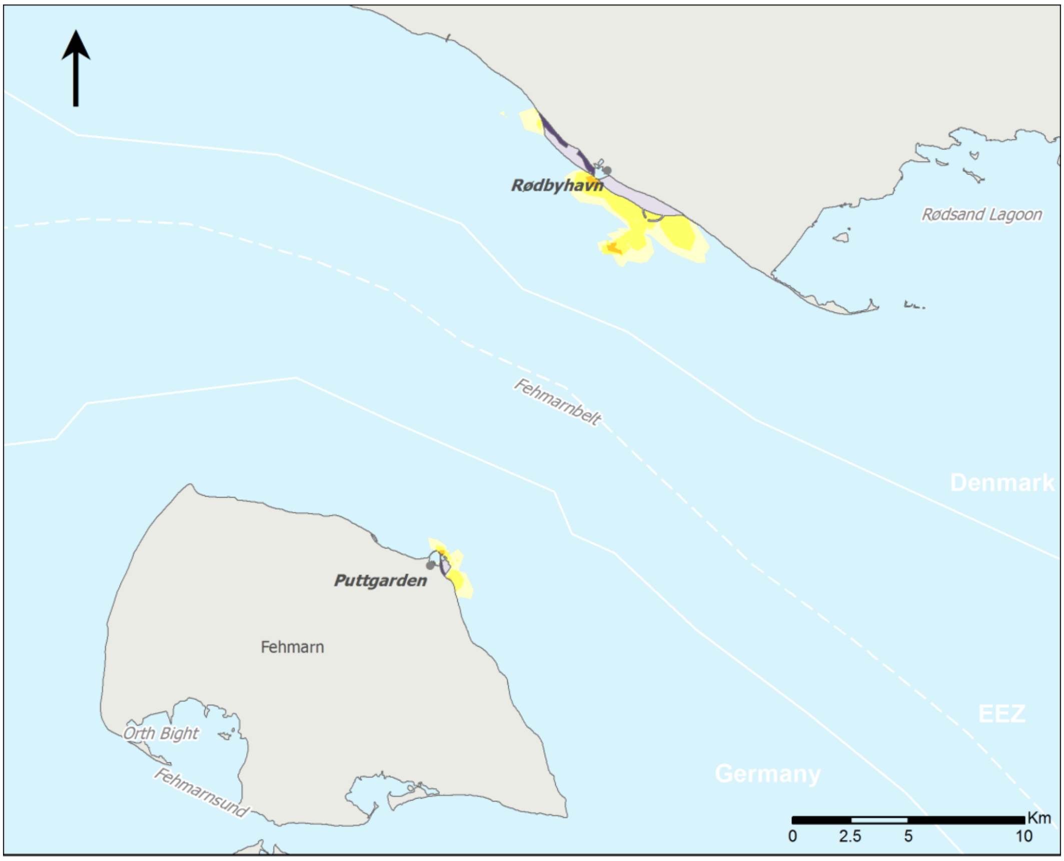
**Final Report**

# FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES (FEHY)

## Marine Water – Impact Assessment

## Hydrography of the Fehmarnbelt Area

**E1TR0058 - Volume II**

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## *ACRONYMS AND ABBREVIATIONS*

DHI: DHI - Water Environment Health

BB: Bolding & Burchard

IOW: Leibniz Institute for Baltic Sea Research, Warnemünde

MIKE 3: Commercial 3D numerical modelling tool by DHI

GETM: "General Estuarine Transport Model", applied by Bolding & Burchard

MOM: "Modular Ocean Model" code version 3.1 (MOM 3.1), used by IOW

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).

## CONTENTS

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# 0 EXECUTIVE SUMMARY

**Fixed link alternatives and 0-alternative**
This Volume of the Impact Assessment regards the impacts to the marine water sub-factor component *Fehmarnbelt hydrography* for the two fixed link solutions:

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

The fixed link alternatives have been compared to a 0-alternative, which is the continuation of the present ferry service. Therefore, the 0-alternative is assumed to be similar to the baseline conditions.

In all background reports, the time for start of construction is tentatively set to 1 October 2014 for the immersed tunnel and 1 January 2015 for the bridge. However, the actual period for the construction work is not fixed. In the VVM and UVS/LBP, the terminology is therefore "year 0" (equivalent to year 2014 in the background reports), "year 1", etc.

**Sub-components and indicators**
The assessment has applied a set of sub-components and indicators, see Table 0.1. The specific indicators are relevant statistical properties of the dynamic sub-components, typically referring to 2D fields at surface or bottom level.

*Table 0.1 Sub-components and indicators applied for the assessment of effects to the hydrography component.*

| Component | Sub-component | Indicators |
|---|---|---|
| Hydrography | Water level | Mean and max water level |
| | Currents | Mean speed at surface and bottom |
| | Salinity and temperature | Mean at surface and bottom (annually and summer period) |
| | Stratification | Mean (annually and summer period) |
| | Waves | 5% exceedence level for significant wave height |

For each sub-component indicator impact criteria are prepared, dividing the impacts into degree levels of "negligible", "low", "medium", "high" or "very high". This method and the combination with the baseline importance mapping, etc, follows the generic methodology specified in the (EIA Scoping Report; Femern A/S, June 2010).

**Project pressures**
The primary pressures for the hydrography issues in relation to the immersed tunnel and the cable stayed bridge alternatives include:

- Permanent structures and seabed/coastline changes, such as bridge piers/pylons, coastal reclamations, protective reefs or leftover access channels

- Temporary structures in the construction phase, such as work harbours to be removed and associated dredging and seabed areas to be re-established.

**Assessment tools**
The assessment of degree of impairment due to the project pressures is undertaken mainly by detailed numerical modelling. For the hydrodynamic issues a dual approach concept is used, with two independent local model tools, MIKE 3 and GETM. These local models cover the entire transition area from Bornholm to Kattegat, with a high resolution in Fehmarnbelt. Potential effects in the Baltic Sea are assessed by regional models covering the entire Baltic Sea, see the separate Volume (FEHY 2013b).

This dual method is implemented to increase confidence in the modelling, and provide information on the uncertainty. Both of these model tools have been carefully calibrated and validated before they are used for scenario modelling.

The scenario runs then include the specific project pressures, such as piers or reclamations. Piers and pylons are included by sub-scale parameterisation, representing the drag and transverse force at the structure and the mixing effects caused by the extra turbulence as well. Reclamations and seabed excavations are represented by changing water depth and land sea delineation in the model bathymetry. The scenario runs normally cover a full hydrographically typical year, i.e. 2005.

The dual modelling approach has been fully implemented for the bridge alternative, which has the largest impacts. Here the two model tools give comparable results. For the immersed tunnel only the MIKE 3 model is suited to represent the relative narrow reclamations along the coast.

For wave effects a single numerical modelling is used, see (FEHY 2013a).

**Assessment results**
For both fixed link alternatives the future impacts are assessed assuming continued respectively terminated ferry service. The difference between these assumptions for the future of the ferry service has been found to be limited.

The following assessment for the two alternatives focuses on the “fixed link+ferry” scenario, but is also a valid (and slightly conservative) approximation for the “fixed link” scenario (without continued ferry service).

The two alternatives for the fixed link in Fehmarnbelt are affecting the hydrography component quite differently. The permanent impact areas are shown in Fig. 0.1 and Fig. 0.2 and summarised in Table 0.2.

The water exchange effect is -0.01% for the tunnel alternative and reaches about -0.5% for the bridge alternative. Associated impacts to Baltic Sea conditions are described in detail in (FEHY 2013b).

While the total permanent impact area for the immersed tunnel is only 0.2% of the Western Baltic Sea area and is mainly found in the vicinity of the project reclamations, about 18% are affected by the cable stayed bridge alternative, with an impact area extending into Kiel Bight and Mecklenburg Bight.

When focussing on the “medium” to “very high” degree of impairment areas the figures become 0.1% for tunnel and 0.6% for bridge (relative to the Western Baltic Sea area). Thus the impact areas in these categories are much smaller that the full impact area.

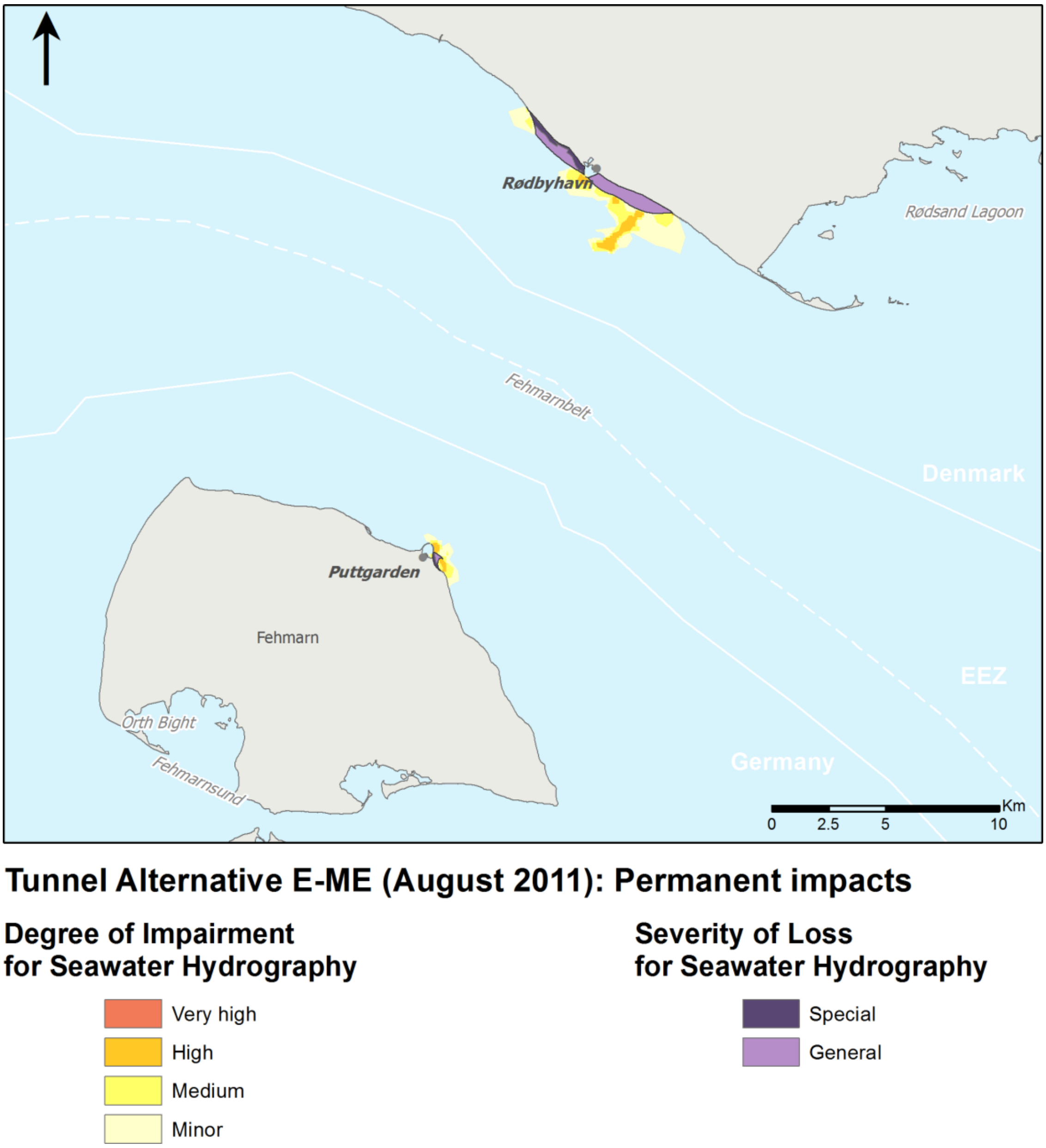


*Fig. 0.1 The degree of impairment and loss severity distribution for the permanent hydrography impacts of the immersed tunnel E-ME (August 2011)*

Only for the loss category does the tunnel show a larger area (343ha) than the bridge (50ha). This is due to the tunnel reclamation affecting water areas in front of beaches 1-3 km west of the Rødbyhavn breakwater and immediately east of the Puttgarden breakwater. As the plans for both the tunnel and bridge projects include new beaches close by, this will actually not be a negative net impact in reality for the beach water and hydrography.

Table 0.2 documents that the impacted areas in relation to hydrography at the later stage of the construction period will also be largest for the bridge alternative. This bridge construction impact area increases to about the permanent size in accordance with the deployment of the bridge piers and pylons. The earlier part of the construction period where parts of the tunnel trench are still open will not change the tunnel to have a larger effect on the hydrography for the construction period.

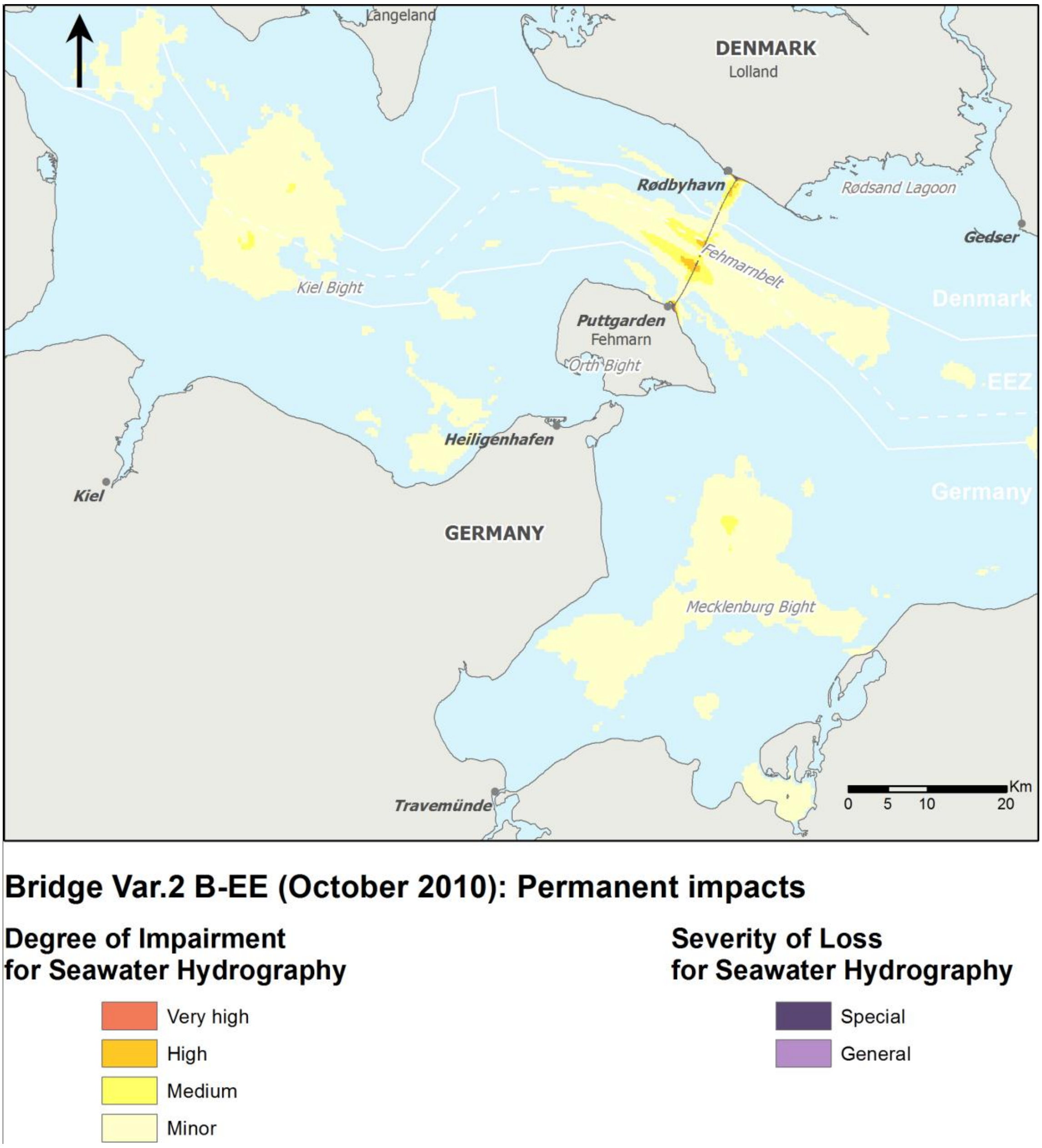


*Fig. 0.2* *The degree of impairment and loss severity distribution for permanent hydrography impacts of the cable stayed bridge Var. 2 B-EE (October 2010)*

**Significance of impacts for tunnel alternative**
Based on the minor impact area for the immersed tunnel alternative (Table 0.2) the permanent impacts to the hydrography are assessed to be insignificant for the general hydrography in the Fehmarnbelt and the Belt Sea (and also for the Central Baltic Sea).

The local loss of beach areas is planned to be compensated by new beach areas and will thus not become a net loss. The effect to navigation into and out of the present ferry terminals is found to become a tendency to reduced currents, and will thus not add any adverse effect for the navigation.

The impacts to hydrography in the construction period are also assessed as being insignificant for the general hydrography.

**Significance of impacts for bridge alternative**

The above permanent effect to the hydrography for the cable stayed bridge alternative is assessed as having no significance for the general hydrography in the Fehmarnbelt, the Western Baltic Sea and the Belt Sea. This conclusion comes mainly from the "medium" to "very high" severity areas only covering 0.6% of the Western Baltic Sea area and not extending to other parts of the Belt Sea.

In the construction period the impacts to hydrography will be similar to the permanent impacts.

The effect to the water exchange with the Baltic Sea of -0.5% can be compared to the criteria used for the other fixed links in the Belt Sea and Sound:

- Great Belt Fixed Link: Is designed as a zero blocking solution, where the flow blocking of the link elements of 2% is compensated by dredging. The potential, remaining flow effect is linked to the uncertainty of ±0.2% of the models used for the analysis. However, as the used model only covered an area representing about 1/5 of the total flow resistance between Kattegat and Darss, the accepted flow uncertainty is in the order of ±0.04% when compared to the above Fehmarnbelt bridge effect of -0.5%.

- Øresund Fixed Link: This was also implemented as a zero blocking solution with a remaining uncertainty of the match of about ±0.25%.

Compared to these former fixed link solutions the bridge effect of -0.5% to the water exchange with the Baltic Sea in Fehmarnbelt is found to be larger than the uncertainty of the zero solutions implemented for the other fixed links.

For the specific predictions of Baltic Sea impacts see (FEHY 2013b).

**Other issues**

There are no cumulative impacts to consider for any of the fixed link solutions, as there are no other project plans in the vicinity which may change the hydrography in the same area.

The transboundary impacts of the fixed link alternatives are analysed in the IA for Baltic Sea hydrography and water quality, see (FEHY 2013b).

With respect to the effect of climate change to the above impact assessment it is evaluated that the predicted isolated impact of the fixed link alternatives under new climate setting (e.g. 2080-2100) will be similar to the estimated impacts for the present climate setting.

*Table 0.2 The impact areas at a later stage of the construction period and for the permanent situation for hydrography impacts of the immersed tunnel E-ME (August 2011) and the cable stayed bridge Var. 2 B-EE (October 2010)*

| **Component: Hydrography** | **Immersed Tunnel E-ME (August 2011)** | **Cable Stayed Bridge Var 2. B-EE (October 2010)** |
|---|---|---|
| | **Total area (ha)[1]** | **Total area (ha)[1]** |
| **CONSTRUCTION PERIOD** | | |
| **Construction period severity of loss** | | |
| Special importance | 60[2] | 24[2] |
| General importance | 298 | 26 |
| **Total severity of loss** | **359 (0.0%)** | **50 (0.0%)** |
| **Construction period degree of impairment** | | |
| Very high | 23 (0.0%) | 50 (0.0%) |
| High | 212 (0.0%) | 564 (0.1%) |
| Medium | 416 (0.1%) | 4,140 (0.5%) |
| Minor | 636 (0.1%) | 121,943 (15.8%) |
| **Total degree of impairment** | **1,287 (0.2%)** | **126,697 (16.5%)** |
| **TOTAL CONSTRUCTION PERIOD** | **1,645 (0.2%)** | **126,747 (16.5%)** |
| **PERMANENT IMPACTS** | | |
| **Permanent severity of loss** | | |
| Special importance | 64[2] | 25[2] |
| General importance | 279 | 31 |
| **Total severity of loss** | **343 (0.0%)** | **56 (0.0%)** |
| **Permanent degree of impairment** | | |
| Very high | 0 (0.0%) | 32 (0.0%) |
| High | 136 (0.0%) | 572 (0.1%) |
| Medium | 274 (0.0%) | 4,144 (0.5%) |
| Minor | 575 (0.1%) | 121,943 (15.8%) |
| **Total degree of impairment** | **985 (0.1%)** | **126,691 (16.5%)** |
| **TOTAL PERMANENT** | **1,329 (0.2%)** | **126,747 (16.5%)** |

Note 1: Relative to the area of the Western Baltic Sea (see Fig. 3.1): 770,000 ha

Note 2: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

The effect to the Fehmarnbelt in the bridge decommissioning period after year 2140 is evaluated as being small. After decommissioning all of the effects to the Fehmarnbelt hydrography will have disappeared. There are no marine effects of the envisaged tunnel decommissioning, leaving the coastal reclamations and not removing the buried tunnel elements.

**Mitigation and compensation measures**

Both the immersed tunnel and the cable stayed bridge project include new beach areas which will compensate the effect of lost water areas in front of beaches due to reclamations.

It does not seem relevant to implement any other mitigation measures for the immersed tunnel, taking the limited impacts identified into account.

It has earlier been assessed whether the blocking effect to the water exchange with the Baltic Sea for the bridge structures can be mitigated by compensation dredging. The conclusion was that this is only an effective mitigation measure if the dredging takes place in reef areas. It has not been possible to identify any local reef areas of a sufficient size for compensation effects. Furthermore, the local and more regional reef areas in the Western Baltic are generally protected and are thus not available as compensation dredging areas. Therefore this option has not been evaluated further in the present impact assessment.

# 1 INTRODUCTION

## 1.1 Indication of construction period

In all background reports, the time for start of construction is tentatively set to 1 October 2014 for the immersed tunnel and 1 January 2015 for the bridge. However, the actual period for the construction work is not fixed. In the VVM and UVS/LBP, the terminology is therefore "year 0" (equivalent to year 2014 in the background reports), "year 1", etc.

## 1.2 Hydrography theme

The assessment of the likely environmental impacts related to construction and operation of a fixed link in Fehmarnbelt is divided into effects to the various environmental themes, referred to as environmental factors.

The present Impact Assessment (IA) binder relates to the sub-factor Marine Waters under the factor Water. This Volume II of the binder deals with the Seawater Hydrography component of the impacts in the Fehmarnbelt and adjacent water areas. Other volumes of the Marine Water binder deal with Seawater Quality of the Fehmarnbelt and adjacent water areas and with impacts to Hydrography and Water Quality in the Baltic Sea.

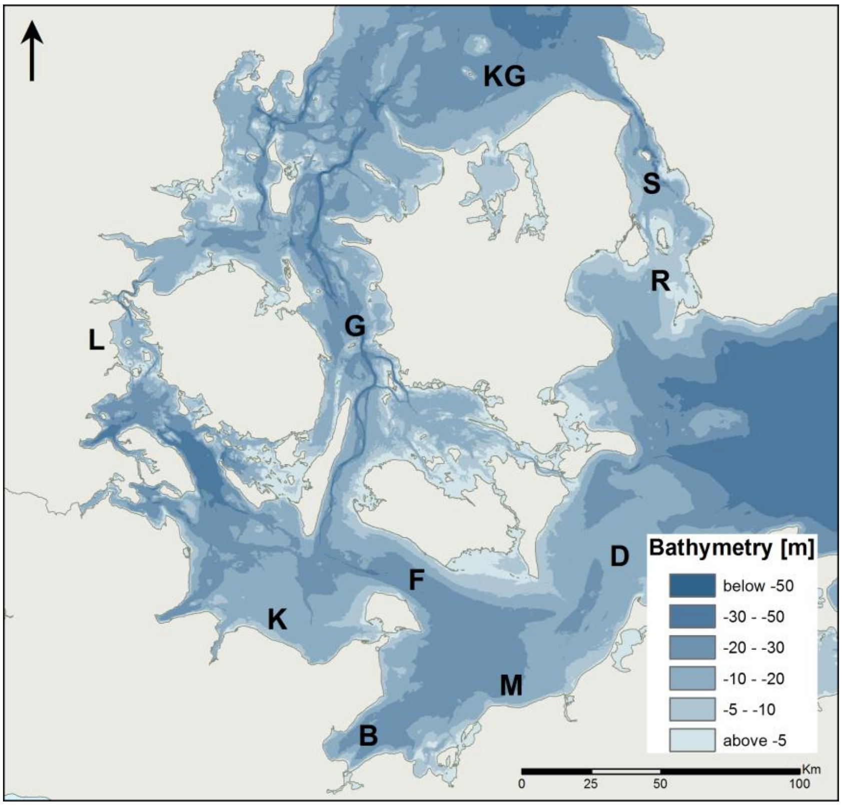


*Fig. 1.1 Overview map of Fehmarnbelt and the Belt Sea: southern Kattegat (KG), Little Belt (L), Great Belt (G), Sound (S), Fehmarnbelt (F), Kiel Bight (K), Mecklenburg Bight (M), Lübeck Bight (B), Darss Sill (D) and Drogden Sill (R).*

The hydrography of the Fehmarnbelt and adjacent water areas (see Fig 1.1) is important for nearly all other marine water impact issues, as the water transport, physical property and wave action set the frame for these other environmental factors.

The baseline hydrography conditions are described in details in (FEHY 2013d). Below is given a brief summary.

The water masses in the Fehmarnbelt consist of low saline water from the Central Baltic Sea, which, close to the surface, flows through the Belt Sea and the Kattegat, and high saline water from the North Sea which forms a lower layer. In summer, the wind conditions are typically weak, and the two-layer exchange flow between the North Sea and the Central Baltic Sea is clearly identified to provide a strongly stratified water column in the Fehmarnbelt.

The dominating driving force for the flow in the transition area is the meteorological conditions over the North Sea and the Baltic Sea. The local wind field over the transition area, the runoff to the Baltic Sea, the tidal flow or the density driven flow only play a minor role. The density driven flow is a relatively slow outwards directed flow.

High and low air pressure fields pass Scandinavia on a weekly time scale and generate set-up or set-down of the water levels in the North Sea and Baltic Sea. This setup drives inflow or outflow of the Baltic Sea and dominates over the density driven flow, except during calm weather conditions.

Stormy wind will cause a strong mixing of water masses in the Fehmarnbelt area and thus time scales ranging from days to inter-annual variations have to be considered to characterize the meteorological forcing and the response of the sea.

The wave conditions in Fehmarnbelt are generally mild, although more rough than in other Danish straits. Waves are governed primarily by the local wind conditions and the fetch limitations due to land such as Fehmarn to the South, Lolland to the North, Falster and Mecklenburg-Vorpommern to the E-SE and Langeland and Schleswig-Holstein to the W. However, occasionally waves from the south eastern Baltic Sea (Arkona Basin) can contribute to the wave climate in the Fehmarnbelt area.

The various driving forces for the currents result in a complex flow pattern with large scale eddies, fronts, up and down-welling and coastal jets. And when the exchange flow reverses either from inflow to outflow or vice versa, complicated transients flow situations and distributions develop.

Furthermore, the current is affected by the vertical stratification that can decouple the upper and lower layers. During outflow conditions the outflow is restricted to the upper part of the water column, whereas the dense saline lower part may show insignificant currents or even reversed flow.

The stratification also acts to reduce the flow resistance as it reduces the turbulence at the interface between the upper and lower layer, thus reducing the effective flow friction. Furthermore, the separation of the upper and lower layer can contribute to the development of oxygen depletion in the bottom waters.

Salinity and temperature variations at Fehmarnbelt both show seasonal variations and short term meteorological variations.

Upwelling at the northern or southern rim of the Fehmarnbelt is often found. It is induced by the winds along the belt and the geostrophical adjustment of the flow.

## *1.3 Hydrography sub-components assessed*

The hydrography component impact assessment has been divided into specific assessments for various sub-components. The sub-components include water level, currents, salinity, temperature, stratification and wave conditions, see Table 1.1.

For each subcomponent are selected specific quantitative indicators for the potential change in condition resulting from the fixed link, like the change to the maximum sea level etc. These indicators are all regarded as spatial measures, varying in the area around the fixed link. For each indicator is selected a specific temporal statistical measure to use for the dynamic response of the fixed link (e.g. temporal mean value of change). The justification of this choice is further discussed in Chapter 3.5.

These indicators constitute the backbone of the actual assessment of the impacts to hydrography conditions and have therefore been selected carefully to represents all possible significant impacts of the fixed link alternatives to be assessed.

*Table 1.1 Sub-components and indicators applied for the assessment of effects to the hydrography component.*

| **Component** | **Sub-component** | **Indicators** |
|---|---|---|
| Hydrography | Water level | Mean and max water level |
| | Currents | Mean speed at surface and bottom |
| | Salinity and temperature | Mean at surface and bottom (annually and summer period) |
| | Stratification | Mean (annually and summer period) |
| | Waves | 5% exceedence level for significant wave height |

# 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 Fig. 2.1. 2.1 along with near-by NATURA2000 sites.

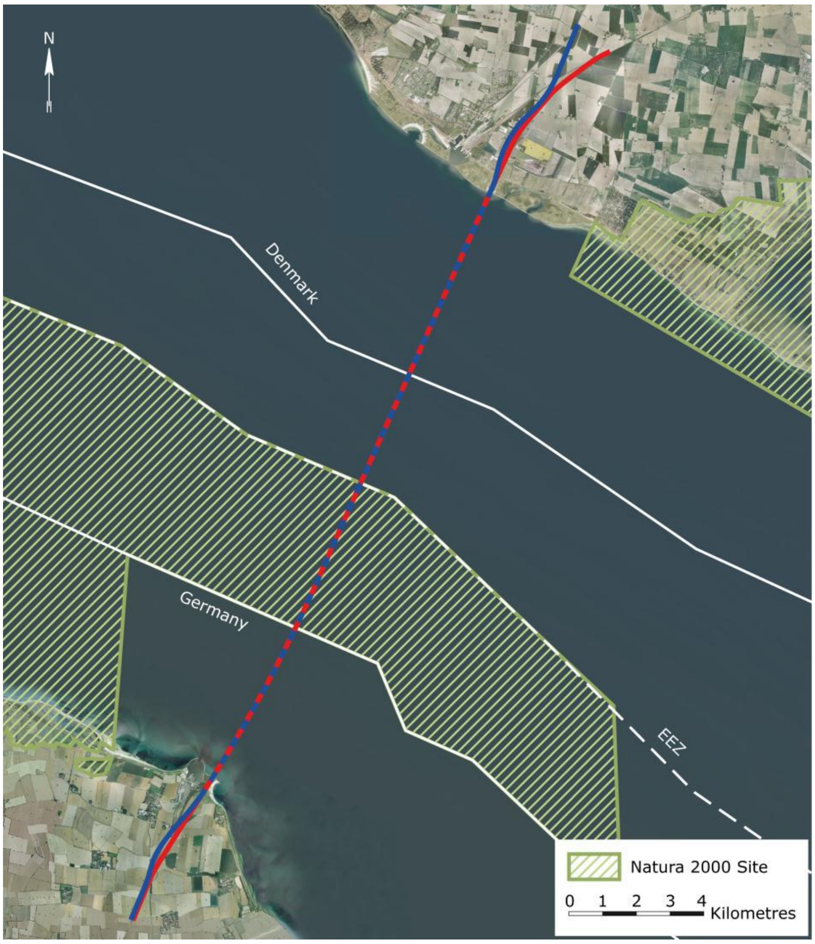


*Fig. 2.1 Conceptual design alignment for immersed tunnel E-ME (August 2011)*

**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 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.

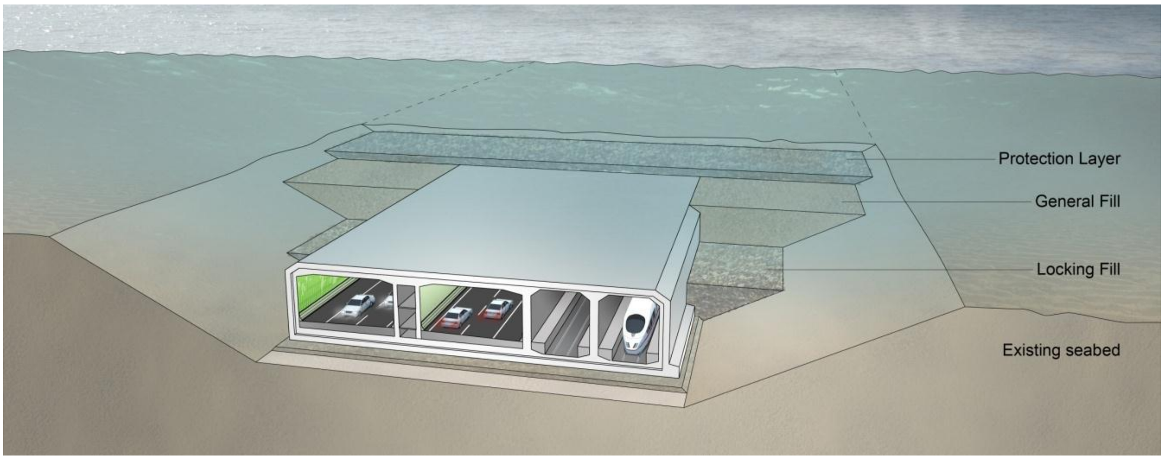


*Fig. 2.2 Cross section of dredged trench with tunnel element and backfilling*

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.

