<u>**Final Report**</u>

FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES (FEHY)

Marine Soil - Impact Assessment

Sea Bed Morphology of the Fehmarnbelt Area

E1TR0059 - Volume I

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

0 EXTENDED SUMMARY

0.1 Environmental theme and assessed components

The impacts on the sea bed morphology due to the construction of the Fehmarnbelt Fixed Link is mapped and described in the present report.

This report deals with the impacts on the sea bed morphology and mainly the dynamic morphological elements of the sea bed. Non-dynamic elements on the sea bed such as hard substrate are treated in (FEMA 2013a). Within the present report, it is assessed whether the impacts from the tunnel or bridge project change the dynamic character of the sea bed morphology. Morphological features and landscape related to the coastal processes in the near-shore zone, such as for instance sand bars in the coastal profile as well as the special morphological features such as Grüner Brink on Fehmarn and the Hyllekrog/Rødsand formations on the Danish side, are treated in the report on coastal morphology (FEHY 2013f).

Large areas of the Fehmarnbelt are covered by morphologically active bed forms. Two main types of bed forms are **sand waves** and **lunate bed forms**. Sand waves are large-scale flow-transverse ridges of sand up to 4 m in height and are found at 10-20 m water depth. Lunate bed forms are up to 1 m high, 3-dimensional in their nature and have lunate shape with the "arms" pointing in the direction of the Baltic Sea. They consist of loose sediment (fine sand) on an otherwise hard bed and mainly occur where the water depths are greater than 20 m. The two main types cover mostly large-scale sea bed features but other less characteristic forms exist. Such bed forms are identified as "**other active bed forms**". The areas with prominent bed forms in the Fehmarnbelt are shown in Figure 0.1. Further information on the bed forms is available in (FEHY 2013a).

The bed forms are impacted by changes in the sediment transport capacity or the availability of loose sea bed sediment. The bed forms are formed and maintained in their shape and geometry by this transport of sea bed material.

Sediment transport takes place primarily during events with high near-bed current speeds occurring typically 2-5 times/year. The bed forms migrate in the order of 1-5 m during such events in the direction of the near-bed flow. On an annual basis, the net migration of the bed forms, up to 10 m/year, is in the direction of the net sediment transport towards the Baltic Sea.

The four sub-components assessed in the present report under the component 'Sea Bed Morphology' are listed in Table 0.1. Only large-scale morphologically active bed forms of the sea bed are treated.

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 1 January).

Table 0.1 *Component Sea Bed Morphology with sub-components*

Component	Sub-components
Sea Bed Morphology	Sand waves Lunate bed forms Other active bed forms Sea bed morphology outside of areas with prominent bed forms

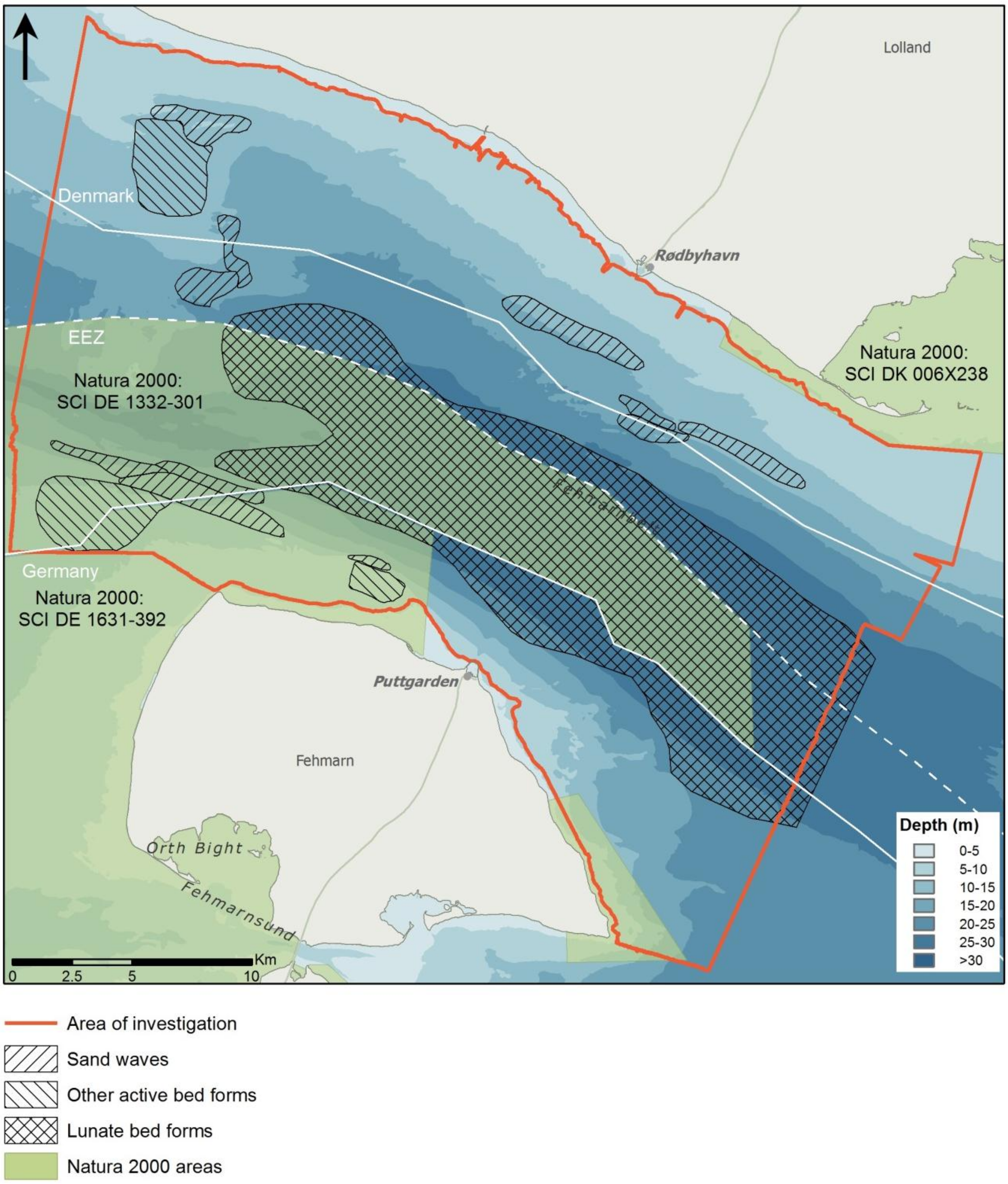

Figure 0.1 *Prominent bed forms in the Fehmarnbelt (from FEHY 2013a). The marine parts of the relevant Natura 2000 areas are shown. The "area of investigation" shows the area where prominent bed forms have been mapped*

0.2 *Assessment of impacts of main tunnel alternative*

Impacts on the sea bed morphology from the main tunnel alternative E-ME/August 2011 were assessed. The project pressures are the following:

- Removal of bed forms and sea bed by dredging activities for tunnel trench
- Structures (reclamations, protection reefs, work harbours)
- Access channel to production facility on Lolland
- Deposition of dredging spill

The areas of impacted sea bed and bed forms (four sub-components) were quantified by comparing the detailed mapping of the bed forms with respectively a) the size of the footprints of the trench/structures/access channel for the tunnel solution, b) calculated depositions of spilled material from (FEHY 2013d). The sensitivity of the sea bed components to the pressures were evaluated based on knowledge on the dynamics of bed forms from the literature and calculated rates of the natural transport of sea bed material along the sea bed (FEHY 2013a).

The impacted areas of the sub-components aggregated from the various sources of pressures are shown in Figure 0.2 to Figure 0.3 for loss and temporary impairments, respectively. A summary of the impacted areas sub-divided on sub-parts of the Fehmarnbelt is listed in Table 0.2.

Sea bed morphology is predicted to be impacted by pressures from the immersed tunnel project in a total area of 1,471 ha. The impacts are composed of 356 ha of loss of sea bed area mainly due to the reclamation and an area of 1,115 ha of impairments, where the sea bed will fully recover primarily within a time scale of 30 years, see Table 0.2.

Bed forms
Two potential pressures from the tunnel are causing the impacts on the bed form components: removal of the bed forms during dredging for construction (tunnel trench) and deposition of dredging spill. A total of 989 ha of bed forms (5 ha of sand waves and 984 ha of lunate bed forms – see Table 6.9) are impacted corresponding to 0.4% of the sand waves and 6.7% of the lunate bed forms within an area extending 10 km east and west of the alignment.

The impacts from both of these pressures are assessed to be of a temporary character as the sea bed will recover on a time scale in the order of 25-30 years or less. The trench will become fully backfilled as the transport of natural sea bed material will become trapped in the trench area. The bed forms will recover when they regenerate in the backfilled sea bed material and migrate across the area from the sides.

Deposited sediment spill material is trapped in the troughs of the bed forms. The fine sediment spill is expected to wash out of the bed form areas with time.

The time scales for recovery of the bed forms from both types of pressures are expected to be in the order of decades. For the lunate bed forms 15-30 years and for the large sand waves west of the alignment on the Danish side 30-40 years in the area where they are removed by dredging.

Sea bed outside areas with prominent bed forms

The pressures from the dredging for the tunnel trench, the reclamations and structures and from the access channel have impacts on the sea bed morphology in areas outside the bed form areas. A total area of 482 ha is impacted of which 356 ha are lost and 126 ha are impaired temporarily (see Table 6.9).

The sea bed is expected to recover to a natural state within 5 years after the structures for the temporary work harbour are removed/dismantled. In the area of the tunnel trench, the time for recovery of the sea bed is predicted to vary along the alignment between 1 and 18 years. The access channel to the production facility on Lolland is left open after end of construction, but will fill in naturally. The time scale for the sea bed to recover in the area of the channel is 5-30 years with the longest infill time nearest the Lolland reclamation, where the channel is wider and deeper.

The only sea bed areas lost due to construction of the tunnel are the areas of the permanent reclamations and protection reefs on the Lolland and Fehmarn sides.

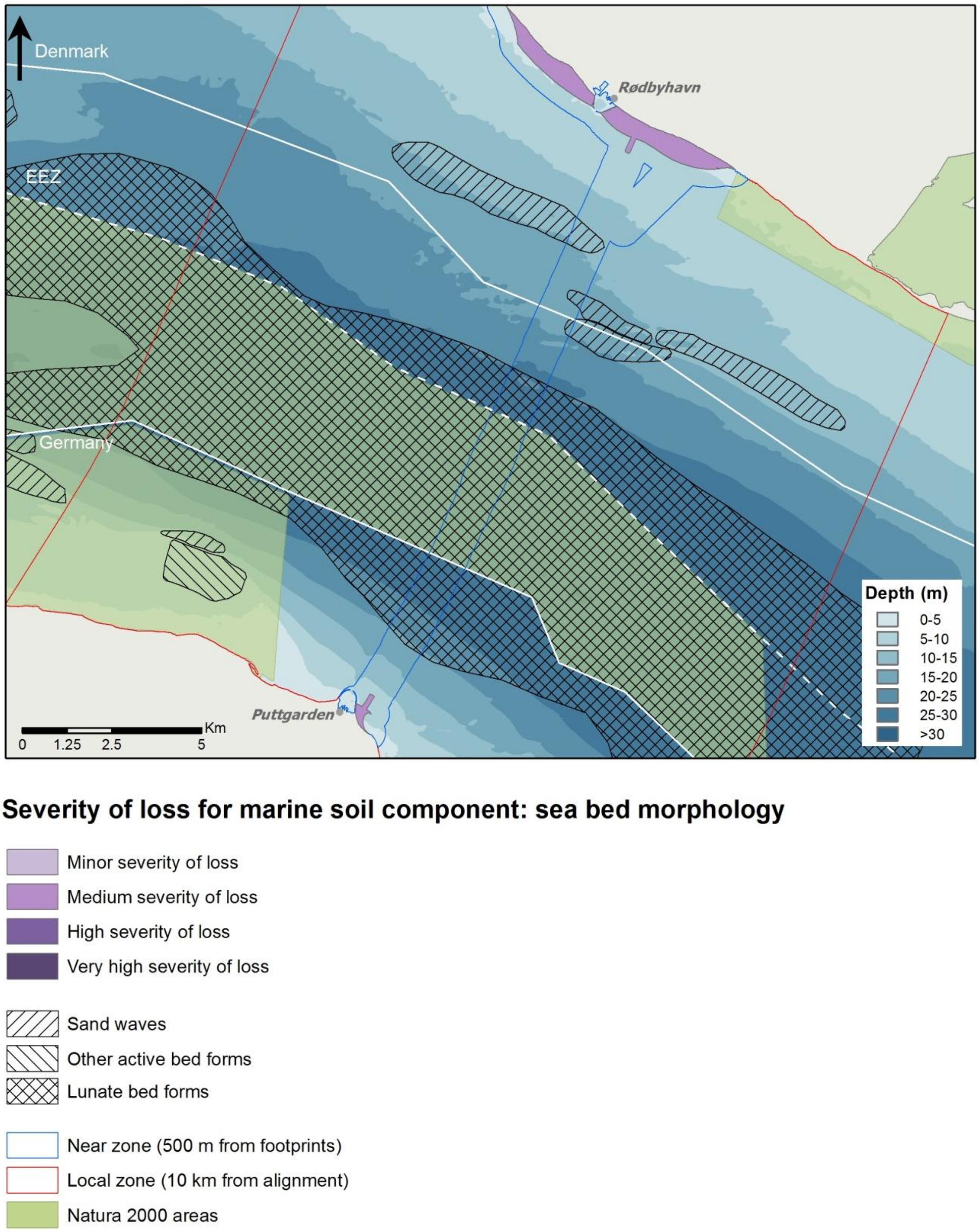

Figure 0.2 Severity of loss for main tunnel alternative E-ME/August 2011. Aggregated impacts from various sources of pressure. The marine parts of the relevant Natura 2000 areas are shown

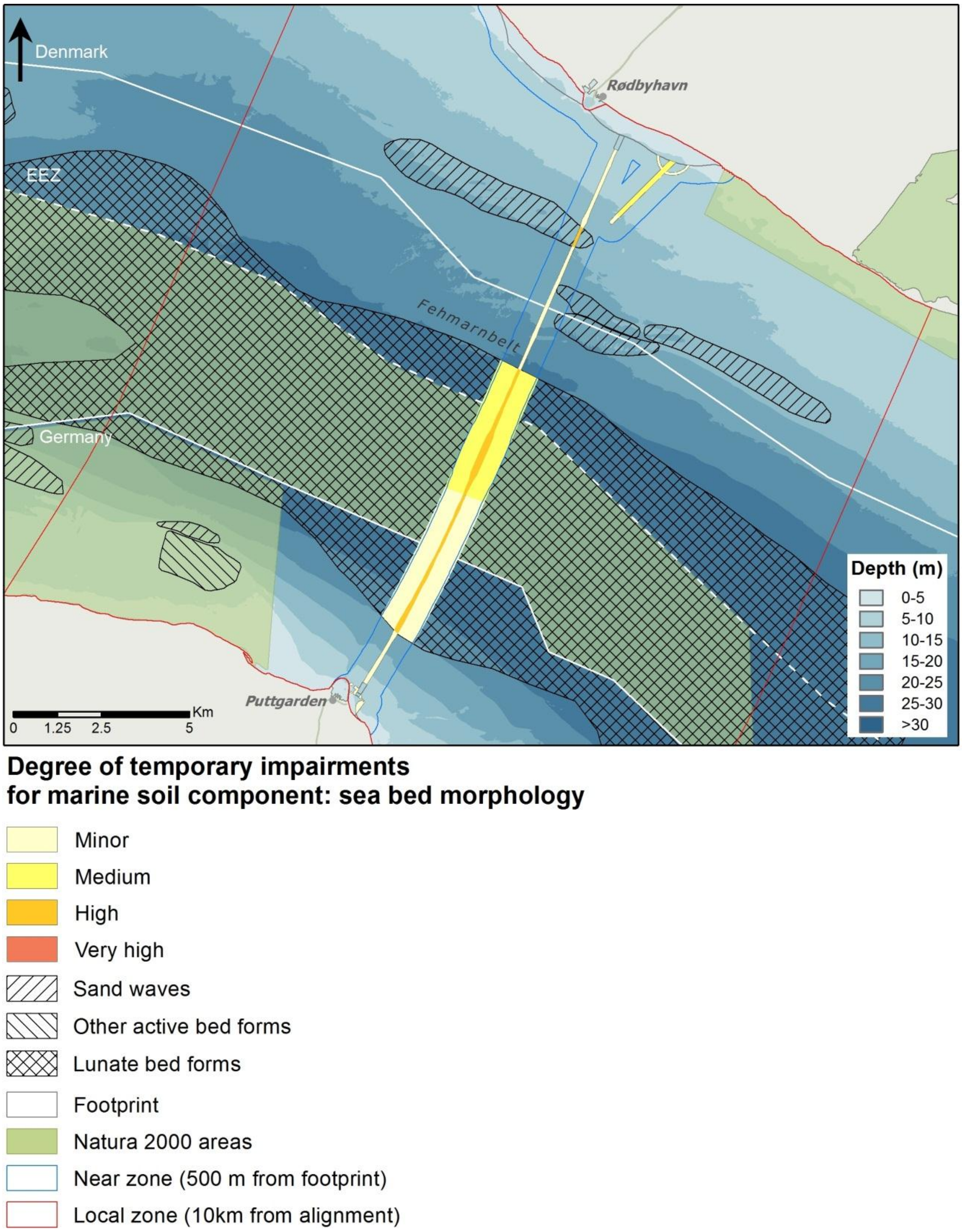

Figure 0.3 Degree of temporary impairments for main tunnel alternative E-ME/August 2011. Aggregated impairments from various sources of pressure. The marine parts of the relevant Natura 2000 areas are shown

Table 0.2 Summary of severity of loss and degree of impairments from the main tunnel solution (E-ME/August 2011) on sub-parts of the Fehmarnbelt. Parts of impacted areas (%) are provided as percentage of the given sub-areas (reference area). Parts of total impacted area (%) are provided as percentage of local 10 km zone + near zone.

Component:	**Sea bed morphology for tunnel E-ME (August 2011)**					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Permanent impacts: Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	0	0	0	0	0	0
Medium severity	356 (0.9%[1])	356 (11.8%)	0	335	21	0
Minor severity	0	0	0	0	0	0
Total permanent impacts	356 (0.9%)	356 (11.8%)	0	335	21	0
Temporary impacts: Temporary impairments						
Very high impairment	0	0	0	0	0	0
High impairment	103 (0.2%)	103 (3.4%)	0	15	56	30
Medium impairment	442 (1.1%)	389 (12.9%)	53 (0.1%)	172	0	270
Minor impairment	570 (1.4%)	431 (14.3%)	139 (0.4%)	72	303	195
Total temporary impacts	1,115 (2.7%)	923 (30.6%)	192 (0.5%)	256	359	495
Maximum period of temporary effects (years)	40	40	30	40	30	30
Total – permanent and temporary impacts	1,471 (3.6%)	1.279 (42.4%)	192 (0.5%)			
Reference area (ha)	41,446	3,019	38,427	-	-	-

0.3 Assessment of impacts of main bridge alternative

Impacts on the sea bed morphology from the main bridge alternative Variant 2 B E-E/October 2010 were assessed. The pressures are:

- Structures (piers/pylons, temporary work harbours, peninsulas incl. new beaches)
- Changes in the near bed currents
- Deposition of dredging spill

The areas of impacted sea bed and bed forms (four sub-components) were quantified by comparing the detailed mapping of the sea bed components with respectively a) the size of the footprints of the structures for the bridge solution, b) calculations of changes to the near bed currents due to bridge piers and pylons from (FEHY 2013e), c) calculated depositions of spilled material from (FEHY 2013d). The sensitivity of the sea bed components to the pressures was evaluated based on knowledge on the dynamics of bed forms from the literature and calculated rates of the natural transport of sea bed material along the sea bed (FEHY 2013a).

The impacted areas of the sub-components aggregated from the various sources of pressures are shown in Figure 0.4-Figure 0.6 for loss, permanent and temporary impacts, respectively. The total areas, where impacts on the bed forms are predicted, are summarised and divided in sub-areas in the Fehmarnbelt in Table 0.3.

A total of 4,292 ha will be lost/impaired by the main bridge solution. The area is composed of 56 ha of loss of sea bed due to structures on the sea bed and an area of 4,236 ha, where the sea bed will be impaired (4,216 ha permanently impaired, 20 ha is only temporarily impaired - see Table 0.3). Within the majority of the impaired area, the bed forms will increase in size primarily due to increase in the near-bed currents. The bed forms will, however, remain in the area and the overall morphology and dynamics of the bed forms will not change.

Bed forms
The impacts on the bed form components are caused by the following project pressures: removal of the bed forms during dredging for construction (piers/pylons), changes in the near bed currents and deposition of dredging spill. A total area of 4,229 ha of bed forms is impacted of which 3,989 ha are within 10 km from the alignment and 240 ha are further away. The area is composed of 594 ha of sand waves, 3,436 ha of lunate bed forms and 199 ha of other active bed forms (Table 7.6). 24.5% of the bed forms (3,989 ha out of 16,293 ha, Table 3.1) within 10 km east and west of the alignment are assessed to be impacted.

Piers and pylons will cause a loss of bed forms in areas corresponding to their footprints (structure dimension and scour protection around).

Changes in the near bed current field affect mainly the bed forms by permanently changing (primarily increasing) their geometrical properties (height and length). Locally near the piers and pylons, a variety of bed forms will occur (bed forms higher/lower than in the surrounding area, small-scale ripples, scour holes near the protecting stone layer around the structures) or plane bed will occur due to increase in current speeds and increased turbulence levels. The impact of the sediment spill is similar to the situation for the tunnel case, but much less sediment spill is expected for the bridge solution than for the tunnel solution. The spill is expected to wash out with time such that the bed forms return to their baseline conditions.

The impacted areas due to changes in the current speeds are considerably larger than the areas impacted by dredging for the bridge piers/pylons. The impacts on the bed forms caused by the changed currents are permanent but for the vast majority of the area, the impact on the bed forms is assessed to be of a minor degree of impairment. The bed forms will remain in the area and the sea bed will maintain the overall dynamics and morphology; see also the description above. Impacts from deposition of sediment spill only affect an area close to the centre pylon temporarily. The impact is classified with minor severity.

Sea bed outside areas with prominent bed forms
Structures (work harbour, peninsulas and piers/pylons) will cause potential impacts on 63 ha of the sea bed morphology in areas outside the bed form areas. Permanent structures cause a loss of natural sea bed. The sea bed in the areas of the temporary structures is assessed to recover to a natural state in less than 5 years. Pressures from changes in the near bed currents and dredging spill are assessed to have only insignificant effects on the sea bed morphology outside the bed form areas.

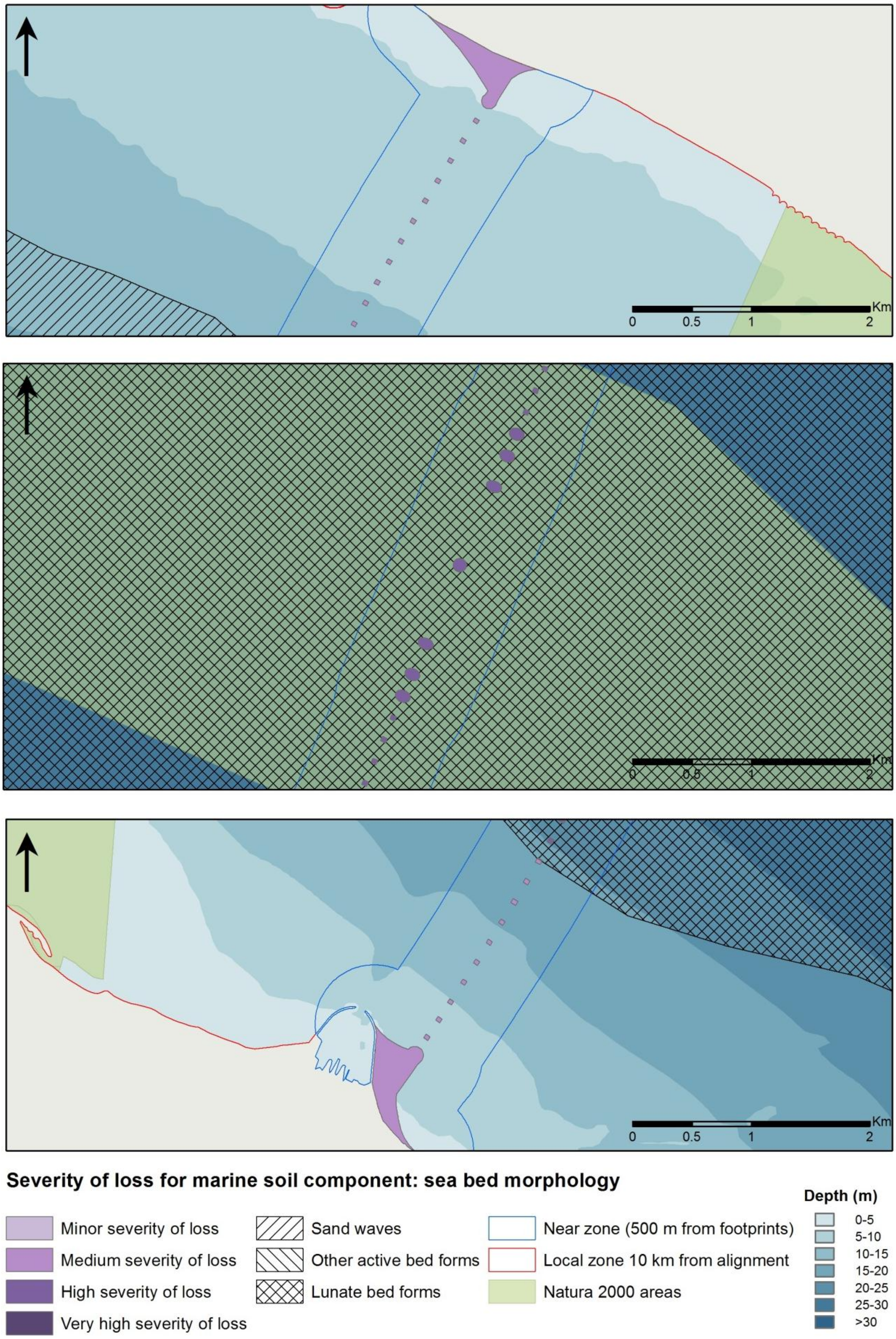

Figure 0.4 Severity of loss for main bridge solution. Aggregated impacts from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown

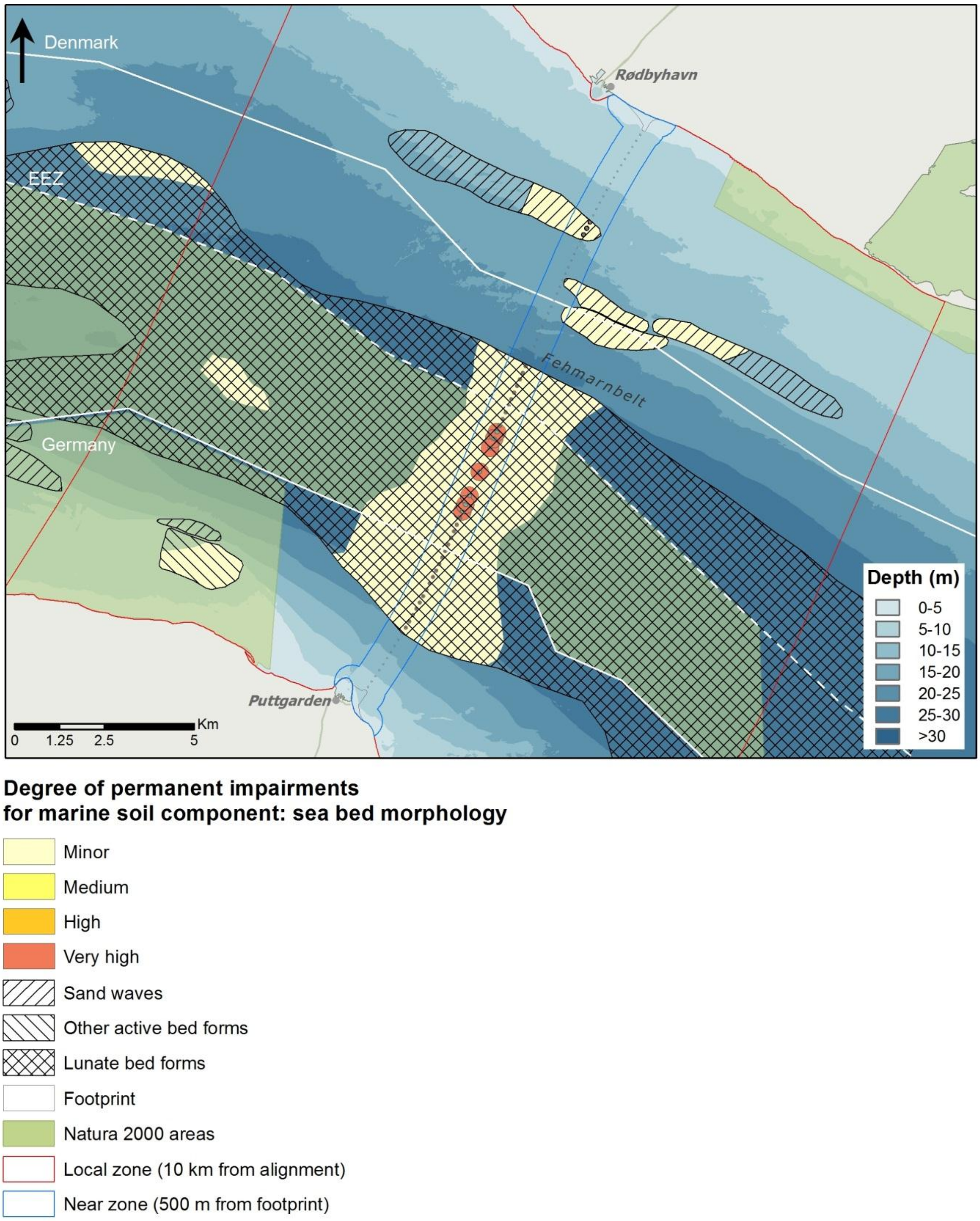

Figure 0.5 Degree of permanent impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown

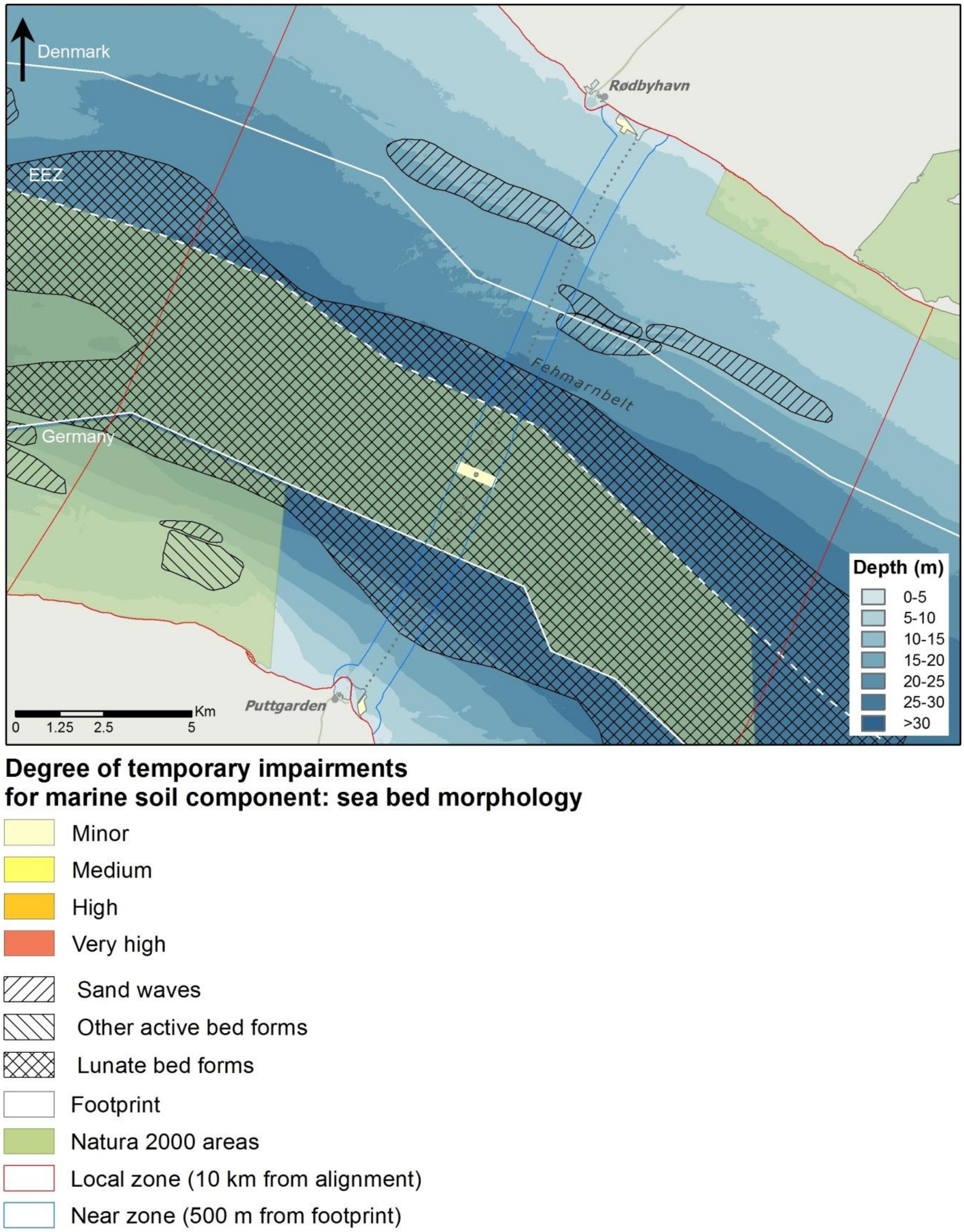

Figure 0.6 *Degree of temporary impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown*

Table 0.3 *Summary of severity of loss and degree of impairments from the main bridge solution (Variant 2 B E-E/October 2010) on sub-parts of the Fehmarnbelt. Parts of impacted areas are provided as percentage (%) of the given sub-areas (reference areas). Parts of total impacted area, excluding impacts outside of local zone+near zone, are provided as percentage (%) of sea bed area within local zone + near zone (reference area)*

Component:	**Sea bed morphology for bridge Variant 2 B E-E/October 2010**					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Permanent impacts: Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	13 (0.03%)	13 (0.03%)	0	2	2	9
Medium severity	43 (0.1%)	43 (0.1%)	0	22	22	0
Minor severity	0	0	0	0	0	0
Total	56 (0.1%)	56 (2.7%)	0	24	24	9
Permanent impairments						
Very high impairment	128 (0.3%)	128 (6.2%)	0	9	12	107
High impairment	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0
Minor impairment	4,088[1] (9.3%)[2]	817 (39.8%)	3,032[1] (7.7%)[2]	1,275	1,560	1,253
Total	4,216[1] (9.6%)[2]	944 (46.0%)	3,032[1] (7.7%)[2]	1,284	1,572	1,360
Total permanent impacts	4,272[1] (9.7%)[2]	1,000 (48.7%)	3,032[1] (7.7%)[2]	1,308	1,596	1,369

Continues next page

Table 0.3 Continued from previous page

Component:	Sea bed morphology for bridge Variant 2 B E-E/October 2010					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Temporary impairments						
Very high impairment	0	0	0	0	0	0
High impairment	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0
Minor impairment	57[3] (0.1%)	54[4] (2.6%)	3[5] (0.01%)	11	9	37[3]
Total temporary impacts	57[3] (0.1%)	54[4] (2.6%)	3[5] (0.01%)	11	9	37[3]
Maximum period of temporary effects (years)	30	30	30	5	5	30
Total impacted area. (Permanent + temporary)	4,292[1] (9.8%)[2]	1,020 (49.7%)	3,032[1] (7.7%)[2]			
Reference area (ha)	41,446	3,019	38,427			

[1]includes 240 ha outside local and near zone, [2]percentage of impacted area within local zone+near zone; i.e. excludes 240 ha of impacted area outside of this area. [3]37 ha overlaps with the permanently impaired area with a minor impairment classification,[4]34 ha overlaps with the permanently impaired area with a minor impairment classification,[5]overlaps with the permanently impaired area with a minor impairment classification

0.4 Comparison of bridge and tunnel alternatives

The cable stayed bridge alternative impacts a larger part of the sea bed in the Fehmarnbelt than the immersed tunnel alternative, see comparison in Table 0.4.

