigation measures, which have been included in the project following the present impact assessment.

A new beach section in the land reclamation at Fehmarn is included in the assessed design of the project.

The planned additional mitigation measurements include monitoring and new/improved coastal protection structures, if required, at Ohlenborgs Huk to prevent potential erosion along this section of the coast.No further mitigation or compensation measures are recommended.

Table 6.10 Mitigation and compensation measures

Mitigation and compensation measures included in the conceptual assessed design	Additional mitigation and compensation measures
A new beach section in the reclamation on Fehmarn	Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk

6.2.10 Decommissioning

Decommissioning is foreseen to take place in the year 2140, when the fixed link has been in operation for the design lifetime of 120 years.

The decommissioning will leave the reclaimed areas untouched. The shoreline evolution of the coastline is therefore considered to continue as in the situation with the tunnel project, i.e. the increased erosional pressure on the coastal protection at Ohlenborgs Huk southeast of Puttgarden is expected to continue. No changes are expected due to the decommissioning process.

7 ASSESSMENT OF IMPACTS OF BRIDGE ALTERNATIVE

The impacts from the bridge are described below. The impacted sections of the coast (loss and impairment) are derived based on the magnitudes of the pressure from the bridge project and the sensitivity to the pressure of the sub-components of the Marine Soil Component Coastal Morphology.

The impacts from the bridge project on the Lolland and the Fehmarn coasts are treated separately.

The comparison of the baseline situation and the situation with the bridge project is carried out for the 'with ferry' situation only. The 'no ferry' scenario is not assessed. The effect from the ferry on the hydrodynamics (waves and currents) which interacts with the coastal morphology is negligible and the assessment for the 'no ferry scenario' will therefore be identical to the assessment below for the situation with the ferry.

It is noted that the assessment is based on the following **mitigation measures included in the assessed design of the bridge project**:

- Two new sections of beach are included as part of the design of the marine ramp on Lolland and compensate for loss of the existing coastline in the area which will be covered by the marine ramp and hinders corners with potentially poor water quality/traps for sea weed.
- A new beach section is included as part of the design of the marine ramp on Fehmarn to compensate for the existing beach east of Puttgarden, which will be lost due the marine ramp on Fehmarn.

Following the impact assessment below, the following **additional mitigation measures**, have been planned for:

- Nourishment of costal sections exposed to erosion on Lolland by the bridge project (approximately 1,500 m^3/year at Bredfjed 10,000-12,000 m^3/year east of the marine ramp) to keep the baseline situation
- New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of the eastern breakwater at Rødbyhavn)
- Measures to establish a new and adequate water water outlet at Rødbyhavn
- Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk, Fehmarn
- Nourishment of costal sections on the coast southeast of Puttgarden (approximately 2,000 m^3/year between Marienleuchte and Presen on Fehmarn)

- Regular monitoring of the outlet from Blankenwisch west of Puttgarden and improved/new structure, if required

- Regular monitoring of the beach in front of Marienleuchte and new/improved structures, if required, to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte, Fehmarn

Comments on the effects of the additional mitigation measures on the assessed impacts are provided, where relevant.

7.1 Lolland

7.1.1 Magnitude of pressure 1: piers/pylons and marine ramps with beaches

Impacts on the Lolland coastline are caused only by the permanent structures: the marine ramp with the attached beaches east of Rødbyhavn and the piers and pylons of the bridge, see Figure 7.1.

A total length of 1,300 m of the baseline coastline is integrated into the area of the marine ramp with the beaches to both sides.

The magnitudes of the pressure on the coastal sections outside of this area is related to a) the effects these structures have on the sediment budget by blocking the transport and b) the impacts on the sediment budget related to the changes of the waves caused by the structures. These impacts on the sediment budget on the Lolland side were described in the previous Section 5.2.3. The impacts on the sediment budget were analysed based on the average year hydrodynamic conditions.

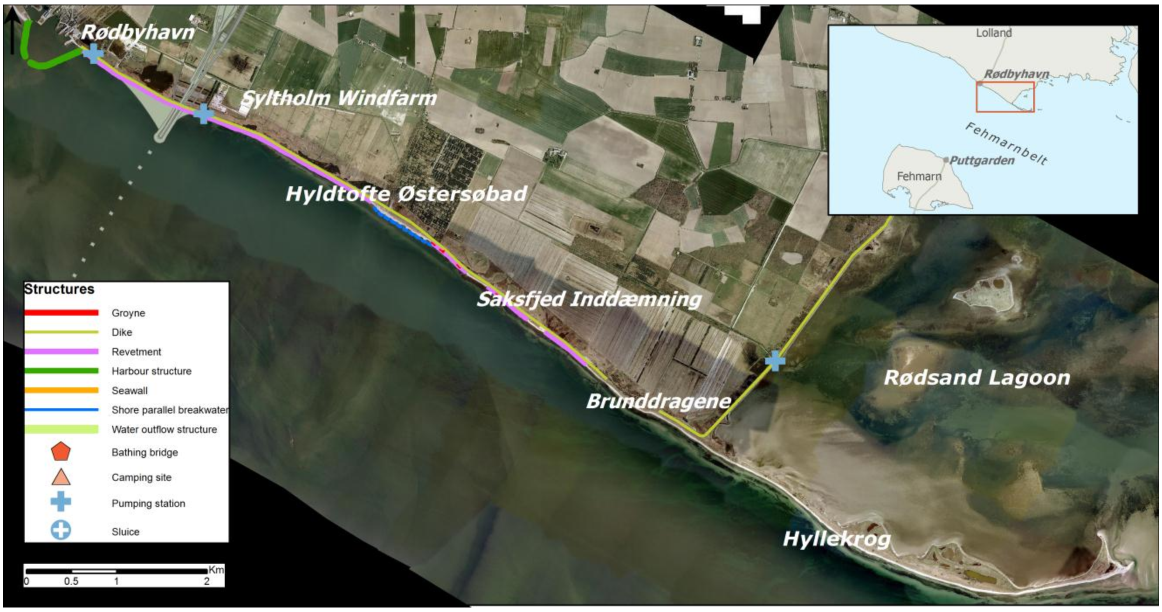

Figure 7.1 Permanent structures for the bridge project along and near Lolland. Marine ramp with beaches east of Rødbyhavn and bridge piers/pylons are indicated in grey. Baseline coastal and marine structures are included. Aerial photo from 2009 (©COWI Orthophoto April 2009)

7.1.2 Severity of loss and degree of impairment

The impacts on the coastline are analysed based on the modelling of changes in the transport of sediment (sediment budget) and of the initial shoreline evolution along the Lolland coast caused by the permanent structures of the bridge project – the marine ramp east of Rødbyhavn and the piers/pylons.

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more than 25-30 years. The permanent effects are evaluated for the lifetime of the project, which is 120 years.

The impacts on the coastal morphology from the bridge develop with time and the coast does not recover from the impacts. All impacts from the bridge project are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the work harbour. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The impacts for sections of the coast are described below. The impacts are assessed with the four levels scales for severity of loss and degree of impairment described in Section 3.7 and Section 3.8, respectively.

Severity of loss is assigned based on the importance levels given in the previous Section 3.9 (Figure 3.16), whereas the degrees of impairment are assigned based on the assessment criteria for impairments Table 3.8.

The impacts and the severity of loss and the degree of impairment for sections of the coast are described below and summarized in Figure 7.2 and Table 7.1.

West of Kramnitze
No changes to the coast west of Kramnitze are expected above the negligible threshold according to the assessment criteria in Table 3.8.

Kramnitze to Bredfjed
The bridge causes a slight dampening of the nearshore wave heights from east which results in an increase in the net eastward sediment transport rates by 1,000-1,500 m^3/year corresponding to about 2.5-5%.

The increase varies slightly along the coast, as described in Section 5.2, and this variation gives rise to additional shoreline retreat or advance along the coast. Shoreline retreat caused by the bridge project is expected to initiate east of the stretches with revetments, since the revetments prevent the increase in the transport to effectuate and hence the sections downstream of the revetment (where the increase of the transport *will* be effectuated) will lack some sediment supply from the upstream section. The northern part of the beach in front of Bredfjed is estimated to lack a supply of sediment in the order of 500 m^3/year. The erosion caused by the bridge project is found to be in the order of 0.5 m/year corresponding to about 1.5 m^3/m/year. The shoreline is therefore predicted to advance with a slower rate than the present approximately 0.5-1 m/year for average conditions or retreat slightly faster (Figure 5.26). A section of 1 km of the beach in front of the summerhouse area of Bredfjed is therefore classified with a minor degree of impairment.

The present shoreline advance between Sandholm and the western part of Lalandia is expected to remain the same at about 0.5 m/year, since the gradient in the net transport is practically unchanged.

The beach southeast of the protected section in front of Kramnitze is not expected to suffer any significant erosion due to the bridge project, since the revetment is fronted by a beach.

Note: Following the above assessment, nourishment of about 1,500 m^3/year to the coast at Bredfjed has been included as an additional mitigation measure. It is predicted that the retreat of the coast at Bredfjed with this nourishment does not become effectuated.

Dragsminde Sluice at Sandholm

The water outlet at Dragsminde Sluice in front of Sandholm may experience increased deposition in the outlet area due to the predicted increase in the net transport rate. The additional accretion is estimated to be less than 2.5 m^3/m/year per m of the outlet and is hence classified as a minor impairment of the marine structure.

Note that a new/improved structure is included as an additional mitigation measure. The impairment of the outlet will hence not become effectuated.

Lalandia to beach west of Rødbyhavn

Along the remaining sections of the coast, the slight increase in the net transport is not expected to change the coastline.

As the net transport increases with about the same rate along the beach west of Rødbyhavn (the accumulation area), the gradient in the alongshore littoral drift is unchanged. The bridge project is therefore not expected to enhance the accumulation of sand west of Rødbyhavn. The present rate of advance of the shoreline of about 3-4 m/year is therefore expected to continue.

Rødbyhavn

The sedimentation of sand in the harbour basins and the access channel to Rødbyhavn was estimated to be in the order of 15,000-20,000 m^3/year during the period 1999-2009 (FEHY 2013a). The sedimentation occurs primarily because of by-pass around the western breakwater.

The maintenance volumes are predicted to increase by about 10% or 1,500 m^3/year caused by the bridge project due to the increase in the net eastward sediment transport along the coast west of Rødbyhavn. The increase will initiate right after erection of the piers/pylons and is predicted to last throughout the lifetime of the project.

The impairments to Rødbyhavn are classified with a minor degree of impairment.

Rødbyhavn to marine ramp

This stretch is a closed sediment cell, where an artificial beach will be constructed in the eastern part of the bay.

The new beach west of the ramp shall be designed to be aligned with the equilibrium orientation such that the net transport along the beach is zero for the average conditions. In years with predominant easterly storms, the beach will turn anticlockwise and some of the beach material will be caught in the western corner. In years with many westerly storms, the beach will turn clockwise. The shoreline will adjust in this way to a dynamic equilibrium shape. The stretch between the eastern break water of Rødbyhavn is classified as no impairments and the stretch, where the new reclamation will occupy the original coastline in the baseline situation is classified as 'loss'. The loss is classified with a minor degree of severity since this stretch is assigned a 'minor' importance level. It should be noted that the new reclamation includes about 900 m of new beach at the location, which is now covered by a revetment.

The water outlet in the corner is classified with a minor degree of impairment due to the predicted accumulation in the western corner, which may impair the outlet.

Note that measures to establish a new and adequate waste water outlet at Rødbyhavn is included as an additional mitigation measure following this assessment.

Marine ramp to Sylthom Windfarm
The coastal section east of the ramp will be exposed to permanent erosion since the marine ramp blocks for the supply of sediment from west to this part of the Lolland coastline.

The coastal section between the marine ramp with beaches and in the order of 1,300 m east of the ramp has also in the *baseline* situation a net deficit of sand due to that lack of input from west caused by Rødbyhavn. As described in (FEHY 2013a and Section 6.1.2), the erosion has in the baseline situation caused starvation of the coastal profiles about 0-2,500 m east of Rødbyhavn, which includes the stretch 0-1,100 m east of the marine ramp.

With the bridge project, the blocking of sand is moved further east by about 1,200 m.

East of the marine ramp, the sea bed in front of the present revetment will potentially be exposed to further erosional pressure since the ramp blocks the sediment supply from west.

It is difficult to estimate, how much loose sea bed material remains in the coastal profiles along the coastal section nearest the ramp (after years of erosion due to Rødbyhavn).

In average this section has (initially) a reduction in the net supply of sand of 10,000-12,000 m^3/year taking into account a small westward transport towards the corner between the ramp and the existing beach and the reduced net eastward transport of 10-15% caused by the reduction in the heights for waves from west (Section 5.2.2 and Figure 5.27).

This corresponds to potential erosion in the order of additional 10-15 m^3/m/year along the coastal section 0-1,100 m east of the ramp. The erosional pressure hence increases due to the bridge project and the revetment along this section is predicted to be at risk of failure. The impairment to this section is therefore classified as very high according to the assessment criteria.

Just east of the ramp and the small beach of about 300 m in the conceptual design, the westward transport may in the initial period cause a small depositional area. The beach is expected to be designed as a stable beach with an orientation corresponding to the equilibrium orientation. The accumulation from the westward transport is expected to be small due to lack of sediment in the area, but can cause deposition in front of the water outlet east of the ramp. The outlet is therefore classified with a minor degree of impairment.

Note: As described in the beginning of Chapter 7, nourishment to the coast east of the marine ramp of approximately 10,000-12,000 m^3/year has been included as an additional planned mitigation measure. Nourishment initiated at the beginning of the project, will prevent the above-mentioned erosion to initiate from the coastal profiles and the coastline immediately east of the marine ramp (0-1,100 m). The nourishment of 10,000-12,000 m^3/year will maintain the coastal development (erosion/deposition) expected for the existing conditions without the bridge project. Furthermore a new/improved structure to secure the functionality of the outlet just east of the ramp is included as an additional mitigation.

Syltholm Wind Farm to Brunddragene
Erosion, which already takes place in the baseline situation due to blocking by Rødbyhavn, will continue with the bridge project. The erosion east of the 1,100 m from the ramp is not expected to be enhanced by the bridge project since the blocking by Rødbyhavn has already caused starvation of sediment from the coastal profiles in the area of the marine ramp extending to about Syltholm Wind Farm.

The impacts on the nearshore waves from the piers/pylons cause a reduction of the net transport of about 10-15% with the bridge project compared to the baseline situation along the coastline further east than about 1,100 m from the ramp.

The milder gradients mean that the erosion/accretion will slightly decrease. The decrease is estimated to 0.25 m/year or less. The reduced net transport rates cause the erosion to spread eastward with a slower rate. The reduction is 10-15%.

The erosion from the coastal profiles continues from about 2,500 m east of Rødbyhavn (in front of Syltholm Wind Farm). The available volume of erodible sediment in the coastal profiles (prior to the erosion due to Rødbyhavn, i.e. in the baseline situation further east than 2,500 m from Rødbyhavn and with the bridge project further east than 1,100 m from the ramp) was estimated to be about 470 m^3 in Section 6.1.2. The net transport eastward is in the case of the bridge project in the order of 15,500 to 19,000 m^3/year. The predicted progression eastwards in the case of the bridge project is therefore estimated to a rate of 30-40 m/year.