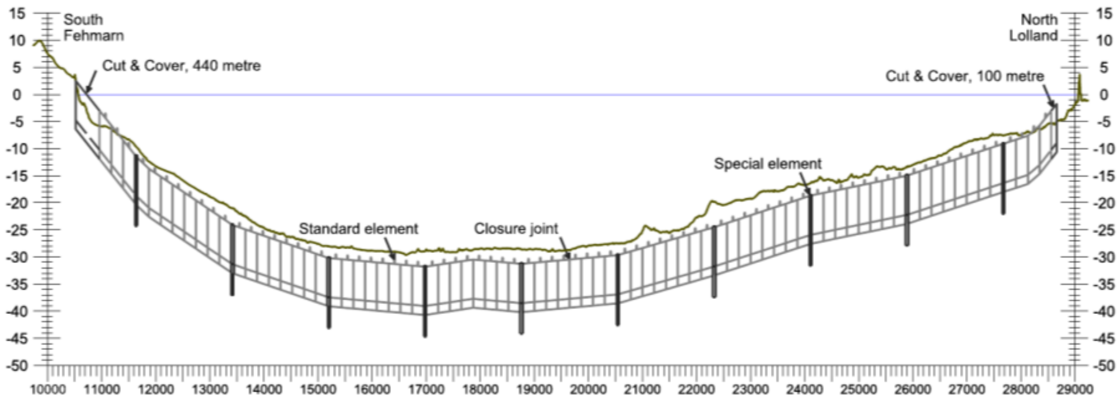


*Fig. 2.3 Vertical tunnel alignment showing depth below sea level*

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. Firefighting 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 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.

*Fig. 2.4 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 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.

*Fig. 2.5  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.

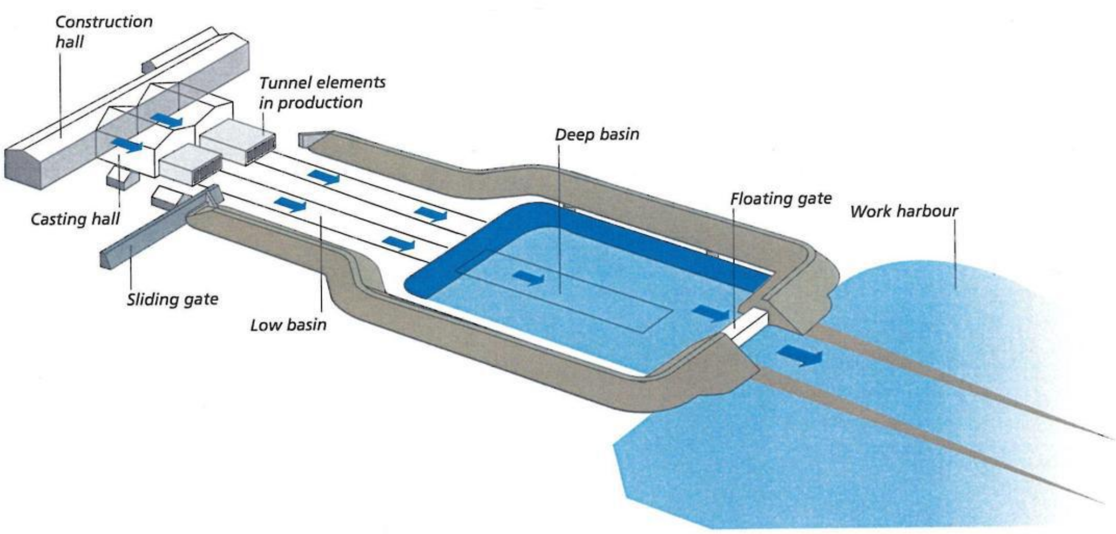


*Fig. 2.6 Production facility with two production lines*

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 mio. $m^3$ soil is required to create sufficient depth for temporary harbours, access channels and production site basins.


*Fig. 2.7  Proposed lay-out of the production site east of Rødbyhavn*

***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.

*Fig. 2.8 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 railway 680m long. The profile of the railway and motorway descend to the natural terrain surface.

*Fig. 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.

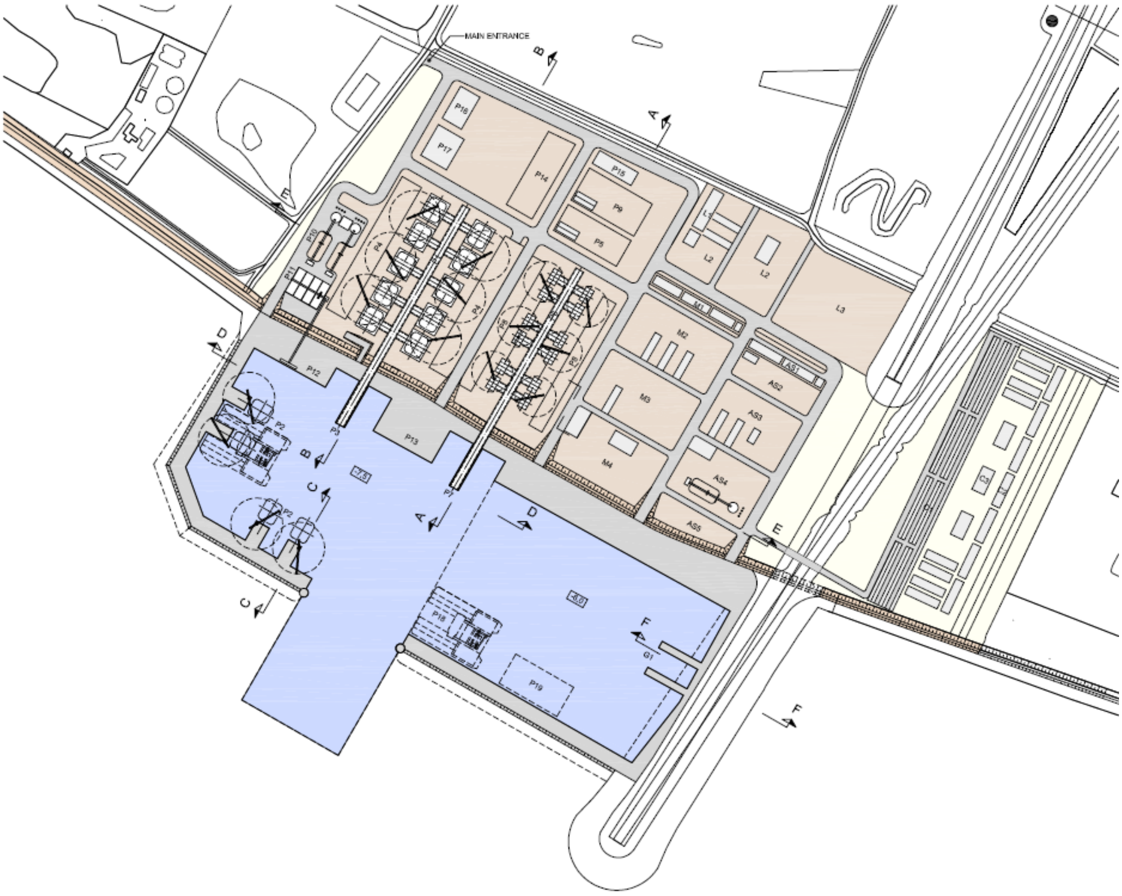


*Fig. 2.10 Proposed lay-out of the production site at Lolland east of Rødbyhavn*

## 2.2 *Relevant project pressures*

The impact assessment for the immersed tunnel and the cable stayed bridge alternatives for the fixed link is based on the following general pressures for the future fixed link:

- Permanent structures and seabed/coastline changes, such as bridge piers/pylons, coastal reclamations, protective reefs or leftover access channels
- Temporary structures in construction phase, such as work harbours and associated dredging to be removed and seabed to be re-established
- Permanent or temporary effluents arising from project (or changes in existing effluents due to project), such as dewatering or relocation of existing wastewater discharge at Rødbyhavn
- The potential cessation of ferry service in the future

In relation to the above potential effluent effects only the effects connected to hydrography should be assessed in this Volume, i.e. only if the effluents affect water levels, salinity, temperature, currents, waves to a significant extent. Pollutants in the effluents are assessed in (FEMA & FEHY 2013).

Regarding the effluents arising from project or being changed by the project a screening has revealed that these are all effluent below 1 $m^3/s$ discharge rate and with salinity and temperatures within normal ranges for freshwater runoff. Thus these effluents will not have an effect to the salinity and general hydrography to any significant degree close to the source point or on larger scales, taken into account the normal variation in salinity in the areas is in the range 9-25 psu and the efficient flushing with mean speed of about 0.4 m/s. Therefore these effluents are not further assessed as a pressure in the present Volume.

The remaining project pressures assessed more detailed are listed in Tables 2.1 and 2.2 for the immersed tunnel and cable stayed bridge alternatives.

*Table 2.1 Pressures in relation to immersed tunnel having a potential effect on the hydrography component.*

| **Sub-component** | **Construction period pressures** | **Permanent pressures** | |
|---|---|---|---|
| | | **Structures and sea bed changes** | **Operation** |
| Water level | (see permanent pressure assessment) | Reclamations, protection reefs and access channels | Potential cessation of ferry traffic |
| Currents | Work harbors in combination with reclamations etc. | Reclamations, protection reefs and access channels | Potential cessation of ferry traffic |
| Salinity and temperature | (see permanent pressure assessment) | Reclamations, protection reefs and access channels | Potential cessation of ferry traffic |
| Waves | (see permanent pressure assessment) | Reclamations, protection reefs and access channels | |

*Table 2.2 Pressures in relation to the cable stayed bridge having a potential effect on the hydrography component.*

| **Sub-component** | **Construction period pressures** | **Permanent pressures** | |
|---|---|---|---|
| | | **Structures and sea bed changes** | **Operation** |
| Water level | (see permanent pressure assessment) | Piers, pylons, marine ramps etc. | Potential cessation of ferry traffic |
| Currents | (see permanent pressure assessment) | Piers, pylons, marine ramps etc. | Potential cessation of ferry traffic |
| Salinity and temperature | (see permanent pressure assessment) | Piers, pylons, marine ramps etc. | Potential cessation of ferry traffic |
| Waves | (see permanent pressure assessment) | Piers, pylons, marine ramps etc. | - |

# 3 DATA AND METHODS

## 3.1 Areas of investigation

The assessment of hydrographical effects covers various scales:

- The immediate near zone of the project, defined as <500m on both sides of the project footprint
- The local Fehmarnbelt scale (10 km on both sides of the alignment)
- The more regional scale (equivalent to the Western Baltic Sea from Gedser to Little Belt)

There is also a trans-regional scale (including the whole Baltic Sea) related to the hydrography, but impacts here are assessed in another Volume (FEHY 2013b).

Finally the calculation has been undertaken for the part of the total impact area being situated within Danish waters, German national waters and German waters inside the EEZ zone. The difference scales are displayed in Fig. 3.1.

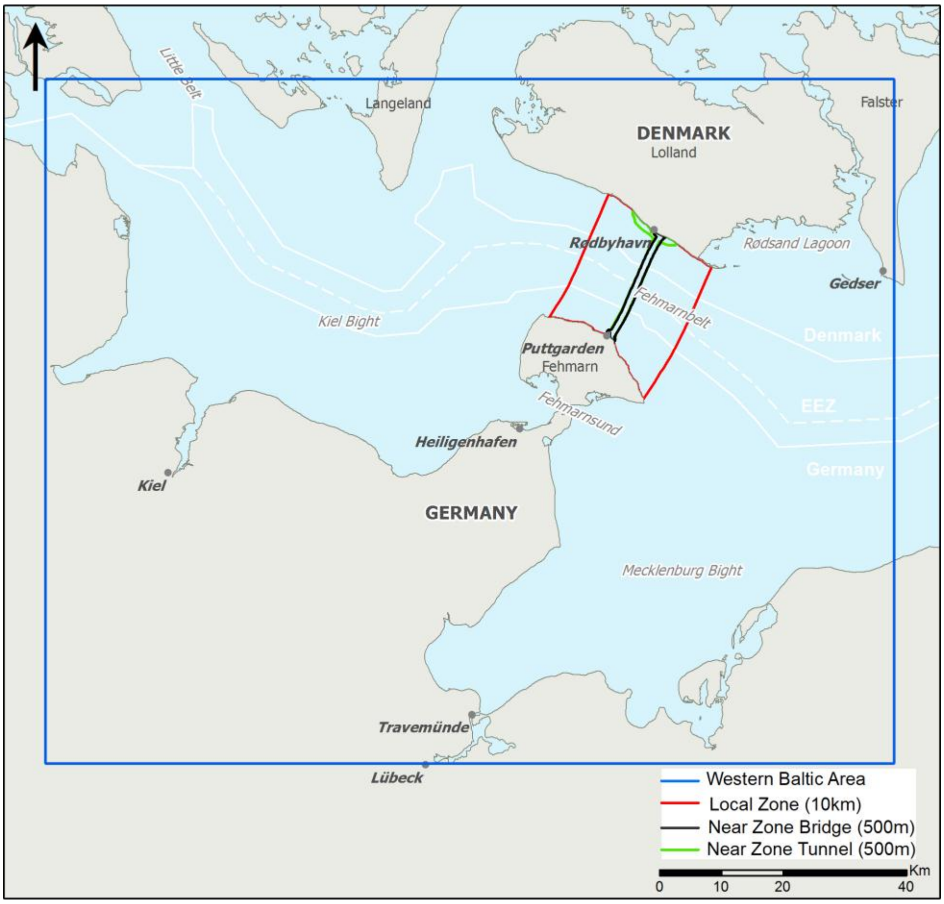


*Fig. 3.1 Area of investigation for hydrography*

For detailed description of the hydrography of the investigation area see (FEHY 2013d).

## 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.<br><br>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.<br><br>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 | Anlæg | Anlage |

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

| Term | Explanation | Term DK | Term DE |
|---|---|---|---|
| | of loss is described by the intensity, the duration and if feasible, the range. | | |
| **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 |
| ***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, subfactors, 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 Fig. 3.2 to 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 3.1 and Table 3.2, respectively.

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

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

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

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

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

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

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

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

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

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

### *3.2.4 Assessment Criteria and Grading*

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

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

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

### *3.2.5 Identifying and quantifying the pressures from the Project*

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

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

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

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

### *3.2.6 Importance of the Environmental Factors*

The importance of the environmental factor is assessed for each environmental subfactor. Some sub-factors are assessed as one unity, but in most cases the importance assessment has been broken down into components and/or subcomponents 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 (Fig. 3.2). 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 Fig. 3.3 of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

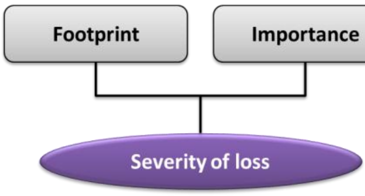


*Fig. 3.2 The assessment scheme for severity of loss*

### *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 (Fig. 3.3). 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.

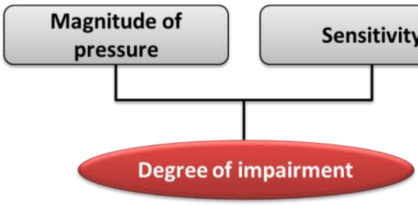


*Fig. 3.3. The assessment scheme for degree of impairment*

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 (Fig. 3.4) using the matrix in Table 3.3. If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

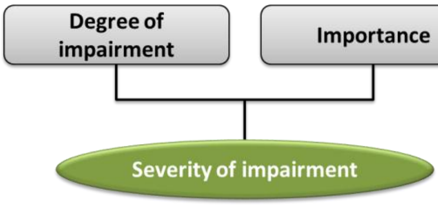


*Fig. 3.4 The assessment scheme for severity of impairment*

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 Fig. 3.5. 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.

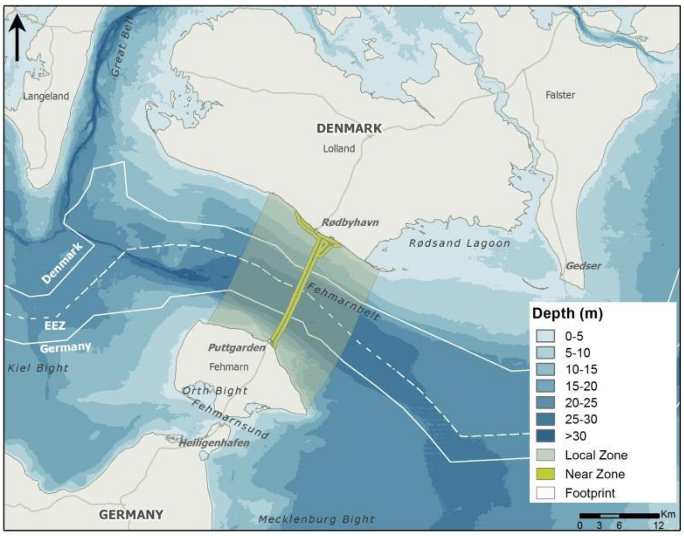


*Fig. 3.5* *The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders are approximately 10 km from the centre of the alignment.*

### 3.2.12 *Duration of impacts*

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

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

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

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 |

| Project | Placement | Present Phase | Possible interactions |
|---|---|---|---|
| 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 Assessment of magnitude of pressures

For hydrography the magnitude of the pressures comes from the marine parts of the layout specifications and the construction plans for the two final link alternatives:

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

These specifications include details on position and size of the permanent structures, reclamations, dredgings etc. and of temporary elements in the construction period being removed and the area re-established after construction is finished.

These specifications are implemented directly in the numerical tools used for the impact assessment by their position and size. For elements smaller than the spatial resolution of the models a subscale representation technique has been applied, e.g. for the drag and mixing effects from the pier and pylons and of the present ferry service.

It should be mentioned that the numerical hydrodynamic modelling (currents, salt and temperature) undertaken for the cable stayed bridge has used specifications from an earlier bridge variant B-EE of April 2010. This variant differs from the final Var. 2 (October 2010) as follows:

- It had a slightly more S-shaped alignment
- It did not have marine ramps but the approach bridge extended all the way to land (3 extra piers in total)
- One additional pier had a ship protection caisson at the two transfers to the main bridge
- The main bridge span was 900m compared to 724m span in the October 2010 version
- The main pylon had a diameter of 80m compared to 72 m in the October 2010 version

The difference in flow blocking between the two bridge variants has been assessed to be limited, with a tendency to the April 2010 version having a slightly larger flow blocking effects and thus also slightly larger overall hydrodynamic effects.

Therefore, the results from the April 2010 version of the cable stayed bridge have been used for the final October 2010 bridge assessment as well, constituting a slightly conservative quantification of the hydrodynamic impacts.

## 3.4 Assessment of sensitivity

The methodologies applied in the impact assessment of the hydrography sub-components are in general numerical dynamic modelling of the specific sub-component in the investigation area, literature information and expert evaluation.

The sensitivity is understood as the relationship between pressure and effects (loss or degree of impairment). For the numerical models applied to assess the physical component hydrography these relationships are formulated in basic deterministic equations of the models, like the conservation of mass and momentum in hydrodynamic models.

A large effort has been put into establishing numerical models and calibrating and validating the tool to a high degree of accuracy before used for scenario modelling of the impact for the fixed link alternatives.

## 3.5 Assessment criteria

### 3.5.1 Loss

A loss in relation to hydrography is defined for an area only if the water column is completely disappearing. According to this definition the loss areas are the reclamation areas and pier/pylon footprints. The breakwaters of the temporary work harbours are included as temporary loss areas.

Areas with increased or reduced water depth due to dredging or placing of protection reefs not penetrating the water surface are treated under impairment.

### 3.5.2 Impairment

The degree of impairment to the individual sub-components is assessed based on the quantitative impact criteria quoted in Table 3.6.

The assessment is undertaken for each geographical position within the investigation area. It can be seen that the principle in the assessment of the degree of impairment is that if for a certain position just one indicator for one of the sub-components is rated as belonging to a higher degree of impairment class, the entire hydrography component gets this higher degree class in that geographical position.

The basic concept in the impact criteria is to relate the degree of impairment to various classes of changes compared to the baseline conditions. For some sub-components like the maximum water level (to be used for potential flooding assessments) the assessment criteria classes are given by predefined fractions of the difference between a 50 and a 20 year return period level (reductions in maximum water level is regarded as not important), whereas other assessment criteria classes are related to changes compared to the natural variability of the sub-component.

As many of the indictors are assessed by numerical models giving impact values from the numerical precision of numbers in the models and upwards everywhere in the modelling domain, a threshold has been applied for separation of negligible impact magnitudes and the low impact class.

Most of the impacts to the hydrography component are related to the structures and will therefore persist forever after construction as long as the fixed link is present. These impacts are referred to as permanent impacts. However, there are some impacts which will only be present in the construction period. Therefore, the impact assessment also provides information for the maximum degree of impacts during the construction period.

For the degree of impairment for construction period impacts the same impact criteria as for the permanent impacts (Table 3.6) are used.

The justification for the applied impairment criteria is:

**Water level**
The degree of impact of the fixed link "water level" subcomponent is high if the link causes a significant increase in extreme water levels so that coastal flooding may be initiated in the low-lying areas along the Lolland south coast and along the Fehmarn north coast, which are protected by dikes. If the change in extreme water levels is so high that the dikes lose their function, then the change can be characterized as very high. The magnitude of such a change is discussed in the following.

The characteristics of extreme water levels in the area can be characterized by the return periods and extreme water levels in Table 3.5.

*Table 3.5 Extreme water levels established for the project area.*

| Return Period (years) | Water Level above MSL (cm) | Standard deviation (cm) |
|---|---|---|
| 20 | 150 | 5 |
| 50 | 159 | 6 |
| 100 | 165 | 8 |

It is seen that there is a difference of 9 cm in the water levels exceeded with a return period of 20 and 50 years, respectively, and a difference of 15 cm in the water levels exceeded with a return period of 20 and 100 years, respectively. This indicates that if the impact of the fixed link on extreme water levels is in the order of 10 cm then the impact can be said to be severe, as this corresponds to an increase in the return period of an event with a factor of about 3.

Factors of 0.5 have been applied to go from Very High to High, from High to Medium and from Medium to Low and from Low to Negligible, corresponding to a threshold level for Negligible being 1 cm, which is also significantly below the standard deviation of the 20 year-return period level.

For the mean water level indicator the indicator relates more to the general hydrographical conditions. Here the proposed classes are 25%, 10%, 5% and 2%, respectively, of the annual standard deviation in Fehmarnbelt, an estimation based on the Gedser water level gauge. This standard deviation is 0.24m, and thus the classes will be 5cm, 2cm, 1cm and 0.5cm (from Very High to Low).

*Table 3.6 Impact criteria use for the degree of impairment in relation to the hydrography component.*

| Component | Project pressure | Impact criteria | Duration | Degree of impairment |
|---|---|---|---|---|
| **Hydrography, (hydrodynamic)** | Project structures and construction activities | • Water level of events with a return period of about 20 years increases by 10cm or mean water level change exceeds 5cm, or<br>• Value of Hs exceeded 5% of the time is changed more than 50%, or<br>• At least for one of the other subcomponents the change in the indicator value will exceed 100% of the natural temporal standard deviation. | Permanently or for construction period | Very high |
| | | • Water level of events with a return period of about 20 years will increase by 5-10cm and/or mean water level change by 2-5cm, or<br>• Value of Hs exceeded 5% of the time is changed 20-50%, or<br>• At least for one of the other subcomponents the change in the indicator value will be 20-100% of the natural temporal standard deviation and the other components less. | Permanently or for construction period | High |
| | | • Water level of events with a return period of about 20 years increases 2.5-5cm, or mean water level change by 1-2cm, or<br>• Value of Hs exceeded 5% of the time is changed 10-20%, or<br>• At least for one of the other subcomponent the change in the indicator value will be 10-20% of the natural temporal standard deviation and the other components less. | Permanently or for construction period | Medium |
| | | • Water level of events with a return period of about 20 years increases by 1cm or mean water level change exceeds 0.5cm, or<br>• Value of Hs exceeded 5% of the time is changed more than 2%, or<br>• At least for one of the other subcomponents the change in the indicator value will be 5-10% of the natural temporal standard deviation and the other components less. | Permanently or for construction period | Low |
| | | • Below above threshold levels | | Negligible |

**Sea state**

Regarding sea state focus is generally on the more extreme waves, both with regard to navigation, design and sediment transport. For the subcomponent "wave height" a change of 10%/20%/50% of the value exceeded 5% of the time is therefore taken as a measure of the limits between Low, Medium, High and Very High class criteria. It is noted that the significant wave height exceeds 1.35 m at the location of MS02 5% of the time during the baseline simulation period from 1990-2009. The insignificance threshold is set to 2% change in the wave height, which is 0.03m.

**Other subcomponent indicators**

The other seawater subcomponents aim mainly at characterisation of potential changes to the general hydrographical regime. The hydrographical regime is characterised by a large variability in the Fehmarnbelt area, and a somewhat smaller variability in the Baltic Sea. The extremes for the parameters are generally controlled by the brackish water flowing from the Baltic Sea and the more ocean water coming via the Kattegat bottom water.

It is therefore proposed to base the impact classification on changes in the mean values of the parameters compared to the standard variation of the parameters in the baseline condition.

A change in the mean value of 5% of the standard deviation (STD) means an overlap of 98% in the distributions before and after (assuming a normal distribution). For surface salinity at the alignment the STD is 3.2psu and the criteria thus a change limit of 0.16psu. Furthermore, this change is close to the uncertainty level of the measurement and thus cannot be detectable in practice.

Similarly a change of 10%/20%/100% of the STD means that the overlap is 96%/92%/60% respectively, see Fig. 3.6. These classification levels are proposed as the Low/Medium, Medium/High and High/Very High class separators.

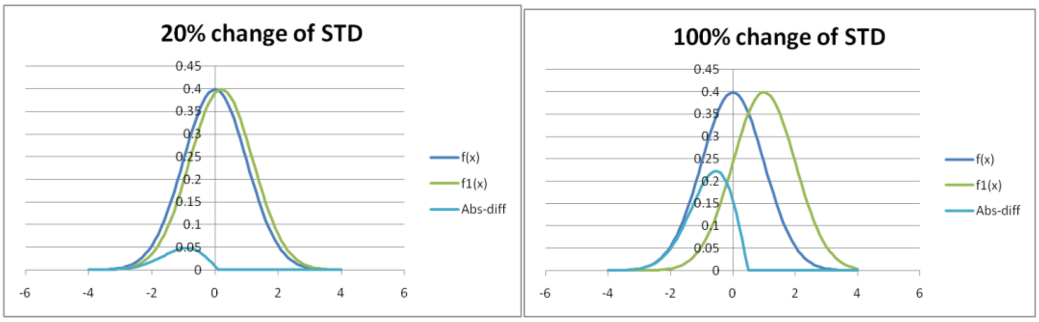


*Fig. 3.6 Illustration of overlap for change in mean value of 20%, respectively 100% of STD*

In Table 3.8 the STD values of the applied subcomponents, taken from the baseline reporting activity (FEHY 2013d), are provided.

*Table 3.7 STD values of the subcomponents, based on baseline study (MIKE model, see Chapter 3.7)*

| **Subcomponent** | **Fehmarnbelt**<br>**Station N01 (1990-2007) or MS02 (2009-2010)**<br>**Standard deviation** |
|---|---|
| Water level | 0.24m<br>(Gedser 2004-2009) |
| Surface current speed | 0.23m/s<br>(3m below surface at MS02) |
| Bottom current speed | 0.13m/s<br>(2 m above bottom at MS02) |
| Surface salinity | 3.2psu<br>(NO1) |
| Bottom salinity | 3.5psu<br>(NO1) |
| Surface temperatures | 5.7°C<br>(NO1) |
| Bottom temperature | 3.6°C<br>(NO1) |
| Bottom<br>summer temperature | 2.3°C<br>(NO1) |
| Stratification<br>(bottom - surface density) | 4.5kg/$m^3$<br>(NO1) |
| Stratification summer<br>(bottom - surface density) | 2.8kg/$m^3$<br>(NO1) |

## 3.6 *Assessment of degree of loss*

The degree of loss is assessed by a simple overlay of the permanent reclamation and structure footprints on the baseline importance map, see Fig. 3.7.

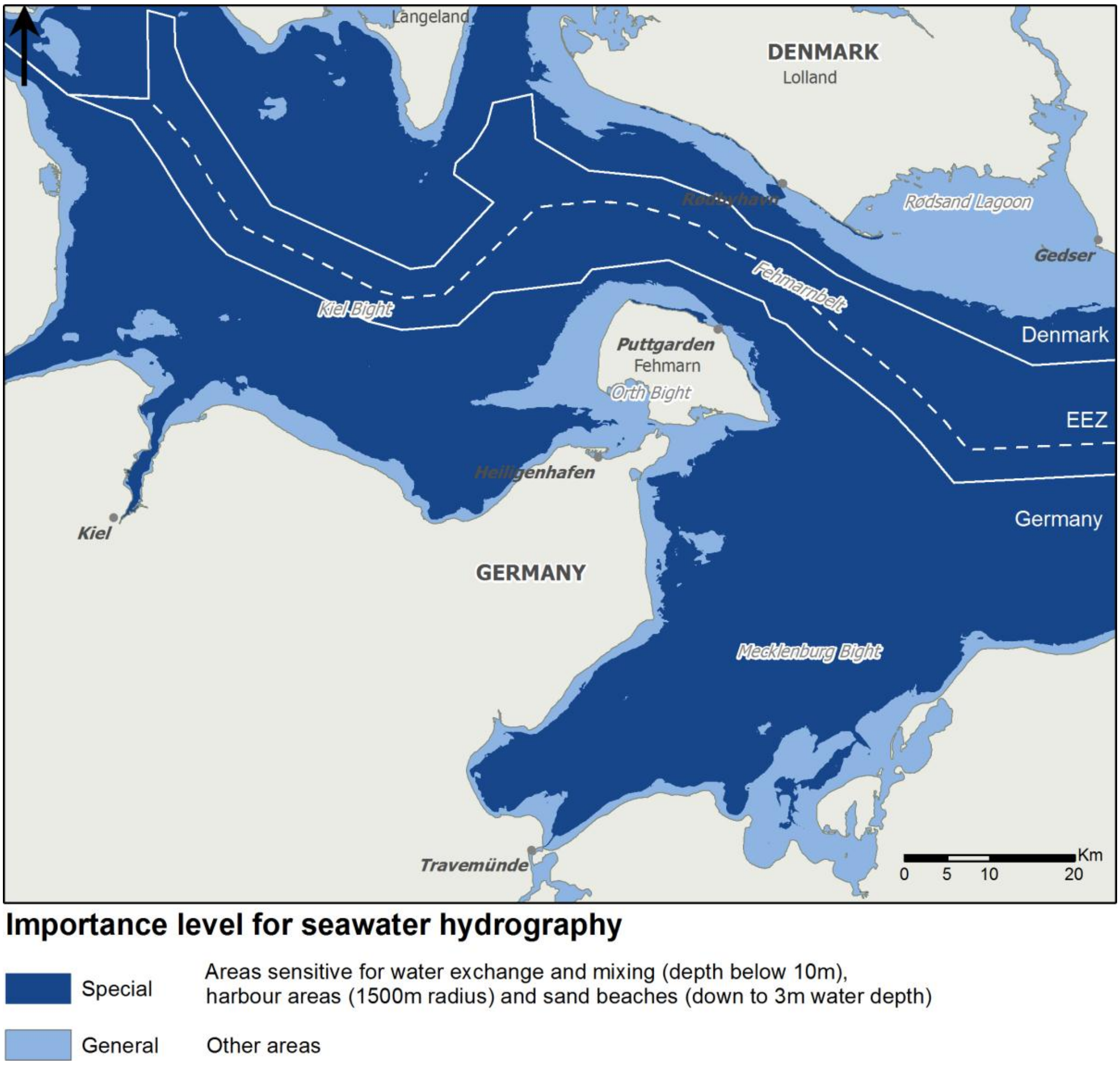


*Fig. 3.7 Baseline importance map for hydrography (FEHY 2013d)*

## 3.7 Assessment of degree of impairment

### 3.7.1 Hydrodynamic modelling with dual model approach

The hydrodynamic modelling includes the assessment of the sub-components water level, currents, salinity and temperature. The assessed changes to these sub-components come from numerical hydrodynamic modelling on a Belt Sea scale. These models are referred to as local models, to distinguish them from the regional models mainly used for Baltic Sea scale effect assessment (FEHY 2013b).