The bridge is assessed to impact a total of 4,292 ha of which 4,052 ha are within 10 km from the alignment. 9.8% of the sea bed within 10 km from the alignment is impacted. The tunnel impacts a total of 1,471 ha corresponding to 3.6% of the sea bed within 10 km from the alignment.

The nature of the impacts from the bridge project differs from the impacts from the tunnel project. The impacts related to the bridge are primarily current-induced changes causing the heights/lengths of the bed forms to increase by 10-25%. These changes are permanent, but due to the character of the impacts classified with a minor severity.

The changes from the tunnel project are mainly related to the dredging activities by which some bed forms will be removed during the dredging for the tunnel trench and some will be affected by deposition of dredged sea bed material. These impacts will be of a temporary character since the bed forms are predicted to recover in less than 30-40 years. The majority of these temporary impairments are classified as having a minor or medium severity. The impacts from the bridge are therefore to a higher degree permanent, while the impacts from the tunnel are primarily temporary impacts.

The total loss of sea bed is, however, smaller for the bridge than for the tunnel. This is primarily due to the large reclamation on the Danish side in case of the tunnel.

For both projects, however, only very limited areas are impaired to a high or very high degree. For the immersed tunnel project these account for 103 ha and for the cable stayed bridge project 128 ha are impaired with high or very high degree of impairment. In the baseline study, the influence of the bed forms on the current field and flow through the Fehmarnbelt was found to be insignificant (FEHY 2013a). The above-mentioned changes to the bed forms in either project do not change this situation.

In conclusion, the impacts from the bridge project as well as the tunnel project are assessed as insignificant for the marine soil component sea bed morphology. The differences in the impacted areas as well as the difference in the character of the impacts from the projects do not lead to one or the other project being the preferred option based on the impacts on sea bed morphology. Table 0.5 summarises the comparison of the immersed tunnel and cable stayed bridge.

Table 0.4 Comparison of impacts for immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridge (main alternative Variant 2 B E-E/October 2010)

Component:	**Sea bed morphology**	
	Immersed tunnel E-ME/August 2011	**Cable stayed bridge Variant 2 B E-E/October 2010**
	Total area (ha) (Part of area, %) [1]	**Total area(ha) (Part of area, %)** [1]
Severity of loss		
Very high	0	0
High	0	13
Medium	356	43
Minor	0	0
Total loss	356	56
% of local + near zone	0.9%	0.1%
Degree of permanent impairments		
Very high impairment	0	128
High impairment	0	0
Medium impairment	0	0
Minor impairment	0	4,088[2]
Total permanent impairments	0	4,216[2]
% of local + near zone	0%	9.6%[3]
Degree of temporary impairments		
Very high impairment	0	0
High impairment	103	0
Medium impairment	442	0
Minor impairment	570	57[4]
Total temporary impair-Ments	1,115	57[4]
% of local +near zone	2.7%	0.1%
Total temporary and permanent impacts	1,471	4,292[2]
% of local + near zone	3.6%	9.8%[3]

[1] Part of area (%) refers to part of impacted sea bed area within the area of the local 10 km zone + near zone, [2] including 240 ha outside the local 10 km zone. [3]percentage of impacted area within local zone+near zone; excludes 240 ha of impacted area outside of this area, [4]37 ha overlaps with the permanently impaired area with a minor severity classification

Table 0.5 *Comparison matrix of impacts from Immersed tunnel and Cable stayed bridge. For each factor is the relatively environmentally best alternative 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**	
Sand waves	Insignificant temporary effects due to construction/dredging for tunnel trench	0	Insignificant permanent effects on sand waves due to changes to currents caused by bridge structures. Insignificant loss of sand waves caused by bridge structures	0
Lunate bed forms	Insignificant temporary effects due to construction/dredging for tunnel trench	0	Insignificant permanent effects on lunate bed forms due to changes to currents caused by bridge structures. Insignificant loss of lunate bed forms caused by bridge structures	0
Other active bed forms	No impacts	0	Insignificant permanent effects on other active bed forms due to changes to currents caused by bridge structures	0
Sea bed outside areas with prominent bed forms	Insignificant temporary effects due to construction/dredging for tunnel trench and work harbours. Insignificant loss of sea bed due to construction of land reclamations. Insignificant temporary effects due to work harbours	0	Insignificant loss of sea bed caused by bridge structures. Insignificant temporary effects due to work harbours	0
Total – sea bed morphology	No significant impacts Insignificant temporary impacts on sea bed morphology (including bed forms) primarily due to construction/ dredging for tunnel trench and access channel. Insignificant loss of sea bed	0	No significant impacts Insignificant permanent effects on sea bed morphology (bed forms) due to changes to currents caused by bridge structures. Insignificant loss and temporary effects	0

1 INTRODUCTION

1.1 Environmental theme

An infrastructure project like the Fehmarnbelt project will unavoidably have some impact on the sea bed morphology due to the construction of large physical structures on the sea bed and dredging of sea bed material in relation to the construction.

In some areas, the sea bed morphology will be impacted by these structures, temporarily or permanently. The present report maps these areas and the impacts affecting them.

This report deals with the impacts on the sea bed morphology. The sea bed forms are the result of interaction between loose sediments on the sea bed and the flow above the sea bed. Other morphological elements, such as reefs, are usually areas under erosion where coarser materials such as stones and other hard substrates occupy larger parts of the sea bed. Such reefs may constitute important habitats for benthic flora and fauna. Reefs are therefore considered a biotope in relation to the EIA for the Fehmarnbelt Fixed Link and mapping and assessment of reefs are hence not treated along with the dynamic sea bed morphology in this report, but as a part of the marine biology in (FEMA 2013a).

Morphological features and landscape related to the coastal processes in the nearshore zone, such as for instance sand bars in the coastal profile as well as the special morphological features such as Grüner Brink on Fehmarn and the Hyllekrog/Rødsand formations on the Danish side, are treated in the report related to coastal morphology (FEHY 2013f).

Large areas of the Fehmarnbelt are covered by dynamic and morphologically active bed forms. They mainly occur as larger undulations of the sea bed on the slopes of the bottom, where the water depth typical is in the range 10-20 m, and as smaller undulations in the deeper areas.

The bed forms were studied extensively. The primary purposes for the interest in the bed forms in relation to the EIA for the Fehmarnbelt are:

- Parts of the bed forms are part of the conservation objectives within environmentally protected Natura 2000 areas

- The bed forms are special morphological features and contribute as such to the diversity of the sea bed in the Fehmarnbelt

- The bed forms impose resistance on the flow field

The mapping of the bed forms in the Fehmarnbelt is carried out as part of the baseline study (FEHY 2013a), see Figure 1.1. In the baseline study it is concluded that the effect of bed forms on the flow through the Belt is very small. The potential effect on the flow resistance due to changes to the bed forms by the link (the last bullet above) has therefore not been further investigated.

Two main types of bed forms were found on the sea bed of the Fehmarnbelt: **sand waves** and **lunate bed forms**. Sand waves are large-scale flow-transverse ridges of sand, i.e. the crests of the sand waves are flow transverse, but may also be inclined at an angle to the main flow direction where there is a gradient in the flow. Lunate bed forms are 3D in their nature and have lunate shape with the "arms" pointing in the direction of the Baltic Sea. They consist of loose sediment (fine sand) on an otherwise more or less immobile bed. The two main types cover most sea bed features but other less characteristic large-scale forms exist which clearly indicate that the flow over loose sediments on the sea bed is strong enough to cause movement of sand grains and formation of rhythmic features. Such bed forms are identified as "**other active bed forms**".

Such bed forms are impacted by changes to the transport capacity of loose sea bed sediment. The bed forms are formed and maintained in their shape and geometry by this transport of sea bed material.

Sediment transport occurs only during events with high current speeds, which are typically related to passing of low-pressure systems 2-5 times a year. The sea bed morphology is dynamic and the bed forms migrate by erosion and deposition processes. Erosion from the upper layer of sediment on the upstream side and deposition on the downstream side make the bed forms migrate in the order of 1-5 m/event in the direction of the near-bed flow, i.e. they migrate either towards the Baltic Sea or towards the Kattegat during such events depending on the nearbed currents. On an annual basis, the net migration of the bed forms is in the direction of the primary sediment transport direction towards the Baltic Sea.

During each event the bed forms may slightly reshape as they migrate. The migration rates are small compared to the length of the bed forms and the overall evolution and changes of the bed forms are caused by the integrated effect of sediment transport during many events and therefore takes place on a time scale of years. For a further description of the bed forms, see FEHY 2013a.

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 1 January).

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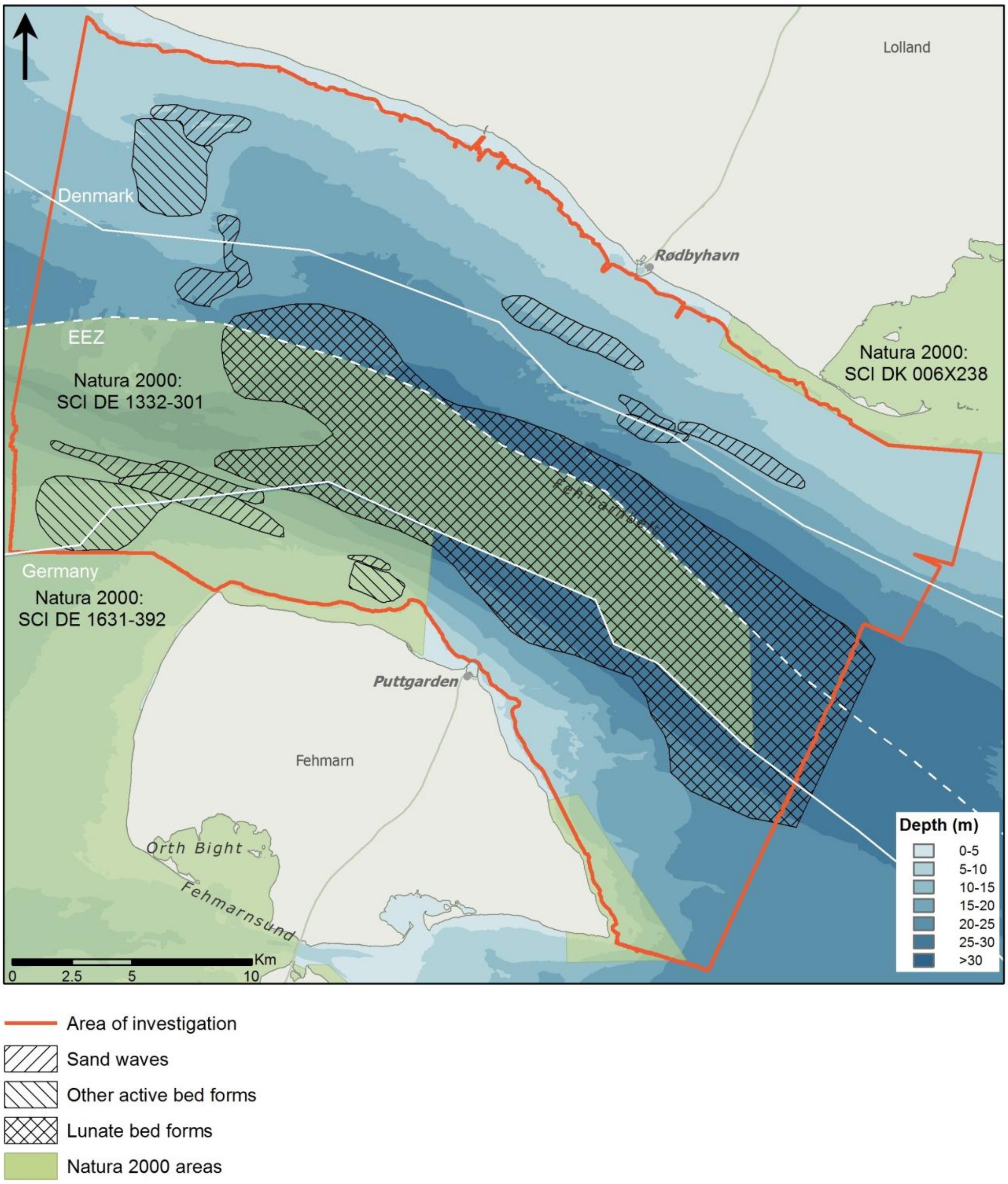


Figure 1.1 The bed form classification map. The marine parts of the relevant Natura 2000 areas are shown. The area of investigation shows the area where prominent bed forms have been mapped.

1.2 Environmental components assessed

Sea Bed 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 Sea Bed Morphology. These include the three types of special bed forms described above and the general sea bed morphology outside these areas. Only large-scale morphologically active bed forms of the sea bed are treated.

Morphological features on the sea bed closer to the coast than the 6 m DVR90 depth contour are described in the impact assessment related to coastal morphology (FEHY 2013f). This accounts for near-shore bars and special morphological features such as the Grüner Brink formation on the Fehmarn coast.

Sea bed sediment is not assessed as a separate environmental component. Impacts from the project will not change the composition of the sediment to a degree where the geomorphological processes are influenced, see discussion in Section 2.2.

The influence of deposition of spill of sea bed material from the dredging activities on the surface sea bed material is treated in (FEHY 2013d).

Table 1.1 Marine area Factor Soil with Sub-factors and components. Sea bed 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 Sea Bed Morphology with sub-components

Component	Sub-components
Sea Bed Morphology	Lunate bed forms Sand waves Other active bed forms Sea bed morphology outside of areas with (larger and) prominent bed forms

2 THE FEHMARNBELT FIXED LINK PROJECT

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.

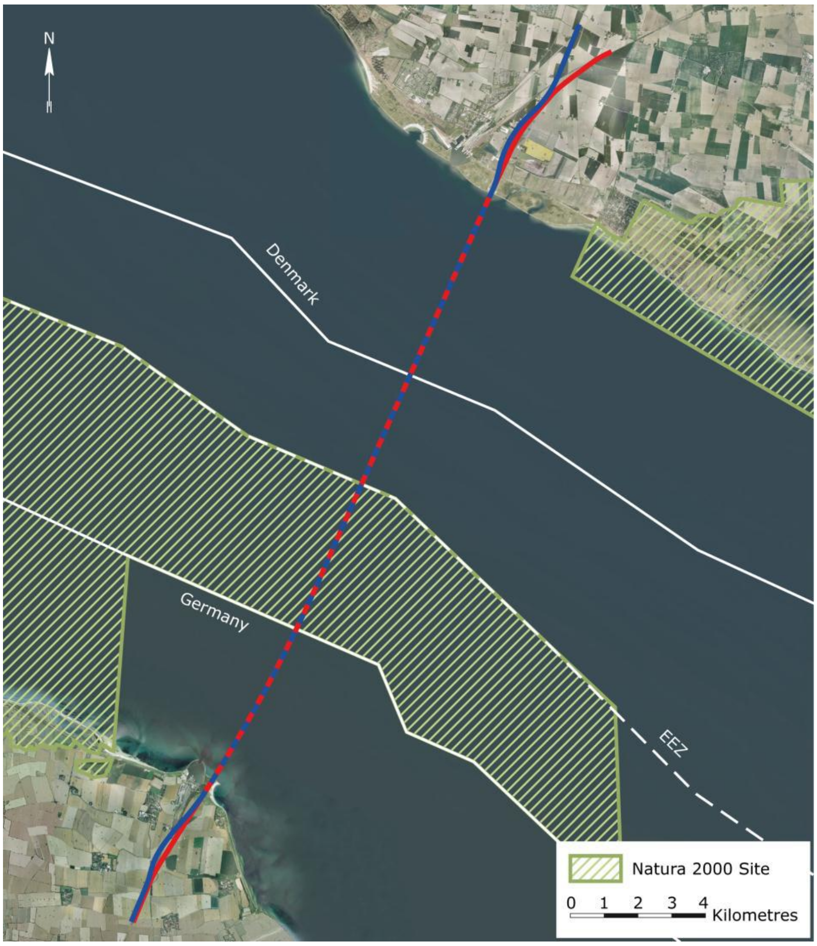


Figure 2.1 Proposed alignment for immersed tunnel E-ME (August 2011)

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.

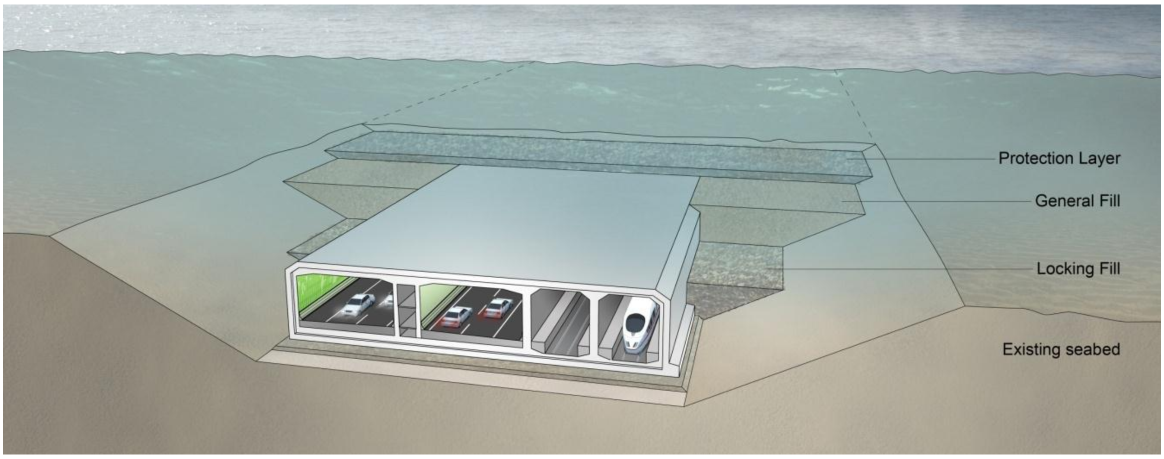


Figure 2.2 Cross section of dredged trench with tunnel element and backfilling

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.

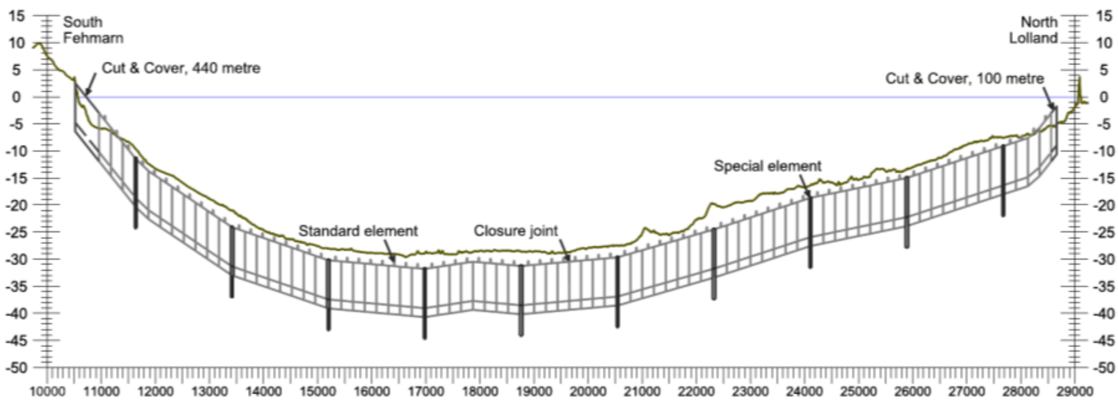


Figure 2.3 Vertical tunnel alignment showing depth below sea level

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.

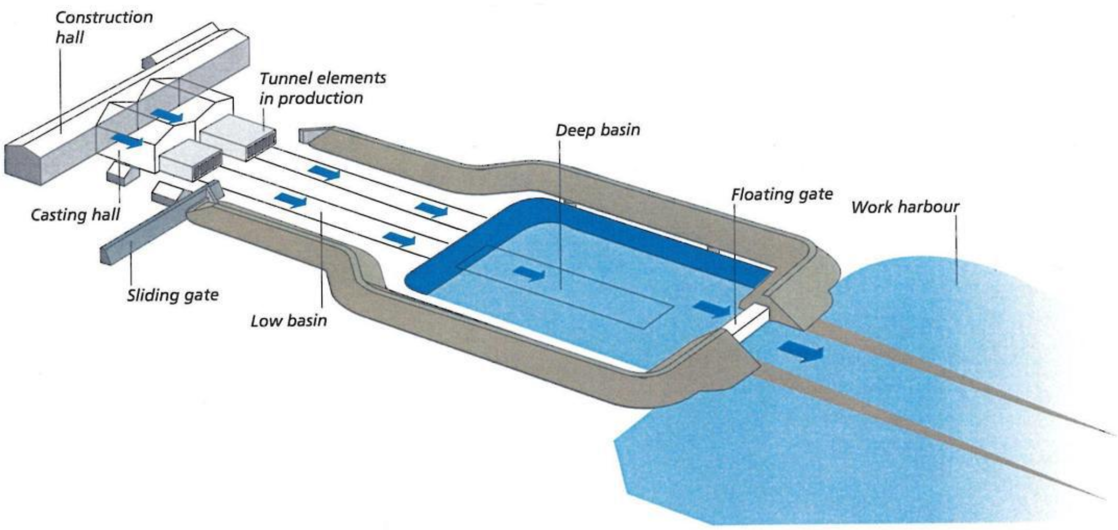


Figure 2.6 Production facility with two production lines

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.

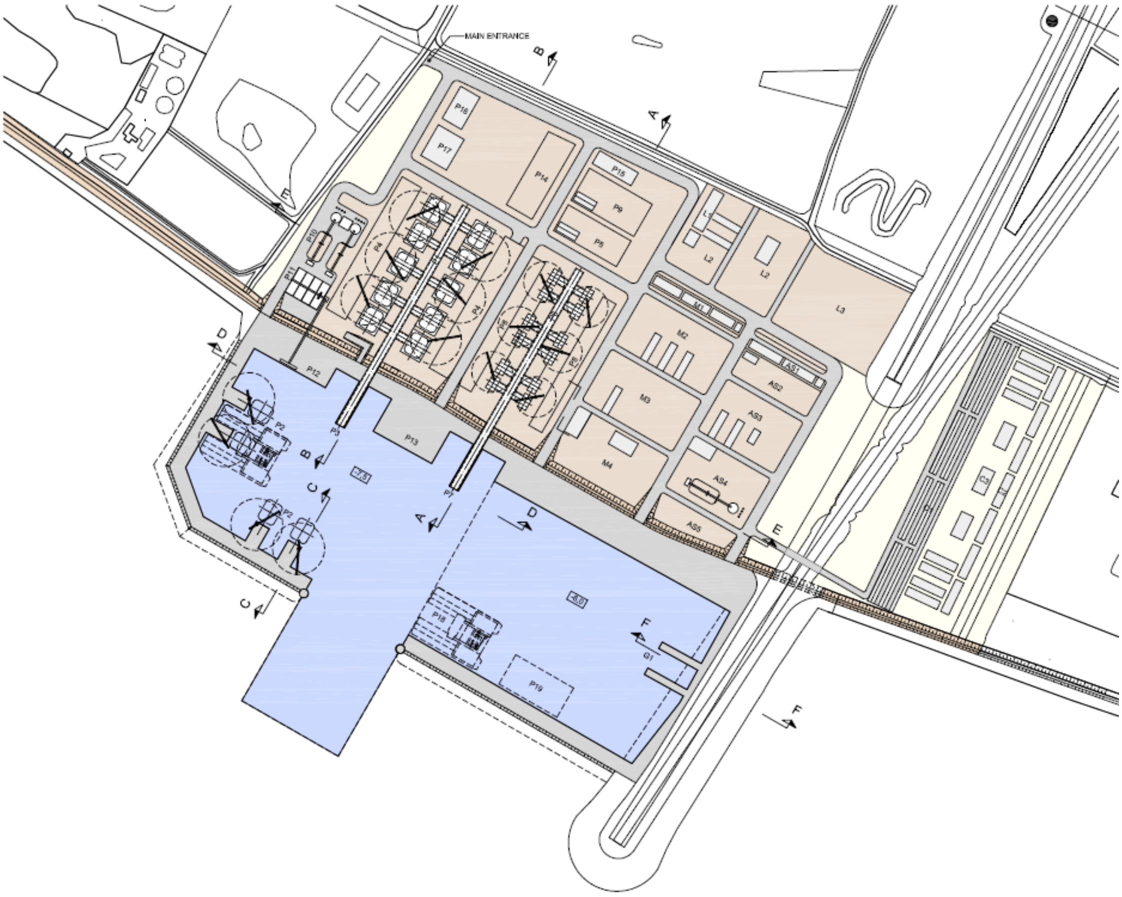


Figure 2.10 Proposed lay-out of the production site at Lolland east of Rødbyhavn

2.2 Relevant project pressures

The project pressures for sea bed morphology are related to the construction of the structures and the temporary/permanent structures. A project pressure is defined as features related to the tunnel or bridge that constitutes an impact on the investigated issue, i.e. in this report the sea bed morphology.

The pressures and potential impacts are discussed below for the tunnel and the bridge project, respectively.

Of relevance for sea bed morphology is considered only project pressures, which have an impact on the sea bed morphology at the end of the construction period. Deposition of sediment from dredging activities, which is resuspended and carried out of the area of investigation at the time the construction has ended, is not considered relevant for sea bed morphology, since the time-span of influence is small compared to the dynamics of the sea bed. Areas of the temporary footprints, which will be integrated into the permanent structures at the end of the construction period, are also not assessed separately during the construction period.

2.2.1 Project pressures for the main tunnel alternative

The pressures from the immersed tunnel E-ME/August 2011 are partly related to the actual removal/disturbance of the natural sea bed and partly to the sediment deposition caused by the dredging operations for structures, the tunnel trench and the work harbours. The pressures and the associated potential impacts are summarised in Table 2.1.

The impacts caused by the structures are related to the occupancy of sea bed area by the structures (pressure 2-3) and/or to the disturbance of the sea bed caused by dredging for the structures (pressure 1 and 4). The actual sizes of the disturbed areas are indicators for the magnitude of the pressure they impose on the sea bed.
The depositions of sediment spill in the areas of sea bed forms can reduce the heights of the bed forms or add to the volumes of such bed forms. The deposition depths are a measure for the impact on the bed forms.

Deposition of sea bed material from dredging activities is assessed to have no impact on the sea bed morphology outside areas with prominent bed forms. Results from the spill simulations in (FEHY 2013d), show that most of the fine sediments are resuspended from the sea bed in the Fehmarnbelt before the end of construction and carried to areas with a calmer hydrographic environment where deposition is possible. The added volume of loose sea bed material from the dredging activities is too small for prominent bed forms to generate from this material. Sea bed material from the dredging operations will therefore increase the natural sediment transport in these areas (until it is eventually washed away from the area and distributed over a large area with time); a change in the state of the sea bed morphology of these areas is not expected due to this and to temporarily slight change in sediment composition and sediment transport. In the areas with prominent bed forms, the sea bed is more dynamic and some influence of the deposited sea bed material cannot be excluded prior to assessment.

Only insignificant changes to the current field from the tunnel solution are expected (FEHY 2013e). The minor changes that may occur are mainly near the reclamations and scour protection around these on the coast and will not affect the sea bed morphology.

Table 2.1 *Project pressures for component Sea Bed Morphology in the case of the main alternative of the tunnel*

Project Features	Comprising	Environmental pressure	Potential impacts
Permanent structures	Immersed tunnel	**Pressure 1:** Tunnel trench for immersed tunnel (horizontal footprint and depth at end of construction)	Removal of lunate bed forms and sand waves. Recovery. Removal of natural sea bed area without prominent bed forms. Recovery.
	Reclamations and protection reefs	**Pressure 2:** Reclamations and protection reefs (horizontal footprints)	Removal of natural sea bed area. Loss
Construction areas offshore	Offshore construction sites, including temporary harbours and storage areas	**Pressure 3:** Temporary work harbours and storage areas (horizontal footprint)	Removal of natural sea bed area. Recovery.
	Access channel to production facility on Lolland	**Pressure 4:** Access channel to production facility on Lolland (horizontal footprint and depth at end of construction)	Removal of natural sea bed area. Recovery
	Excavation of tunnel trench Deposition of excavated material (reclamations at Lolland and Fehmarn coasts)	**Pressure 5:** Deposition of sea bed material from dredging activities	Impacts to geometry and sediment composition of lunate bed forms, sand waves and other active bed forms. Recovery depending on deposition depths

2.2.2 *Project pressures for the main bridge alternative*

The pressures from the Cable Stayed Bridge Variant 2 B E-E/October 2010 are related to the permanent or temporary structures and to the sediment deposition caused by the dredging operations for these structures. The pressures and the associated potential are summarised in Table 2.2.

The impacts caused by the permanent structures (the piers/pylons and the peninsulas at the land falls) are partly related to the actual occupancy of sea bed area by the structures (pressure 1). The sizes of the sea bed areas occupied by the structures are indicators for the magnitude of the pressure. A derived effect of the structures is the changes they impose on the current field (pressure 2). Loose sea bed material along the sea bed is transported by the current, when the current speed exceeds a critical speed for mobility of the sea bed material depending on the grain sizes. The transport of loose sea bed material along the sea bed in the Fehmarnbelt therefore depends on the intensity of the current during events with relatively high current speeds and the duration of such events. The influence of the changes in the current is assessed by the changes in the near-bed current speeds, as these determine the mobility of sea bed material, which determine the sea bed morphology.

The depositions of sediment spill (pressure 3) in the areas of sea bed forms can reduce the heights of the bed forms or add to the volumes of such bed forms. The deposition depths are a measure for the impact on the bed forms. Outside areas with bed forms, the thicknesses of deposited sediment due to spill are so small that changes to sea bed morphology can be excluded, see discussion above.

The impacts caused by the temporary structures (the work harbours and storage areas, pressure 4) are the disturbance of the natural sea bed. As in the case of pressure 1, the actual size of the disturbed sea bed area is an indicator for the magnitude of the pressure.

Deposition of sea bed material from dredging activities is assessed to have no impact on the sea bed morphology outside areas with prominent bed forms, refer to discussion above.

Table 2.2 Project pressures for component Sea Bed Morphology in the case of the main alternative of the bridge

Project features	Comprising	Environmental pressure	
Permanent structures	Approach bridge and Main bridge	**Pressure 1:** Footprint for piers/pylons and peninsulas (horizontal footprint)	Removal of natural sea bed area. Loss
		Pressure 2: Changes in the near bed currents	Change of character of lunate bed forms, sand waves and other active bed forms if current speeds change to be outside regime for existence of present type of bed form Impacts to geometry of lunate bed forms, sand waves and other active bed forms
Temporary construction areas offshore	Establishment of peninsulas at Fehmarn and Lolland, dredging and deposition of material Excavations for caissons Dredging and backfilling of temporary access channels and harbours Backfilling around caissons and scour protection	**Pressure 3:** Deposition of sea bed material from dredging activities	Impacts to geometry and sediment composition of lunate bed forms, sand waves and other active bed forms. Recovery
	Work harbours and storage areas	**Pressure 4:** Temporary work harbours and storage areas (horizontal footprint)	Removal of natural sea bed area. Recovery

3 DATA AND METHODS

3.1 Area of investigation

3.1.1 Bathymetry

The investigated area in the baseline study and the impact assessment cover the area in the Fehmarnbelt shown in Figure 1.1.

The bathymetry of the Fehmarnbelt is also shown in Figure 3.1. Since the final retreat of glaciers from the South-Western Baltic area, the Fehmarnbelt has been characterised by highly variable sedimentary processes and environments (Novak and Björck 2002).

The Fehmarnbelt is part of a shallow transition area between the North Sea and the Baltic Sea, connecting the southern part of the Great Belt and the Kiel Bight to the west with the Mecklenburg Bight in the east.

3.1.2 Surface sediments

Figure 3.2 shows a substrate map of the Fehmarnbelt. According to this it is seen that the surface sediments on the sea bed on the Danish side (>-15 m) consist of sand and coarser sediments. The bed on the German side (>-15 m) also mainly consists of sand in the area west of Puttgarden and mainly of coarser sediment south-east of Puttgarden. In general, the sediment is finer on the German side than on the Danish side. At depths below -20 m the bed consists of sandy mud or thin sandy mud.

The current is the dominant mechanism in transporting material along the sea bed in the deeper part of the Fehmarnbelt. Waves act to increase the mobility of sediment in shallower areas and very near the coast also to drive a coastal current.

3.1.3 Sea bed forms

As mentioned in Section 1.1, a feature of the sea bed is the large scale bed forms. The characteristics of the bed forms in the Fehmarnbelt are summarised in Figure 3.1. The bed forms are described by their height, length and local maximum steepness. Their primary migration direction is also included in the figure. Where available, their migration rates are provided.

The areas of the three types of bed forms within 10 km from the alignment of the planned project are supplied in Table 3.1.

