Final Report

FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES (FEHY)

Marine Water - Impact Assessment

Baltic Sea Hydrography, Water Quality and Plankton

E1TR0058 - Volume I

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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

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Appendix A: Tables of impacts for the bridge case (without ferry service)

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

0 EXECUTIVE SUMMARY

Fixed link alternatives and 0-alternative
This Volume of the Impact Assessment deals with the impacts in The Central Baltic Sea to the marine water sub-factor components *hydrography, water quality and plankton* 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 with 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, water quality and plankton components of the Central Baltic Sea

Component	Sub-component	Indicators
Hydrography	Water level	Mean and max water level
	Water exchange at Darss Sill	Relative change in instantaneous flow and salt flux
	Salinity and temperature	Mean value at surface and bottom and variation over depth
	Stratification	Mean value (bottom minus surface density)
Water quality	Dissolved oxygen	Mean value at surface and bottom and variation over depth
	Transparency	Mean S ecchi depth (at surface)
Plankton	Chlorophyll	Mean value at surface
	Blue-green algae	Mean carbon biomass at surface

Chemicals and hazardous substances are not considered relevant to assess in this context as it has been assessed elsewhere as not being a problem in the Fehmarnbelt area where the dredging takes place (FEMA 2013a).

For each sub-component indicator impact criteria are prepared, dividing the impacts into five levels of degree: "Negligible", "Low", "Medium", "High" or "Very High". This method and the combination with the baseline importance mapping, etc, follow the generic methodology specified in the Scoping Report (Femern A/S 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 and water quality issues a dual approach concept is used, with two independent regional model tools, MIKE 3 and MOM. These regional models cover the entire Baltic Sea area out to the Skagerrak. In addition, a set of local high resolution models have been applied for the transition area (Fehmarnbelt, the Belt Sea and the Sound), 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 calibration has applied the multiyear period 1970-1999 and the independent validation the following period 2000-2007 (partly also 2009).

The calibrated MOM model provides current speeds in Fehmarnbelt being 40% too low for surface currents. This is mainly due to representation of the Fehmarnbelt in the applied 3 nautical mile mesh, which is somewhat coarse for this narrow strait, with only 3 mesh cells being applied across Fehmarnbelt. It has not been possible to compensate for this speed deviation without affecting the salinity compliance in the Central Baltic Sea to a large degree. This effect means that MOM scenario effect is probably underestimated by about a factor 3. This factor correction is applied in the following, but MOM predictions may be less accurate, as it is not known if the scaling can be used for all parameters. Therefore, the MOM results are mainly used to validate the MIKE model results.

The scenario runs then include the specific project pressures, such as piers or reclamation. 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 regional model scenario runs cover the multiyear period 1990 - 2007 with a sufficient spin-up period for the new semi-stationary conditions to build-up.

The dual modelling approach has been fully implemented for the bridge alternative, which has the larger impacts. Here the two model tools give comparable results (after MOM is scaled with the factor for too low current speeds in the Fehmarnbelt).

For the immersed tunnel no regional modelling is undertaken, as the high resolution local hydrodynamic modelling showed no significant effect for this alternative (FEHY 2013b).

Furthermore, results from the sediment spill modelling are applied (FEHY 2013f).

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 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 affect the hydrography component quite differently. The impacts within the Central Baltic Sea are characterised as negligible for the tunnel alternative. The degree of impairment classification for the bridge and tunnel is summarised in Table 0.2. There is no loss area in the Central Baltic Sea, as the footprints of the project alternatives are all within Fehmarnbelt.

Table 0.2 The degree of impairment area for the Central Baltic Sea 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 (km^2)[1]	**Total area (km^2)[1]**
Construction period impairment	**0**	**0 (impacts typically about 40 years to develop**
Permanent impairment		
Very high	0 (0.0%)	0 (0.0%)
High	0 (0.0%)	2310 (0.6%)
Medium	0 (0%)	22,231 (6%)
Minor	0 (0%)	320,600 (84%)
Total permanent	**0 (0%)**	**345,100 (90%)**

Note 1: Relative to area of Baltic Sea out to the Drogden and Darss Sills

This assessment is based on the following results from the underlying models.

Magnitude of impacts for tunnel
The effect to the instantaneous water exchange in and out of the Fehmarnbelt is found to be -0.01% for the tunnel alternative. This is a very marginal effect, and therefore effects to any other components inside the Central Baltic Sea are assessed as negligible. Furthermore, during the construction period the effect to the

Central Baltic Sea water from spilled sediment in Fehmarnbelt is found to be negligible.

Magnitude of impacts for the bridge

For the cable stayed bridge the effect to the instantaneous water exchange is estimated at -0.5%. The related effects of this are listed in Table 0.3. The most pronounced effect is the slight effect to salinity of about -0.03psu for much of the Central Baltic Sea and an effect of up to 0.08psu in subparts of the Arkona Basin. The effect to stratification is in general below -0.02 kg/m^3, with effects up to 0.08 kg/m^3 in the Arkona Basin. These changes can be compared to a mean stratification of 5.2 kg/m^3 (±0.8 kg/m^3 standard deviation).

Table 0.3 Summary of magnitude for key effects in the Baltic Sea for "Bridge+ferry" case, 18-year period (1990-2007 forcing). The table is also a valid approximation for the "Bridge" only case.

"Bridge+ferry" compared to "Ferry" case	**Upper limit for estimated change in the Central Baltic Sea**	**Monitoring data K02 Bornholm Basin (1990-2007)**	
		Standard deviation	**Mean value**
Mean water level (annual mean)	Locally up to 0.0006m, typically much less	0.2m (MIKE3 results)	-
Max water level (18 years)	Locally up to 0.003m	0.2m (MIKE3 results)	-
Blocking of instantaneous flow across Darss	0.5% (0.4-0.7%)	-	-
Redistribution of flow from Darss to Drogden	25-40m^3/s	111,500 m^3/s (MIKE3 at Darss)	10,400 m^3/s (MIKE3 at Darss)
Surface salinity (annual mean)	Arkona Basin down to -0.05 to -0.08psu, remaining Baltic Sea down to -0.03psu	0.34psu (mean for Baltic Sea stations)	7.5psu
Bottom salinity (annual mean)	Everywhere down to -0.05psu	1.1psu	16.3psu
Surface temperatures (annual mean)	Less than ±0.005ºC	5.8°C	10.5°C
Bottom temperature (annual mean)	Bornholm Basin locally up to +0.09ºC, elsewhere typically below ±0.05ºC	1.5°C	6.5°C
Stratification (annual mean)	In Arkona Basin up to 0.08kg/m^3 locally, elsewhere about -0.014kg/m^3	0.8kg/m^3	5.3kg/m^3
Bottom Oxygen (minimum)	MIKE down to -0.002mg/l, MOM larger effects (max ±0.09mg/l after scaling)	2.3mg/l	1.6mg/l
Surface Chlorophyll (annual mean)	Up to 0.01 µg/l	1.8µg/l	2.3µg/l

"Bridge+ferry" compared to "Ferry" case	Upper limit for estimated change in the Central Baltic Sea	Monitoring data K02 Bornholm Basin (1990-2007)	
		Standard deviation	Mean value
Surface Bluegreen algae Carbon (annual mean)	Locally +0.5µgC/l, typically below +0.2µg/	30-60µg/l (MIKE3 and MOM)	17-35µgC/l (MIKE3 and MOM)
Secchi depth (annual mean)	Up to +0.02m	3.2m (1910-1999)	9.8m (1910-1999)

Related water quality effects of the slightly reduced water exchange are minimal. The distribution of the dissolved oxygen is found to change slightly at mid-depth in the Eastern Gotland Basin with ±0.04mg/l as the maximum change for the annual mean oxygen concentration. Along the seabed the oxygen concentration may change by -0.02mg/l (or -0.09 mg/l for the MOM model after scaling). For plankton and transparency (Secchi depth) the associated effects are minimal.

Impact areas and significance

The tunnel is found not to result in any non-negligible effects to the Central Baltic Sea during construction or in the long run.

For the cable stayed bridge alternative Table 0.4 provides the overview of the distribution of the permanently impacted areas within the various Baltic Sea nations. Following the definition of degree of impairment classes, the high and medium degree areas are mainly from the Arkona Basin and are affecting national waters of Denmark, Sweden, Germany and Poland and also the waters within the European Economic Zone (EEZ). The minor degree areas affect all Baltic countries.

Table 0.4 The degree of impairment and loss area for permanent Central Baltic Sea impacts to hydrography, water quality and plankton after implementation of the cable stayed bridge Var. 2 B-EE (October 2010)

Component	Central Baltic Sea impacts for Bridge Var. 2 B-EE (October 2010)										
	Total area [km^2]	Various subpart areas (km^2)									
		DK	D	POL	RUS	LT	LV	EST	FIN	S	EEZ
Loss area	0	0	0	0	0	0	0	0	0	0	0
Impairment area											
Very high	0	0	0	0	0	0	0	0	0	0	0
High	2,310	247	206	0	0	0	0	0	0	716	1,141
Medium	22,213	3,657	1,259	1,820	0	0	0	0	0	4,920	10,558
Minor	320,584	1,883	1,622	7,743	15,049	2,317	12,796	25,872	46,891	57,600	148,811
Total impairment	**345,108**	**5,787**	**3,087**	**9,562**	**15,049**	**2,317**	**12,796**	**25,872**	**46,891**	**63,235**	**160,510**
Total	**345,107**	**5,787**	**3,087**	**9,562**	**15,049**	**2,317**	**12,796**	**25,872**	**46,891**	**63,235**	**160,509**

Component	Central Baltic Sea impacts for Bridge Var. 2 B-EE (October 2010)										
	Total area [km²]	Various subpart areas (km²)									
		DK	D	POL	RUS	LT	LV	EST	FIN	S	EEZ
permanent	**(90.6%)**										
Reference area[1]	380,976										

Note 1: Area of the Baltic Sea out to the Drogden and Darss Sills

The overall assessment of effects to the hydrography, water quality and plankton conditions for the cable stayed bridge is that it has no significance for the general Central Baltic Sea conditions. The identified effects of a non-negligible level according to the established impact criteria is dominated by the reduced salinity of about 0.03psu, which for the upper layer causes the areas of minor/medium (and high) impairment. The other indicators (bottom salinity, temperature, oxygen, plankton and transparency) come out with negligible effects except for minor areas. As a changed salinity of the order of 0.03psu not itself can be claimed to be significant for the Baltic Sea system, the overall assessment is that effect is of no significance to Baltic Sea hydrography, water quality and plankton.

The reduction in upper layer salinity of 0.03psu corresponds to about 9% of the standard deviation for the surface salinity in the Central Baltic Sea. It will hardly be possible to measure this in practice - not even over a very long time span.

Furthermore, climate changes within the same timespan will probably cause salinity changes which are much larger.

The effect of the cable stayed bridge to the instantaneous water exchange with the Central 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% flow effect is compensated by dredging (DHI/LIC JV 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 JV 2000).

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

Other issues
There are no cumulative impacts to consider for any of the fixed link solutions, as there are no large project plans in the transition area or Central Baltic Sea which may change the conditions in the Central Baltic Sea.

With respect to the effect of climate change to the above impact assessment it is evaluated that the predicted isolated impact of the cable stayed bridge alternative under a new climate setting (e.g. 2080-2100) will not change significantly from the estimated impacts for the present climate setting. For the tunnel alternative the assessment of only negligible effects will also be valid under other climate settings.

The effect to the Central Baltic Sea in the bridge decommissioning period after year 2140 is evaluated as being small. After decommissioning the minor impacts to the Central Baltic Sea will slowly regenerate over some decades to the state which the Baltic Sea would have developed into without the blocking effect from the bridge.

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
Mitigation and compensation measures are not relevant for the tunnel alternative in relation to impacts in the Central Baltic Sea, as the effects are practically nil.

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 at contractions, typically 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 Sea 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 I of the binder deals with the seawater hydrography, water quality and plankton components of the impacts in the Central Baltic Sea. Other volumes of the Marine Water binder deal with seawater hydrography, water quality and plankton components in Fehmarnbelt and adjacent water areas.

The hydrography, water quality and plankton conditions in the Central Baltic Sea (see Fig 1.1) are very important for nearly all other marine water impact issues, as the water transport, physical property, water quality and plankton conditions set the frame for other environmental factors.

The baseline hydrography, water quality and plankton conditions are described in detail in (FEHY 2013e). Below is given a brief summary.

Bathymetry of the Baltic Sea
The total surface area of the Baltic Sea (including Kattegat and the Belt Sea) is 411,700 km^2 and the volume 21,100 km^3. The bathymetry of the Baltic Sea is characterised by contractions and sills which influence the currents and mixing between the water masses.

The border between the Baltic transition area and the Central Baltic Sea are the Darss Sill east of Mecklenburg Bight and Drogden Sill in the Sound. The maximum depth at the two sills is only about 18m and 7m, respectively. The transition area limits the inflow of highly saline water from the North Sea into the Central Baltic Sea and in this manner it has a significant impact on the hydrographical conditions inside the Central Baltic Sea. If and when highly saline water masses originating from the North Sea pass the two sills, they are trapped inside the Central Baltic Sea by the sills and propagate further into the Central Baltic along the bottom. The highly saline water masses can only leave the Central Baltic Sea again by being entrained into the upper less saline water mass at the surface and diluted flow out of the Central Baltic Sea again.

Inside the Central Baltic Sea several basins separated by underwater sills and relatively narrow channels are found, see Fig. 1.1.

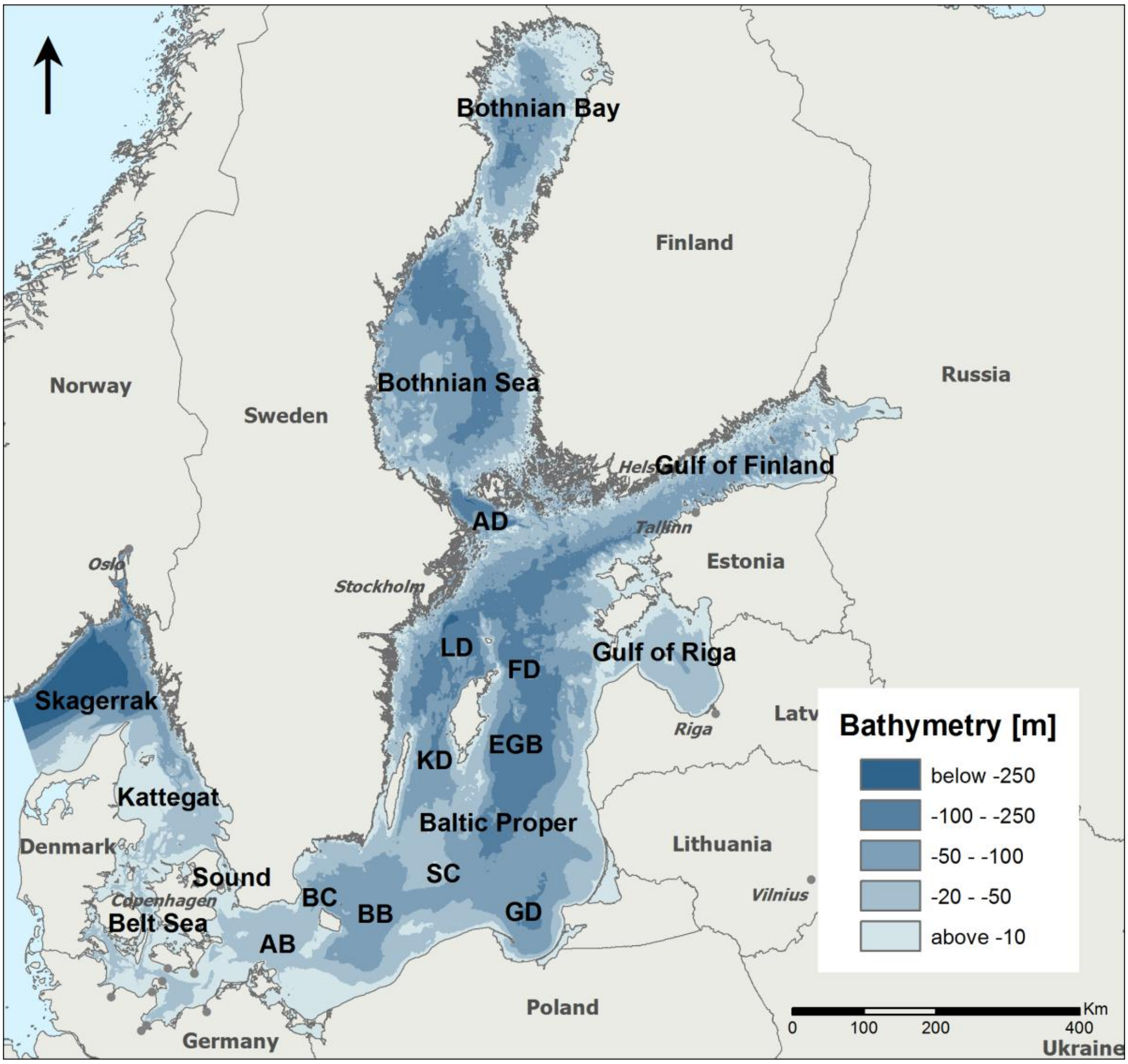


Fig. 1.1 Overview map of bathymetry and geographical structures of the Baltic Sea.. Acronyms indicate some basins and connecting channels: Arkona Basin (AB), Bornholm Channel (BC), Bornholm Basin (BB), Stolpe Channel (SC, also called Slupsk Furrow), Gdansk Depression (GD), Eastern Gotland Basin (EGB), Landsort Deep (LD), Fårö Deep (FD), Karlsö Deep (KD) and Aland Deep (AD).