However, some effect estimates from the regional models are also used directly in the present reporting on Belt Sea scale impacts.

To be able to evaluate the uncertainty of the effect estimates it has been decided to use a dual modelling concept where two different local model tools are used and where two different regional model tools are also applied.

All models are 3D models, with national and international applications for other studies. The applied models are:

**Local models**

- MIKE 3, a commercial modelling software developed by DHI
- GETM/ERGOM, where GETM is developed by Bolding & Burchard (BB) and ERGOM is the water quality module used also for MOM3 by IOW (see below)

**Regional models**

- MIKE 3, see above
- MOM3/ERGOM, a version of the public domain "Modular Ocean Model" code version 3.1 (MOM 3.1) combined with the ecosystem module ERGOM, both used at IOW

For more information on the regional models see (FEHY 2013b).

This dual approach has been implemented in full for the bridge alternative.

However, for the tunnel alternative, due to the limited extent of the coastal protrusions and bathymetrical changes, the GETM local modelling tool is not appropriate for this task, as the rectangular mesh elements of 400m spatial resolution used are too coarse for a proper representation of the physical changes. A much finer resolution of say 30m or less would have to be applied in the entire modelling domain and would imply too long runtimes.

Furthermore, it has been decided only to undertake local hydrodynamic modelling for the tunnel scenario, and skip the regional modelling (and also water quality modelling), as the estimated effects with the MIKE 3 local model are so small and cannot initiate effects on a large scale (or on the water quality).

### *3.7.2 Local models on the Belt Sea scale*

The two local models have been set up with exactly the same position of the open boundaries, one in southern Kattegat and two open boundaries in the Baltic Sea end, and one on each side of Bornholm. Thus, the local models cover both the Fehmarnbelt/Great Belt/Little Belt connection and the Sound connection of the transition area between the Baltic Sea and Kattegat.

The bathymetry basis is the same high resolution (50m) dataset for both models. Furthermore, the models are driven by the same set of forcings, like meteorology, water level, salinity and temperature variations at the open boundaries and internal sources.

**MIKE 3**

The MIKE 3 local model domain and bathymetry are shown in Fig. 3.8.

Fig. 3.9 shows a zoom-in of the mesh on Fehmarnbelt and the fixed link alignment. The MIKE 3 local model has a horizontal resolution of about 500-700 m in the potential alignment of the area in Fehmarnbelt and the narrow parts of Great Belt and Little Belt, increasing to 5000m in the more open waters further away from the alignment. The vertical resolution is with 10 layers for water depths up to 10 m (a sigma-layer approach) and 1m resolution below.

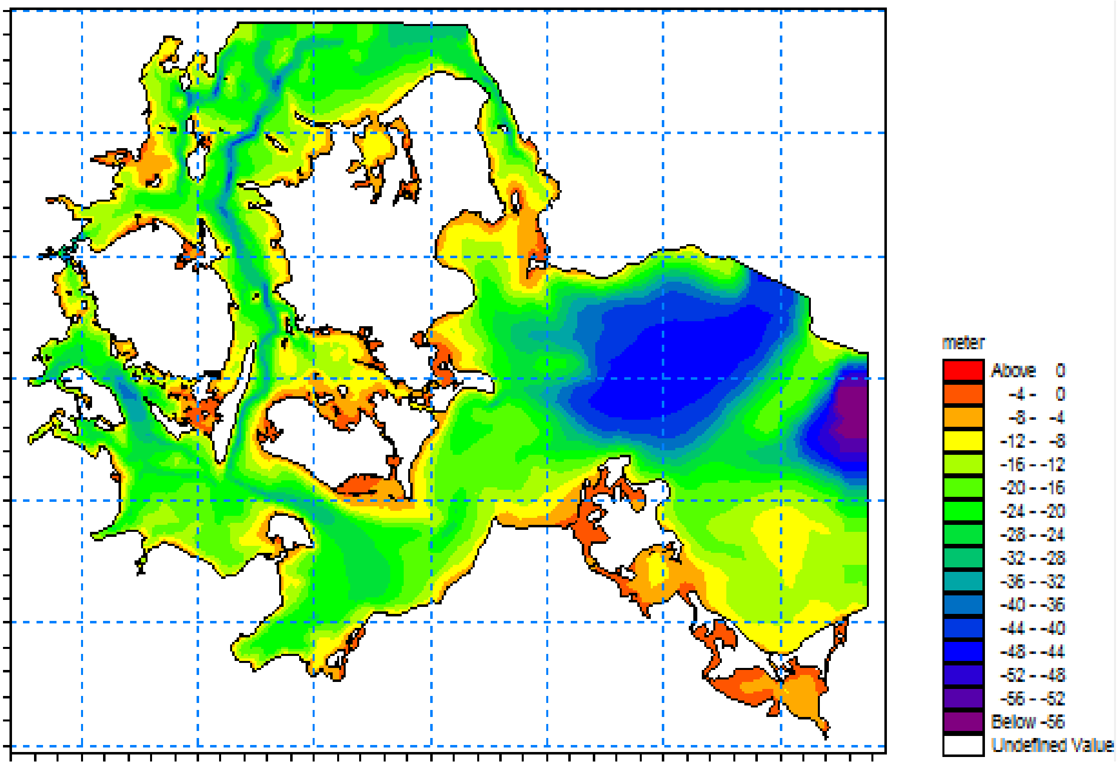


*Fig. 3.8 Model domain and bathymetry for the MIKE 3 local model*

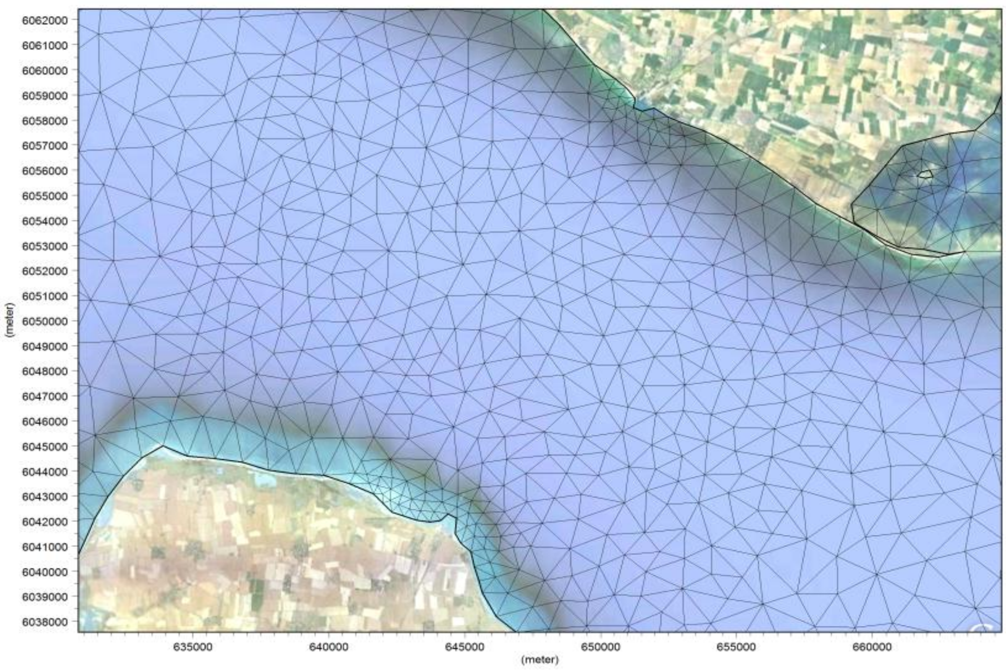


*Fig. 3.9 Zoom-in on the Fehmarnbelt mesh representation in the MIKE local model used for bridge alternative*

**GETM**

The numerical model used in this work is the GETM (General Estuarine Transport Model, see www.getm.eu), which is a fully baroclinic and hydrostatic ocean model using bottom-following vertical coordinates (sigma coordinates). For horizontal discretisation the model uses the Arakawa C-grid. The model simulations carried out in this work are applied with the help of higher order advection schemes (here: TVDSuperbee) as well as with the well-tested and state-of-the-art turbulence model GOTM (see www.gotm.net). The turbulence closure model used is the k-e model with transport equations for turbulent kinetic energy, k, and the turbulence dissipation rate, e. The advection of turbulent quantities is neglected in this work.

The ERGOM WQ module from the MOM model has been incorporated in the GETM model. For further information see (FEHY 2013b).

GETM is applied in a 400m horizontal resolution (see Fig. 3.10 and 3.11) for the hydrodynamic part and a separate 800m resolution for the water quality part (based also on a 800m hydrodynamic basis) to speed up the runtime.

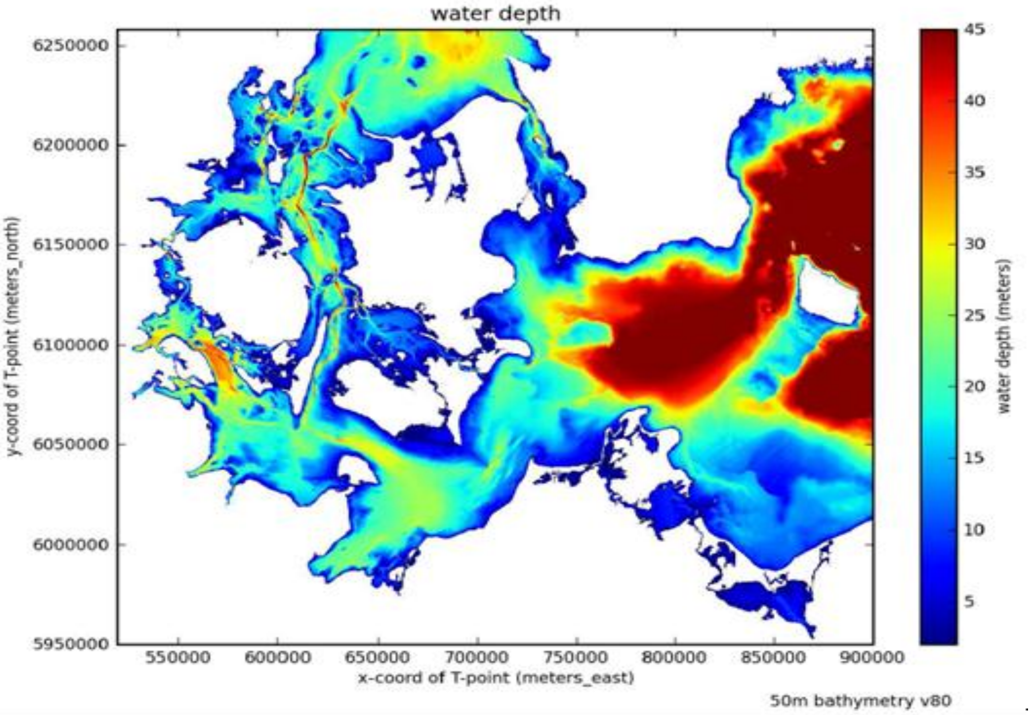


*Fig. 3.10 Model domain and bathymetry for the GETM local model (400 m version)*

*Fig. 3.11 Zoom-in on the Fehmarnbelt mesh representation in the GETM local model (400 m version).*

### *3.7.3 Modelling periods and spin-up*

**Calibration and validation periods**

The calibration and validation periods have been selected based on the availability of data, the time scales of the processes studied and the representativeness of key hydrodynamic and water quality characteristics within potential periods.

For the local modelling, 2005 was selected as the calibration year and 2009 as the validation year. For 2009, the period was restricted to 1 January to 1 October not to delay the modelling. For both periods, three months were included for model spin-up prior to the onset of the year, i.e. the total simulation periods are 1 October 2004 – 1 January 2006 and 1 October 2008 – 1 October 2009, respectively. At the onset of the calibration phase for the FEHY modelling, limited data were available from the FEHY monitoring programme. The year 2005 was considered a good candidate because of the good temporal and spatial coverage of monitoring data for the area of interest and its fair representation of dynamic features of interest for studying fixed link impacts.

Fig. 3.12 shows the comparison of 2005 and 2009 monthly mean wind speed, surface salinity and bottom salinity, respectively, for a position in Fehmarnbelt. The wind data is a SN-REMO re-analysis product (obtained from Helmholtz-Zentrum Geesthacht), and the salinity data are produced by multi-decadal modelling with the regional model (FEHY 2013b).

The years 2005 and 2009 are concluded to be representative for studying the local area impact of a Fehmarnbelt Fixed Link.

**Scenario modelling**

The local scenario modelling uses the year 2005, as this year is considered representative for a typical year.

Each scenario simulation is initiated with the three-month spin-up period October-December 2004 for the new conditions to build-up before the full year analysis period. It has been checked that this period is of sufficient duration to ensure a full spun-up situation at the start of the analysis period 1 January 2005.

The current effects for the final tunnel layout (E-ME from August 2011) have only been assessed in detail for a shorter design period 9-27 Nov 2005. This short period is selected so that it represents the entire year 2005 generally applied appropriately, see Table 3.8.

*Table 3.8 Comparison of short design period statistics with full design period.*

| | **Full year design period 1 Jan -31 Dec 2005** | | | **Short design period 9-27 Nov 2005** | | |
|---|---|---|---|---|---|---|
| | Outflow | Inflow | Total | Outflow | Inflow | Total |
| Percentage of time (%) | 55.8 | 44.2 | 100.0 | 60.6 | 39.4 | 100.0 |
| Average discharge ($m^3/s$) | 74,150 | -66,516 | 12,646 | 82,106 | -76,199 | 14,485 |

Regarding regional model periods please refer to (FEHY 2013b).

### *3.7.4 Calibration and validation results for local models*

The local and regional models developed are calibrated and validated against an extensive data set (see overview in Fig. 3.21 and Fig. 3.22). The calibration procedure has been targeted at achieving a model performance which adheres to the model acceptance criteria described in the following.

The developed model acceptance criteria mainly focus on a proper capability of the models to reproduce the overall level and variability of the hydrodynamic and water quality parameters. This is ensured by requiring a proper visual match between modelled and monitored conditions, including general levels, intra- and inter-annual variations and more short-term events.

In addition some statistical model acceptance criteria have been added to quantify the statistical match of the models.

It should be noted that the model acceptance criteria are not taken as strict pass or no-pass criteria, but express desired target levels. Every deviation from the criteria is analysed with respect to the uncertainty added to the fixed link impact assessments.

Below is described the model acceptance criteria for the local model hydrodynamics.

**Statistical parameters**
The applied statistical parameters are:

- SDE = standard deviation error
- EV = explained variance
- RMSE = root mean square error
- BIAS = mean deviation

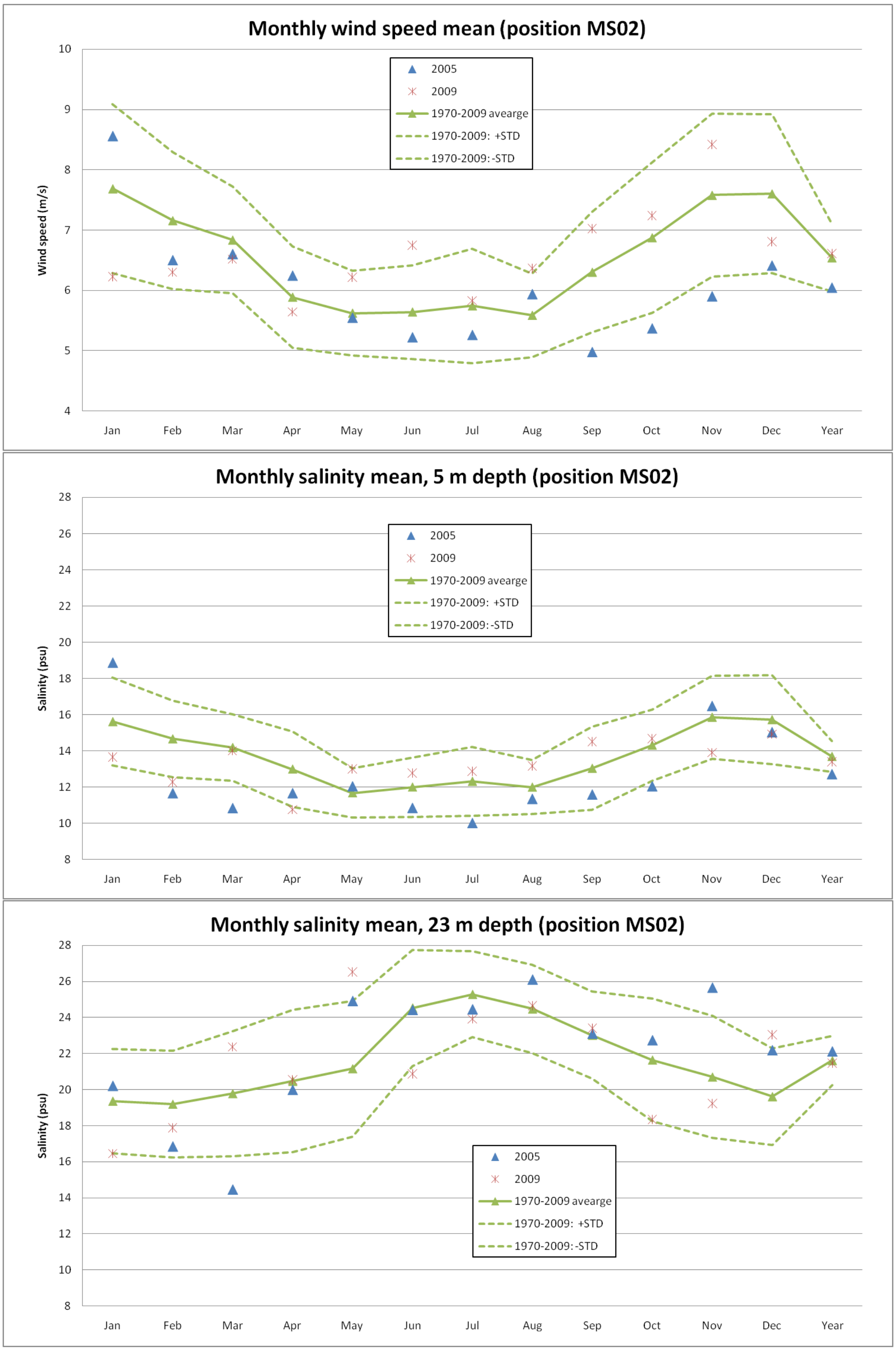


*Fig. 3.12 Representativeness of the years 2005 and 2009 , looking at wind speed from SN-REMO (Helmholtz-Zentrum Geesthacht) and model results from regional modelling (FEHY 2013b) at station MS02 close to the alignment.*

## Water level criteria

The qualitative model acceptance criteria for water level conditions include capability to reproduce both the astronomical tide and the meteorology determined wind set-up and set-down conditions. This has been documented by:

- Visual comparisons for the individual monitoring stations. These comparisons shall be undertaken after compensation for datum differences, as these vary in the monitoring data from area to area.

The quantitative model acceptance criteria for water level are:

- SDE<0.1m for 80% of stations

- EV > 0.8 for 80% of stations

These statistical comparisons take place on about half-hourly basis for the transition area stations.

The value for SDE of 0.1 m corresponds to about 50% of the SD of the monitored data in the areas. It should be noted that when applied on instantaneous values the SDE and EV values will add-up both deviations in tidal phase, tidal range and meteorology determined variations in the models as well as uncertainty in monitoring data.

**Salinity and temperature criteria**
The qualitative model acceptance criteria are that the models shall be capable of reproducing the general conditions. This has been checked visually by plots of the following for all key stations:

- Time series of model and monitoring parameters at surface and bottom, where general levels and trends as wells as intra-annual, inter-annual and more event based variations (e.g. Baltic Sea major inflow events for the regional models) are checked visually

- Similarity in variations over depth between model and monitoring data, particularly in salinity stratification, including also stratification structure with well mixed layers separated by interface layers at the monitored levels

Furthermore, the modelled patterns of sea surface temperature are qualitatively compared to earth observations:

- Visual similarity for selected earth observation data sets (particularly near link alignment)

The quantitative model acceptance criteria for salinity and temperature to support the above qualitative criteria include:

- BIAS ≤ 1psu/1°C and RMSE ≤ 3psu/2°C in local models for 80% of all station levels (data sets only included if N≥5).

The above local salinity criteria should be compared to salinity values of about 8-30psu in the Fehmarnbelt, inter-annual standard deviations of 3-4psu, and typical vertical differences of 10psu, so the accepted BIAS and RMSE are limited.

The temperature criteria can be compared to a standard deviation in temperatures in Fehmarnbelt of 4-6°C, so the criteria values correspond to about 20% and 40%, respectively.

**Currents criteria**
Current conditions often change significantly within a short distance in the transition area due to fronts and bathymetry gradients. The models typically apply a horizontal spatial resolution of 400-1000m for the local models. The match to the ADCP data sets representing currents within about 10m scales may thus be less accurate.

The developed qualitative model acceptance criteria include:

- A proper visual time series match with respect to variability, level and direction of currents, particularly for the two main stations in the alignment in Fehmarnbelt (MS01 and MS02).

- Visual similarity for model conditions with transect ADCP plots from the monthly cruises, particularly for transects in link alignment

The quantitative model acceptance criteria are based on main station current roses for multiple levels:

- Inflow and outflow main directions max deviation ±10°, and average speed max deviation of ±25% (or 0.1m/s if this is larger), achieved for 80% of MS01/MS02 levels (about 3m/5m/10m/15m/20m/25m or 3m above bottom)

It can be mentioned that the typical surface current speeds are about 0.4 m/s in Fehmarnbelt, so 0.1m/s corresponds to about 25% of this value.

**MIKE local model compliance**
Overall performance of the MIKE local model for both calibration and validation is considered to be fine. Fig. 3.13 shows an example of current rose comparison of model results vs. ADCP measurement data. The model generally reproduces currents well, with a tendency to less variation in direction and lower maximal speeds. Also the average directions seem to be slightly more east-west orientated compared to observation data.

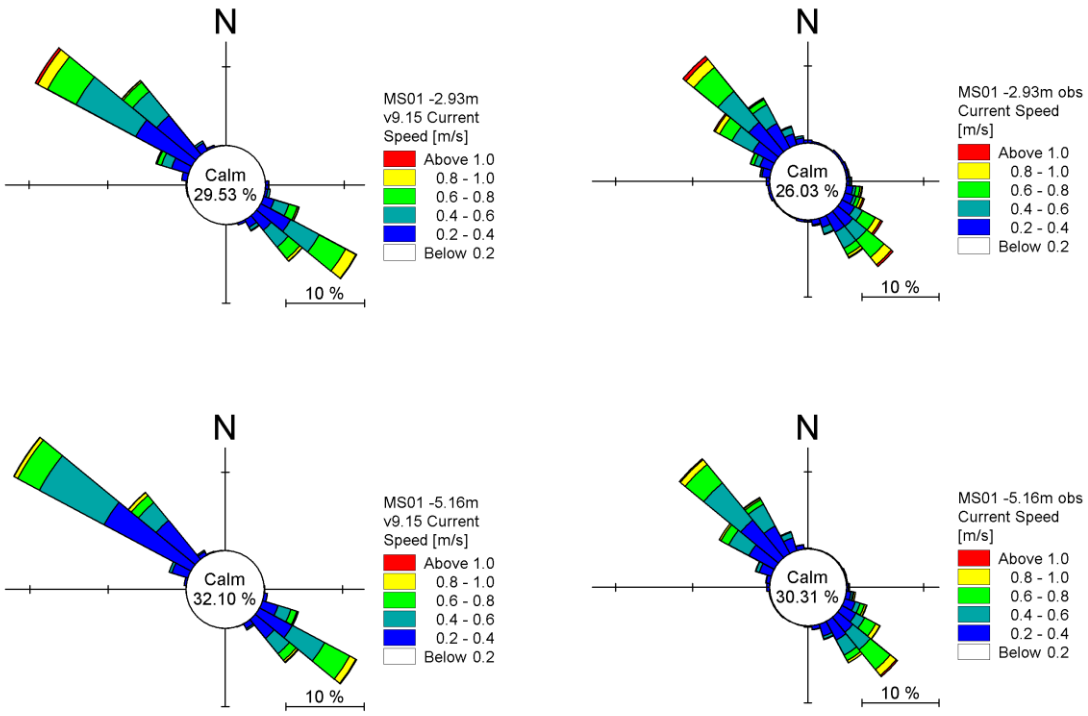


*Fig. 3.13 Current roses for two depth levels (upper row:-2.93m, below: -5.16m) at MS01, left: MIKE model results, right: ADCP measurements, each segment covers 11.25°.*

The established quantitative model acceptance criteria are widely met as can be seen from Table 3.9. The only criterion not fulfilled is the BIAS in comparison of modelled vs. observed salinity and this model acceptance criterion is only slightly missed. The visual time series inspection further demonstrates a good representation of key processes and that remaining biases are still small compared to the general range of variability of considered parameters (mainly salinity), see example in Fig. 3.18. Hence the model constitutes a robust tool for the impact assessment, which measures the relative impact with and without a fixed link.

*Table 3.9 Summary of MIKE local model fulfilment of model acceptance criteria for calibration and validation period. Target is minimum 80%.*

| **FEHY Compliance Criteria** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Salinity | | Temperature | | Water level | | Current | |
| | RMSE (< 3PSU) | \|Bias\| (< 1PSU) | RMSE (< 2ºC) | \|Bias\| (< 1ºC) | Std Dev (< 0.1m) | EV (> 0.8) | Avg speed (Δ<0.1m/s) | Avg. dir. (Δ<10°) |
| **Calibration (ID8.4)** | ✓ **88%** (126/142) | x **78%** (111/142) | ✓ **95%** (140/147) | ✓ **97%** (143/147) | ✓ **100%** (7/7) | ✓ **86%** (6/7) | | |
| **Validation (ID9.15)** | ✓ **88%** (378/432) | x **76%** (327/432) | ✓ **98%** (428/435) | ✓ **92%** (399/435) | ✓ **100%** (7/7) | ✓ **86%** (6/7) | ✓ **98%** (112/114) | ✓ **81%** (92/114) |

Fig. 3.14 shows examples of the salinity profile compliance.

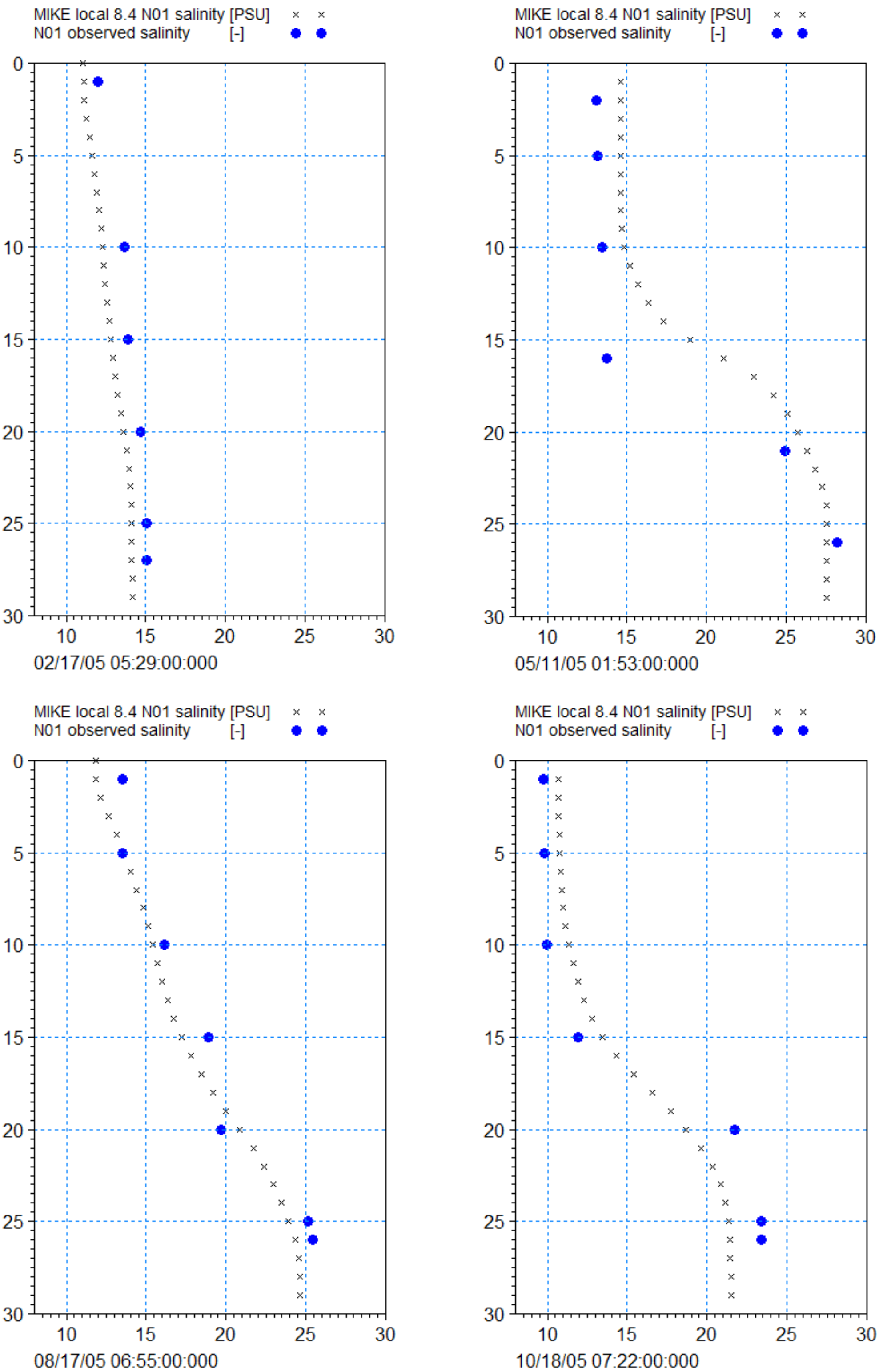


*Fig. 3.14 Four profile plots of MIKE local model salinity versus observation at N01 in 2005 (unit vertically is m)*

**GETM local model compliance**

The GETM compliancy in the calibration and validation period also fulfils most criteria as shown in Table 3.10.

*Table 3.10 Summary of GETM local model fulfilment of model acceptance criteria for calibration and validation period. Target is minimum 80%.*

| FEHY Compliance Criteria | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Salinity | | Temperature | | Water level | | Current | |
| | RMSE (< 3PSU) | \|Bias\| (< 1PSU) | RMSE (< 2ºC) | \|Bias\| (< 1ºC) | Std Dev (< 0.1m) | EV (> 0.8) | Avg speed (Δ<0.1m/s) | Avg. dir. (Δ<10°) |
| **Calibration (v017)** | ✓ **97%** (144/153) | x **43%** (87/153) | ✓ **89%** (144/153) | ✓ **89%** (143/153) | ✓ **90%** (7/8) | ✓ **100%** (8/8) | | |
| **Validation (v006)** | ✓ **95%** (373/387) | x **51%** (188/387) | ✓ **100%** (392/392) | ✓ **89%** (338/392) | ✓ **100%** (10/10) | ✓ **100%** (10/10) | ✓ **94%** (58/62) | x **66%** (41/62) |

Deviations are seen for salinity and current direction. The representation of instantaneous current directions by the model has been found to differ by about 10° from observations, see also Fig. 3.15. Fig. 3.16 shows the calibration result for salinity at station N01 in Fehmarnbelt.