This progression is expected to continue on a long-term basis for the entire lifetime of the bridge project. Within 0-120 years, the coastal stretch 0-4,800 m east of the marine ramp extending to Brunddragene is predicted to be impacted.

The impact to the coastline will reduce somewhat as the erosion will diminish with the distance from the reclamation. The erosion will with time take place along a longer stretch and smooth out the erosional pressure and a small input of sediment from the offshore will also occur.

The small sections of unprotected beach along this section will retreat and risk loss of functionality and failure of the coastal protection (revetments, 10 coast parallel breakwaters in front of Hyldtofte Østersøbad and three groynes east of Hyldtofte Østersøbad).

As mentioned above this erosion would also take place in the baseline situation. No impairment from the bridge project is therefore predicted along this coast.

Hyllekrog/Rødsand
Hyllekrog/Rødsand barrier system is a special morphological feature separating the Rødsand Lagoon and the Fehmarnbelt.

The first 1.5-2 km of the Hyllekrog barrier island nearest Brunddragene has the smallest width, see Figure 7.1. Along this part of the barrier island, the beach orientation curves around from approximately 210 degr. N where Hyllekrog connects to land in the west, to 205 degr. N approximately 600-700 m further east and to 220 degr. about 1.5 km from the connection to land. This causes an increase in the net littoral transport and a small tendency for erosion along the first part where the coast curves anticlockwise. Along the next coastal section, where the beach turns clockwise, the net littoral transport will decrease and the shoreline accretes in the baseline situation (see FEHY 2013a). The Q-alpha relation between the beach orientation and the transport rates (net, eastward and westward components) are seen in Figure 5.30 in Section 5.2.3, calculated for the average wave conditions at D20 and applying the coastal profile and sea bed conditions similar to D17.

The bridge project reduces the littoral transport rates and the gradient in the transport rates. The impact from the bridge project is hence predicted to slightly reduce the erosion of the Hyllekrog barrier island where it has the minimum width and to decrease the shoreline advance east of here. However, the changes to the gradients in the transport rates are small and the changes to the morphology are expected to be negligible compared to natural variations from year to year.

The eastern tip of Hyllekrog has moved about 30 m/year during 1999 and 2009. The reduction in the net littoral transport of about 10-15% is expected to reduce the movement of the spit by about 10-15% due to the bridge project.

The gap between Hyllekrog and the next barrier between the Rødsand Lagoon and Fehmarnbelt, is about 1500 m. This gap is important for the coastal and sea bed morphology and the water exchange between Rødsand and the Fehmarnbelt. The historical development of Hyllekrog is outlined in the baseline report (FEHY 2013a). The Hyllekrog spit historically shifts between two types of developments, a northward and an eastward extension. Since 1999, the spit has moved towards the east - and thereby reduced the gap - but it is expected to shift to a northward development again with time. The gap between Hyllekrog and Rødsand has been reduced by about 150-200 m in the period 1945-2009, i.e. about 2.5-3 m/year in average. The reduction in the movement of the spit extension of about 10-15% therefore corresponds to a reduced closing of the gap of about 30 m within the 0-120 years after construction of the project. The impairment to Hyllekrog from the bridge project is therefore small. The impairment to the most eastern part of Hyllekrog is classified with a minor degree of impairment corresponding to a ‘change in morphological elements of special morphological features’ according to the assessment criteria. No favourable mitigation methods can be recommended. It is not possible to increase the sediment transport without imposing an even larger impact to the coast.

No changes to the coastal morphology are predicted east of Hyllekrog above the negligible threshold. No changes are hence expected to East and West Rødsand.

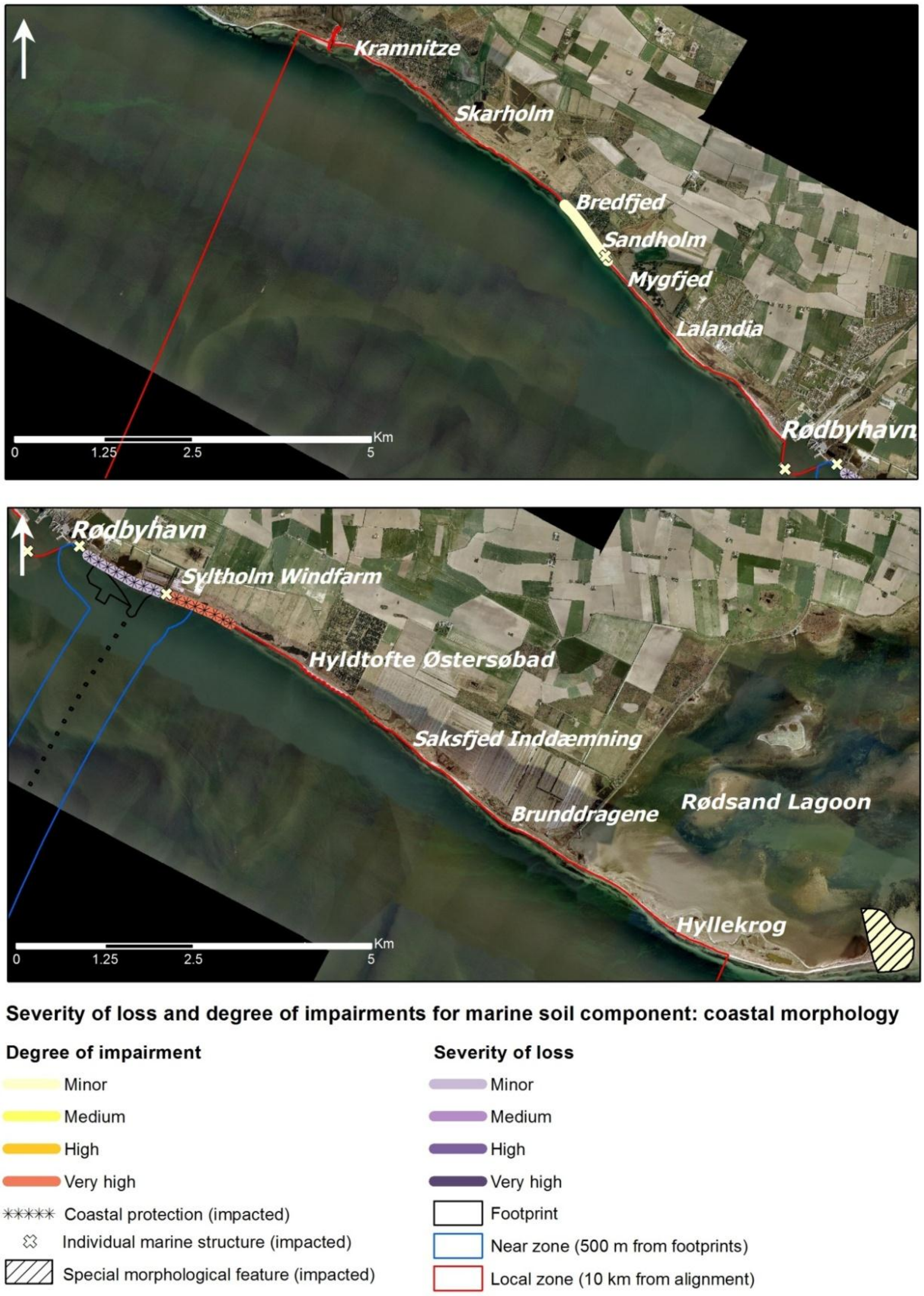

Figure 7.2 *Degree of impairment and severity of loss assigned to sections of the coast due to the pressure from permanent structures of the bridge, the marine ramp on the Lolland side and the piers/pylons. Var. 2 B E-E/October 2010. Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the loss and impairment of such structures/features. Note: following this assessment, additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast west and east of Rødbyhavn, and the impairments to the three outlets (individual structures) west and east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 7.1 *Summary of impacts on the coastal morphology on Lolland from bridge project (Var. 2 B E-E/October 2010). Impacts on unprotected and protected sections are provided in lengths* *(m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.*

Summary of impacts	Total m	Individual structures (No.)	Special morphological features (No.)
Severity of loss			
Very high severity	0	0	0
High severity	0	0	0
Medium severity	0	0	0
Minor severity	1,300[1]	0	0
Total	**1,300**[1]	**0**	**0**
Degree of impairments			
Very high impairment	1,100[2]	0	0
High impairment	0	0	0
Medium impairment	0	0	0
Minor impairment	1,000[2]	3[3]	1[4]
Total	**2,100**[2]	**3**[3]	**1**[4]

[1]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [2]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text, [3]new/improved structures included as additional mitigation structures will prevent impairments to these structures, please refer to text, [4]outside local + near zone.

7.1.3 Severity of impairments

Sections of the impaired coastline with/without structures, impaired individual structures and special morphological features are assigned severity levels by combining the map of degrees of impairment (Figure 7.2) with the importance levels for the respective sections of the coast. The importance levels for the relevant sections of the Lolland coastline were shown in the previous Section 3.9 (Figure 3.16). The results are shown in Figure 7.3 and summarised in Table 7.2.

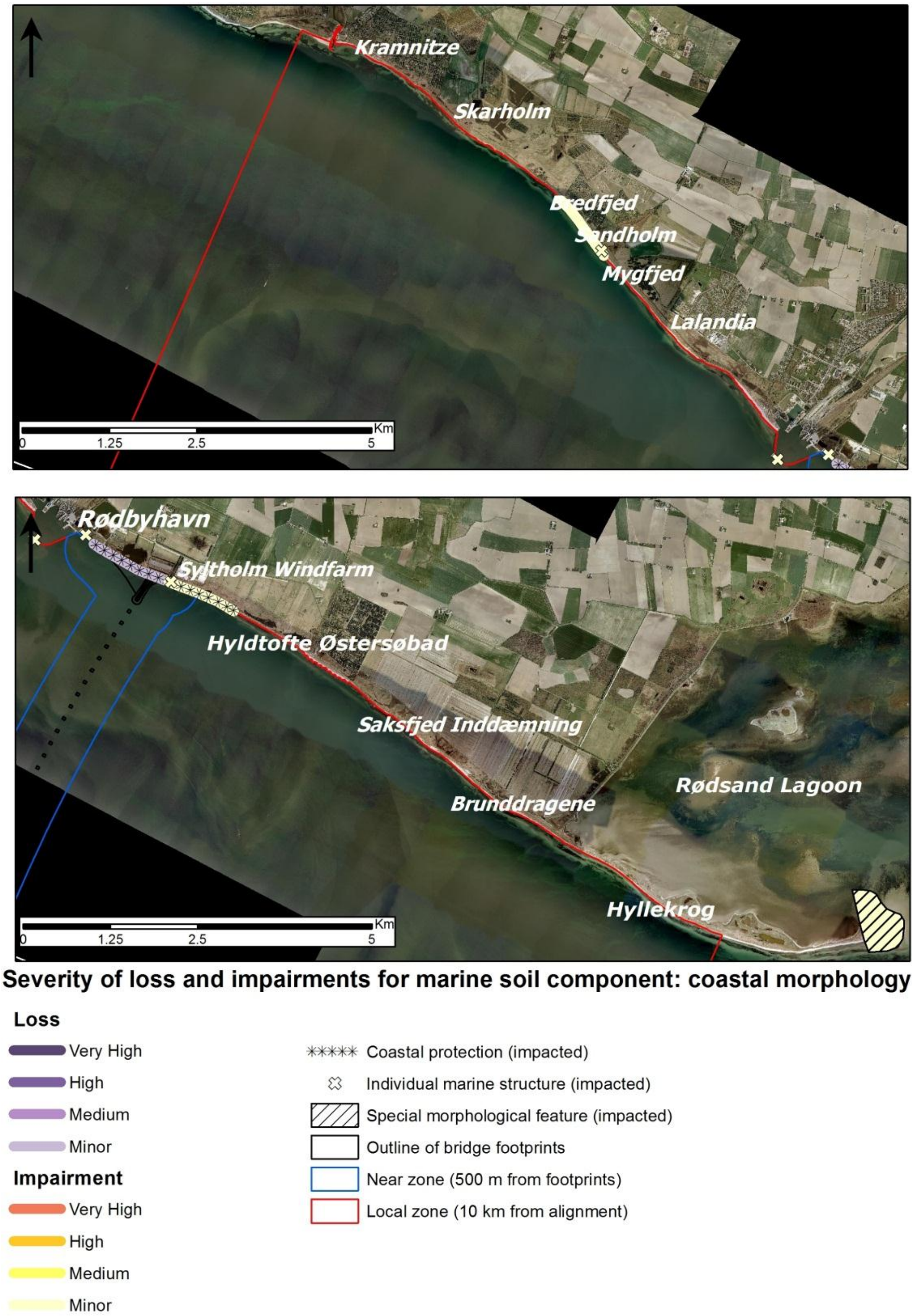

Figure 7.3 *Severity of loss and severity of impairments along the Lolland coastline for the bridge project. (Var. 2 B E-E/October 2010). Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the severity of loss and impairment for such structures/features. Note: following this assessment, additional planned mitigation measures have been included. These are assessed to mitigate the impairments to the coast west and east of Rødbyhavn, and the impairments to the three outlets (individual structures) west and east of Rødbyhavn, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Table 7.2 Summary of severity of impairments on the coastal morphology on Lolland from bridge project. (Var. 2 B E-E/October 2010). Impairments on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent

Severity of impairments	**Total m**	**Individual structures (No.)**	**Special morphological features (No.)**
Very high severity	0	0	0
High severity	0	0	0
Medium severity	0	0	0
Minor severity	2,100[1]	3[2]	1[3]
Total	**2,100**[1]	**3**[2]	**1**[3]

[1]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text, [2]new/improved structures included as additional mitigation structures will prevent impairments to these structures, please refer to text, [3]outside local + near zone.

7.1.4 *Summary of impacts*

A total stretch of the Lolland coast of 3,400 m is impacted. 1,300 m are lost and 2,100 m are impaired by the bridge project.

The lost coastline is all classified with a minor degree of severity as the loss occurs where the coast is presently covered by a revetment. No individual marine structure will be lost.

1,100 m of the coast are impaired with a very high degree of impairment and 1,000 m is impaired with a minor degree of impairment. Three individual structures (outlet at Dragsminde at Sandholm, and two outlets east of Rødbyhavn) are impaired with a minor degree of impairment.

The special morphological feature, the easternmost part of the spit of Hyllekrog, is assigned with a minor degree of impairment.

The impacted spit of Hyllekrog is considered a morphological element belonging to conservation objectives within Natura 2000.

It is noted that following this assessment, Femern A/S, has included additional planned mitigation measures, which are assessed to prevent the impairments of 2,100 m of the coastal sections caused by the project. Additional mitigation measures to the three outlets (individual structures) west and east of Rødbyhavn are also included to prevent assessed impairments.

Remaining impacts including these additional mitigation measures accounts for a section of lost coastline (1,300 m).

Sub-components

The impact severity is evaluated for each of the four sub-components (beaches/unprotected coastline, coastal protection, individual marine structures and special morphological features) to distinguish between the impacts on different functionalities of the coastline.

A table providing the impacted stretches of the individual sub-components is given below (Table 7.3). The impacts are divided into the four impact severity levels.