Hydrography of the Baltic Sea
The driving forces that determine the flow and stratification in the Central Baltic Sea can be divided into:

- Oceanographic conditions in the North Sea (high salinity, wind set-up and tide);
- Hydrology of the adjacent watershed (river discharge and low salinity); and
- Meteorological conditions (wind, air pressure and heat exchange).

The average salinity in the North Sea is 35psu and close to the salinity in the oceans, because of the North Sea‛s wide opening towards the Atlantic Ocean. Therefore water masses in the North Sea are denser than water masses in the Central Baltic Sea being brackish. In the northern Kattegat or south-eastern Skagerrak the North Sea water masses subside (at the Northern Kattegat front, see e.g. (Jakobsen 1997) and flow under the less dense water masses in the Baltic transition area, towards the bathymetrical restriction at the two sills at Drogden in the Sound and Darss east of Fehmarnbelt. In connection with wind-driven exchange flow between the North Sea and the Central Baltic Sea, the dense water mass is then lifted across the two sills and continues into the Central Baltic Sea. In recent years, inflow events have also been observed under calm forcing conditions during summer.

Tidal waves propagate from the Atlantic Ocean but with significantly reduced tidal amplitudes and the tide is only of limited importance for the flow and stratification in the Central Baltic Sea.

The mean runoff is 14,136 m^3/s according to (HELCOM 2009b). The net precipitation corresponds to roughly 5%-10% of the river runoff. The fresh water surplus to the Central Baltic Sea creates a low saline water mass close to the sea surface that flows towards the North Sea, wherefore the water masses in the Baltic Sea are stratified. At the sills to the transition area the surface water has reached about 8psu due to mixing with underlying more saline waters having entered as bottom inflows through the transition area and across the sills at Drogden and Darss. Inside the Central Baltic Sea the bottom salinities vary from up to 22psu in Arkona to only few psu in the innermost parts.

High and low air pressure fields pass Scandinavia on a weekly time-scale and raise or depress the water levels in the North Sea and Baltic Sea, respectively. The water level difference which it causes between the North Sea and the Central Baltic Sea drives an exchange flow between the two seas that either transports low saline waters from the Baltic Sea out to the North Sea or higher saline water masses from the North Sea into the Baltic Sea. Hence the wind-driven exchange flow enhances the estuarine circulation. Actually the wind-driven exchange in the Danish Straits is an order of magnitude higher than the net outflow generated by the freshwater runoff and therefore it is difficult to identify and quantify the density driven circulation in flow measurements collected in the straits. Furthermore, the wind shear stress on the sea surface produces turbulence that mixes the water masses. Seiching after wind setup can cause an extra exchange flow in the transition area.

Inside the Central Baltic Sea the wind also creates:

- Ekman currents in the more open sea areas;
- Coastal jets closer to the coast line;
- Kelvin waves on sea surface, thermocline or halocline; and
- Upwelling of water masses from below either the thermocline or the halocline.

All these resulting currents have an impact on the redistribution and mixing of the waters in the area.

Furthermore, during summer the water masses are heated and during winter they are cooled by the heat exchange with atmosphere. The heating creates a warm low-density layer at the surface with a thermocline located in the upper 20-30 m of the water column, both in the North Sea and in the central Baltic Sea.

The residence time for the upper layer in the Central Baltic Sea is about 30 years. The waters below the upper layer consist of numerous layers and intrusions with different salinity, temperature and age (measured from when it flowed into the Central Baltic Sea). Hence it is more difficult, or at least makes less sense, to define one residence time for the lower lying water masses in the Central Baltic Sea. Even so values between 1 to 10 years can be found in literature. It has been noted that in general the higher the salinity of a water mass flowing into the Central Baltic Sea is, the longer its residence time in the Central Baltic Sea will be.

In connection with especially large inflows the water mass follows the bottom all the way through the Central Baltic Sea without intruding the water column. Such large inflows are referred to as Major Baltic Inflows. During the last 25 years only few Major Baltic Inflows took place. Because of the often strong winds during the Major Baltic Inflows, a large mixing of the inflowing water mass takes place already in the Arkona Basin.

The winds and the currents are the most important sources to the mixing in the Baltic Sea and in general one can distinguish their relative importance depending roughly on the local bathymetrical features:

- In contraction and sill areas and in channels, the entrainment and mixing caused by currents are the most important ones. Areas are for example Belt Sea, Sound, Bornholm Channel and Stolpe Channel; and

- In more open sea areas, the entrainment and mixing caused by winds are most important. Areas are for example Kattegat, Arkona Basin, Bornholm Basin and Gotland Basin.

Marine optics, transparency
A high content of coloured dissolved organic matter and suspended matter which strongly influences light transfer is typical for Baltic Sea water masses. Generally, chlorophyll is also a major factor in optical properties, not least due to its seasonal variability.

Nutrients and oxygen in the Baltic Sea
The Baltic Sea is endangered by anthropogenic nutrient inputs modifying the structure and function of the ecosystem (Nixon 1995), (Ærtebjerg et al. 2003). Eutrophication is analogous to the natural aging in the broadest sense of the word, the increased supply of plant nutrients to waters due to human activities in the catchment areas that result in an increased production of algae and higher water plants (EUTROSYM, 1976). Thereby the excessive input of nitrogen and phosphorus is a main concern.

(HELCOM 2010b) reported that for the period of 2001 – 2006, the average annual total waterborne input of nitrogen (riverine load, coastal areas, direct point and diffuse sources) amounted to 641,000 t. An additional quarter of the total nitrogen input is caused by atmospheric deposition. This pathway amounts to 198,000t N in 2006. In total, yearly around 840,000 t of nitrogen are introduced into the Baltic Sea.

For phosphorus, the average annual input for the period 2001-2006 amounts to 30,200t (HELCOM 2010a), (HELCOM 2010b). It is believed that the airborne phosphorus deposition accounts for a maximum of 5%.

The distribution of inorganic nutrients in the surface layer of the Baltic Sea is characterized by a pronounced seasonality reaching high concentrations in winter, the seasons with lowest biological activity, and a decrease to around the detection limit during the period of high biological productivity which begins in early spring and ends in late summer (Nausch and Nehring 1996), (Nausch & Lysiak-Pastuszak 2002).

The reason for the different seasonal cycles of phosphate and nitrate is a disturbed Redfield ratio. Phytoplankton incorporates carbon, nitrogen and phosphorus in a molar ratio of around 106:16:1 (Redfield et al. 1963). When primary production is limited by light, a similar ratio is found in seawater caused by the mineralization of organic matter. In the Baltic Sea, denitrification in suboxic water layers and at the sediment surface is thought to be responsible for this anomaly. First measurements at the end of the 1950 / beginning of 1960s also give a molar N/P ratio of 7-10.

Nutrient concentrations in the deep basins of the Central Baltic Sea are closely correlated with the hydrographic regime governed by the alternation between Major Baltic Inflows (MBIs) and stagnation periods. In the presence of oxygen, phosphate is partly bound in the sediments and onto settling particles in the form of an iron-III-hydroxophosphate complex. If the system turns from oxic to anoxic conditions, this complex is reduced by hydrogen sulphide (Hille et al. 2005). Phosphate and iron(II) ions are liberated leading to an increase in phosphate in the water column.

The oxygen budget of the sea is characterized by the input from the atmosphere and through primary production of algae and submerged vegetation and the consumption through respiration, decomposition of organic matter and loss to the atmosphere. Temperature and salinity cause stratification, but vertical circulation, advection and convection can influence the oxygen content. The oxygen situation in the surface layer is normally good. Changes in the oxygen content here are mainly caused by the annual cycles of temperature and the seasonally differing production and consumption processes (Matthäus 1978), (Nausch et al. 2009). Below permanent or temporarily occurring pycnoclines, however, a significant loss of oxygen can take place because in these water layers the absence of light prevents production processes and only oxygen consumption is relevant. The oxygen consumption can be so intensive that anaerobic conditions occur and the formation of hydrogen sulphide starts as in the deep basins of the Central Baltic Sea.

In the more eastern basins of the Central Baltic Sea, a permanent halocline exists, preventing vertical mixing down to the bottom. Therefore, the oxygen situation is coined through the occurrence or absence of barotropic or baroclinic inflow events. Not only Major Baltic Inflows of higher saline water, but also regular inflows of lower volumes of water frequently penetrate across the Darss and Drogden Sills, pass the Arkona Basin, and are trapped in the deep water of the Bornholm Basin causing a high variability in temperature, salinity and oxygen concentration. In contrast to the Bornholm Deep, no regular seasonal variations can be observed in the Gotland Deep, Fårö Deep, Landsort and Karlsö Deep. The so far latest MBI was detected in January 2003 followed by a stagnation period which continues until today. The oxygen system reacted as described before. From 1993 onwards, stagnation effects were observed also in the Western Gotland Basin. The 2003 inflow had only small effects on the oxygen conditions there (Nausch et al. 2006) owing to the relatively high salinity in the deep waters which caused a higher stability of stratification and hampered vertical exchange.

Cyanobacteria and phytoplankton in the Baltic Sea
Marine phytoplankton is the principal primary producer and is influenced by hydrological and biological parameters. However, the marine phytoplankton itself influences a cascade of biological and hydrological parameters, especially during the eutrophication process: increasing nutrient input goes along with increasing phytoplankton biomass and leads to decreasing light penetration, which hampers the growth of macrophytes and higher plants. The loss of macrophyte cover changes

the structure of the benthic habitat with negative consequences for benthic diversity and fish breeding. In addition, excessive blooms of plankton lead to increasing oxygen consumption and finally oxygen depletion. Increasing nutrient supply results in an increase of duration and frequency of algal blooms.

In general the vertical gradients of biomass and primary production are stronger than the horizontal gradients. They depend mainly on light penetration and stratification. The horizontal distribution is associated with the estuarine gradients (trophic conditions and salinity), the upwelling gradients (nutrient availability, temperature and salinity), and the large scale marine gradients of decreasing salinity from Kattegat to the Bothnian Sea. Within the west-northeast gradient the regional species composition changed on the basis of main taxa groups as well as on the basis of individual taxa. According to (Wasmund & Siegel 2008) the diversity seems to be lowest in the Bornholm and Gotland Basin due to unfavourable salinity conditions for both marine and limnetic species. Diatoms decreased along the west-east gradient towards lower salinities, whereas cryptophytes and dinophytes increased.

Bloom-forming cyanobacteria normally represent the main phytoplankton group in the eastern and northern parts during summer. Especially the diazotrophic (N-fixing) potential harmful species, like Nodularia spumigena and Aphanizomenon spp. are adapted to the conditions in the Central Baltic Proper, but have rarely been observed in the Kattegat and the northern Gulf of Bothnia (Kahru et al. 1994), (Wasmund 1997).

1.3 Baltic Sea sub-components assessed

The impact assessment for hydrography, water quality and plankton in the Central Baltic Sea has been divided into specific assessments for various sub-components. The sub-components include water level, salinity, temperature, stratification, Chlorophyll, dissolved oxygen, water transparency and blue-green algae biomass, see Table 1.1. Chemicals and hazardous substances are not considered relevant to assess in this context as it has been assessed elsewhere that it is not a problem in the Fehmarnbelt area where the dredging takes place (FEMA 2013a).

For each subcomponent specific quantitative indicators are selected for the potential change in the condition resulting from the fixed link in Fehmarnbelt, like the change to the maximum sea level, etc. These indicators are all regarded as spatial measures, varying with their position in the Central Baltic Sea. For each indicator a specific temporal statistical measure is selected 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 represent 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, water quality and plankton components of the Central Baltic Sea

Component	Sub-component	Indicators
Hydrography	Water level	Mean and max water level
	Water exchange at Darss Sill	Relative change in instantaneous flow and salt flux
	Salinity and temperature	Mean value at surface and bottom and variation over depth
	Stratification	Mean value (bottom minus surface density)
Water quality	Dissolved oxygen	Mean value at surface and bottom and variation over depth
	Transparency	Mean Secchi depth at surface
Plankton	Chlorophyll	Mean value at surface
	Blue-green algae	Mean carbon biomass at surface

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. 2.1ure 2.1 along with near-by NATURA2000 sites.

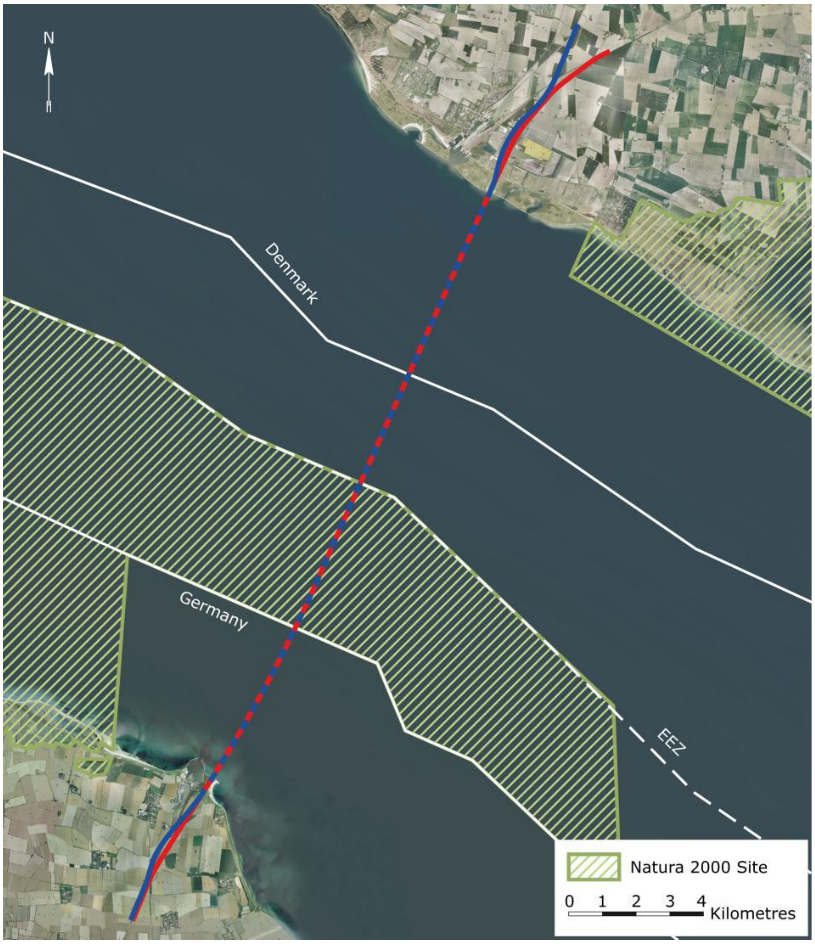


Fig. 2.1 Conceptual design alignment for immersed tunnel E-ME (August 2011)

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.