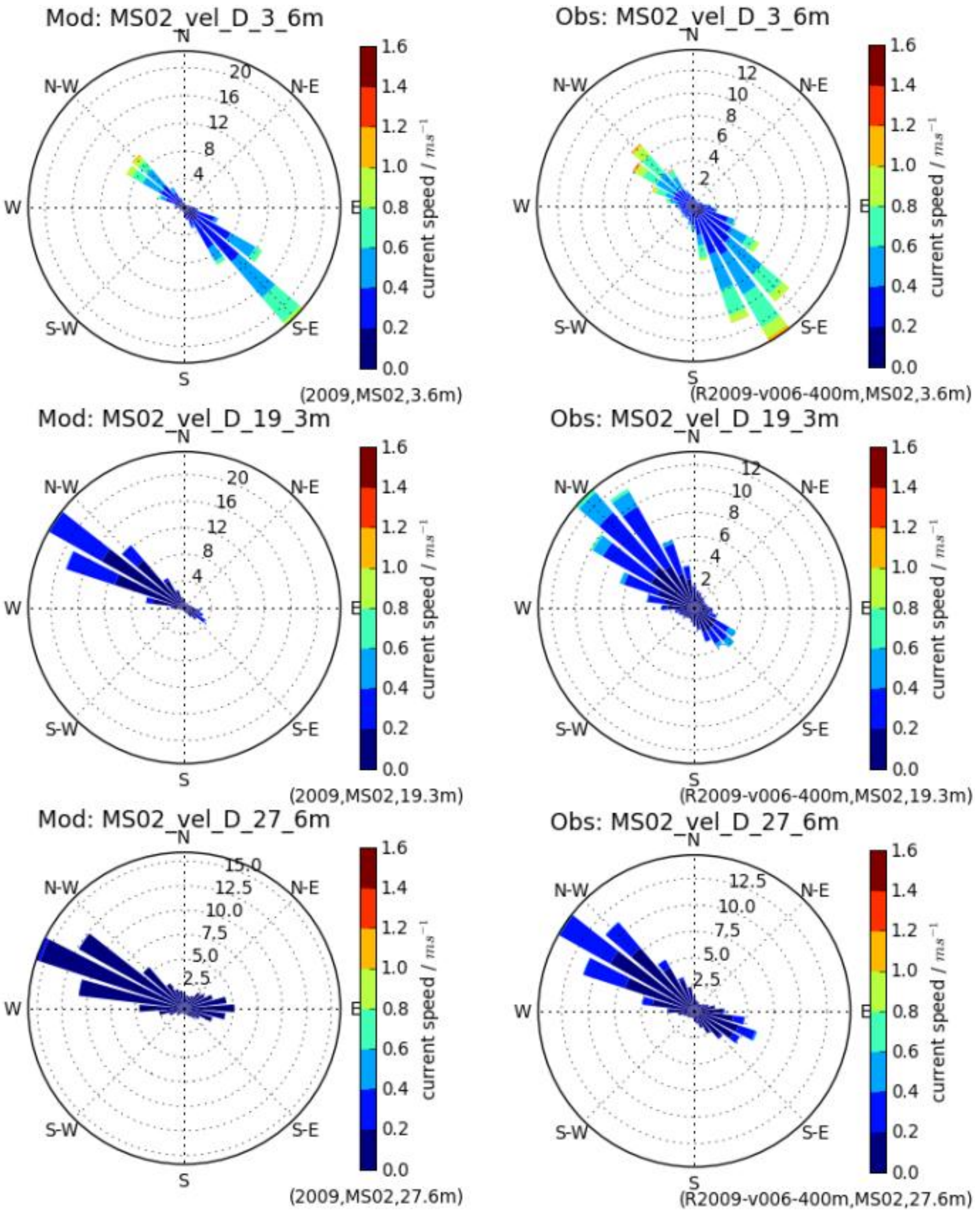


*Fig. 3.15* *Current rose plots for MS02 station in 2009 for GETM model (left column) compared to measurements (right column) for three different depths (3.6m, 19.3m, 27.6m).*

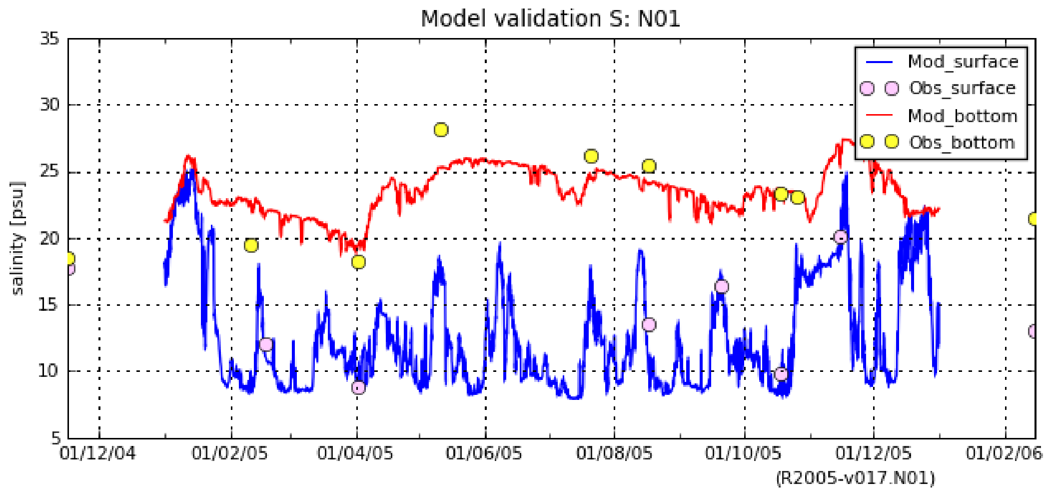


*Fig. 3.16 GETM local model bottom and surface calibration result for salinity at N01 station in 2005.*

It can be summarized that the GETM model is able to capture the basic dynamics of the western Baltic Sea concerning sea surface elevations and transport and dilution of dense bottom currents.

### 3.7.5 Implementation of bridge in models

The implementation of the bridge piers and pylons with their protection caissons is based on a sub-grid parameterisation, where each structure is allocated to the closest mesh cell and implemented with a certain flow drag and lift (or transverse) force and with a certain mixing effect.

The drag and lift of the structures depend on the actual geometry, the local current speed and direction. The mixing effect is a result of the drag and lift and the mixing efficiency, where the mixing efficiency is dependent on the local flow conditions via a densimetric Froude number dependency.

All models have used a common bridge pier specification file, giving the actual position, dimensions and other specifications for the sub-grid parameterisation in each model.

In the MIKE 3 local modelling the following scenario ID refers to the final bridge simulations:

- 10.41 is the "Bridge" only case
- 10.42 is the "Ferry" only case (reference and 0-alternative
- 10.43 is the "Bridge+ferry" case

In the GETM modelling the following scenario ID refers to the final bridge simulations:

- v027 is the "Bridge+ferry" case
- v028 is the "Ferry" only case (reference and O-alternative)
- v029 is the "Bridge" only case

### *3.7.6 Modelling tool for immersed tunnel assessment*

The blockage elements of the preferred immersed tunnel solution E-ME are defined by the coastal reclamations and the protection reefs for the tunnel roof. Both types of blockage elements are of limited physical extent and are furthermore located next to the existing blockage elements of the ferry harbour breakwaters, thus requiring a proper representation in the models of the flow interaction with these existing structures.

The way of implementing these elements in the modelling tool is by changing the coastline positions and the local water depths.

The MIKE local model used for the bridge assessments uses a flexible mesh of triangles of varying sizes to represent the coastline and other blockage elements in an accurate way. However, the local mesh resolution is too coarse (around 400-700m in the vicinity of the link alignment), but has been increased locally without changing the mesh and model setup elsewhere, and thus with a technically feasible overhead on runtime.

Two variants of the local MIKE model setup described in section 3.7.2 have been used for the immersed tunnel assessment task:

- A 100m local model, where the mesh elements around the landfalls are reduced to about 100m scale
- A 30m local model, where the mesh elements around the landfalls/reclamations are reduced to about 30m scale.

The 30m version has been used to test that the spatial resolution applied in the 100m version is adequate and does not give rise to effects due to lack of representation of important flow details. The test has shown that the 30m version and the 100m version give the same patterns in flow effects and also the same overall exchange flow blocking.

Therefore, the 100m version has been used for the final assessments. Fig. 3.17 shows the 100m mesh version of the local model in the vicinity of Rødbyhavn and Puttgarden.

It has been checked that all three versions of the local model give about the same results when comparing the modelled salinity at the N01 station in the centre of Fehmarnbelt, see Fig. 3.18. This documents that the higher resolutions are implemented without changing the validity of the calibration of the local model.

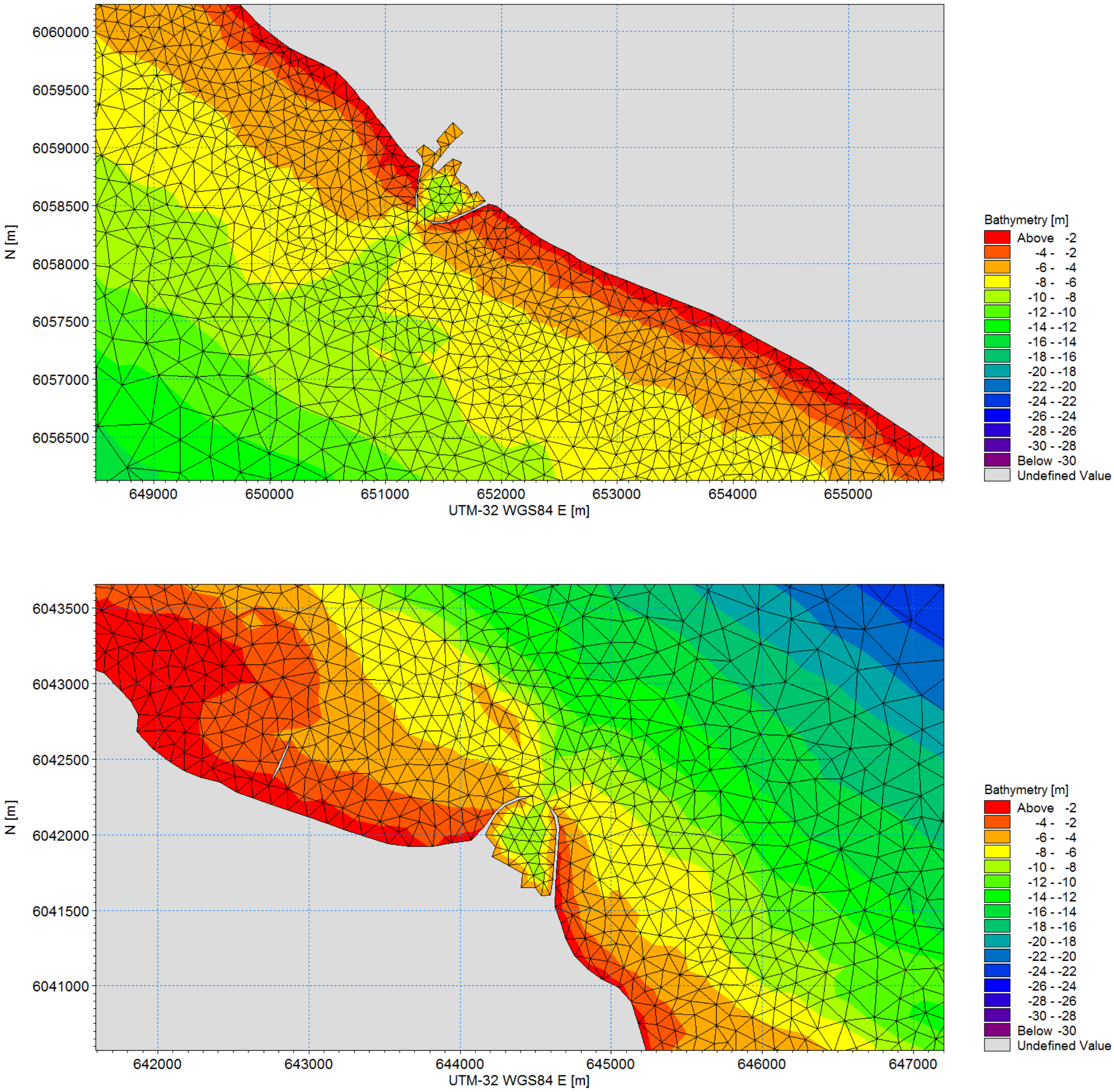


*Fig. 3.17 Zoom-in on mesh in the reference case (ID 14.12) at Rødbyhavn (top panel) and Puttgarden (lower panel) in the 100m local model version used for immersed tunnel assessment*

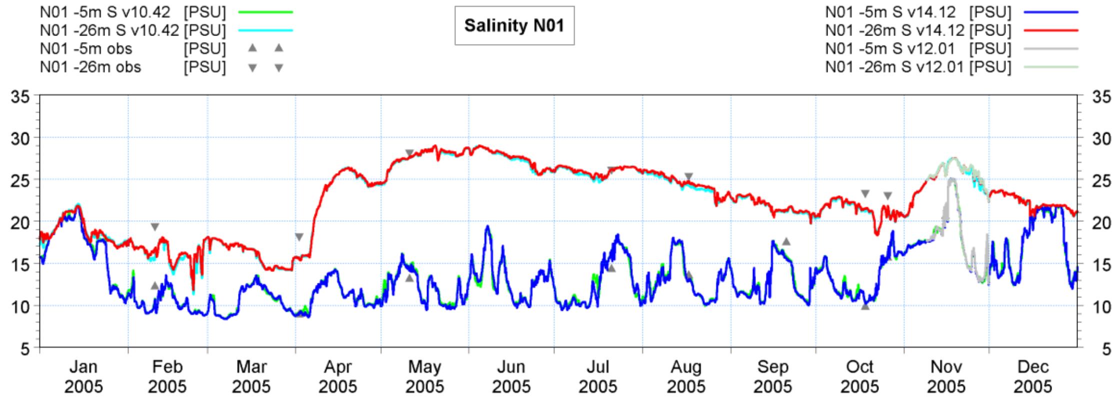


*Fig. 3.18 Simulated salinity at top and bottom at station N01 for the three versions of the local MIKE model: Original local model (ID 10:42), 100m version (ID 14.12) and 30m version (ID 12.01, only short design period).*

### 3.7.7 Implementation of tunnel solution in model

The blockage elements of the immersed tunnel solution version E-ME have been implemented by removing individual mesh cells where these are being reclaimed and by reducing the water depth where the protection reef will be implemented and increasing the bottom roughness to 0.2m to represent the additional friction from the stone cover. Alternatively a method for reclamations has been to add a wall in the mesh separating reclaimed area from the open water. Technically the new coastline alignment was already built into the reference case mesh as a pre-given arc, so the results are an accurate description of the new coastline and protection reef.

The result is shown in Fig. 3.19 where the reclamations and reefs can clearly be seen when comparing with Fig. 3.17.

In the MIKE 3 local tunnel modelling the following scenario ID refers to the final simulations:

- Reference and 0-alternative: ID14.12 (full year) and ID17.01 (short design period)
- "Tunnel+ferry" case: ID:15.12 (full year for layout March 2011) and ID17.03 (short design period for layout August 2011)
- "Tunnel+ferry" case during construction period: ID17.04 (short design period for layout August 2011)
- "Tunnel" only case: ID17.05 (short design period for layout August 2011)

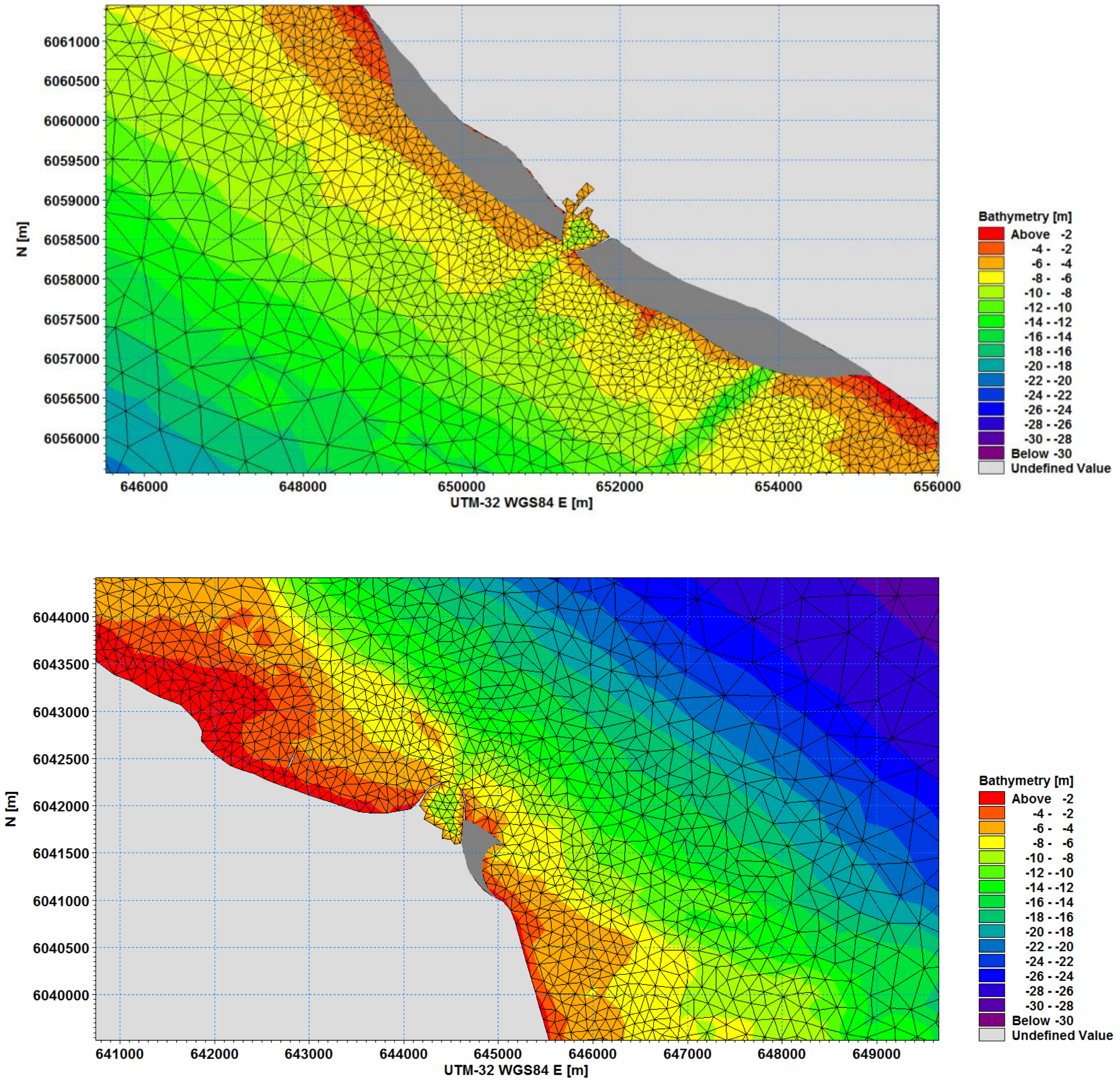


Fig. 3.19 *Zoom-in on mesh in the immersed tunnel case August 2011 (ID 17.03) at Rødbyhavn (top panel) and Puttgarden (lower panel) in the 100m local model. For old coastline compare to Fig. 3.17.*

### *3.7.8 Key effect parameters*

The four hydrodynamic and water quality models all produce 3D information on the development in time throughout the simulation period.

To limit the post processing of the results to a manageable result set various key parameters have been agreed and post-processed from the model runs. These key effects include also the subcomponents used later in the assessment of degree of impairment for the component hydrography.

**Hydrodynamics**

For the hydrodynamics the key effect parameters include:

- Effect to water level, particularly annual mean water level and maximum water level

- Effect to annual mean current speed at surface and at seabed level
- Effect to water exchange between the Baltic Sea and Fehmarnbelt, respectively the Sound
- Effect to annual mean salinity and temperature at surface and along the seabed.
- Effect to mean summer temperature (June-August) at seabed level
- Effect to annual and summer (June-August) mean stratification, defined as bottom density minus surface density
- Effect to vertical annual mean distribution of salinity, temperature and density, particularly for two Fehmarnbelt longitudinal transects (Little Belt-Fehmarnbelt/Lübeck Bight and Great Belt-Fehmarnbelt-Darss)
- Effect to vertical mean summer temperature along the above transects (June-August)

The modelling results for most of these key parameters are presented in Chapters 6.1.2, 6.2.2 and 7.1.2.

It can be clarified that the blocking is defined as the deviation from unity of the linear regression coefficient between the reference flux and the scenario flux, measured at the entrances to the Central Baltic Sea at the Darss Sill (representing the flow through Fehmarnbelt). The concept is illustrated in Fig. 3.20. A negative blocking value is used to denote reduction in water flux. This method is applied for both water flow and salt flux.

### *3.7.9 Overview map*

In the following chapters the scenario effects are references to various geographical sites and specific monitoring stations. Fig. 3.21 and Fig. 3.22 provide an overview of the most important positions, including applied HELCOM monitoring stations and Fehmarnbelt main stations.

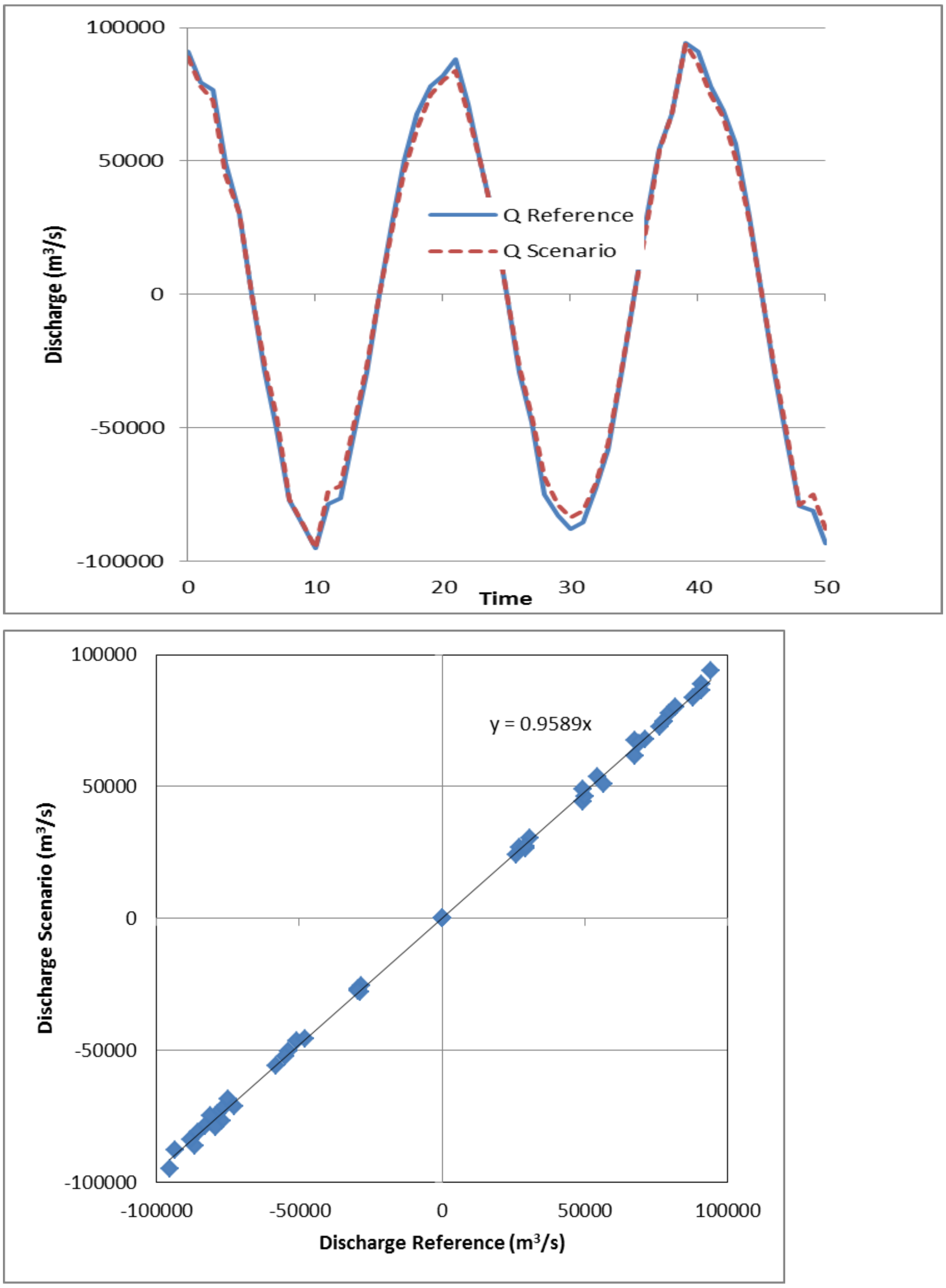


*Fig. 3.20* *Illustration of concept of how to measure blocking. In this hypothetical case the blocking is found as 0.9589-1.0000=-0.0411=-4.1%*

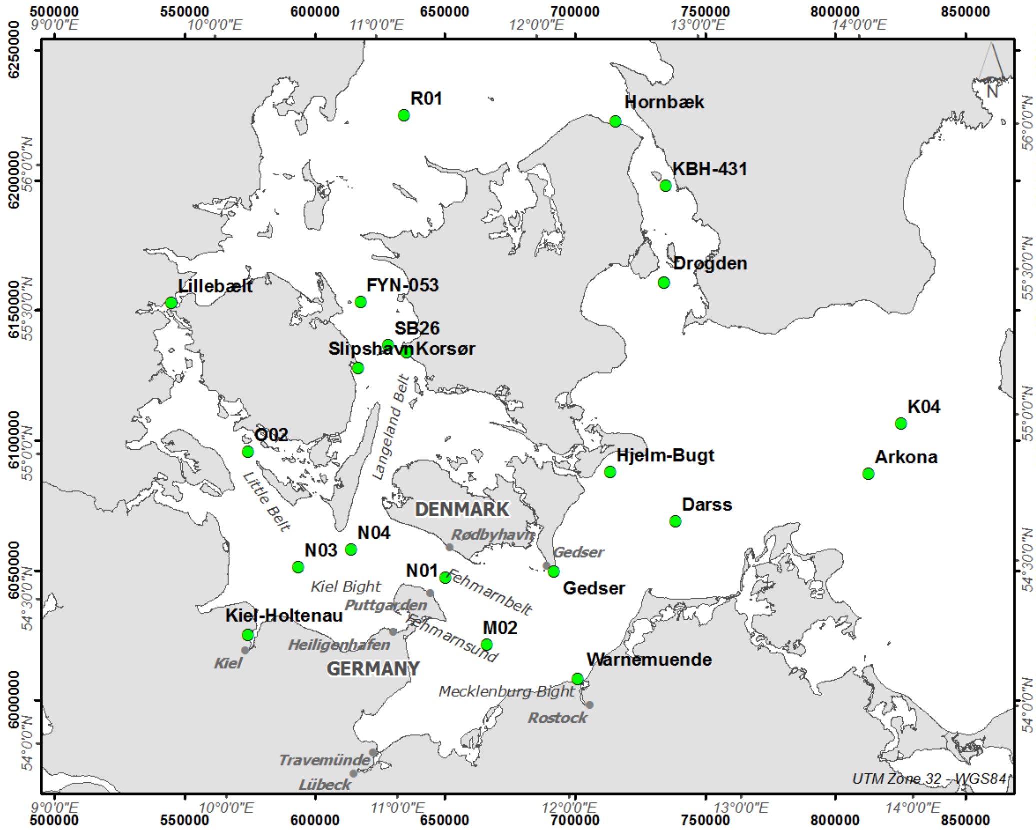


Fig. 3.21 *Overview map for referred geographical sites and standard monitoring stations*

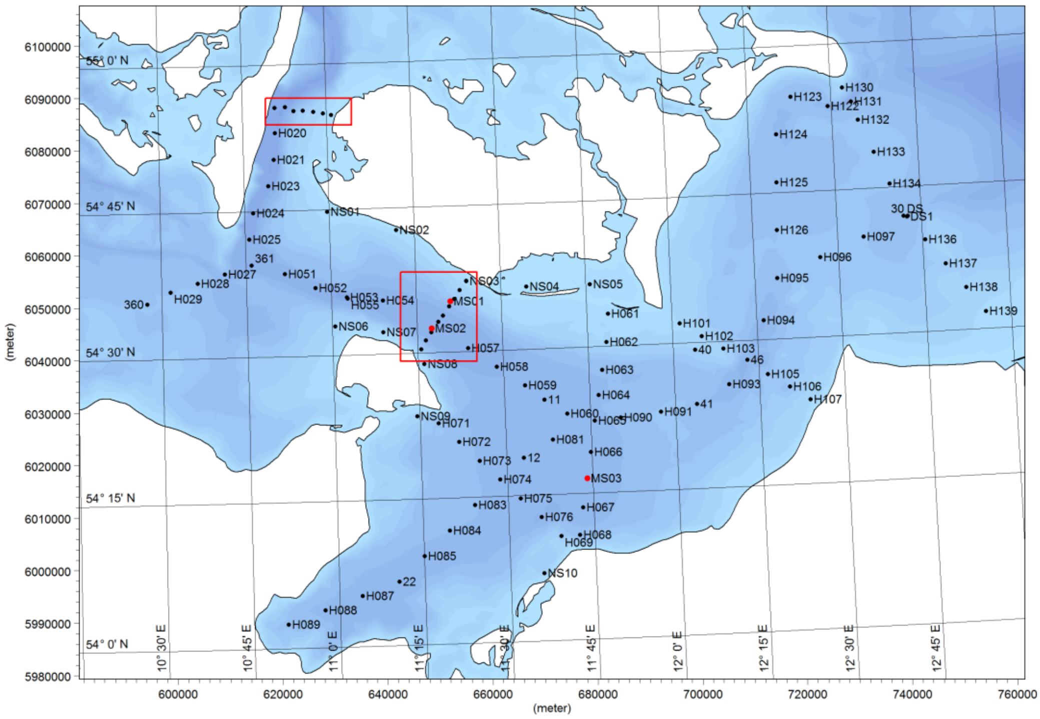


Fig. 3.22 *Location of Fehmarnbelt dedicated monitoring stations: fixed stations (MS01, MS02 and MS03) and profile stations at monthly cruises in 2009*

### 3.7.10 Aggregation of results from dual modelling

In the cases where the dual modelling is fully implemented, the aggregation of the results for e.g. salinity effects at surface is undertaken by averaging the spatial distributed surface salinity results from the two independent models into one spatial distribution surface salinity field.

This aggregated field is then applied for the degree of impairment classification and further aggregation with other fields of degree of impairment for other components.

#### 3.7.11 *Local changes to currents near structures*

The above numerical models do not resolve the details of current effects in the immediate vicinity of each of the link structures.

Instead the assessment is based on expert assessments, applying a conservative impact area around each pier and pylon where the mean bottom current speed is changed up to 25-45% within a distance of 4 times the diameter of the pier or pylon (including ship protection where relevant). The surface current changes less within the same distance.

Also for the lee zone around the marine ramps of the cable stayed bridge an expert assessment is applied for the current effects, with effect levels to the mean current speed going from -50% in the corner between coast and marine ramp and then linearly increasing in the direction offshore to the tip of the ramp and along the coast to five times the length of the marine ramp.

#### 3.7.12 *Sea State (waves)*

The effects to wave conditions are estimated using numerical wave modelling. The applied model including calibration is described in the coastal morphology baseline report ((FEHY 2013e).For the scenario assessment of effect from the fixed link, the approach has been to implement the structures, reclamations and dredgings for each individual link alternative in the numerical model and then run the same design period as used for the baseline assessment (1989-2010). More details on this method are provided in the IA report on coastal morphology (FEHY 2013a).

The post processing from the wave modelling includes calculation of the significant wave height distribution (Hs) and compares the scenario results to the baseline results.

## 3.8 *Aggregation of degree of impairment for various subcomponents*

After assessing the degree of impairment for each subcomponent, see Chapter 3.2), the aggregated degree of impairment for the subcomponent is calculated by superposition of the individual subcomponent fields taking the highest degree of impairment for each position.

## 3.9 *Assessment of severity*

The severity is achieved by a folding of the impact degree with the baseline importance, see Fig. 3.2. The folding matrices are described in Chapter 3.2.

The result is the spatial distribution of impact severity ranging from positions with Minor severity to Very High severity. This severity distribution is compiled for permanent impacts present for the entire lifetime of the fixed link, but also in a separate presentation for impacts mainly related to the construction period.

## *3.10 Assessment of significance*

The final assessment of significance of the impacts is an expert evaluation based on comparison of size of the various degree of impairment and loss severity areas and the overall size of the Fehmarnbelt and adjacent water areas.

# 4 ASSESSMENT OF 0-ALTERNATIVE

The 0-alternative for the impact assessment of a fixed link in Fehmarnbelt is the continuation of the ferry service.

Femern A/S has assessed that the future ferry service, if the fixed link is not implemented, will be with similar ferries as today, however potentially with extended versions of the present ferries with a new centre section build in or new ferries of similar extended size, if the capacity needs to be increased.

An increase in departures annually is not seen as likely as the present schedule does not leave space for more than the present number of departures due to terminal constraints.

This implies that the present conditions as described in the baseline hydrography reports (FEHY 2013d) can also act as the O-alternative scenario.


| M/V Deutschland | |
|---|---|
| Route | Puttgarden-Rødby |
| Type | Ro-Pax |
| Construction year | 1997 / 2004 |
| Gross tonnage | 15,187 |
| Shipbuilder | Van der Giessen de Noord, The Netherlands |
| Port of registry | Puttgarden |
| Flag | German |
| Engines | 3 pc Mak, Type 8M32<br>2 pc Mak, Type 6M32 |
| KW | 15,840 |
| Length, oa | 142 m |
| Breadth incl. fender | 25.4 m |
| Service speed | 18.5 kn |
| Length, oa | 1 track, 118 m |
| Lanemeter, lorries | 625 |
| Lanemeter, cars | 1,747 |
| Car capacity | 364 |
| Passenger capacity | 1,200 |


| M/V Prinsesse Benedikte | |
|---|---|
| Route | Puttgarden-Rødby |
| Type | Ro-Pax |
| Construction year | 1997 / 2003 |
| Gross tonnage | 14,822 |
| Shipbuilder | Ørskov Staalskibsværft A/S, Denmark |
| Port of registry | Rødbyhavn |
| Flag | Danish |
| Engines | 4 pc Mak, Type 8M32 / 1 pc MAN Type 6L32 / 44CR |
| KW | 17,440 |
| Length, oa | 142 m |
| Breadth incl. fender | 25.4 m |
| Service speed | 18.5 kn |
| Length, oa | 1 track, 118 m |
| Lanemeter, lorries | 580 |
| Lanemeter, cars | 1,747 |
| Car capacity | 364 |
| Passenger capacity | 1,140 |

*Fig. 4.1 Two of the present ferries servicing the Rødbyhavn-Puttgarden transfer*

# 5 SENSITIVITY ANALYSIS

As described in Chapter 3.4 the sensitivity is understood as the relationship between pressures and effects (loss or degree of impairment). For the numerical models applied to assess the physical component hydrography these relationships are formulated in the basic deterministic equations of the models, like the conservation of mass and momentum in hydrodynamic models.