Table 3.1 Areas of bed forms within 10 km from alignment

Sand waves (ha)	Lunate bed forms (ha)	Other active bed forms (ha)	Total area of prominent bed forms (ha)
1261	14789	243	16,293

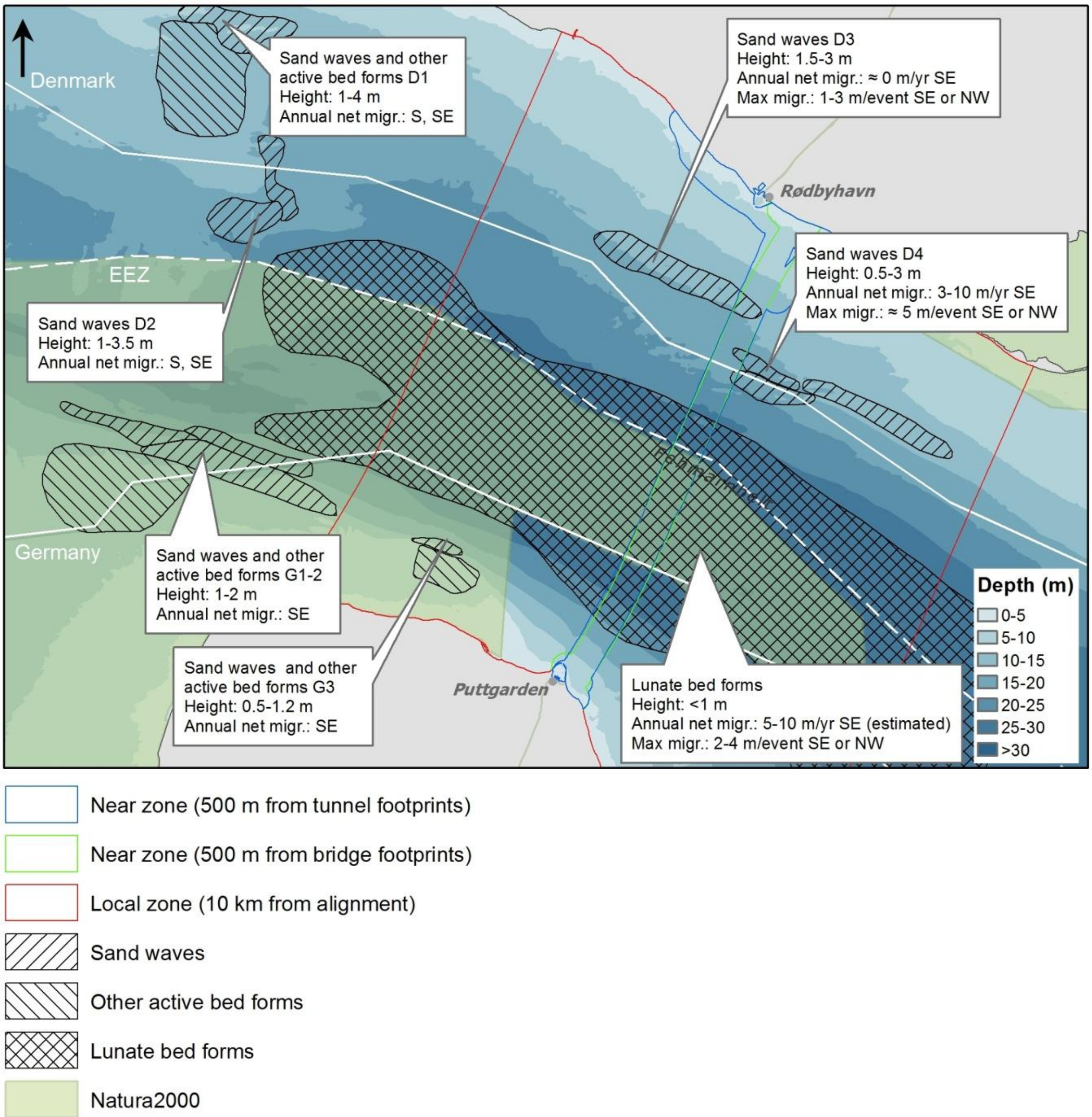


Figure 3.1 Investigation area in the Fehmarnbelt. Bathymetry and main bed form areas with their main characteristics. The maximum migration rates are related to events, which cause the bed forms to migrate in the direction of the current during the event (i.e. either SE or NW). Such events occur typically 2-5 times a year and last approximately 2 days. (note: D1-D4 and G1-G3 refer to sub-areas used for the detailed classification). Migration rates of the bed forms are based on calculations of annual sediment transport rates representative for the alignment area only. From (FEHY 2013a)

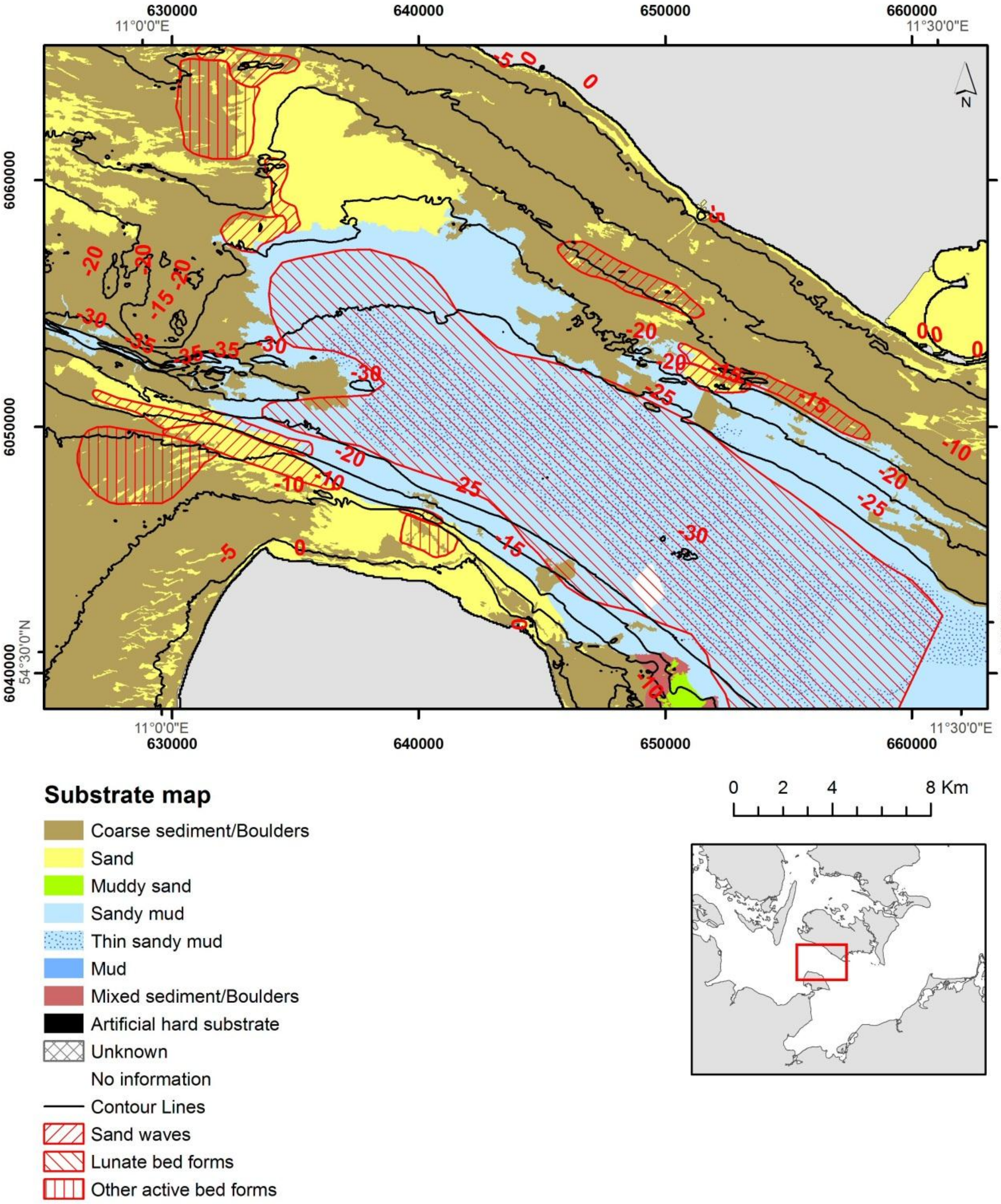


Figure 3.2 Substrate map based on backscatter analysis from multibeam echo soundings 2009

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.	Belastnings-størrelse	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.	Vurderings-kriterier og graduering	Bewertungs-kriterien 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.		

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 3.3 - Figure 3.5. 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 3.2 and Table 3.3, respectively.

Table 3.2 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 3.3 (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 3.3 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 3.4.

Table 3.4 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 3.3. 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 3.2).

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

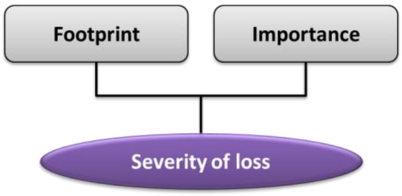


Figure 3.3 The assessment scheme for severity of loss

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 3.4). 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.

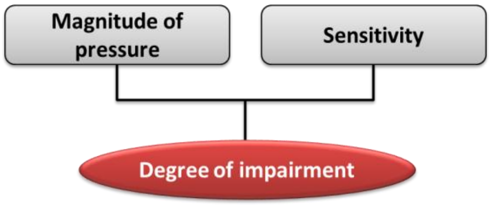


Figure 3.4 The assessment scheme for degree of impairment

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 3.5) using the matrix in Table 3.4.

Table 3.4 If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

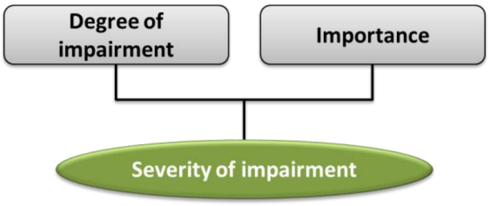


Figure 3.5 The assessment scheme for severity of impairment

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 3.6. 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.

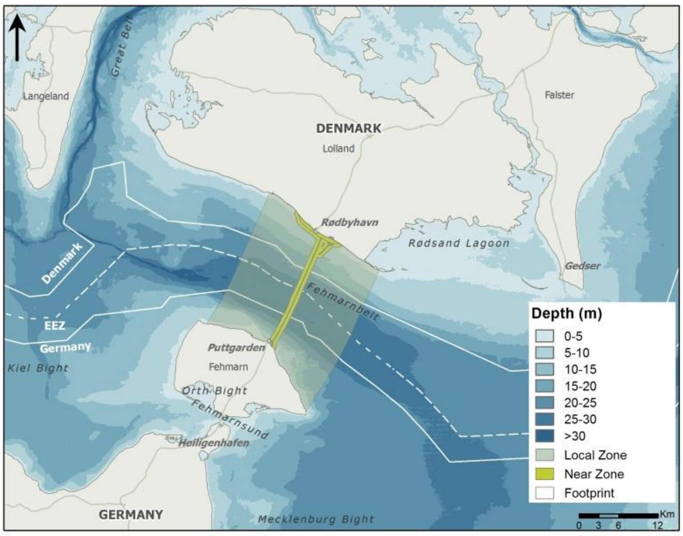


Figure 3.6 The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders 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 3.5 as a framework.

Table 3.5 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

It should be noted that in the background reports, the construction phase has been indicated by exact years (very late 2014-2020 (tunnel) and early 2014-2020 (bridge). As the results are generic and not dependent on the periodization of the construction phase, the years are in the VVM and the UVS indicated as calendar year 0, year 1, etc. This means that the construction of the tunnel starts in Year 0 (only some initial activities) and the bridge construction commence in year 1.

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 lane	Guldborgsund to Rødbyhavn	Construction	Area loss, noise and dust
		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 Data and model results applied

The key datasets and model results applied in the assessment of the sensitivity of the sea bed morphology originate from the baseline study (FEHY 2013a) or from various other reports. They are shortly described below.

The quantification of the changes to the bed forms caused by the tunnel and the bridge project is based on these data and model results. The quantitative changes and recovery times (for temporary effects) are estimated to be correct within a factor of two, which corresponds to the general uncertainty in the estimation of sediment transport.

3.3.1 Maps and characteristics of the bed forms

Large scale bed forms in the Fehmarnbelt were mapped and described in details in the baseline study (FEHY 2013a). The mapping was based on a detailed echo sounding multibeam survey. A summarizing map was shown in Figure 3.1 above.

The geometrical properties of the bed forms (height, length, bed slopes) in the individual areas were derived. The annual migration speed (m/year) and their mobility were also evaluated as a part of the baseline study (see also Figure 3.1) based on calculations of the transport of sediment along the sea bed, see below.

3.3.2 Sediment transport rates

Annual transport rates of loose sea bed material were evaluated for a cross section in the alignment area for the fixed link in the baseline study (FEHY 2013a).

The annual gross and net sediment transport rates and sediment transport in each of the main directions of the flow - eastwards and westwards have been calculated, see Figure 3.7. All results are given in annual sediment transport volumes per m along the alignment between the Danish and the German coasts.

The transport rates were evaluated for a lower limit and an upper limit of the sediment grain size. Sediment transport rates are very sensitive to the grain size and this approach supplies information on the uncertainty in the calculated sediment transport rates.

The sediment transport rates were based on simulations of the 2005 hydrodynamic conditions. The year 2005 is a representative year for the typical hydrodynamic conditions in the Fehmarnbelt. Comparison of near-bed currents modelled for the period April-November for 2005 and 2009 showed that the eastwards current speeds were less dominating in 2009. 2009 showed a more even distribution between the main current directions, also during periods with higher current speeds. This indicates that in some years the westward transport rates may be larger than estimated for 2005 and net sediment transport rates may be smaller for these years. Note that due to asymmetry of the flow field in the in- and outflow situations from the Baltic Sea through the Fehmarnbelt, the maximum rates of transport towards the east and the west are not geographically located at the same positions along the alignment. The sum of the east and west transport components in Table 3.6 does therefore (correctly) not necessarily equal the gross transport.

Transport of sediment along the sea bed depends on complicated physical processes, which are only conceptually represented in sediment transport models for practical purposes such as MIKE21 ST, which was used in (FEHY 2013a). The general accuracy on sediment transport modelling in these models is within a factor of about two.

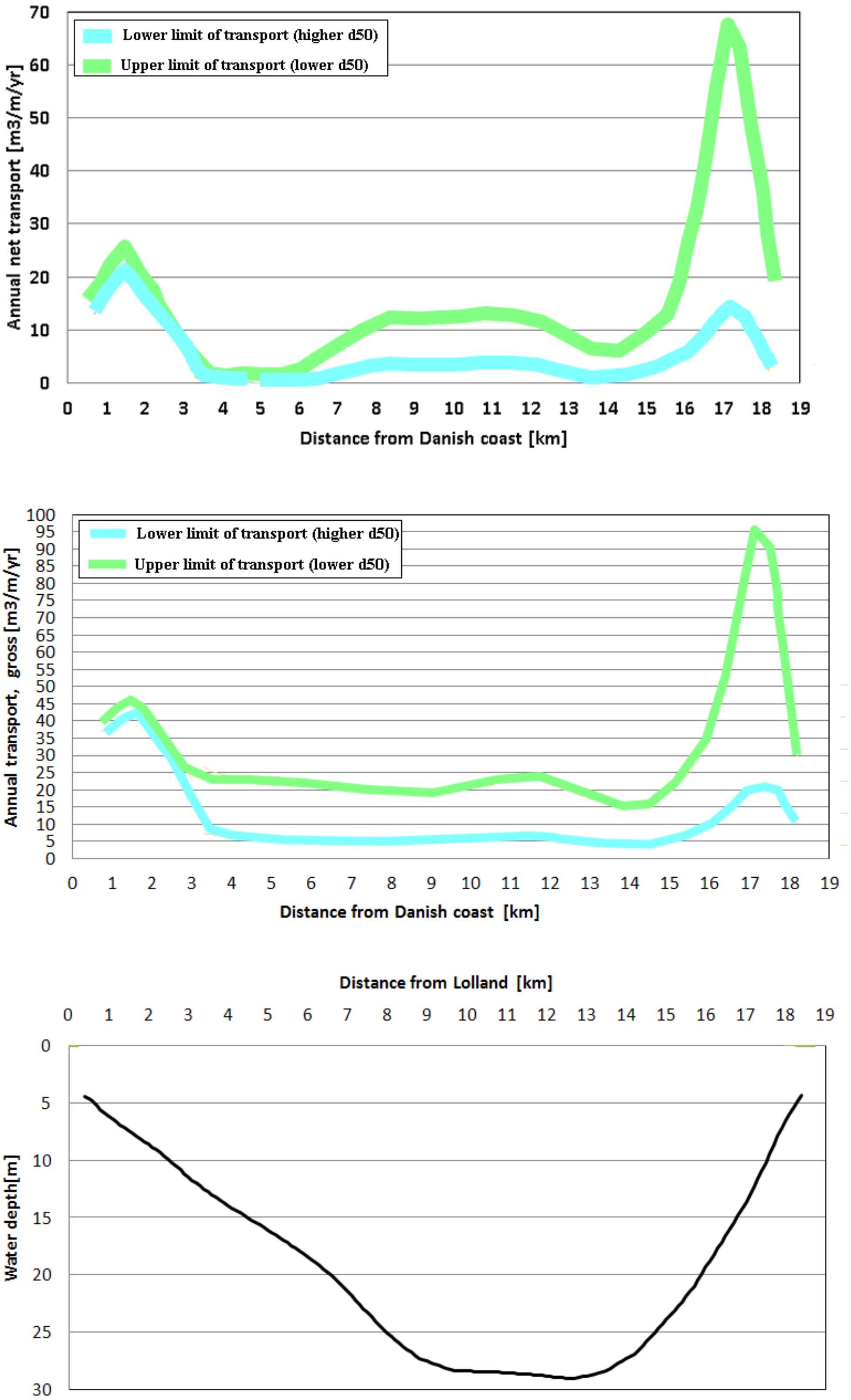


Figure 3.7 *Estimated annual net sediment transport rates, positive towards east (upper figure) and gross (central figure) sediment transport rates (2005) across the Fehmarnbelt in the alignment area for the fixed link. The lower figure shows the water depth along the alignment*

Table 3.6 Estimated annual sediment transport rates across the alignment, water depth > 4m

	Water depth [mDVR90]	Length [m]	Annual transport of non-cohesive sediment across the alignment [m^3/m/year]			
Stretch			**Gross**	**Net**	**Eastwards**	**Westwards**
Danish side	4-12	2,500	15-45	10-25	10-35	5-15
Central area	>12 (DK) >20 (G)	12,500	5-25	1-15	3-20	2-12
German side	4-20	2,500	7-95	3-70	5-85	2-15

3.3.3 Sediment spill

During dredging for construction, sediment spreading and deposition will take place. The deposition of dredged material, immediately after the dredging activities has finalized, is used in the present assessment. The deposition thicknesses applied are calculated for the following alternatives of the bridge and tunnel:

- Bridge alternative, B E-E/April 2010
- Tunnel alternative, E-ME/November 2010

The deposition fields are results from simulations of sediment spreading reported in (FEHY 2013d). The simulations show that the finest fractions (clay, silt) of the dredging spill depositing on the sea bed do not remain within the Fehmarnbelt area. They are carried with the flow to areas with a calmer hydrographic environment where settling is possible.

The deposition of dredging spill at the sea bed at the end of the construction period is the sand fraction (FEHY 2013d). The magnitude of the pressure from the dredging spill is calculated based on the volume of spilled sand during the dredging activities for the bridge or tunnel project, respectively. The difference in terms of sediment spill between the bridge alternative B E-E/April 2010 and the main bridge alternative Variant 2 B E-E/October 2010 is that the newest layout has been optimized such that the spill is 48% less than for the calculated scenario.

The applied spill scenario in the sediment spill simulations for the tunnel alternative, E-ME November 2010, includes 6% more sediment spill than the main tunnel scenario.

The deposition thicknesses are therefore considered conservative for the bridge as well as the tunnel.

The alignment of the tunnel alternative, E-ME/November 2010 is unchanged from the main tunnel alternative assessed in the present report. The calculated position of the deposition is therefore considered in agreement with the expected deposition for the main tunnel alternative. The alignment of the bridge alternative B E-E/April 2010 is changed. A comparison of this alignment with the main bridge alternative

Variant 2 B E-E/October 2010 is shown in Figure 3.8. The calculated deposition in the bridge scenario is therefore located incorrectly compared to the expected deposition for the main bridge alternative. This is discussed in Section 3.4, where assessment of the magnitudes of the pressures is discussed.

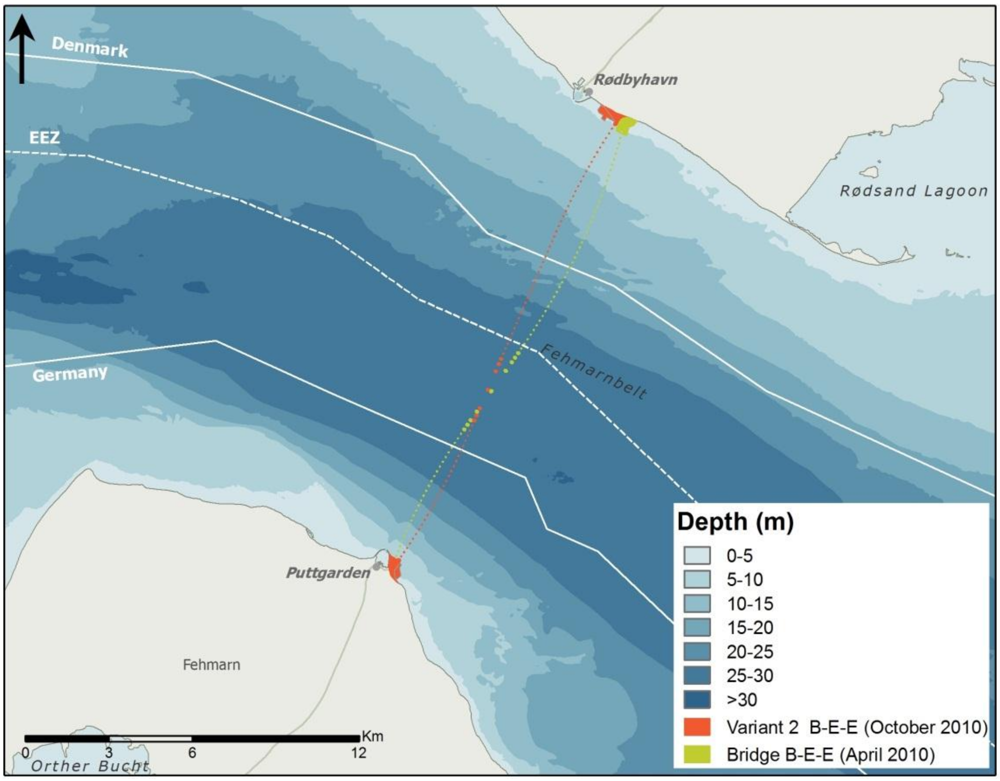


Figure 3.8 Comparison of the Main bridge alternative Bridge Variant 2 B E-E/October 2010 with Bridge alternative/April 2010 for which sediment spill and changes to the current field are simulated in detail

3.3.4 Changes to current field due to the project

The impacts on the near-bed currents from the Fixed Link project are based on the calculations from (FEHY 2013e).

The tunnel project does not lead to any or only insignificant changes to the currents.

Changes to the current speeds in the Fehmarnbelt area due to the additional flow resistance and mixing from the bridge piers/pylons are evaluated by a 3D flow model. The model is run with and without the effect of the bridge.

The Bridge alternative, B E-E/April 2010, has been studied in detail, see (FEHY 2013e).

A comparison of the studied alignment and the main bridge alternative Variant 2 B E-E/October 2010 is shown in Figure 3.8 above. The diameters of the bridge piers/pylons are furthermore slightly different to the main bridge alternative assessed in the present report. This is discussed in Section 3.4, where assessment of the magnitudes of the pressures is discussed.

3.4 Assessment of magnitude of the pressures

The assessment of magnitude of the pressures for the main tunnel alternative is assessed as summarised in Table 3.7 and for the main bridge alternative as summarised in Table 3.8.

The pressure indicators were discussed in Section 2.2.

Assessment of the majority of the pressures is straight-forward as described in Table 3.7.

Only the assessment of Pressure 2 and Pressure 3 for the main bridge alternative requires some additional discussion. For both of these pressures, the assessment is based on results calculated with a previous bridge alternative; bridge alternative B E-E/April 2010.

With regard to Pressure 2 (bridge): the changes to the near bed current speeds are limited to the local area around each pier. A geographical translation of the effects on the near-bed current speeds is therefore carried out in order to assess the effects of the changes to the current field on the sea bed morphology components for the actual layout.

With regard to Pressure 3 (bridge): the deposition of sea bed material from dredging spill, the actual deposition field after the end of construction period is located in the immediate vicinity of the bridge piers/pylons. The extent of the impacted areas around the structures are estimated and transferred to the bridge areas around the structures in the main bridge alternative.

Table 3.7 Methods for assessment of magnitude of pressures for the main tunnel alternative

Environmental pressure	Assessment of magnitude of pressure
Pressure 1: Tunnel trench for submersed tunnel (horizontal footprint and depth at end of construction)	Area of footprint on sea bed (GIS-analysis) and depth of trench after end of construction The depth of the trench is evaluated from drawings showing immersed tunnel plan and profile (RAT 2011)
Pressure 2: Reclamations and protection reefs	Area of footprint on sea bed (GIS-analysis)
Pressure 3: Temporary work harbours and storage areas (horizontal footprint)	Area of footprint on sea bed (GIS-analysis)
Pressure 4: Access channel production facility on Lolland (horizontal footprint and depth at end of construction)	Area of footprint on sea bed (GIS-analysis)
Pressure 5: Deposition of sea bed material from dredging activities	Deposition depth after end of construction. Results from FEHY (2013d) are applied

Table 3.8 *Methods for assessment of magnitude of pressures for the main bridge alternative*

Environmental pressure	Assessment of magnitude of pressure
Pressure 1: Footprint for piers and pylons (horizontal footprint)	Area of footprint on sea bed (GIS-analysis)
Pressure 2: Changes in the near bed currents	Assessment of magnitude of the changes to the time-average of the absolute near bed current speeds caused by the main bridge alternative. Results from (FEHY 2013e), scenario with continued ferry. See discussion in text
Pressure 3: Deposition of sea bed material from dredging activities	Deposition depth after end of construction. Results from FEHY (2013d) are applied. See discussion in text
Pressure 4: Work harbours	Area of footprint on sea bed (GIS-analysis)

3.5 Assessment of sensitivity

The methods for assessing the sensitivity of the components to the project pressures are described below. The main data sources applied in the assessments of sensitivity are listed.

3.5.1 Sub-components: sand waves, lunate bed forms and other active bed forms

The sensitivity of the three types of bed forms to the project pressures is very similar since the physical behaviour of these bed forms and the requirements for their existence are very similar. Differences are noted where required.

Sensitivity to tunnel trench (tunnel alternative only)

The bed forms are eliminated due to dredging of the tunnel trench. They will be able to regenerate and recover to a natural fully-developed stage, once the sea bed has been re-established.

The recovery time for the sea bed forms are estimated based on general knowledge of bed form dynamics. The recovery times depend on the geometrical properties of the bed forms and the sediment transport rates in the area. The calculations of annual sediment transport rates in the alignment area carried out in the baseline study (FEHY 2013a) are applied, see further information above.

The sea bed is re-established with natural sea bed material as a part of the tunnel project within the Natura2000 area. Outside the Natura2000 area, the time scale for the sea bed to reach a natural state is estimated based on infill rates of the natural sediment from the sides. The above-mentioned calculations of sediment transport rates in the alignment area are used.

Sensitivity to deposition of sea bed material (tunnel and bridge)

The sensitivity of the bed forms to the deposition of fine sediment from the dredging activities is assessed based on:

- an evaluation of the ratio between the deposition depth and the height of bed forms in case of sand waves or other active bed forms
- a volumetric approach considering volumes of the lunate bed forms versus the volumes of the deposited material

Calculations of the deposition depths from (FEHY 2013d) are used, see further information below. The deposition depths after end of the construction period are applied. The characteristics of the spill are obtained from (FEHY 2013d).

Sensitivity to changes in the near bed currents
The expected changes to the bed forms due to changes in the near-bed flow are quantified based on the limited knowledge in the literature on this issue. Bed form morphology and, in particular, the stability of bed forms are still research topics.

3.5.2 Sub-component: Sea bed morphology outside of areas with prominent bed forms

Sensitivity to tunnel trench (tunnel alternative only)
The time scale for the sea bed to reach a natural state is estimated based on infill rates of the natural sediment from the sides of the tunnel trench. The calculations of annual sediment transport rates in the alignment area carried out in the baseline study (FEHY 2013a) are applied, see below.

Sensitivity to temporary work harbours and storage areas (tunnel)
The annual sediment transport rates in the areas of the temporary work harbours and storage areas mentioned above are used to evaluate the morphological dynamics of the sea bed in the areas.

Sensitivity to access channel to production facility on Lolland (tunnel alternative only)
Same as tunnel trench above.

3.6 Assessment criteria

Assessment criteria are required to make a transparent and coherent impact assessment of impairments to the sea bed morphology.

The degree of impacts on the sea bed morphology are evaluated based on a 4-level scale ranging from Very high to Minor, see Table 3.9

The assessment criteria for impacts on the sea bed morphology for each of the four levels are described in Table 3.9. The justification of the assessment criteria is provided below the table.

The differentiator between temporary effects and permanent effects is 25-30 years as further described in Section 3.8 on assessment method for assessment of impairments.

Table 3.9 Assessment criteria and associated colours

Assessment criteria			
Very high	High	Medium	minor

Table 3.10 Criteria for assessment of changes to the sea bed morphology and assignment of degrees of impairments

	Criteria for assessment of changes to sea bed morphology			
Factor Sub-factor component	**Impact by project**	**Critera for assessment of changes (short description)**	**Duration**	**Degree of impairment**
Soil Marine soil Sea bed morphology	Mobilisation of sediment, changed near bed currents, changed sediment transport and changes to areal use due to dredging or construction related structures below water	• Permanent removal or permanent change of character of the bed forms	Permanent	Very high
		• Removal or temporary change of character of the bed forms for cases where a regeneration time up to 25-30 years is expected	Temporary	High
		• Change of height of bed forms (sand waves, lunate bed forms and other bed forms) of more than 25% • More than 25% change of volume of lunate bed forms • Lowering of sea bed with more than 2 m below natural sea bed level in areas outside of areas with prominent bed forms	Permanent/ temporary	Medium
		• Change of height of bed forms of 10-25% or 10-25% change of volume for lunate bed forms • Lowering of sea bed with 0.5-2 m below natural sea bed level in areas outside of areas with prominent bed forms • Temporary occupancy of sea bed area by structures (construction period)	Permanent/ temporary	Minor

Very High degree of impact on the bed forms is related to the situation where the character of the bed forms (sand waves, lunate bed forms or other active bed forms) will change permanently. This is the case in the very near vicinity of structures (within some diameters). In such areas the near-bed currents will increase significantly and the turbulence level will be high. These changes are expected to change the morphological regime of the sea bed and the character of the bed forms. The existing bed forms will change and instead a variation of bed forms may occur within the vicinity of the structures (flat bed, higher/lower bed forms than in the surrounding area, small-scale ripples and scour holes near the scour protection). Other pressures (deposition of sediment spill, dredging) from which the bed forms are not expected to recover within 25-30 of the project) could also lead to a very high degree of impact.

High degree of impact is defined as areas, where the bed forms (all three subcomponents) will change character, but are expected to regenerate naturally with time. This is expected to be the case within the tunnel construction zone, where dredging for the construction will eliminate the bed forms, but where the bed forms will regenerate with time after the tunnel elements have been covered by active or natural backfilling of the tunnel trench to the existing sea bed level. The impact is temporary, but the time scale for full regeneration may be long (year-decades). Deposition of sediment spill could also lead to a temporary change of character of the bed forms.

Medium degree of impact is assigned to areas where the heights of the fully-developed bed forms are expected to change permanently by more than a quarter of their heights due to a permanent change in the near-bed current speeds. On a temporary time-scale a medium degree of impact is also denoted areas where the heights of the sand waves or other active bed forms change more than 25% due to deposition of sediment from dredging activities. For lunate bed forms the medium class impact is the situation, where the volume of the lunate bed forms temporarily changes by more than 25% due to deposition of spill. The bed forms will remain in the area and keep their overall dynamics and characteristic as bed forms. However, a 25% change of the heights is expected to be large enough to be visible if measurements are carried out after a number of years.

Sea bed outside of areas with prominent bed forms is classified with a medium degree of impact in case of lowering of the sea bed to a depth of more than 2 m below the natural sea bed level. An abrupt drop of 2 m in the sea bed level, such as in the case of dredging for the access channel to the production facility at Lolland, will have a measurable influence on the current speeds near the bed. Furthermore a hole/trench in the sea bed of more than 2 m will act as a sediment trap for the natural transport of sand along the sea bed.

Areas where the height of the bed forms changes by 10-25% (permanently or temporarily) are classified as **Minor impact** areas. Such changes do not change the characteristics of the bed forms and will probably not be measurable due to the natural variability. A permanent change is related to a change in the hydrographic regime, but the sand waves may also experience a temporary change in the height due to deposition of the dredging spoil. Areas of the lunate bed forms, which experience more than a 10% temporary change in volume due to dredging spills, are also classified as Minor impact. Sea bed outside of areas with prominent bed forms is classified a minor degree of impact, where the natural sea bed level is lowered by 0.5-2 m, such as in the area of the tunnel trench or parts of the access channel to the production facility at Lolland. This will remove the mobile layer of sediment in most places and create a hole which will capture all sediments moving towards the hole/trench.

Areas, where the bed form heights or volumes are expected to change by 10% or less, are considered to maintain characteristics comparable to the natural variation. A 10% change in the bed form height/volume is within the order of magnitude which can be expected for the natural variations from year to year.

Lowering of the sea bed level with less than 0.5 m is considered negligible for the sea bed morphology in areas without bed forms.

3.7 Assessment of loss

Loss does for all sub-components under Sea Bed Morphology take place only where the projects' **permanent footprints** occupy parts of the sea bed. No other pressures cause loss of the sub-components under Sea Bed Morphology. Temporary (construction related) footprints are evaluated as impairments.

3.7.1 Method of assessment

The magnitude of loss is evaluated as an area of the given sub-components. The areas are found by combining maps of magnitudes of footprints with maps of sea bed sub-components from FEHY (2013a) in GIS analysis.

The assessment of loss of the individual sub-components within the component Sea Bed Morphology is summarised in Table 3.11.

Table 3.11 Method for assessment of loss (tunnel and bridge)

Component	Sub-component	Pressure	Assessment of loss
Sea Bed Morphology	Sand waves Lunate bed forms Other active bed forms	Footprint areas (horizontal extension) of piers/pylons (**bridge – pressure 1**)	Areas found by combining maps of magnitudes of footprints with maps of sea bed sub-components from FEHY (2013a) in GIS analysis
	Sea bed outside of areas with prominent bed forms	Footprint areas (horizontal extension) of reclamations and protection reefs (**tunnel - pressure 2**)	Areas found by combining maps of magnitudes of footprints with maps of sea bed sub-components from FEHY (2013a) in GIS analysis.
		Footprint areas (horizontal extension) of piers/pylons (**bridge – pressure 1**)	Areas found by combining maps of magnitudes of footprints with maps of sea bed sub-components 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 situation. In the context of the present report areas of impairment include **all impacted areas that are not included in the areas of loss** due to the permanent footprints. This implies that areas, where the function of the sub-component is impaired permanently or temporary, are considered impaired. This also covers the areas of the temporary footprints, which are not a subset of the permanent footprint.

Temporarily impaired areas are defined as areas where the sub-components will return to a natural state **within 25-30 years or faster** after the end of construction. If the effect of the pressures on the sub-components is predicted to last **longer than 25-30 years after the end of construction**, the impairment is considered **permanent**. Recovery times are commented on in the report.

Only pressures, which have an impact after the end of the construction period is considered relevant for sea bed morphology, refer to discussion in Section 2.2. The time scales for the temporary impacts are determined from the end of the construction period.

The degree of impairment is defined as the magnitude of the impairment. The magnitude of impairment is for all sub-components under Sea Bed Morphology evaluated as an area where the bed forms/sea bed (sub-component) is impaired. In general, the impaired areas are therefore in the present report determined by GIS-analysis combining maps of pressures, for instance maps of dredging deposition depths, with maps of the bed form components.

The degrees (very high, high, medium or minor) of impairment are determined by combining the sensitivity of the bed forms and the sea bed morphology (see Section 3.5) with magnitude of the pressure.

The impaired areas are compared to the total area of each sub-component within the 10 km zone from the alignment. The 10 km zone is shown in Figure 3.1.

The methodologies for assessment of the degrees of impairment are listed for pressures relevant for impairment in Table 3.12 for the main tunnel alternative and in Table 3.13 for the main bridge alternative.

The data and model results described in Section 3.3 are applied.