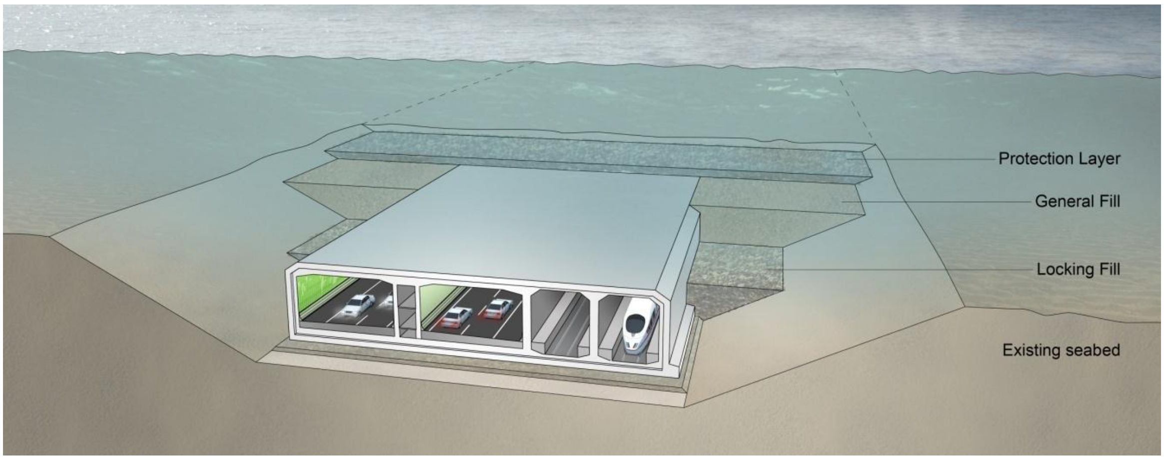


Fig. 2.2 Cross section of dredged trench with tunnel element and backfilling

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.

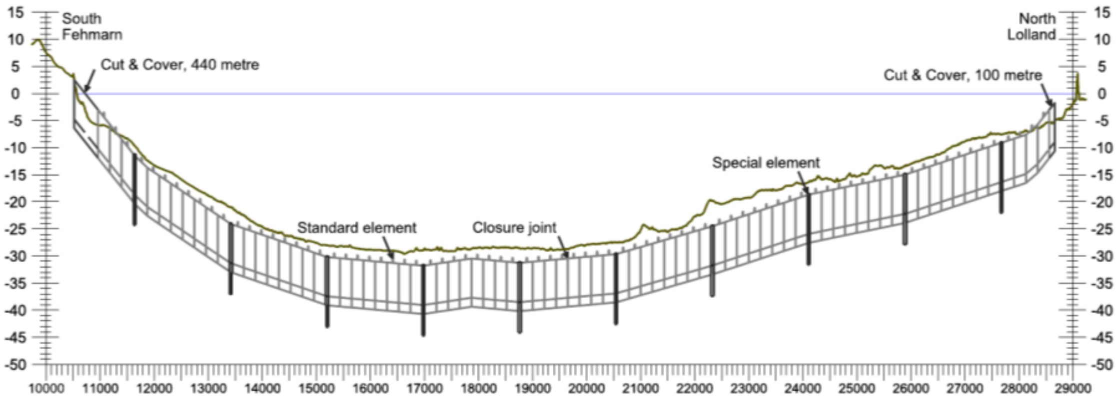


Fig. 2.3 Vertical tunnel alignment showing depth below sea level

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.

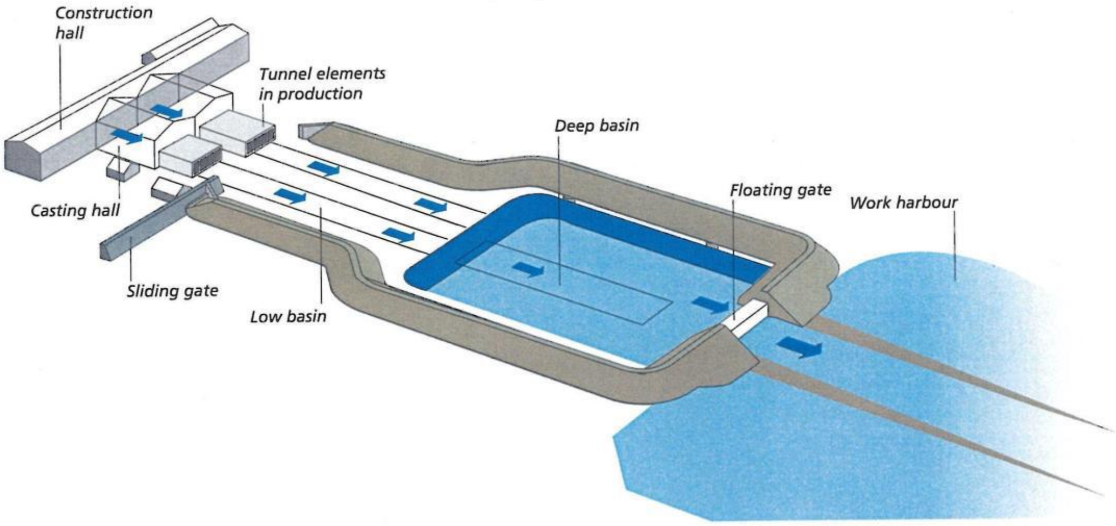


Fig. 2.6 Production facility with two production lines

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

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

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

Bridge concept

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

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

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 the railway 680m long. The profile of the railway and motorway descends 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.

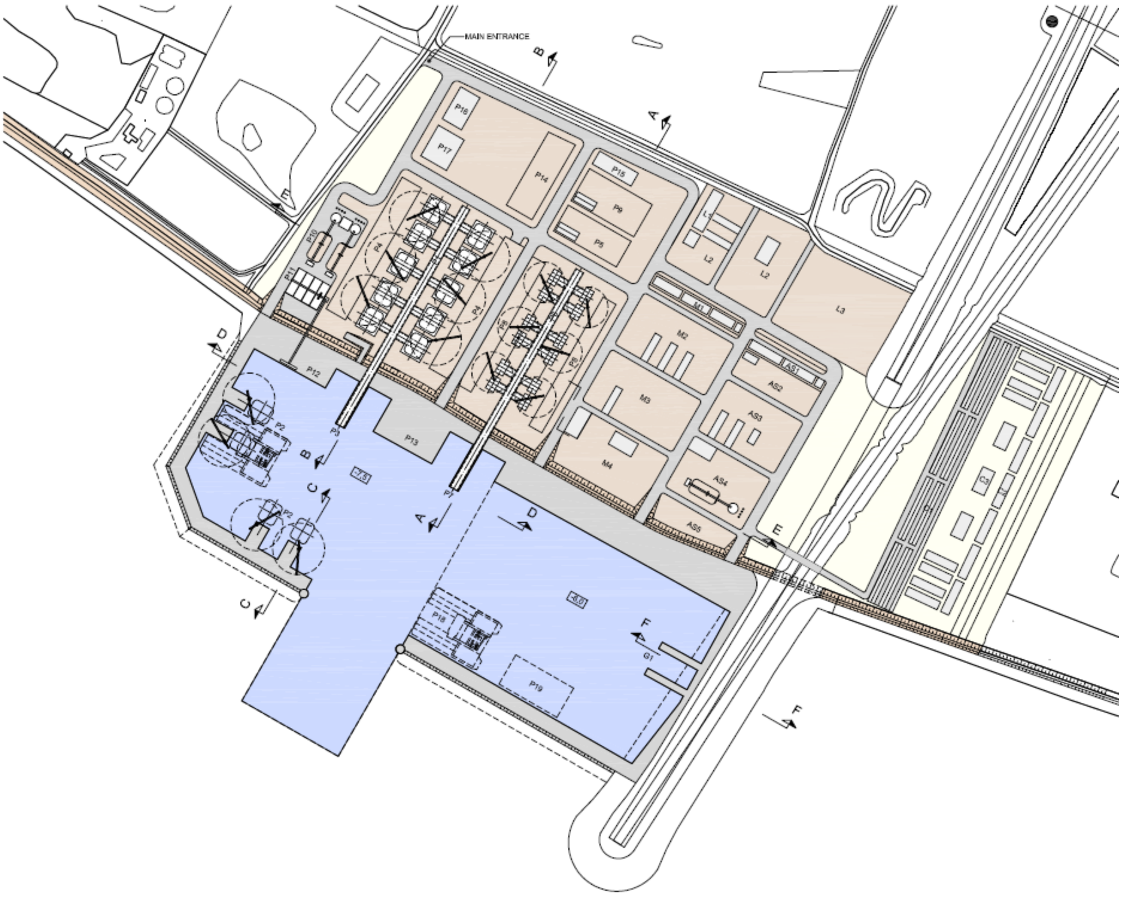


Fig. 2.10 Proposed lay-out of the production site at Lolland east of Rødbyhavn

2.2 *Relevant project pressures*

The Baltic Sea impact assessment for the immersed tunnel and the cable stayed bridge alternatives for the fixed link is based on the following general pressures in Fehmarnbelt 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 during the construction phase, such as work harbours to be removed and dredging and seabed area to be re-established
- Permanent or temporary effluents arising from project (or changes in existing effluents due to the project), such as dewatering or relocation of an existing wastewater discharge at Rødbyhavn

- The potential cessation of ferry service in future.

Regarding the effluents arising from the 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, temperature and water quality within normal ranges for coastal discharges. Thus, these effluents will not affect the Central Baltic Sea to any significant degree, and are therefore not further assessed as a pressure in the present Volume.

The remaining project pressures which are assessed in more detail 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 the immersed tunnel having a potential effect to the Central Baltic Sea components.

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
Water and salt flux (at Darss)	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
Water quality	Sediment spill (see also permanent pressure impact)	Reclamations, protection reefs and access channels	Potential cessation of ferry traffic
Plankton	(see permanent pressure assessment)	Reclamations, protection reefs and access channels	Potential cessation of ferry traffic

Table 2.2 Pressures in relation to the cable stayed bridge having a potential effect on the Central Baltic Sea 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
Water flux (at Darss)	(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
Water quality	Sediment spill (see also permanent pressure impact)	Piers, pylons, marine ramps etc.	Potential cessation of ferry traffic
Plankton	(see permanent pressure assessment)	Piers, pylons, marine ramps etc.	Potential cessation of ferry traffic

3 DATA AND METHODS

3.1 Areas of investigation

The assessment of potential impacts to the Central Baltic Sea includes the entire Baltic Sea out to the transition area, defined as starting at the Darss Sill in the Sound and the Drogden Sill east of Fehmarn. Please cite as:

FEHY (2011). Fehmarnbelt Fixed Link EIA. Marine Soil Sediment Spill during Construction of the Fehmarnbelt Fixed Link – with local sand mining and backfilling of access channel. Report No. E1TR0065; 91 pp belt, see Fig. 3.1.

The assessment of local effects in the Fehmarnbelt and adjacent bays is provided in (FEHY 2013b) and (FEHY & FEMA 2013).

Fig. 3.1 Area of investigation for effect to Central Baltic Sea

For detailed description of the baseline conditions in the Central Baltic Sea see (FEHY 2013e).

3.2 The Assessment Methodology

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

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

3.2.1 Overview of terminology

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

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

Term	Explanation	Term DK	Term DE
	ements of the Project (e.g. bridge pillar for bridge alternative and land reclamation at Lolland for tunnel alternative), or provisional 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.	Belastnings-størrelse	Wirkintensität
Footprint	The footprint of the Project comprises the areas occupied by structures. It comprises two types of footprint; the permanent footprint deriving from permanent confiscation of areas to structures, land reclamation etc., and provisional footprint which are areas recovered after decommissioning of provisional structures. The recovery may be due to natural processes or Project aided re-establishment of the area.	Areal-inddragelse	Flächeninan-spruchnahme
Assessment criteria and Grading	Assessment criteria are applied to grade the components of the assessment schemes. Grading is done according to a four grade scale: very high, high, medium, minor or a two grade scale: special, general. In some cases grading is not doable. Grading of magnitude of pressure and sensitivity is method dependent. Grading of importance and impairment is as far as possible done for all factors.	Vurderings-kriterier og graduering	Bewertungs-kriterien und Einstufung
Importance	The importance is defined as the functional values to the natural environment and the landscape.	Betydning	Bedeutung
Sensitivity	The sensitivity describes the environmental factors capability to resist a pressure. Dependent on the subject assessed, the description of the sensitivity may involve intolerance, recovery and importance.	Følsomhed/ Sårbarhed	Empfindlichkeit
Impacts	The impacts of the Project are the effects on the environmental factors. Impacts are divided	Virkninger	Auswirkung

Term	Explanation	Term DK	Term DE
	into Loss and Impairment.		
Loss	Loss of environmental factors is caused by permanent and provisional loss of area due to the footprint of the Project; meaning that loss may be permanent or provisional. The degree of loss is described by the intensity, the duration and if feasible, the range.	Tab af areal	Flächenverlust
Severity of loss	Severity of loss expresses the consequences of occupation of land (seabed). It is analysed by combining magnitude of the Project's footprint with importance of the environmental factor lost due to the footprint.	Omfang af tab	Schwere der Auswirkungen bei Flächenverlust
Impairment	An impairment is a change in the function of an environmental factor.	Forringelse	Funktionsbeeinträchtigung
Degree of impairment	The degree of impairments is assessed by combining magnitude of pressure and sensitivity. Different methods may be used to arrive at the degree. The degree of impairment is described by the intensity, the duration and if feasible, the range.	Omfang/grad af forringelser	Schwere der Funktionsbeeinträchtigung
Severity of impairment	Severity of impairment expresses the consequences of the Project taking the importance of the environmental factor into consideration; i.e. by combining the degree impairment with importance.	Virkningens væsentlighed	Erheblichkeit
Significance	The significance is the concluding evaluation of the impacts from the Project on the environmental factors and the ecosystem. It is an expert judgment based on the results of all analyses.		

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

3.2.2 The Impact Assessment Scheme

The overall goal of the assessment is to arrive at the severity of impact where impact is divided into two parts; loss and impairment (see explanation above). As stated in the scoping report, the path to arrive at the severity is different for loss and impairments. For assessment of the *severity of loss* the footprint of the project (the areas occupied) and the *importance* of the environmental factors are taken into consideration. On the other hand, the assessment of severity of impairment comprises two steps; first the *degree of impairment* considering the magnitude of pressure and the sensitivity. Subsequently the severity is assessed by combining the degree of impairment and the importance of the environmental factor. The assessment schemes are shown in 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 sub-factor. Some sub-factors are assessed as one unity, but in most cases the importance assessment has been broken down into components and/or 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. 3.2). The loss is estimated as hectares of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

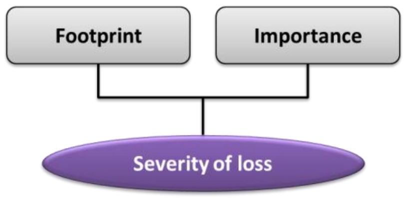


Fig. 3.2. The assessment scheme for severity of loss

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.

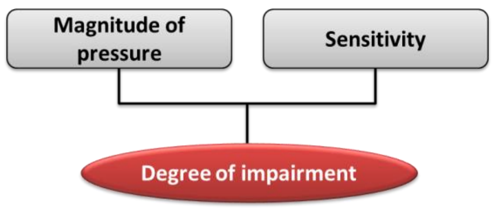


Fig. 3.3 The assessment scheme for degree of impairment

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.

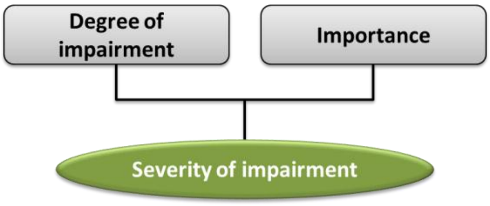


Fig. 3.4 The assessment scheme for severity of impairment

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.

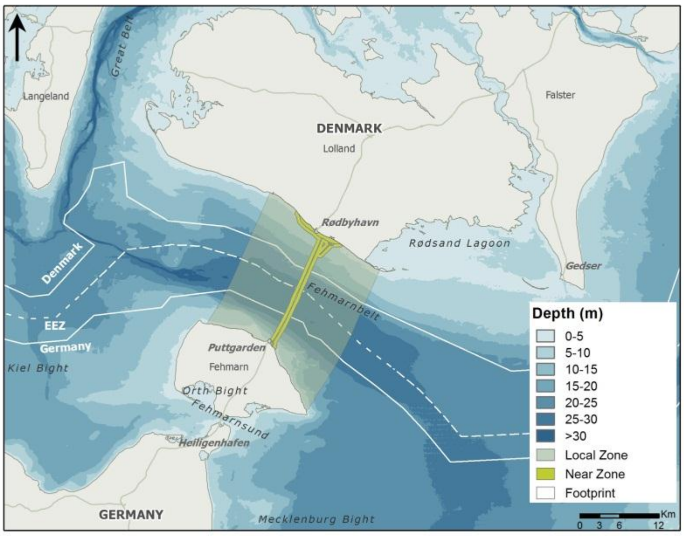


Fig. 3.5 The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders 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
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 emer-	Guldborgsund to Rødby-	Construction	Area loss, noise and dust

Project	Placement	Phase	Possible cumulative impact
gency lane	havn	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

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, dredging, etc. and of temporary elements in the construction period being removed and the area re-established after construction has been 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 from the present ferry service.