The principles of the flow effect by a structure placed in a current are shown in Figure 5.1.

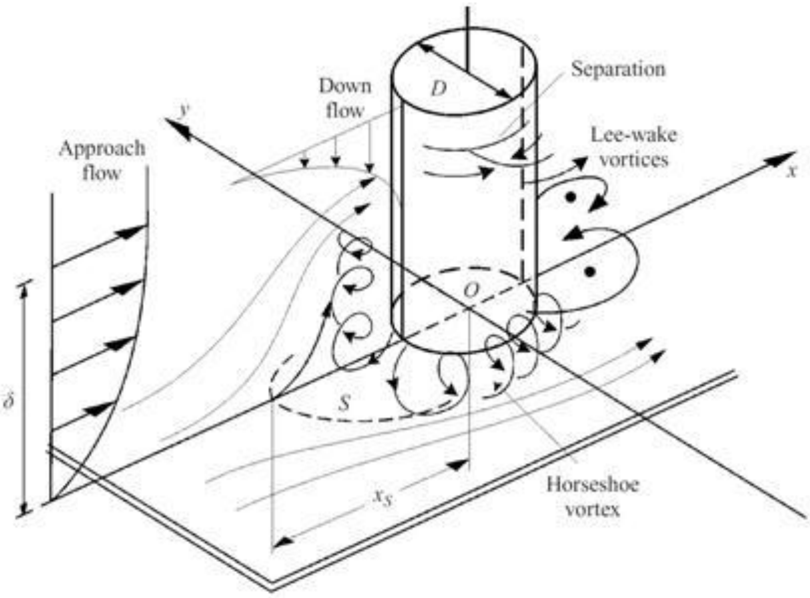


*Fig. 5.1 Sketch of large turbulent flow structures generated by the presence of a vertical pylon in a channel flow.*

Figure 5.2 shows an example of CDF modelling of the effect on the flow around a bridge pier for various current approach angles. The CFD modelling is used to quantify the drag and lift forces applied in the local models.

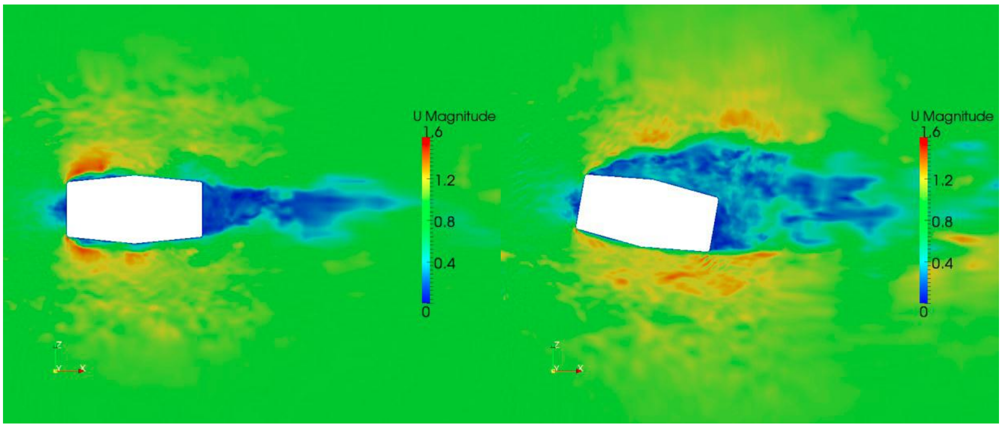


*Fig. 5.2 Contour plot of instantaneous velocities at 14m above the seabed for hexagon type pier, current direction at 0 and 10 degrees.*

# 6 ASSESSMENT OF IMPACTS OF MAIN TUNNEL ALTERNATIVE

The underlying detailed modelling and assessment for the immersed tunnel E-ME has focussed on the comparison of a future situation with tunnel and continued ferry service ("tunnel+ferry") with the 0-alternative of continued ferry service (0-alternative equal to reference situation "ferry").

However, modelling has also been undertaken to check if the impact would be significantly different for a "tunnel" alone compared to the 0-alternative than for the "tunnel+ferry" compared to the 0-alternative.

The result is that for both comparisons the effect to the water exchange blocking is very similar (and minimal). This is explained by the effect of the ferry service via extra mixing etc. to the hydrography being minimal.

Therefore the following assessment for the immersed tunnel focuses on the "tunnel+ferry" scenario as this gives the isolated effect of the tunnel, but is also a valid approximation for the "tunnel" scenario (without ferry). The same approach is applied for the bridge assessment in Chapter 7.

Below the permanent impacts from the tunnel (Chapter 6.1) are assessed as well as the impacts during the construction period with temporary structures (Chapter 6.2).

## 6.1 Permanent reclamations and sea bed changes

### 6.1.1 Magnitude of pressure

The permanent pressure elements for the immersed tunnel E-ME (August 2011) include the reclamations at Lolland and Fehmarn, the protection reefs above the tunnel extending from the landfall and about 500 m offshore and the access channel to the production facility at Rødbyhavn, which is planned to be left open for natural backfilling. This natural backfilling is assessed to take many years (for parts even more than 30, see (FEHY 2013c)). Therefore it has been included as a pressure in this permanent impact assessment.

The pressure elements are shown in Fig. 6.1 and the extent summarised in Table 6.1. The Lolland reclamation is by size far the largest.

*Table 6.1 The dimensions of the immersed tunnel E-ME (August 2011) pressure elements.*

| Pressure element | Dimension | Area (ha) |
|---|---|---|
| Reclamations<br>Lolland<br>Fehmarn | <br>6000m * 500m<br>300m * 450m | <br>330<br>14 |
| Protection reefs<br>Lolland<br>Fehmarn | <br>450m * 150m<br>450m * 150m | <br>6<br>6 |
| Open access canal<br>Lolland (deepening 0-6m) | <br>2500m * 150m | <br>32 |

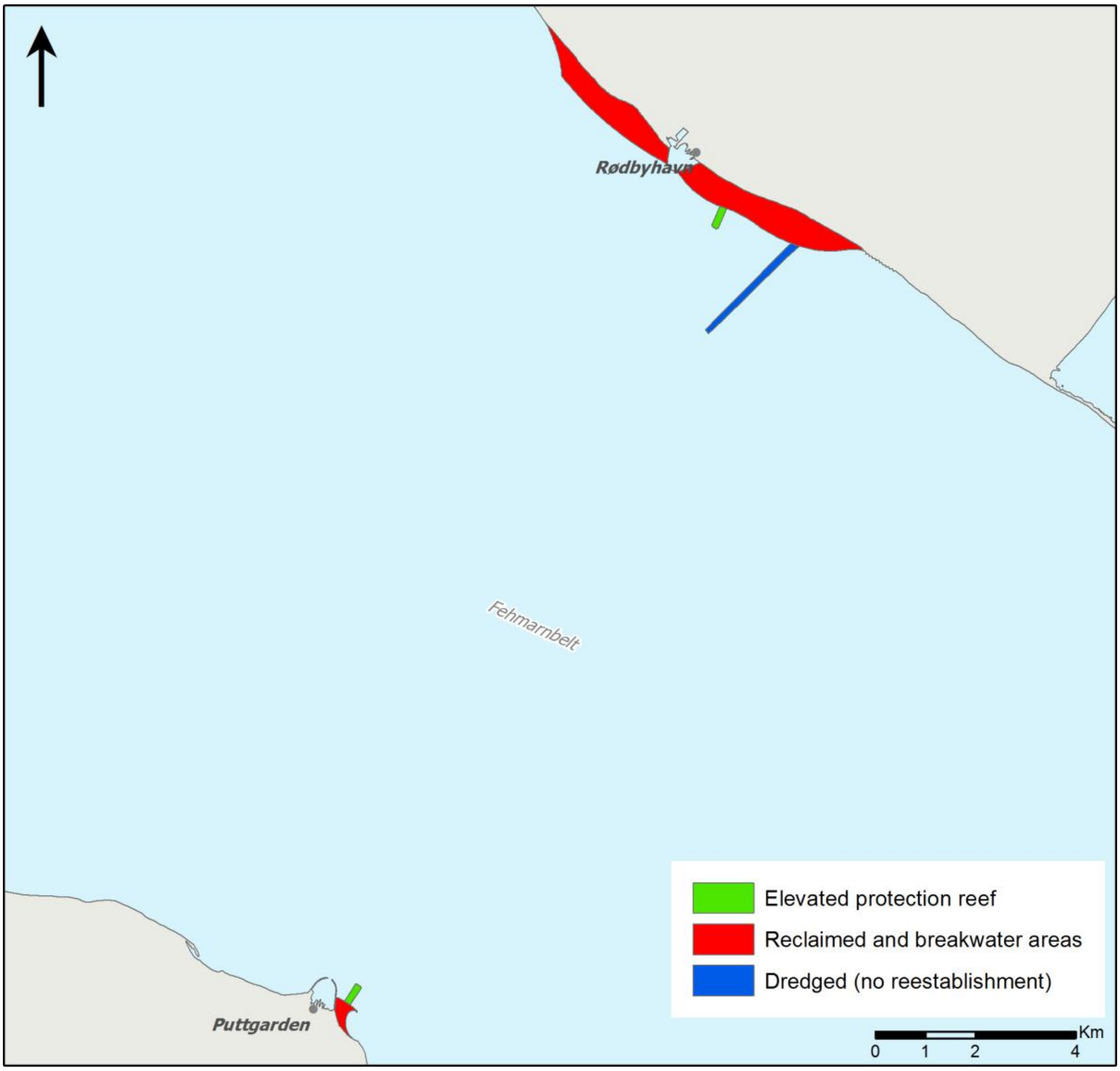


*Fig. 6.1* *Permanent immersed tunnel E-ME (August) elements acting as pressure factors for the hydrography assessment.*

### 6.1.2 Impact magnitude

**Hydrodynamics**

Results from the underlying hydrodynamic modelling with the MIKE local tunnel model are displayed in Fig. 6.2 and Fig. 6.3. The figures show reduced current speeds at the end of the Lolland reclamation, in front of the ferry harbour, and near the protection reef with reduced mean speeds from 0.02-0.06m/s (baseline mean speeds about 0.15m/s). Above the access channel an area with increased speeds of up to 0.08m/s is seen.

For the Fehmarn side the surface and bottom current reductions are seen immediately north and east of the small reclamation of down to -0.1m/s, but at 500 m from the reclamation the reductions are less than 0.03m/s.

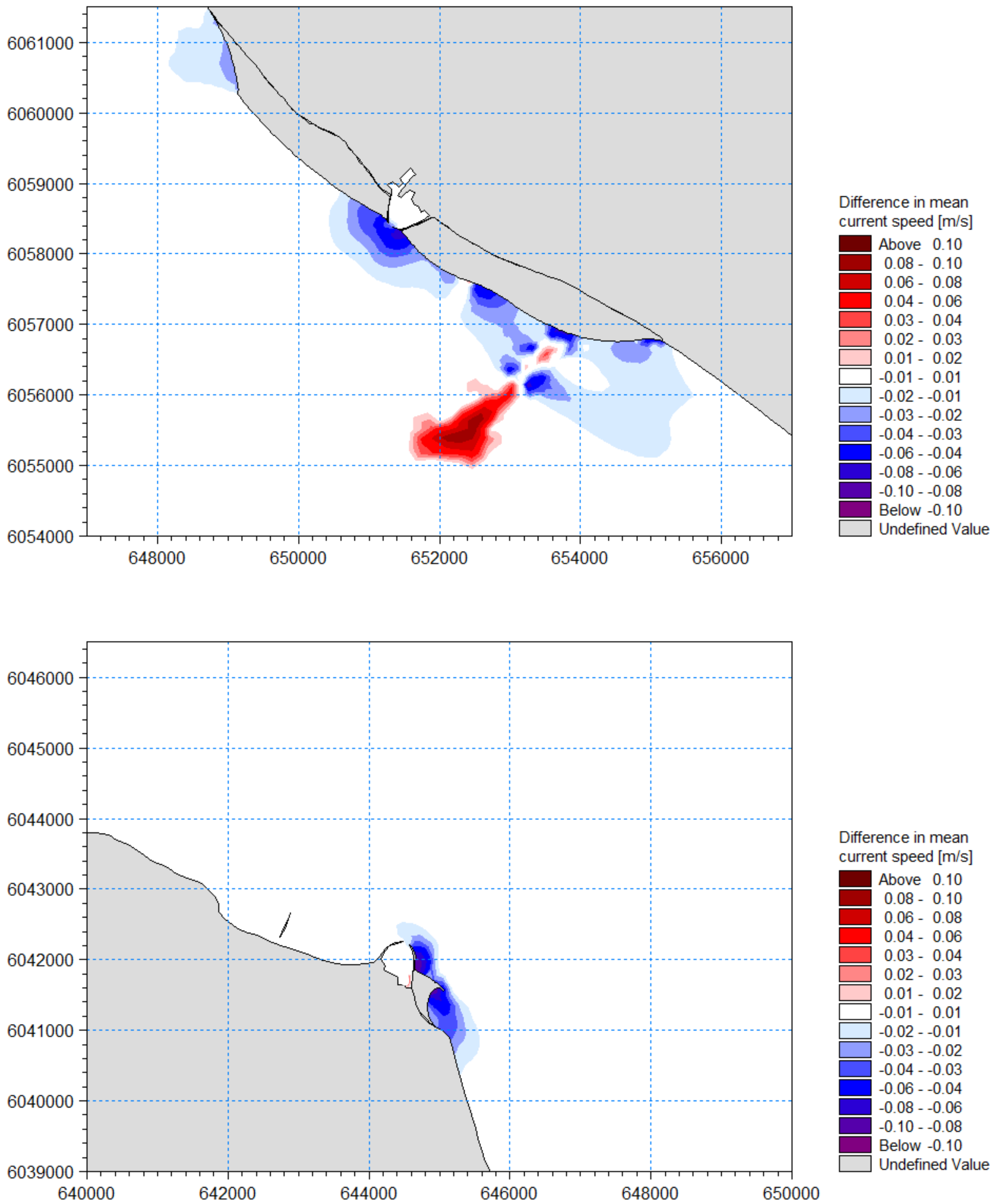


*Fig. 6.2* *Close-up of estimated permanent effects to mean surface current speed for the E-ME immersed tunnel case (August 2011, ID17.03) with access channel left open. Small area with increased current speed inside Puttgarden harbour assumed being a model artefact.*

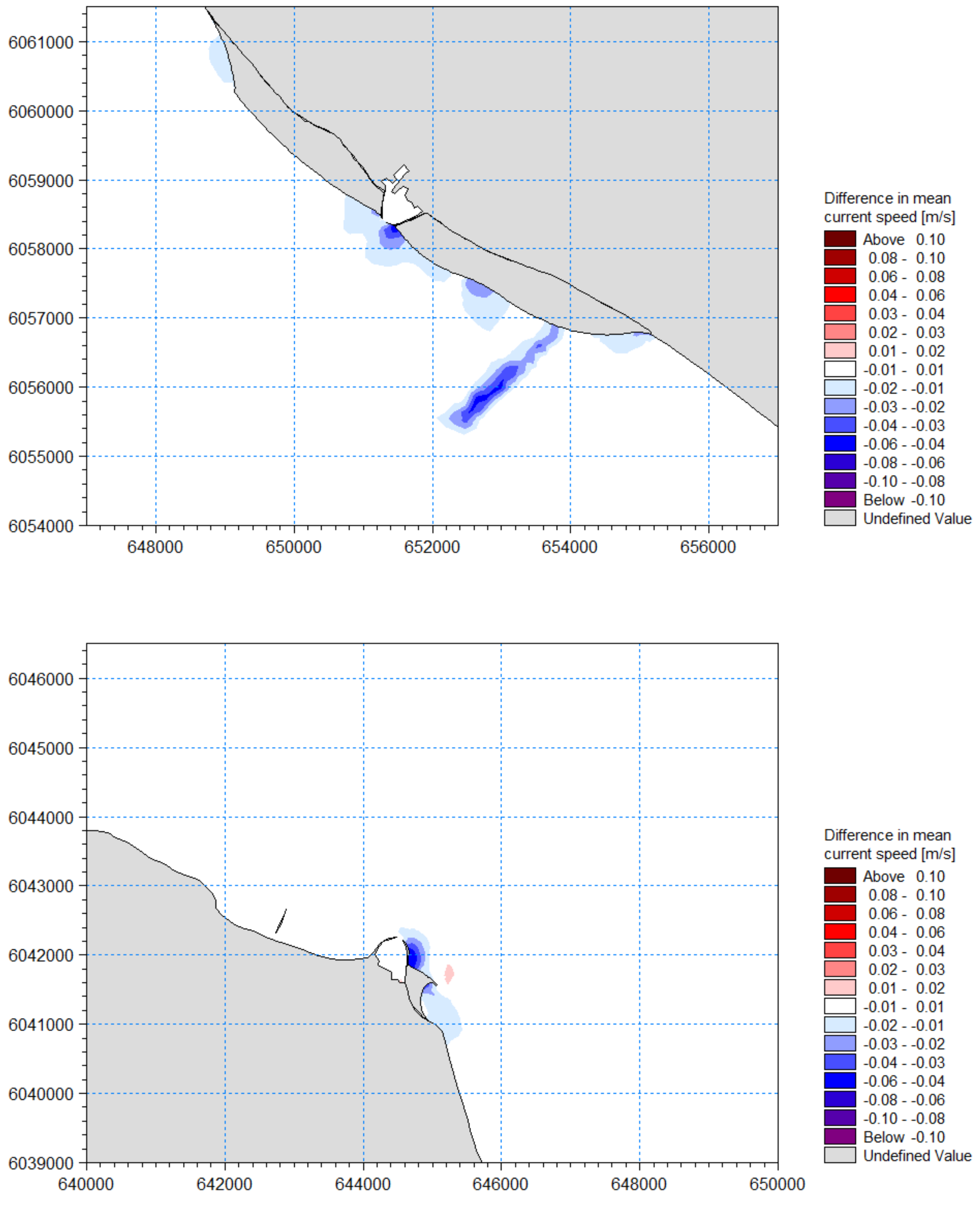


*Fig. 6.3 Close-up of estimated effects to mean bottom current speed for the "Tunnel+ferry" case (August 2011) with access channel left open (August 2011, ID17.04).*

Outside the vicinity of the reclamations the current effects are negligible, and the same applies for other sub-components of the hydrography everywhere.

Table 6.2 summarises the maximum effects calculated in the underlying modelling. Water level changes are seen to be negligible.

*Table 6.2 Summary of magnitude for permanent key effects in the Fehmarnbelt and nearby areas for immersed tunnel E-ME case.*

| **"Tunnel+ferry" compared to "Ferry" case** | **Upper limit for estimated change in local model area** | **Station N01 Fehmarnbelt (1990-2007)** | |
|---|---|---|---|
| | | **Standard deviation** | **Mean value** |
| Mean water level | Everywhere less than 0.0001m | 0.24m (Gedser) | - |
| Max water level | Locally up to 0.0002m, elsewhere much less | 0.24m (Gedser) | - |
| Blocking of Darss flow | -0.01% | - | - |
| Darss salt transport blocking | 0.00% | | |
| Surface currents (annual mean) | Locally off reclamation stretches down to ±0.08m/s, elsewhere less than ±0.01m/s | 0.23m/s (MS02 station 2009-2010) | 0.41m/s (MS02 station 2009-2010) |
| Bottom currents (annual mean) | Locally off reclamation stretches down to -0.06m/s, elsewhere less than ±0.005m/s | 0.09m/s (MS02 station 2009-2010) | 0.13m/s (MS02 station 2009-2010) |
| Mean surface salinity (annual mean) | Locally off reclamations up to ±0.1psu, elsewhere less than ±0.05psu | 3.2psu | 12.7psu |
| Mean bottom salinity (annual mean) | Locally off reclamations up to ±0.2psu, elsewhere less than ±0.05psu | 3.5psu | 21.9psu |
| Surface temperatures (annual mean) | Less than 0.05°C everywhere | 5.7°C | 9.4°C |
| Bottom temperature (annual mean) | Less than 0.05°C everywhere | 3.6°C | 6.6°C |
| Summer bottom temperature (mean) | Less than 0.05°C everywhere | 2.3°C | 9.9°C |
| Stratification (annual mean) | Less than ±0.04kg/$m^3$ elsewhere | 4.5kg/$m^3$ | 7.7kg/$m^3$ |
| Stratification summer (mean) | Less than ±0.04kg/$m^3$ elsewhere | 2.8 kg/$m^3$ | 10.6 kg/$m^3$ |

The blocking of the exchange flow with the Baltic Sea is only a supporting indicator, which to some extent integrates many other effects. For the tunnel scenario the flow effect is -0.01%, which is a minimal value.

The estimated maximum changes for salinity, temperature and stratification are very low and considered negligible.

This implies that there is no real effect to the Baltic Sea of the tunnel scenario (see also (FEHY 2013b)).

**Sea State (waves)**
Fig. 6.4 shows the effect to the wave indicator. Changes are only seen in the immediate vicinity of the reclamations and appear mostly as lee effect on the eastern side of the reclamations. Above the access channel a slight tendency to increased waves is seen.

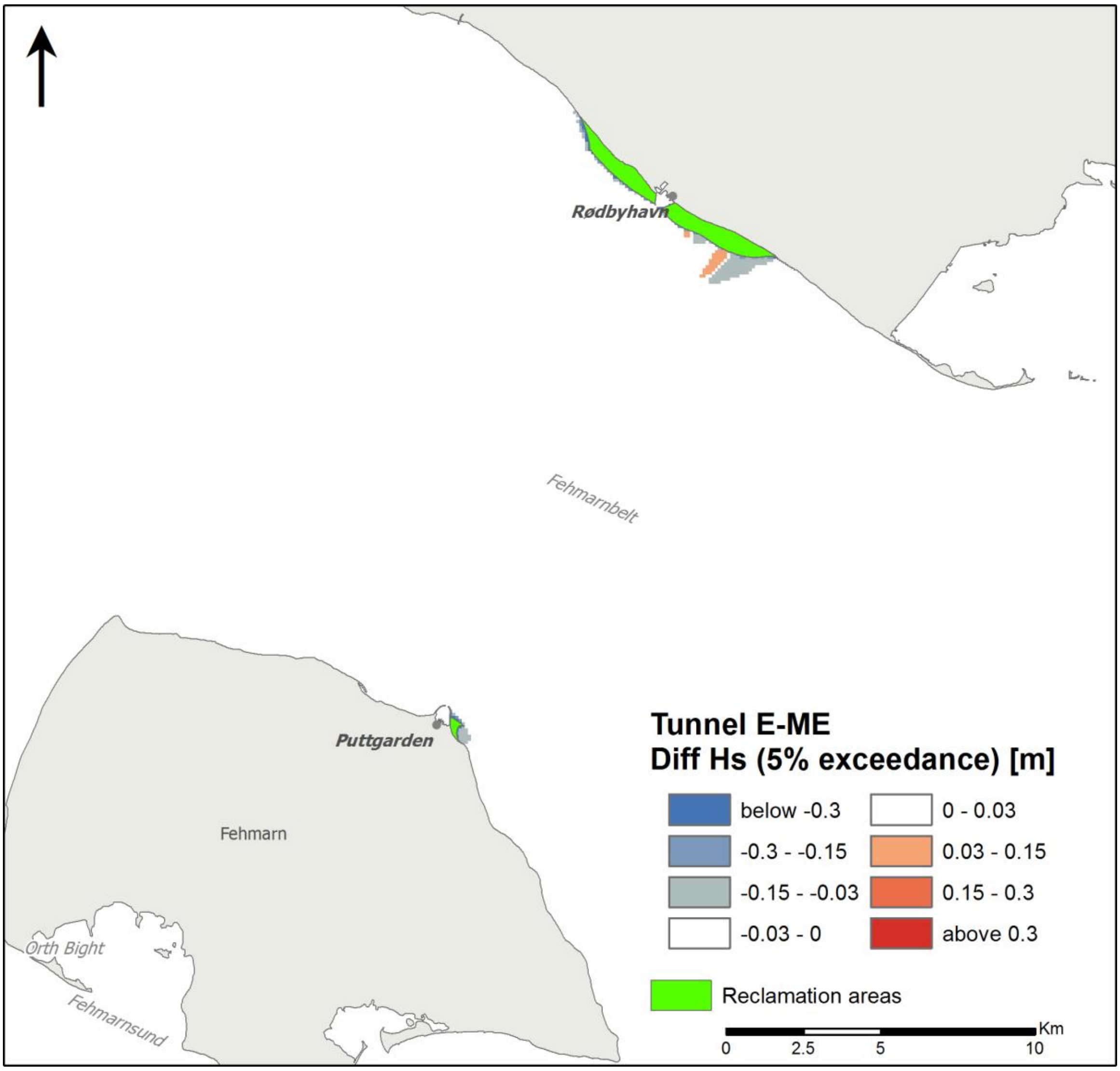


*Fig. 6.4 Changes to the 5% exceeded significant wave height (in meters) for immersed tunnel E-ME (August 2011) variant.*

A separate evaluation of wave effect to the coastal morphology is available in (FEHY 2013a).

### 6.1.3 *Loss and degree of impairment*

The aggregation of the loss severity and the degree of impairment for the individual sub component indicators results in the distribution of degree of impairment shown in Fig. 6.5. The degree of impairment reaches the "high" level mainly in the open access channel on Lolland due to the reduced bottom currents. In the immediate vicinity of the Fehmarn reclamation there is also a small "high" impairment, due to the lee effect for currents in general.

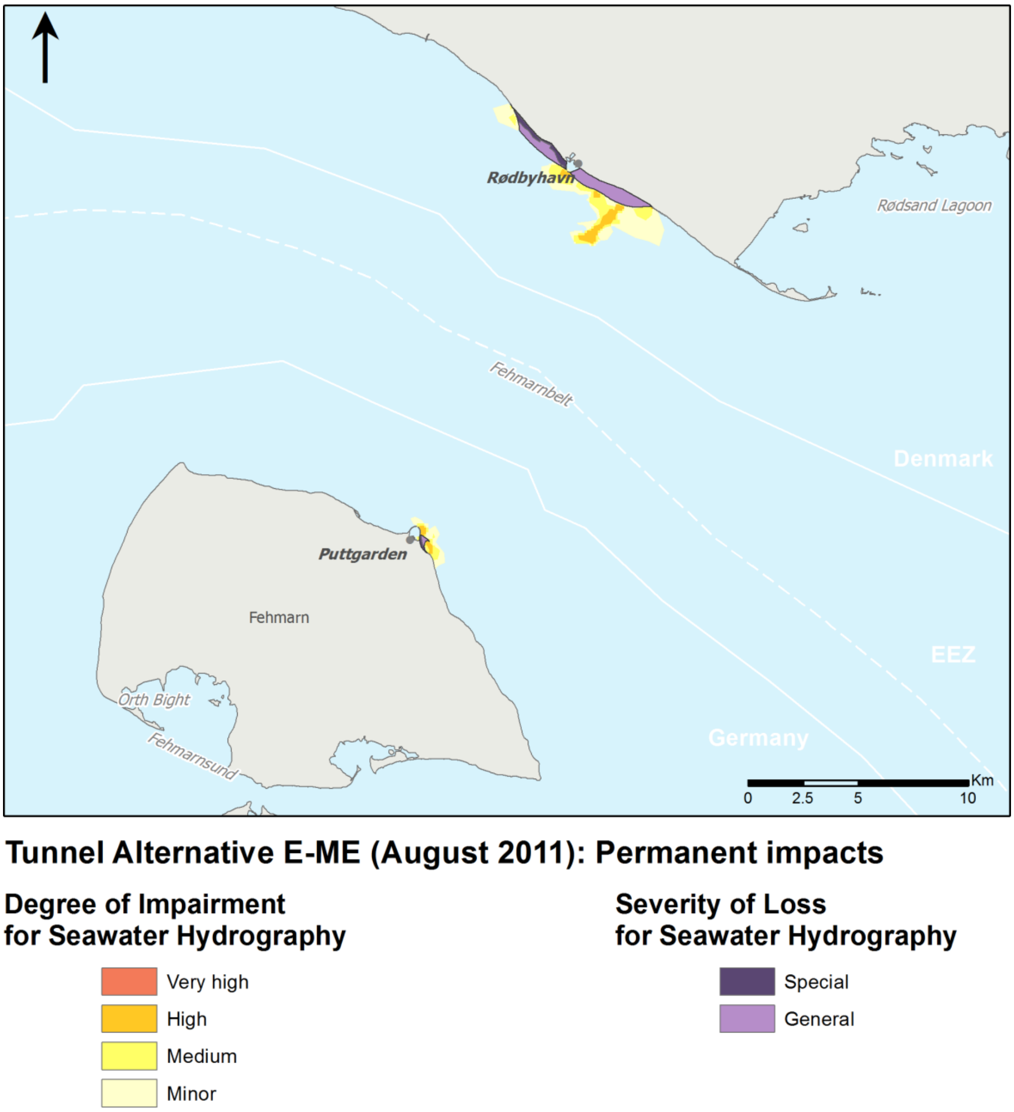


*Fig. 6.5 The degree of impairment and severity of loss distribution for permanent hydrography impacts of the immersed tunnel E-ME (August 2011)*

Fig. 6.5 also shows the loss areas due to the reclamations.

Outside the above areas all sub-components indicator changes are negligible.

Table 6.3 provides the area of the various impact classes, both for the total impact area and sub-divided into near zone, local zone, national waters and EEZ waters.

*Table 6.3 The degree of impairment and severity of loss areas for permanent hydrography impacts after implementation of the immersed tunnel E-ME (August 2011).*

| **Permanent impacts** | **Hydrography for Tunnel E-ME (August 2011)** | | | | | |
|---|---|---|---|---|---|---|
| | **Total area (ha)** | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 64[1] | 64[1] | 0 | 58[1] | 6[1] | 0 |
| General | 279 | 279 | 0 | 271 | 8 | 0 |
| **Total severity of loss** | **343** | **343** | **0** | **329** | **14** | **0** |
| **Degree of impairment** | | | | | | |
| Very High | 0 | 0 | 0 | 0 | 0 | 0 |
| High | 136 | 65 | 71 | 114 | 22 | 0 |
| Medium | 274 | 199 | 75 | 235 | 40 | 0 |
| Low | 575 | 211 | 364 | 497 | 78 | 0 |
| **Total degree of impairment** | **985** | **475** | **510** | **845** | **140** | **0** |
| **Total permanent** | **1.329 (0.2%)** | **819 (34%)** | **510 (1.3%)** | **1.174** | **154** | **0** |
| **Reference areal** | 770.000[2] | 2.440 | 39.006 | - | - | - |

Note 1: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

Note 2: Area of the Western Baltic Sea

### 6.1.4 *Impact severity of loss and impairment*

When combining the degree of impairment and the loss with the importance for the hydrography component the result becomes as displayed in Fig. 6.6.