The impacts are given in lengths of the coastal sections occupied by the given sub-component and in parts (%) of the total length the given sub-component occupies along the Lolland coast within the near zone and local 10-km zone. The near zone and local 10-km zone are seen in Figure 7.3. The number of the impacted marine structures is supplied.

Note comments about effects of additional mitigation impacts in the beginning of this section and in the footnote to the table below.

Table 7.3 Summary of impacts at Lolland from the bridge project (Var. 2 B E-E/October 2011) divided on sub-components. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline with the given sub-component (reference) within the near zone + local 10 km zone.

Impacts on coastal morphology	**Coastal sub-components**							
	Total coastline		Beaches/ unprotected coastline		Coastal protection		Individual structures	Special morph feat.
	m	**%**	**m**	%	m	%	No	No
Severity of loss								
Very high severity	0	0	0	0	0	0	0	0
High severity					0	0	0	0
Medium severity	0	0	0	0	0	0	0	0
Minor severity	1,300[1]	6.5[1]	0	0	1,300[1]	15.4[1]	0	0
Total loss	**1,300[1]**	**6.5[1]**	**0**	**0**	**1,300[1]**	**15.4[1]**	**0**	**0**
Degree of impairment								
Very high impairment	1,100[2]	5.5[2]	0	0	1,100[2]	13.1[2]	0	0
High impairment	0	0	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0		0
Minor impairment	1,000[2]	5.0[2]	1,000[2]	8.3[2]	0	0	3[3]	1[4]
Total	**2,100[2]**	**10.5[2]**	**1,000[2]**	**8.3[2]**	**1,100[2]**	**13.1[2]**	**3[3]**	**1[4]**
Reference	**20,035**		**12,020**		**8,415**			

[1]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [2]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text, [3]new/improved structures included as additional mitigation structures will prevent impairments to these structures, please refer to text, [4]outside local + near zone.

Total impact for specific areas

The impacted areas of the component coastal morphology are divided into sub-parts of the Fehmarnbelt in Table 7.4. All impacts are considered permanent.

The loss of coastline takes place only within the near zone of 500 m around the project during construction. All impairments from the bridge are categorised with a minor classification. Approximately half of the impacted coastline is within the near-zone.

Note comments about effects of additional mitigation impacts at the beginning of this section and in the footnote to the table below.

Table 7.4 Summary of impacts at Lolland from the bridge project (Var. 2 B E-E/October 2010) divided on sub-parts of the Lolland coastline. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline (reference) within the sub-part.

Impacts on coastal morphology	Impacts divided on sub-parts of the coastline of Lolland						
	Total		Near zone		Local 10 km zone		Denmark National
	m	%	m	%	m	%	m
Severity of loss							
Very high severity	0	0	0	0	0	0	0
High severity	0	0	0	0	0	0	0
Medium severity	0	0	0	0	0	0	0
Minor severity	1,300[1]	6.5[1]	1,300[1]	61.9[1]	0	0	1,300[1]
Total	**1,300**[1]	**6.5**[1]	**1,300**[1]	**61.9**[1]	**0**	**0**	**1,300**[1]
Degree of impairments							
Very high impairment	1,100[2]	5.5[2]	545[2]	26.0[2]	555[2]	3.1[2]	1,100[2]
High impairment	0	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0	0
Minor impairment	1,000[2]	5.0[2]	0	0	1,000[2]	5.6[2]	1,000[2]
Total	**2,100**[2]	**10.5**[2]	**545**[2]	**26.0**[2]	**1,555**[2]	**8.7**[2]	**2,100**[2]
Reference (m)	**20,035**		**9,190**		**10,845**		

[1]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [2]Impairments, which will not to be effectuated following additionally planned mitigation measures, please refer to text,

7.1.5 *Impact significance*

Assessed design of the project

The bridge project has been assessed to cause loss or impairments on a total of 3,400 m of the Lolland coastline. The impacts are on a permanent time scale.

Only a short section of the coastline at Lolland is lost. The ramp with the two beaches to the east and west occupies about 1,300 m of the original coastline, which is heavily protected with large stones in the baseline situation. The two new beaches – a total of about 1.3 km new beach - will provide a new section of coast with recreational value near Rødby. The significance of the loss is therefore considered insignificant.

The impairment of the coastline 0-1,100 m east of the marine ramp may potentially cause a risk of failure of the revetment since enhanced erosion along this section is expected. Monitoring of the erosion from the sea bed in front of the structures is recommended. The predicted erosion in front of this revetment and also further east than 1,100 m from the ramp is expected even without the bridge project since Rødbyhavn causes similar impacts on the coastline. In front of Bredfjed, the relatively weak increase in erosion is considered significant unless mitigated.

The impacts on the impacted outlets are evaluated as being significant; however, it is primarily an issue of creating new/improved structures to replace the functionality of the present structure.

The impacts on Hyllekrog are assessed to be a localised issue concerning a weakly reduced migration of the spit on a longer time scale. The impacts to the overall morphological development of Hyllekrog are considered insignificant.

In conclusion, it is assessed that the impacts from the bridge project in the assessed design have sections of the coast with potentially very high impacts.

Project including additional mitigation measures
Following the assessment above, additional mitigation measures have been planned for. These are mentioned in the beginning of Chapter 7.

On Lolland the additional mitigation measures include nourishment of approximately 1,500 m^3/year at Bredfjed and 10,000-12,000 m^3/year to the coast east of the ramp. With this nourishment is assessed that erosion from the beach at Bredfjed and from coastal profiles in front of the coastal protection east of the ramp due to the bridge project can be prevented. New/improved structures to secure two outlets (at Dragsminde Sluice at Sandholm and east of Rødbyhavn) and measures to secure the waste water outlet at Rødbyhavn are also included as additional migitation measures.

Conclusion
In conclusion, it is assessed that the impacts from the bridge project in the conceptual design when including the additional mitigation measures are restricted to the insignificant loss of original coastline in the area of the marine ramp. The bridge project imposes a minor impact on the special morphology feature, Hyllekrog, which will not change the overall coastal morphology of the barrier. The impact is hence assessed as insignificant.

The project is therefore concluded to have no significant impacts on Lolland with the additional mitigation measures included in the bridge project.

7.1.6 Cumulative impacts
Rødsand 1 and 2 Offshore Wind Farms are not included in the wave modelling for the coastal morphology impact assessment. The wind farms will have only negligible influence on the wave conditions near the Link and along the coastline of Lolland except for in the immediate vicinity of the wind farms. It is furthermore noted that the lifetime of the Wind Mill Park is "only" 30 years while the tunnel and bridge project have a project lifetime of 120 years. Consequently, it was decided to exclude Rødsand 1 and 2 Offshore Wind Farms from the wave modelling.

The morphological impacts on the Rødsand barriers from the offshore wind farms were described in Section 6.1.6.

Cumulative impacts
The cumulative impacts for the Rødsand 1+2 offshore wind farms are assessed as follows.

Rødbyhavn to Hyllekrog: Along the stretch Rødbyhavn to Hyllekrog, the impact on the shoreline from Rødsand 2 was in (DHI 2007c) assessed to cause a very weak additional erosional pressure. The increased erosion was estimated to about 0.1 m/year and assessed to be insignificant.

This impact is insignificant compared to the increased erosional pressure in the area 0-1,100 m from the ramp. Further east, the weak *increase* in the erosion caused by the wind farm is in the same order as the weak *decrease* in the erosion (up to 0.25 m/year) caused by the bridge project. The combined effect does not change the assessment above – the impacts on this section from the bridge project are insignificant.

Hyllekrog, The western one third of the barrier: the impacts on this part of the barrier from Rødsand 2 were evaluated to cause a weak additional erosional pressure. This includes the stretch where the barrier has the smallest width. The impacts from the bridge project are assessed to have the opposite effect, i.e. slightly stabilise the erosion. The order of magnitude of the two effects is about the same but in both cases evaluated to be insignificant.

Hyllekrog, The eastern two thirds of the barrier: the effect of the bridge is assessed to decrease the gradients in the transport, i.e. weakly reduce tendencies for erosion/deposition. The effect of Rødsand 2 was assessed to decrease the tendency for erosion along this section observed historically. The cumulative effect is therefore that erosion as well as deposition is expected to decrease compared to the situation without either projects.

Hyllekrog, The eastern spit: The migration rate of the eastern spit is predicted to reduce caused by both projects. The reduction in the migration caused by the bridge project is in the order of 10-15%. The reduction in the migration caused by Rødsand 2 was assessed to be <5%. The cumulative impact is a reduction of 15-20%. As described in Section 7.1.2, the impacts on the overall morphology of the barrier system and the Rødsand Lagoon assessed to be insignificant.

West and East Rødsand: The bridge project is not assessed to have impacts on West and East Rødsand. There are therefore no cumulative impacts from the wind farms and the bridge project.

It is noted that with the additional mitigation measures mentioned in the beginning of Chapter 7, no cumulative effects will be present between the bridge project and the Rødsand 1+2 offshore wind farms.

7.1.7 Transboundary impacts

Transboundary impacts are not relevant for coastal morphology.

7.1.8 Climate change

The climate changes up to year 2080-2100 has been evaluated at a workshop at the start of the Fehmarnbelt workshop, see (FEHY 2009). The outcome was the following main predictions:

- Air temperature will increase up to 4°C in the area
- The extreme wind speed (50 year return period) may increase by 3 m/s or 10%. Preliminary results suggest a small increase for more moderate to strong wind speeds (15-35 m/s)
- A sea level rise up to 1m

The parameters of importance for the coastal morphology are normally occurring wave conditions and sea level rise. The future wave conditions have not been studied until now, but the change in normally occurring wave heights follows the trend for the moderate to strong wind speeds, which indicated only a small increase in wave heights. A possible change in the wave directions may also impact the coastal morphology. The possible change in wind and wave directions has not been investigated. From the present knowledge it is not possible to conclude how the changes in the wind and wave climate will affect the morphological stability of the Lolland coastline. Even relatively small changes in the wave directions may change the pattern and rates of erosion and deposition, especially for longer sections of unprotected shoreline. Sediment transport may increase or decrease depending on the change in wave direction.

The predicted sea level rise of 1 m will have the following general impacts on the coastal morphology:

- The Lolland coastal area is in general very low-lying and a sea level rise of 1 m will drastically reduce the protection of the hinterland by the present dike and other coastal structures. Furthermore, the present coastal structures will at many locations not be sufficient to protect the dike against erosion

- Many of the small-scale coastal structures (revetments, groynes) will become submerged or partly submerged. They will still offer some protection of the coastline and reduce the transport of sediment along the coast as they will occupy a part of the coastal profile

Based on the above it is likely that means for protecting the south coast of Lolland from sea level rise (with or without the bridge project) will be effectuated. However, it is concluded:

- Climate change is expected to increase the effect of the bridge piers and pylons, since the wave heights are predicted to increase. The relative effect of the bridge on the sediment transport rates in the situation with climate change will therefore increase compared to the situation with the 0-alternative. The relative effect of the bridge on feeding sediment to Hyllekrog will therefore increase

- Gradients in the sediment transport are not expected to change significantly due to climate change. The effects of the bridge on the sediment budget are therefore not expected to change significantly. However, due to sea level rise and the following reduced beach widths and less effective coastal structures (unless strengthened), the predicted erosion by the bridge project may put the coastline at a higher risk than evaluated for the 0-alternative

- The bridge project is not expected to change the effects of climate change on the southcoast of Lolland significantly

7.1.9 Mitigation and compensation measures

The conceptual design of the bridge project includes beaches at each side of the marine ramp on the Lollandi. The beaches are considered mitigation methods since they prevent the erosion which would otherwise occur along/near these sections as the hydrodynamic forcing would act to build up these beaches 'naturally' after the construction of the marine ramp.

Following the assessment, nourishment of approximately 1,500 m^3/year at Bredfjed and 10,000-12,000 m^3/year to the coast east of the ramp have been included as additional mitigation measures. With this nourishment is assessed that erosion from the beach at Bredfjed and from coastal profiles in front of the coastal protection east of the ramp due to the bridge project can be prevented.

It is noted that nourishment with these volumes does not prevent erosion from the shoreline that already takes place in the baseline situation.

Monitoring and new/improved structures to ensure the functionality of the two outlet structures (one east of Rødbyhavn and one outlet from Dragsminde Sluice at Sandholm) are also included as additional mitigation measures. Measures to secure the waste water outlet at Rødbyhavn are also planned for.

The mitigation and compensation measures are tabulated in Table 7.5. No further mitigation or compensation measures are recommended.

Table 7.5 Mitigation and compensation measures

Mitigation and compensation measures included in the assessed conceptual design	Additional mitigation and compensation measures
Beaches east and west of the marine ramp	Nourishment of costal sections exposed to erosion on Lolland by the bridge project (approximately 1,500 m^3/year at Bredfjed and 10,000-12,000 m^3/year east of the marine ramp) to keep the baseline situation New/improved structures to secure two outlets (one at Dragsminde Sluice and one outlet east of the eastern breakwater at Rødbyhavn) Measures to establish a new and adequate waste water outlet at Rødbyhavn

7.1.10 Decommissioning

Decommissioning is foreseen to take place in the year 2140, when the fixed link has been in operation for the design lifetime of 120 years.

The evolution of the coastline continues as in the baseline situation, i.e. the erosional pressure on the coast east of Rødbyhavn is expected to continue unless mitigated as described in the sections above. No changes are expected due to the decommissioning process.

7.2 Fehmarn

7.2.1 Magnitude of pressure 1: Reclamation on Fehmarn and piers/pylon

The potential impacts on the Fehmarn coastline from the bridge project are caused by the reclamation east of Puttgarden and the piers/pylons.

The bridge attaches to land by a marine ramp east of the eastern breakwater of Puttgarden. An overview of the planned reclamation is provided in Figure 7.4 together with the present structures. A curved beach facing a southeasterly direction is suspended between the marine ramp and the original coastline. No new structures are planned west of Puttgarden, see Figure 7.5.

A total length of 700 m of the baseline coastline is integrated into the planned reclamation.

The magnitudes of the pressure on the coastal sections outside of this area are related to the impacts on the sediment budget related to the changes to the waves caused by the structures. These impacts on the sediment budget on the Fehmarn side were described in the previous Section 5.2.6. The impacts on the sediment budget were analysed based on the average year hydrodynamic conditions.

No sediment by-passes Puttgarden in the coastal zone, so the reclamation does not additionally block any exchange of sediment transport between the north coast and the northeast coast of Fehmarn.