It should be mentioned that the numerical hydrodynamic and water quality modelling 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 B-EE (October 2010) as follows:

- It had a slightly more S-shaped alignment, see Fig. 3.6.
- 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 slightly larger flow blocking effects and thus also slightly larger overall hydrodynamic and water quality 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.

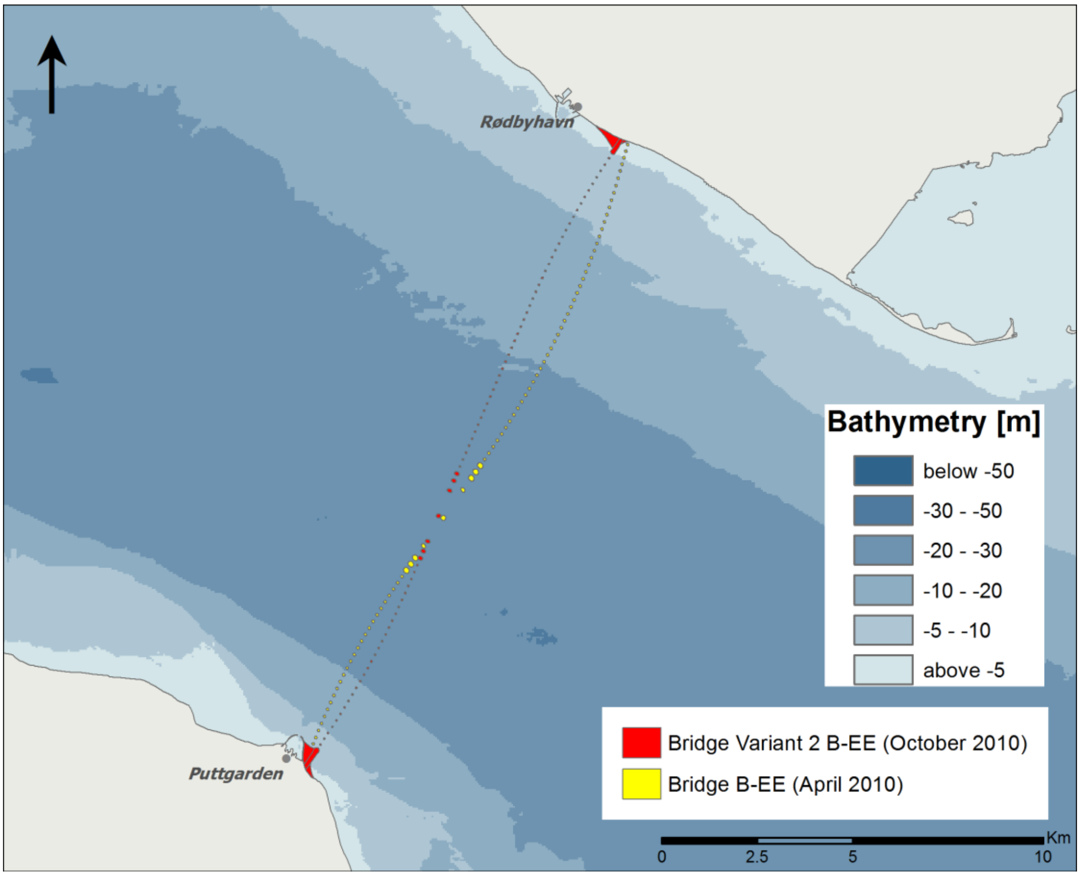


Fig. 3.6 Alignment and structures of the cable stayed bridge B-EE (April 2010) and Var. 2 (October 2010)

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 used to assess the physical component hydrography these relationships are the basic deterministic equations of the models, like the conservation of mass and momentum in hydrodynamic models. In the same way the water quality model includes deterministic relations for nutrients, oxygen and plankton dynamics taken from literature.

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

3.5 Assessment criteria

3.5.1 Loss

There are no direct losses to consider in relation to the Central Baltic Sea impacts, as the fixed link with its structures etc. is located in Fehmarnbelt outside the Central Baltic Sea domain.

3.5.2 Impairment

The degree of impairment to the individual sub-components in the Central Baltic Sea is assessed based on the quantitative impact criteria quoted in Table 3.1.

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 and water quality components of the Central Baltic Sea are related to the structures and will therefore, after a build-up time, persist forever after construction as long as the fixed link is present. These impacts are referred to as permanent impacts. However, there are some pressures which will only be present in the construction period. Therefore, the impact assessment also addresses impacts to the Central Baltic Sea during the construction period.

For the degree of impairment for construction period impacts the same impact criteria as for the permanent impacts are used, see Table 3.5. The same concept for hydrographical impact criteria was also used for the local Fehmarnbelt impacts in (FEHY 2013b).

Table 3.5 Impact criteria used for the degree of impairment in relation to the hydrography and water quality components in the Central Baltic Sea.

Component	**Project pressure**	**Impact criteria**	**Duration**	**Degree of impair-ment**
Hydrogra-phy, (hydrody-namic) and water quality	Project structures and con-struction activities	• Water level of events with a return period of about 20 years increases by 10cm or mean water level change exceeds 5cm, or • At least for one of the other subcom-ponents the change in the indicator value will exceed 100% of the natu-ral temporal standard deviation.	Perma-nently or for construc-tion 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 • At least for one of the other subcom-ponents the change in the indicator value will be 20-100% of the natural temporal standard deviation and the other components less.	Perma-nently or for construc-tion 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 • At least for one of the other subcom-ponent the change in the indicator value will be 10-20% of the natural temporal standard deviation and the other components less.	Perma-nently or for construc-tion period	Medium
		• Water level of events with a return period of about 20 years increases by 1cm or mean water level change ex-ceeds 0.5cm, or • At least for one of the other subcom-ponents the change in the indicator value will be 5-10% of the natural temporal standard deviation and the other components less.	Perma-nently or for construc-tion period	Low
		• Below above threshold levels		Negligible/ impercep-tible

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 around the Baltic Sea. If the change in extreme water levels is so high that existing 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 for relevant positions in the Baltic Sea area. The present assessment uses Fehmarnbelt statistics as proxy for Baltic Sea statistics, see Table 3.6.

Table 3.6 Extreme water levels established for the project area in Fehmarnbelt.

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 long term standard deviation at the Gedser gauge in the downstream end of the Central Baltic Sea. This standard deviation is 0.24m, and thus the classes will be 5cm, 2cm, 1cm and 0.5cm (from Very High to Low).

Other subcomponent indicators

The other seawater subcomponents aim at characterising potential changes to the general hydrographical and water quality regime. The hydrographical regime is characterised by a somewhat smaller variability than in the Fehmarnbelt area, see Table 3.7. The extremes for the state variables are generally controlled by the freshwater runoff to the Central Baltic Sea and the ocean-like Kattegat bottom water entering via the Belt Sea and The Sound.

It is therefore proposed to base the impact classification on changes of the mean values of the state variables 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, for surface salinity at stations in the Central Baltic Sea the STD is 0.34psu and the criteria thus a change limit of 0.017psu) means an overlap of 98% in the distributions before and after (assuming a normal distribution). In reality 0.017psu is below 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. 3.7. These classification levels are proposed as the "Low"/"Medium", "Medium"/"High" and "High"/"Very High" class separators.

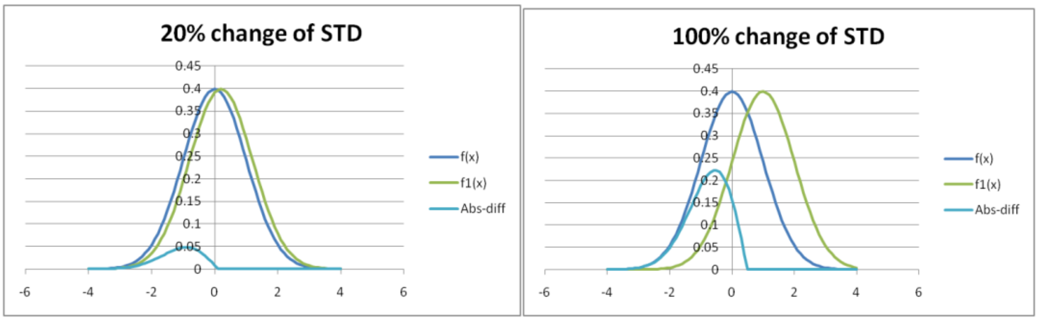


Fig. 3.7 Illustration of overlap for change in mean value of 20%, respectively 100% of STD

In Table 3.7 the STD values of the applied subcomponents, taken from the baseline reporting activity, are provided.

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

Subcomponent	**Fehmarnbelt Station N01 (1990-2007) or MS02 (2009-2010)**	**Central Baltic Sea K02 Bornholm Basin (1990-2007)**
	Standard deviation	**Standard deviation**
Water level	0.24m (Gedser 2004-2009)	0.24m (Gedser 2004-2009)
Surface salinity	3.2psu (NO1)	0.34psu (Baltic Sea stations)
Bottom salinity	3.5psu (NO1)	1.1psu
Surface temperatures	5.7°C (NO1)	5.8°C
Bottom temperature	3.6°C (NO1)	1.5°C
Stratification (bottom - surface density)	4.0kg/m^3 (MIKE model)	0.8kg/m^3 (MIKE model)
Bottom Oxygen (annual minimum)	3.7mg/l	2.3mg/l
Surface Chlorophyll (annual mean)	2.1µg/l	1.8µg/l
Surface Bluegreen Carbon (annual mean)	-	30-60µg/l (MIKE3 and MOM)
Secchi depth (annual mean)	1.9m (1984-97)	3.2m (1910-1999)

3.6 Assessment of degree of loss

The degree of loss assessment is not relevant for the Baltic Sea, as there are no footprint parts inside the Baltic Sea.

3.7 Assessment of degree of impairment

3.7.1 Hydrodynamic and water quality modelling with dual model approach

The key tools applied for the Central Baltic Sea assessment are hydrodynamic and water quality modelling on a Baltic Sea scale, referred to as regional models. Some results from a set of local models are also applied in the Central Baltic Sea impact assessment.

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

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

Regional models

- MIKE 3, a commercial modelling software developed by DHI

- 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

Local models

- MIKE 3, see above

- GETM/ERGOM, where GETM is developed by Bolding & Burchard (BB) and ERGOM is the water quality module used also for MOM3 by IOW

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

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

For the tunnel alternative, only local modelling and only of the hydrodynamic effects has been undertaken. Regional modelling has not been undertaken, as the local modelling showed no significant hydrodynamic effects to the water exchange with the Central Baltic Sea.

Furthermore, only one local model has been applied. The GETM local modelling tool is less appropriate due to the limited extent of the coastal protrusions and bathymetrical changes, 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 very long runtimes.

3.7.2 Regional models on the Central Baltic Sea scale

The two regional models have been set up with exactly the same domain, including the Central Baltic Sea, the transition area (the Belt Sea and the Sound), Kattegat and Skagerrak. The outer limit is the section between Skagerrak and the North Sea.

The bathymetry basis is the same high resolution (500m) dataset for the entire Baltic Sea. Furthermore, the models are driven by a similar set of forcings, like meteorology, water level, salinity and temperature variations at the open boundaries and internal sources.

MIKE 3

MIKE 3 is a fully baroclinic and hydrostatic ocean model using bottom-following vertical coordinates (sigma coordinates) combined with z layers. For horizontal discretisation the model uses an unstructured flexible mesh. 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 water quality part is an ECO Lab module, with state variables for nutrients, oxygen, plankton (diatoms, flagellates and blue-green algae) and chlorophyll.

The MIKE 3 regional 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. In this subpart of the model the horizontal resolution of the model is about 3000 m, using a flexible mesh of triangles of varying size and forms. In the Central Baltic Sea the resolution increases up to 20,000m. The vertical resolution is with 10 layers for water depths up to 10 m (a sigma-layer approach) and 1m resolution below increasing to 30 m near the seabed at very large depths.

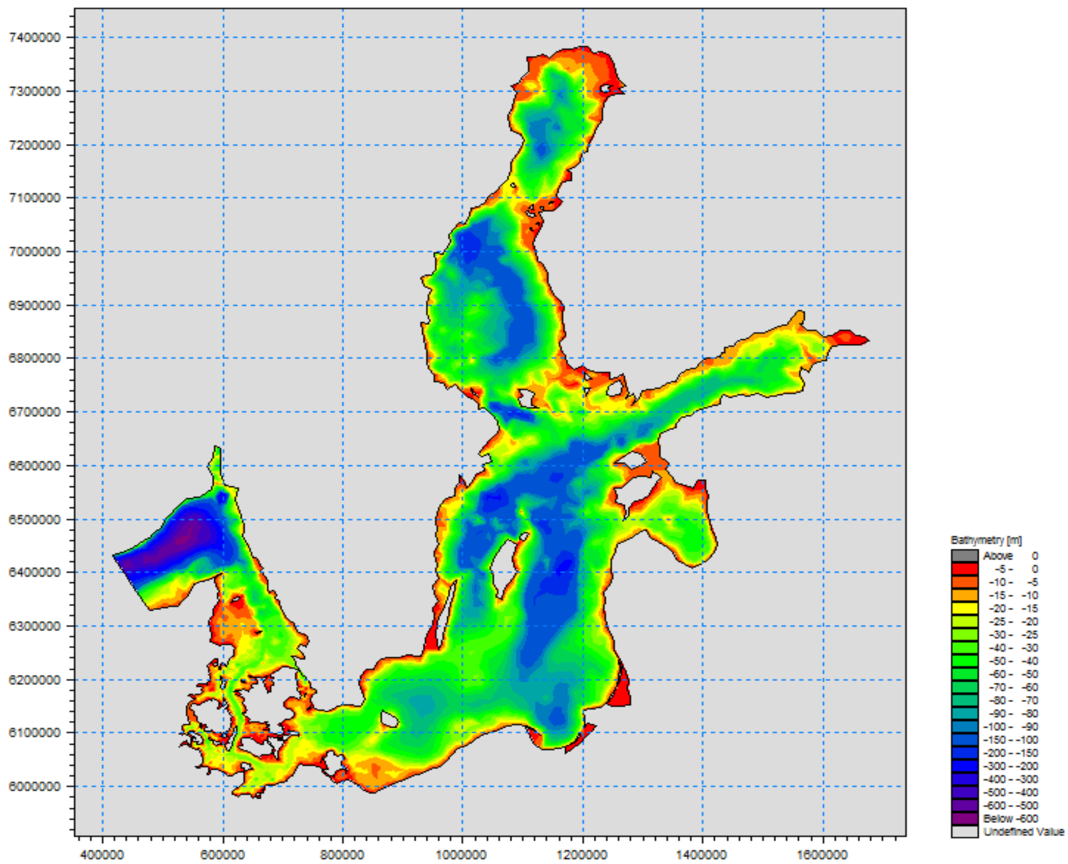


Fig. 3.8 Model domain and bathymetry for the MIKE 3 regional model

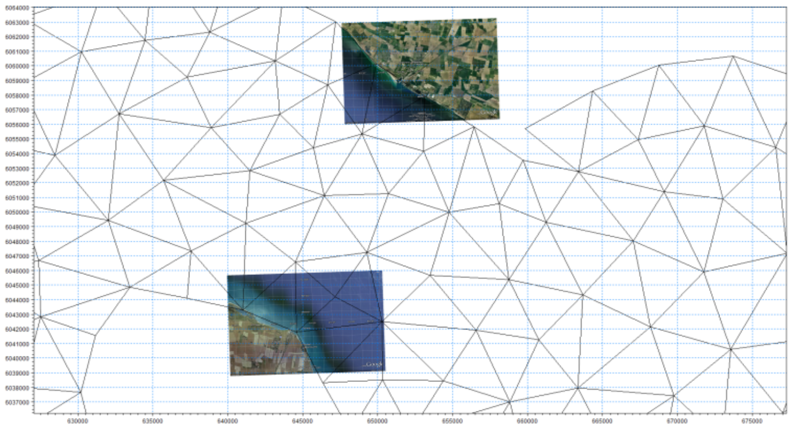


Fig. 3.9   Zoom-in on the Fehmarnbelt mesh representation in the MIKE regional model.