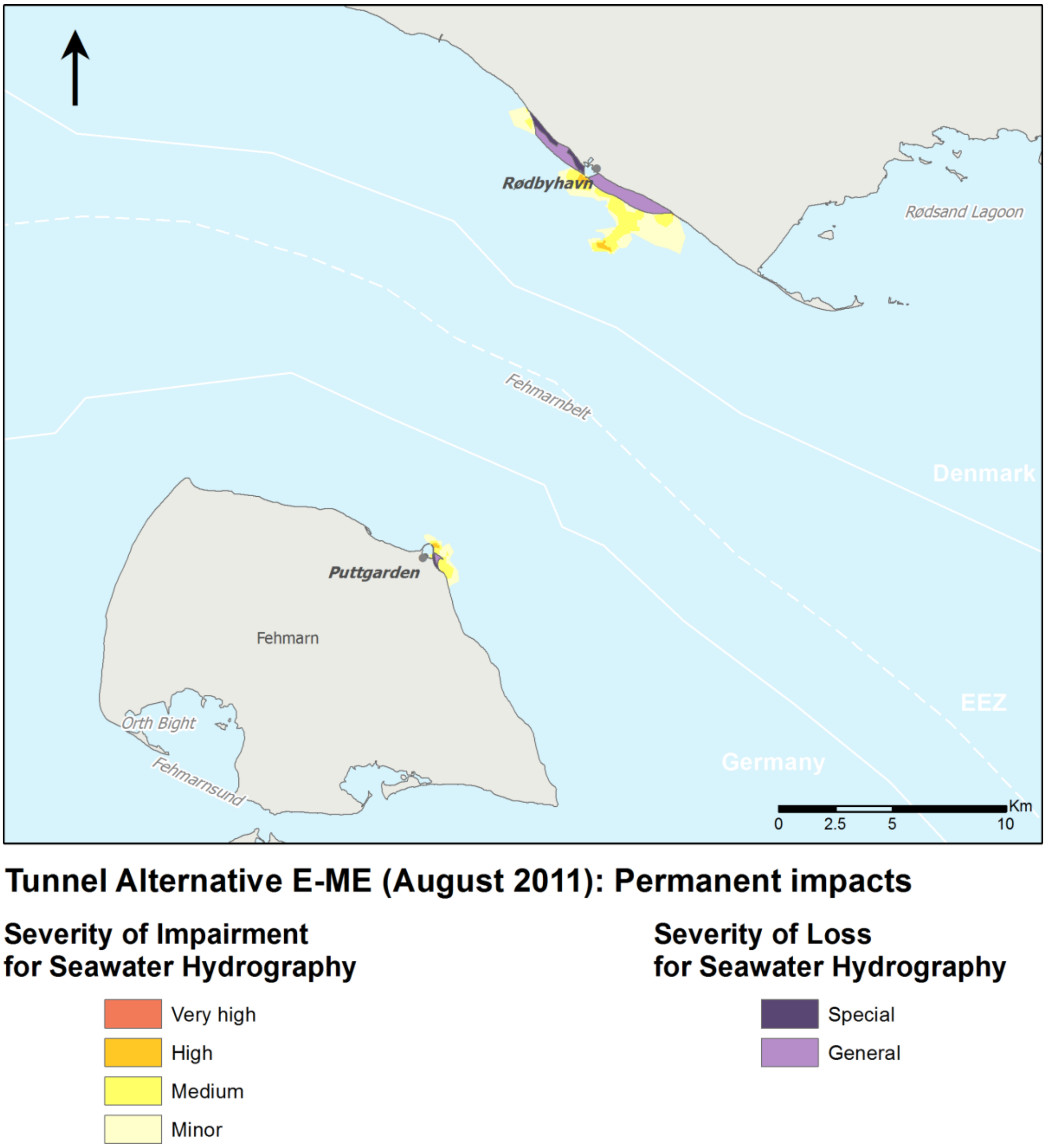


*Fig. 6.6 The impact severity distribution for permanent hydrography impacts of the immersed tunnel E-ME (August 2011).*

There are loss areas of "special" severity due to the reclamation in front of present beach areas west of Rødbyhavn. However, these beach areas are planned to be compensated by new bathing areas in the reclaimed part and on the west end of the reclamation, see Chapter 6.7.

The impairment severity reaches minor and medium in the vicinity of the reclamations due to the lee effect and the access channel left open. The tip of the access channel is assigned a "high" severity as the depth here is more than 10m, and thus the area is characterised as being important for the general water exchange. However, the underlying modelling has revealed that the actual blocking effect is marginal.

*Table 6.4 The impact severity area for permanent hydrography impacts after implementation of the immersed tunnel E-ME (August 2011).*

| Permanent impacts | Hydrography for Tunnel E-ME (August 2011) | | | | | |
|---|---|---|---|---|---|---|
| | Total area (ha) | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of Loss** | | | | | | |
| Special | 64[1] | 64[1] | 0 | 58[1] | 6[1] | 0 |
| General | 279 | 279 | 0 | 271 | 8 | 0 |
| **Total severity of Loss** | **343** | **343** | **0** | **329** | **14** | **0** |
| **Severity of impairment** | | | | | | |
| Very high | 0 | 0 | 0 | 0 | 0 | 0 |
| High | 38 | 27 | 12 | 32 | 7 | 0 |
| Medium | 381 | 237 | 144 | 322 | 59 | 0 |
| Minor | 603 | 211 | 392 | 523 | 80 | 0 |
| **Total severity of impairment** | **1,022** | **475** | **547** | **877** | **145** | **0** |
| **Total permanent** | **1,365 (0.2%)** | **818 (33.5%)** | **547 (1.4%)** | **1,206** | **159** | **0** |
| Reference area | 770,000[2] | 2,440 | 39,006 | - | - | - |

Note 1: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

Note 2: Area of the Western Baltic Sea

The actual severity impact area size is summarised in Table 6.4. In total the areas affected by "minor" to "very high" severity adds to 1,365ha. Half of this falls inside the near zone of the project, and this zone also includes all the "very high" severity areas, constituting the reclaimed sea at the beach areas.

Table 6.4 also shows that no impacted area lies outside the defined local area (±10km around link alignment, excluding the near zone). The impacted area constitutes 34% of the near zone and only 1.4% of the local area. Most of the impacted area is within Danish waters.

The majority of the reclamation appears as "medium" severity, as this area is assigned a "general" importance with respect to hydrography.

### *6.1.5 Impact significance*

The above permanent impacts to the hydrography is assessed to be of no significance for the general hydrography in the Fehmarnbelt and the Belt Sea (and also for the Baltic Sea), due to the minimal extent of the impact area.

The local loss of beach areas is planned to be compensated by new beach areas and will thus not become a net loss.

Finally, the effect to navigation in and out of the present ferry terminals is a tendency to reduced currents, and thus does not add any adverse effect for the navigation.

## 6.2 Construction period with temporary structures

### 6.2.1 Magnitude of pressure

In the construction period the permanent structures are implemented relatively fast and then the tunnel trenching and backfilling gradually progress. Furthermore, the temporary work harbour at Fehmarn and the production facility with its offshore breakwaters at Lolland are in place. Just before the removal of the temporary structures the pressures shown in Fig. 6.7 are present, with an almost fully backfilled tunnel trench. The sizes of these temporary structures and the tunnel trench are summarised in Table 6.5.

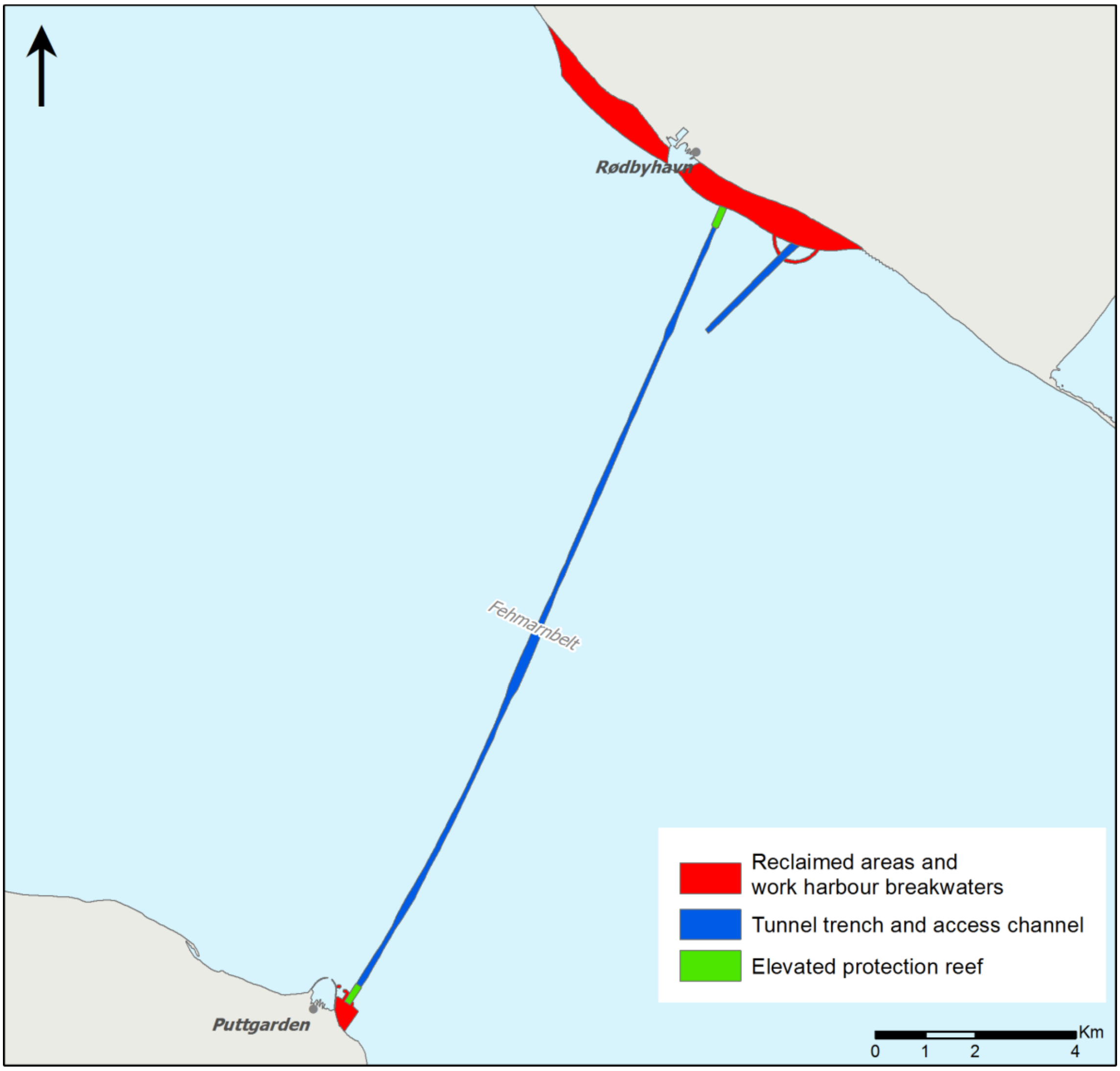


*Fig. 6.7 Immersed tunnel elements in the construction period acting as pressure factors for the hydrography assessment.*

*Table 6.5 The dimensions of the additional immersed tunnel E-ME pressure elements during the construction period*

| Additional pressure element in construction period | Dimension | Area (ha) |
|---|---|---|
| Tunnel trench | 17500m * 100m | 194 |
| Work harbours outside permanent footprint | | |
| Lolland | 800m * 400m | 26 |
| Femern | 400m * 200m | 8 |

### 6.2.2 *Impact magnitude*

**Hydrodynamics**

Fig. 6.8 shows a local large area of reduced current speed in the lee of the temporary breakwaters at the Lolland production facility, but elsewhere a similar impact area as for the permanent current effects (Fig. 6.2).

The blocking of the exchange flow with the Baltic Sea in this phase of the construction period is -0.01% as for the permanent conditions after the construction period, showing that the work harbour and production facility effects on the water exchange are negligible.

This implies that there is no real effect to the Baltic Sea of the tunnel scenario also in the construction period (see also FEHY 2013b).

The effect to local salinity, temperature and stratification is also negligible in this phase.

**Sea State (waves)**

This is not estimated separately during the construction period. The wave effect from the permanent impact assessment in Chapter 6.1.2 can be applied as a proxy.

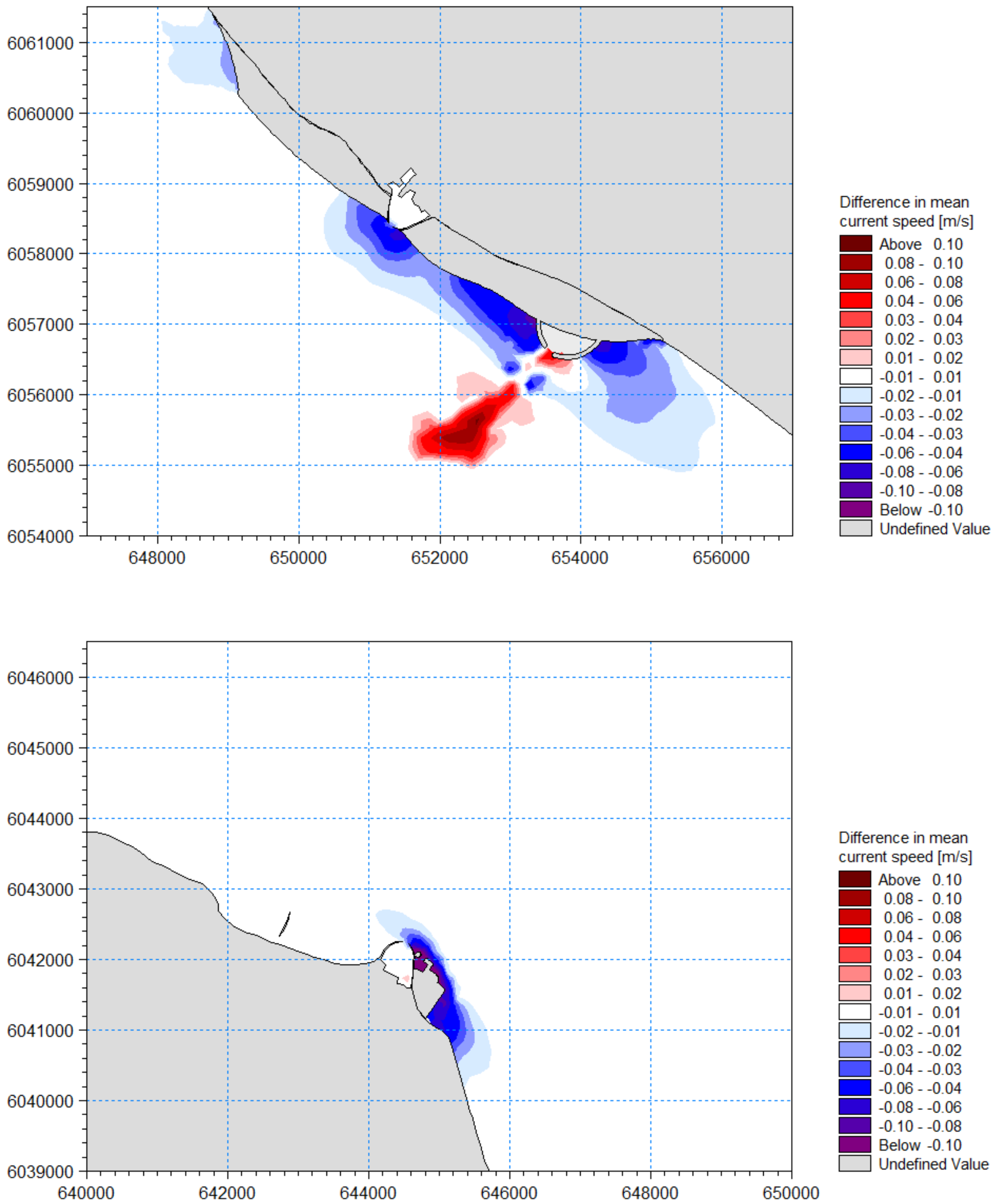


*Fig. 6.8* *Close-up of estimated temporary effects to mean surface current speed for the E-ME immersed tunnel case (August 2011) during the construction period with production facility*

### 6.2.3 Loss and degree of impairment

The aggregation of the degree of impairment for the individual sub-component indicators in the construction period results in the distribution of degree of impairment shown in Fig. 6.9. The degree of impairment reaches the "very high" level inside the area sheltered by the breakwaters at both temporary facilities, due to the nearly stagnant water here. The "high" level area is increased in the lee zone outside the breakwaters at Lolland, and also slightly at Puttgarden.

Fig. 6.9 also shows the extra temporary loss areas due to the breakwaters.

Outside the above areas all sub-components indicator changes are negligible.

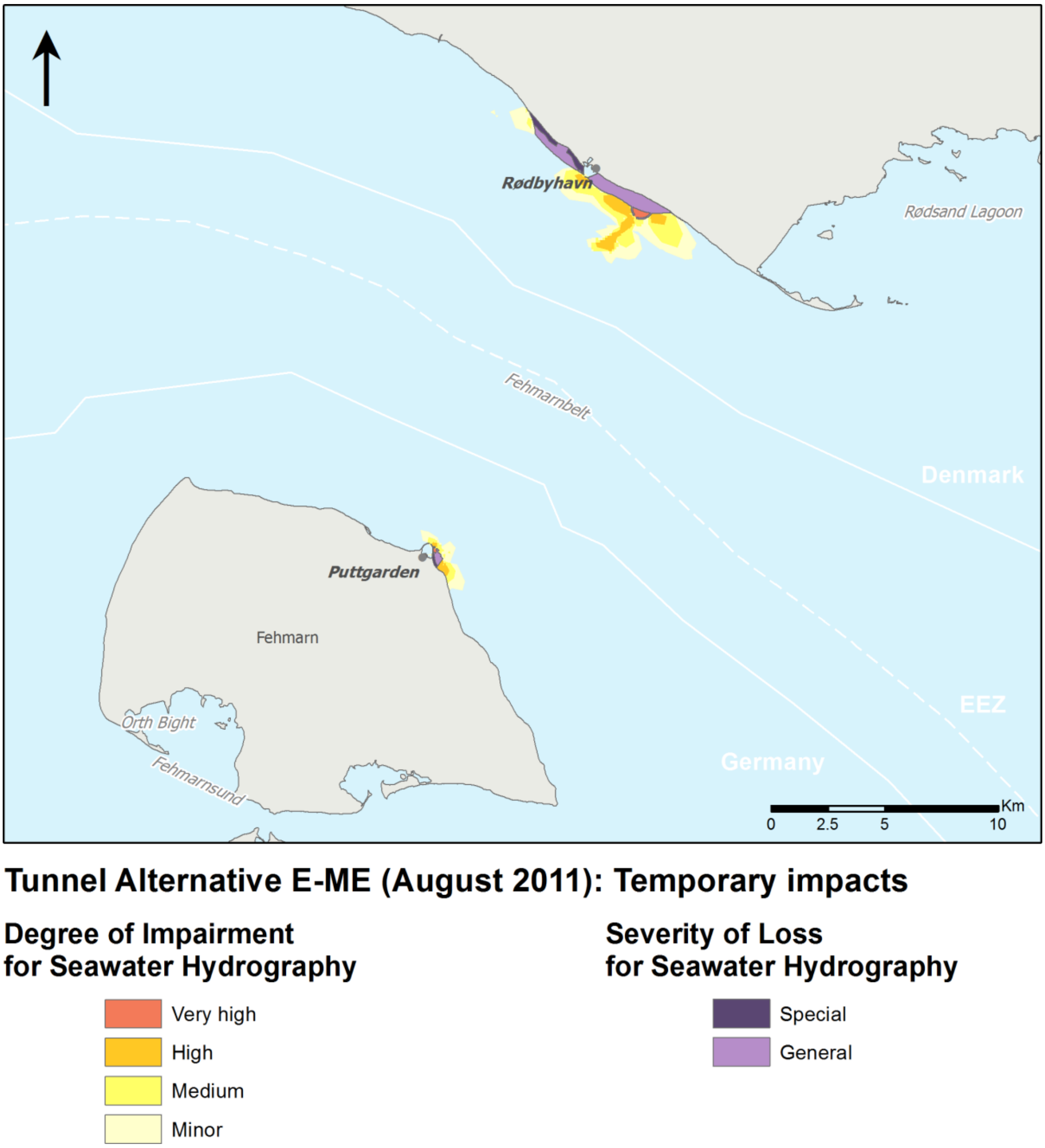


*Fig. 6.9 The degree of impairment and severity of loss distribution in the construction period for hydrography impacts of the immersed tunnel E-ME (August 2011)*

The quantification of the impact areas is provided in Table 6.6, showing very marginal impact areas compared to the overall size of Fehmarnbelt.

*Table 6.6 The degree of impairment and severity of loss areas for hydrography impacts during construction period of the immersed tunnel E-ME (August 2011).*

| Construction period impacts | Hydrography for Tunnel E-ME (August 2011) | | | | | |
|---|---|---|---|---|---|---|
| | Total area (ha) | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 60 | 60 | 0 | 54 | 6 | 0 |
| General | 298 | 298 | 0 | 282 | 16 | 0 |
| **Total severity of loss** | **359** | **359** | **0** | **336** | **22** | **0** |
| **Degree of impairment** | | | | | | |
| Very High | 23 | 20 | 0 | 20 | 3 | 0 |
| High | 212 | 136 | 69 | 187 | 24 | 0 |
| Medium | 416 | 179 | 240 | 373 | 43 | 0 |
| Low | 636 | 170 | 466 | 521 | 115 | 0 |
| **Total degree of impairment** | **1,287** | **505** | **775** | **1,102** | **185** | **0** |
| **Total permanent** | **1,645 (0.2%)** | **863 (35.4%)** | **775 (2.0%)** | **1,438** | **207** | **0** |
| **Reference areal** | 770.000[1] | 2.440 | 39.006 | - | - | - |

Note 1: Area of the Western Baltic Sea

### *6.2.4 Impact severity of loss and impairment*

The severity mapping for the construction period phase is displayed in Fig. 6.10.

The change compared to the permanent severity inventory is only for the vicinity of the two work/production harbours.

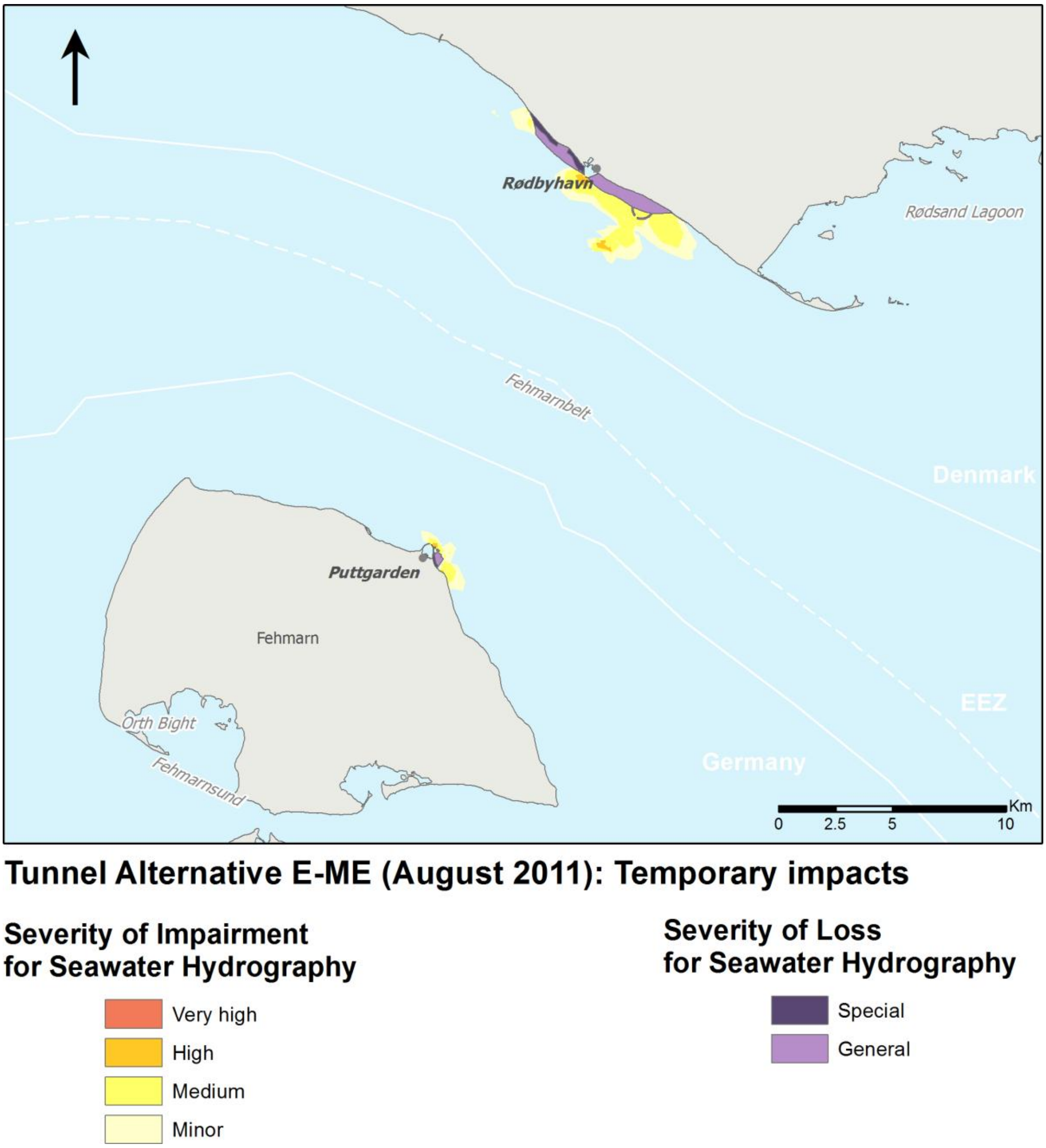


*Fig. 6.10 The impact severity distribution in the construction period for hydrography impacts of the immersed tunnel E-ME*

The total impact area in this phase of the construction period is estimated to 1688ha (compared to 1365ha for the permanent situation), see Table 6.7. The explanation of the slightly larger impact area is primarily the work harbours.

*Table 6.7 The impact severity area size at a later stage of the construction period for hydrography impacts of the immersed tunnel E-ME*

| **Construction period** | **Hydrography for Tunnel E-ME (August 2011)** | | | | | |
|---|---|---|---|---|---|---|
| | **Total area (ha)** | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of Loss** | | | | | | |
| Special | 60 | 60 | 0 | 54 | 6 | 0 |
| General | 298 | 298 | 0 | 282 | 16 | 0 |
| **Total severity of Loss** | **359** | **359** | **0** | **336** | **22** | **0** |
| **Severity of impairment** | | | | | | |
| Very high | 0 | 0 | 0 | 0 | 0 | 0 |
| High | 44 | 29 | 12 | 35 | 8 | 0 |
| Medium | 627 | 316 | 308 | 564 | 63 | 0 |
| Minor | 657 | 174 | 483 | 541 | 117 | 0 |
| **Total severity of impairment** | **1,329** | **519** | **802** | **1,141** | **188** | **0** |
| **Total Construction** | **1,688 (0.2%)** | **878 (36.0%)** | **802 (2.1%)** | **1,477** | **210** | **0** |
| Reference area | 770,000[1] | 2,440 | 39,006 | - | - | - |

Note 1: Area of the Western Baltic Sea

### 6.2.5 *Impact significance*

The temporary impact area is as for the permanent impact area still evaluated as being of no significance for the general hydrography in the Fehmarnbelt and the Belt Sea (and also for the Baltic Sea).

The two working harbour areas without any through flow will not be fully stagnant, but will exchange water slowly with tide and wind generated circulation. Thus they are not considered a problem in relation to hydrography.

The local loss of beach areas will not be fully compensated by new beach areas until relatively late in the construction period, thus there will be some temporary net loss during the construction period.

Regarding effects to navigation in and out of the present ferry terminals the tendency to a reduced cross current, which will be slightly beneficial to the navigation, will be present as soon as the outer perimeter of the reclamations is in place.

It should be mentioned that earlier in the construction period up to about 10km of the tunnel trench may be open. This will add about 150ha to the temporary impact area.

## 6.3 *Aggregation of impacts*

The above severity maps should not be aggregated as they relate to two different time spans: The permanent impacts after construction and the impacts during the construction period with some extra temporary pressures.

## 6.4 *Cumulative impacts*

The present pressures for the hydrography according to the baseline assessment (FEHY 2013d) include:

- Major constructions;
- Ship and ferry traffic; and
- Expected climate change

At present there are no plans for nearby major constructions that will have a cumulative impact in the future. The wind mill parks at Rødsand are already established and thus part of the baseline. Other wind mill parts on the German side are not assumed to cause any significant effects to the hydrography.

The ship traffic is expected to increase in Fehmarnbelt in the future. However the present assessment shows that the effect of the ferry service Rødbyhavn-Puttgarden is marginal. This is assumed to be relevant also for other ship traffic, and thus not significant for cumulative impacts.

The major likely pressure is the expected climate change, but this is not a project and thus not relevant with regard to cumulative impacts (see also Chapter 6.6).

Therefore, there are no cumulative impacts to consider.

## 6.5 *Transboundary impacts*

The transboundary impacts of the immersed tunnel is analysed in the IA for Baltic Sea hydrography and water quality, see (FEHY 2013b).

## 6.6 *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 3m/s or 10%. For more typical wind speeds there are no indications of significant changes
- The ocean water level may rise up to 1m, which will propagate into Fehmarnbelt and the Baltic Sea

The isolated 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.

## 6.7 Mitigation and compensation measures

In general the impacts of the immersed tunnel project to the hydrography are local and of no significance for the general hydrography.

An integrated part of the project is the establishment of two new beaches at the western part of the Lolland reclamation and at the eastern end of the Puttgarden reclamation. These new facilities will result in no net loss of the high importance seawater area in front of beaches.

The local impact to hydrography in the area of the access channel left open, until it naturally is backfilled over some decades, could be mitigated if found necessary by project backfilling.

Other mitigation measures seem not to be relevant taking the minimal impacts identified into account.

## 6.8 Decommissioning

Decommissioning is foreseen to take place in the year 2140, when the fixed link will have been in operation for the design lifetime of 120 years. Any structure on the seabed must be levelled with the seabed in order to allow ship traffic, fishery and similar activities at sea.

The reclaimed areas of the tunnel project are designed to maintain or even improve the conditions for flora and fauna. Several habitats for rare species are foreseen in the reclaimed areas. Therefore Femern A/S foresees that it will not be desirable or in some cases not even legal to change the status of the reclaimed areas. The decommissioning will leave the reclaimed areas untouched.

The tunnel is also assumed to stay buried in the trench after removal of internal installations and filling the inside.

Therefore there will be no impacts to the marine environment of the decommissioning, and the Fehmarnbelt hydrography will not sense the project leftovers after the decommissioning.

# 7 ASSESSMENT OF IMPACTS OF CABLE STAYED BRIDGE ALTERNATIVE

The following assessment for the cable stayed bridge focuses on the “bridge+ferry” scenario, but is also a valid (and slightly conservative) approximation for the “bridge” scenario (without ferry), as underlying modelling has shown limited difference in impacts for the two assumptions for the continued ferry service in case of a bridge in Fehmarnbelt.

## 7.1 Permanent reclamations and structures

### 7.1.1 Magnitude of pressure

The permanent pressure elements for the cable stayed bridge Var. 2 B-EE (October 2010) include the marine ramps with new beaches at Lolland and Fehmarn, the approach bridge piers, some with ship protection caissons and the main bridge pylons.

The pressure elements are shown in Fig. 7.1 and the extent summarised in Table 7.1. The Fehmarn affected area is slightly larger than at the Lolland coast, mainly because of the reclaimed area between the marine ramp and the Puttgarden breakwater.

*Table 7.1 The dimensions of the cable stayed bridge Var. 2 B-EE (October 2010) pressure elements*

| Pressure element | Dimension | Area (ha) |
|---|---|---|
| Reclamations | | |
| Lolland marine ramp | 460m x 120m | 5 |
| Lolland new beach | 600m x 200m | 11 |
| Fehmarn marine ramp | 600m x 120m | 7 |
| Fehmarn new beach and reclamation area | 450m x 250m | 13 |
| Pier and pylons (with scour protection) | | |
| Standard approach piers (28+47 Nos.) | 45m x 40m | 13 |
| Protected piers (4 Nos.) | 135m x 100m | 4 |
| Outer pylons (2 Nos.) | 140m x 100m | 2 |
| Centre pylon | 110m diameter | 1 |

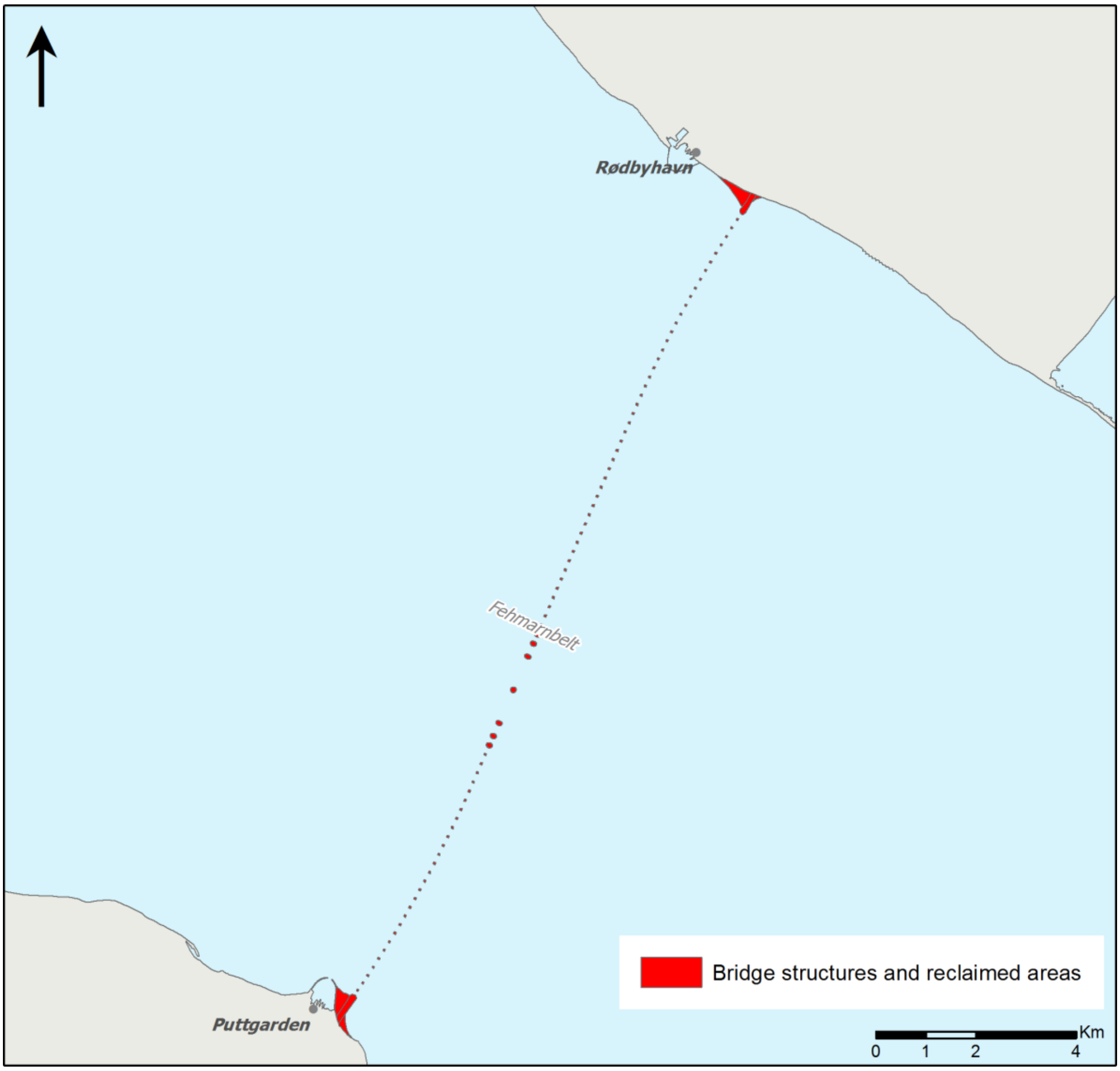


*Fig. 7.1 Permanent cable stayed bridge Var. 2 B-EE (October 2010) elements acting as pressure factors for the hydrography assessment*

### *7.1.2 Impact magnitude*

**Hydrodynamics**
Results from the underlying hydrodynamic modelling with the MIKE and GETM local models are displayed and discussed below for the various sub- components.