Figure 7.4 *New permanent structures along the Fehmarn coast in the bridge project – east of Puttgarden. Aerial photo from 2009 (©COWI Orthophoto April 2009) . Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

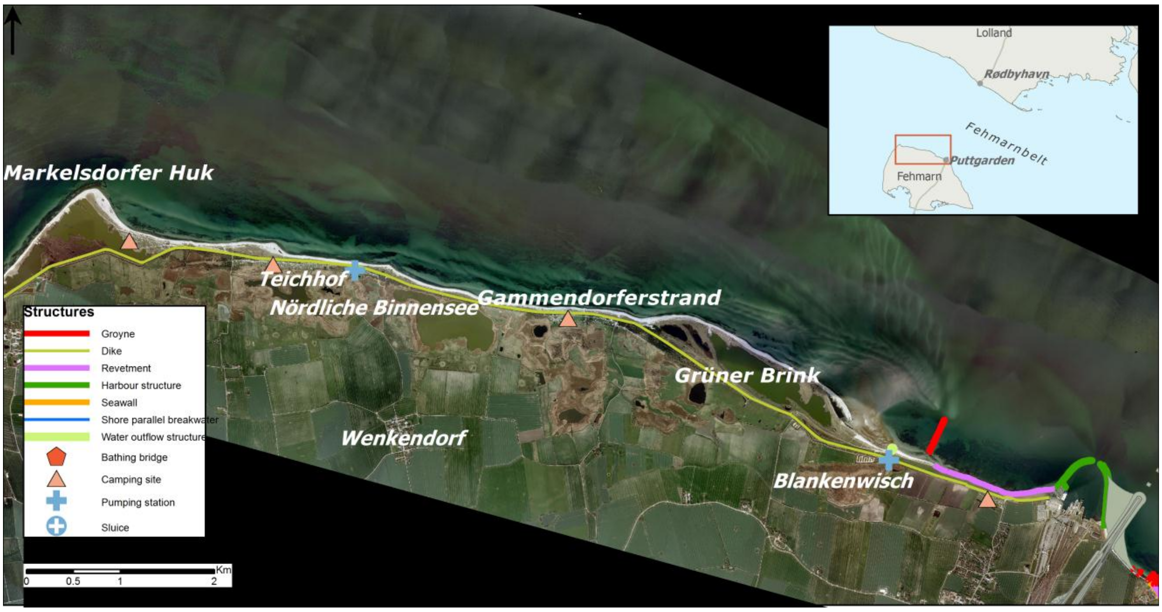

Figure 7.5 No permanent structures are planned west of Puttgarden. The planned reclamation east of Puttgarden is visible in the right side of the figure. Aerial photo from 2009 (©COWI Orthophoto April 2009)

7.2.2 Severity of loss and degree of impairment

The impacts on the coastline are analysed based on the modelling of changes in the transport of sediment (sediment budget) and of the shoreline evolution along the Fehmarn coast caused by the bridge project (the latter only for the coast southeast of Puttgarden), refer to Section 5.2.

The time scales for various impacts are evaluated. Effects lasting less than 25-30 years are denoted temporary effects. Permanent effects are those lasting more than 25-30 years. The permanent effects are evaluated for the lifetime of the project, which is 120 years.

The impacts on the coastal morphology from the bridge develop with time and the coast does not recover from the impacts. All impacts from the bridge project are therefore assessed as permanent.

Impacts on the coastal morphology may start during the construction period due to pressure from temporary structures such as the temporary work harbour. However, these impacts will be of the same character as the impacts caused at a later stage by the permanent structures. The impacts from the temporary structures on the coastal morphology are hence not assessed separately.

The impacts and the severity of loss and degree of impairment for sections of the coast are described below.

Severity of loss are assigned based on the importance levels given in the previous Section 3.9 (Figure 3.14 and Figure 3.15), whereas the degrees of impairment are assigned based on the assessment criteria for impairments Table 3.8.

The impacts and the severity of loss and degree of impairment for sections of the coast are described below and illustrated Figure 7.6 and Figure 7.7 tabulated in Table 7.6.

Markelsdorfer Huk to Grüner Brink
Changes of sediment transport rates due to the bridge alignment are very small west of Grüner Brink (less than 2%). Only negligible impairments to this shoreline are predicted. No impacts are classified to this section.

Grüner Brink
The net eastward transport along the special morphological feature of Grüner Brink formation increases due to the effect of the bridge piers and pylons on the waves.

The increase of the net transport is about 15-20% along the main part of Grüner Brink. This increase raises the migration rate of the formation. The migration rate of the submerged front of Grüner Brink (seen in Figure 7.5, a zoom of the formation is seen in Figure 5.35) was estimated at about 10 m/year in the period 1999-2009 (FEHY 2013a). The migration rate with the bridge project is expected to increase by about 15-20% to approximately 12 m/year. The migration of the formation will continue for the present conditions as well as for the situation with the bridge project, see below.

The sand spit was estimated to migrate with about 20 m/year in the baseline situation. The sand spit is predicted to attach to the coastline within a few years and reach land before the initiation of the project. New spits may develop in the life time of the project. The character of these spits will not be affected by the bridge but the migration rate will be slightly increased.

The changes of the Grüner Brink due to the bridge project are classified with a minor degree of impairment according to the assessment criteria. No favourable mitigation methods can be recommended. It is not possible to change the sediment transport rate without imposing an even larger impact on the coast.

Sedimentation in front of the water outlet from Blankenwisch west of the long groyne will take place. This will also occur in the baseline case, but slightly faster due to the bridge project. The outlet is classified with a minor degree of impairment.

Note that regular monitoring of the outlet and a new/improved structure, if required, is included as an additional mitigation measure. The impairment of the outlet will hence not become effectuated

Grüner Brink to Puttgarden

<u>Short-term, < 10-20 years</u>

Very small shoreline changes have taken place between the long groyne and Puttgarden along this coast between 1999 and 2009 (FEHY 2013a) and the bridge project is not expected to change this situation. The small net increase in sediment transport towards the east is not expected to cause erosion from the shoreline along the coast between the long groyne and Puttgarden harbour. The by-pass of sediment around the offshore part of the long groyne is expected to start as the submerged front of Grüner Brink approaches the long groyne. The by-pass will be about 15-20% larger with the bridge project than for the baseline situation.

<u>Long-term, 10-120 years</u>

Sediment will deposit and fill in west of the long groyne and with time also east of the long groyne. Deposition will occur in front of the drainage outlet from Blankenwisch west of the long groyne.

The distance between the western breakwater of Puttgarden and the easternmost part of the submerged front is about 1,400 m (2009). With the baseline migration rate, 10 m/year, the offshore submerged front of Grüner Brink will reach the western breakwater in about 140 years. With the increased migration rate estimated for the situation with the bridge alternative, the formation may reach the western breakwater slightly faster. However, the formation is highly dynamic and may change its form before it reaches the harbour. The morphological evolution in this complex area cannot be predicted in an accurate manner on a time scale of 120 years. It is assessed that the bridge will not affect the character of the development of this feature but may increase the development rate slightly.

The coastal morphology and shoreline west of Puttgarden will change without and with the bridge project and is – on the long term - expected to become similar to the present situation west of the long groyne. The character of the development will not change due to the bridge but the development rate may be slightly increased. The stretch is therefore considered 'not impaired'.

Puttgarden
The harbour experiences presently no sedimentation in the harbour basin and access channel. On a long time scale in the order of the lifetime of the project (120 years) this may change when the submerged front of Grüner Brink reaches Puttgarden.

This morphological development will take place both in the baseline case and with the bridge project, but may happen slightly earlier with the bridge in place.

Puttgarden to Ohlensborgs Huk
The impacts on the coast between the eastern breakwater of Puttgarden and Ohlenborgs Huk are that the reclamation including the marine ramp and a new beach east of the ramp will occupy part of the original coastline.

The present shoreline in this area consists of the eastern breakwater of Puttgarden and a small accumulation of sand in the transition between the harbour and the coast. The impacts in this area are considered 'loss'. The severity of loss of this 700 m long section is classified with a high degree of severity, since the importance level for this coastline is high. A new beach of about 500 m is a part of the new reclamation.

The new beach attaches to the original coastline west of Ohlensborgs Huk. Ohlensborgs Huk is protected by a number of small groynes and the new beach terminates just west of these as seen in Figure 7.4. Very little sediment is expected to bypass Ohlensborg Huk from the southeast, so the accumulation of sand at the new beach is expected to be very limited.

Ohlenborgs Huk/Marienleuchte
The erosional pressure on the groynes and the seawall protecting the Ohlenborgs Huk from erosion will increase as described in Section 5.2.6 due to the potential increase of about 8000 m^3/year in the transport towards the northwest.

The additional *potential* erosion caused by the bridge project is about 8 m^3/m/year (increase of 8000 m^3/year along a section of about 1000 m). This is an estimated increase of about 20-35%. The erosion is expected to be effectuated only to a smaller degree due to the already existing coastal protection (sea wall, glacier and groynes). Erosion of much of the finer sea bed material (assumed to be available in the calculations) has been removed by years of erosion from this section already. However, some lowering of the sea bed and increased erosion from the shoreline/beach in between the groynes can take place. The magnitude is difficult to predict. Monitoring of the structures is recommended and strengthening of the structures/new structures may be required with time (within 5-10 years after construction). The coastal section is classified with a medium degree of impairment.

Note: Following the above assessment, which is mapped in Figure 7.7, regular monitoring and strengthening of the coastal protection structures, if required, to prevent erosion at Ohlensborgs Huk is included as an additional mitigation measure. The impairments are assessed as negligible with these mitigating measures and possible strengthening of coast protection structures, if required.

Marienleuchte to Presen
The changes to the shoreline evolution south of the protected stretch at Ohlensborgs Huk are caused by a small increase in the gradient of the net northwest sediment transport along the section between Presen and Marienleuchte. The increased erosion due to the bridge project is up to 0.25 m/year for the average conditions. This corresponds to erosion of about 1 m^3/m/year. The section is classified with a minor degree of impairment according to the assessment criteria.

The coast is presently nearly stable at this section with shoreline changes of less than 0.5 m/year in average. With the bridge project this (unprotected) coastline will be exposed to erosion of estimated 0-0.5 m/year.

The marine structures (a bathing bridge in front of Marienleuchte and a pumping station/water outlet at the coast in front of Presen, see Figure 7.4) are predicted to be exposed to erosion. They are classified with a minor degree of impairment.

Following the above assessment regular monitoring of the beach in front of Marienleuchte, new/improved structures, if required, to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte as well as nourishment of about 2,000 m^3/year to the coast between Marienleucthe and Presen have been included as additional mitigation measures. The nourishment will stabilize the retreat of the beach. With these additional mitigation measures, the described impairments will be negligible.

South-east of Presen
The coast southeast of Presen is not expected to experience any impacts related to the bridge project within 120 years after the construction of the project.

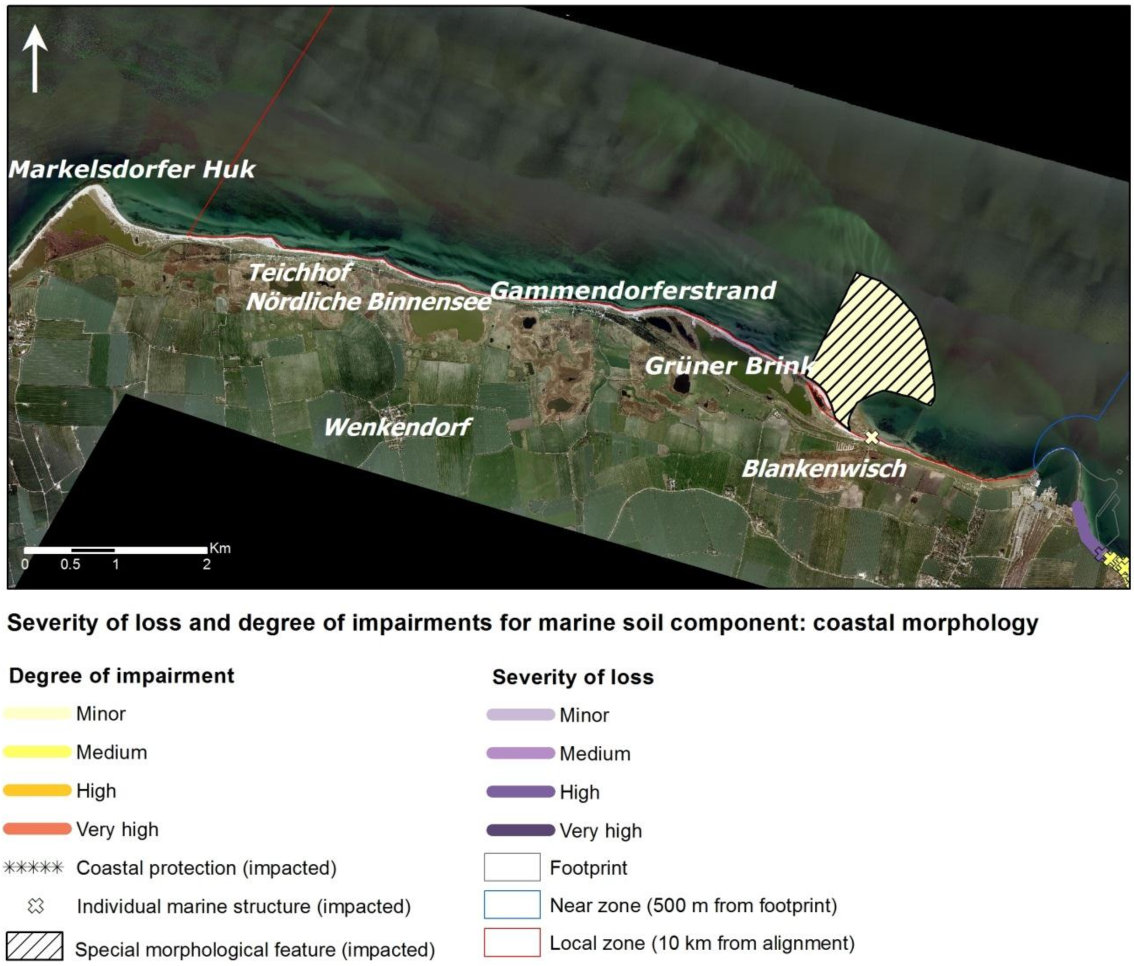

Figure 7.6 *Degree of impairment and severity of loss assigned to sections of the coast of Fehmarn west of Puttgarden due to the pressure from the bridge project. Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the loss and impairment of such structures/features. Note: following this assessment, additional planned mitigation measures have been included. The impairments to the outlet from Blankenwisch (individual structure) west of Puttgarden will not become effectuated, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)*

Figure 7.7 Degree of impairment and severity of loss assigned to sections of the coast of Fehmarn southeast of Puttgarden due to the pressure from the bridge project. Note that legends for structures along the coast (coastal protection and individual marine structures) are shown on top of signs for loss/impairment. These indicate hence the loss of and degree of impairment for such structures. Note: following this assessment, additional planned mitigation measures have been included. The impairments to coastline and structures southeast of Puttgarden will hence not become effectuated, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen

Table 7.6 Summary of impacts on the coastal morphology on Fehmarn from bridge project (Var. 2 B E-E/ October 2010). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent

Severity of impacts	Total m	Individual structures (No.)	Special morph. features (No.)
Severity of loss			
Very high severity	0	0	0
High severity	700[1]	1	0
Medium severity	0	0	0
Minor severity	0	0	0
Total	**700**[1]	**1**	**0**
Degree of impairments			
Very high impairment	0	0	0
High impairment	0	0	0
Medium impairment	370[2]	5[2]	0
Minor impairment	2,165[2]	3[2]	1
Total	**2,535**[2]	8[2]	**1**

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

7.2.3 Severity of impairment

Impairments to sections of the coast with/without structures and individual structures are assigned severity levels by combining the maps of degree of impairments (Figure 7.6 and Figure 7.7) with the importance levels for the respective areas of impairments. The importance levels for the relevant sections of the Fehmarn coastline were shown in the previous Section 3.9 (Figure 3.14 and Figure 3.15).