Table 3.12 Method for assessment of degree of impairment for project pressures for the main tunnel solution

Component	Sub-component	Pressure	Assessment of degree of impairment for various pressures
	Sand waves Lunate bed forms Other active bed forms	**Pressure 1:** Tunnel trench for immersed tunnel	a) Evaluation of possibility and time scale for sea bed to return to natural level and morphology given the type of backfilling along the trench (no backfilling, re-establishing of sea bed) b) Assessment of possibility/time for bed forms to recover according to criteria for impact and sensitivity c) Assessment of impaired areas applying GIS analysis combining footprints with maps of sea bed sub-components
		Pressure 3: Temporary work harbours and storage areas **Pressure 4:** Access channel to production facility at Lolland	Not relevant since no bed forms in the areas
		Pressure 5: Deposition of sea bed material from dredging activities	a) Assessment of impaired areas applying GIS analysis combining deposition depths of spill of sea bed material with maps of sea bed sub-components b) Possibility of recovery and time scale is evaluated based on assessed sensitivity and existing knowledge on the physical behaviour of bed forms.
	Sea bed outside of areas with prominent bed forms	**Pressure 1:** Tunnel trench for submersed tunnel	a) Evaluation of possibility and time scale for sea bed to return to natural level and morphology given the type of backfilling along the trench (no backfilling, re-establishing of sea bed) b) Assessment of impaired areas applying GIS analysis
		Pressure 3: Footprint area of temporary work harbours and storage areas **Pressure 4:** Access channel to facility at Lolland	a) Evaluation of time scale for sea bed to return to natural level and state after removal of temporary structures b) Assessment of impaired areas applying GIS analysis
		Pressure 5: Deposition of sea bed material from dredging activities	Not relevant according to discussion in Section 2.2.1

Table 3.13 Method for assessment of degree of impairment for project pressures for bridge solution

Component	Sub-component	Pressure	Assessment of degree of impairment for various pressures
Sea Bed Morphology	Sand waves Lunate bed forms Other active bed forms	**Pressure 2:** Changes in the near bed current speeds	a) Assessment of impairment of bed forms caused by the magnitude of the changes of the near bed current speeds caused by the bridge based on existing knowledge on the physical behaviour of bed forms. b) Assessment of impaired areas applying GIS analysis combining magnitude of changes to flow field and maps of sea bed sub-components
		Pressure 3: Deposition of sea bed material from dredging activities	a) Assessment of impaired areas applying GIS analysis combining deposition depths of spill of sea bed materialwith maps of sea bed sub-components b) Recovery and time scale for recovery is evaluated based on assessed sensitivity and existing knowledge on the physical behaviour of prominent bed forms. Results of deposition of spill after end of construction are applied.
		Pressure 4: Footprint area of tempo-rary work harbours and storage areas	Not relevant since no prominent bed forms in the areas
	Sea bed out-side of areas with promi-nent bed forms	**Pressure 3:** Deposition of sea bed material from dredging activities	Not relevant according to discussion in Sec-tion 2.2.1
		Pressure 4: Footprint area of tempo-rary work harbours and storage areas	a) Evaluation of possibility and time scale for sea bed to return to natural level and state after removal of temporary structures b) Assessment of impaired areas applying GIS analysis Calculations of the natural sediment transport along the sea bed are applied

3.9 Assessment of severity

The severity of the impact is assessed by combining loss and degree of impairment in various areas of the Fehmarnbelt with importance levels assigned to these areas.

3.9.1 *Importance levels*

The importance of the sea bed forms has been assessed based on the conservation objectives of the Natura 2000 areas occurring within the area of investigation and for the hydrodynamic conditions in the Fehmarnbelt area.

Some areas within the Fehmarnbelt area have been protected with large-scale, morphological active bed forms as conservation objectives under Natura 2000. These areas are accordingly used in the assignment of importance levels for sea bed morphology.

The bed forms act as roughness elements on the flow. The sensitivity of the flow through the Belt has been quantified in (FEHY 2013a), however, it was found that the importance of the bed forms on the overall hydrodynamics is negligible. Therefore this aspect is not included in the assessment of the importance levels.

The importance levels and descriptions are summarised in Table 3.14 and mapped in Figure 3.9.

Table 3.14 Importance levels for the Marine Soil component: Sea bed morphology

Importance level	Description
Very high	Sand wave areas within Natura 2000 areas, where these are part of the conservation objectives
High	Other sea bed areas with prominent large-scale, morphologically active bed forms (sand waves/lunate bed forms/other prominent bed forms) not included under the 'Very high' category
Medium	All other sea bed areas, which are not heavily influenced by anthropogenic activities as mentioned under the "Minor" category
Minor	Areas under heavy anthropogenic influence, including dredged navigation channels, disposal sites, areas with sand and gravel mining and harbours

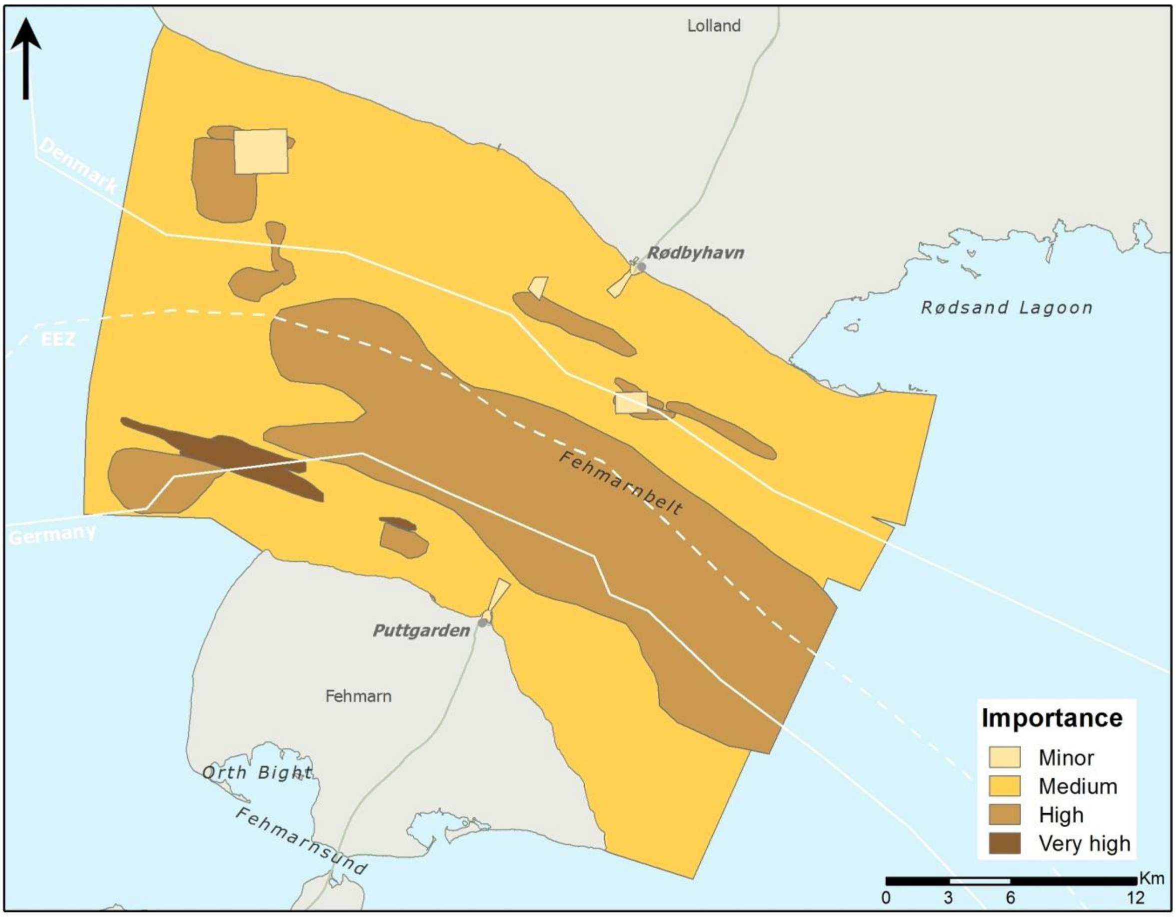


Figure 3.9 Importance map for sea bed morphology.

3.9.2 Degree of Severity

The degree of severity is assigned differently for loss and impairments.

The degree of severity for impairments is derived from a combination of assigned degrees of impairment with the importance levels for the impaired area. The degree of severity obtained by the combination of degree of impairment and the importance levels are given in Table 3.15. The degree of severity follows the four-level scale: very high, high, medium and minor. As an example an impairment, which has been classified as a medium degree of impairment within a high importance level area is evaluated to be of medium severity. It is noted that an impairment, classified as a minor impairment within a minor importance level area, is assigned as having negligible severity.

Areas with loss are assigned a degree of severity matching the assigned importance level for the area, see Table 3.16.

The areas impacted by a certain degree of severity are quantified by GIS-analysis for each of the four components (sand waves, lunate bed forms, other active bed forms and sea bed area outside bed form areas).

Table 3.15 Matrix by which the degree of severity is assigned for impairments. 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 3.16 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 (horizontal axis)

Magnitude of pressure	**Importance** of the environmental factor, sub-factor or component (four levels)			
	Very high	High	Medium	Minor
Very high (caused by foot-print)	**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 the sizes of the impacted areas in comparison with the sizes and state of the areas in the 0-alternative. The evaluation is summarised by a conclusion of the effects on the assessed environmental component as being either 'insignificant' or 'significant'.

4 ASSESSMENT OF 0-ALTERNATIVE

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

Given the present knowledge on the sea bed 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 sea bed morphology to pressures from the project is connected to how morphologically dynamic the sea bed is. The physical response to the project pressures is described in this section. The sensitivity is quantified wherever possible and recovery mechanisms and time scales for recovery are discussed for the relevant sub-components.

A highly dynamic sea bed is able to recover faster to temporary pressures than a weakly dynamic bed. The morphodynamics are strongly related to the natural transport of sea bed material along the sea bed. Annual rates of the transport of sea bed material in the alignment area were calculated in (FEHY 2013a) and summarised in Section 3.3.2 above.

5.1 Sub-components: sand waves, lunate bed forms and other active bed forms

The sensitivity to the project pressures of the three types of bed forms are very similar since the physical behaviour of these bed forms and the requirements for their existence are very similar. Differences are noted where required.

Analysis of the bed form dynamics and response to the project pressures are based on the following references: Deigaard and Fredsøe (1992); Fredsøe (1974); Fredsøe (1982); Niemann (2003); Niemann, Fredsøe, Jacobsen (2011).

5.1.1 Sensitivity to tunnel trench (tunnel alternative only)

The sea bed forms are eliminated in the area of the footprint of the trench when dredging for the tunnel trench. They are expected to recover with time as described below. The bed forms are therefore considered to be temporarily impaired.

After the scour protection above the tunnel elements have been put in place, a shallow trench of about 0.7 m depth with the scour protection (rocks) in the bottom will remain at the sea bed at the end of construction.

Silt, sand, gravel being transported along the sea bed will be trapped in the trench and re-establish the sea bed naturally. The majority of the sediment infill will deposit on the slopes and narrow the tunnel trench. After some time the trench will become a week depression in the sea bed until it has recovered to a natural sea bed level.

Above a stone protection, the turbulence is more violent than above a plane sandy bed and settling of sediment will therefore be somewhat reduced. As the sediment is transported primarily as bed load (rolling and jumping along the bed rather than in the water column), the impact from the protection layer is expected to be small. It is assumed that all sediment is trapped in the trench, see Figure 5.2. The estimated time scales for the trench to fill in are estimated and presented in Section 6.1 for various sections of the trench.

The bed forms will partly re-generate during the process of the trench infill and develop fully after the trench is completely filled in. The lunate bed forms are the result of the interaction between the loose sea bed material and the near-bed currents. The lunate shape is the result of a scarcity of loose sea bed material on a more or less immobile sea bed (FEHY 2013a). The sea bed above the tunnel trench is expected to have a more loose character than the existing sea bed during the time when the trench fills in and some years after this. The increased volume of loose material may cause the lunate bed forms to modify their shape such that the character of the bed forms may eventually change to become sand waves. With time, the bed forms are expected to obtain their natural shape and size.

Recovery times for bed forms

The recovery times for the bed forms are difficult to predict. The time scale for a full regeneration of the bed forms is related to a) the mobility of the sediment and b) the size ("volume and height") of the bed forms. In general, small bed forms will form and regenerate faster than large bed forms and the bed forms will regenerate faster where the sea bed mobility is high. The bed forms are expected to develop and migrate primarily during events with high current speeds. A gross migration distance comparable to a 1-2 times the length of the bed forms is expected before recovery takes place when developing from a plane bed (Niemann 2003).

Fully developed **lunate bed forms in the alignment area** in the Fehmarnbelt are estimated to migrate 2-4 m/event occurring 2-5 times per year (FEHY 2013a), see concept of bed form migration in Figure 5.1. The migration distance is therefore 10-15 m/year. With a length of the bed forms of 100-150 m, the recovery time is therefore estimated to be in the order of **15-20 years after the sea bed level has re-established to plane bed.**

The sand waves near the alignment are estimated to migrate about 1-5 m/event occurring 2-5 times per year (FEHY 2013a). The migration distance is therefore about 10-15 m/year in average. The lengths of the sand waves in area D3 west of the alignment (see Figure 3.1) are 200-400 m. In area D4, just east of the alignment, the sand waves have a length of 50-100 m. The **larger sand waves to the west of the alignment** are predicted to recover in about **30-40 years** from a re-established plane bed, while the recovery times for the **smaller sand waves to the east of the alignment** are about **10-15 years**. A slow regeneration of the sand waves just east of the alignment after sand mining which eliminated parts of the sand waves in this area, supports this (refer to discussion in FEHY 2013a).

The bed forms require a thickness of sea bed material comparable to their own height. **Lunate bed forms** are therefore expected to fully recover since the thickness of sea bed material, 0.7 m above the protection layer is about the same as the height of the lunate bed forms. The **sand waves** are higher - 0.5-3 m near the alignment - than the lunate bed forms. They are expected to recover and migrate across the protected tunnel. The only expected long-term change for the sand waves will be, that due to stochastic variations in the trough level, the protection layer will be exposed occasionally assuming the upper limit of the protection layer is placed 0.7 m below the present mean sea bed level. The deposition near the tunnel trench of sediment from dredging activities, which have not been resuspended at the end of construction period, may contribute to a faster recovery of bed forms.

Recovery times for the sea bed and bed forms are estimated based on the sediment transport capacity for various sections along the trench in Section 6.1.

Due to the **long re-generation time of the bed forms**, the impacts are classified as a **high degree of impairment** according to assessment criteria in Section 3.6. The time scales for full recovery of the sea bed are evaluated in Section 6.1.

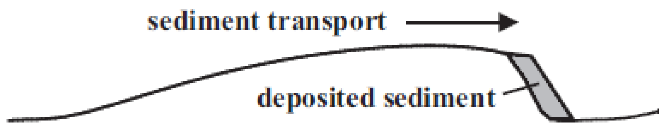


Figure 5.1 Conceptual drawing of sand wave migration

Figure 5.2 Conceptual sketch of infill of coarser non-cohesive sea bed material to the trench. Infill takes place mainly on the trench slopes

5.1.2 *Sensitivity to deposition of sediment from dredging activities (tunnel and bridge)*

Deposition of dredged material may occur in the bed form areas. The influence of the dredged material can be to:

- Reduce the height of the bed forms
- Increase the volume of the bed forms
- Change the composition of sediment in the bed forms

The bed forms are slow-moving features with a gross migration distance less than about 20 m/year. A temporary deposition of even a considerable thickness of dredging spill will not have any significant influence on the bed forms. The deposited dredging spill (FEHY 2013d), which remains at the sea bed at the end of the construction period (primarily sand, as described in Section 3.3.3), is therefore used as a measure for the deposition of spill, which can influence the sea bed forms.

The deposited material may be worked into the volume of the bed forms and mixed up with the natural sediments. As the bed forms migrate, it is expected that material, which is finer than the natural sea bed material, will gradually wash out with time. The time-scale for this process is difficult to estimate, but it may potentially take decades.

Sand waves and other active bed forms

The deposition will initially spread evenly across the bed forms, but will quickly be removed from the higher areas of the sand waves/other active bed forms and deposit in the trough areas/deeper areas of the sand waves, where the current speeds are smaller. The deposition in the deeper areas may hence be somewhat higher than the predicted thickness of the deposition layer depending on the shape of the bed forms (area of the deeper parts relative to the areas of the shallower parts) since all deposited material is gathered in the troughs. The deposition in the deeper parts of the bed forms (troughs) is based on the geometry of bed forms in the effected areas estimated to be 2.5 times higher than the calculated (average) deposition depths.

A predicted deposition of 20-50 mm may hence cause a layer of dredged material of up to 125 mm in the trough areas. For the smaller sand waves of about 0.5-1m such an infill does significantly change their height.

A change of the height of the sand waves/other active bed forms of less than 10 % is accepted as insignificant according to the assessment criteria (Section 3.6). A deposition in the troughs up to 50 mm is accepted for the smallest bed forms. For the larger bed forms a larger deposition can be accepted.

The following relation between degree of impact and deposition is used:

A change in the bed form heights between 10 and 25% is classified as a **Minor degree of impairment**. This corresponds to a deposition of 50-125 mm in the troughs for the smaller sand waves/other active bed forms with a height of 0.5 m, or an evenly distributed thickness of deposited spill of approximately **between 20 and 50 mm**.

A change in the bed form heights of more than 25% is classified as a **Medium degree of impairment**. This corresponds to a deposition of above 125 mm in the troughs for the smaller sand waves/other active bed forms with a height of 0.5 m, or an evenly distributed thickness of deposited spill of **above 50 mm**.

Sand waves/other active bed forms with a height of 0.5 m in areas with a deposition of spill with a thickness more than 200 mm are considered temporarily eliminated and are therefore classified with a **High degree of impairment** according to the assessment criteria**.**

The relation between degrees of impairment and deposition for sand waves of varying heights is described in Table 5.1.

Changes of less than 10% to the height of sand waves/other active bed forms are considered within the natural variation. Such changes cannot be measured. Sand waves/other active bed forms in areas with a deposition below 10 mm are therefore not considered to be affected by the dredging spill.

Table 5.1 Relation between deposition depth (mm) and degree of impairment for sand waves of varying height assuming the change in height of the sand waves is 2.5 times the even depth of deposition.

Relation between deposition depth and degree of impairment on sand waves	**Sand wave height (m)** 0.5	1	2	**3**
	Average deposition depth (mm)			
Degree of impairment				
High (temporary change of character of sea bed forms)	>200	>400	>800	>1200
Medium (More than 25% change of height)	50-200	100-400	200-800	300-1200
Minor (10-25% change of height)	20-50	40-100	80-200	120-300
Imperceptible	<20	<40	<80	<120

Lunate bed forms

A deposition in the areas of the lunate bed forms adds to the limited volume of the available loose bed material in the area, which forms the lunate bed forms. Although the deposition will initially spread evenly across the area, it is expected to accumulate around the lunate bed forms. It will most likely deposit in the lee areas and contribute to the formations of bed forms in the area.

A volumetric approach considering volumes of the lunate bed forms versus the volumes of the deposited material is applied in estimating to which degree the bed forms will be affected.

A single lunate bed form is estimated to consist of approximately 1000 m^3 of sand. With a number of 10-50 bed forms per 1 km^2, each bed form takes up an area in the order of 35,000 m^2 on average. An evenly distributed deposition of 10 mm (to take an example) will hence add a volume of 350 m^3 of loose material to the average lunate bed form, corresponding to about one third of the present volume.

A cut off level of 5 mm is chosen for when the effect on lunate bed forms is considered significant. This corresponds to an added volume of 10-20%.

Areas of lunate bed forms with a deposition depth of dredging spill between **5-10 mm is classified as minor degree of impairment**, corresponding to the assessment criteria in Section 3.6 of increased volume of the lunate bed forms of about 10-25%.

Areas with a **deposition depth above 10-200 mm are classified as medium degree of impairment**, corresponding to an increased volume of the lunate bed forms higher than 25%.

Lunate bed forms in areas with a deposition of spill with a thickness of more than 200 mm are considered temporarily eliminated and are therefore classified with a **high degree of impairment** according to the assessment criteria**.**

Not all of the finest material (mud) is expected to add to the lunate bed forms, but will probably frequently be eroded and deposited from the area with the varying flow conditions. The lee effects on the current field around the lunate bed forms are less pronounced than the trough area in the sand wave field. The added volume of loose material may cause the lunate bed forms to modify their shape. Where large volumes are added near the alignment, the character of the bed forms may eventually change to become sand waves. Where smaller volumes of material are added, the lunate bed forms may become higher due to a potential increase in sediment transport along the sea bed as the material becomes finer.

Table 5.2 Relation between deposition depth (mm) and degree of impairment for lunate bed forms

Relation between deposition depth and degree of impairment on lunate bed forms	**Lunate bed forms** **Average deposition depth (mm)**
Degree of impairment	
High (temporary change of character of bed forms)	>200
Medium (> 25% change of volume)	10-200
Minor (10-25% change of volume)	5-10
Imperceptible (< 10 % change of volume)	<5

5.1.3 *Sensitivity to changes in the near bed currents (bridge alternative only)*

The impact on the bed forms from a modified flow field is related to the sediment transport. Increases or decreases in the near-bed current speeds, when these exceed the critical current speeds for movement of sediment, will inevitably change the sediment transport rates and therefore the bed forms. In the Fehmarnbelt area, the current speeds near the bed are often below or close to the critical current speed for sediment mobility. With grain sizes of about 0.1-0.2 mm, sediment transport initiates around 0.2 m/s at 3 m water depth. Sediment transport occurs therefore mainly during peaks in the current speeds and small changes in the current speed will be relatively important for the sediment transport rates. At these current speeds, the sediment transport rates increase or decrease with the change in the current speed to a power of 3-10. As an example, a 2.5% increase in the near-bed current velocity is hence expected to increase the sediment transport rate by 10-30%, depending on the current speed and sediment grain size. An impact of a change in the sediment transport rate is expected to:

a) change the migration rate of the bed forms and

b) change the geometry of the bed forms

The change in the migration rate for the bed forms is proportional to the change in the sediment transport rate.

A 15% increase in the sediment transport will hence increase the migration rate by about 15%.

The change in the geometry is dependent on how much the sediment transport changes. A large increase in the sediment transport rate may even cause the bed forms to disappear. For smaller changes to the transport rates, a growth or a decay of the bed forms is expected. An estimate on the growth or decay of the bed forms following a change in the transport capacity is connected with significant uncertainty. The estimates are based on a theory developed by (Fredsøe 1982 and Deigaard and Fredsøe 1992) for dunes in a unidirectional and steady current (such as river flow):

$$\frac{H}{D} = \frac{2(\theta' - \theta_c)}{7\theta' - \theta_c}$$

H is the bed form height, D is the water depth, θ' is the non-dimensional skin friction (called the Shields parameter) and θ_c is the critical skin friction for sediment mobility ($\approx$0.045). The equation is illustrated in Figure 5.3. The relationship between the bed form height and the skin friction implies that the smaller bed forms will experience a relatively higher impact than the higher bed forms for the same relative change in the current speed. A 2.5% change in the current velocity is expected to cause a 3.5-13% change in the height of the bed forms.

The following relation between degree of impact in Section 3.6 and change in near bed current speeds is used based on the above:

A **change in the current speed of 2.5-10%** is expected to cause changes to the bed form heights of 10-25%. Such a change in the height of the bed forms, in the order of 10%, is classified as a **minor degree of impairment** according to the criteria in Section 3.6. Within areas of the bed forms there is a natural variation of the height. The change of 25% of the height is related to the larger bed forms in such an area as these are the fully developed bed forms. Smaller bed forms may experience a larger change until they too reach the fully-developed stage.

A **change in the current speed of 10-25%** is expected to change the bed forms heights by more than a quarter, are classified as a **medium degree of impairment**.

The robustness in the morphological regime for the range of skin friction parameters predicted in the Fehmarnbelt (Shields" parameter~O(0.1)) means that such changes do not lead to a change in the morphological regime, so the bed forms will not change character or disappear in the medium impact areas.

A change in the morphological regime is expected in the vicinity of the bridge piers/pylons. Here the turbulence levels increase due to large eddies being generate by the interaction between the structures and the flow and the current speeds increase. An area of approximately **four diameters from the structures** is impacted near the bed (FEHY 2013e). In these areas the changes to the current cause a **very high degree of impairment** on the bed forms, which are expected to disappear in this area.

A **high degree of impairment** (associated with a temporary elimination of bed forms in the criteria matrix in Section 3.6) is not related to a change in the current, since changes to the current relevant for bed forms are only related to the permanent structures.

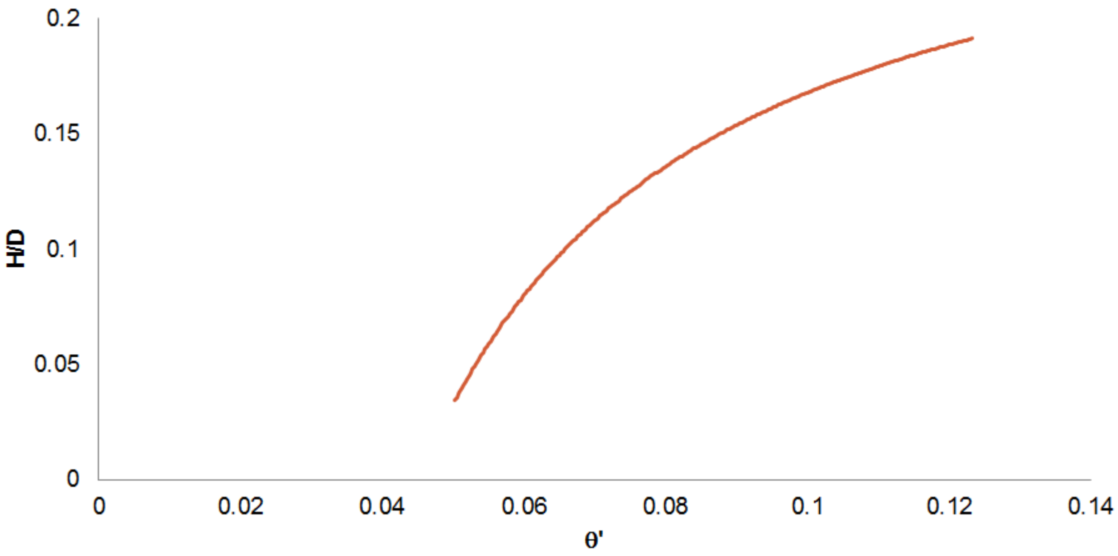


Figure 5.3 Relation between bed form height, water depth and the non-dimensional skin friction. From (Deigaard and Fredsøe, 1992).

Table 5.3 Relation between change in near-bed current speed and degree of impairment for bed forms

Degree of impairment	Change in near-bed current speed (%)
Very high (change in character of bed forms without expected recovery)	Assessed
High (change in character of bed forms with expected recovery)	Assessed
Medium (>25 % change of bed form height)	>10
Minor (10-25 % change of bed form height)	2.5-10
Imperceptible (<10 % change of bed form height)	<2.5

5.2 Sub-component: sea bed morphology outside of areas with prominent bed forms

5.2.1 Sensitivity to tunnel trench and access channel (tunnel alternative only)

Areas with a depression in the sea bed after the end of the construction period such as the tunnel trench (outside the Natura 2000 areas) or the access channel to the production facility will re-establish naturally. Loose sea bed material (silt, sand, gravel) being transported along the sea bed will be captured in the trench areas and infill the holes until the natural sea bed level is re-established. The sea bed material is rolling and jumping along the sea bed and the majority of the sediment infill will hence deposit on the slopes or be trapped between the large stones in the scour protection above the tunnel elements. The trench will hence narrow. After some time the trench will become a weak depression in the sea bed until it has recovered to a natural sea bed level.

The recovery times of the sea bed to a natural level are estimated in the relevant sections (Section 6.1 (tunnel trench) and Section 6.4 (access channel)) based on the calculated sediment transport rates referred in Section 3.3.2. The recovery times depend on the transport rates and the volume of trenches to fill in.

The sea bed in the Fehmarnbelt outside the areas of bed forms is relatively smooth. A large-scale hole in the sea bed of more than **2 m** is therefore classified as a **medium degree of impairment** and **between 0.5 and 2 m** is classified as a **minor degree of impairment**.

5.2.2 Sensitivity to permanent footprints

Permanent footprints such as the reclamation areas and protection reefs for the tunnel alignment and the bridge piers/pylons and the peninsulas/beaches will on a permanent time-scale occupy the natural sea bed. Such areas area characterised as **loss**.

5.2.3 Sensitivity to temporary work harbours and storage areas (tunnel and bridge)

The temporary work harbours at the Fehmarn side and the Lolland side will mainly be integrated into the planned reclamation areas for the tunnel alternative and into the peninsulas/beaches for the bridge alternative. Within these areas the natural sea bed will be lost as part of the permanent footprints described above.

The following information is available about the dismantling/removal process:

Tunnel alternative
Two work harbours are planned: one on the German side at Puttgarden and one on the Danish side at Rødbyhavn. Both these harbours will be integrated into the planned reclamation areas. Upon completion of the tunnel construction works, they will be dismantled/removed and backfilled (Femern A/S 2011).

Bridge alternative
The harbours and work yards are temporary. After completion of the construction, quay walls, breakwaters, buildings and pavements will be removed (Femern A/S 2011).

It is assumed that the sea bed in the areas of the work harbours and storage areas, which are outside the permanent footprints (primarily where harbour breakwaters are removed), are re-established upon completion of the tunnel or bridge construction works, respectively, and dismantling/removal of structures. Backfilling (only informed for the tunnel) with sea bed material with a composition comparable to the natural sea bed material and to the natural depths is assumed.

The sea bed will recover to the natural state within a few years (<5 years). The natural sediment transport processes in the areas (FEHY 2013a) will smooth out and recover the sea bed to its natural morphology. For sea bed morphology the time scale of impact is small and the impact is therefore classified as a **minor degree of** impairment.

6 ASSESSMENT OF IMPACTS OF MAIN TUNNEL ALTERNATIVE

The impacts from the main tunnel alternative E-ME/August 2011 are described below. The areas of the impacts (loss and impairment) are derived based on the magnitudes of the pressures and the sensitivity to the pressures of the sub-components of the Marine Soil Component Sea bed morphology.

Loss of sea bed due to the permanent reclamations takes place due to the planned land reclamations which will occupy a total of 356 ha of sea bed without prominent bed forms. Table 6.1 summarises the areas of sub-components impaired by various pressures. The areas exclude effected areas, where the impairments are assessed as insignificant in the following.

The impacts from the project pressures from the tunnel are evaluated one by one below.

Table 6.1 Summary of areas with impairments (all temporary). Relation between pressures and areas of impairments subdivided on sub-components. Maximum period with temporary impairments is given for each pressure

Areas of temporary impairments caused by below pressures [ha]	Sub-components of sea bed morphology					
	Sand waves	Lunate bed forms	Other active bed forms	Sea bed outside areas with prominent bed forms	Total	Maximum period with temporary impairments
Tunnel channel	5	98	0	80	183	Sand waves: up to 40 years Lunate bed forms: up to 28 years Sea bed outside areas with prominent bed forms: up to 18 years
Work harbours	0	0	0	15	15	Sea bed outside areas with prominent bed forms: up to 5 years
Access channel	0	0	0	32	32	Sea bed outside areas with prominent bed forms: up to 30 years
Deposition of sediment	0	887	0	0	887	Lunate bed forms: up to 30 years
Total	5	984	0	126	1.115	

6.1 Pressure 1: Tunnel trench

6.1.1 Magnitude of pressure

The area of the tunnel trench footprint is evaluated to a **total of 183 ha**. There is no information of a work area along the tunnel trench. The tunnel trench is shown in Figure 6.1 together with sub-components of the Marine Soil Component Sea bed morphology.

A shallow trench with a depth of about 0.7 m and a width varying between 80 to 160 m will be found at the sea bed after the end of construction. The scour protection (large rocks) will appear in the bottom of the trench.

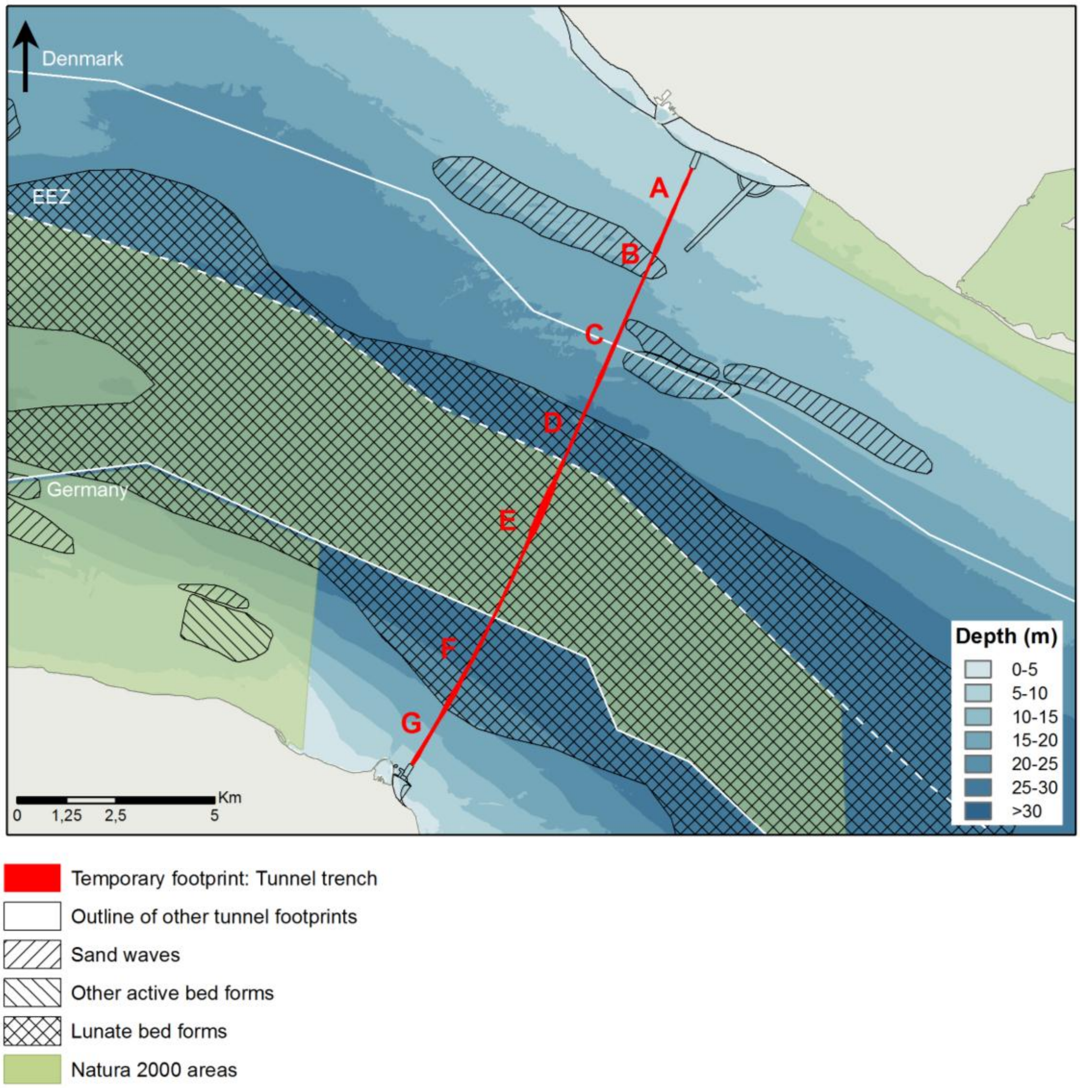


Figure 6.1 *Pressure 1: tunnel trench and the sub-components of the Marine Soil Component Sea bed morphology. The sub-component 'Sea bed morphology outside areas with prominent bed forms' covers the sea bed, where there are no bed forms. A-G refers to sections along the trench separated by limits of the bed form areas and the German/Danish/EEZ border lines. The marine parts of the relevant Natura 2000 areas are shown*

6.1.2 *Loss and degree of impairment*

The impacts from the tunnel trench are of a **temporary character** as the sea bed sub-components are expected to fully recover along all parts of the trench.