**Currents**
The changes for the surface currents are up to a reduction of -0.03m/s at 5km on each side of the main bridge structures, decreasing to less than -0.01m/s about 20km from the alignment, see Fig. 7.2. Off the coastline at Fehmarn the effect is up to an increase of 0.02m/s. Elsewhere, including along the coastline, the effects are below 0.015m/s.

Bottom current effects estimated in MIKE 3 are less than ±0.005m/s outside the link corridor with the locally adjusted flow between piers (corridor width less than 500m), to be seen in relation to a mean speed of 0.13m/s. GETM estimates a narrow corridor along the Danish side of the alignment with bottom current increases of up to 0.04m/s.

Annual mean at surface Annual mean at bottom

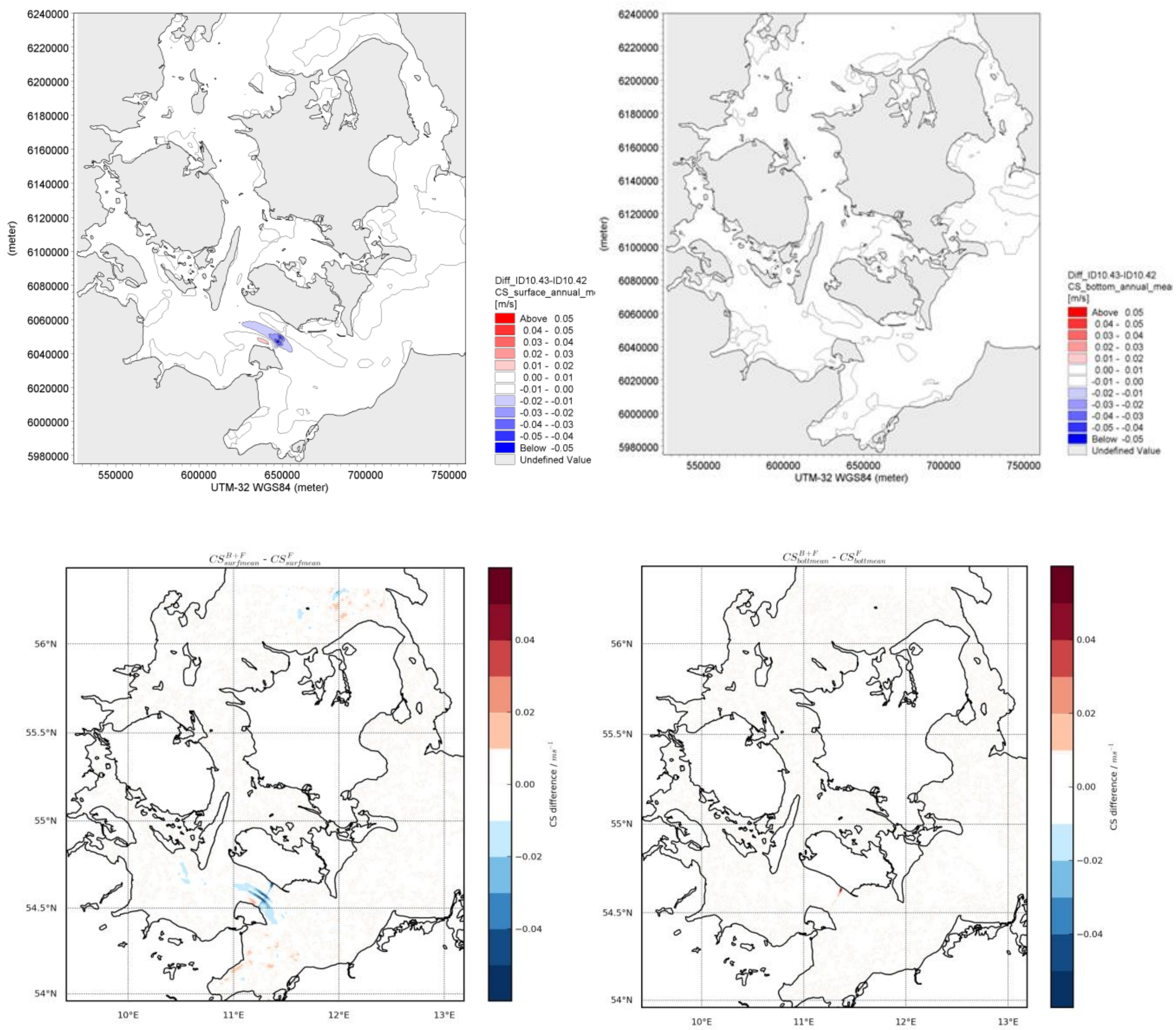


*Fig. 7.2 Effect on mean current speed estimated with MIKE 3 (top) and GETM (lower) local models to surface (left plots) and bottom (right plots) for "Bridge+ferry" case. Note that white indicates a change less than ±0.01m/s.*

**Salinity and temperature**

The detailed assessment of flow blocking and mixing effects in the local models shows that surface and bottom salinities in the southern Lillebælt- Kiel Bay area may increase up to 0.08psu (MIKE) and 0.08-0.25psu (GETM) and decrease -0.08psu (MIKE) and -0.2psu in the Mecklenburg Bay – Lübeck Bay area, see Fig. 7.3. Both models also show slight decreases in surface salinity off the Fehmarn north coast of less than -0.1psu. The GETM model has some changes further away near the Kattegat boundary which are considered to be model artefacts.

For the bottom salinity the estimated effects are up to -0.2psu in the deep part of Fehmarnbelt just east of the alignment, extending into Mecklenburg Bight. At larger distances in Kiel Bight and Lübeck Bight the reduction in salinity is less and also less than for the surface salinity (generally less than 0.08psu). The GETM model also finds small bottom salinity reductions down to -0.1psu across the Darss Sill and extending into Arkona Basin (MIKE model has less reduction here). In the Arkona Basin the regional models estimated a reduced bottom salinity of about -0.05psu (FEHY 2013b).

These effects are associated with the increased mixing from the bridge structures, mixing surface water down into the bottom layer and vice versa.

Elsewhere in the water column away from the link alignment the changes will differ from the above mentioned changes for surface and bottom waters, but not exceed the values mentioned for surface and bottom significantly.

Annual mean at surface | Annual mean at bottom

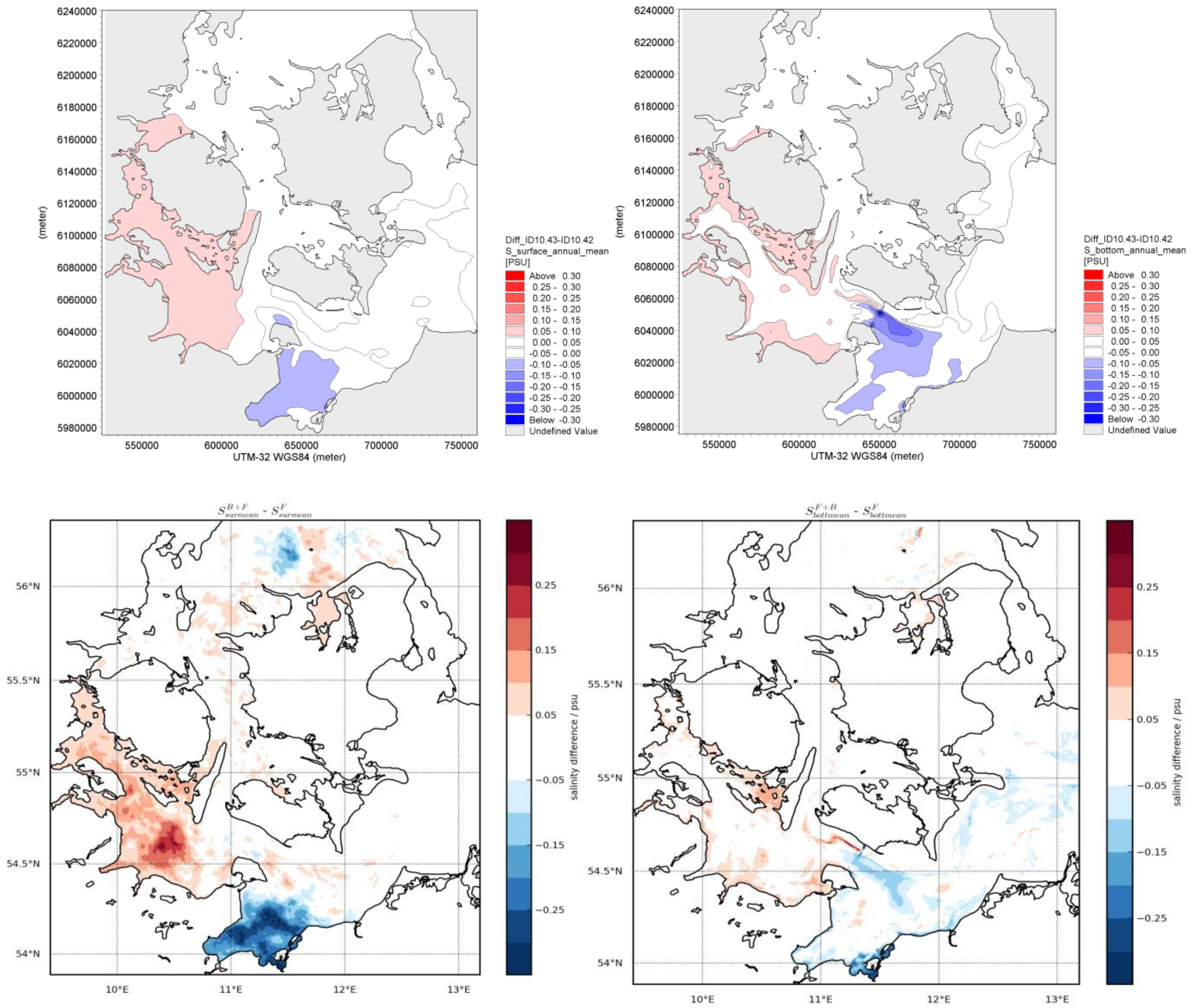


*Fig. 7.3 Effect on mean salinity estimated with MIKE 3 (top) and GETM (below) local models to salinities for "Bridge+ferry" case. Surface salinity effects left, bottom salinity effects right.*

The effect on the annual mean surface and bottom temperature is minimal, only exceeding ±0.05ºC at a few spots.

Regarding bottom summer temperatures there is a minor effect. The summer bottom changes are shown in Fig. 7.4, showing increased bottom temperatures east of the alignment of up to 0.25ºC, and reductions in the central Mecklenburg Bight of down to -0.2ºC in the MIKE local model but up to a 0.2ºC increase in the GETM model in this area. The bottom temperature effect is linked to the mixing effect above for bottom salinity.

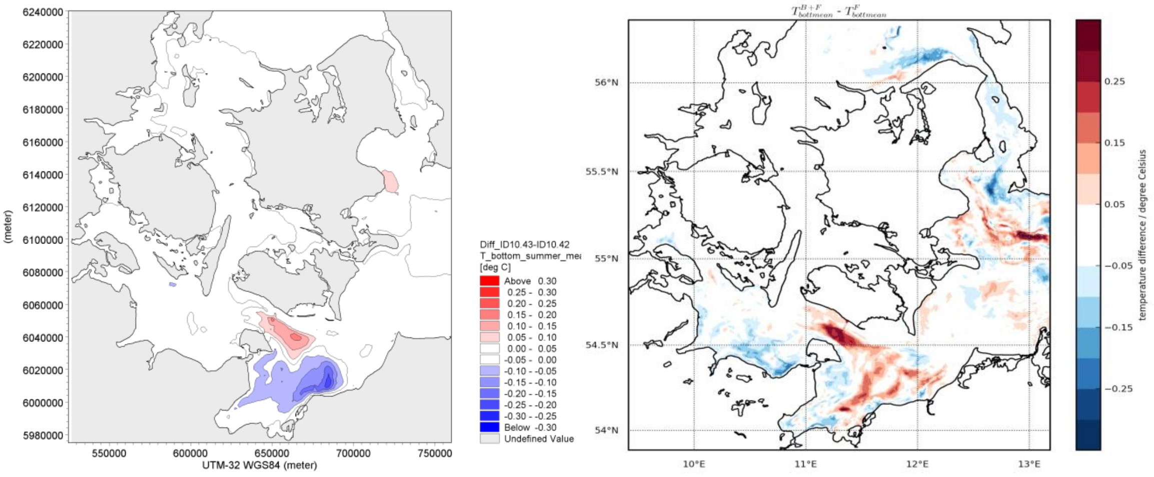


*Fig. 7.4 Effect on mean bottom summer temperature estimated with MIKE 3 (left) and GETM (right) local models for "Bridge+ferry" case.*

Somewhat higher effects (up to ±0.3ºC) can be found close to the interface level at about 15-20 m in the summer time.

**Stratification**

The resulting stratification effects of the above effects on salinity and temperature are that the annual mean stratification is reduced somewhat in the area east of the bridge alignment (up to -0.18kg/m$^3$), see Fig. 7.5. Just west of the alignment minor areas with increased stratification up to 0.06kg/m$^3$ may occur, expressed as annual mean values. In the GETM model changes are also found further away in Southern Lillebælt and Lübeck Bight with changes up to ±0.2kg/m$^3$. The typical annual mean stratification value in the reference conditions is 6-8kg/m$^3$ at large water depths in the area.

The effect on stratification in summer is somewhat larger with values up to ±0.2 to 0.3kg/m$^3$ in large areas east and west of the link, see Fig. 7.5.

Annual mean startifcation Summer mean stratification

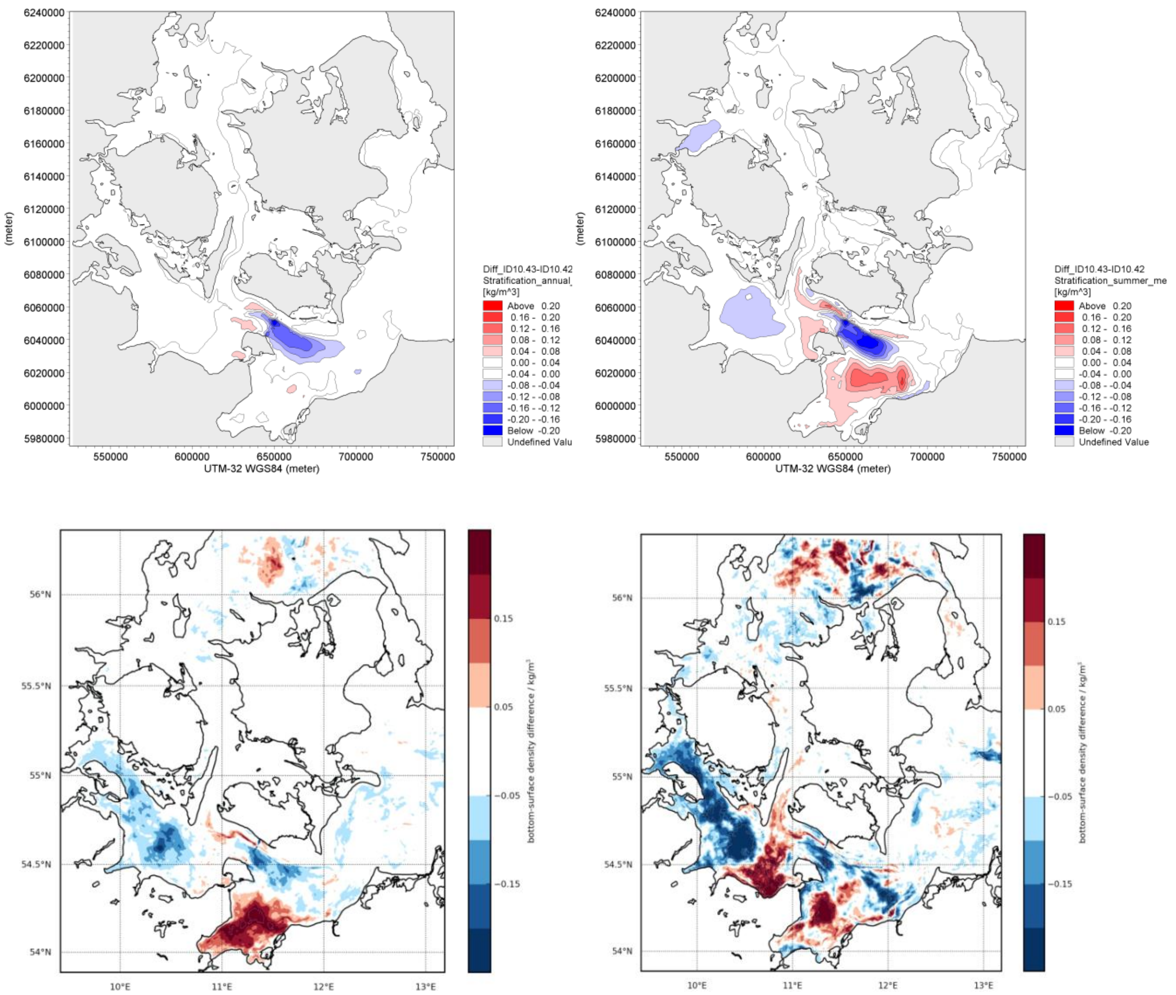


*Fig. 7.5 Effect on stratification estimated with MIKE 3 (upper) and GETM (lower) local models for "Bridge+ferry" case. Left plots show annual mean changes and right plots summer period changes.*

Table 7.2 summarises the maximum estimated effect in the underlying modelling. Water level changes are seen to be negligible.

The blocking of the exchange flow with the Baltic Sea is only a supporting indicator, as the effects in the Baltic Sea are modelled directly in the regional models (FEHY 2013b). However it integrates all effects to some extent. For the bridge scenario the flow effect is -0.5%.

The effect to currents exceeds the applied threshold level of about 0.01m/s at distances up to 20km up and downstream of the main bridge structures.

The estimated maximum changes for salinity, stratification and summer bottom temperature are also exceeding the threshold level for the negligible/low impact separation. This takes place in larger parts of the Western Baltic.

*Table 7.2 Magnitude for key effects in the Fehmarnbelt and nearby areas for cable stayed bridge.*

| **Bridge+ferry" compared to "Ferry" case** | **Upper limit for estimated change in local model area (off alignment)** | **Fehmarnbelt (Station NO1 1990-2007)** | |
|---|---|---|---|
| | | **Standard deviation** | **Mean value** |
| Mean water level | Locally up to 0.001-0.003m, typically much less | 0.24m (Gedser 2004-2009) | - |
| Max water level | Locally east of alignment less than +0.01m (MOM scaled result), MIKE reduced down to -0.004m, elsewhere less | 0.2m (MIKE 3) | - |
| Blocking of instantaneous flow across Darss | 0.5% (0.4-0.7%) | - | - |
| Surface current speeds (annual mean) | 5 km downstream main bridge reduced down to -0.03m/s, along coastline off alignment less than ±0.01m/s | 0.23m/s (MS02 station 2009-2010) | 0.41m/s (MS02 station 2009-2010) |
| Bottom current speed (annual mean) | Less than ±0.005m/s outside alignment corridor ± 250m max) | 0.09m/s (MS02 station 2009-2010) | 0.13m/s (MS02 station 2009-2010) |
| Surface salinity (annual mean) | Locally up to 0.25psu, larger areas around ±0.1psu | 3.2psu | 12.7psu |
| Bottom salinity (annual mean) | East of alignment down to -0.2psu, elsewhere less than ±0.1psu | 3.5psu | 21.9psu |
| Surface temperature (annual mean) | Less than ±0.05°C | 5.7°C | 9.4°C |
| Bottom temperature (annual mean) | Less than ±0.05°C | 3.6°C | 6.6°C |
| Summer bottom temperature (mean) | Less than ±0.25°C and typically below ±0.05°C | 2.3°C | 9.9°C |
| Stratification (annual mean) | Up to ±0.25kg/m$^3$ in larger areas, less than ±0.08kg/m$^3$ elsewhere | 4.5kg/m$^3$ | 7.7kg/m$^3$ |
| Stratification summer (mean) | Up to ±0.25kg/m$^3$ in large parts of Western Baltic Sea area | 2.8kg/m$^3$ | 10.6kg/m$^3$ |

As mentioned in Chapter 3.7.11, the above numerical models do not resolve the details of current effects in the immediate vicinity of each of the link structures.

Instead an area of changed bottom current speed is superimposed to 25-45% within a distance of 4 times the diameter of the pier or pylon (including ship protection where relevant). The surface current changes less within the same distance.

In the lee zone around the marine ramps of the cable stayed bridge an expert assessment for the current effects is applied, with effect levels to the mean current speed going from -50% in the corner between coast and marine ramp and then linearly increasing in the direction offshore to the tip of the ramp and along the coast to five times the length of the marine ramp.

**Sea State (waves)**
Fig. 7.6 shows the effect to the wave indicator. Changes are seen mainly on the eastern side of the alignment, as a result of dominating westerly winds and the row of bridge pier and pylons. There are also small areas west of the alignment with increased waves resulting from reflection in the protection caissons.

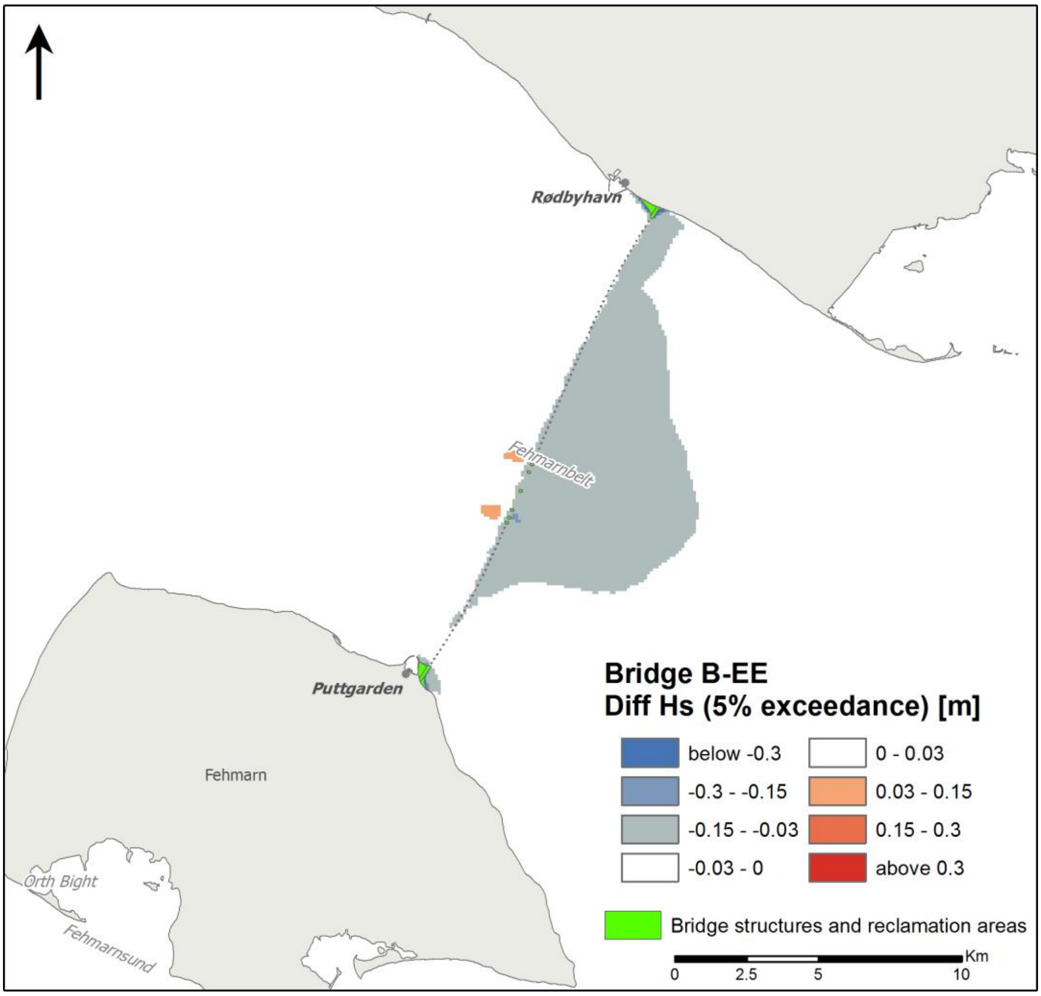


*Fig. 7.6 Changes to significant wave height exceeded 5% of time (meters) for cable stayed bridge Var. 2 B-EE (October 2010) variant*

A separate evaluation of wave effect to the coastal morphology is available in (FEHY 2013a).

### *7.1.3 Loss and degree of impairment*
The aggregation of the degree of impairment and loss for the individual sub component indicators for the bridge results in the distribution shown in Fig. 7.7.

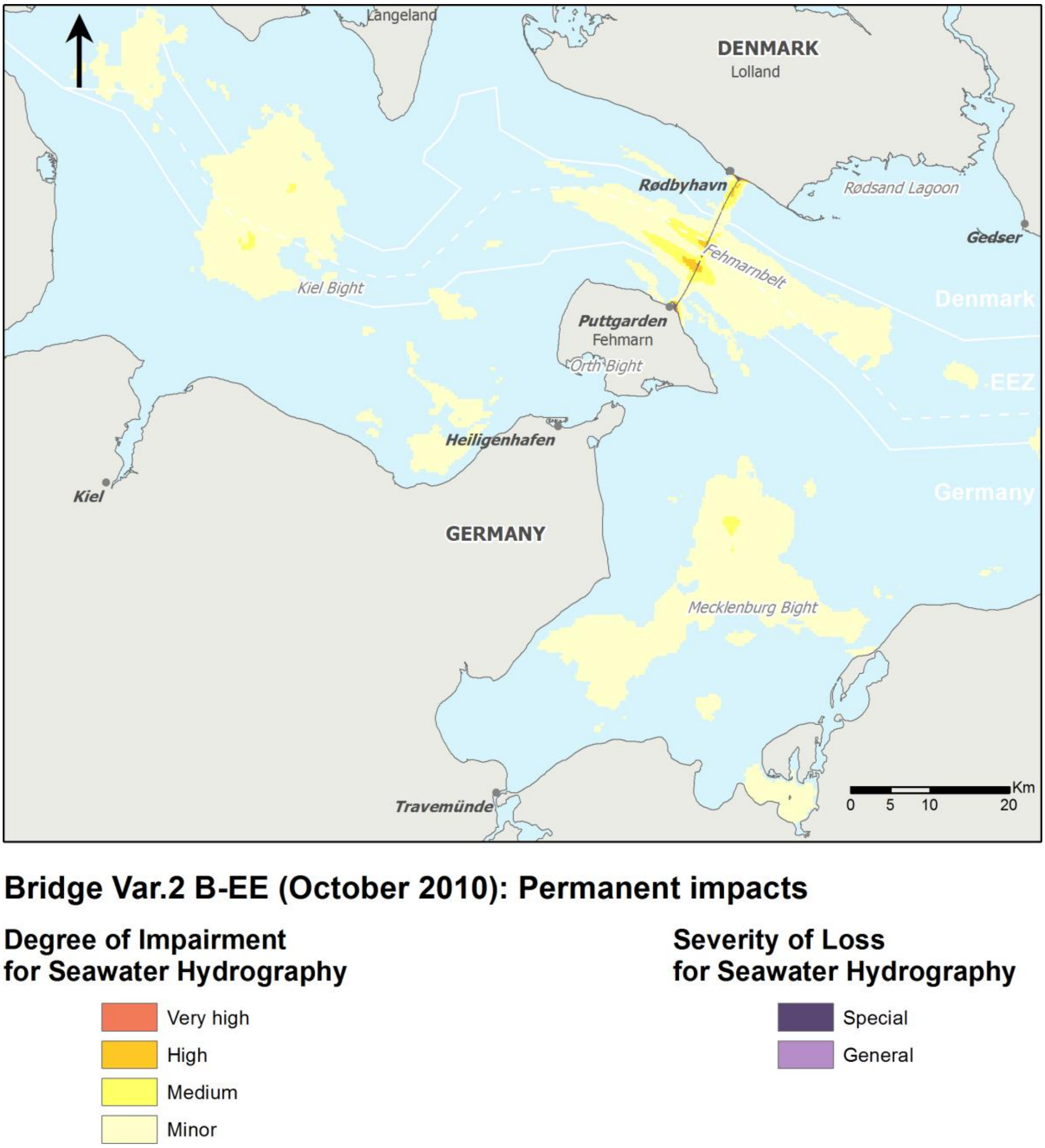


*Fig. 7.7 The degree of impairment and severity of loss distribution for permanent hydrography impacts of the cable stayed bridge Var. 2 B-EE (October 2010)*

The degree of impairment reaches the "high" and "medium" levels in the vicinity of the marine ramps and in the centre of Fehmarnbelt where the additional mixing is largest.

The "low" degree of impairment areas extends about 20km east and west of the alignment and isolated areas are also present in Kiel Bight and Mecklenburg Bight with single spots reaching "medium", mainly caused by changes to the summer stratification strength.

Outside the above areas all sub components indicator changes are negligible.

*Table 7.3 The degree of impairment and severity of loss areas for permanent hydrography impacts after implementation of the cable stayed bridge Var. 2 B-EE (October 2010)*

| Permanent impacts | Hydrography for bridge Var. 2 B-EE (October 2010) | | | | | |
|---|---|---|---|---|---|---|
| | Total area (ha) | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 25[1] | 25[1] | 0 | 6[1] | 11[1] | 9 |
| General | 31 | 31 | 0 | 18 | 13 | 0 |
| **Total severity of loss** | **56** | **56** | **0** | **24** | **24** | **9** |
| **Degree of impairment** | | | | | | |
| Very High | 32 | 32 | 0 | 18 | 13 | 0 |
| High | 572 | 330 | 241 | 100 | 40 | 432 |
| Medium | 4,144 | 789 | 2,630 | 1,140 | 751 | 2,253 |
| Low | 121,943 | 789 | 15,312 | 43,670 | 62,717 | 15,557 |
| **Total degree of impairment** | **126,691** | **1,940** | **18,184** | **44,928** | **63,521** | **18,242** |
| **Total permanent** | **126,747 (16.4%)** | **1,996 (97.2%)** | **18,184 (46.2%)** | **44,951** | **63,545** | **18,250** |
| Reference areal | 770.000[2] | 2.054 | 39.392 | - | - | - |

Note 1: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

Note 2: Area of the Western Baltic Sea

Table 7.3 summarises the areas of the degree of impairment and loss of severity for the permanent effects. The loss area is very limited with a total of 56ha, of which the beach water parts actually will be compensated by the planned additional beaches. The total of the degree of impairment area is 126,700ha, with only 604ha in the high to very high class. Most of this area is in the defined near zone in the immediately vicinity of the link alignment.

Most of the impacted area is within German waters, mainly because the main bridge structures are situated on the German side of the international boarder (actually in the German EEZ zone).

All of the reclamation loss area for the marine ramps and beaches at the ramp intersections with the coast appears as “general” severity, as this area is assigned a “general” importance with respect to hydrography.