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

- 6.47 is the "Bridge" only case (WQ part EU21.6x)
- 6.48 is the "Ferry" only case (reference) (WQ part EU21.4x)
- 6.49 is the "Bridge+ferry" case (WQ part EU21.8x)

MOM
The Modular Ocean Model code version 3.1 (MOM 3.1) is provided by the Geophysical Dynamics Laboratory in Princeton, USA. This code is a toolbox of state-of-the-art numerical schemes which are applied by many user groups around the world for global as well as regional circulation modelling.

Water quality state variables like concentrations of nutrients, phytoplankton, and zooplankton are calculated by an ecosystem module ERGOM which is integrated into the circulation model, thus assuring a complete coupling of model components. ERGOM describes the nutrient cycle based on nitrogen, whereas bio mass is considered by three functional groups referring to pythoplankton, zooplankton, and cyanobacteria. The successful application of MOM-ERGOM to long-term simulations of the Baltic Sea ecosystem, including the climate perspective, has been published in a series of scientific papers, for example (Neumann and Schernewski 2008) and (Neumann 2010).

The modelling domain is shown in Fig. 3.10 and the local mesh resolution in Fehmarnbelt in Fig. 3.11.

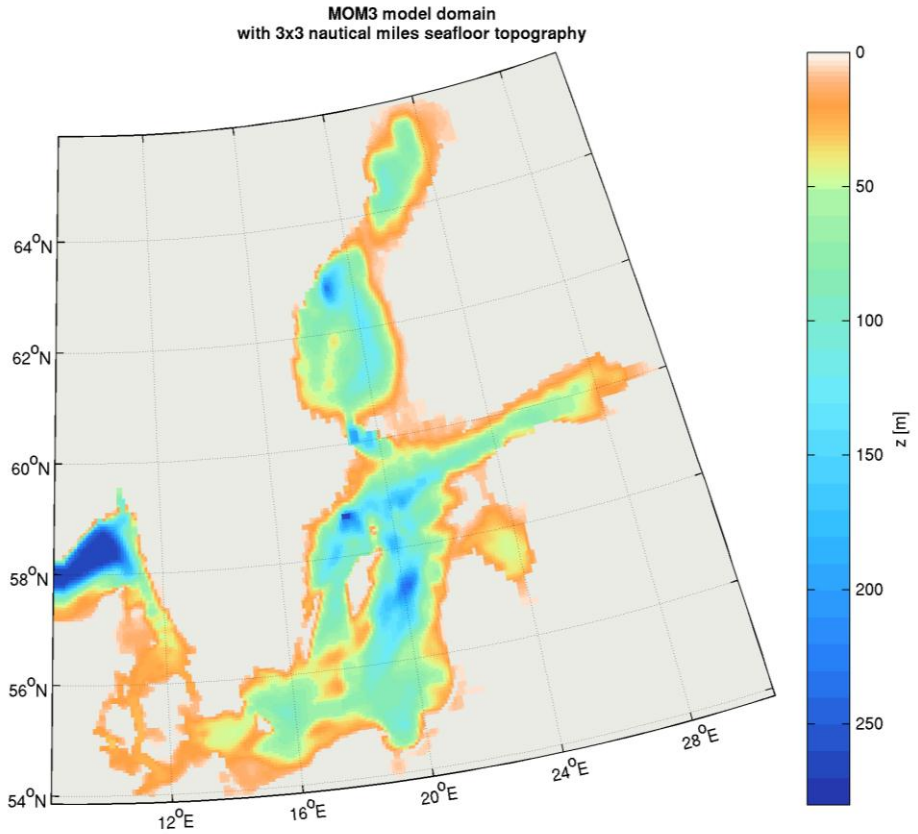


Fig. 3.10 Model domain and bathymetry for the MOM regional model.

In the MOM modelling the following scenario IDs refer to the final simulations:

- V07 R03 is the "Bridge" only case
- V07 R02 is the "Ferry" only case (reference)
- V07 R01 is the "Bridge+ferry" case

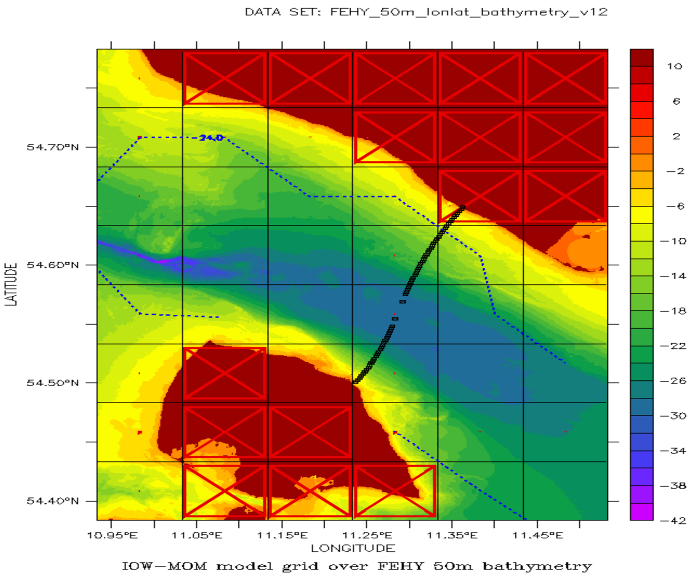


Fig. 3.11 Zoom-in on the Fehmarnbelt mesh representation in the MOM regional model.

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. The retention time of the Central Baltic Sea is over 20 years, so a multiyear period is needed.

For the regional modelling tools have been the period 1960-1999 for the regional model calibration (MOM: 1970-1999) and the period 2000-2007 for validation. This 40-50 years period qualifies by representing recent conditions, including events of Major Baltic Inflows (particularly 1973, 1993 and 2003) and is sufficiently long compared to the retention time of the Central Baltic Sea.

Scenario modelling

The link alternative has been implemented in the regional models from the start of the available model period, which is from 1960 in the MOM model and from 1970 in the MIKE model. The two regional models have then been run for the remaining part of the historical simulation period up to 2007.

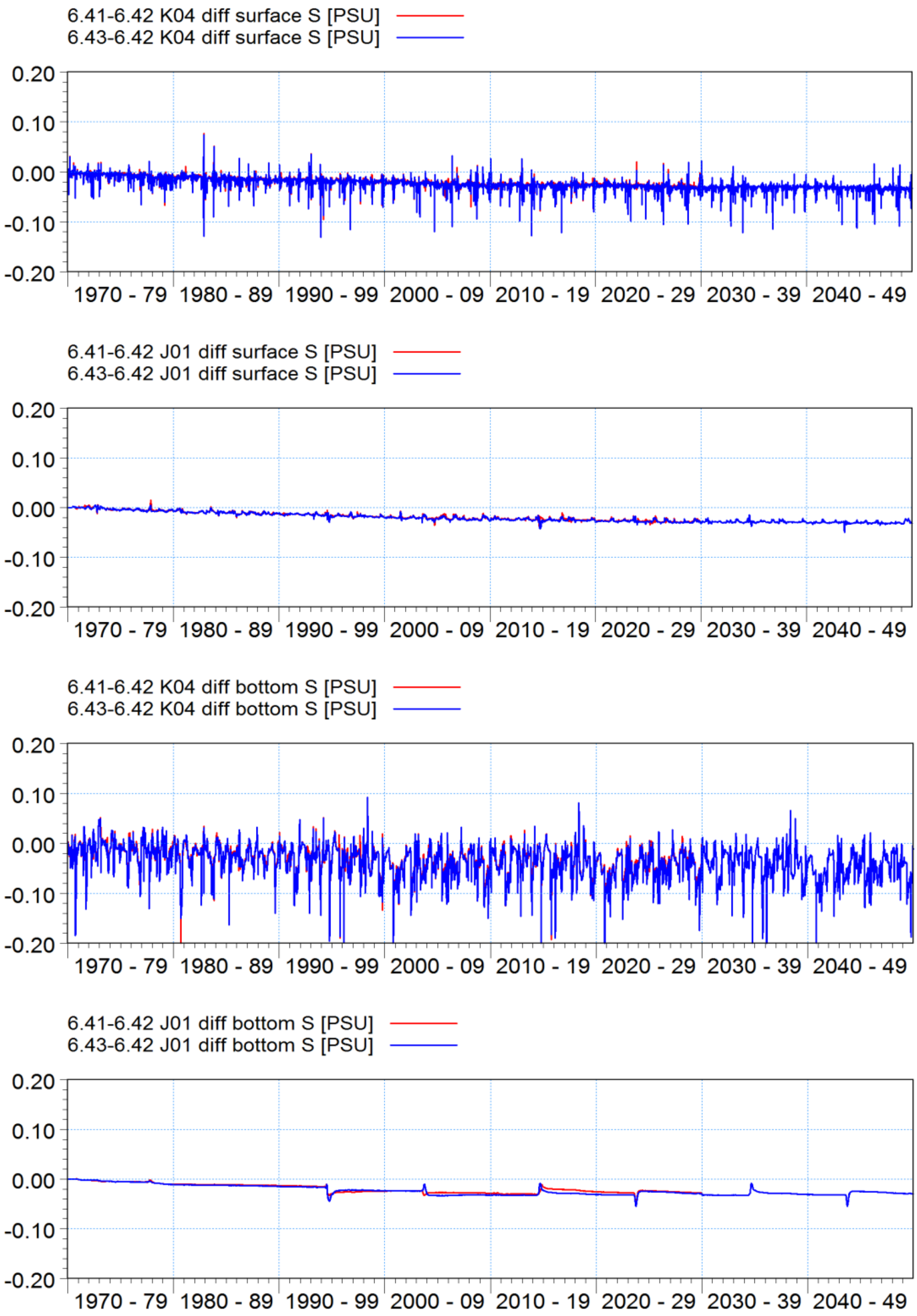


Fig. 3.12 *Documentation of the development in effect for the MIKE 3 regional model for salinity at two positions: Arkona Basin (J01) and Eastern Gotland Basin (J01). Development shown for "Bridge+ferry" case 6.43 and "Bridge" case 6.41 by subtracting reference simulation ("ferry" case 6.42). Periods 2010-2029 and 2030-2049 are with 1990-2009forcing data.*

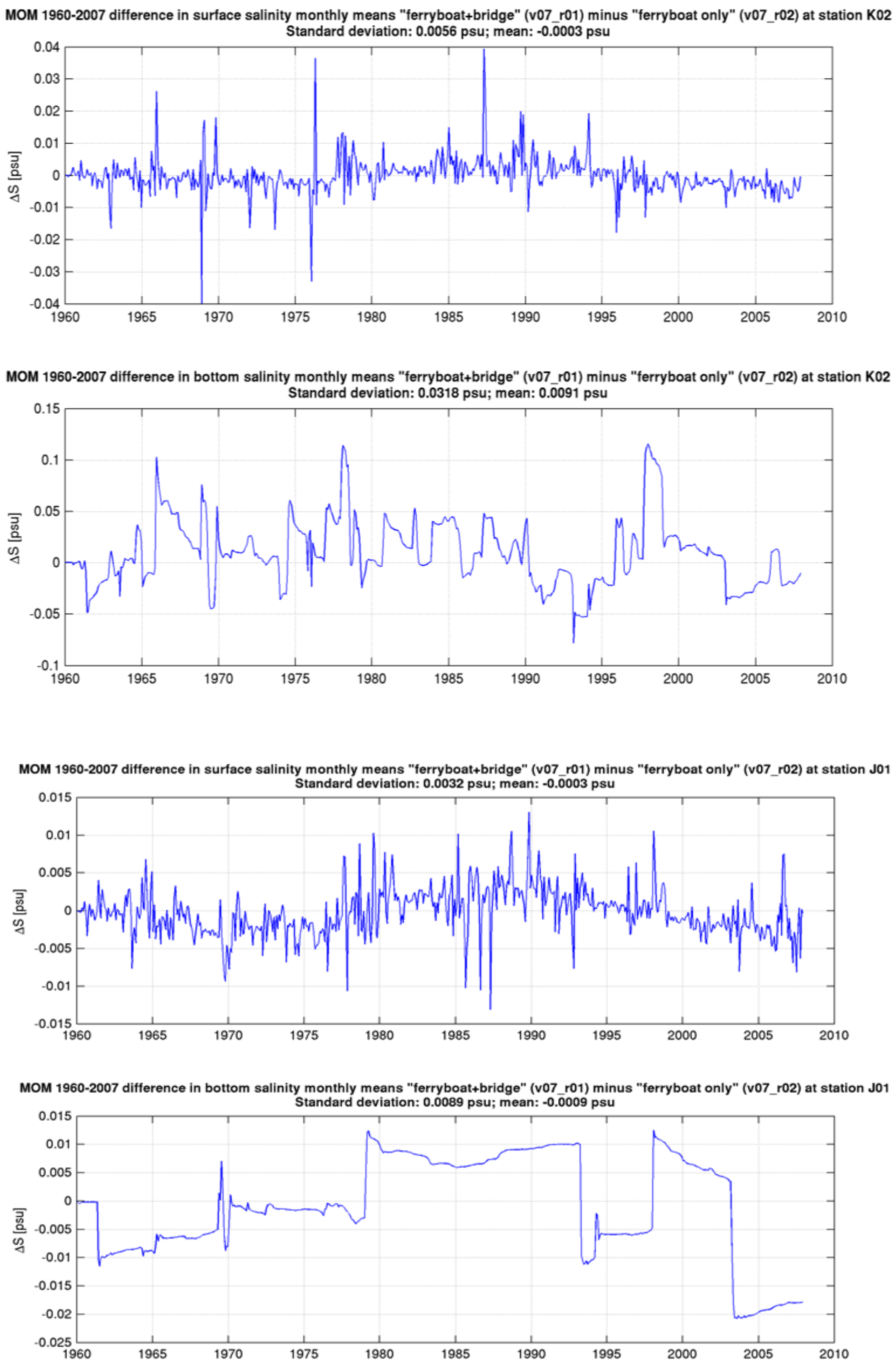


Fig. 3.13 Documentation of the development in effect for the MOM regional model for monthly mean salinity at the Bornholm Basin (K02) and Eastern Gotland Basin (J01). Development shown for "Bridge+ferry" case by subtracting reference simulation ("ferry" case).

It was decided to apply an 18-year period after sufficient spin-up with the link implemented to represent the permanent effects, where the period is based on historical 1990-2007 forcing data. This long production period includes both years without Major Baltic Inflow events and the years 1993 and 2003 with Major Inflow events and is thus assumed to be representative for the driving forces for present conditions of the Baltic Sea.

For the MIKE model it was discovered that the hydrodynamic spin-up was not completed in 1990 after 20 years of modelling, see Fig. 3.12. Therefore the following period 1990-2009 had to be assigned as belonging also to the hydrodynamic spin-up period. To extend the simulation beyond 2009 forcing data from 1990-2007 were used again to drive the model for the next 18 years, here referred to as 2010-2028 or 40-58 years after implementation of the link alternatives in the MIKE model.

Fig. 3.12 documents that this production period 40-58 years after implementation of the link in the MIKE model (referred to as 2010-2028) is very close to having reached a new steady state condition. This was further checked by modelling a subsequent period 2029-2047, see Fig. 3.12.

The MOM model has used the 30-year period 1960-1989 as a spin-up period. Fig. 3.13 shows that the MOM model stabilises very quickly, and that it is appropriate to use the period 1990-2007 as being representative for the new permanent effects in the Baltic Sea. The difference in response between the two models is discussed later.

3.7.4 Calibration and validation results for regional models

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

The developed calibration 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 statistical calibration acceptance criteria have been added to quantify the match of the models.

It should be noted that the calibration 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 calibration acceptance criteria for the regional models.