Degree of impairment

A total area of 183 ha is impaired by the tunnel trench.

The tunnel trench cuts through the tip of the area with large sand waves west of the alignment in the Danish territory and through the area of lunate bed forms in the German as well as the Danish territory.

The impaired areas caused by the tunnel trench for each of the sub-components are supplied in Table 6.3 in the following Section 6.1.3. The areas are given as a total area (in ha) and as parts of the relevant sub-component within an area extending 10 ha east and west of the alignment, see Figure 6.2 (local zone + near zone).

A total of 98 ha of lunate bed forms are impaired by the tunnel trench of which 56 are within the Natura 2000 area. 5 ha of sand wave area are impaired, and 80 ha of sea bed outside the areas of bed forms are impaired.

The sea bed is expected to fully recover to its natural state in the area of the lunate bed forms, but the bed forms may temporarily have a character more similar to sand waves as described in Section 5.1.1. The protection layer will be exposed occasionally in Section B, where the tunnel trench cuts through the sand wave area with the large sand waves west of the alignment.

Recovery times

The processes for recovery of the sub-components were described above in Chapter 5 on sensitivity. The recovery times of the sub-components depend on the infill times of the trench and time for recovery of the bed forms.

The estimates of the recovery time of the tunnel trench to a natural state are therefore carried out in two steps. **Step 1** is a calculation of the time it takes for the area of trench to return to a natural sea bed level. **Step 2** is an estimation of the time it takes for the bed forms to recover into a fully-developed stage. These time estimates were discussed in Section 5.1.1 for different areas of bed forms near the alignment. For the sub-component 'Sea bed outside of areas with prominent bed forms' Step 1 is sufficient.

Step 1 is calculated as the time it takes for the natural sediment transport along the sea bed to backfill the trench. All sediment moving along the sea bed is expected to infill the trench as described in Chapter 5.

The trench/hole will on a time scale of a few years turn into a depression in the sea bed. The estimated time scales for the trench to backfill into a natural sea bed level are estimated and supplied in Table 6.2 for various sections of the trench. The sections of the trench are selected based on the presence of bed forms and whether it is within/outside Natura 2000.

The time scales are estimated based on the calculations of annual gross sediment transport rates in the alignment area (Figure 3.7) and the depth of the trench. A depth of 0.7 m is used for the entire stretch. The backfilling rates in Table 6.2 are given as annual reductions in the width of the trench for the individual sections along the trench. It is assumed that the sediment is distributed evenly on the slope of the bed, see Figure 5.2. The backfilling rates in volumes per metre of the trench are also supplied in the table.

The backfilling rates are very sensitive to the grain sizes of the sea bed material. As the sea bed material is found to vary in a patchy manner in the tunnel alignment area, the transport rates may vary considerably within short stretches. Furthermore, calculated sediment transport rates are in general evaluated with an accuracy of about a factor of two as mentioned in Section 3.3.2. These are the reason for the large span given in the infill rates and the recovery times.

In areas with prominent bed forms (sand waves or lunate bed forms, Sections B, D and F) these will regenerate in the deposited material and by bed forms from the sides migrating across the trench as further described in Section 5.1.1.

The recovery times for the bed forms were evaluated in Section 5.1.1. Lunate bed forms in the alignment area were estimated to recover in 15-20 years from a *plane* bed and the impacted sand waves west of the alignment area were estimated to recover in 30-40 years from a plane bed.

The bed forms will re-establish along with the natural backfilling of the trench. The total time for recovery of the sea bed forms in the area is therefore less than the sum of a complete backfill of the trench and the time for recovery of the bed forms from a plane bed. If the backfilling time of the trench is less than the recovery times of the bed forms, it can be assumed that the sea bed with the bed forms regenerates in about the same time as bed forms from a plane bed. In the case, where the trench may take longer to regenerate than the recovery time for the bed forms (Section E and F, only), the sea bed with the bed forms can be assumed to be recovered once the trench has filled in. The time estimates are provided in Table 6.2.

Degree of impairment

The degree of impairment caused by the tunnel trench is found by applying the assessment criteria described in Section 3.6.

The degree of impairment is high for all areas of the lunate bed forms. They are predicted to recover in less than about 20-28 years after the end of construction, which means they are considered temporarily eliminated.

The impaired area with sand waves in the Danish territory is also classified as impaired to a high degree. The sand waves are predicted to recover within 30-40 years as described above.

For the sea bed outside of the bed form areas, the impact is classified as “minor” due to the lowering of the sea bed level by about 0.7 m.

The degrees of impairment are indicated in Table 6.2 for individual sections of the trench.

Table 6.2 *Assessment of recovery times for temporary footprint of the tunnel trench. Recovery times for various sections of the sea bed along the trench*

Recovery times for sea bed in footprint of the tunnel trench						
Section **Sub-component** **(territory)**	**Water depth** **[m DVR90]**	**Width/ depth of the trench after end of construction** **[m]**	**Approximate rate of reduction in width of access channel [m/year]** **(average annual infill [m^3/m/year])**	**Infill time for trench** **[years]**	**Full recovery of sea bed morphology [years]**	**Degree of impairment, time-scale. Area (ha)**
A: **Sea bed outside areas with prominent bed forms (Danish)**	8-13	85-147/ 0.7	14-64 (10-45)	1-10	1-10	Minor, temporary 24 ha
B **Sand waves (Danish)**	13-15	84-100/ 0.7	10-33 (7-23)	3-10	30-40	High, temporary 5 ha
C **Sea bed outside areas with prominent bed forms (Danish/ Danish EEZ)**	15-25	84-128/ 0.7	7-33 (5-23)	3-18	3-18	Minor, temporary 37 ha
D **Lunate bed forms (Danish EEZ)**	25-28	83-118/ 0.7	7-33 (5-23)	3-17	15-20	High, temporary 12 ha
E **Lunate bed forms (German EEZ and Natura 2000)**	28-30	82-201/ 0	- (5-25)	2-28	15-28	High, temporary 56 ha
F **Lunate bed forms (German)**	20-28	82-157/ 0.7	7-50 (5-35)	2-22	15-22	High, temporary 30 ha
G **Sea bed outside of areas with prominent bed forms (German)**	8-20	92-136/ 0.7	14-136 (10-95)	1-10	1-10	Minor, temporary 19 ha

6.1.3 Impact severity of loss/impairment

The areas impacted due to the tunnel trench are assigned severity levels by combining the degrees of impairment with the importance levels for the respective areas of impact.

A total area of 103 ha of sea bed is impacted with a high severity level. This area includes the area of the temporary impacted lunate bed forms (98 ha) and sand waves (5 ha), which are classified with a high importance level and high impairment. The areas categorized with a minor severity level (80 ha) are 'sea bed area outside of areas with prominent bed forms'. The impact severity is summarised in Table 6.3.

Table 6.3 Impacted areas and severity of impacts from tunnel trench (Pressure 1) on the bed forms and sea bed in the Fehmarnbelt. Main tunnel solution (E-ME/August 2011)

Severity of impacts from Pressure 1: tunnel trench	**Total ha**
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	103
Medium severity	0
Minor severity	80
Total temporary	**183**

6.2 Pressure 2: Reclamations and protection reef

6.2.1 Magnitude of pressure

The reclamations and protection reefs on the Danish and German side occupy a part of the sea bed on a permanent time scale. The magnitudes of the pressures are identical to the areas of the structures, which are shown in Figure 6.2.

The permanent structures take up to 356 ha out of 41,446 ha within the local 10 km zone corresponding to 0.9%.

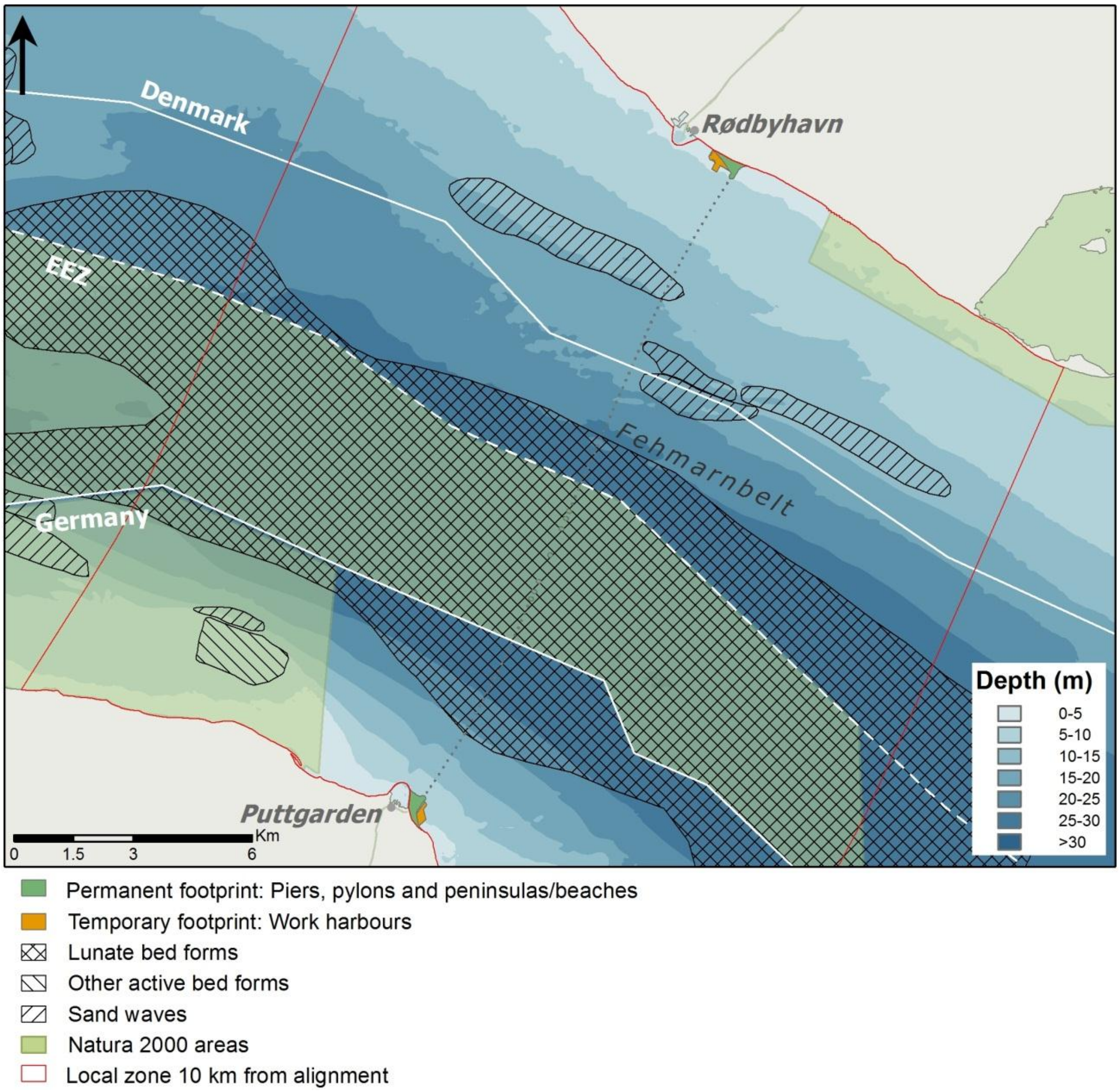


Figure 6.2 Footprints of the reclamations and protection reefs (permanent footprints). The part of the work harbours/storage areas and access channel (all temporary footprints) which are not included in the permanent reclamations/protection reefs, when these are constructed, are also shown. The marine parts of the relevant Natura 2000 areas are shown

6.2.2 Loss

The impact from the permanent structures, the reclamations and the protection reefs, are considered "loss".

The total area of the impacted areas is 356 ha. Only areas within the sub-component 'sea bed outside areas with prominent bed forms' are impacted by this pressure.

6.2.3 Impact severity of loss

The impact severity for the loss caused by the reclamations and protection reefs is supplied in Table 6.4.

The reclamations and protection reefs occupy sea bed areas categorized with medium importance level and the loss is therefore classified with medium degree of severity.

Table 6.4 Impacted areas and severity of impacts from reclamations and protection reef (Pressure 2) to the bed forms and sea bed in the Fehmarnbelt. Main tunnel solution (E-ME/August 2011)

Severity of impacts from Pressure 2: Reclamations and protection reef	**Total ha**
Loss	
Very high severity	0
High severity	0
Medium severity	356
Minor severity	0
Total	**356**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total temporary	**0**

6.3 Pressure 3: Temporary work harbours and storage areas

6.3.1 Magnitude of pressure

The magnitude of the pressures from the temporary work harbours and storage areas are identical to the area they cover, a total of 15 ha. Only the area of the work harbours and storage areas, which are not integrated into the permanent structures are assessed, refer to discussion in Section 2.2 on relevant project pressures. These areas were shown in Figure 6.2 in the previous section.

These areas include primarily breakwaters protecting the work harbours on the German as well as the Danish side during construction and on the German side also a small part of the storage area east of the harbour, a total of approximately 7.3 ha at the German side and 7.2 ha at the Danish side.

6.3.2 Degree of impairment

The areas of the breakwaters and storage areas are expected to recover after the structures are dismantled and the sea bed re-established by active backfilling. The impact is therefore considered temporary impairment of the sea bed. It is expected that the sea bed morphology will recover to a natural state within a time scale of about 5 years, refer to the discussion on sensitivity in Section 5.2.3.

The degree of impairment for these areas is classified as minor according to the assessment criteria in Section 3.6.

6.3.3 Impact severity of impairment

The impaired areas (15 ha) are all classified with a minor degree of severity, see Table 6.5, as a combination of the minor degree of impairment and the medium importance level sea bed areas off Puttgarden and Rødbyhavn.

Table 6.5 Impacted areas and severity of impacts from temporary work harbours and storage (Pressure 3) to the bed forms and sea bed in the Fehmarnbelt. Main tunnel solution (E-ME/August 2011)

Severity of impacts from Pressure 3: Temporary work harbours and storage area	**Total ha**
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	15
Total temporary	**15**

6.4 Pressure 4: Access channel to production facility on Lolland

6.4.1 Magnitude of pressure

The magnitude of the pressure is identical to the area of the access channel off the reclamation area on the Danish side; see Figure 6.2 in Section 6.2. The area is 32 ha.

The channel is dredged to a level of -12 m DVR90. The natural sea bed level along the access channel is shown in Figure 6.3. The depth of the channel is 6 m below the natural sea bed level in the area near the reclamation, where the natural water depth is about -6 m DVR90. The dredged depth decreases as the water depth increases towards the offshore to the required depth of the access channel, -12 m DVR90.

The width of the access channel varies from 170 m nearest the reclamation to 100 m at the offshore termination.

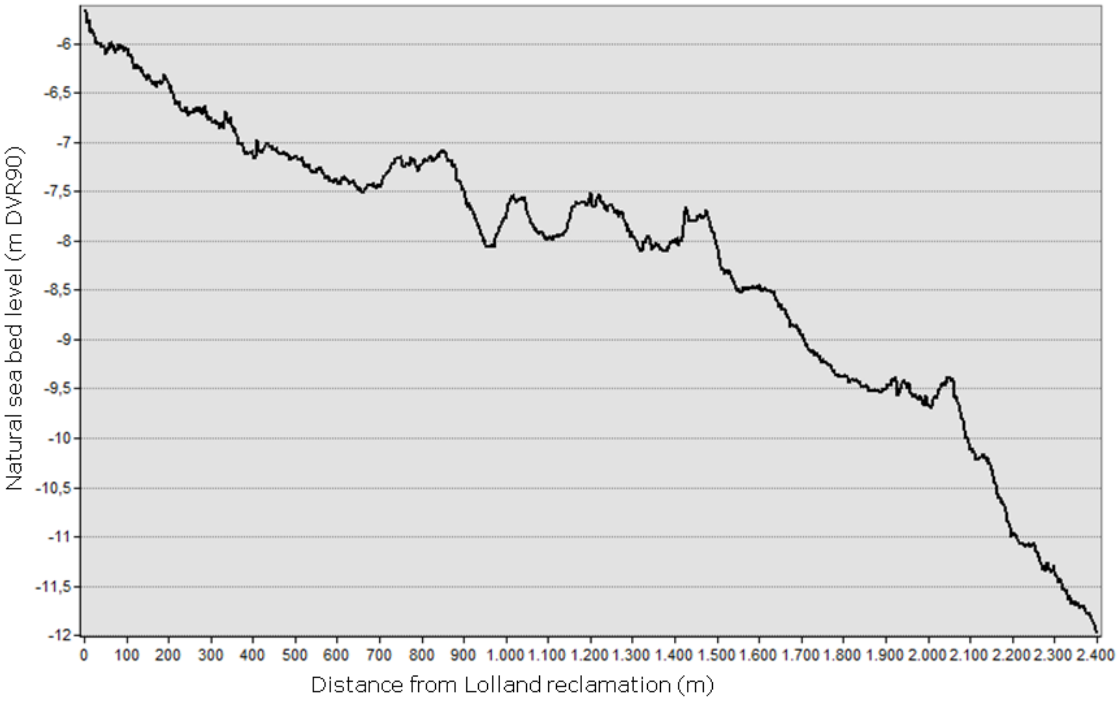


Figure 6.3 Natural sea bed level along the access channel to the temporary work harbour on the Danish side

6.4.2 Degree of impairment

The dredging of the access channel leaves a relatively large channel/hole in the natural sea bed at the end of construction. The access channel is not located within areas with prominent bed forms. Only the sub-component 'sea bed outside areas with prominent bed forms' will be affected.

The channel will block the (small) natural eastwards/westwards transport. The blockage of the natural transport of sea bed material across the channel area does not imply any significant impact on the morphology in the area. The sea bed in the vicinity of the channel may experience a slight lowering (in the order of 0.1 m) of the sea bed level due to erosion.

The trench will fill up with time as described in Section 5.2.1 on sensitivity.

Recovery time

The recovery time for the access channel to fill in by the natural sediment transport along the sea bed is calculated applying the same procedure as described for the tunnel trench above (Step 1, Section 6.1).

The time for recovery varies along the trench since the depth and width of the channel vary along the alignment as described above. The required volume of sediment to backfill the trench to a natural sea bed level therefore varies along the alignment. Furthermore, the rate of the natural sediment on the sea bed varies along the trench. Sediment transport rates calculated for the relevant water depths in the alignment area at the Danish side are applied (Figure 3.7).

The estimated time for natural backfilling of the access channel is presented in Figure 6.4. The recovery times vary from up to 30 years nearest the reclamation, where the trench is deep and wide, to about just 1-2 years for the outer shallow part of the trench. The estimated annual reductions in the width of the channel and annual infill volumes are tabulated for sections of the trench in Table 6.6.

At the stage when the channel has completely filled in, the sea bed has also recovered to natural sea bed morphology due to the slow process of the backfilling. The recovery time is therefore identical to the time estimated to infill the channel.

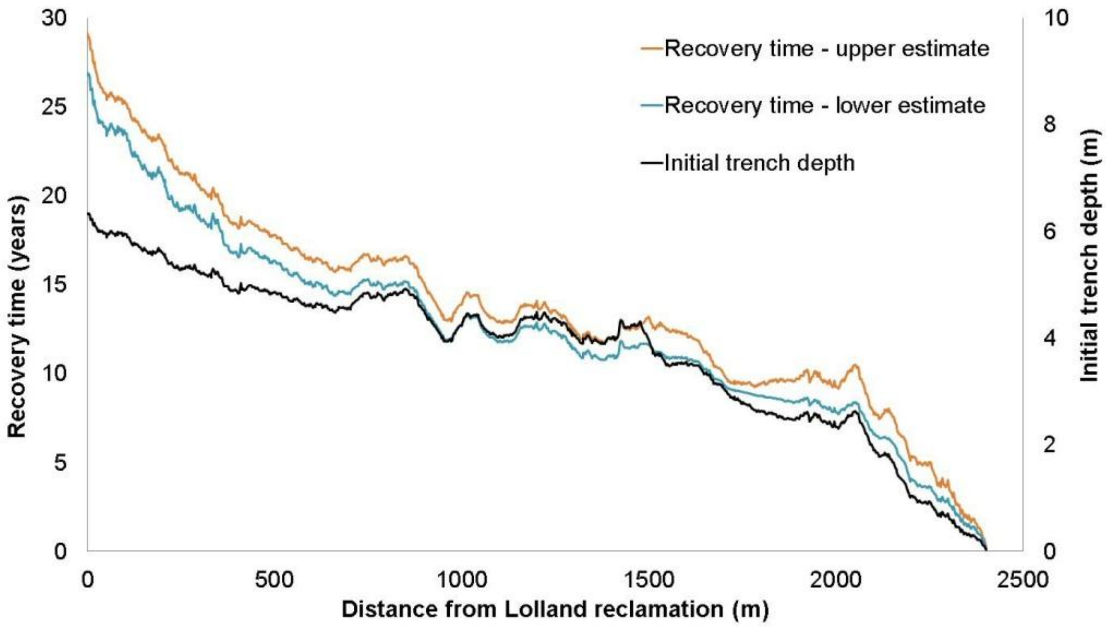


Figure 6.4 *The estimated recovery time for the sea bed in the area of the temporary access channel varies along the channel*

Table 6.6 Summary of estimated recovery time for access channel to temporary Work Harbour on the Danish side

Recovery times for sea bed in footprint of the access channel						
Section **Approx. distance from Lolland reclamation** **Sub-component** **(territory)**	**Water depth** **[m DVR90]**	**Width/ depth of channel after end of construction** **[m]**	**Dredging depth below natural sea bed** **[m]**	**Approximate rate of reduction in width of access channel [m/year]** **(average annual infill [m³/m/ year])**	**Infill time for trench** **[years]**	**Degree of impairment, time-scale**
Inner part 0-500 m **Sea bed outside areas with prominent bed forms (Danish)**	5.5-7	150-170	5-6	6-10 (37-46)	16-30	Medium, temporary
Central part 500-2000 m **Sea bed outside areas with prominent bed forms (Danish)**	7-9.5	120-170	2-5	9-14 (26-47)	7-18	Medium, temporary
Outer part 2100-2400 m **Sea bed outside areas with prominent bed forms (Danish)**	10-12	100-120	0-2	>12 (16-33)	0-8	Minor, temporary

Degree of impairment
The degree of impairment is classified as medium degree (29 ha) on the sea bed where the channel causes lowering of the sea bed by more than 2 m below the natural sea bed (water depths less than 10 m DVR90) and with a minor degree of impairment (3 ha) where the dredging depth is 0.5-2 m deep (water depths 10-12 m DVR90). The impairment is considered temporary as all parts of the sea bed in the area of the access channel are expected to recover to the normal sea bed level within a maximum of 30 years..

6.4.3 *Impact severity of impairment*
The combination of the impairments and importance level (medium) for the area of the access channel causes the impacts from the access channel to become classified with minor (3 ha) and medium severity (29 ha) in the areas where the degree of impairments described above is minor and medium, respectively, see Table 6.7.

Table 6.7 *Impacted areas and severity of impacts from access channel to production facility on Lolland (Pressure 4) to the bed forms and sea bed in the Fehmarnbelt. Main tunnel solution (E-ME/August 2011)*

Severity of impacts from Pressure 4: Access channel	Total ha
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	29
Minor severity	3
Total temporary	**32**

6.5 Pressure 5: Deposition of sediments from dredging activities

6.5.1 Magnitude of pressure

During construction, sediment spreading and deposition will take place. The dredging period is planned to last up to 6½ years.

The sediment spreading and deposition fields are simulated as a part of (FEHY 2013d). The simulations show that the finest fractions (clay, silt) of the dredging spill depositing on the sea bed do not remain within the Fehmarnbelt area. They are carried with the flow to areas with a calmer hydrographic environment where settling is possible.

The deposition of dredging spill at the sea bed at the end of the construction period is the sand fraction (FEHY 2013d). The magnitude of the pressure from the dredging spill is calculated based on the volume of spilled sand when dredging for the tunnel trench.

The volume of sand with an average fall velocity of 0.015 m/s is estimated to deposit within a zone of 0-600 m to each side from the centre of the tunnel alignment (FEHY 2013d). For the present work it is assumed that the sand deposits evenly across that area. In reality the majority of the sediment will deposit within a few hundred metres from the alignment and less will travel as far as 600 m from the centre of the alignment. The conservative assumption of an evenly distributed sand volume is applied, since the geographical distribution of the thickness of the sand fraction is not known within the 0-600 m limit. No dredging spill is expected within the tunnel trench area. It is assumed that such spill is re-dredged before the tunnel elements and scour protection are located in the trench. The total area of sand waves and lunate bed forms with deposition of sediment spill more than 5 mm around the tunnel trench area at the end of construction is found to be 914 ha.

The variation in the deposition thickness along the tunnel trench is shown in Figure 6.5. The deposition thickness varies between 5 and 15 mm along the trench.

The thickness of the deposition layer is expected to decrease further with time after the end of the construction period, but to which degree is not known.

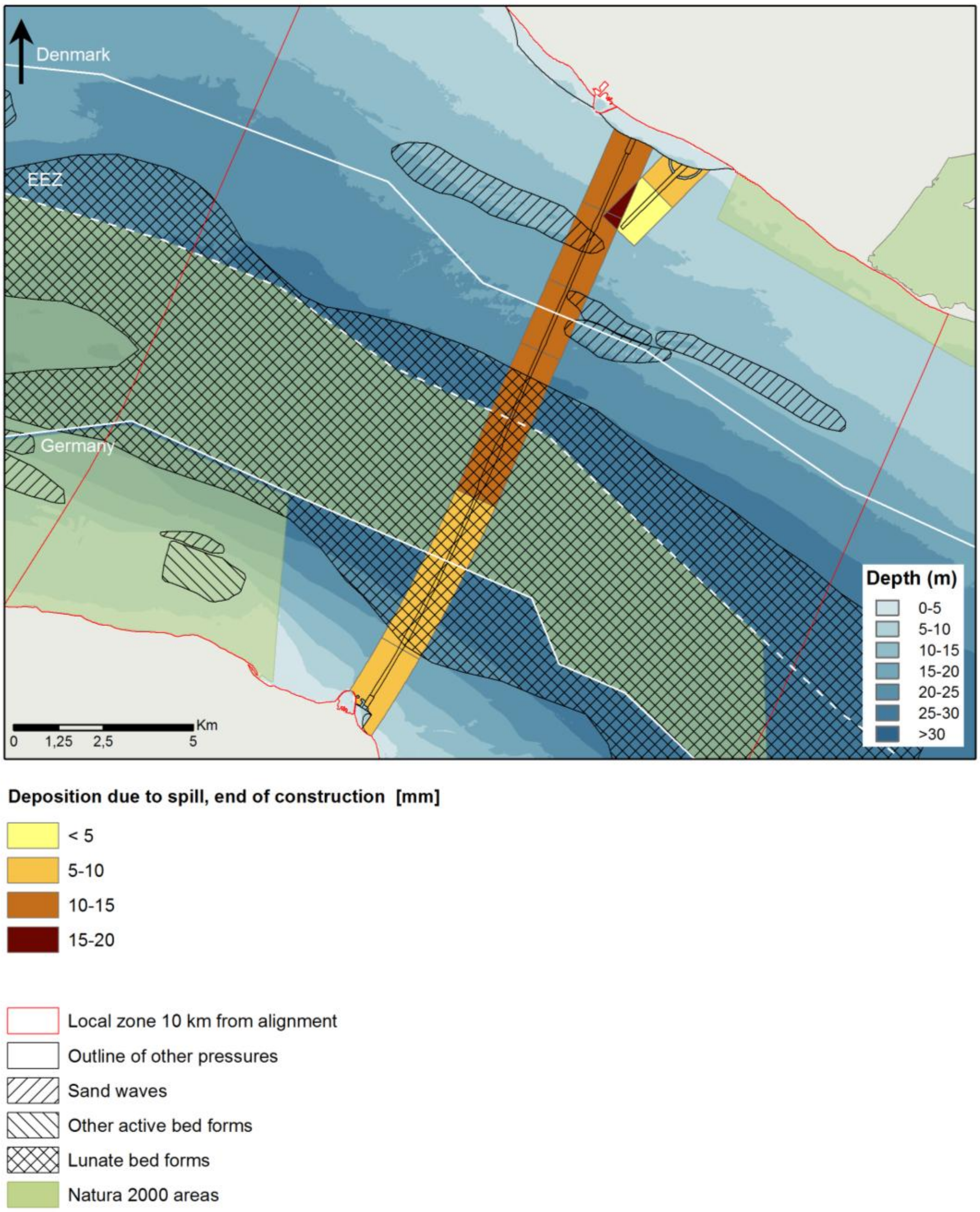


Figure 6.5 Variation of deposition thickness of sand along the tunnel trench with indications of sub-components. The marine parts of the relevant Natura 2000 areas are shown

6.5.2 *Loss and degree of impairment*

The sediment spill is predicted to deposit in the deeper areas of the sand waves and accumulate around the lunate bed forms. The geometrical properties of the bed forms will therefore change. For the sub-component 'Sea bed outside areas with prominent bed forms' the deposition is considered to have a negligible effect on the sea bed morphology as described in Section 2.2.

The impact from the sediment spill is characterised as temporary impairment according to the assessment criteria. The bed forms are expected to adjust to their natural geometrical properties with time.

The deposition volumes are not large enough to cause a temporary elimination of the bed forms by completely covering them in spill.

Degree of impairment

The relevant sub-component is marked for sections of the trench alignment in Figure 6.5 together with the deposition thicknesses along the trench.

Sediment will deposit within areas of both of the two sand wave fields near the alignment in the Danish territory. The sand wave field west of the alignment has bed forms of a typical height of 1.5-3 m. The calculated deposition in this area is around 13 mm. With a gathering of the deposited sediment spill in the deeper areas to a thickness of about 33 mm (see discussion in the chapter on sensitivity, Section 5.1.2) the expected reduction in the height of the sand waves is about 0.5-1%. The impacts from the dredging deposition to these sand waves are therefore well below 10% of the heights of the bed forms and therefore negligible according to the assessment criteria.

The smaller sand waves to the east of the alignment are typically 0.5-1 m. The deposition in this area is about 15 mm. After redistribution of the sediment to the deeper areas, the deposition will reduce the height of the sand waves by 38 mm or about 8%. The impacts to the height of the sand waves are also less than 10%.

The deposition within the lunate bed forms of 5-10 mm is predicted to add 10-25% to the volumes of the lunate bed forms (473 ha), and more than 25% where the deposition is above 10 mm (414 ha). The bed forms are therefore expected to grow in size. With the predicted rate of deposition, the lunate shape of the bed forms is expected to remain the dominant shape of the bed forms in the area.

Recovery times

The bed forms are expected to return to their baseline geometrical properties with time.

Some of the deposited sediment will probably wash out of the bed forms with time. Some sediment spill will become integrated into bed forms as they migrate, whereby they will also recover to their natural equilibrium geometrical shape and properties.

The recovery time for the lunate bed forms is difficult to predict, but it is expected that the time scale is similar or possibly even slightly larger than re-generation of the lunate forms from a plane bed (refer to Section 5.1). The effect is expected to be negligible within 30 years.

Degree of impairment

The degree of impairment is determined based on the assessment criteria in Section 3.6.

In the areas of the lunate bed forms, 473 ha are classified with minor and 414 with medium. The impairments from deposition in the sand wave areas are less than 10% of the bed form height and considered imperceptible.

6.5.3 Impact severity of loss/impairment

The impaired areas are classified with degrees of severity by combining the above degrees of impairments with the importance levels.

The impacted lunate bed forms along the alignment have a high importance level. A total of 473 ha are impaired temporarily with a medium degree of severity and 414 ha with a minor degree, see Table 6.8.

Table 6.8 Impacted areas and severity of impacts from deposition spill from dredging activities (Pressure 5) to the bed forms and sea bed in the Fehmarnbelt. Main tunnel solution (E-ME/August 2011)

Severity of impacts from Pressure 5: Deposition of spill	Total ha
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	414
Minor severity	473
Total temporary	**886**

6.6 Aggregation of impacts on components

The impacts for all project pressures from the main immersed tunnel alternative are summarised below. The impacts is evaluated for each of the four sub-components (three types of bed forms and the sea bed outside areas with prominent bed forms) to distinguish between the impacts to different types of sea bed morphology.

The impact areas within different regions of the Fehmarnbelt (near zone, local area, and Danish and German territories) are also evaluated.

The aggregation of the impacts for the pressures is simple in case of the tunnel project, since the impacts for the different pressures do not overlap. The aggregated impacts are shown in Figure 6.6 for severity of loss, and in Figure 6.7 and Figure

6.8 for degree of temporary impairments and severity of temporary impairments, respectively.

6.6.1 Sub-components

Tables providing the impacted areas of the individual sub-components are given below. The impacts are divided into the four impact levels for severity of loss and for degree of impairments in Table 6.9. Impairments are further divided on the four impact severity levels in Table 6.10.

It is noted that in all cases the assigned degree of severity of impairments is identical to the degree of impairments.

The impacts are given in areas (ha) and in parts (%) of the areas of the given sub-component within 10 km from the alignment (local area + near zone). The total impacted area (ha) is also provided (in ha) and as part of the total sea bed area (%) within 10 km from the alignment.

Sand waves

The total area of sand waves within the area within 10 km from the alignment is 1,261 ha. In total 5 ha of these are impaired by the tunnel project. This corresponds to 0.4% of the sand waves.

The impairment of the 5 ha of sand waves is caused by the elimination of the bed forms during the process of dredging for the tunnel trench. The sand waves will recover, but the large size of the sand waves in the impacted area (sand wave field west of the tunnel trench in Danish territory) causes a re-generation time of estimated 30-40 years.

None of the sand waves are within Natura 2000.

Lunate bed forms

A total of 984 ha of lunate bed forms are impacted by the main tunnel alternative B E-E August/2011. This corresponds to 6.7% of the total area of lunate bed forms within 10 km from the alignment.

The impacts to the lunate bed forms are all of a temporary character. The lunate bed forms are predicted to recover to their natural condition with time. The lunate bed forms in the trench alignment (corresponding to the 98 ha impaired with a high degree of impairment), which are eliminated by the dredging for the trench, will re-generate above the tunnel trench to a fully developed stage within 15-28 years.

The remaining area of the impaired lunate bed forms is caused by deposition of dredging spill. This pressure accounts for the temporary impairments classified as minor (473 ha) and medium (414 ha) degree depending on the deposition thickness in the area. The lunate bed forms are predicted to increase in size in this area as the deposition spill will gather around the bed forms and become integrated as a part of the bed forms. Within 30 years, the bed form area is predicted to return to a stage, where the bed forms have their natural geometrical properties.

Within Natura 2000, 56 ha of lunate bed forms are impaired temporarily to a high degree, 267 ha to a medium degree and 195 ha to a minor degree.

In summary, the majority (90%) of the impacted lunate bed forms will remain in the area, with a minor-medium change of geometrical properties which will gradually return to natural conditions. The remaining part of the bed forms is temporarily eliminated but will re-generate within 30 years or less.

Other active bed forms
No areas with ‘other active bed forms’ are impacted.

Sea bed outside of areas with prominent bed forms
482 ha outside of areas with prominent bed forms corresponding to 1.9% of the area without such morphological features are impacted by the tunnel project. The impacts are primarily a loss of sea bed (356 ha) where the new reclamations and protection reefs (primarily on the Danish side) are planned.