The results are shown in Figure 7.8 and Figure 7.9 and summarised in Table 7.7 (total severity of impairments)

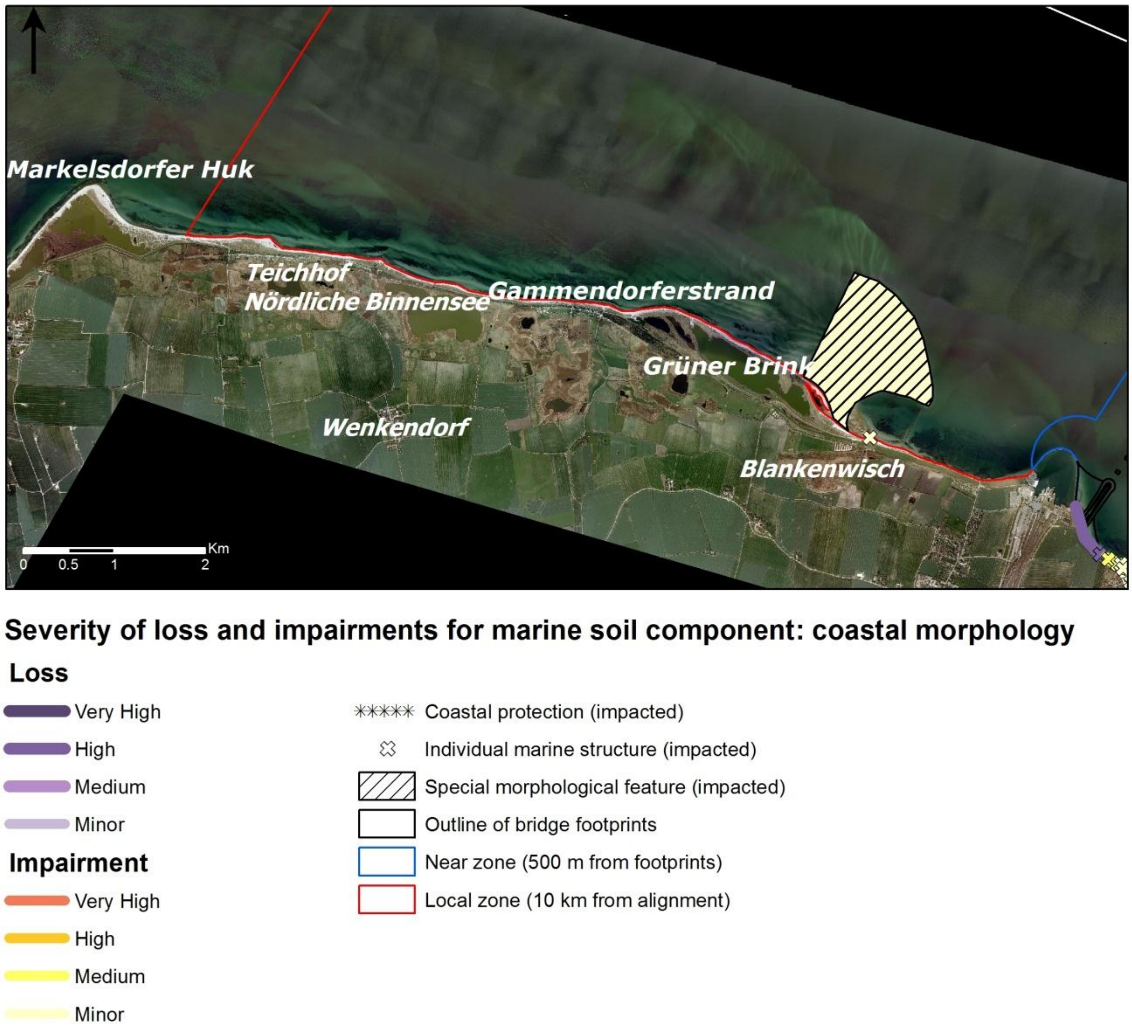

Figure 7.8 Severity of loss and severity of impairments west of Puttgarden. Bridge alternative Var. 2 B E-E/ October 2010. Note that legends for impacted structures (coastal protection and individual marine structures) and impacted parts of special morphological features along the coast are shown on top of signs for loss/impairment. These indicate hence the severity of loss and impairment for such structures/features. Note: following this assessment, additional planned mitigation measures have been included. The impairments to the outlet from Blankenwisch (individual structure) west of Puttgarden, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009)

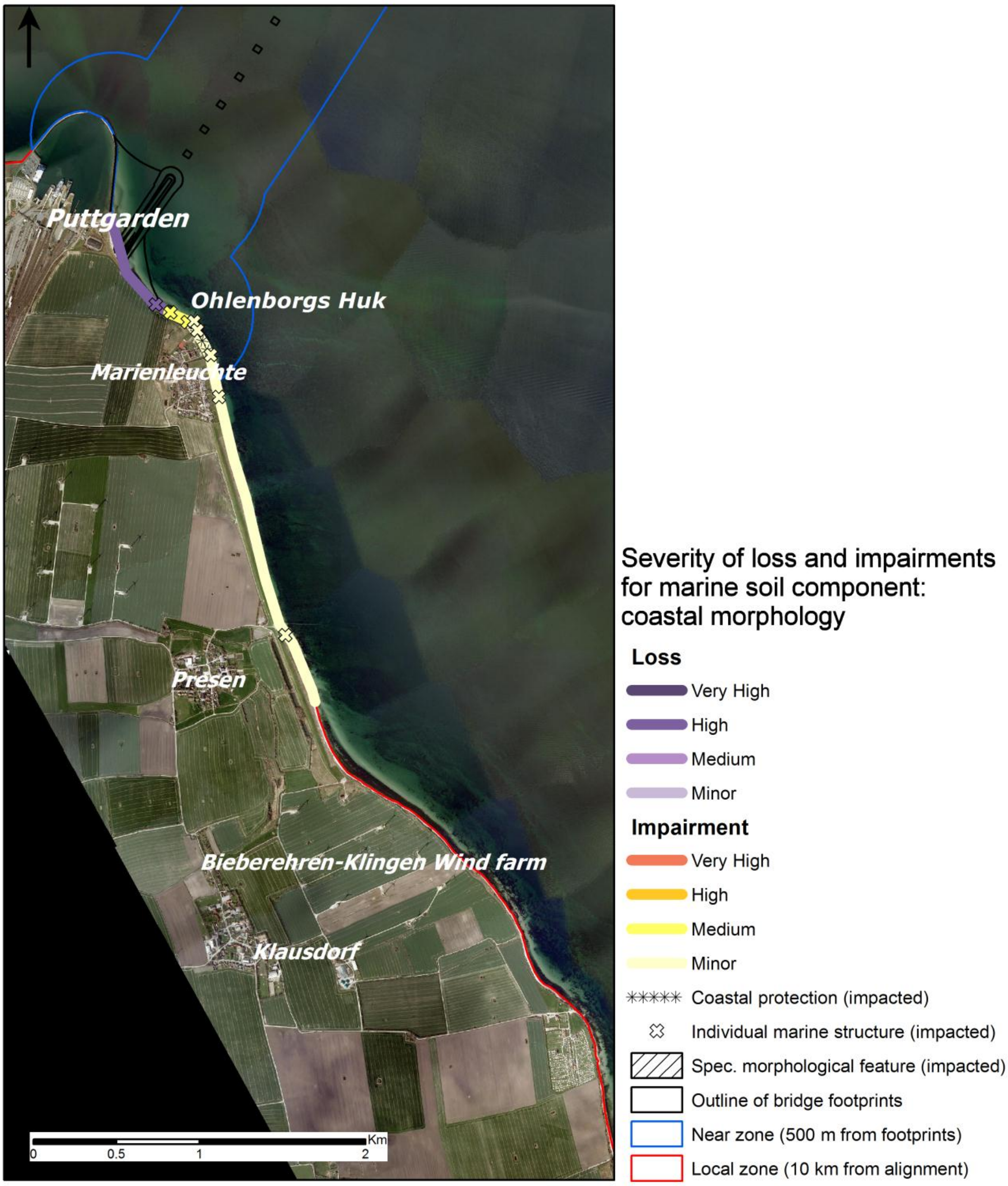

Figure 7.9 *Severity of loss and severity of impairments southeast of Puttgarden. Bridge alternative Var. 2 B E-E /October 2010. Note: following this assessment, additional mitigation measures have been included. Hence the impairments to coastline and structures south-east of Puttgarden will not become effectuated, please refer to the text. Aerial photo from 2009 (©COWI Orthophoto April 2009). Note: Bieberehren-Klingen wind farm is not the correct name of the wind farm south of Presen*

Table 7.7 Summary of severity of impairments on the coastal morphology on Fehmarn from bridge project (Var. 2 B E-E/October 2010). Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent.

Severity of impacts	Total m	Individual structures (No.)	Special morph. features (No.)
Very high severity	0	0	0
High severity	0	0	0
Medium severity	135[1]	2[1]	0
Minor severity	2,400[1]	6[1]	1
Total	**2,535[1]**	**8[1]**	**1**

[1]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

7.2.4 Summary of impacts

A total stretch of the Fehmarn coast of 2,535 m is impaired by the bridge project, see Table 7.6.

700 m of coastline is lost since it will be covered by the marine ramp. The loss is assigned a high degree of severity, since the existing coast is a small sand accumulation area/beach. One groyne (individual structures) in this area is also lost.

A total of 2,535 m of coastline is impaired. 370 m is impaired with a medium degree of impairment (coastal section between Ohlenborgs Huk and Marienleuchte) and 2,165 m are impaired with a minor degree of impairment (unprotected coast between Marienleuchte and Presen). A total of eight structures are impacted with a medium-minor degree of impairment).

The special morphological feature of Grüner Brink is considered impaired with a minor degree of impairment.

The impacted eastern front of Grüner Brink is belonging to conservation objectives within Natura 2000.

It is noted that following this assessment, additional planned mitigation measures have been included, which are assessed to prevent the impairments of 2,535 m of the coastal sections caused by the project. Additional mitigation measures will further prevent impairments to the eight impaired structures.

The residual impacts from the bridge project including the additional mitigation measures on Fehmarn include the above mentioned loss in the marine ramp area.

Sub-components
Impacts are distributed on sub-components in Table 7.8.

700 m of beach with a high degree of severity are lost and 2,300 m are impaired with a medium-minor degree of impairment. A total of 11.0% of the coastline with beaches/unprotected sections within the local area+near zone are impacted by the bridge project. 235 m of coastal protection are impaired to a medium degree.

One groyne is lost (within the reclamation), five groynes are impaired with a medium degree of impairment and three other structures (the outlet from Blankenwish west of Grüner Brink, the water outlet in front of Presen and a bathing bridge off Marienleuchte) are assessed impaired to a minor degree.

The special morphological feature of Grüner Brink is considered impaired with a minor grade of severity.

Note the above comments about effects of additional mitigation and in the footnotes to the table below.

Total impact for specific areas
Impacts are distributed on sub-areas of the Fehmarnbelt in Table 7.9. 58.3% of the near zone is lost and 41.7% is impaired, which means that 100% of the coastline within the near zone is impacted by the bridge project.

2,035 m of coastline within the local area are impaired to minor degree.

Note the above comments about effects of additional mitigation and in the footnotes to the table below.

Table 7.8 Summary of impacts at Fehmarn from the bridge project on Fehmarn (Var. 2 B E-E /October 2010) divided on sub-components. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. Impacts on individual structures and special morphological features are provided as a number of impacted structures/features. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline with the given sub-component (reference) within the near zone + local 10 km zone

Impacts on coastal morphology	**Coastal sub-components**							
	Total coastline		Beaches/ unprotected coastline		Coastal protection		Individu-al struc-tures	Special morph feat.
	m	**%**	**m**	%	m	%	No	No
Severity of loss								
Very high severity	0	0	0	0	0	0	0	0
High severity	700[1]	3.1[1]	700[1]	3.3[1]	0	0	1	0
Medium severity	0	0	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0	0	0
Total loss	**700[1]**	**3.1[1]**	**700[1]**	**3.3[1]**	**0**	**0**	**1**	**0**
Degree of impairment								
Very high impairment	0	0	0	0	0	0	0	0
High impairment	0	0	0	0	0	0	0	0
Medium impairment	370[2]	1.6[2]	135[2]	0.6[2]	235[2]	13.4[2]	5[2]	0
Minor impairment	2,165[2]	9.5[2]	2,165[2]	10.3[2]	0	0	3[2]	1
Total	**2,535[2]**	**11.2[2]**	**2,300[2]**	**11.0[2]**	**235[2]**	**13.4[2]**	8[2]	**1**
Reference	**22,680**		**20,925**		**1,755**			

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

Table 7.9 Summary of impacts at Fehmarn from the bridge project (Var. 2 B E-E/October 2010) divided on sub-parts of the Fehmarncoastline. Impacts on unprotected and protected sections are provided in lengths (m) of impacted coast. All impacts are permanent. Parts of impacted sections of the coast (%) are provided as part of the coastline (reference) within the sub-part

Impacts on coastal morphology	**Impacts divided on sub-parts of the coastline of Fehmarn**						
	Total		**Near zone**		**Local 10 km zone**		**German National**
	m	**%**	**m**	**%**	**m**	**%**	**m**
Severity of loss							
Very high severity	0	0	0	0	0	0	0
High severity	700[1]	3,1[1]	700[1]	58.3[1]	0	0	700[1]
Medium severity	0	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0	0
Total	**700**[1]	**3,1**[1]	**700**[1]	**58.3**[1]	**0**	**0**	**700**[1]
Degree of impairments							
Very high impairment	0	0	0	0	0	0	0
High impairment	0	0	0	0	0	0	0
Medium impairment	370[2]	1.6[2]	370[2]	30.8[2]	0	0	370[2]
Minor impairment	2,165[2]	9.5[2]	130[2]	10.8[2]	2,035[2]	9.5[2]	2,165[2]
Total	**2,535**[2]	**11.2**[2]	**500**[2]	**41.7**[2]	**2,035**[2]	**9.5**[2]	**2,535**[2]
Reference (m)	**22,680**		**1,200**		**21,480**		

[1] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach in the new reclamation, [2]Impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

7.2.5 Impact significance

Assessed design of the project

The bridge project has been assessed to cause impacts on a total of 2,535 m of the coastline on Fehmarn. The impacts are on a permanent time scale.

700 m of the beach east of Puttgarden is integrated into the new reclamation. The planned reclamation is planned to have a beach facing an east-south-eastern direction. The new beach has about the same length and is orientated against the equilibrium orientation. The quality of the beach is expected to be the same or slightly better than the existing beach. The loss of original beach due to the occupancy of the reclamation is therefore considered insignificant.

Erosion around the coastal protection structures east of the reclamation at Ohlenborg Huk and the structures further south is considered a potential significant impact without regular monitoring. Sedimentation in front of the outlet from Blankenwisch will occur slightly faster in time due to the bridge than in the baseline situation. Monitoring of the outlet is recommended, however, the impacts due to the bridge are estimated to be insignificant.

Erosion along the beach southeast of Marienleuchte and around the outlet structure in front of Presen is assessed and can be effectively prevented by nourishment.