Statistical parameters

The applied statistical parameters are:

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

The definition of the statistical parameters is:

$$\overline{mod} = \frac{1}{N}\sum_{i=1}^{N} mod_i$$

$$\overline{obs} = \frac{1}{N}\sum_{i=1}^{N} obs_i$$

$$SDE = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left[\left(mod_i - \overline{mod}\right) - \left(obs_i - \overline{obs}\right)\right]^2}$$

$$EV = \frac{\sum_{i=1}^{N}\left[\left(obs_i - \overline{obs}\right)\right]^2 - \sum_{i=1}^{N}\left[\left(mod_i - \overline{mod}\right) - \left(obs_i - \overline{obs}\right)\right]^2}{\sum_{i=1}^{N}\left[\left(obs_i - \overline{obs}\right)\right]^2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[(mod_i - obs_i)]^2}$$

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(mod_i - obs_i)$$

Water level criteria
The qualitative calibration acceptance criteria for water level conditions include capability to reproduce both the astronomical tide and the meteorologically 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 calibration acceptance criteria for water level are:

- SDE<0.1m for the Landsort station in the centre of the Baltic Sea (daily mean values available)

- EV > 0.8 for the Landsort station

The value for SDE of 0.1 m corresponds to about 50% of the standard deviation (SE) of the monitored data at Gedser tide gauge.

The reason for only assessing the match quantitatively in the regional models for the Landsort gauge is that this station is of particular relevance for the overall Baltic Sea water exchange, as this station is known to be a proper proxy of the mean sea level in the Baltic Sea. Furthermore, the coarser spatial resolution of the regional models in the transition area of the Baltic Sea implies that instantaneous check measures as for SDE and EV will be distorted in this transition area and therefore is not part of the quantitative criteria. It should be noted that the Baltic Sea water exchange is mainly driven by the meteorological wind set-up and set-down changes happening on time scales larger than a few hours.

Salinity and temperature criteria
The qualitative calibration 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 calibration acceptance criteria for salinity and temperature to support the above qualitative criteria include:

- BIAS ≤ 1 psu/1°C and RMSE ≤ 3 psu/2°C in regional Baltic Sea multiyear modelling for 80% of station levels.

The above salinity criteria should be compared to salinity values of about 3-20psu in the Baltic Sea, standard deviations of 0.34psu for surface and 1.1psu at bottom salinity (see Table 3.7) and typical vertical differences of 3-12psu, so the accepted BIAS and RMSE are limited. The challenge of maintaining appropriate levels in multiyear modelling without any relaxation to monitored conditions and taking the uncertainty in driving forces (freshwater runoff, net precipitation etc.) also justifies these salinity criteria.

The temperature criteria can be compared to a standard deviation in temperatures in in the Baltic Sea 2-6°C (Table 3.7), so the criteria values correspond to about 20-50% and 40-100%, respectively.

Currents criteria
Particular focus has been on the currents in Fehmarnbelt, which will interact with the fixed link structures.

Current conditions often change significantly within a short distance in the transition area due to fronts and bathymetry gradients. The regional models typically apply a horizontal spatial resolution of 3000-8000m in Fehmarnbelt. The match to the ADCP data sets representing currents within about 10m scales may thus be less accurate.

The developed qualitative calibration acceptance criteria include:

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

The quantitative calibration 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.

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.

Water quality criteria
The qualitative calibration acceptance criteria for water quality parameters include capability to reproduce the overall conditions. This should be documented by:

- 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. The key parameters to check include nutrients, oxygen, Chlorophyll, transparency (Secchi depth) and blue-green algae biomass at surface level

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

Furthermore, the simulated patterns of surface chlorophyll are qualitatively compared to earth observations:

- Visual similarity for selected earth observation data sets

The developed quantitative calibration acceptance criteria include:

- Nutrients: For 80% of the stations, the criteria for surface inorganic nutrient concentrations specified in Table 3.8 are fulfilled

- Oxygen: For 80% of the stations, the criteria for surface and bottom dissolved oxygen concentrations specified in Table 3.8 are fulfilled.

Table 3.8 Calibration acceptance criteria for water quality model variables

Statistical Parameter	Dissolved Oxygen mg/l	PO_4-P µg/l	DIN µg/l
BIAS surface	1.0	3.1	28
RMSE surface	2.0	9.3	56
BIAS bottom	1.0	(-)	(-)
RMSE bottom	2.0	(-)	(-)

The quantitative water quality criteria can be compared to typical variability (standard deviation) of the parameters, which is 2.3 mg/l for bottom DO at station K02 in Bornholm Basin (Table 3.7). Thus, the applied BIAS and RMSE criteria are equivalent to about 45-90% of the natural variability. Similarly, the phosphate and DIN BIAS criteria are equivalent to about 15% and 30%, respectively, of the typical winter values or about 50-70% of the annual mean values in the area.

MIKE regional model compliance

Overall performance of the MIKE regional model for both calibration and validation is considered to be appropriate.

For hydrography the qualitative acceptance criteria are met. The quantitative compliance criteria fulfilment is summarized for the MIKE regional model in Table 3.9. Some are not met, but most are only marginally on the wrong side. For water level compliance the model EV value for the Landsort gauge in the calibration period is thus 0.72 (target min. 0.8) and for standard deviation 0.11m (target max. 0.1m).

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

FEHY Compliance Criteria								
V6.42	Salinity		Temperature		Water level		Velocity	
	RMSE (< 3PSU)	|Bias| (< 1PSU)	RMSE (< 2°C)	|Bias| (< 1°C)	Std Dev (< 0.1m)	EV (> 0.8)	Avg CS (Δ< 0.1m/s)	Avg CD (Δ<10°)
Calibration (1970-1999)	✓ **88%** (422/477)	x **74%** (355/477)	x **77%** (372/484)	✓ **86%** (418/484)	x **0%** (0/1)	x **0%** (0/1)	-	-
Validation (2000-2007)	✓ **82%** (283/347)	x **65%** (227/347)	x **76%** (267/350)	✓ **86%** (302/350)	✓ **100%** (1/1)	x **0%** (0/1)	✓ **100%** (106/110)	✓ **100%** (83/110)

Fig. 3.14 shows examples of the modelled and observed salinity profile at J01 before and after the Baltic Sea deep water inflow event in 2003. The plot demonstrates that the model is capable of giving an excellent representation of the vertical stratification of salinity in the Central Baltic Sea as well as the gross dynamics of inflows. This is important in order to assure accurate impact results from a fixed link in Fehmarnbelt.

For the water quality calibration and validation the qualitative criteria are generally met. Fig. 3.11 shows examples from Bornholm Basin.

The quantity criteria match is shown in Table 3.10. Nutrients in the surface waters are generally close to the target of 80% of stations within the limits specified in Table 3.8. This is important for the primary production. The dissolved oxygen at surface is very good, whereas the bottom values are below the target. The less good RMSE performance appears in the transition area, where the coarse model mesh makes it difficult to reproduce, the station in Riga Bay shows a less good performance, which is assumed to be caused by a local bathymetry inaccuracy.

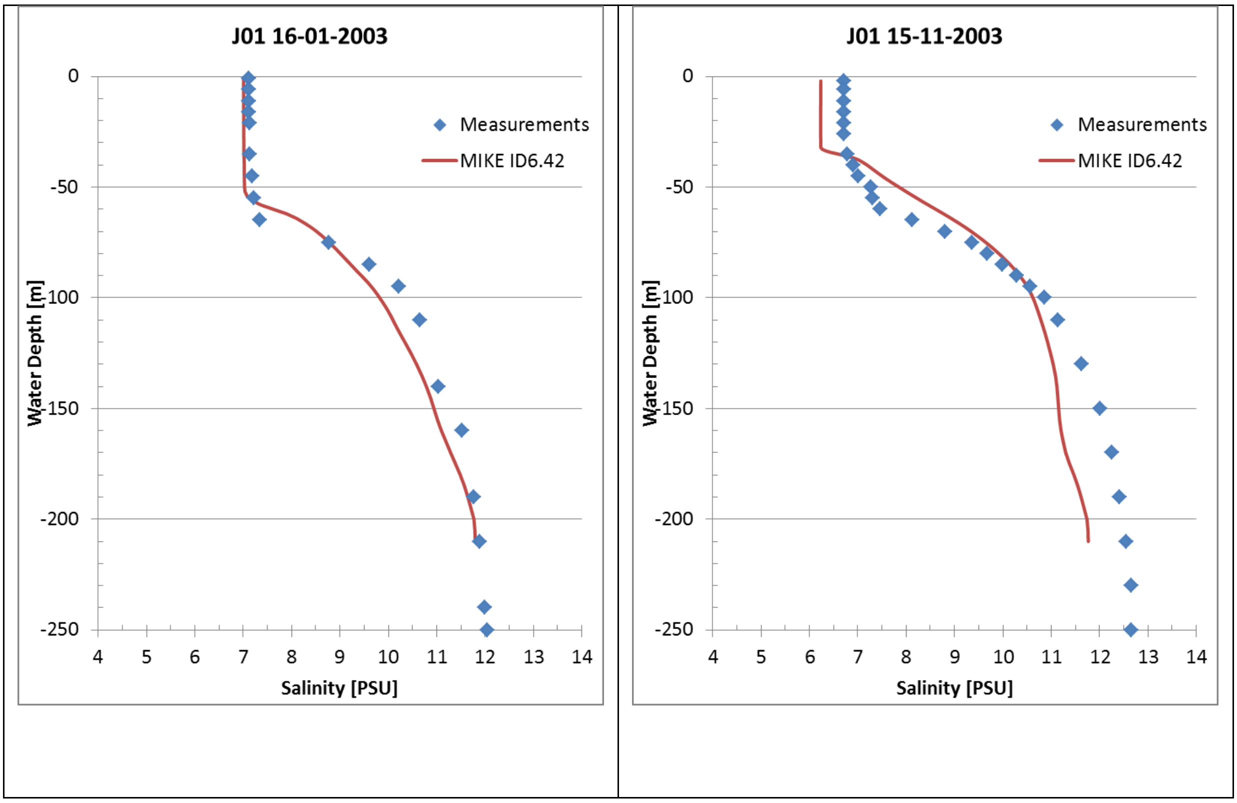


Fig. 3.14 Profile plots of salinity at J01 before (left) and after (right) the Baltic Sea deep water inflow event in 2003.

Table 3.10 Quantitative performance figures for water quality in the MIKE regional model

	Calibration		Validation	
	RMSE	**Bias**	**RMSE**	**Bias**
Inorganic Nitrogen	(<56µg/l) **83%** (15/18)	(<28µg/l) **83%** (15/18)	(<56µg/l) **89%** (16/18)	(<28µg/l) **89%** (16/18)
Phosphate	(<9.3µg/l) **94%** (17/18)	(<3.1µg/l) **56%** (10/18)	(<9.3µg/l) **100%** (18/18)	(<3.1µg/l) **72%** (13/18)
DO Surface	(<2mg/l) **100%** (18/18)	(<1mg/l) **94%** (17/18)	(<2mg/l) **100%** (18/18)	(<1mg/l) **100%** (18/18)
DO bottom	(<2mg/l) **28%** (5/18)	(<1mg/l) **61%** (11/18)	(<2mg/l) **44%** (8/18)	(<1mg/l) **72%** (13/18)

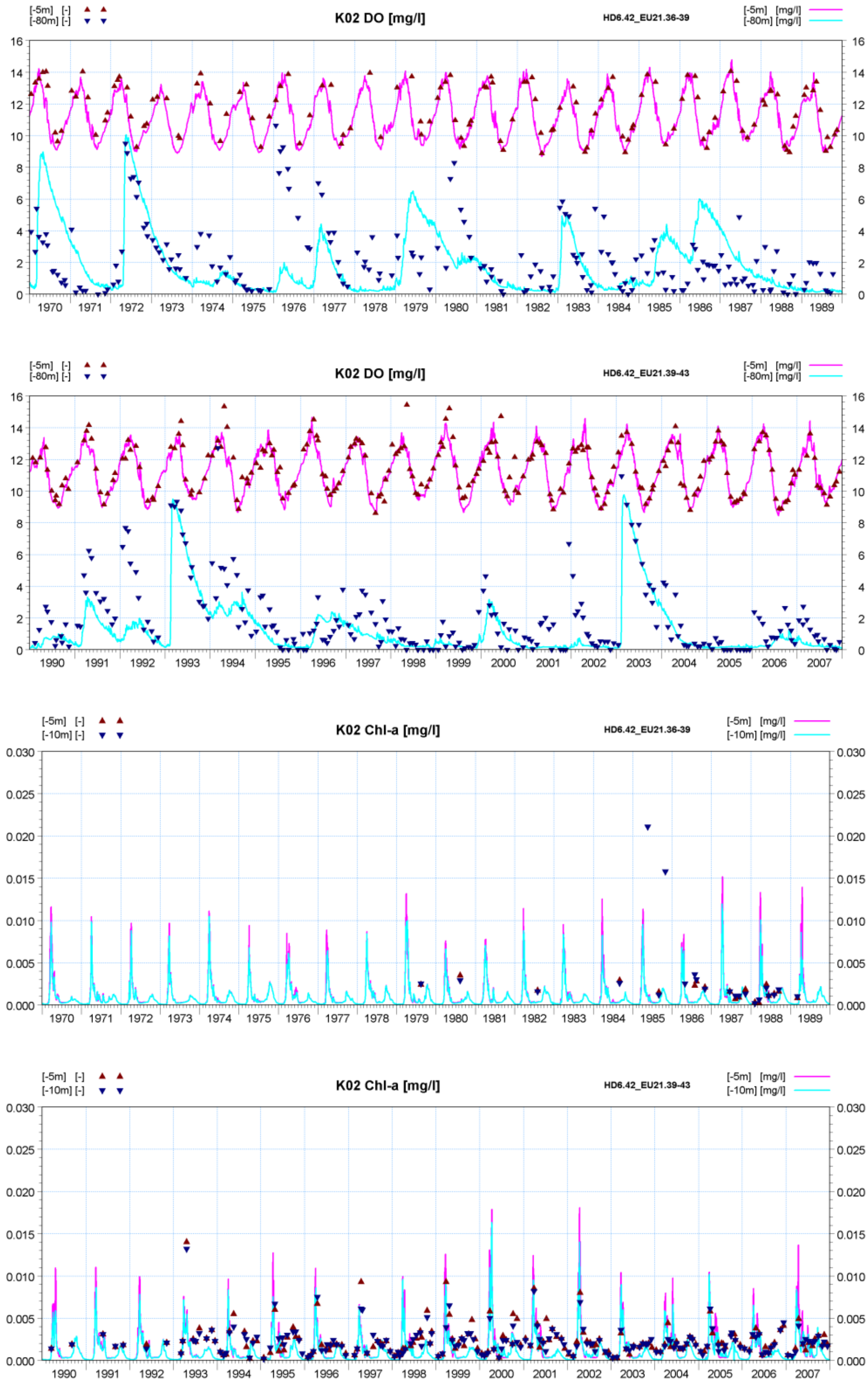


Fig. 3.15 Example of performance fir MIKE regional model: dissolved oxygen (top) and chlorophyll (bottom) results in calibration (1970-1999) and validation period (2000-2007)

In summary, the calibration and validation of the MIKE regional model has had emphasis on representing the basin-scale Central Baltic Sea long-term circulation, water mass distribution and water quality dynamics, while simultaneously securing an accurate, stratified flow distribution in the alignment and a realistic model background resistance through the transition area.

This enables a realistic parameterization of blocking and mixing in the Fehmarnbelt from structures and modelling of the impact of blocking with respect to background resistance and the onwards propagation of impacts to the Central Baltic Sea environment. This objective has been achieved.

MOM regional model compliance
Overall performance of the MOM regional model for both calibration and validation is also considered to be appropriate.

For hydrography the qualitative calibration acceptance criteria are met, however with a somewhat smaller simulated stratification in the Baltic Sea, see Fig. 3.16. Part of the general deviation comes from less perfect initial conditions. Seasonal temperature dynamics are reproduced well. The salinity deviation is also seen in the quantitative compliance criteria fulfilment summarized in Table 3.11. The final calibration of cross sections in the Belt Sea assured that salinity in the Baltic Proper stayed within the established calibration acceptance criteria.

With regard to exchange flow MOM performs well for the filling and emptying, represented by the water level at Landsort. However, for currents speed in Fehmarnbelt the MOM does not meet the criteria, providing current speeds being 40% too low for surface currents. This is mainly due to the representation of the Fehmarnbelt in the 3 nautical mile mesh, which is somewhat coarse for this narrow strait, with only 3 mesh cells being applied across Fehmarnbelt, see Fig. 3.16. It has not been possible to compensate for this speed deviation without affecting the salinity compliance in the Central Baltic Sea to a larger degree.

Table 3.11 Summary of MOM regional model fulfilment of hydrographical calibration acceptance criteria for calibration and validation period. Target is minimum 80%.