The remaining 126 ha are temporarily impacted by temporary structures (work harbours/storage areas) or dredging activities (tunnel trench, access channel to Lolland). The natural sea bed morphology will recover in these areas after the end of construction.

It is noted that the loss of beach area for recreational purposes and impacts related to the near-shore sea bed morphology (morphological elements in water depths less than 6 m DVR90) are treated separately in (FEHY 2013f). Only the loss of sea bed in the footprint area is included in this report.

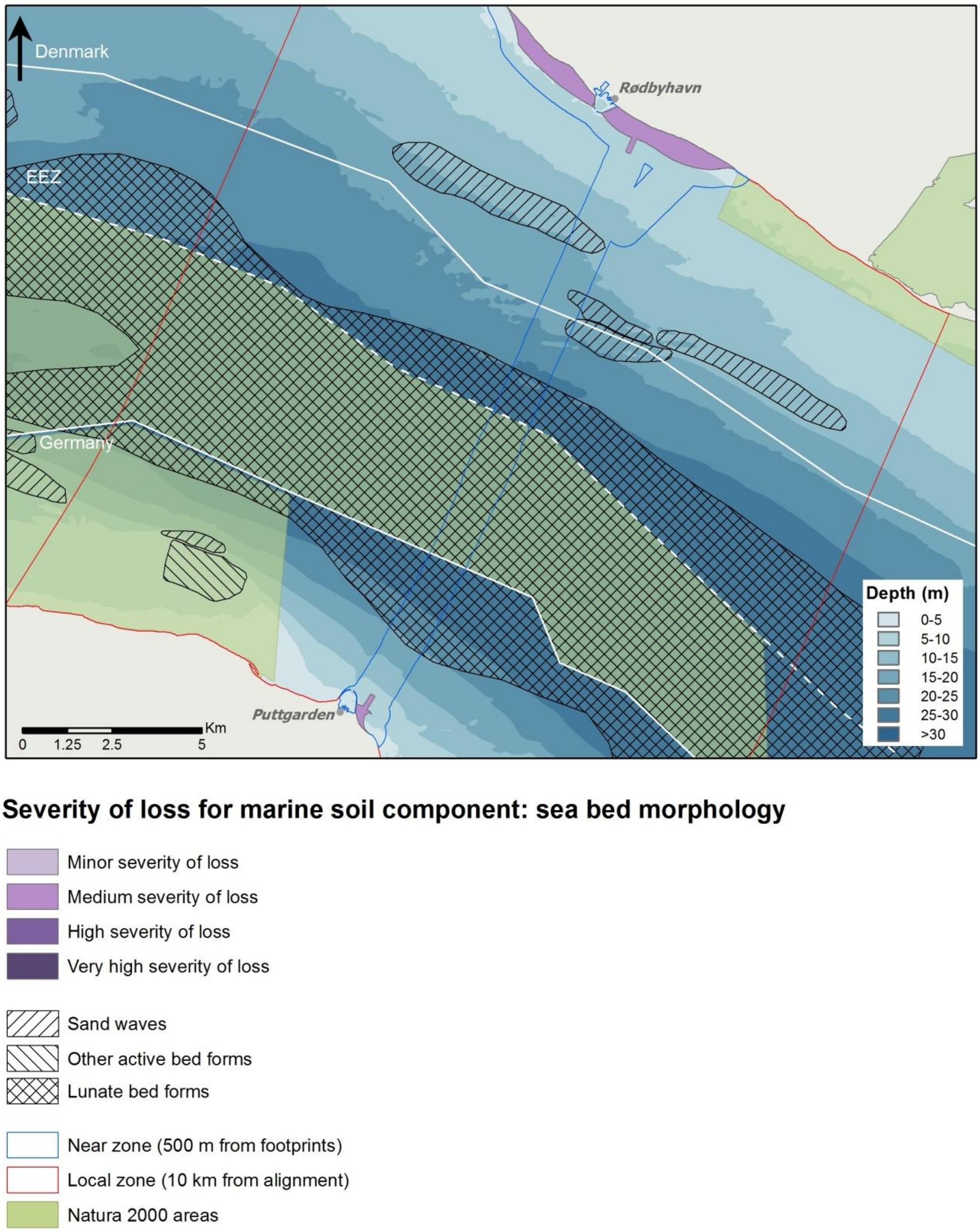


Figure 6.6 *Severity of loss for main tunnel solution. Aggregated impacts from various sources of pressure. Main tunnel alternative E-ME/August 2011. The marine parts of the relevant Natura 2000 areas are shown*

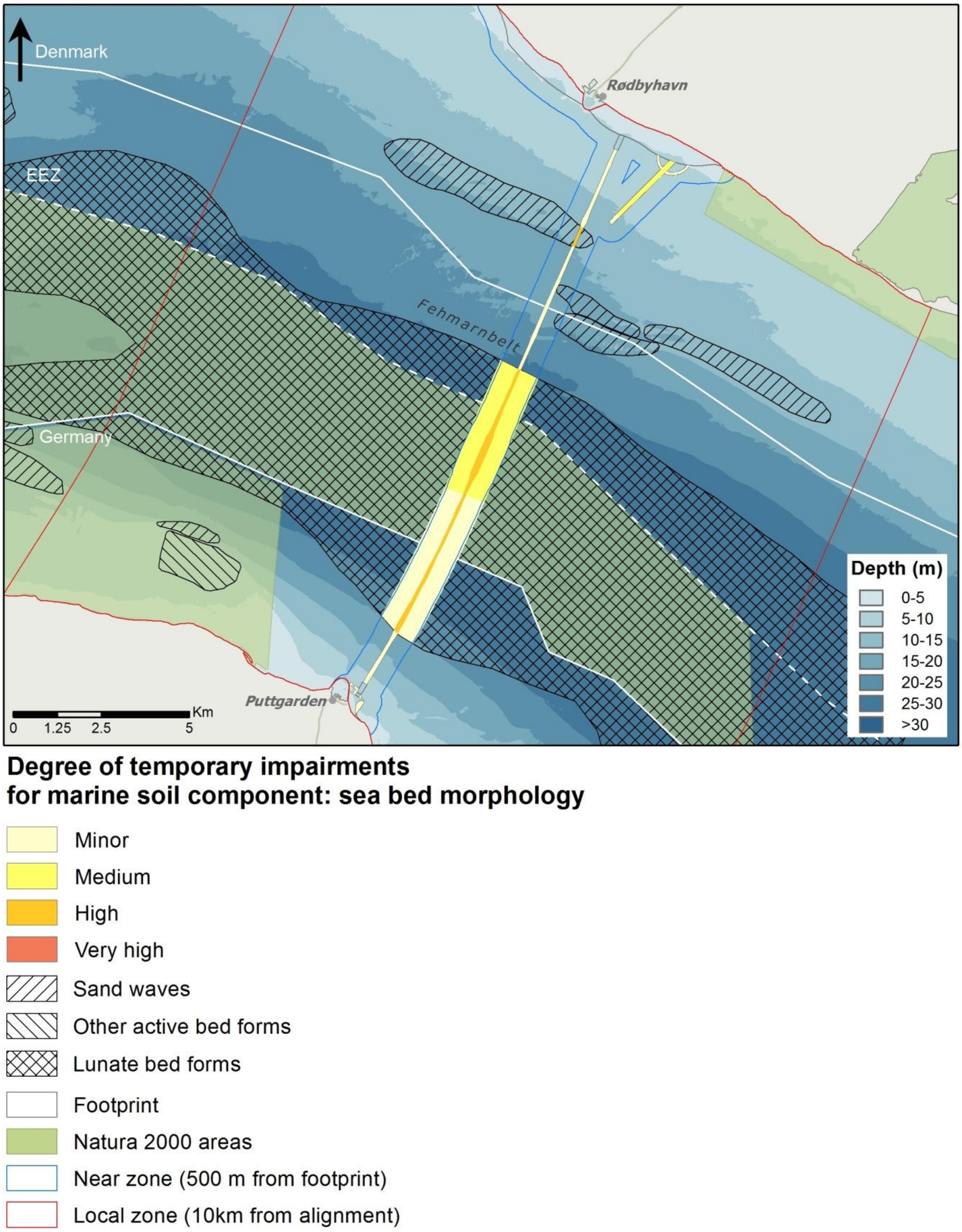


Figure 6.7 *Degree of temporary impairments for main tunnel solution. Aggregated impairments from various sources of pressure. Main tunnel alternative E-ME/August 2011. The marine parts of the relevant Natura 2000 areas are shown*

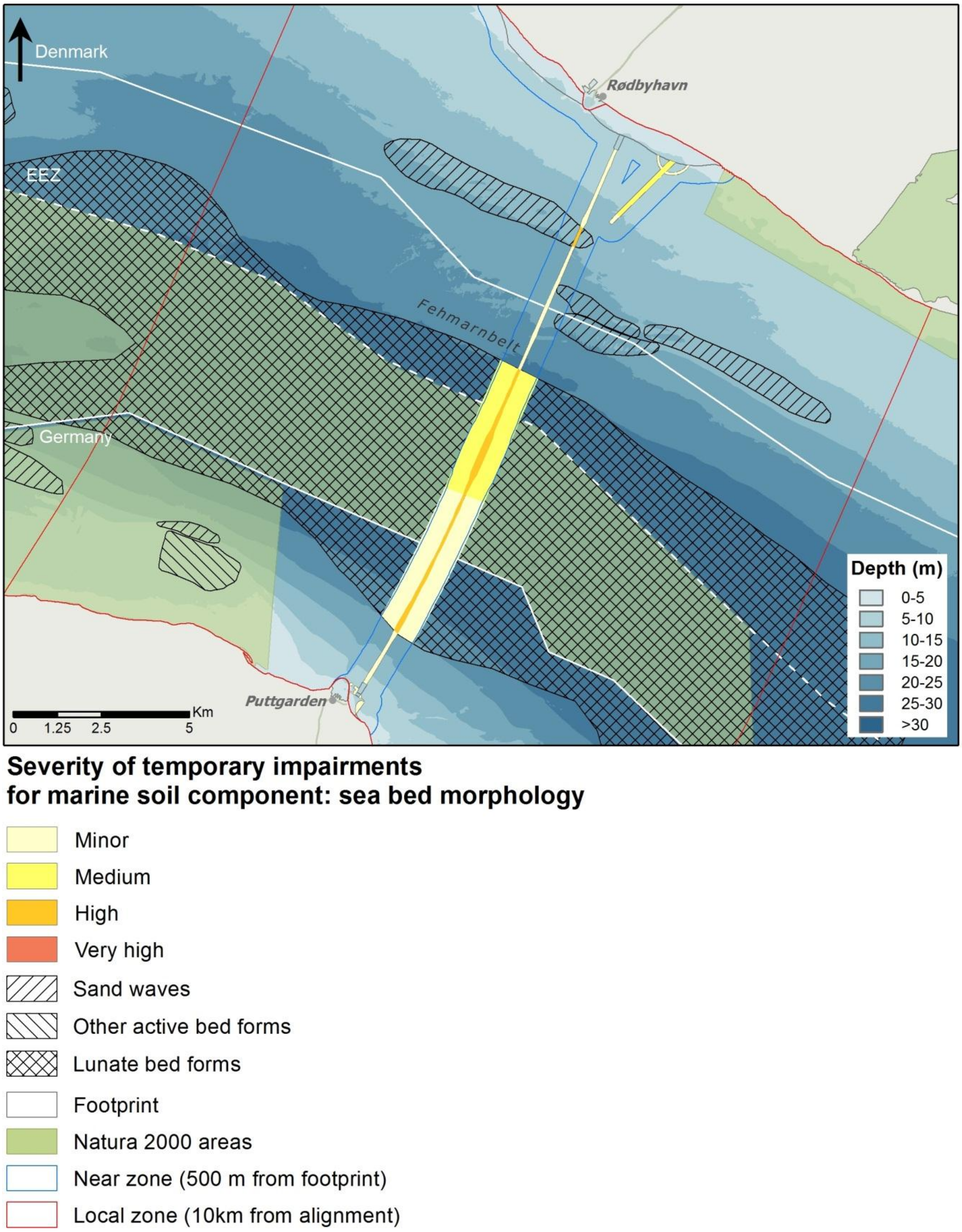


Figure 6.8 Severity of temporary impairments for main tunnel solution. Aggregated impairments from various sources of pressure. Main tunnel alternative E-ME/August 2011. The marine parts of the relevant Natura 2000 areas are shown

Table 6.9 *Summary of impacts from the main tunnel solution (E-ME/August 2011) on sub-components of the Marine Soil component sea bed morphology. Impacts divided on severity of loss and degree of impairments. Part of impacted areas of the sub-component are provided as percentage (%) of the reference area of the given sub-component within 10 km from the alignment (i.e. within near zone + local zone)*

Sub-component for Sea bed morphology	**Total**		Sand waves		Lunate bed forms		Other active bed forms		Outside areas with prominent bed forms	
	ha	**%**	ha	%	ha	%	ha	%	ha	%
Permanent impacts:										
Severity of loss										
Very high severity	0	0	0	0	0	0	0	0	0	0
High severity	0	0	0	0	0	0	0	0	0	0
Medium severity	356	0.9	0	0	0	0	0	0	356	1.4
Minor severity	0	0	0	0	0	0	0	0	0	0
Total	**356**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**356**	**1.4**
Total permanent	**356**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**356**	**1.4**
Temporary impacts:										
Degree of impairments										
Very high impairment	0	0	0	0	0	0	0	0	0	0
High impairment	103	0.2	5	0.4	98	0.7	0	0	0	0
Medium impairment	442	1.1	0	0	414	2.8	0	0	29	0.1
Minor impairment	570	1.4	0	0	473	3.2	0	0	98	0.4
Total	**1,115**	**2.7**	**5**	**0.4**	**984**	**6.7**	**0**	**0**	**126**	**0.5**
Total temporary	**1,115**	**2.7**	**5**	**0.4**	**984**	**6.7**	**0**	**0**	**126**	**0.5**
Maximum period of temporary effects (years)	**40**		**40**		**30**		**-**		**30**	
Total. Permanent + temporary impacts	**1,471**	**3.6**	**5**	**0.4**	**984**	**6.7**	**0**	**0**	**482**	**1.9**
Reference areas (ha)	**41,446**		**1,261**		**14,789**		**244**		**26,046**	

Table 6.10 Summary of severity of impairments from the main tunnel solution (E-ME/August 2011) on sub-components of the Marine Soil component sea bed morphology. Part of impacted areas of the sub-component are provided as percentage (%) of the reference area of the given sub-component within 10 km from the alignment (i.e. within near zone + local zone)

Sub-component for Sea bed morphology	**Total**		Sand waves		Lunate bed forms		Other active bed forms		Outside areas with prominent bed forms	
	ha	**%**	ha	%	ha	%	ha	%	ha	%
Severity of impairments, temporary										
Very high severity	0	0	0	0	0	0	0	0	0	0
High severity	103	0.2	5	0.4	98	0.7	0	0	0	0
Medium severity	442	1.1	0	0	414	2.8	0	0	29	0.1
Minor severity	570	1.4	0	0	473	3.2	0	0	98	0.4
Total temporary	**1,115**	**2.7**	**5**	**0.4**	**984**	**6.7**	**0**	**0**	**126**	**0.5**
Reference areas (ha)	**41,446**		**1,261**		**14,789**		**244**		**26,049**	

6.6.2 *Total impact for specific areas*

The impacted areas of the component sea bed morphology are divided on sub-parts of the Fehmarnbelt in Table 6.11.

The majority of the impacts to the sea bed morphology are assessed to take place within the near zone of 500 m around the project during construction. Only 192 ha corresponding to 13.1% of the total impacted area are impacted outside the near zone. The impact outside the near zone is caused by deposition of dredging spill within areas with lunate bed forms. The impacts are considered a temporary impairment of the bed forms.

Table 6.11 *Summary of severity of loss and degree of impairments from the main tunnel solution (E-ME/August 2011) on sub-parts of the Fehmarnbelt. Parts of impacted areas (%) are provided as percentage of the given sub-areas (reference area). Parts of total impacted area (%) are provided as percentage of local 10 km zone + near zone.*

Component:	**Sea bed morphology for tunnel E-ME (August 2011)**					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Permanent impacts: Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	0	0	0	0	0	0
Medium severity	356 (0.9%[1])	356 (11.8%)	0	335	21	0
Minor severity	0	0	0	0	0	0
Total permanent impacts	356 (0.9%)	356 (11.8%)	0	335	21	0
Temporary impacts: Temporary impairments						
Very high impairment	0	0	0	0	0	0
High impairment	103 (0.2%)	103 (3.4%)	0	15	56	30
Medium impairment	442 (1.1%)	389 (12.9%)	53 (0.1%)	172	0	270
Minor impairment	570 (1.4%)	431 (14.3%)	139 (0.4%)	72	303	195
Total temporary impacts	1,115 (2.7%)	923 (30.6%)	192 (0.5%)	256	359	495
Maximum period of temporary effects (years)	40	40	30	40	30	30
Total – permanent and temporary impacts	1,471 (3.6%)	1.279 (42.4%)	192 (0.5%)			
Reference area (ha)	41,446	3,019	38,427	-	-	-

6.6.3 Impact significance

The main tunnel solution has been assessed to cause impairments on a total of 989 ha of bed forms. All impacts to the bed forms are on a temporary time scale. No loss of bed forms is predicted.

The total area of bed forms within the local 10 km zone is 16293 ha, see Section 3.1.3. The impacted area of bed forms (989 ha) therefore corresponds to 6.1% of the bed forms within 10 km from the alignment.

All impacted bed forms are expected to recover. The bed forms will recover to their baseline conditions where they are dredged away for tunnel trench or remain in the area with a minor-medium degree of impairment due to dredging spill causing a temporary change in their heights and lengths. The longest predicted recovery time is 30-40 years for the sand waves west of the alignment to fully recover to their natural size due to their large size. For other areas of impacted bed forms, the recovery time is less.

In the baseline study, the influence of the bed forms on the flow through the Fehmarnbelt was found to be insignificant (FEHY 2013a). The above-mentioned changes of the bed forms do not change this situation and it is therefore assessed that the summarised impacts on the bed forms in the Fehmarnbelt caused by the tunnel project are therefore evaluated to be insignificant.

The primary contribution to the impacts on the sea bed morphology outside of the areas with the prominent bed forms is caused by the loss of sea bed in the areas of the coastal reclamations incl. the protection reefs. In total, they occupy 356 ha or 0.9% of the total sea bed area within 10 km from the alignment. For the sea bed morphology, this loss is considered insignificant.

In conclusion, it is assessed that the impacts from the main tunnel solution have no significant impacts on the marine soil component sea bed morphology.

Table 6.12 Summary of impacts to assessed sub-components

Significance of impacts to sea bed morphology **Sub-divided on sub-components**	**Sub-components**			
	Sand waves	**Lunate bed forms**	**Other active bed forms**	**Sea bed without prominent bed forms**
Significance of impacts	Not significant	Not significant	Not significant	Not significant

6.7 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 sea bed morphology.

6.8 Transboundary impacts

Transboundary impacts are not relevant for this component.

6.9 Climate change

The climate change 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%. For more typical wind speeds there are no indications of significant changes

- The ocean water level may rise up to 1 m, which will propagate into the Fehmarnbelt and the Baltic Sea

The impact of the immersed tunnel in such a new climate setting is evaluated as being similar to the estimated impacts for the present climate setting.

6.10 Mitigation and compensation measures

It is assumed that the sea bed areas are re-established in the areas of the temporary work harbours/storage areas, which are not integrated into the permanent reclamations although this is not explicitly stated in the technical description (see Section 5.2).

Possible mitigation measures to be considered in the final design are 1) active backfilling of the tunnel trench above the scour protection, and 2) active backfilling of the access channel to the Lolland production facility.

Backfilling of the tunnel trench would prevent the sea bed from having a shallow (0.7 m) trench (i78 ha in the Danish territory and 56 ha (D-EEZ) + 49 ha (D) in the German territory) with hard substrate (scour protection) in the bottom of the trench appearing after the end of the construction period. Backfilling would re-establish the sea bed to a plane bed where natural flora and fauna could possibly re-establish. In the areas of the lunate bed forms the re-generation of the bed forms would initiate across the entire backfilled trench immediately. Recovery of the bed forms to their fully-developed stage in the entire width of the trench area, however, is for the lunate bed forms in the Natura 2000 area predicted to be on the same time-scale with (15-22 years) and without (15-28 years) the active backfilling.

Similarly, backfilling of the access channel would prevent the sea bed from having a trench of up to 6 m below natural sea bed level remaining after the end of construction.

The mitigation measures are tabulated in Table 6.13. However, none of the above possible mitigation measures relate to significant impacts from the project, and they are therefore only included as technical options.

Table 6.13 Mitigation measures

Mitigation measures included in the conceptual design	**Recommended/possible mitigation measures for the final design**
Re-establishing of sea bed in areas of work harbours/storage areas	Active backfilling of tunnel trench above scour protection Active backfilling of access channel to production facility on the Danish side

6.11 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, and the tunnel elements themselves along with fill over the elements will also remain in the ground. The decommissioning process is therefore not predicted to cause any impacts on the sea bed morphology.

7 ASSESSMENT OF IMPACTS OF MAIN BRIDGE ALTERNATIVE

The assessment of project pressures from the main bridge alternative B E-E/Oct 2010 is described below. The impacts from the pressures on Marine Soil component sea bed morphology are found by combining the magnitudes of the pressures with the sensitivity of the assessed sub-components.

Loss of sea bed due to the permanent structures takes place in the areas of the marine ramps and at each bridge pier position. The structures will occupy a total of 56 ha. Table 7.1summarises the areas of sub-components impaired by various pressures.

The impacts from the pressures are described one by one below. Aggregation of the impacts provides a full overview of the impacts from the bridge. Aggregated results are described in Section 7.5.

Table 7.1 Summary of areas with impairments due to main bridge alternative. Relation between pressures and areas of impairments sub-divided on sub-components. Maximum period with temporary impairments is given for each pressure

Areas of impairments caused by below pressures [ha]	**Sub-components of sea bed morphology**					
	Sand waves	**Lunate bed forms**	**Other active bed forms**	**Sea bed outside areas with prominent bed forms**	**Total**	**Maximum period with temporary impairments**
Permanent impairments:						
Changes in near bed currents	594	3424	199	0	4216	(permanent impairments)
Temporary impairments:						
Work harbours	0	0	0	20	20	Sea bed outside areas with prominent bed forms: Up to 5 years
Deposition of sediments	0	37[1]	0	0	37[1]	Lunate bed forms: Up to 30 years
Total	594	3424[1]	199	20	4236	

[1] The area overlaps with impairments due to changes in near-bed currents

7.1 Pressure 1: Footprint of piers, pylons and peninsulas

7.1.1 Magnitude of pressure

During the construction of the bridge, land falls are constructed at the German and Danish side and piers and pylons will be erected with scour protection at the sea bed to prevent erosion around the structures.

The magnitude of the pressure on sea bed morphology from the piers and pylons is evaluated as the area of the footprint of the structures (incl. the scour protection) on the sea bed, see Figure 7.1.

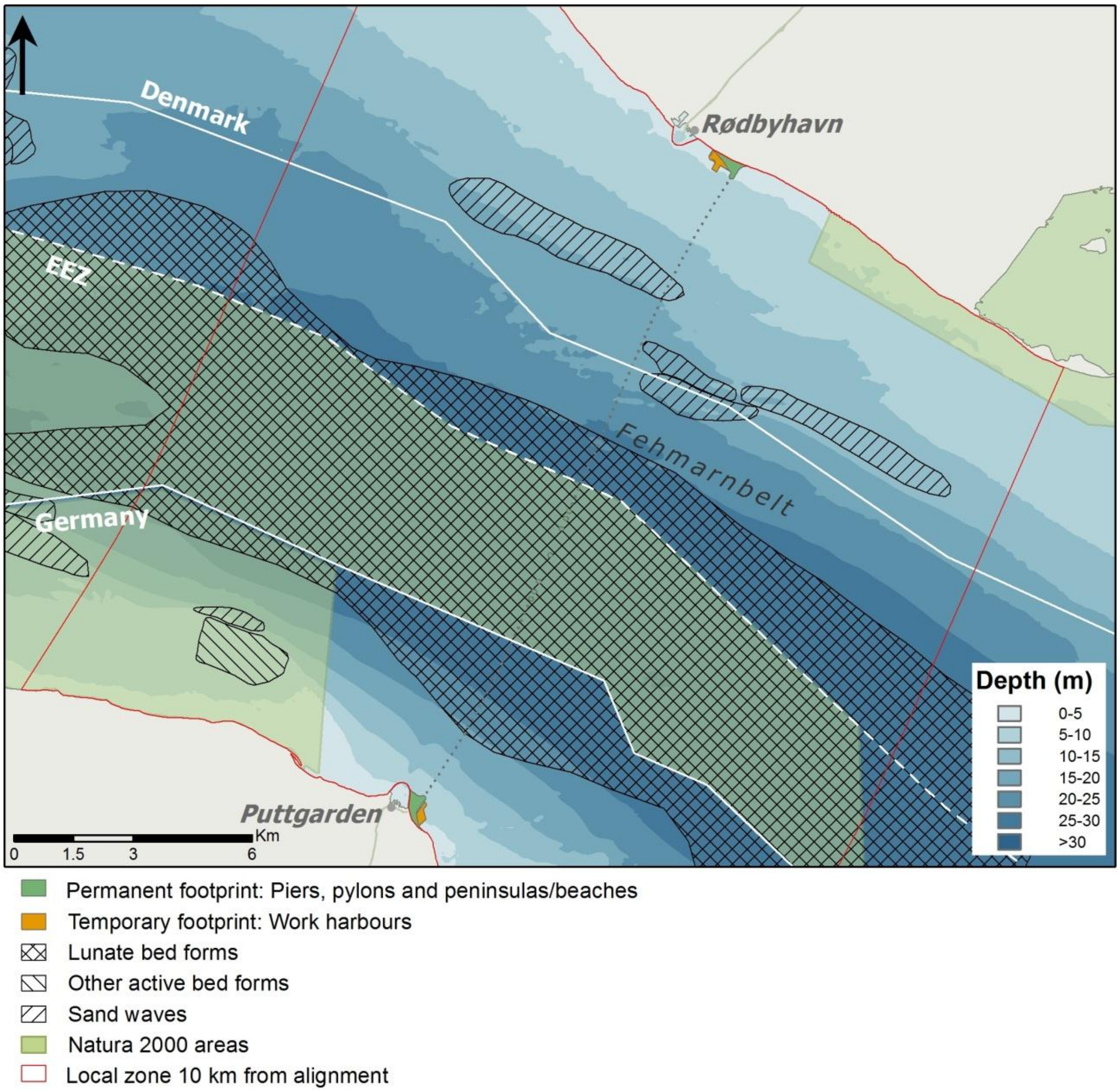


Figure 7.1 Footprint of pressure 1: piers, pylons and peninsulas including beaches. The marine parts of the relevant Natura 2000 areas are shown

7.1.2 Loss

In the affected areas, the sea bed will be occupied by structures and the natural sea bed morphology is lost.

The bridge alignment cuts through areas with sand waves on the Danish territory and lunate bed forms in Danish/German territory. The footprints of the piers and pylons therefore affect the sub-components sand waves (0.4 ha), lunate bed forms (12 ha) as well as sea bed outside of areas with prominent bed forms (43 ha). The peninsulas affect only sea bed area without bed forms.

The total area of the piers/pylons and peninsulas including the artificial beaches in east and west of the peninsula on the Danish side and east of the peninsula on the German side is 56 ha.

7.1.3 Impact severity of loss

The impact severity is the same as the importance levels for the impacted areas in case the impact is characterized as 'loss' (ref. Section 3.9).

The impacted bed forms (sand waves and lunate bed forms) are classified with a high importance level and hence they are categorized with a high impact severity level (13 ha). Sea bed in front of beaches to a water depth of 3 m DVR90 is also classified with a high importance level.

The sea bed outside of areas with prominent bed forms is classified as minor or medium importance level depending primarily on the level of anthropogenic activities. The impacted areas from the permanent footprints are therefore classified with medium impact severity (43 ha). The impact severity areas are summarised in Table 7.2.

Table 7.2 Impacted areas and severity of impacts from piers, pylons and peninsulas (Pressure 1) to the bed forms and sea bed in the Fehmarnbelt. Main bridge solution (Variant 2 B E-E/October 2010)

Severity of impacts from Pressure 1: Piers, pylons and peninsulas	Total ha
Loss	
Very high severity	0
High severity	13
Medium severity	43
Minor severity	0
Total	**56**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**56**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total temporary	**0**

7.2 Pressure 2: Changes in near bed currents

7.2.1 Magnitude of pressure

The flow in the Fehmarnbelt is affected by the bridge structures in three levels of geographical scale: immediate vicinity of structures, local effects and regional effects.

Immediate vicinity of structures

When the flow is forced around the bridge piers and pylons, the flow increases on the sides of the structures and on the downstream side of the pier/pylon a lee-zone is created. Local eddies or vortices are created near the bed and in the lee-zone behind the structures, recirculation and dynamic eddies may generate. Near-bed current speeds may change by more than 25% within four diameters from the piers/pylons. The total area within which such an increase will take place is 166 ha; of these are 128 ha within areas with bed forms. In such a flow regime the bed forms are expected to change character and a variation of bed forms (bed forms higher/lower than in the surrounding area, small-scale ripples, scour holes near the protecting stone layer around the structures or flat bed) may occur. The magnitude from the changes to the near-bed flow to the sea bed morphology is assessed as the area within four diameters from the piers/pylons (excluding the scour protection).

Local effects

Local effects to the flow are changes to the current field due to the increased resistance and the increased mixing of the water column the structures impose on the flow. The effects to the flow impact the bed forms by changing the sediment transport which has a direct influence on the height of the bed forms.

The changes to the near-bed current speeds are evaluated from a comparison of flow simulations with and without the bridge included in the numerical model carried out as a part of (FEHY 2013e). The simulations are carried out for the bridge solution B E-E/April 2010, which is slightly different from the main alternative assessed in this report, Variant 2 B E-E/October 2010. Results from the April 2010 alignment are translated geographically to the October 2010 alignment as described below to evaluate the magnitude of the pressure to the sea bed morphology from changes to the currents caused by the main alternative. The alignments of the two bridges are compared in Figure 3.8 in Section 3.3. The limited differences between the two bridges with regard to the hydrodynamic flow blocking are assessed in (FEHY 2013e). For the present work, the applied results are considered to imply slightly conservative hydrodynamic effects.

The relative changes to the annual mean near-bed current speeds (time-average of the absolute current speeds) due to the bridge structures (April 2010) are illustrated with shaded colours in Figure 7.2. The figure illustrates the relative changes between modelled near-bed flow fields for the baseline situation (ferry included) and the situation with the bridge structures and the ferry included in the simulations. The flow fields have been evaluated for the year 2005. The areas influenced by the 2005 simulations and the magnitudes of influence are assumed to be representative for average conditions.

The changes of the near-bed current speeds are located primarily along the alignment of the bridge alignment in the simulations (April 2010). The blocking effect from the piers and pylons imposes a blocking effect on the flow through the Fehmarnbelt. The total discharge through the Belt therefore slightly reduces; see below in the section related to "Regional effects". The piers and pylons cause a general increase in the currents in the gaps between the piers and pylons and an increase in the mixing of the water column. On a larger scale differences in the resistance between different sections of the bridge (caused by difference in the bridge piers or by differences in the current velocities and directions along the alignment) may also cause the flow to diverge to areas with smaller resistance.

The water column in the Fehmarnbelt is typically stratified since the salty and dense water originating from the North Sea and Kattegat is overlaid by the less dense and less salty water from the Baltic Sea. Flow directions may be in opposing flow directions in the upper and lower parts of the water column. The increased mixing of the water column due to the bridge structures causes a weaker stratification and increased momentum exchange between the upper and lower parts of the water column. During events with strong currents, where most of the sediment transport occurs, the flow is typically orientated in the same flow direction across the water column. The mixing of the water column due to the bridge piers and pylons increases the relatively lower current speeds near the bed, since water with high momentum (higher current speeds) will be mixed downwards.

Changes to the near current speeds of more than 2.5% are considered to impose a significant change to the bed form heights, refer to discussion in the sensitivity analysis in Section 5.1.3. The magnitude of the pressure from the changes to the near-bed flow is therefore established from the magnitude of the current changes in Figure 7.2 in areas of the Fehmarnbelt, where this limit is exceeded.

The impact areas along the alignment, where the changes to the current speeds exceed 2.5% are translated geographically in three sections, northern/central/ southern section, to the new bridge alignment with the distance between the alignments for these three sections. The hatched area in red is the impact area for the main bridge alternative. The areas where the changes to the near-bed current speeds exceed the 2.5% limit for impact on bed forms outside the bridge alignment are not translated geographically. The area, where changes to near-bed currents from the main bridge Variant 2 B E-E/October 2010 are assessed to have an order of magnitude which can lead to changes to bed forms (according to the assessment criteria in Table 3.10) are shown inFigure 7.3.

Regional effects

The regional effects relate to the overall water exchange between the Baltic Sea and the North Sea. These effects are described in (FEHY 2013g). A reduction in the order of about 0.5% reduced water exchange is estimated due to the overall blocking effect of the bridge piers and pylons as described above.

The reduction in the water exchange is an integrated value representing the time-averaged changes in the current speeds across the full water depth. There are no implications on the bed forms due to this effect.