The special morphological feature Grüner Brink is impaired to a minor degree due to the slight increase in eastward net littoral drift. However, the area is a highly dynamic feature and the effects are assessed not to influence the character of the feature and how it develops but only slightly increase the rate of development. The impact is therefore estimated to be insignificant.

Project including additional mitigation measures
Following the assessment, additional mitigation measures have been planned for. These are mentioned in the beginning of Chapter 7.

On Fehmarn regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk are planned for. Furthermore, regular monitoring of the beach in front of Marienleuchte, new/improved structures, if required, to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte as well as nourishment of about 2,000 m^3/year to the coast between Marienleucthe and Presen have been included as additional mitigation measures. The residual impacts on the coastline southeast of Putgarden are with these mitigation measures considered insignificant.

Monitoring and new/improved structure around the water outlet from Blankenwisch west of Puttgarden is similarly included as additional mitigation and the impairment to this outlet is hence also considered significant.

Conclusion
In conclusion, the impacts from the bridge project on the coastline of Fehmarn are assessed as insignificant with the included additional mitigation measures.

The residual impacts include the above mentioned loss in the marine ramp area and a slight increase in the rate of development of the Grüner Brink. The residual impacts are considered insignificant.

7.2.6 Cumulative impacts
At present there are no plans for new nearby major constructions that will have a cumulative impact in the future. No cumulative impacts are therefore assessed for the coastal morphology along Fehmarn.

7.2.7 Transboundary impacts
Transboundary impacts are not relevant for coastal morphology.

7.2.8 Climate change
The climate changes up to year 2080-2100 have been evaluated at a workshop at the start of the Fehmarnbelt workshop, see (FEHY 2009). The outcome was the following main predictions:

- Air temperature will increase up to 4°C in the area
- The extreme wind speed (50-year return period) may increase by 3 m/s or 10%. Preliminary results suggest a small increase of moderate to strong wind speeds (15-35 m/s)
- A sea level rise up to 1 m

The parameters of importance for the coastal morphology are normally occurring wave conditions and sea level rise. The future wave conditions have not been studied until now, but the change in normally occurring wave heights follows the trend for the moderate to strong wind speeds, which indicated only a small increase in wave heights. A possible change in the wave directions may also impact the coastal morphology. Also, the possible change in wind and wave directions has not been investigated. From the present knowledge it is not possible to conclude how the changes in the wind and wave climate will affect the morphological stability of the Fehmarn coastline. Even relatively small changes in the wave directions may change the pattern and rates of erosion and deposition, especially for longer sections of unprotected shoreline. Sediment transport may increase or decrease depending on the change in wave direction.

The predicted sea level rise of 1 m will have the following general impacts on the coastal morphology on Fehmarn:

- The Fehmarn coastal area is in general very low-lying and a sea level rise of 1 m will drastically reduce the protection of the hinterland by the present dike and other coastal structures. Furthermore, the present coastal structures will at many locations not be sufficient to protect the dike against erosion

- The small-scale coastal structures (revetments, groynes) will become submerged or partly submerged. They will still offer some protection of the coastline and reduce the transport of sediment along the coast as they will occupy a part of the coastal profile

Based on the above it likely that means for protecting the coastal area of Fehmarn from sea level rise (with or without the bridge project) will be effectuated. However, it is concluded:

- Climate change is expected to increase the effect of the bridge piers and pylons, since the wave heights are predicted to increase. The relative effect of the bridge on the sediment transport rates in the situation with climate change will therefore increase compared to the situation with the 0-alternative. The relative effect of the bridge on sediment transport rates and migration of the Grüner Brink formation will therefore increase

- The gradients in the sediment transport are not expected to change significantly due to changes in wave directions or wave heights caused by climate change. The effect of the bridge project of increasing the erosional pressure at Ohlenborgs Huk/Marienleuchte is therefore not expected to change significantly from the assessment of the 0-alternative above. However, due to sea level rise and the reduced beach widths and less effective coastal structures (unless strengthened), the predicted erosion by the bridge project may put the coastline at a higher risk than evaluated for the 0-alternative

- The bridge project is not expected to change the effects of climate change on the Fehmarn north coast significantly

7.2.9 Mitigation and compensation measures

A new beach section in the marine ramp is included in the assessed design of the project.

Following the impact assessment additional mitigation measures have been included in the project. These are listed in Table 7.10 along with the mitigation measures included in the assessed design.

The planned additional mitigation measurements include monitoring and new/improved coastal protection structures, if required, at Ohlenborgs Huk to prevent potential erosion along this section of the coast.

Monitoring and new/improved structures, if required, at the outlet from Blankenwish and between Marienleuchte and Presen (a bathing bridge and a water outlet in front of Presen) are included as planned mitigation measures to prevent possible impairments of these structures.

Erosion of the beach between Marienleuchte and Presen caused by the bridge can be prevented by artificial nourishment included as additional mitigation measure. The required volume is in the order of 2,000 m^3/year. It is noted that nourishment with these volumes does not prevent erosion from the shoreline that already takes place in the baseline situation.

No further mitigation measures are recommended.

Table 7.10 Mitigation and compensation measures

Mitigation and compensation measures included in the assessed conceptual design	**Additional mitigation and compensation measures**
New beach section included in the marine ramp on Fehmarn	Regular monitoring and strengthening of coastal protection structures, if required, to prevent potential erosion at Ohlenborgs Huk, Fehmarn Nourishment of costal sections on the coast southeast of Puttgarden (approximately 2,000 m^3/year between Marienleuchte and Presen on Fehmarn) Regular monitoring of the outlet from Blankenwisch west of Puttgarden and improved/new structure, if required Regular monitoring of the beach in front of Marienleuchte and new/improved structures, if required, to ensure the functionality of the water outlet in front of Presen and the bathing bridge at Marienleuchte, Fehmarn

7.2.10 Decommissioning

Decommissioning is foreseen to take place in the year 2140, when the fixed link has been in operation for the design lifetime of 120 years.

During decommissioning the marine ramps will be removed. The sediment budget is expected to return to the baseline situation, i.e. the erosional pressure on the coastal protection at Ohlenborgs Huk southeast of Puttgarden will reduce and the erosional pressure on the beach between Marienleuchte and Presen will reduce.

8 COMPARISON OF BRIDGE AND TUNNEL MAIN ALTERNATIVES

8.1 Comparison of tunnel and bridge alternatives with continued ferry operation

The impacts from the tunnel and the bridge alternatives are compared below. The impact assessments of the tunnel and the bridge alternatives are based on a number of mitigation measures included in the assessed designs of the projects.

It is noted that following the impact assessments additional mitigation measures have been planned for, which will reduce/eliminate some of the assessed impacts.

In the comparison below, the projects are compared based on the assessed design of the projects. The consequences of the additional mitigation measures and a comparison of the residual effects for the two projects are commented on in separate sections further below

Comparison of impacts from assessed designs of the projects
Lolland

A comparison of the impacts from the assessed tunnel and the bridge projects on the Lolland coastline are provided in Table 8.1.

A larger part of the coastline of Lolland will become impacted by the tunnel project compared with the bridge project due to the relatively large reclamation area on the Danish side, which is a part of the tunnel project.

Furthermore, the tunnel project has more impacts classified with a very high, high or medium degree of impact (severity of loss or degree of impairment) than the bridge project, which only has impacts classified with a medium and minor degree of impact to the coastline of Lolland.

Both projects impose impacts within the Natura 2000 area SCI DK 006X238. The tunnel project impacts the protected coastal landscape along the shoreline east of the reclamation. The bridge project imposes an impact on the special morphology feature, Hyllekrog, further east. Mitigation of the impact on Hyllekrog is not possible.

The overall evaluation of the impacts from the assessed design of the tunnel project on the coastline of Lolland is that a) the assessed impairments to the Lolland coastline and structures can be mitigated effectively and at a relatively low cost and b) the added value of the new reclamation with respect to coastal landscape compensates the loss of original coastline.

The impact from the bridge on Hyllekrog is assessed to be of a minor impact, which will not change the overall coastal morphology of the barrier.

Fehmarn

Table 8.2 provides the comparison of the assessed tunnel and bridge alternative of the impacts on the coastline of Fehmarn. The assessed design of the bridge project causes larger impacts on the Fehmarn side, which is contrary to the situation on Lolland, where the tunnel project impacts a larger part of the coastline.

The main difference between the impacts on the Fehmarn coastline caused by the bridge and the tunnel project is the impacts from the bridge on a) Grüner Brink and

b) the mild increase in erosion along the coastline between Marienleuchte and Presen caused by the impact on the waves caused by the piers/pylons.

The bridge is assessed to increase the rate of the morphological development of Grüner Brink. No mitigation methods can be recommended. Grüner Brink is part of the Natura 2000 area SCI DE 1532-391 and Naturschützgebiete 'Grüner Brink'; however, the effects are assessed not to influence the character of the feature. The impact is therefore assessed to be insignificant. The mild increase in erosion along the coast between Marienleuchte and Presen can be mitigated effectively and at a relatively low cost and is also evaluated as insignificant.

<u>Conclusion based on assessed designs</u>

In conclusion, the main difference between the assessed bridge and tunnel project for the marine soil component coastal morphology is the relatively large new reclamation along the coast of Lolland, which is a part of the tunnel project. The reclamation is, however, also considered to add value to the area with respect to recreational value and coastal landscape and to compensate the loss of original coastline.

The impacts on the remaining sections of the coastlines of Fehmarn and Lolland from the tunnel as well as the bridge project are assessed to be insignificant, if mitigated where possible. Effective mitigation is possible for all significant impacts at a relatively low cost for the bridge as well as the tunnel project.

The differences in the impacted areas as well as the differences in the character of the impacts from the assessed designs of the projects do not lead to one or the other project being the preferred option based on the impacts on coastal morphology.

Projects including additional mitigation measures
Following the assessment, additional mitigation measures have been planned for. These are mentioned in the beginning of Chapter 6 (tunnel) and Chapter 7 (bridge).

<u>Lolland</u>

The residual impacts after including the effects of the additional mitigation measures are the loss of coastline in the areas where the projects occupy the existing coastline due to reclamations/ramps. The bridge project imposes a minor impact on the special morphology feature, Hyllekrog, which will not change the overall coastal morphology of the barrier.

Coastal sections exposed to increased erosion caused by either of the projects are with the additional mitigation measures mitigated by nourishment and effects to structures such as outlet structures are handled by including regular monitoring and, if required, new/improved structures to ensure their functionality.

The main difference between the bridge and the tunnel project is therefore also with the additional mitigating measures included in the project designs the relatively large new reclamation on Lolland.

The differences in the loss of coastline as well as the minor impact to Hyllekrog from the bridge solution, do not lead to one or the other project being the preferred option based on the impacts on coastal morphology on Lolland.

Fehmarn

The residual impacts after including the effects of the additional mitigation measures are for both projects the loss of the same part of the coastline east of Puttgarden in the area, where the projects occupy the existing coastline due to reclamation (tunnel) or marine ramp (bridge). The bridge project imposes a minor impact on the special morphological feature, Grüner Brink, which will not change the overall coastal morphology of the formation.

Coastal sections exposed to increased erosion from the projects are planned to be mitigated by nourishment and effects to structures such as water outlets are handled by including regular monitoring and if required new/improved structures to ensure their functionality.

The only difference between the two projects is therefore the minor impact to Grüner Brink from the bridge project. This impact is insignificant, since the effects from the bridge are assessed not to influence the character of the feature.

The impact to Grüner Brink from the bridge solution, do hence not lead to one or the other project being the preferred option based on the impacts on coastal morphology.

Conclusion

In conclusion, the main difference between the bridge and the tunnel project for the marine soil component coastal morphology is the relatively large new reclamation along the coast of Lolland, which is a part of the tunnel project. The reclamation is, however, also considered to add value to the area with respect to recreational value and coastal landscape and to compensate the loss of original coastline.

The impacts on the remaining sections of the coastlines of Fehmarn and Lolland are assessed to be insignificant with the additional mitigation measures.

The differences in the loss of coastline as well as the differences in the character of the residual impacts from the projects including the additional mitigation measures do not lead to one or the other project being the preferred option based on the impacts on coastal morphology. Table 8.3 summarises the comparison of the immersed tunnel and cable stayed bridge.

Table 8.1 Comparison of impacts on Lolland for the assessed immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridgeprojects (main alternative Var. 2 B E-E/October 2010)

Component:	**Coastal morphology, Lolland**					
	Immersed tunnel E-ME/August 2011			**Cable stayed bridge Var. 2 B E-E/October 2010**		
	Total coastline (m)	**Individual structures**	**Spec. Morph. features**	**Total coastline (m)**	**Individual structures**	**Spec. Morph. features**
Severity of loss						
Very high severity	0	2[4]	0	0	0	0
High severity	3,180[2]	0	0	0	0	0
Medium severity	0	0	0	0	0	0
Minor severity	4,290	0	0	1,300[3]	0	0
Total	**7,470[2]**	**2[4]**	**0**	1,300[3]	0	0
Part of coastline (%)[1]	37.3[2]	-	-	6.5[3]	-	-
Degree of impair-ments						
Very high impairment	750[4]	2[4]	0	1,100[4]	0	0
High impairment	0	0	0	0	0	0
Medium impairment	3,280[4]	3[4]	0	0	0	0
Minor impairment	0	0	0	1,000[4]	0	0
Total	**4,030[4]**	**5[4]**	**0**	**2,100[4]**	**3[4]**	**0**
Part of coastline (%)[1]	20.1[4]	-	-	10.5[4]	-	-
Reference (m)	20,035			20,035		

[1] Refers to part of coastline (%) within the near zone + local 10-km zone, [2]includes 3,180 m of loss of beach west of Rødbyhavn which will be compensated by artificial beaches and a lagoon as a part of the conceptual design, [3]the lost section of the coast is compensated by new beaches east and west of the marine ramp, [4]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to text

Table 8.2 Comparison of impacts on Fehmarn for the assessed immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridgeprojects (main alternative Var. 2 B E-E/October 2010)

Component:	**Coastal morphology, Fehmarn**					
	Immersed tunnel E-ME/August 2011			**Cable stayed bridge Var. 2 B E-E/October 2010**		
	Total coastline (m)	**Individual structures**	**Spec. Morph. features**	**Total coastline (m)**	**Individual structures**	**Spec. Morph. features**
Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	700[2]	1	0	700[2]	1	0
Medium severity	0	0	0	0	0	0
Minor severity	0	0	0	0	0	0
Total	**700**[2]	**1**	**0**	**700**[2]	**1**	**0**
Part of coastline (%)[1]	3.1	-	-	3.1	-	-
Degree of impairments						
Very high impairment	0	0	0	0	0	0
High impairment	0	0	0	0	0	0
Medium impairment	370[3]	5[3]	0	370[3]	5[3]	0
Minor impairment	0	0	1	2,165[3]	3[3]	1
Total	**370**[3]	**5**[3]	**1**	**2,535**[3]	8[3]	**1**
Part of coastline (%)[1]	1.6	-	-	11.2	-	-
Reference (m)	22,680			22,680		

[1]refers to part of coastline (%) within the near zone+ local 10-km zone, [2] includes 700 m of loss of beach east of Puttgarden, which will be compensated by a new artificial beach, [3]impacts, which are assessed not to be effectuated following additionally planned mitigation measures, please refer to the text

Table 8.3 Comparison matrix of impacts from Immersed tunnel and Cable stayed bridge including additional mitigating measures. For each factor, the relatively environmentally best alternative is identified. 0: No difference; (+) Small environmental benefit; + Environmental benefit; ++ Large environmental benefit. Note that even an alternative is evaluated less environmental beneficial, this does not imply that there are significant impacts on the environment

Component	**Sea bed morphology**			
Assessed sub-components	**Immersed tunnel** **E-ME/August 2011**		**Cable stayed bridge** **Variant 2 B E-E/October 2010**	
Beaches / unprotected coastline	Loss of beaches compensated by new beaches (Fehmarn and Lolland) and new coastal landscape (Lolland).	0	Insignificant loss of beach (at Fehmarn), compensation by new beach. Loss of beach/unprotected coastline smaller than for tunnel project.	0
Coastal protection	No impairments on the coastal protection on Lolland and Fehmarn Insignificant loss of coastal protection (covered by the Lolland land reclamation)	0	No impairments on the coastal protection protection on Lolland and Fehmarn Insignificant loss of coastal protection (covered by the marine ramp)	0
Individual structures	No significant effects on the individual structures on Lolland and Fehmarn	0	No significant effects on the individual structures on Lolland and Fehmarn	0
Special morphological features	No effects	0	Insignificant minor impact to Hyllekrog but no morphological effects on the barrier. Insignificant minor impact to Grüner Brink, but no changes to character of formation	0
Total coastal morphology	No significant impacts on the coastline of Lolland. Loss of beaches compensated by new beaches and new coastal landscape. Femern: no significant impacts.	0	No significant impacts on the coastline of Lolland. Loss of coastline significantly smaller than for tunnel project. New beaches included in project design. Femern: no significant impacts.	0

8.2 *Comparison of tunnel and bridge alternatives without ferry operation*

The comparison of the tunnel and bridge alternative without the continued ferry operation is not carried out for coastal morphology.