FEHY Compliance Criteria								
v06_r01	Salinity		Temperature		Water level		Velocity	
	RMSE (< 3PSU)	|Bias| (< 1PSU)	RMSE (< 2°C)	|Bias| (< 1°C)	Std Dev (< 0.1m)	EV (> 0.8)	Avg CS (Δ< 0.1m/s)	Avg CD (Δ<10°)
Calibration (1970-1999)	✓ **83%**	x **61%**	✓ **92%**	✓ **92%**	✓ **100%** (1/1)	✓ **100%** (1/1)	-	-
Validation (2000-2007)	✓ **82%**	x **44%**	✓ **94%**	✓ **94%**	✓ **100%** (1/1)	✓ **100%** (1/1)	x **50%** (5/10)	✓ **80%** (8/10)

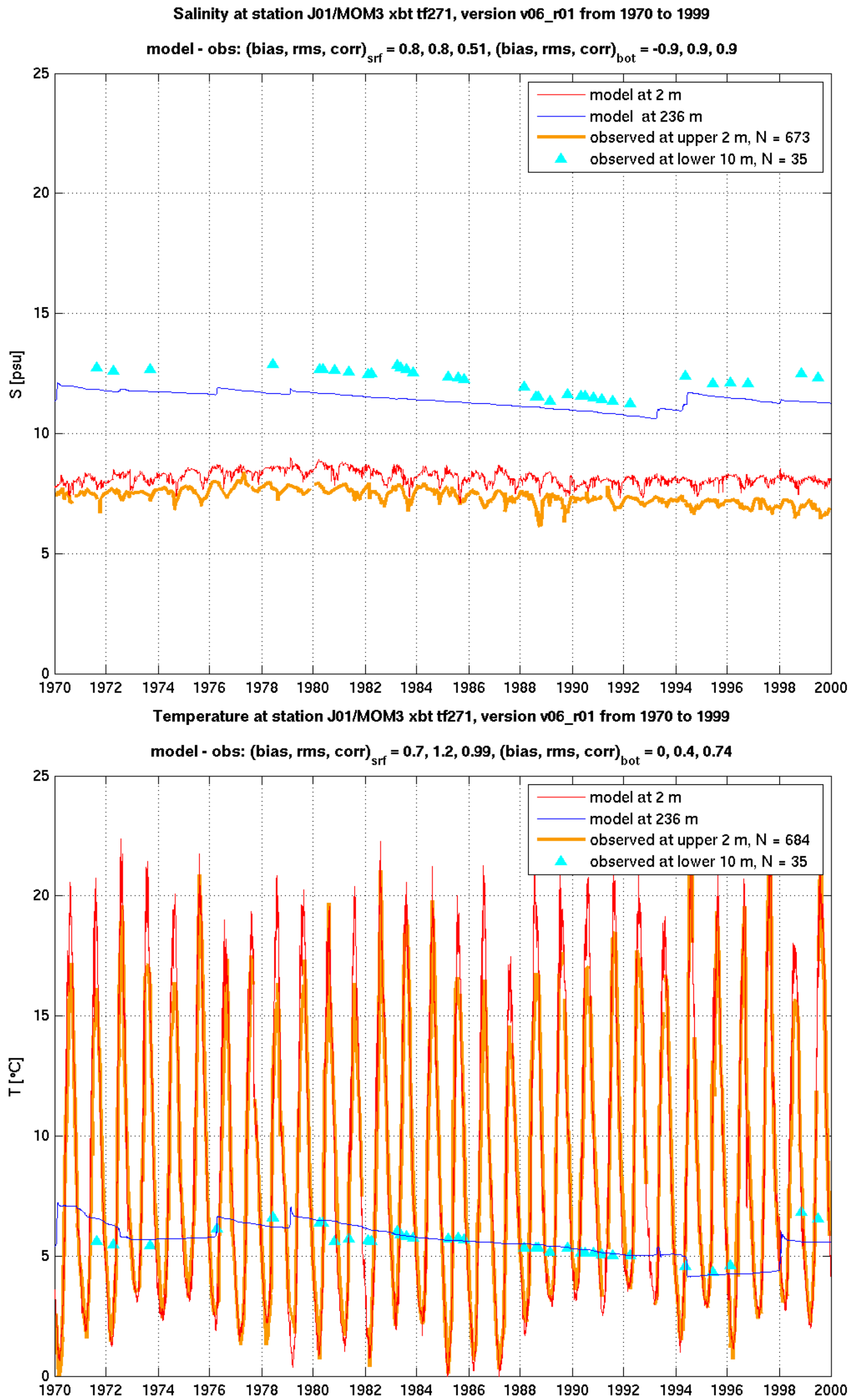


Fig. 3.16 *Salinity and temperature at the Eastern Gotland Basin for the calibrated MOM model. The surface annual cycle is well reproduced by the model as well as variations in the observed bottom salinity, however with a bias of the salinities at bottom levels. Some of this BIAS is due to a too low initial stratification.*

For the water quality calibration and validation the qualitative criteria are generally met. Figs. 3.17 to 3.19 show examples from various basins of the Baltic Sea and parameters. The seasonal dynamics are well reproduced.

The quantities criteria match is shown in Table 3.12. Nutrients in the surface waters are generally close to the target of 80% of stations within the limits specified in Table 3.8, and better for the validation period than for the calibration period. The dissolved oxygen over the full profile depth is close to the target level.

Table 3.12 Quantitative performance figures for water quality in the MOM regional model.

	Calibration		Validation	
	RMSE	**Bias**	**RMSE**	**Bias**
Inorganic Nitrogen (surface)	(<56µg/l) **65%**	(<28µg/l) **65%**	(<56µg/l) **100%**	(<28µg/l) **100%**
Phosphate (surface)	(<9.3µg/l) **67%**	(<3.1µg/l) **76%**	(<9.3µg/l) **100%**	(<3.1µg/l) **93%**
DO (full profile)	(<2mg/l) **71%**	(<1mg/l) **78%**	(<2mg/l) **77%**	(<1mg/l) **88%**

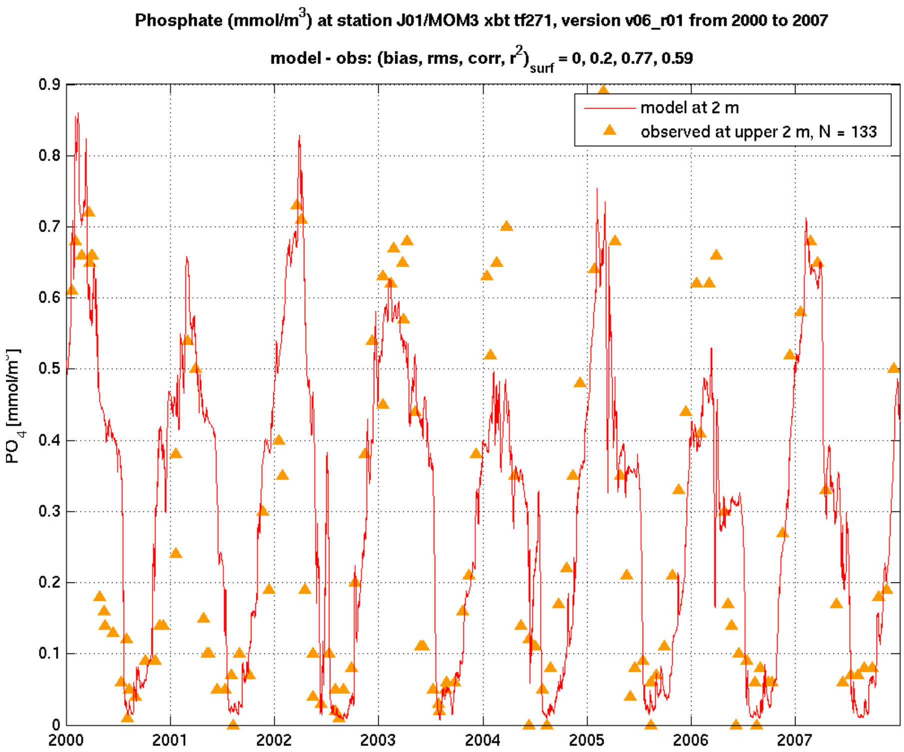


Fig. 3.17 Validation results of phosphate at J01 in the Eastern Gotland Basin.

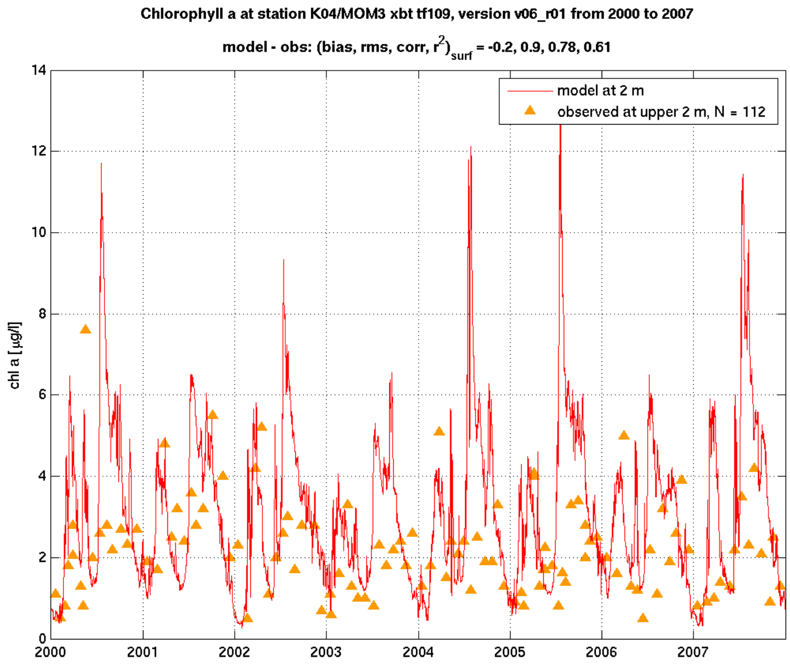


Fig. 3.18 *Simulated and observed surface layer concentration of chlorophyll a in the Arkona Basin (station K04) for the validation period.*

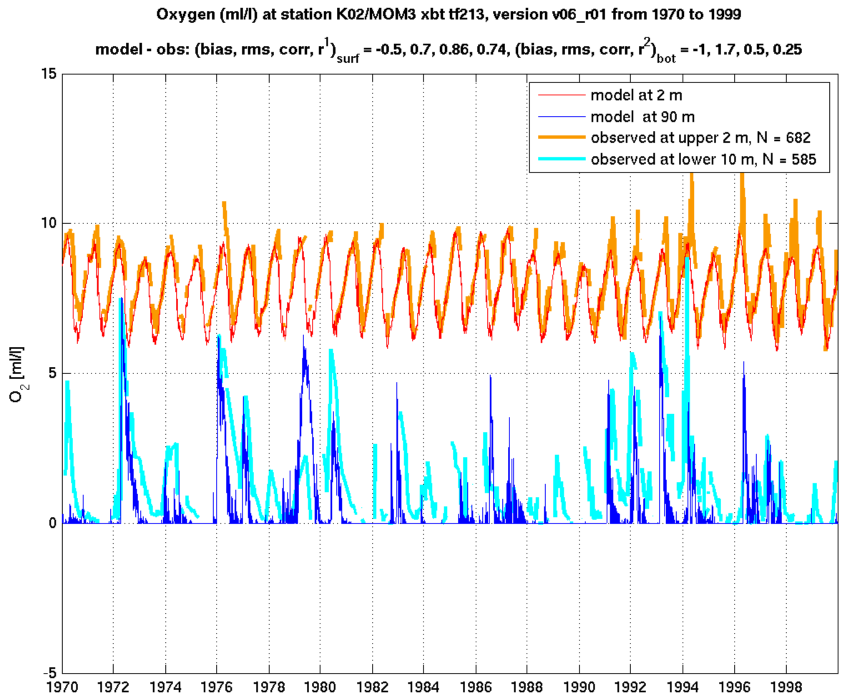


Fig. 3.19 *Oxygen at BMP monitoring station K02 (Bornholm Basin) as observed and modelled. Note the low bias and the good reproduction of the annual cycles at the surface (red and orange lines). The comparison for bottom values shows that inflows of oxygen-enriched bottom water and annual cycles are reproduced.*

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 with the ID 'fehy-piers-v04_regional.xyz', giving the actual position, dimensions and other specifications for the sub-grid parameterisation in each model.

3.7.6 Key effect parameters

The applied 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 selected and post-processed from the model runs. These key effects also include the subcomponents used later in the assessment of degree of impairment for the component hydrography.

Hydrodynamics

For the regional hydrodynamics the key effect parameters include:

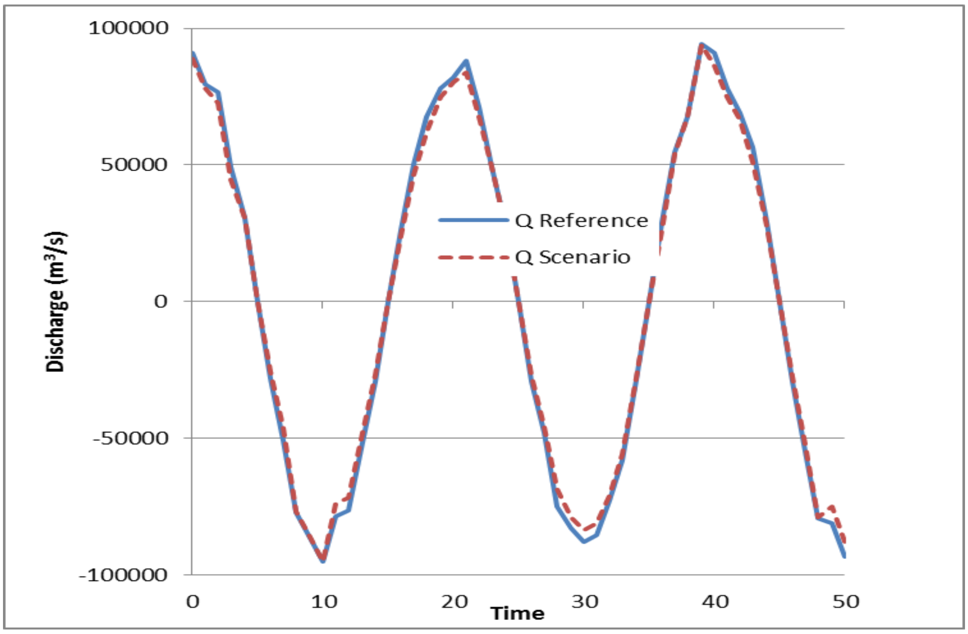
- Effect to water level, particularly annual mean water level and maximum water level
- Effect to water exchange between the Baltic Sea and Fehmarnbelt, respectively the Sound
- Effect to annual mean salinity and temperature at surface and along the seabed
- Effect to annual mean stratification, defined as bottom density minus surface density
- Effect to vertical annual mean distribution of salinity, temperature and density, particularly for a Baltic Sea longitudinal transect (Kattegat to Gulf of Finland).

Water Quality

The regional water quality key effect parameters include:

- Effect to annual mean surface Chlorophyll, representing the total plankton biomass
- Effect to annual mean DO along the seabed
- Effect to annual minimum DO along the seabed
- Effect to vertical annual distribution of mean DO, particularly for a Baltic Sea longitudinal transect (Kattegat to Gulf of Finland)
- Effect to annual mean Secchi depth (transparency)
- Effect to annual mean blue-green algae carbon.

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.



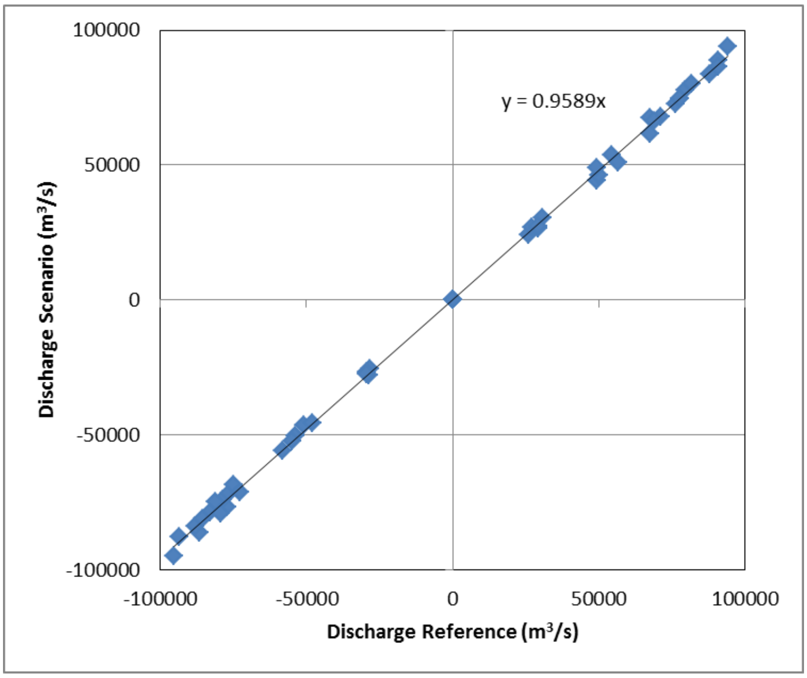


Fig. 3.20 Concept of blocking measure. Here blocking is 0.9589-1.0000=-0.0411=-4.1%

The redistribution between Fehmarnbelt and the Sound is assessed as the change in long term average net flow through each strait.