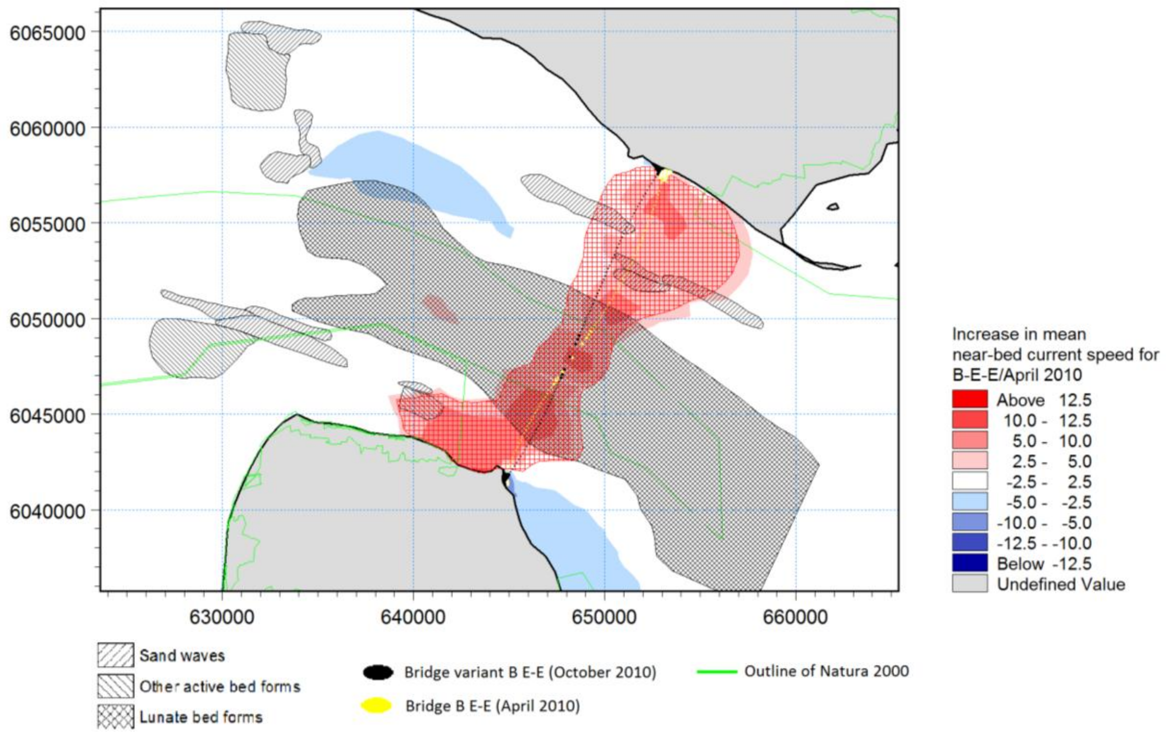


Figure 7.2 Local influence of the bridge piers and pylons to the annual time-average of the absolute near-bed flow speeds (2005). Relative changes as percentage (increase/decrease) of the near-bed current speeds approximately 3 m above the sea bed. Bridge alternative B E-E/April 2010 (shaded colours). Pressure area translated (red hatched area) to main bridge alternative Variant 2 B E-E/October 2010

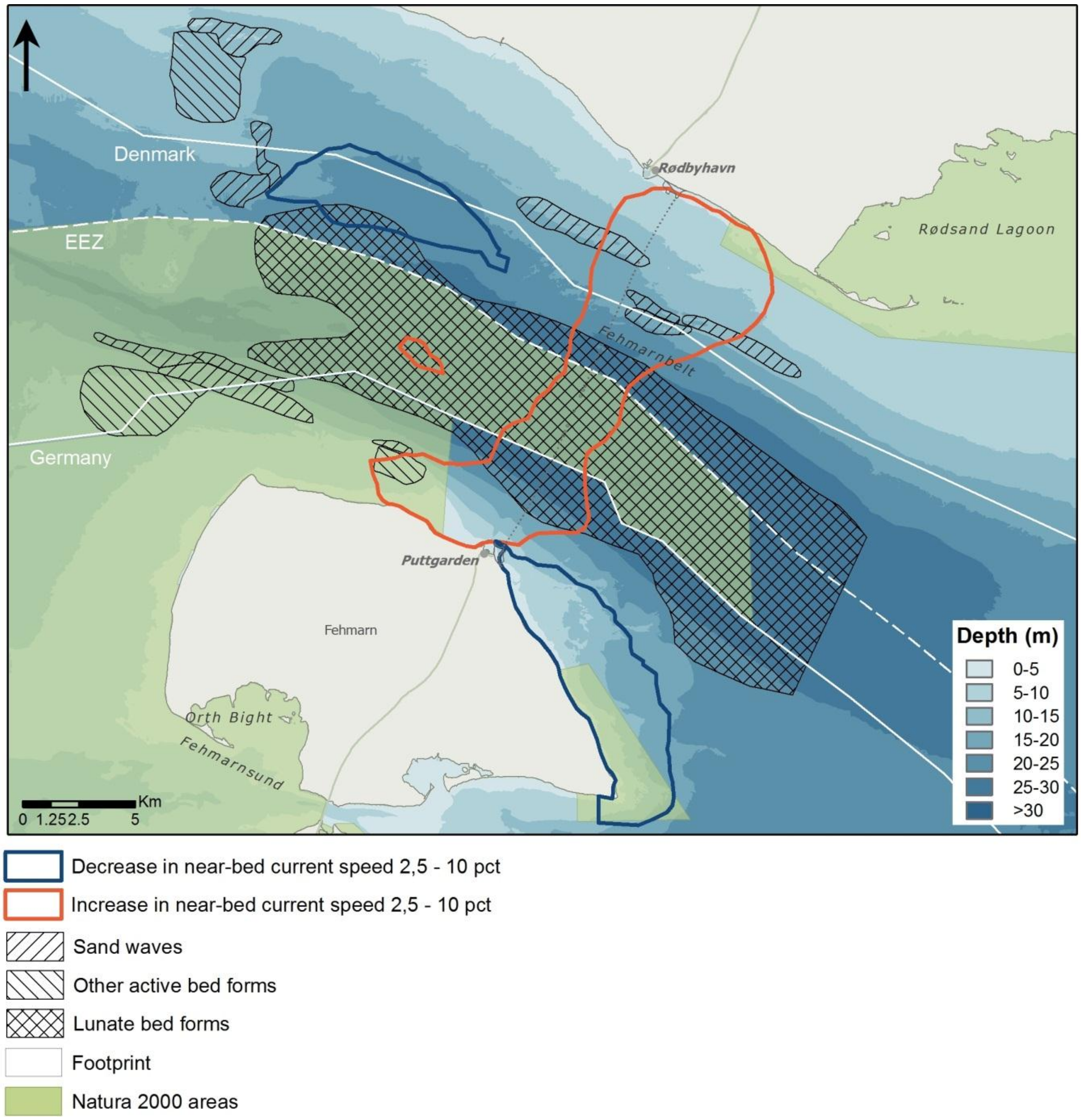


Figure 7.3 Areas, where changes to near-bed currents due to main bridge alternative Variant 2 B E-E/October 2010 have a magnitude, which may lead to impairments of bed forms

7.2.2 Degree of impairment

Changes to the near-bed current speeds are predicted to change the heights of the bed forms within the areas of the sand waves, lunate bed forms as well as 'other active bed forms'. These areas are categorised as permanently impaired.

The changes of the near-bed current speeds in areas of the sub-component 'sea bed outside areas with prominent bed forms' have the effect that the natural sediment transport increases/decreases. The lack of bed forms in these areas in the baseline situation is considered an indicator that there is not much available loose sea bed material on the sea floor. New areas with prominent bed forms are therefore not likely to appear. The changes of the near-bed currents are therefore considered to impose no impact on the sea bed morphology in areas of the sub-component 'sea bed outside areas with prominent bed forms'.

Within an area of four diameters from the piers/pylons, changes to the flow are so severe (>25%) that a change in the morphological regime is predicted. Bed forms are expected to change character and a variation of bed forms (bed forms higher/lower than in the surrounding area, small-scale ripples, scour holes near the protecting stone layer around the structures or flat bed) may occur in these areas for the new flow conditions with the bridge. The impairment on the sea bed morphology can hence be characterised as loss and is classified with a 'very high' degree of impairment. The areas within four diameters of the bridge piers/pylons include 3 ha within the area of the sand waves west of the alignment on the Danish side and 125 ha within the lunate bed forms in Danish/German territory.

Within the areas, where the near-bed current speeds increase or decrease by 2.5-10%, see Figure 7.2, the bed form heights are predicted to respectively increase or decrease by 10-25%. For the large sand waves (west of the alignment, Danish side) this corresponds to up to 0.75 m, for the small sand waves up to 0.25m (east of the alignment, Danish side and 5 km west of the alignment, German side) and for the lunate bed forms up to about 0.15 m.

The impacts in these areas are therefore classified as permanent with a minor degree of impairment according to the assessment criteria in Section 3.6. These areas constitute a total of 4088 ha (591 ha of sand waves; 3,299 ha of lunate bed forms; 199 ha of other active bed forms).

The bed form heights will not change abruptly to new flow conditions. An adjustment period is expected. The time for adaptation is difficult to predict. The bed forms change as they migrate and a migration distance in the order of the length of the sand waves can be expected (probably less than required for a full development of sand waves from a plane bed, refer to discussion in Section 5.1.1). For the smaller sand waves east of the alignment in the Danish territory and the sand wave field 5 km west of the alignment within German Natura 2000 area, this means in the order of 5-10 years. For the larger sand waves west of the alignment an adaptation period of 15-20 years is expected and for the lunate bed forms about 10-20 years.

The lowering of the general level of the sea bed is estimated by the following overall sediment budget for the local area of the bridge alignment with the bridge structures in place. The increase in the near-bed current speeds in the order of 5% causes an increase of about 20-60% of the sediment transport within the area where the near-bed current speeds increase (Figure 7.2). The annual net outflow of sea bed material from this confined area is therefore approximately 20-60% of the annual sediment transport in the situation of the 0-alternative. The annual net transport in the alignment area was found to about 5-25 m^3/m/year towards south-east, i.e. the loss of sea bed material is in the order of 2-10 m^3/m/year.

A loss of sea bed material in the order of 2-10 m^3/m/year causes a lowering of the sea bed along the bridge alignment within the area where the near-bed currents are increased. The lowering will initiate in the western part of this area and spread towards the east. The width of the area is in the order of 2 km. The rate of lowering the sea bed is therefore about 1-5 mm/year. The increased water depth following a lowering of the sea bed results in reduced current speeds and the lowering of the sea bed hence stabilises. Such a new equilibrium situation will take place on a time scale larger than the lifetime of the project.

7.2.3 Impact severity of impairment

The sand waves in the Danish territory and the lunate bed forms are classified with a high importance level, except for the sand waves (133 ha) within the sand mining area in the Danish territory. The sand waves within the German Natura 2000 area are classified with very high importance level. In these areas, the impact severity is high within the four diameters from the piers/pylons (combination of very high degree of impairment and high importance level) and minor in the areas where the current speeds are changed by 2.5-10% (minor degree of impairment and high/very high importance level). Impairments of the sand waves within the sand mining area are assessed with no severity of impacts having the combination of minor impairments in an area of minor importance, which according to Table 3.15 are classified as 'negligible' impact. The impact severity caused by the changes to the near-bed current speeds is tabulated in Table 7.3.

Table 7.3 Severity of impacts caused by changes to the near-bed currents (Pressure 2) to the bed forms and sea bed in the Fehmarnbelt. Main bridge solution (Variant 2 B E-E/October 2010)

Severity of impacts from Pressure 2: Changes in near-bed currents	**Total Ha**
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	128
Medium severity	0
Minor severity	3,955
Total	**4,083**
Total permanent	**4,083**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total temporary	**0**

7.3 Pressure 3: Deposition of sediments from dredging activities

7.3.1 Magnitude of pressure

During the dredging-activities for the bridge, sediment spreading and deposition will take place. The dredging period is planned to last six years for the bridge.

Magnitude of the pressure is based on simulations of sediment spreading and deposition fields reported in FEHY 2013d. The simulations are carried out for a previous version of the bridge, the B E-E/April 2010 alternative. A comparison of two alternatives is shown in Figure 3.8 in Section 3.3.3.

The simulations show that the finest fractions (clay, silt) of the dredging spill depositing on the sea bed do not remain within the Fehmarnbelt area. They are carried with the flow to areas with a calmer hydrographic environment where settling is possible. The deposition of dredging spill at the sea at the end of the construction period is the sand fraction (FEHY 2013d). Only the sediment which remains in the area at that time is considered important for sea bed morphology, refer to discussion in Section 2.2.

Due to the relatively high settling velocity of sand grains (relative to finer fractions such as clay/silt), the sand fraction drops out of the water column and deposits very near the points of dredging, i.e. in the immediate vicinity of the piers and pylons.

Since the simulations are carried out for a slightly different alignment of the bridge (April 2010), the results for the deposition around the main bridge alternative assessed in this report are found by:

1. Estimating the thickness of the deposition around the bridge piers/pylons in bridge alternative B E-E/April 2010

2. Translating the estimated deposition thicknesses around the piers/pylons in the previous bridge alternative to the bridge piers/pylons in the main alternative, which are located in the vicinity of the piers/pylons in the previous alternative

Step 2 ensures that the deposition around the piers in the main alternative corresponds to the sand content in the dredged sea bed material at the locations of the piers/pylons in the assessed alternative.

The deposition from the dredging spill is calculated based on the volume of spilled sand around the individual piers/pylons in the previous alternative when dredging for the structures and scour protection. The sand with an average fall velocity of 0.015 m/s is estimated to travel no further than 600 m from the point of dredging in the flow directions (FEHY 2013d). For the present work it is assumed that the sand deposits evenly within an area of +/- 600 m perpendicular to the alignment of the approach bridges and evenly within a diameter of 600 m from the centre of the pylons. In reality much of the sediment will deposit within a few hundred metres from the structures and less will travel as far as 600 m. The conservative assumption of an evenly distributed sand volume is applied, since the geographical distribution of the thickness of the sand fraction is not known within the 0-600 m limit.

The estimated variation in the deposition thickness along the bridge alignment calculated with the above methodology is shown in Figure 6.5. The deposition thickness is less than 5 mm along the approach bridges and 10 mm around the centre pylon.

The thickness of the deposition layer is expected to decrease further with time after the end of the construction period, but to which degree is not known.

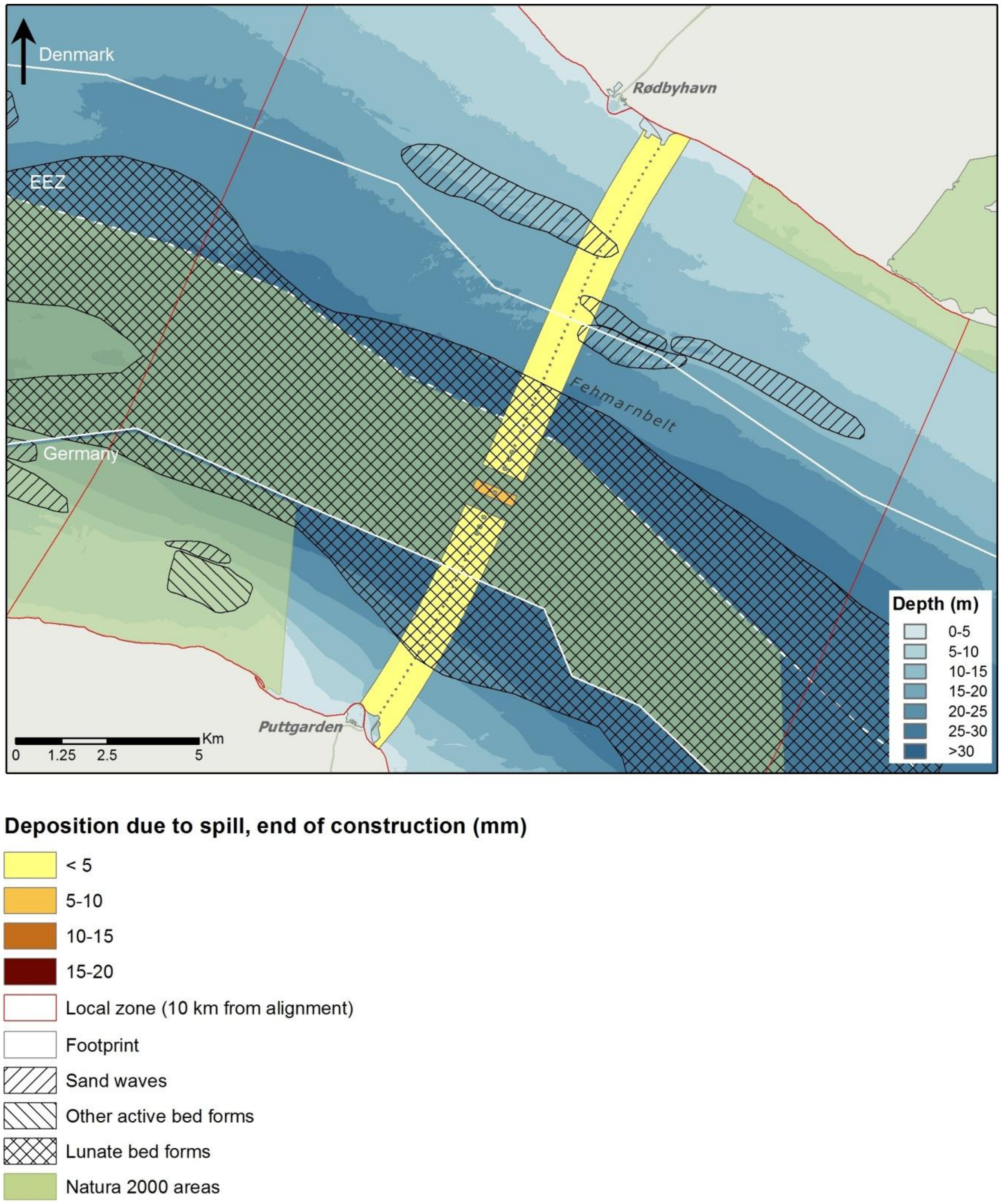


Figure 7.4 Variation of estimated deposition thickness of sand at the end of construction along the main bridge alternative Variant 2 B E-E/October 2010 with indications of sub-components. The deposition is estimated from simulations of bridge alternative B E-E/April 2010. The marine parts of the relevant Natura 2000 areas are shown

7.3.2 Degree of impairment

The sediment spill can change the geometrical properties of the bed forms. The bed forms are expected to return to their natural state with time and the impact is therefore characterised as a temporary impairment according to the assessment criteria described in Section 3.6. For the sub-component 'Sea bed outside areas with prominent bed forms' the deposition is considered to have a negligible effect on sea bed morphology as described in Section 2.2.

Degree of impairment
Sediment will deposit within both of the two sand wave fields near the alignment in the Danish territory, see Figure 7.4. East of the bridge alignment the typical sand wave heights are between 0.5 and 1 m. The calculated evenly distributed deposition in this area is around 3 mm. The deposited material gather in the deeper areas of the sand wave field and the heights of the sand waves are reduced by about 2.5 times the thickness of the deposition corresponding to 7.5 mm, refer to discussion in Section 5.1.2. This corresponds to a height reduction of 1.5% of the bed forms, which is well below the 10% limit for a significant impact on the sand waves according to the assessment criteria in Section 3.6.

The sand waves west of the bridge alignment are larger, 1.5-3 m, and the deposition is of a similar size as in the sand wave field with the smaller bed forms east of the alignment. The deposition does therefore also not impact these bed forms to a significant degree.

The deposition within the lunate bed forms is less than 5 mm along the majority of the alignment, and hence below the critical thickness of deposition of sediment spill within the lunate bed forms (refer to discussion on sensitivity in Section 5.1.2). Around the centre pylon, the deposition of around 10 mm is predicted to add 10-25% to the volumes of the lunate bed forms in a relatively small area (37 ha). The bed forms are therefore expected to grow in size. With the predicted rate of deposition, the lunate shape of the bed forms is expected to remain the dominant shape of the bed forms in the area.

Recovery times
The bed forms are expected to return to their baseline geometrical properties with time.

Some of the deposited sediment will probably wash out of the bed forms with time. Some sediment spill will become integrated into bed as they migrate, whereby they will also recover to their natural equilibrium geometrical shape and properties.

The recovery time for the lunate bed forms is difficult to predict, but it is expected that the time scale is similar or possibly even slightly larger than re-generation of the lunate forms from a plane bed (refer to Section 5.1). The effect is expected to be negligible within 30 years.

Degree of impairment
The degree of impairment is determined based on the assessment criteria in Section 3.6.

In the areas of the lunate bed forms, 37 ha are classified with a minor degree of temporary impairment. The impairments from deposition in the sand wave areas are less than 10% of the bed form height and considered imperceptible.

7.3.3 Impact severity of impairment
The impaired areas are classified with degrees of severity by combining the above degrees of impairments with the importance levels.

The impacted lunate bed forms along the alignment have a high importance level. The impacted area of 37 ha is impaired temporarily with a minor degree of severity, see Table 7.4.

Table 7.4 Impacted areas and severity of impacts from deposition of sediment from dredging activities (Pressure 3) to the bed forms and sea bed in the Fehmarnbelt. Main bridge solution Variant 2. B E-E/October 2011

Severity of impacts from Pressure 3: Deposition of sediments from dredging activities	**Total ha**
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	37
Total temporary	**37**

7.4 Pressure 4: Temporary work harbours and storage areas

7.4.1 Magnitude of pressure

The magnitude of the pressures from the temporary work harbours and storage areas are identical to the area they cover, a total of 20 ha. Only the area of the work harbours and storage areas, which are not integrated/covered by the peninsulas or new beaches are assessed, refer to discussion in Section 2.2 on relevant project pressures. These areas were shown in Figure 7.1 in Section 7.1.

7.4.2 Degree of impairment

The areas of the breakwaters and storage areas are expected to recover after the structures are dismantled and the sea bed re-established by active backfilling. The impact is therefore considered temporary impairment of the sea bed. It is expected that the sea bed morphology will recover to a natural state within a time scale of about 5 years, refer to the discussion on sensitivity in Section 3.5.2.

The degree of impairment for these areas is classified as minor according to the assessment criteria in Section 3.6.

7.4.3 Impact severity of impairment

The impaired areas (20 ha) are all classified with a minor degree of severity, see Table 7.5, as a combination of the minor degree of impairment and the medium importance level sea bed areas off Puttgarden and Rødbyhavn.

Table 7.5 *Impacted areas and severity of impacts from temporary work harbours and storage areas (Pressure 4) to the bed forms and sea bed in the Fehmarnbelt. Main bridge solution (Variant 2 B E-E/October 2010)*

Severity of impacts from Pressure 4: Temporary work harbours and storage areas	**Total Ha**
Loss	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Permanent impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	0
Total	**0**
Total permanent	**0**
Temporary impairment	
Very high severity	0
High severity	0
Medium severity	0
Minor severity	20
Total temporary	**20**

7.5 Aggregation of impacts on components

The impacts to the component sea bed morphology caused by all project pressures caused by the main bridge solution (Variant 2 B E-E/October 2010) are summarised below. The impact severities are evaluated for the four sub-components and for sub-areas of the Fehmarnbelt (near zone, local 10 km zone, German and Danish territories).

Two of the pressures from the bridge project influence the sea bed morphology in the same areas: deposition of sediment spill and changes in near-bed currents. Deposition of spill affects a smaller area than change to the currents. The temporary impairment from the deposition of spill initiates immediately when dredging activities take place, and decreases with time. The permanent impairments due to the changes to the near-bed currents initiate immediately when the piers/pylons are erected, but the impact is a slow change to the heights over time until they have adjusted to the new flow situation. The influence of these two types of pressures to the bed forms is therefore shifted in time and does not enhance the effects of one another.

The remaining impacts from the two other pressures (footprints of piers, pylons and peninsulas and footprints of temporary work harbours and storage areas) do not overlap.

The aggregated impacts are shown in Figure 7.5 and Figure 7.6 for severity of loss; for degree of permanent impairments and severity of permanent impairments in Figure 7.7 and Figure 7.8; and in Figure 7.9and Figure 7.10 for degree of temporary impairments and severity of temporary impairments , respectively.

7.5.1 Sub-components

The impacts on the four sub-components, sand waves, lunate bed forms, other active bed forms and 'sea bed outside of areas with prominent bed forms' are summarised below.

The impacts are divided into the four impact levels for severity of loss and for degree of impairments in Table 7.6. Impairments are further divided on the four impact severity levels in Table 7.7.

The impacts are given in areas (ha) and in parts (%) of the areas of the given subcomponent within 10 km from the alignment (local zone + near zone). The total impacted area (ha) is also provided (in ha) and as part of the total area (%) within 10 km from the alignment.

Sand waves

In total 594 ha of sand waves are impacted out of the total area of sand waves of 1261 ha within 10 km from the alignment. This corresponds to 47.1% of the sand waves.

The impacts are partly loss due to structures (0.4 ha) and partly permanent impairment (594 ha). Of the permanently impaired sand waves, 3 ha are impaired to a very high degree, where the sand waves as such are considered 'lost', i.e. the sea bed forms are considered to significantly change character.

The small areas of such a 'loss' of sand waves are all within Danish territory. The loss is caused by piers/pylons occupying the sea bed and the drastic change in the flow field in the immediate vicinity of the structures.

The remaining areas of impaired sand waves (within Danish as well as German territory) are expected to have increasing heights of the bed forms by 10-25% due to increasing near-bed current speeds caused by the piers/pylons. The heights are expected to increase over approximately 5-10 years and reach a new permanent state. Parts of the impacted sand waves (133 ha) are within the areas, where sand mining has been carried out (Danish territory), and these bed forms are assessed with no severity of impacts according to the assessment methodology, see Figure 7.8.

The sand wave fields within the German Natura 2000 area are not affected by the bridge project.

In summary, the majority of the impacted sand waves will remain in the area with a slight modification to their heights.

Lunate bed forms

3,436 ha of the lunate bed forms in the central part of the Fehmarnbelt is predicted to be impacted by the main bridge solution. 21.6% of the lunate bed forms within 10 km from the alignment are impacted and 240 ha further away.

The majority of the impacts (96.0% of the impact area for lunate bed forms) to these bed forms are of a permanent character with a minor degree of impairmentl caused by the predicted changes to the near-bed current speeds due to the piers/pylons. The lunate bed forms are expected to maintain their geometry, but increase in size corresponding to about 10-25% of their heights.

In the alignment area, deposition of sediment spill increases the volumes of the lunate bed forms. The impairment from the sediment spill (37 ha) is expected to be of temporary character with a slow recovery of the geometry of the bed forms to a natural state within approximately 30 years.

There will be a small loss of 137 ha of lunate bed forms due to erection of piers/pylons and strong changes to the currents in the vicinity in the footprints and the immediate vicinity of the piers/pylons. This corresponds to 0.9% of the lunate bed forms within 10 km from the alignment.

Within Natura 2000, 116 ha of lunate bed forms are permanently eliminated (due to piers/pylons and flow changes in the immediate vicinity of these), 1,253 ha are impaired permanently to minor degree of impairment and 37 ha are impaired temporarily to a minor degree of impairment. The latter 37 ha overlaps with the permanently impaired area assigned a minor degree of impairment.

Other active bed forms
The sub-component characterised by 'other active bed forms' are impacted in the area located about 5 km west of the alignment in German territory within Natura 2000. These bed forms are predicted to have increased heights by 10-25% or 0.05-0.25 m. The impacts cover 199 ha.

The 'other active bed forms' in this area are similar to the sand waves, but less regular in their rhythmic pattern and heights than the sand waves. The impacts are not expected to change this.

Sea bed outside of areas with prominent bed forms
63 ha outside of areas with prominent bed forms corresponding to 0.2% of the area without such morphological features are impacted by the main bridge project.

These impacts are all related to the footprints of the piers/pylons and peninsulas of the work harbours/storage areas.

The majority of the impacts are loss of natural sea bed (43 ha) where the peninsulas with beaches will be build.

The remaining 20 ha are temporarily impacted by the areas of the work harbours/storage areas, where these are not integrated into the peninsulas/beaches. The natural sea bed morphology will recover in these areas after the end of construction.

The impacts to these areas do not constitute any significant influence to the sea bed morphology.

It is noted that the loss of beach area for recreational purposes and impacts related to the near-shore sea bed morphology (morphological elements in water depths less than 6 m DVR90) are treated separately in (FEHY 2013f). Only the loss of sea bed in the footprint area is included in this report.

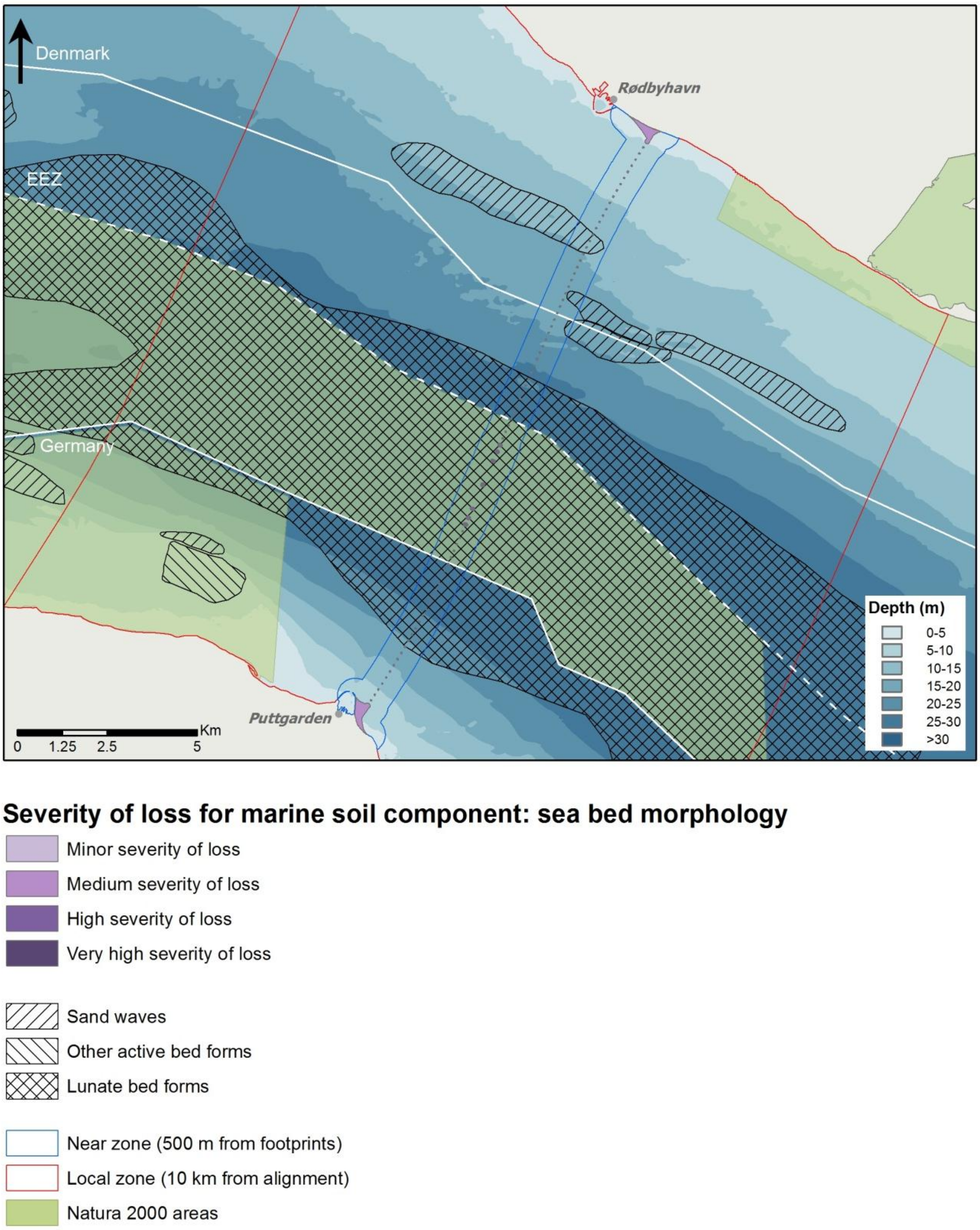


Figure 7.5 Severity of loss for main bridge solution. Aggregated impacts from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown

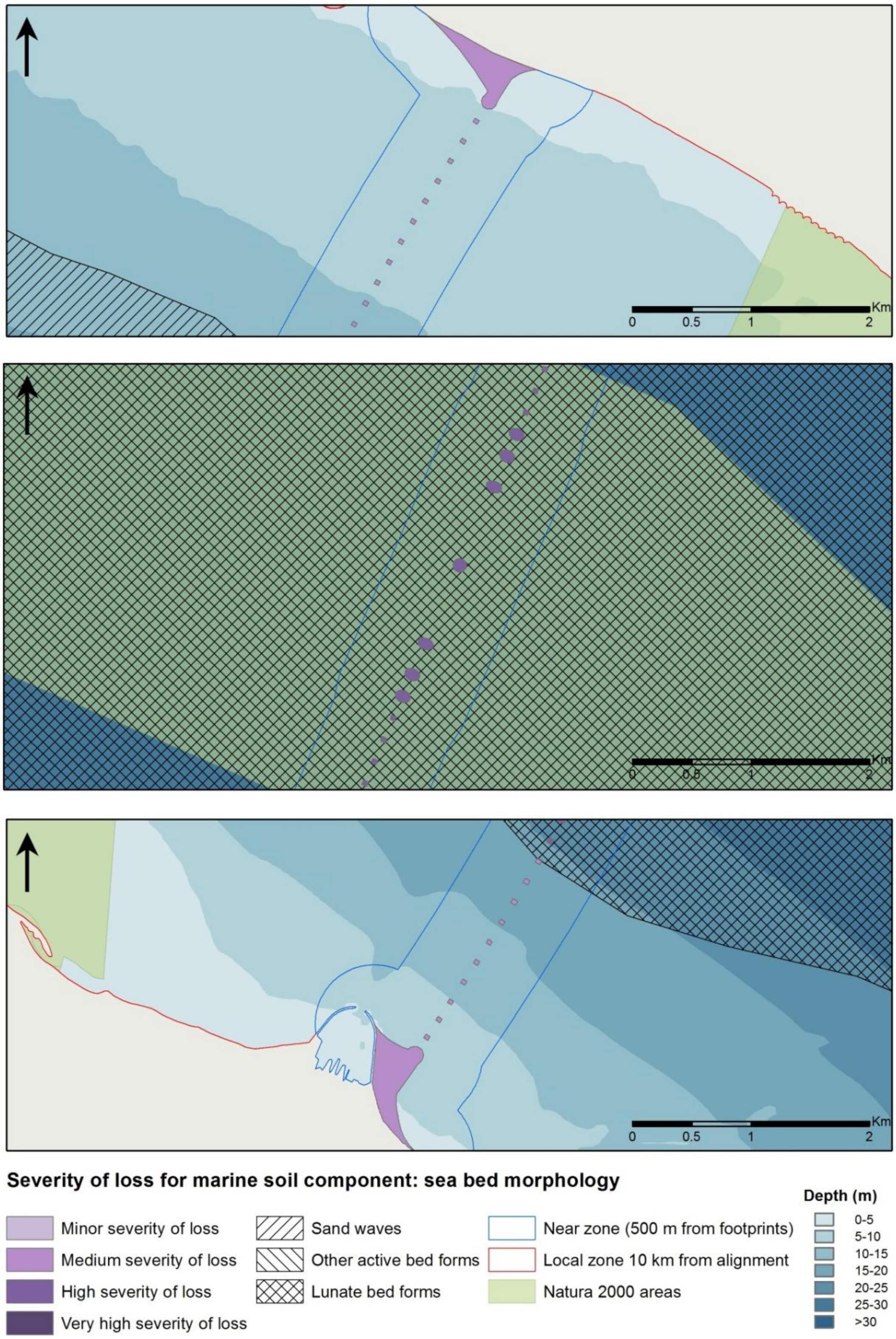


Figure 7.6 Severity of loss for main bridge solution - zooms. Aggregated impacts from various sources of pressure. Main bridge alternative Variant 2/October 2010. The marine parts of the relevant Natura 2000 areas are shown