The ferry operation is not expected to have any significant impacts on the sediment budget for the coastlines of Fehmarn and Lolland. The assessment carried out for the situation with continued ferry operation is therefore expected to cover the situation without continued ferry operation.

9 CONSEQUENCES TO IMPLEMENTATION OF WFD AND MSFD

Neitherthe impacts from the tunnel project nor the impacts from the bridge project on the coastal morphology are assessed to influence the possibilities of fulfilling the criteria for good environmental status for descriptor 6 in the MSFD.

Neither the impacts from the tunnel project nor the impacts from the bridge project are considered to influence the possibilities of fulfilling the purposes of the WFD.

10 KNOWLEDGE GAPS

The assessment of the coastal morphology is based on a detailed baseline study with mapping of the historical and present day coastlines. A well-calibrated modelling system of the sediment budget, which was found able to reproduce the changes to the shoreline changes in the recent years, 1999-2009, is applied.

The responses of coastlines to the pressures from the bridge and tunnel projects are, however, considered to be generally well understood.

In total the assessment of coastal morphology is assessed having a medium degree of uncertainty.

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Wave Modelling using WAMIT

1. WAVE MODELLING USING WAMIT

When waves interact with bridge pier/pylon foundations, spreading of the wave energy takes place, causing reductions of the wave heights in the area of the bridge.

The main cause for the spreading of wave energy in the area of bridge piers/pylons is reflection and diffraction of the waves caused by the structures. Diffraction is the process by which wave energy is transmitted around the structure.

1.1 Methodology

In order to quantify the changes to wave heights and directions a three-step procedure has been used:

1. Detailed calculations of the wave climate around a single foundation: Calculations are performed for a selection of bridge piers/pylons using a separate modelling tool, WAMIT.
2. The results are parameterised to the *Equivalent Blocking Widths* (simply denoted the Equivalent Width in the following), Ref_m. Equivalent Width corresponds to the width of the structure, which allows no energy to pass.
3. Wave modelling including bridge piers/pylons: The change in wave climate from all the bridge-piers/pylons is calculated with the numerical wave model, MIKE 21 SW, now modified to include these blocking widths so that the transmitted and reflected wave energy is altered at each position of a bridge-pier/pylon.

The three steps are described in more details below.

Step 1: Detailed calculations of the wave climate around a selection of single bridge-piers/pylons
The detailed calculations of the wave climate around a single bridge-pier/pylon foundation are carried out with WAMIT. WAMIT is a panel method which models the wave field around an arbitrary shaped structure, based on potential wave theory. WAMIT is described in (Newman, Lee and Korsmeyer 1995).

An example of how a foundation is included in WAMIT is shown in Figure 1.1.

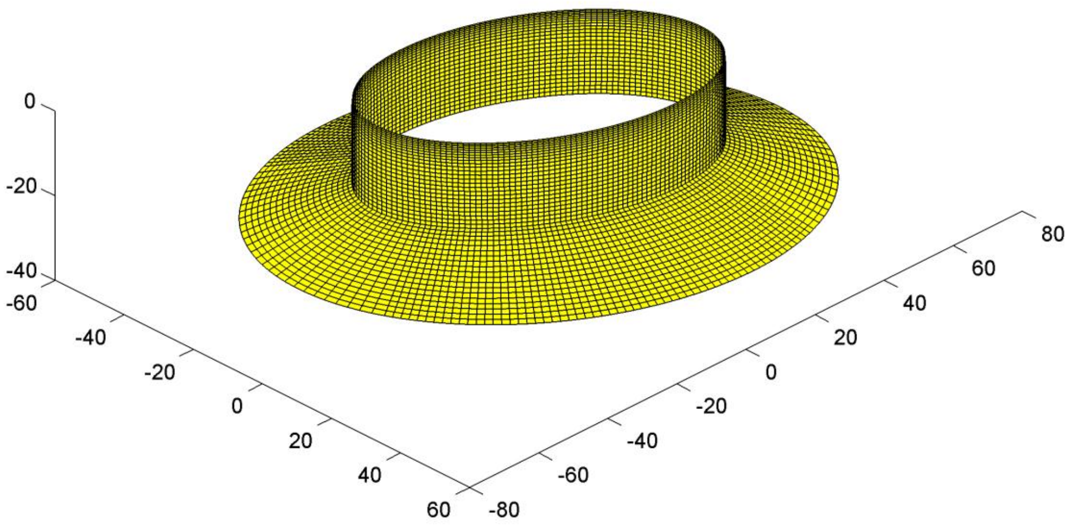

Figure 1.1 *Example of how the foundation is included in WAMIT: Here the pier/pylon is placed in a caisson from seabed level (here -28.7m) up to +4m. The caisson is 80 m long and 50 m wide. From the seabed level up to -20 m the caisson is surrounded by a protection layer.*

Step 2: The Equivalent Width
Based on the results from WAMIT, the reduction factor in the wave energy flux due to the blocking effect of one individual foundation is calculated following this procedure:

1. The incoming wave flux (or the wave flux in case of no bridge piers) can be calculated based on an analytical expression depending on the water depth and wave period.

2. The wave flux including the reflection and diffraction can be calculated from the WAMIT results of the resulting wave climate (which depends on the water depth, wave period and shape/size of foundation).

3. The reflection factor in percent for one structure can then be found from the difference between the incoming wave flux and the resulting wave flux.

4. The reflection factor is parameterized to an Equivalent Width Ref_m by including information of the size of the structure. The Equivalent Width corresponds to the width which reflects all the incoming wave energy, and this is input to the numerical wave model such that the transmitted wave energy is altered at each position of the piers/pylons.

For the WAMIT calculations, the bridge piers and pylons for the bridge project have been grouped in 8 groups, each represented by one pier/pylon foundation; the selection of piers/pylons for the WAMIT calculations and the procedures in the calculations are described in Section 1.2.

Step 3: Local wave model including bridge piers/pylons
The influence on the wave field due to the reflection/dampening caused by the bridge piers/pylons is assessed by including the piers/pylons as structures in the area wave model. The positions of the piers/pylons are shown on top of the bathymetry and mesh of the local wave model in Figure 1.2.

In MIKE 21 SW the effect of the bridge piers/pylons on the waves (reflection/transmission) is dependent on the water depth and wave period. The calculation of the reflection/transmission is based on a wave flux/energy approach through specification of the reflection factors (Equivalent Widths) derived from the WAMIT calculations. The reflection factors supply for each position of a pier or pylon the width for which all incoming wave energy is reflected in MIKE 21 SW. It is assumed that the energy is reflected 180 degrees. The Equivalent Widths are smaller than the actual widths of the piers/pylons indicating that some of the energy is transmitted around the structure. No energy loss is assumed.

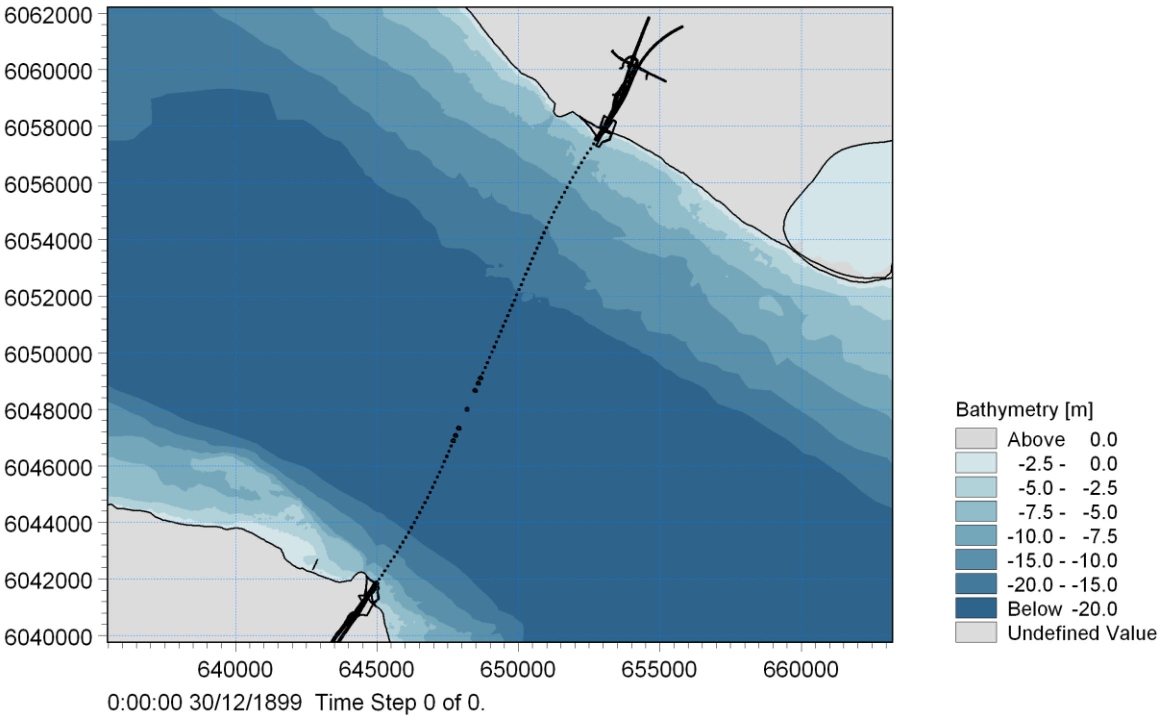

Figure 1.2 Close up of local wave model bathymetry and mesh with locations of the bridge piers/pylons along the bridge alignment

1.2 Wave modelling basis in WAMIT

The reflection/diffraction effect increase with the blocking effect the bridge pier/pylon foundations impose on the wave field, and thereby by the cross-sectional area and the depth. In order to ensure optimal/conservative assessment of the reflection/diffraction effect, the following considerations are made for the representations of the bridge piers/pylons in the wave modelling,

- Depending on the incident wave angle the piers are not symmetrical relative to the direction of wave propagation, so the incident wave angle compared to the orientation of the piers must be considered.
- In order to reduce the computation matrix, the bridge piers and pylons are grouped in a number of groups, each group represented by WAMIT computations of one pier or pylon.

This is described in the following subsections.

The incident wave angle
Depending on the incident wave angle the piers are not symmetrical relative to the direction of wave propagation. An example is shown in Figure 1.. The left-hand cross-section shows waves with incident angle of 0° and the right-hand cross-section is equivalent to waves with incident angle of 67°.

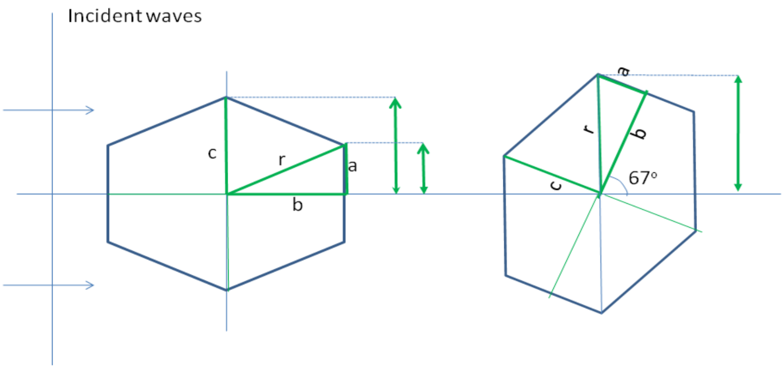

Figure 1.3   Sketch of pier cross-section

From geometrical considerations the reflection is expected to be largest for 67°, as evident from Figure 1.3. However, the diffraction effect may cause some energy to pass around the structure, so more investigation needs to go into this:

In order to select an optimal/conservative incident wave angle for the WAMIT calculations, WAMIT was used to calculate the wave field around one of the piers with various incident wave angles. All of the piers have the same cross-sectional shape, only the size changes, and since these considerations are mainly shape-related this calculation is representative for all of the piers. Regarding the pylons, they are either elliptical (the Outer Pylons) or circular (the Center Pylon); the same argumentation applies for the elliptical shape, and the circular shape is not depending on the incident wave angle.

The results are shown in Figure 1.4for selected wave periods. Evidently the Equivalent Width is largest for 67° - 90°, but incident wave angles close to 90° related to the bridge pier/pylon orientation is not likely. As a conservative choice it was decided to perform the WAMIT wave modelling with an incident wave direction of 67°.

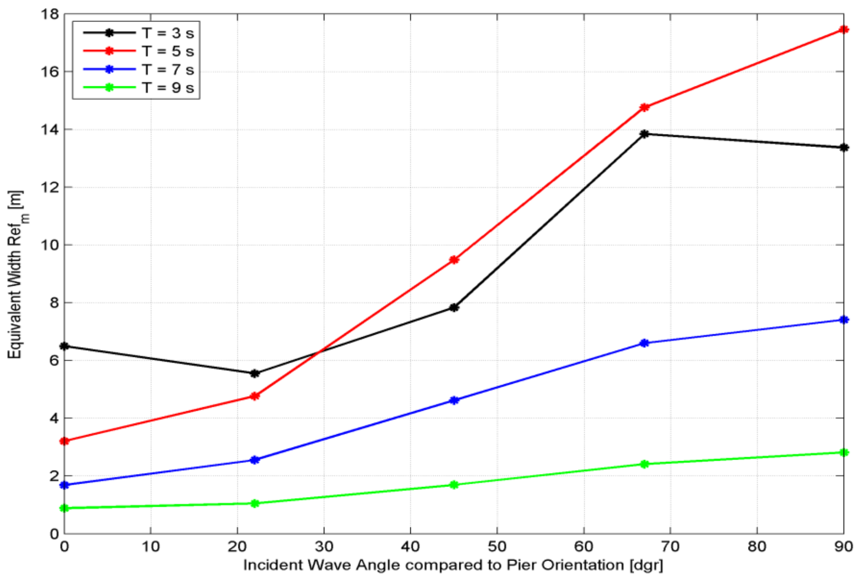

Figure 1.4 The Equivalent Width as function of orientation of a pier (pier L17).