### *7.1.4 Impact severity of loss and impairment*

When combining the degree of impairment with the importance for the hydrography component the result becomes as displayed in Fig. 7.8. The distribution is nearly identical with the degree of impairment, as the dominant part of the impact area falls within the “special” importance category due to the fact that they are areas of importance for the water exchange with the Baltic Sea.

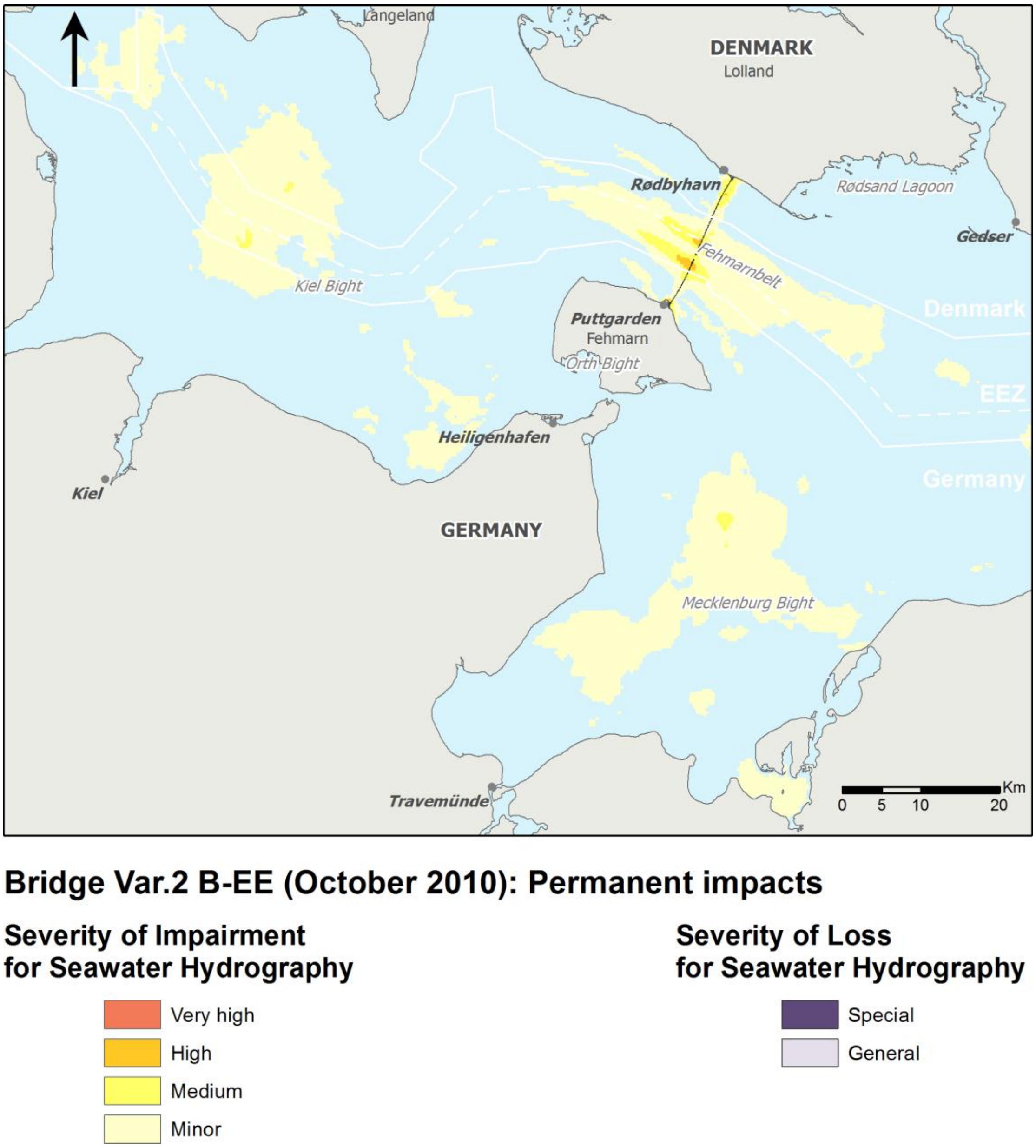


*Fig. 7.8* *The impact severity distribution for permanent hydrography impacts of the cable stayed bridge Var. 2 B-EE (October 2010)*

The permanent severity impact area size is summarised in Table 7.4. In total the areas affected by "minor" to "very high" severity add to 126,700ha, nearly the same as the degree of impairment areas..

Table 7.4 also shows that a significant part of the impacted area extends beyond the defined local area (defined as ±10km around link alignment, excluding the near zone). The impacted area constitutes about 46% of this local area and 97% of the near zone (500m around the bridge footprint). On a Western Baltic Sea scale the impacted area corresponds to 16%.

Most of the impacted area falls in the minor severity category. Only about 5000ha (0.6% of the Western Baltic Sea area) are in the categories "medium" to "very high" and only about 500ha (0.1%) in the "high" to "very high" category. All this area with "high" to "very high" is located inside the defined near zone or local area (±10km around link alignment).

*Table 7.4 The impact severity area size for permanent hydrography impacts after implementation of the cable stayed bridge Var. 2 B-EE (October 2010)*

| **Permanent impacts** | **Hydrography for bridge Var. 2 B-EE (October 2010)** | | | | | |
|---|---|---|---|---|---|---|
| | **Total area (ha)** | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 25[1] | 25[1] | 0 | 6[1] | 11[1] | 9[1] |
| General | 31 | 31 | 0 | 18 | 13 | 0 |
| **Total severity of loss** | **56** | **56** | **0** | **24** | **24** | **9** |
| **Severity of impairment** | | | | | | |
| Very High | 2 | 2 | 0 | 0 | 2 | 0 |
| High | 469 | 236 | 233 | 16 | 21 | 432 |
| Medium | 4,277 | 914 | 2,638 | 1,242 | 782 | 2,253 |
| Low | 121,942 | 789 | 15,311 | 43,670 | 62,716 | 15,557 |
| **Total severity of impairment** | **126,689** | **1,940** | **18,182** | **44,928** | **63,520** | **18,242** |
| **Total permanent** | **126,745 (16.4%)** | **1,996 (97.2%)** | **18,182 (46.2%)** | **44,952** | **63,544** | **18,251** |
| Reference areal | 770.000[2] | 2.054 | 39.392 | - | - | - |

Note 1: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

Note 2: Area of the Western Baltic Sea

The new beach areas in the corners of the marine ramps should actually not be regarded as a negative impact as they will provide better opportunities for recreational activities than at present.

### 7.1.5 Impact significance

The above permanent effect to the hydrography is assessed as having no significance for the general hydrography on a Western Baltic scale. This conclusion comes mainly from the "medium" to "very high" impact areas only covering 0.6% of the Western Baltic Sea area and not extending to other parts of the Belt Sea.

The effect to the water exchange with the Baltic Sea of -0.5% can be compared to the criteria used for the other fixed links in the Belt Sea and Sound:

- Great Belt Fixed Link: Is designed as a zero blocking solution, where the flow blocking of the link elements of 2% is compensated by dredging (DHI/LIC 1999). The potential, remaining flow effect is linked to the uncertainty at ±0.2% of the models used for the analysis. However, as the used model only covered an area representing about 1/5 of the total flow resistance between Kattegat and Darss, the accepted flow uncertainty is in the order of ±0.04% when compared to the above Fehmarnbelt bridge effect of -0.5%.

- Øresund Fixed Link: This was also implemented as a zero blocking solution with a remaining uncertainty of the match of about ±0.25% (DHI/LIC 2000).

Compared to these former fixed link solutions the bridge effect of -0.5% to the water exchange with the Baltic Sea in Fehmarnbelt is found to be larger than the uncertainty of the zero solutions implemented for the other fixed links.

For the specific predictions of Baltic Sea impacts see (FEHY 2013b).

## 7.2 Construction period with temporary structures

### 7.2.1 Magnitude of pressure

In the construction period for the cable stayed bridge the permanent structures are implemented within the first couple of years. Furthermore, the temporary work harbour at Fehmarn and the production facility with its breakwaters at Lolland will be present for the entire construction period. Just before the removal of the temporary structures the pressures shown in Fig. 7.9 are present. The size of these temporary structures are summarised in Table 7.5.

*Table 7.5 The dimensions of the additional pressure elements during the construction period of the cable stayed bridge Var. 2 B-EE (October 2010).*

| Additional pressure element in the construction period | Dimension | Area (ha) |
|---|---|---|
| Work harbours outside permanent footprint | | |
| Lolland | 750m * 320m | 20 |
| Femern | 300m * 350m | 9 |

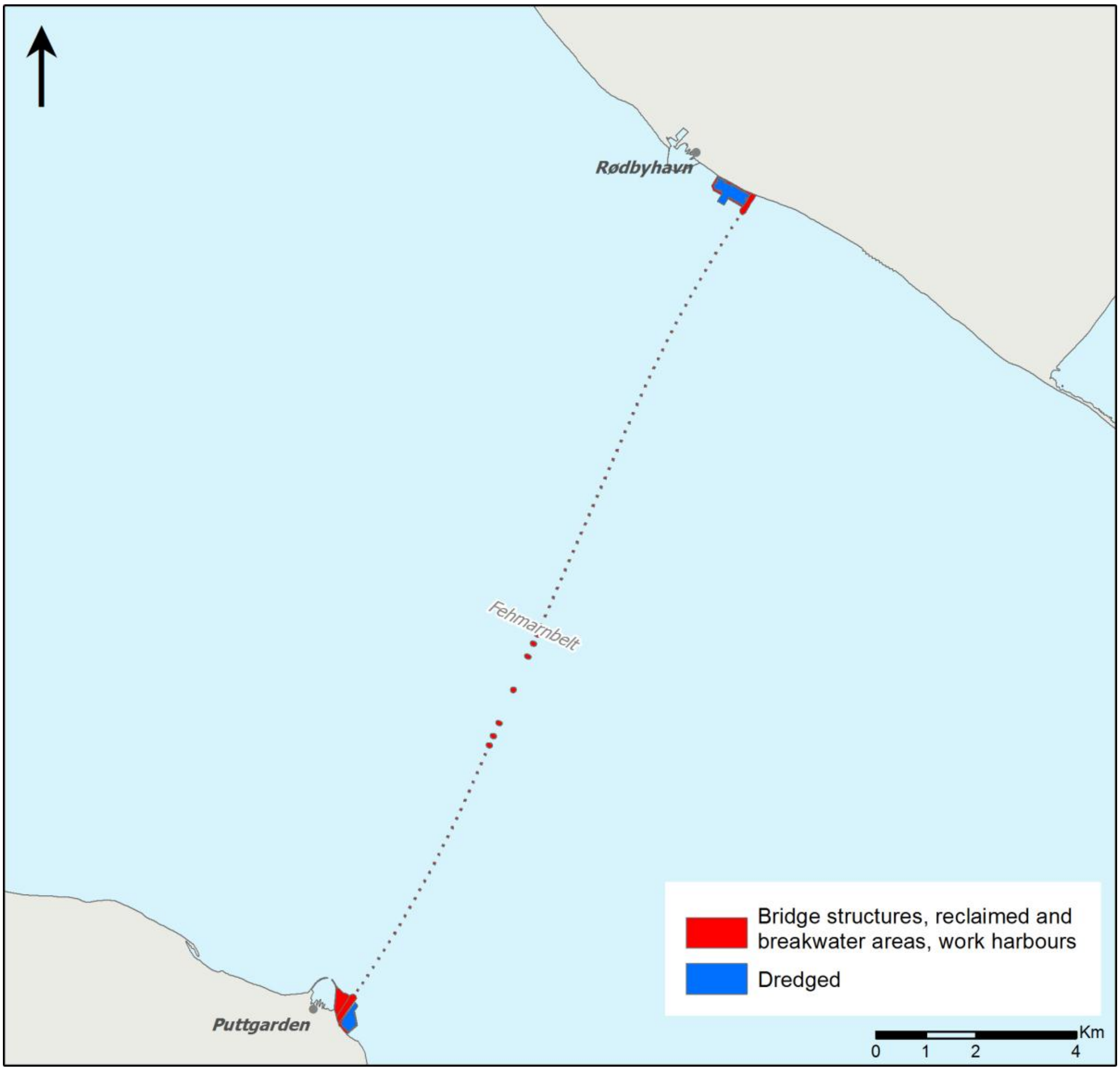


*Fig. 7.9* *Cable stayed bridge Var. 2 B-EE (October 2010) elements in construction period acting as pressure factors for the hydrography assessment.*

### *7.2.2 Impact magnitude*

**Hydrodynamics**

The additional hydrodynamic impacts in the construction period include the temporary loss at the work harbour structures and the associated lee effects downstream and upstream. These areas are not modelled but assessed based on expert evaluations.

Most of the area between the Lolland production facility harbour and the Rødbyhavn breakwater will be affected by considerable reduction in current speeds.

**Sea State (waves)**

This is not assessed separately during the construction period. The wave effect from the permanent impact assessment in Chapter 7.1.2 can be applied as proxy.

### *7.2.3 Loss and degree of impairment*

The aggregation for the individual sub component indicators for the bridge results in the distribution of degree of impairment shown in Fig. 7.10 during the construction period and quantified in Table 7.6.

Compared to the permanent impacts (Chapter 7.1.3), the impairment and loss areas are increased only marginally with the areas at and around the work and production facility harbours.

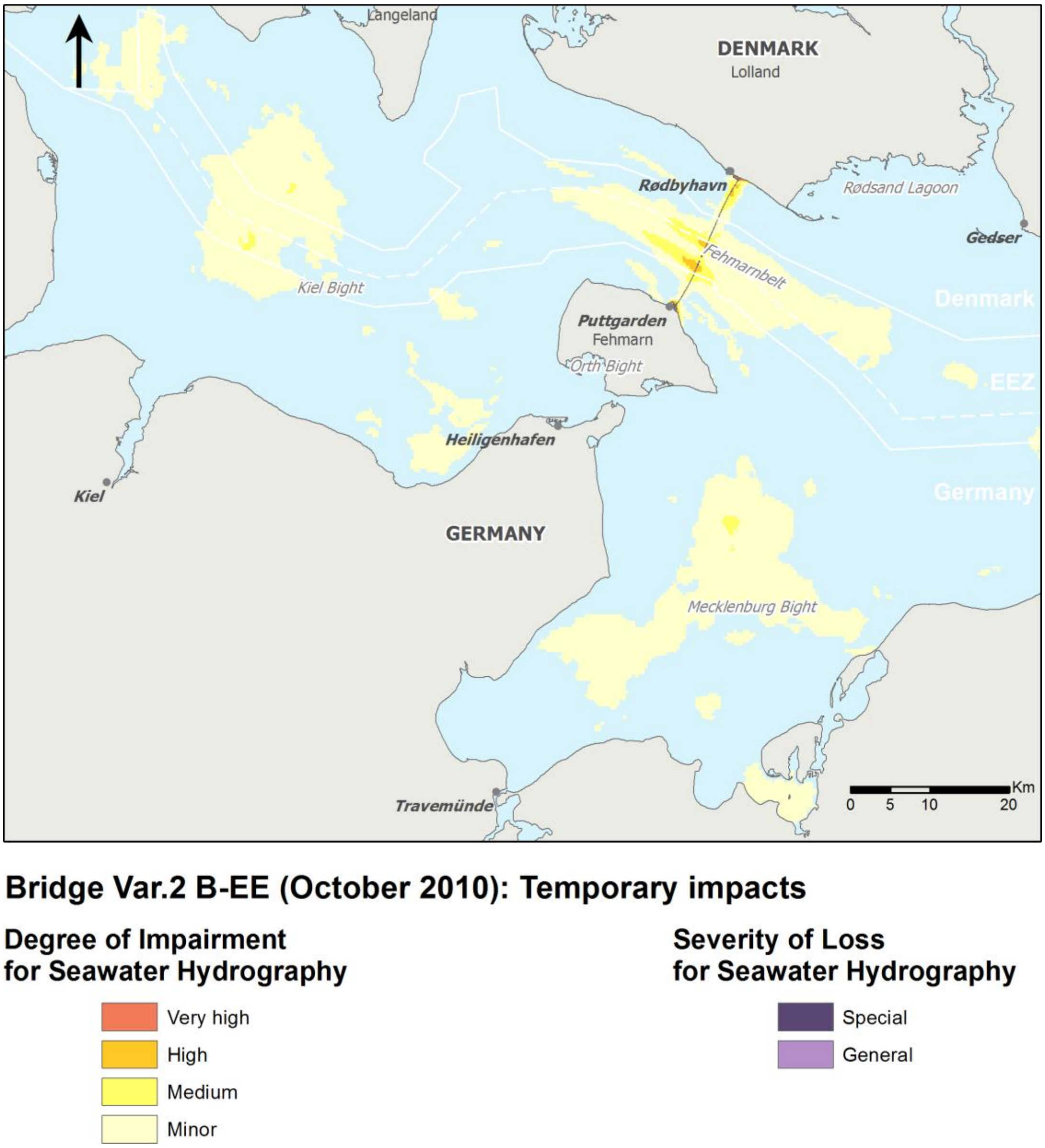


*Fig. 7.10 The degree of impairment and loss distribution during the construction period for hydrography impacts of the cable stayed bridge Var. 2 B-EE (October 2010)*

Outside the above areas the degree of impairment is almost identical to the permanent areas.

Outside the above areas all sub components indicator changes are negligible.

*Table 7.6 The degree of impairment and severity of loss areas for hydrography impacts during implementation of the cable stayed bridge Var. 2 B-EE (October 2010)*

| **Construction period impacts** | **Hydrography for bridge Var. 2 B-EE (October 2010)** | | | | | |
|---|---|---|---|---|---|---|
| | **Total area (ha)** | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 24 | 24 | 0 | 6 | 10 | 9 |
| General | 26 | 26 | 0 | 12 | 14 | 0 |
| **Total severity of loss** | **50** | **50** | **0** | **18** | **23** | **9** |
| **Degree of impairment** | | | | | | |
| Very High | 50 | 50 | 0 | 36 | 14 | 0 |
| High | 564 | 323 | 241 | 92 | 40 | 432 |
| Medium | 4,140 | 786 | 2,630 | 1,136 | 751 | 2,253 |
| Low | 121,943 | 788 | 15,312 | 43,669 | 62,717 | 15,557 |
| **Total degree of impairment** | **126,697** | **1,947** | **18,184** | **44,933** | **63,522** | **18,242** |
| **Total construction period** | **126,747 (16.4%)** | **1,996 (97.2%)** | **18,184 (46.2%)** | **44,951** | **63,545** | **18,250** |
| Reference areal | 770,000[1] | 2,054 | 39,392 | - | - | - |

Note 1: Area of the Western Baltic Sea

### *7.2.4 Impact severity of loss and impairment*

When combining the degree of impairment and the loss for the construction period with the importance for the hydrography component the result becomes as displayed in Fig. 7.11.

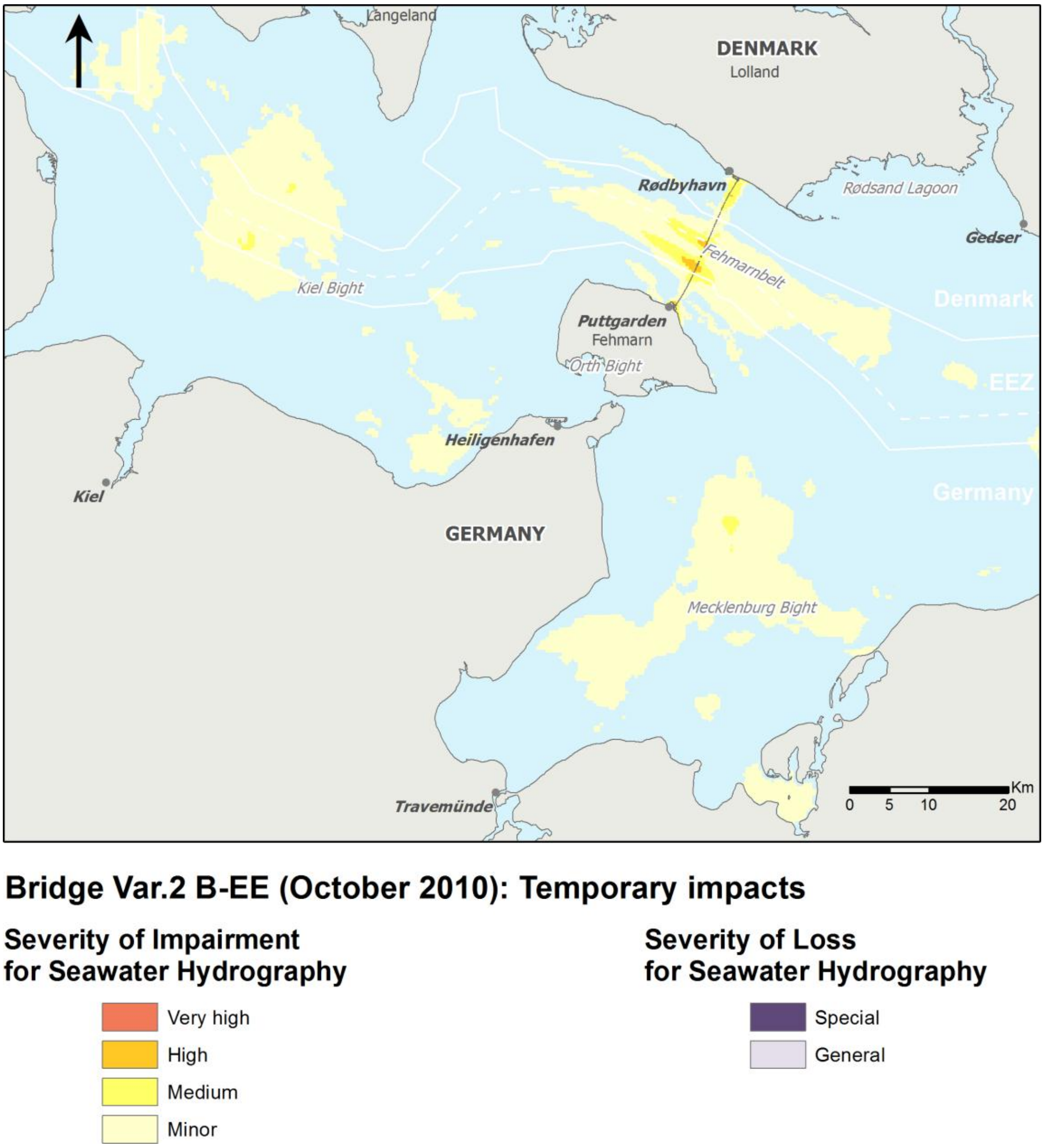


*Fig. 7.11 The impact severity distribution in the construction period for hydrography impacts of the cable stayed bridge Var. 2 B-EE (October 2010)*

The limited additional temporary loss and impairment areas in connection with the temporary harbours become of "medium" to low severity for hydrography due to the location at shallow waters outside special interest zones, see Table 7.7.

### 7.2.5 Impact significance

In total the areas affected by "minor" to "very high" impairment or loss add up to 126,700ha, which is the same as for the permanent impact area.

The above temporary impact to the hydrography is assessed as having the similar no significance for the general hydrography in the Fehmarnbelt and the Belt Sea as the permanent effects.

*Table 7.7 The impact severity area size for hydrography impacts during implementation of the cable stayed bridge Var. 2 B-EE (October 2010)*

| **Construction period impacts** | **Hydrography for bridge Var. 2 B-EE (October 2010)** | | | | | |
|---|---|---|---|---|---|---|
| | **Total area (ha)** | Various subpart areas (ha) | | | | |
| | | Near zone | Local area (excl. n.z.) | Denmark National +EEZ | Germany National | Germany EEZ |
| **Severity of loss** | | | | | | |
| Special | 24 | 24 | 0 | 6 | 10 | 9 |
| General | 26 | 26 | 0 | 12 | 14 | 0 |
| **Total severity of loss** | **50** | **50** | **0** | **18** | **23** | **9** |
| **Severity of impairment** | | | | | | |
| Very High | 3 | 3 | 0 | 0 | 3 | 0 |
| High | 469 | 236 | 233 | 16 | 21 | 432 |
| Medium | 4,283 | 920 | 2,638 | 1,248 | 781 | 2,253 |
| Low | 121,941 | 788 | 15,311 | 43,669 | 62,716 | 15,557 |
| **Total severity of impairment** | **126,696** | **1,947** | **18,182** | **44,933** | **63,521** | **18,242** |
| **Total construction period** | **126,746 (16.4%)** | **1,997 (97.2%)** | **18,182 (46.2%)** | **44,951** | **63,544** | **18,251** |
| Reference areal | 770.000[1] | 2.054 | 39.392 | - | - | - |

Note 1: Area of the Western Baltic Sea

## *7.3 Aggregation of impacts*

The above impact maps should not be aggregated as they relate to two different time spans: The permanent impacts after construction and the impacts during the construction period with some extra temporary pressures.

## *7.4 Cumulative impacts*

As concluded for the tunnel assessment in Chapter 6.4, there are no cumulative impacts to consider for the bridge solution.

## *7.5 Transboundary impacts*

The transboundary impacts of the cable stayed bridge solution are analysed in the IA for Baltic Sea hydrography and water quality, see (FEHY 2013b).

## *7.6 Climate change*

The climate change up to the years 2080-2100 has been discussed in Chapter 6.6 in relation to the tunnel assessment.

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

## 7.7 Mitigation and compensation measures

In general the impacts of the bridge project to the hydrography are of minor significance for the general hydrography, even though the area affected is exceeding the scale of Fehmarnbelt.

An integrated part of the bridge project is the establishment of two new beaches at the marine ramp at Lolland and one beach at the eastern side of the Fehmarn marine ramp. These new facilities will provide new potentially attractive recreational areas.

It has earlier been assessed (Environmental Consultation Report 2006) if the blocking effect of the bridge structures can be mitigated by compensation dredgings. The conclusion was that this is only an effective mitigation measure if the dredging takes place in reef areas. It has not been possible to identify any local reef areas of a sufficient size for compensation effects. Furthermore, the local and more regional reef areas in the Western Baltic are generally protected and are thus not available as compensation dredging areas. Therefore this option has not been evaluated further in the present impact assessment.

## 7.8 Decommissioning

Decommissioning of the bridge is foreseen to take place in the year 2140, when the fixed link has been in operation for the design lifetime of 120 years. Any structure on the seabed must be levelled with the seabed in order to allow ship traffic, fishery and similar activities at sea.

Femern A/S foresees that the majority of bridge components are transported to shore for further dismantling. This will require a designated facility, possibly a shipyard, harbour area or a purpose-built installation. A significant part of the environmental impacts will arise at this location. Furthermore, the marine ramps are expected to be removed by reversing the construction method. After removing the gallery, the high quality sand core and stone revetments will be removed and reused. Finally the quarry run dikes on either side will be excavated and reused.

The effect to the Fehmarnbelt hydrography during the decommissioning period is evaluated as being small. After decommissioning all of the effects to Fehmarnbelt hydrography will have disappeared.

# 8 COMPARISON OF BRIDGE AND TUNNEL MAIN ALTERNATIVES

## 8.1 Comparison of tunnel and bridge alternatives with continued ferry operation

The two alternatives for the fixed link in Fehmarnbelt are affecting the hydrography component quite differently. Table 8.1 summarises the degree of impairment and severity of loss areas. While the total permanent impact area for the immersed tunnel is only 0.2% of the Western Baltic Sea area, about 18% is affected by the cable stayed bridge alternative.

If focussing on the "medium" to "very high" severity areas the figures become 0.1% for tunnel and 0.6% for bridge (relative to the Western Baltic Sea area). The impact areas in these categories are thus much smaller than the full impact area.

Only for the  severity of loss category the tunnel shows a larger area (359 ha) than the bridge (50ha). This is due to the tunnel reclamation affecting beach areas 1-3 km west of the Rødbyhavn breakwater and immediately east of the Puttgarden breakwater. As the plans for both the tunnel and bridge projects include new beach areas close by, this will actually not be a negative net impact in reality for the hydrography.

Table 8.1 documents that the impacted areas in relation to hydrography at the later stage of the construction period also will be largest for the bridge alternative. This bridge construction impact area increases to about the permanent size in accordance with the deployment of the bridge piers and pylons. The earlier part of the construction period, where parts of the tunnel trench is still open, will not change the tunnel to become more affecting to the hydrography for the construction period than permanently.

*Table 8.1 The impact area at a later stage of the construction period and for the permanent situation for hydrography impacts of the immersed tunnel E-ME (August 2011) and the cable stayed bridge Var. 2 B-EE (October 2010)*

| **Component: Hydrography** | **Immersed Tunnel E-ME (August 2011)** | **Cable Stayed Bridge Var 2. B-EE (October 2010)** |
|---|---|---|
| | **Total area (ha)[1]** | **Total area (ha)[1]** |
| **CONSTRUCTION PERIOD** | | |
| **Construction period severity of loss** | | |
| Special importance | 60[2] | 24[2] |
| General importance | 298 | 26 |
| **Total severity of loss** | **359 (0.0%)** | **50 (0.0%)** |
| **Construction period degree of impairment** | | |
| Very high | 23 (0.0%) | 50 (0.0%) |
| High | 212 (0.0%) | 564 (0.1%) |
| Medium | 416 (0.1%) | 4,140 (0.5%) |
| Minor | 636 (0.1%) | 121,943 (15.8%) |
| **Total degree of impairment** | **1,287 (0.2%)** | **126,697 (16.5%)** |
| **TOTAL CONSTRUCTION PERIOD** | **1,645 (0.2%)** | **126,747 (16.5%)** |
| **PERMANENT IMPACTS** | | |
| **Permanent severity of loss** | | |
| Special importance | 64[2] | 25[2] |
| General importance | 279 | 31 |
| **Total severity of loss** | **343 (0.0%)** | **56 (0.0%)** |
| **Permanent degree of impairment** | | |
| Very high | 0 (0.0%) | 32 (0.0%) |
| High | 136 (0.0%) | 572 (0.1%) |
| Medium | 274 (0.0%) | 4,144 (0.5%) |
| Minor | 575 (0.1%) | 121,943 (15.8%) |
| **Total degree of impairment** | **985 (0.1%)** | **126,691 (16.5%)** |
| **TOTAL PERMANENT** | **1,329 (0.2%)** | **126,747 (16.5%)** |

Note 1: Relative to area of the Western Baltic Sea: 770,000 ha

Note 2: New project beaches will replace these lost beaches, so the net effect for beach water will become about 0ha

Table 8.2 and 8.3 summarises the impacts and relative ranking of the alternatives with respect to potential impacts to the Fehmarnbelt and Western Baltic Sea area.

*Table 8.2* *Summary of impacts to the Fehmarnbelt and Western Baltic Sea hydrography, water chemistry and plankton, which differentiates the immersed tunnel and the bridge alternatives*

| Assessed theme | Immersed tunnel | Cable stayed bridge |
|---|---|---|
| Hydrography conditions | No significant impacts | No significant impacts, but minimal permanent changes |

*Table 8.3* *Relative comparison of impacts of the immersed tunnel and bridge alternatives to the Fehmarnbelt and Western Baltic Sea area. For each factor the relatively environmentally best alternative is identified. 0: No difference; (+) Small environmental benefit; + Environmental benefit; ++ Large environmental benefit. Note that even an alternative is evaluated less environmental beneficial, this does not imply that there are significant impacts on the environment.*

| Environmental theme | Immersed tunnel | Cable stayed bridge | Differentiating factors |
|---|---|---|---|
| Hydrography conditions | (+) | | Tunnel gives no permanent changes compared to minimal changes for bridge |

The immersed tunnel alternative gets the best relative score, but the impacts are not considered significant for any of the alternatives.

## 8.2 *Comparison of tunnel and bridge alternatives without ferry operation*

As stated under the individual alternative assessments the termination of the ferry service will give rise to nearly the same hydrography impacts for the two fixed link alternatives as versus the situation with continued ferry service. However, for the bridge alternative the case without ferry service has a tendency to slightly lower impacts. Thus the impact results in Table 8.1, 8,2 and 8.3 also cover the situation where ferry service is assumed to be terminated after the opening of the fixed link.

# 9 CONSEQUENCES TO IMPLEMENTATION OF WFD AND MSFD

Based on the specific hydrographical impact assessment for the immersed tunnel and the cable stayed bridge alternatives for the fixed link it is concluded that none of the alternatives will affect the possibility to implement the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD).

This conclusion is based on the very limited impacts to the hydrography in Fehmarn-belt and the Belt Sea area from the alternatives.

# 10 KNOWLEDGE GAPS

The above assessments for the immersed tunnel and cable stayed bridge alternatives are based on detailed underlying numerical modelling for all the important potential changes. The models used in the underlying modelling are carefully calibrated and validated against monitoring data, and in general they match a predefined set of model acceptance criteria for the modelling.

Furthermore, a dual modelling approach has been fully implemented for the bridge modelling, being the fixed link solution with the largest impacts to hydrography. It is noted that the difference in modelled effects in the two local models applied is within about 50% for the maximum changes to the individual sub component indicators.

The underlying modelling and assessments have not revealed any significant knowledge gaps.

Thus the uncertainty of the assessments is assessed as being relatively low.

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## Table of figures

## List of tables