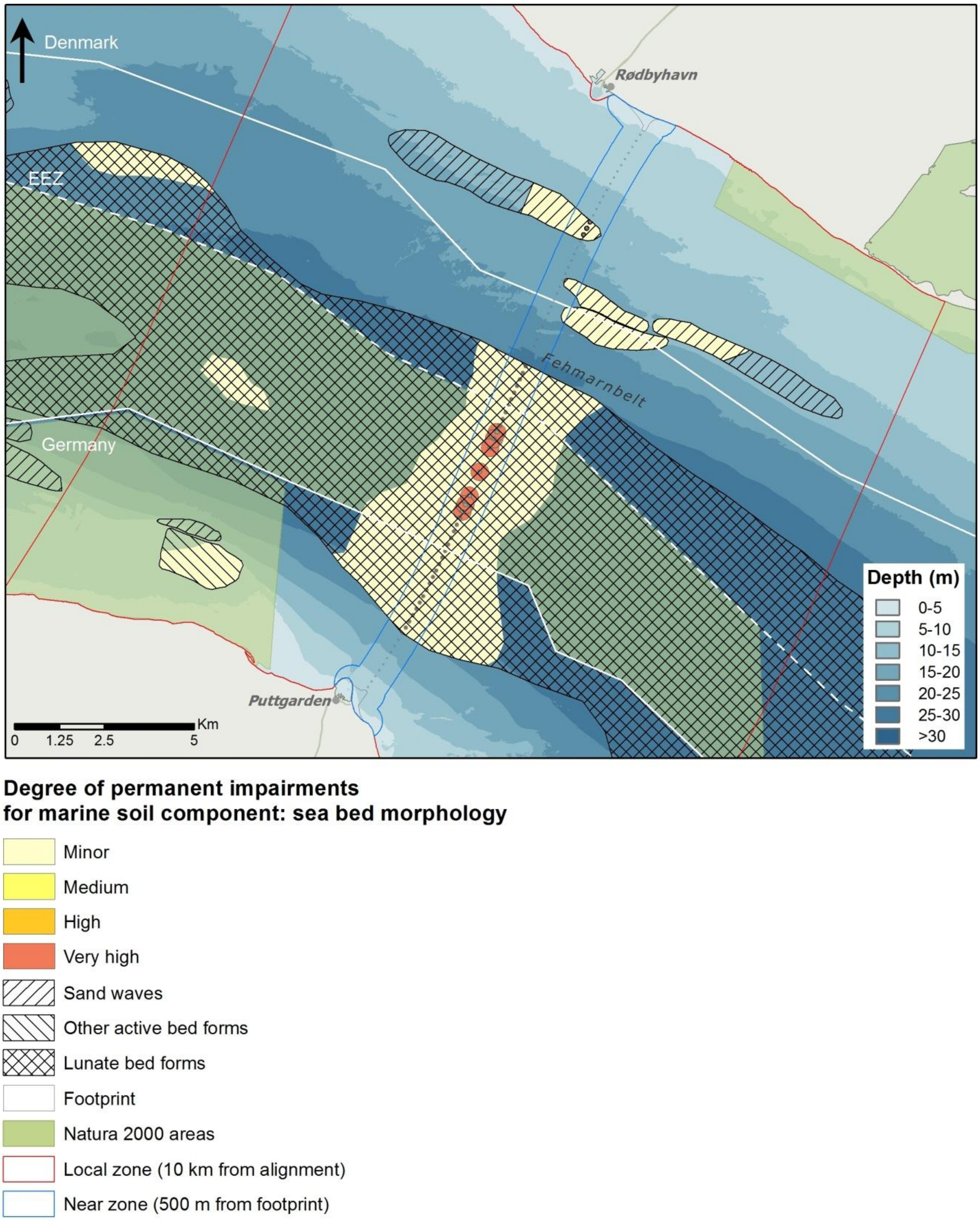


Figure 7.7 Degree of permanent impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2/October 2010. The marine parts of the relevant Natura 2000 areas are shown

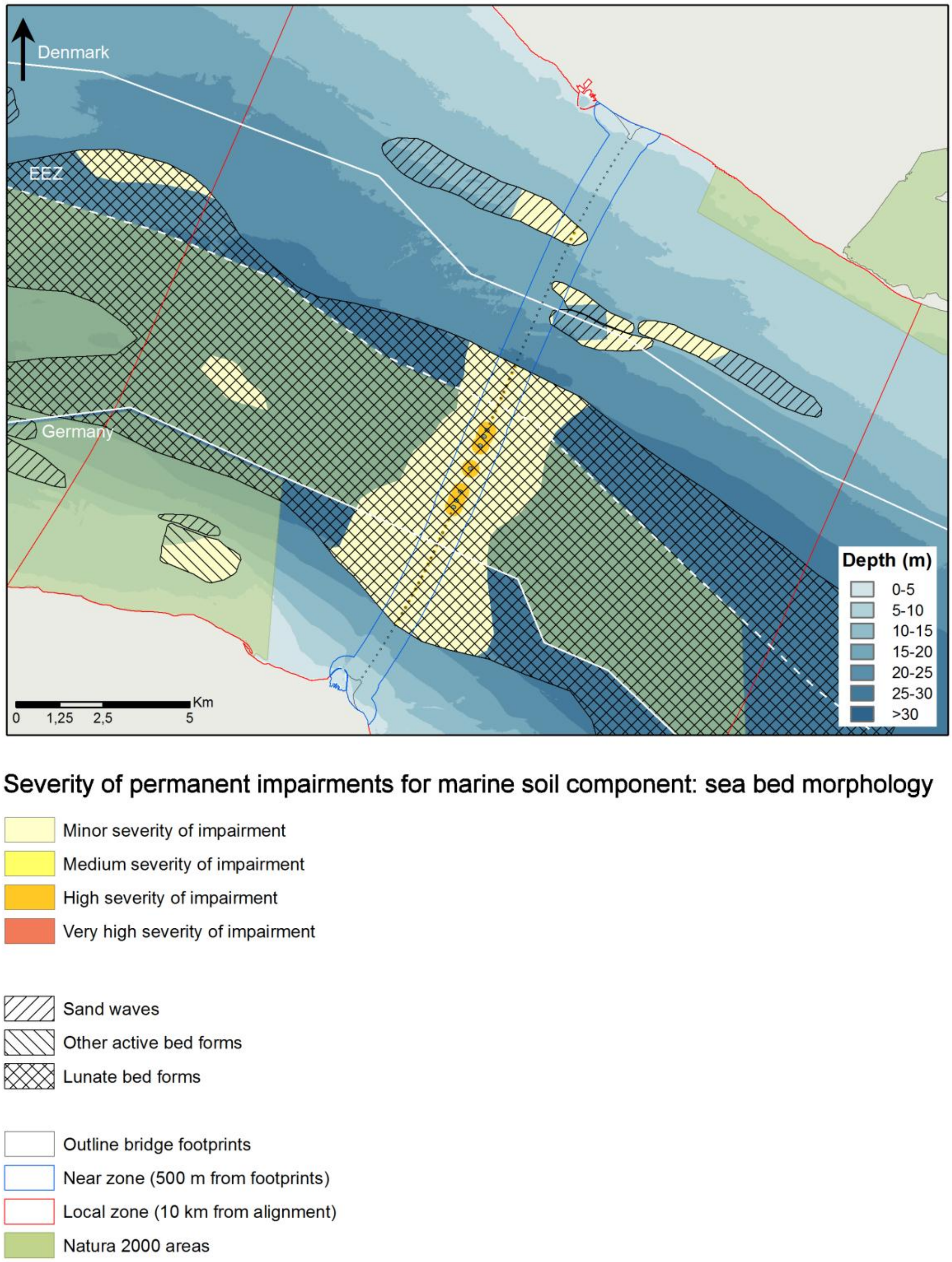
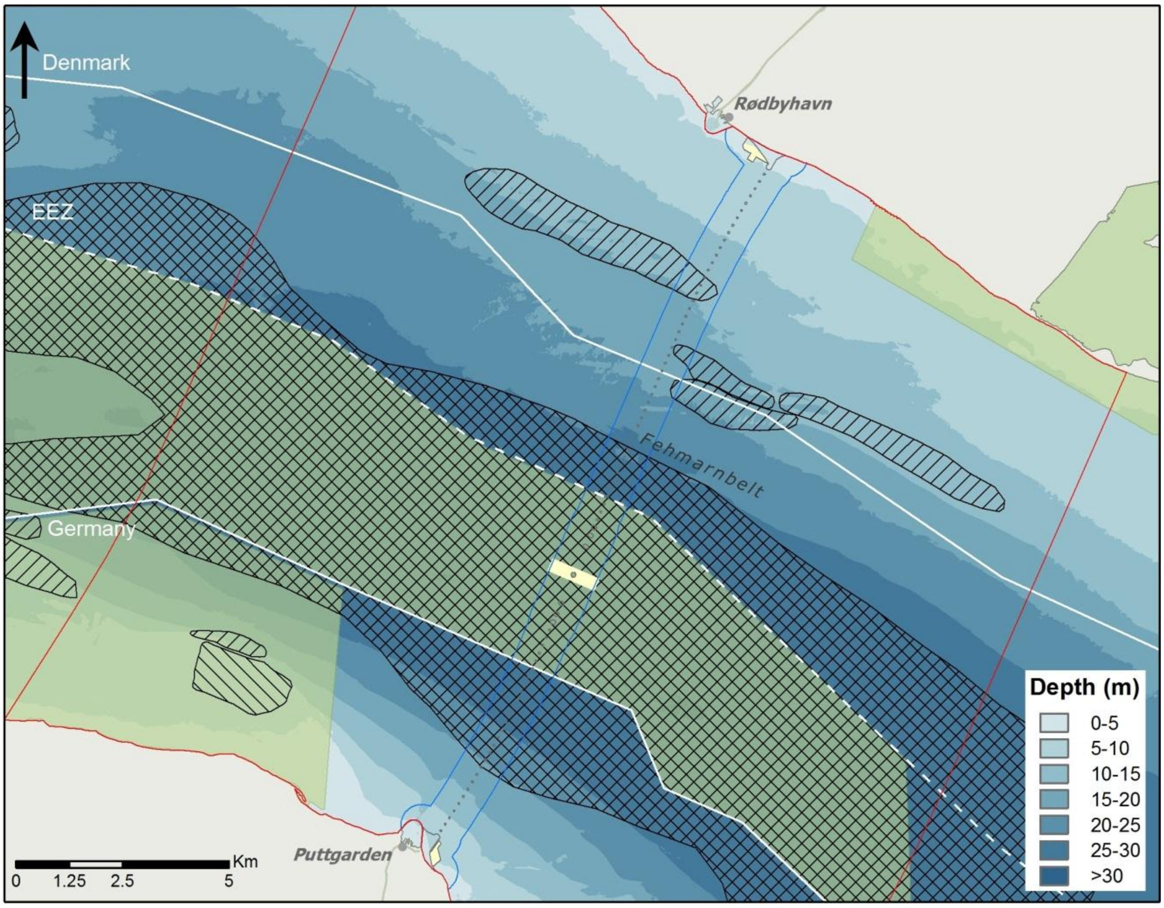


Figure 7.8 *Severity of permanent impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2/October 2010. The marine parts of the relevant Natura 2000 areas are shown*



Degree of temporary impairments for marine soil component: sea bed morphology

- Minor
- Medium
- High
- Very high
- Sand waves
- Other active bed forms
- Lunate bed forms
- Footprint
- Natura 2000 areas
- Local zone (10 km from alignment)
- Near zone (500 m from footprint)

Figure 7.9 Degree of temporary impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown

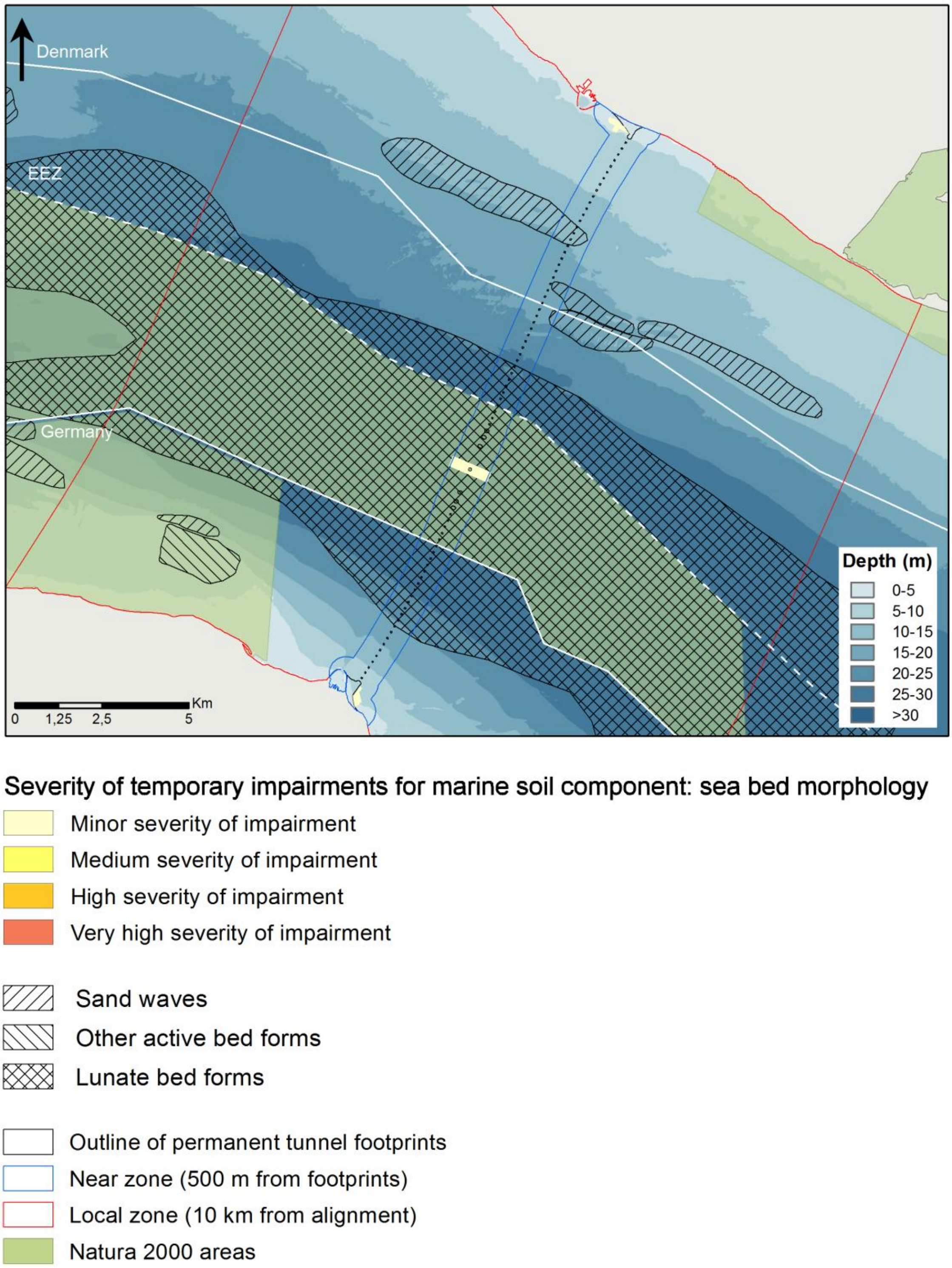


Figure 7.10 Severity of temporary impairments for main bridge solution. Aggregated impairments from various sources of pressure. Main bridge alternative Variant 2 B E-E/October 2010. The marine parts of the relevant Natura 2000 areas are shown

Table 7.6 Summary of impacts from the main bridge solution (Variant 2 B E-E/October 2010)on sub-components of the Marine Soil component sea bed morphology. Impacts divided on severity of loss and degree of impairments. Part of impacted areas of the sub-component are provided as percentage (%) of the reference area of the given sub-component within 10 km from the alignment (i.e. within near zone + local zone)

Sub-component for Sea bed morphology	**Total**		Sand waves		Lunate bed forms		Other active bed forms		Outside areas with prominent bed forms	
	ha	**%**	ha	%	ha	%	ha	%	ha	%
Permanent impacts:										
Severity of loss										
Very high severity	0	0	0	0	0	0	0	0	0	0
High severity	13	0.03	0.4	0.03	12	0.08	0	0	0	0
Medium severity	43	0.1	0	0	0	0	0	0	43	0.2
Minor severity	0	0	0	0	0	0	0	0	0	0
Total	**56**	**0.1**	**0.4**	**0.03**	**12**	**0.08**	**0**	**0**	**43**	**0.2**
Degree of impairments, permanent										
Very high impairment	128	0.3	3	0.2	125	0.9	0	0	0	0
High impairment	0	0	0	0	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0	0	0	0	0
Minor impairment	4,088[1]	9.6[2]	591	46.9	3,299[1]	20.7[2]	199	81.5	0	0
Total	**4,216[1]**	**9.7[2]**	**594**	**47.1**	**3,424[1]**	**21.5[2]**	**199**	**81.5**	**0**	**0**
Total permanent	**4,272[1]**	**9.7[2]**	**594**	**47.1**	**3,436[1]**	**21.6[2]**	**199**	**81.5**	**43**	**0.2**
Temporary impacts:										
Degree of impairments, temporary										
Very high impairment	0	0	0	0	0	0	0	0	0	0
High impairment	0	0	0	0	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0	0	0	0	0
Minor impairment	57[2]	0.1	0	0	37[3]	0.3	0	0	20	0.08
Total temporary	**57[2]**	**0.1**	**0**	**0**	**37[3]**	**0.3**	**0**	**0**	**20**	**0.2**
Maximum period of temporary effects (years)	**30**				**30**				**5**	
Total impacted area. Permanent + temporary effects	**4,292[1]**	**9.8[2]**	**594**	**47.1**	**3,436[1]**	**21.6[2]**	**199**	**81.5**	**63**	**0.2**
Reference area (ha)	**41,446**		**1,261**		**14,789**		**244**		**26,049**	

[1]including 240 ha outside the local 10 km zone, [2]percentage of impacted area within local zone+near zone, i.e. excludes 240 ha of impacted area outside of this area, [3]37 ha overlap with the permanently impaired area with a minor impairment classification

Table 7.7 Summary of severity of impairments from the main bridge solution (Variant 2 B E-E/October 2010) divided on sub-components of the Marine Soil component sea bed morphology. Part of impacted areas of the sub-component are provided as percentage (%) of the reference area of the given sub-component within 10 km from the alignment (i.e. within near zone + local zone).

Sub-component for Sea bed morphology	**Total**		Sand waves		Lunate bed forms		Other active bed forms		Outside areas with prominent bed forms	
	ha	**%**	ha	%	ha	%	ha	%	ha	%
Severity of impairments, permanent										
Very high severity	0	0	0	0	0	0	0	0	0	0
High severity	128	0.3	3	0.2	125	0.9	0	0	0	0
Medium severity	0	0	0	0	0	0	0	0	0	0
Minor severity	3,955[1]	9.0[2]	458	36.3	3,299[1]	20.7[2]	199	81.5	0	0
Total	**4,083[1]**	**9.3[2]**	**461**	**36.5**	**3,424[1]**	**21.5[2]**	**199**	**81.5**	**0**	**0**
Severity of impairments, temporary										
Very high severity	0	0	0	0	0	0	0	0	0	0
High severity	0	0	0	0	0	0	0	0	0	0
Medium severity	0	0	0	0	0	0	0	0	0	0
Minor severity	57[2]	0.1	0	0	37[3]	0.3	0	0	20	0.08
Total temporary	**57[2]**	**0.1**	**0**	**0**	**37[3]**	**0.3**	**0**	**0**	**20**	**0.2**
Reference area (ha)	**41,446**		**1,261**		**14,789**		**244**		**26,049**	

[1]including 240 ha outside the local 10 km zone, [2]percentage of impacted area within local zone+near zone, i.e. excludes 240 ha of impacted area outside of this area, [3]37 ha overlap with the permanently impaired area with a minor severity classification

7.5.2 Total impact for specific areas

The impacted areas of the component sea bed morphology are divided on sub-parts of the Fehmarnbelt in Table 7.8.

The impacts on the sea bed morphology are assessed to cover a total of 4,292 ha of which 4,052 ha are within 10 km from the alignment. 9.8% of the sea bed within 10 km from the alignment is impacted. 4,272 ha of these are permanently impaired. 1,020 ha are impacted within the near zone.

The majority of the impacts (95.7%) are classified with a minor degree of impairment.

Table 7.8 *Summary of severity of loss and degree of impairments from the main bridge solution (Variant 2 B E-E/October 2010) on sub-parts of the Fehmarnbelt. Parts of impacted areas are provided as percentage (%) of the given sub-areas (reference areas). Parts of total impacted area, excluding impacts outside of local zone+near zone, are provided as percentage (%) of sea bed area within local zone + near zone (reference area)*

Component:	**Sea bed morphology for bridge Variant 2 B E-E/October 2010**					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Permanent impacts: Severity of loss						
Very high severity	0	0	0	0	0	0
High severity	13 (0.03%)	13 (0.03%)	0	2	2	9
Medium severity	43 (0.1%)	43 (0.1%)	0	22	22	0
Minor severity	0	0	0	0	0	0
Total	56 (0.1%)	56 (2.7%)	0	24	24	9
Permanent impairments						
Very high impairment	128 (0.3%)	128 (6.2%)	0	9	12	107
High impairment	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0
Minor impairment	4,088[1] (9.3%)[2]	817 (39.8%)	3,032[1] (7.7%)[2]	1,275	1,560	1,253
Total	4,216[1] (9.6%)[2]	944 (46.0%)	3,032[1] (7.7%)[2]	1,284	1,572	1,360
Total permanent impacts	4,272[1] (9.7%)[2]	1,000 (48.7%)	3,032[1] (7.7%)[2]	1,308	1,596	1,369

Continues next page

Table 7.8 Continued from previous page

Component:	**Sea bed morphology for bridge Variant 2 B E-E/October 2010**					
	Total area (ha)	Various subpart areas (ha)				
		Near Zone	Local 10 km zone	Denmark National +EEZ	Germany National	Germany EEZ
Temporary impairments						
Very high impairment	0	0	0	0	0	0
High impairment	0	0	0	0	0	0
Medium impairment	0	0	0	0	0	0
Minor impairment	57[3] (0.1%)	54[4] (2.6%)	3[5] (0.01%)	11	9	37[3]
Total temporary impacts	57[3] (0.1%)	54[4] (2.6%)	3[5] (0.01%)	11	9	37[3]
Maximum period of temporary effects (years)	30	30	30	5	5	30
Total impacted area. (Permanent + temporary)	4,292[1] (9.8%)[2]	1,020 (49.7%)	3,032[1] (7.7%)[2]			
Reference area (ha)	41,446	3,019	38,427			

[1]includes 240 ha outside local and near zone, [2]percentage of impacted area within local zone+near zone, i.e. excludes 240 ha of impacted area outside of this area, [3]37 ha overlaps with the permanently impaired area with a minor impairment classification,[4]34 ha overlaps with the permanently impaired area with a minor impairment classification,[5]overlaps with the permanently impaired area with a minor impairment classification

7.5.3 Impact significance

The main bridge solution has been evaluated to impact a total of 4,292 ha of the sub-component sea bed morphology.

Of these are 4,229 ha with impacts on bed form areas of which 3989 ha are within 10 km from the alignment and 240 ha are further away. The impacted bed forms can be sub-dived on 594 ha sand waves, 3,436 ha lunate bed forms and 199 ha other active bed forms. 13 ha of bed forms are lost due to direct loss of sea bed, and 4083 ha are impaired permanently. Of the latter, 128 ha are impaired to a degree, where the bed forms are expected to permanently change character and possibly turn into a flat bed. The majority of the bed forms are impaired to a minor degree. None of the bed forms are impaired only temporarily.

The total area of bed forms within 10 km from the alignment is 16,293 ha, see Section 3.1.3. The impacted areas of bed forms within this area are 3,989 ha corresponding to respectively 0.1% (loss), 24.5% (permanently impaired) and 0% (temporarily impaired) of the total area of bed forms within 10 km from the alignment. 240 ha of bed forms further away are impaired to a minor degree.

The complete loss of bed forms due to the bridge project is therefore very small. The majority of the impacts cover areas, where the bed forms are permanently impaired by the predicted change to the near-bed current speeds. In these areas the bed forms will still exist and maintain their main characteristic (overall shape and morphodynamics). The only predicted impact is a change in their geometry causing a change (primarily increase) in their heights by 10-25%, which for the majority of the areas corresponds to an increase of the height of the bed form undulations of 0.05-0.25 m. This effect is expected to be just measureable.

In the baseline study, the influence of the bed forms on the current field and flow through Fehmarnbelt was found to be insignificant (FEHY 2013a). The above-mentioned changes to the bed forms do not change this situation and it is therefore assessed that the impacts on the bed forms in the Fehmarnbelt caused by the bridge project are insignificant.

Outside areas with prominent bed forms, the impacts are due to permanent or temporary structures at the coast. The impacts cover small areas and are not considered significant for the sea bed in the Fehmarnbelt.

In conclusion, it is assessed that the impacts from the main bridge solution have insignificant impacts on the marine soil component sea bed morphology.

Table 7.9 Summary of impacts to assessed sub-components

Significance of impacts to sea bed morphology **Sub-divided on sub-components**	**Sub-components**			
	Sand waves	**Lunate bed forms**	**Other active bed forms**	**Sea bed without prominent bed forms**
Significance of impacts	Not significant	Not significant	Not significant	Not significant

7.6 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 sea bed morphology.

7.7 Transboundary impacts

Transboundary impact is not relevant for this component.

7.8 Climate change

The climate change 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%. For more typical wind speeds there are no indications of significant changes
- The ocean water level may rise up to 1 m, which will propagate into the Fehmarnbelt and the Baltic Sea

The impact of the cable stayed bridge in such a new climate setting is evaluated as being similar to the estimated impacts for the present climate setting.

7.9 Mitigation and compensation measures

No mitigation and compensation measures are suggested. The majority of the impacts from the bridge are due to changes to the near-bed flow from the bridge piers. Further optimization of the piers with the purpose of reducing these impacts (of minor degree of impairment) to the bed forms are considered to be too costly and not recommendable.

7.10 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. It is expected that the sea bed will be re-established. The sea bed morphology will in the areas of the marine ramps recover to a natural state in less than 5 years.

Piers and pylons will be removed. This includes the caissons, backfill material around the caissons and scour protection material, which extend to a depth of about 4-5 m below the sea bed. It is expected that the dismantling will leave holes in the sea bed, which will not be backfilled as a part of the decommissioning process.

Natural backfilling of such holes will take place, when the natural sediment transport along the sea bed is trapped in the holes. The sea bed will recover to a natural state. The recovery time depends on the natural transport of sediment on the sea bed and the geometry of the holes (depth, width). Typical widths of the piers/pylons including the scour protection are in the order of 40 m and 90 m, respectively. Typical gross sediment transport rates (refer to Section 3.3.2) are in the order of 20 m^3/m. Recovery times for the sea bed are estimated to be in the order of 10 years for the holes following the removal of the piers and 22 years for the holes following the removal of the pylons.

8 COMPARISON OF BRIDGE AND TUNNEL MAIN ALTERNATIVES

8.1 Comparison of tunnel and bridge alternatives with continued ferry operation

The cable stayed bridge alternative impacts a larger part of the sea bed in the Fehmarnbelt than the immersed tunnel alternative, see comparison in Table 8.1.

The bridge is assessed to impact a total of 4,292 ha of which 4,052 ha are within 10 km from the alignment. 9.8% of the sea bed within 10 km from the alignment is impacted. The tunnel impacts a total of 1,471 ha corresponding to 3.6% of the sea bed within 10 km from the alignment.

The nature of the impacts from the bridge project differs from the impacts from the tunnel project. The impacts related to the bridge are primarily current-induced changes causing the heights/lengths of the bed forms to increase by 10-25%. These changes are permanent, but due to the character of the impacts classified with a minor degree of impairment.

The changes from the tunnel project are mainly related to the dredging activities by which some bed forms will be removed during the dredging for the tunnel trench and some will be affected by deposition of dredged sea bed material. These impacts will be of a temporary character since the bed forms are predicted to recover in less than 30-40 years. The majority of these temporary impairments are classified as having a minor or medium degree of impairment. The impacts from the bridge are therefore to a higher degree permanent, while the impacts from the tunnel are primarily temporary impacts.

The total loss of sea bed is, however, smaller for the bridge than for the tunnel. This is primarily due to the large reclamation on the Danish side in case of the tunnel.

For both projects, however, only very limited areas are impaired to a high or very high degree. For the immersed tunnel project these accounts for 103 ha and for the cable stayed bridge project 128 ha are impaired with high or very high degree of impairment. In the baseline study, the influence of the bed forms on the current field and flow through the Fehmarnbelt was found to be insignificant (FEHY 2013a). The above-mentioned changes to the bed forms in either project do not change this situation.

In conclusion, the impacts from the bridge project as well as the tunnel project are assessed as insignificant for the marine soil component sea bed morphology. The differences in the impacted areas as well as the difference in the character of the impacts from the projects do not lead to one or the other project being the preferred option based on the impacts on sea bed morphology. Table 8.2summarises the comparison of the immersed tunnel and cable stayed bridge.

Table 8.1 Comparison of impacts for immersed tunnel (main alternative, E-ME/August 2011) and cable stayed bridge with continued ferry operation (main alternative Variant 2 B E-E/October 2010)

Component:	Sea bed morphology	
	Immersed tunnel E-ME/August 2011	**Cable stayed bridge Variant 2 B E-E/October 2010**
	Total area (ha) (Part of area, %) [1]	**Total area(ha) (Part of area, %)** [1]
Severity of loss		
Very high	0	0
High	0	13
Medium	356	43
Minor	0	0
Total loss	356	56
% of local + near zone	0.9%	0.1%
Degree of permanent impairments		
Very high impairment	0	128
High impairment	0	0
Medium impairment	0	0
Minor impairment	0	4,088[2]
Total permanent impairments	0	4,216[2]
% of local + near zone	0%	9.6%[3]
Degree of temporary impairments		
Very high impairment	0	0
High impairment	103	0
Medium impairment	442	0
Minor impairment	570	57[4]
Total temporary impairments	1,115	57[4]
% of local +near zone	2.7%	0.1%
Total temporary and permanent impacts	1,471	4,292[2]
% of local + near zone	3.6%	9.8%[3]

[1] Part of area (%) refers to part of impacted sea bed area within the area of the local 10 km zone + near zone, [2]including 240 ha outside the local 10 km zone. [3]percentage of impacted area within local zone+near zone; excludes 240 ha of impacted area outside of this area, [4]37 ha overlaps with the permanently impaired area with a minor severity classification

Table 8.2 Comparison matrix of impacts from Immersed tunnel and Cable stayed bridge. For each factor is the relatively environmentally best alternative 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**	
Sand waves	Insignificant temporary effects due to construction/dredging for tunnel trench	0	Insignificant permanent effects on sand waves due to changes to currents caused by bridge structures. Insignificant loss of sand waves caused by bridge structures	0
Lunate bed forms	Insignificant temporary effects due to construction/dredging for tunnel trench	0	Insignificant permanent effects on lunate bed forms due to changes to currents caused by bridge structures. Insignificant loss of lunate bed forms caused by bridge structures	0
Other active bed forms	No impacts	0	Insignificant permanent effects on other active bed forms due to changes to currents caused by bridge structures	0
Sea bed outside areas with prominent bed forms	Insignificant temporary effects due to construction/dredging for tunnel trench and work harbours. Insignifiant loss of sea bed due to construction of land reclamations. Insignificant temporary effects due to work harbours	0	Insignificant loss of sea bed caused by bridge structures. Insignificant temporary effects due to work harbours	0
Total – sea bed morphology	No significant impacts Insignificant temporary impacts on sea bed morphology (including bed forms) primarily due to construction/dredging for tunnel trench and access channel. Insignificant loss of sea bed	0	No significant impacts Insignificant permanent effects on sea bed morphology (bed forms) due to changes to currents caused by bridge structures. Insignificant loss and temporary effects	0

8.2 Comparison of tunnel and bridge alternatives without continued ferry operation

The comparison of the tunnel and bridge alternative without the continued ferry operation is not carried out for sea bed morphology.

The ferry operation is not expected to have any significant impacts on the near-bed currents in the bed form areas. 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

Neither the impacts from the tunnel project nor the impacts from the bridge project on the sea bed morphology are assessed to influence the possibilities of fulfilling the criteria for good environmental status for descriptor 6 in the MSFD.

The consequences to implementation of WFD are not considered relevant for sea bed morphology.

10 KNOWLEDGE GAPS

The assessment of the sea bed morphology is based on a very a detailed mapping of the bed forms and detailed modelling of currents, waves, sediment transport and sediment spreading.

Bed forms and the response of bed forms to variations in their environment are still research topics. The responses to the pressures from the bridge and tunnel alignment are, however, considered to be generally well understood in a qualitative manner.

The assessment of sea bed morphology is assessed having a medium degree of uncertainty.

11 REFERENCES

Deigaard, R. and Fredsøe, J. (1992). Mechanics of Coastal Sediment Transport . Advanced Series on Ocean Engineering – Volume 3. World Scientic

DHI. MIKE 21 and MIKE3 Flow Model FM. Hydrodynamic Module. Short description. http://www.mikebydhi.com/~/media/Microsite_MIKEbyDHI/Publications/PDF/MIKE213_FM_HD_Short_Description.ashx

Feasibility Study (2006). Fixed Link across the Fehmarnbelt and the Environment. Environmental Consultation Report, 2006, Ministry of Transport and Energy, Denmark. ISBN 87-90917-25-1

FEHY (2009). Fehmarnbelt Fixed Link. Climate Change and the Fehmarnbelt Fixed Link. Report on the Workshop on Climate Scenarios. 13 and 14 May 2009". Report E1TR0020 Final. September 2009

FEHY (2013a). Fehmarnbelt Fixed Link EIA. Marine Soil. Volume I. Sea bed Morphology of the Fehmarnbelt Area – Baseline. Report No. E1TR0056.

FEHY (2013b). Fehmarnbelt Fixed Link EIA. Marine Water- Baseline. Hydrography of the Fehmarnbelt Area. Report No. E1TR0057 Volume II.

FEHY (2013c). Fehmarnbelt Fixed Link EIA. Marine Water – Baseline. Suspended Sediment. Report No. EITR0057 Volume III.

FEHY (2013d). Fehmarnbelt Fixed Link EIA. Marine Soil – Impact Assessment. Sea bed Spill. Report No. E1TR0059 Volume II.

FEHY (2013e). Fehmarnbelt Fixed Link EIA. Marine Water- Impact Assessment. Hydrography of the Fehmarnbelt Area. Report No. E1TR0058 Volume II.

FEHY (2013f). Fehmarnbelt Fixed Link EIA. Marine Soil – Impact Assessment. Coastal Morphology. Report No. E1TR0059 Volume III.

FEHY (2013g). Fehmarnbelt Fixed Link EIA. Marine Water- Impact Assessment. Hydrography, Water Quality and Plankton of the Baltic Sea. Report No. E1TR0058 Volume I.

FEMA (2013a). Fehmarnbelt Fixed Link EIA. Fauna and Flora. Plankton and Benthic Biology - Impact Assessment. Benthic Flora in the Fehmarnbelt Area – Impact Assessment. Report No. E2TR0021 Volume I.

Femern A/S (2011). Consolidated Technical Report

Femern and LBV-SH-Lübeck (2010). Proposal for environmental investigation programme for the fixed link across Fehmarnbelt (coast-coast). EIA Scoping Report.

Femern Sund og Bælt, Miljøkriterier, Marts 2011

Fredsøe, J (1974). The development of oblique dunes, part 3 and part 4, Prog.Rep. 33 and 34, ISVA, DTU

Fredsøe, J. (1982). "Shape and Dimensions of Stationary Dunes in Rivers." Journal of the Hydraulics Division, ASCE 108(8): 932-947

Niemann, S.L, Fredsøe, J. and Jacobsen, N.G. (2011). Sand Dunes in Steady Flow at Low Froude Numbers: Dune Height Evolution and Flow Resistance. Journal of Hydraulic Engineering, 137: 5-14

Niemann, S. L. (2003). Modelling of sand dunes in steady and tidal flow, Phd-thesis, Coastal and River Engineering Section, Technical University of Denmark
http://www.skk.mek.dtu.dk/upload/institutter/mek/skk/pdf/phd_afhandlinger/2003/sanne%20niemann-phd.pdf

Novak and Björk (2002). Late Pleistocene Holocene fluvial faces and depositional processes in the Fehmarnbelt between Germany and Denmark, revealed by high-resolution seismic and litofacies analysis. Sedimentology 49, 451-465

RAT (2011): Data for Impact Assessment by consultants. Technical drawings of Immersed Tunnel: RAT-T-P-X00-1050-2 to RAT-T-P-X00-1057-2. RAT-T-P-M10-0001-2

Tjerry, Søren and Fredsøe, Jørgen (2005). Calculation of dune morphology, Journal of Geophysical Research, vol. 110, F04013

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