The grouping of bridge piers/pylons
The WAMIT computations are for one structure only. The Fehmarnbelt bridge layout V2 has 28 piers on the Fehmarn side (the south side), 46 piers on the Lolland side (the north side), 2 transition piers, 2 anchor piers, 2 Outer Pylons and 1 Centre Pylon.

In order to reduce the computation matrix, the bridge piers and pylons were grouped in a number of groups, each group represented by WAMIT computations of 1 pier or pylon.

When considering the factors of importance for the reflection/diffraction the factors decided by the blocking structures are the depth and the size/shape of the structure. The groupings were made based on considerations concerning these. Descriptions of shape and depth for each type of pier/pylon are given in Table 1.1.

Table 1.1 Overall description of shape and depth of piers and pylons

Bridge pier/pylon	***Description***
Bridge piers: F28->F1 L46->L1	These all have the same cross-sectional area at the top-level, which varies. Therefore the cross-sectional area varies at MWL and at seabed level.
Transition piers: F0 L0	The piers are located in a caisson which goes from seabed level to level +4. The shape is elliptical with length 80m and width 50m. From seabed level (-29.0 at north side and -28.8 at south side) to level -20 the caisson is surrounded by a protection layer with width at seabed level of appr 22m.
Anchor piers	Same as above, though the seabed level is -28.60 (north side) and -28.9 (south side).
Outer Pylons	The caisson goes from seabed (-28.6 at north side and -28.8 at south side) to level -6.5 with an inclination: length and width at seabed is 94m and 54m, and length and width in level -6.5 is 76m and 36m.
Center Pylon	Round caisson with D=75m from seabed level (-28.6) to above MWL.

Based on Table 1.1 it was decided to group as:

- The bridge piers were grouped in 6 groups
- The 2 Transition Piers and the 2 Anchor Piers form 1 group
- The 2 Outer Pylons form 1 group
- The Center Pylon form 1 group

The grouping of the bridge piers in 5 groups is described below.

<u>Grouping of the bridge piers:</u>

All bridge piers have the same cross-sectional area at the top level. The top-level varies along the length of the bridge and therefore the cross-sectional area at the MWL and over the depth varies for the piers.

The seabed level and the top level of the bridge piers are shown in Figure 1.5.

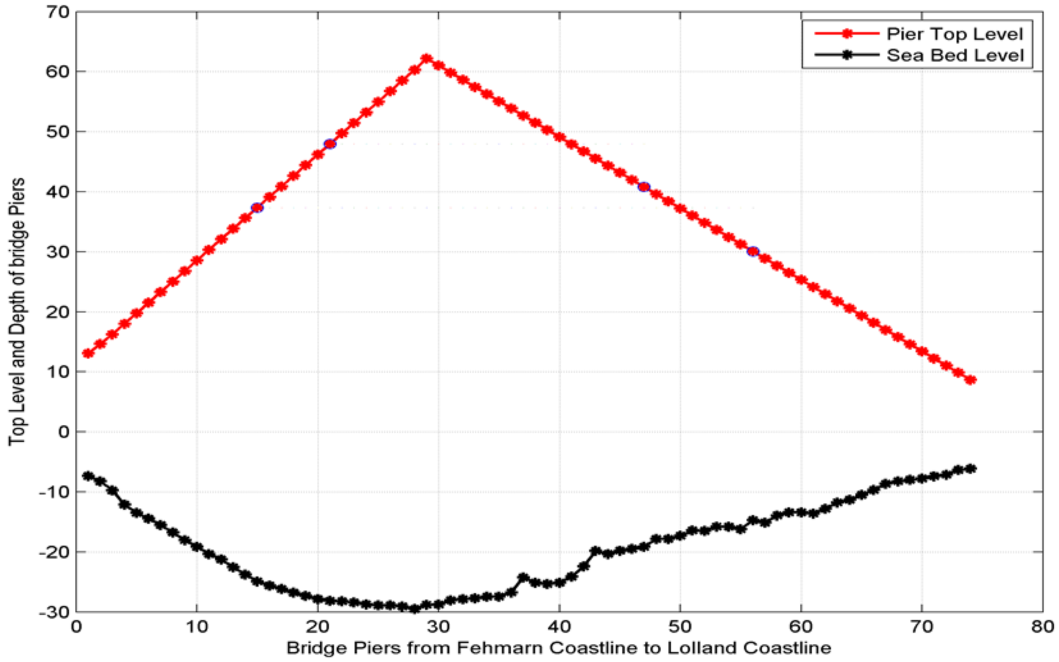

Figure 1.5 Seabed level (black) and Top-level (red) for each pier; left-hand side shows the Fehmarn approach and right-hand side shows the Lolland approach. Blue circles indicate the piers used for the investigation of the effect of cross-sectional area and depth, see Figure 1..

Obviously the same top-level and therefore the same cross-sectional area at MWL for each side is associated with different seabed levels; the seabed level and corresponding cross-sectional area at MWL for each bridge pier are shown in Figure 1.6.

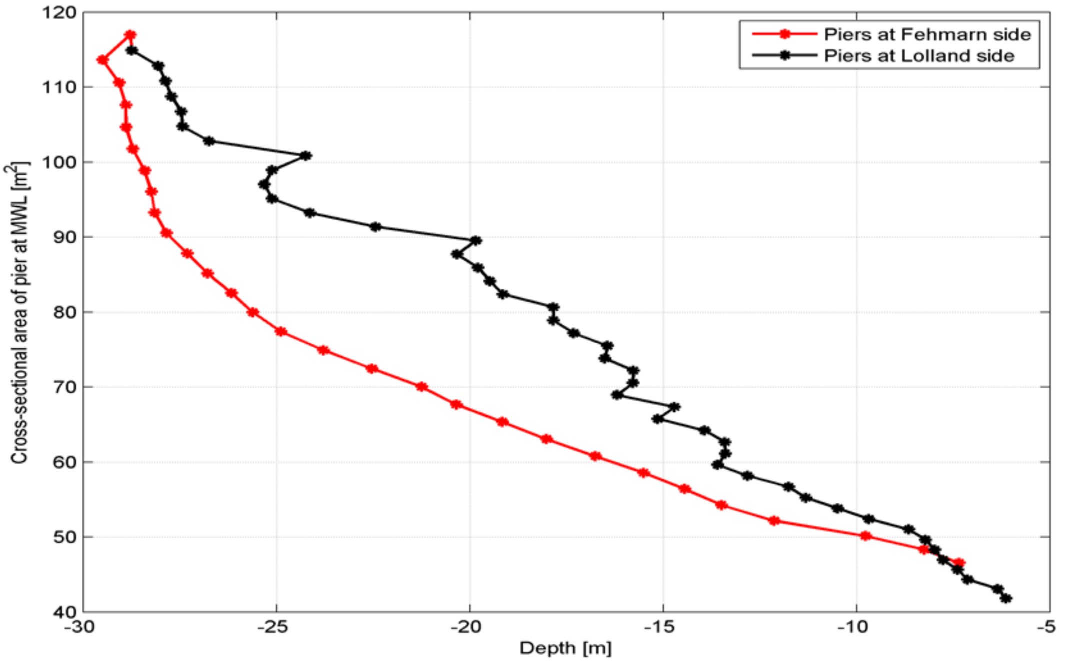

Figure 1.6 Corresponding depth and cross-sectional area at MWL for the bridge piers.

It is expected that a larger cross-sectional area at the MWL results in greater reflection/diffraction effect. In order to investigate the significance of depth and cross-sectional area over the depth, the wave climate for 2 pairs of piers, each with approximately the same cross-sectional area but on different depths have been computed with WAMIT. The Equivalent Widths are shown in Figure 1.7.

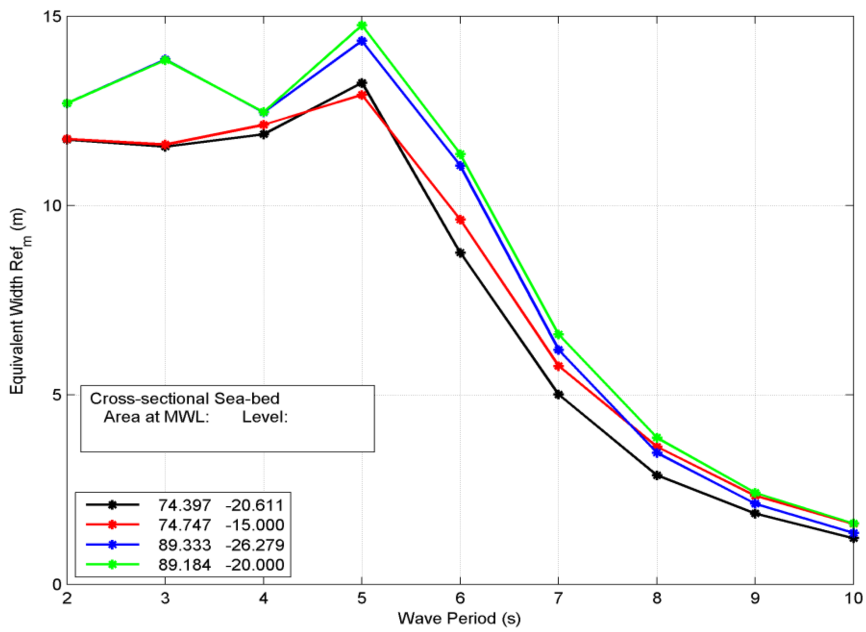

Figure 1.7 The Equivalent Width for 2 pairs of piers, each pair having approximately the same cross-sectional area at MWL but different depths.

It is seen that the pairs with approximately the same cross-sectional area has approximately the same Equivalent Width, irrespective of the depth, especially for the smaller wave periods. For the longer waves 2 opposing effects are present: The longer waves are felt deeper and therefore the depth becomes increasingly important, however the blocking effect of the piers becomes increasingly smaller for the longer waves. It is seen from the figure that the Equivalent Width approaches the same value for longer waves, irrespective of both cross-sectional area at MWL and depth.

It was therefore decided to group the piers based on their cross-sectional area at MWL.

Figure 1.8 shows the Equivalent Width as function of the cross-sectional area at MWL for 3 selected wave periods:

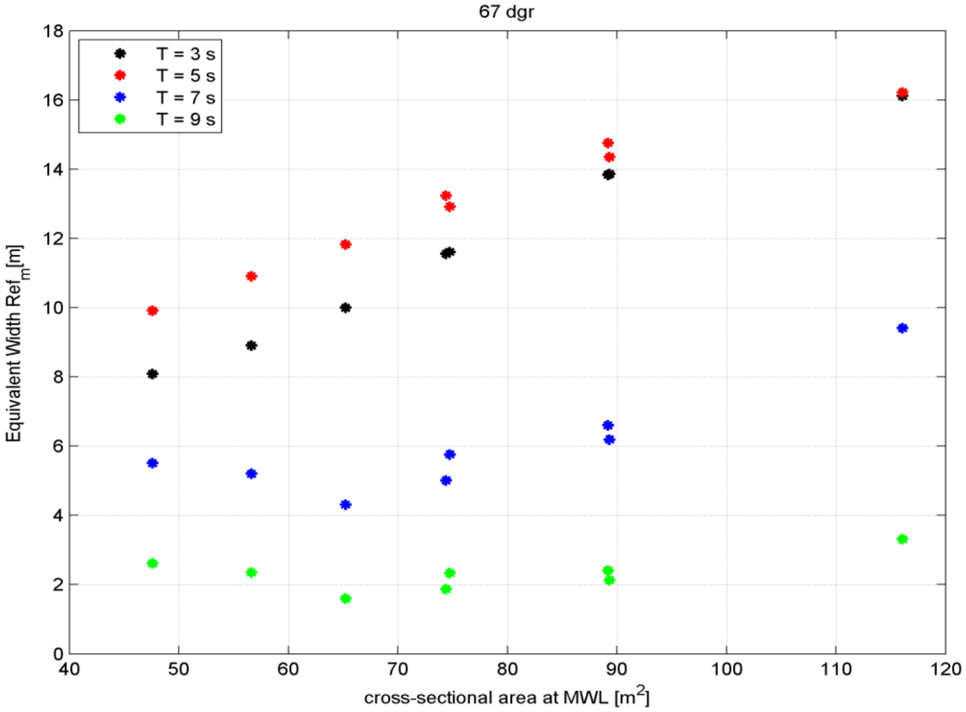

Figure 1.8 The Equivalent Width as function of cross-sectional area at MWL for 3 wave periods.

For the smaller wave periods there seems to be an almost linear connection, which tends to flatten and scatter for the larger wave periods.

Based on this tendency the groups were chosen for relatively small intervals of cross-sectional area:

- 40 m^2 - 50 m^2
- 50 m^2 -60 m^2
- 60 m^2 -70 m^2
- 70 m^2 – 80 m^2
- 80 m^2 -100 m^2
- >100 m^2

In the local wave modelling the piers/pylons in each group are represented by the Equivalent Width for one of the piers/pylons in the group.

Change of wave field due to bridge piers/pylons

The change of wave field due to bridge piers and pylons are calculated based on the procedures and methods described in the main report.

The resulting Equivalent Widths for the groups of bridge piers/pylons applied are shown in Table 1.2.

Table 1.2 Equivalent width based on results from WAMIT.

Type of structure	**Group #**	**Wave Period (s)**								
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Pier	1	9.25	7.94	10.33	9.09	6.25	3.98	2.67	1.80	1.32
Pier	2	10.56	8.90	11.07	10.91	7.88	5.20	3.39	2.35	1.64
Pier	3	11.23	10.00	11.55	11.83	7.40	4.31	2.58	1.60	1.11
Pier	4	11.74	11.56	11.88	13.24	8.75	5.01	2.88	1.87	1.22
Pier	5	12.70	13.86	12.46	14.35	11.05	6.19	3.47	2.13	1.35
Pier	6	14.83	16.11	13.51	16.22	14.63	9.41	5.53	3.31	2.11
Transition- and Anchor pier	7	61.51	61.74	62.18	60.05	62.05	61.49	58.57	61.32	64.57
Outer Py-	8	55.19	61.14	61.22	61.83	62.96	63.70	67.12	68.21	69.28
Center	9	51.39	52.41	52.18	50.58	48.52	50.69	44.92	43.41	44.87

1.3 References

Newman, J. N. Lee, C.H. and F. T. Korsmeyer (1995) *WAMIT version 5.3. A radiation diffraction panel program for wave-body interactions*, (Dept. of Ocean Eng., M.I.T., Cambridge, MA).