3.7.7 *Overview map*

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

3.7.8 *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 generally 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.

It has been decided that the MIKE regional model will provide the quantitative key results for the impact assessment, and the upscaled MOM regional results will be used to evaluate and quality assure the MIKE results. The reason is that the MOM model has the too low current speed in the Fehmarnbelt section (see Chapter 3.7.4) due to a rather coarse grid resolution, and thus underestimates the direct blocking by about a factor 3. Even if the factor correction yields only a rough up-scaling of the MOM predictions, it produces the same order of magnitude and very similar distribution patterns for the link impacts, thus confirming the MIKE results by an independent (or alternative) model approach

Therefore the MOM model results do not quantitatively form the basis for the final quantitative regional impact evaluation:

Bridge regional quantitative effect assessment:

- Only MIKE regional results

Tunnel regional quantitative effect assessment:

- Assessed (to be insignificant) based on local model results showing no blocking of flow

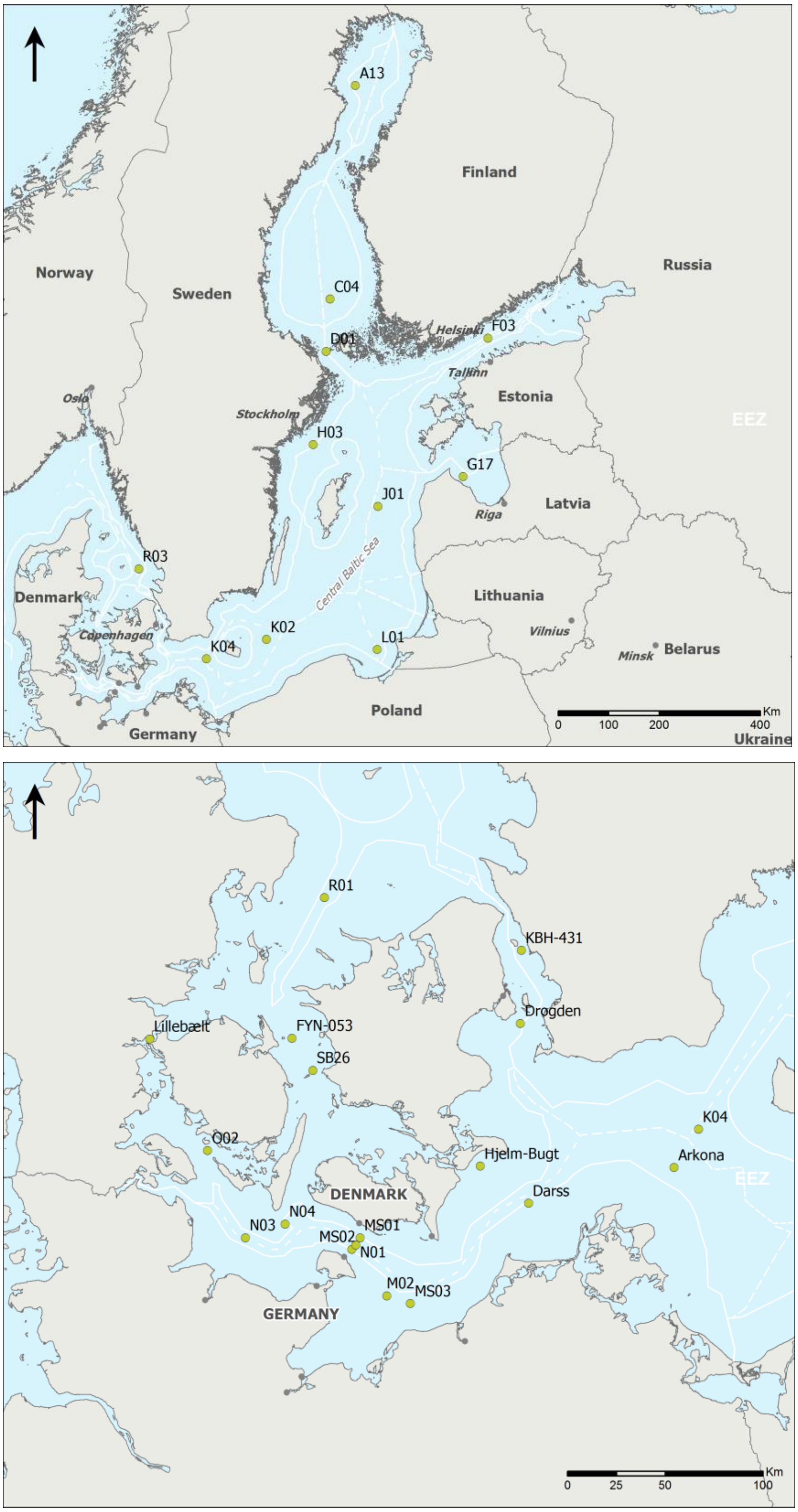


Fig. 3.21 Overview map for referred geographical sites and standard monitoring stations

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, using the highest degree of impairment for each position.

3.9 Assessment of severity

The severity is achieved by a combination of the degree of impairment with the baseline importance. The standard severity 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 impact severity areas and the overall size of the Central Baltic Sea.

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 built-in centre section or new ferries of similar extended size, if the capacity needs to be increased.

An increase in the annual number of departures is not considered likely as the present schedule leaves no 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 2013e) and (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 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 used to assess the hydrography and water quality components these relationships are 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. Figure 5.2 shows CDF modelling of current effect for various current approach angles, use to quantify the drag and lift forces applied in the local models.

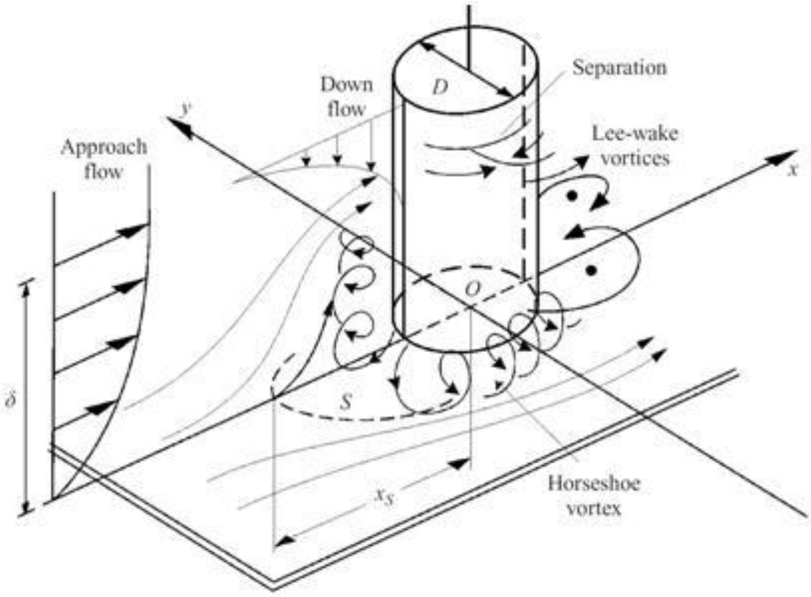


Fig. 5.1 Sketch of large turbulent flow structures generated by the presence of a vertical pylon in a channel flow.

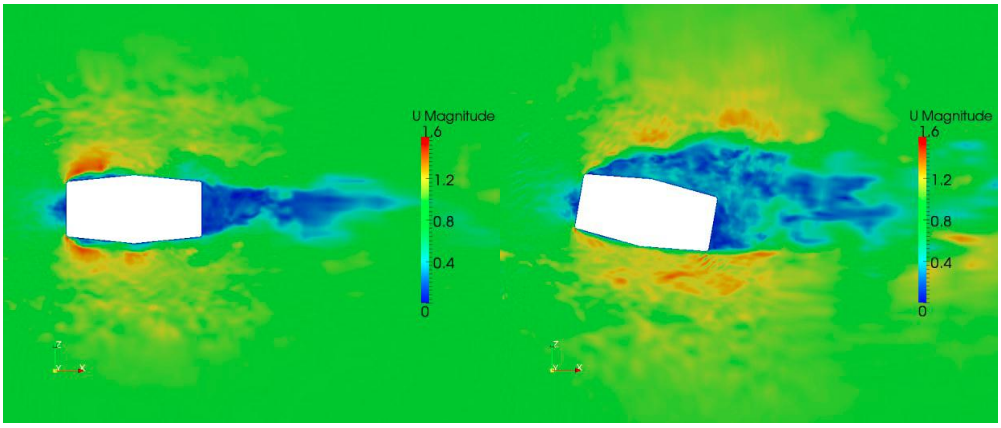


Fig. 5.2 Contour plot of instantaneous velocities at 14m above the seabed for hexagon type pier, current direction at 0 and 10 degrees.

6 ASSESSMENT OF IMPACTS OF MAIN TUNNEL ALTERNATIVE

The underlying detailed modelling and assessment for the immersed tunnel E-ME have focussed on the comparison of a future situation with tunnel and continued ferry service ("tunnel+ferry") to 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 very small). This is explained by the effect of the ferry service via extra mixing etc. to the hydrography being very limited.

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 years, see (FEHY 2013c). Therefore it has been included as a pressure in the 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		
Lolland	6000m * 500m	330
Fehmarn	300m * 450m	14
Protection reefs		
Lolland	450m * 150m	6
Fehmarn	450m * 150m	6
Open access canal		
Lolland (deepening 0-6m)	2500m * 150m	32

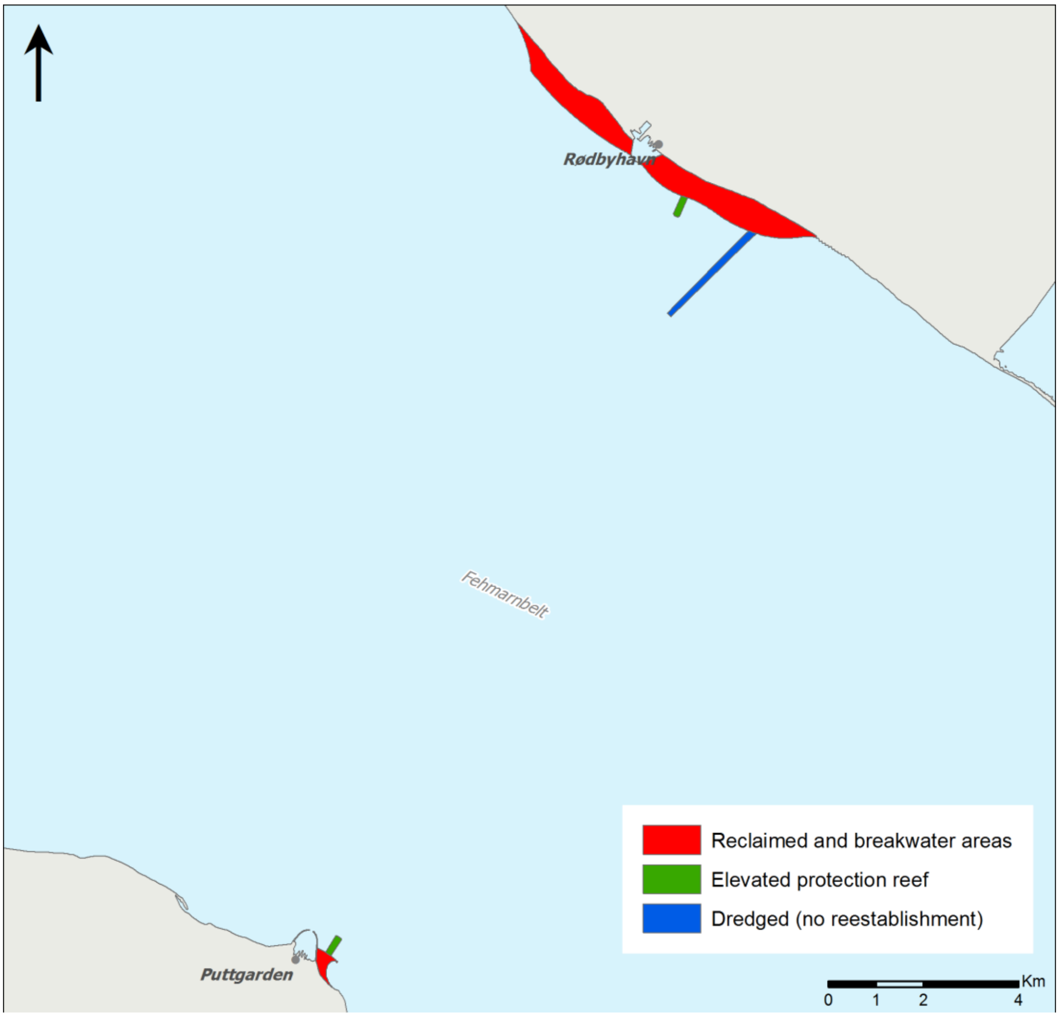


Fig. 6.1 Permanent immersed tunnel E-ME (August) elements acting as pressure factors for the Central Baltic Sea assessment.

6.1.2 Impact magnitude

Hydrodynamics
The local modelling results are reported in (FEHY 2013b). These local effects are restricted to the immediate vicinity of the tunnel reclamations.

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

The effect to the water exchange with the Central Baltic Sea has been extracted from the local modelling results, see Table 6.2. The full year 2005 modelling is only available for the E-ME version from April 2011 where the reclamation west of Rødbyhavn did not extend so far. The final E-ME layout (August 2011) has been modelled using a shorter design period (9-27 Nov. 2011). Table 6.2 shows that the flow blocking results for the full and short design period are very similar for the former layout and also for the final E-ME (August 2011) layout of the tunnel.

Table 6.2 Effect to water exchange parameters for the Central Baltic Sea for immersed tunnel E-ME cases, estimated in local MIKE 3 model using year 2005.

Tunnel cases compared to "ferry" case	**Local model (MIKE 3)**	
	Flow blocking at Darss Sill	Net salt flux effect at Darss Sill
Tunnel + ferry (version March 2011)	-0.01% (0.00%[1])	0.00%
Tunnel + ferry (version August 2011)	-0.01%[1]	NA
Tunnel (no ferry) (version August 2011)	-0.02%[1]	NA
Tunnel + ferry in construction period (version August 2011)	-0.01%[1]	NA

Note 1: Based on a representative shorter design period 9-27 Nov 2005. Therefore no estimation of salt flux effects

Therefore the final E-ME immersed tunnel layout from August 2011 can be assessed as having practically no effect on the water exchange and the salt flux in and out of the Central Baltic Sea across the Darss Sill.

This implies that there is no real permanent effect to the Baltic Sea of the immersed tunnel alternative with respect to any of the hydrographic and water quality sub-components, including Central Baltic Sea water levels, currents, salinity, temperature, stratification, oxygen, transparency, Chlorophyll and blue-green algae.

6.1.3 Loss and degree of impairment

As there is no individual sub-component effect to the Baltic Sea for the immersed tunnel, the aggregated permanent impacts for loss and degree of impairment in the Central Baltic Sea are negligible everywhere.

6.1.4 Impact severity of loss and impairment

In parallel to the above there will be no areas of any severity to the Central Baltic Sea with respect to permanent loss or impairment for the immersed tunnel alternative.

6.1.5 Impact significance

With no areas of degree of impairment or loss in the Central Baltic Sea the assessment is that after the construction period the immersed tunnel has no significance for the hydrography, water quality and plankton in the Baltic Sea in any way.

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. 6.2 are present, with an almost fully backfilled tunnel trench. The sizes of these temporary structures and the tunnel trench are summarised in Table 6.3.

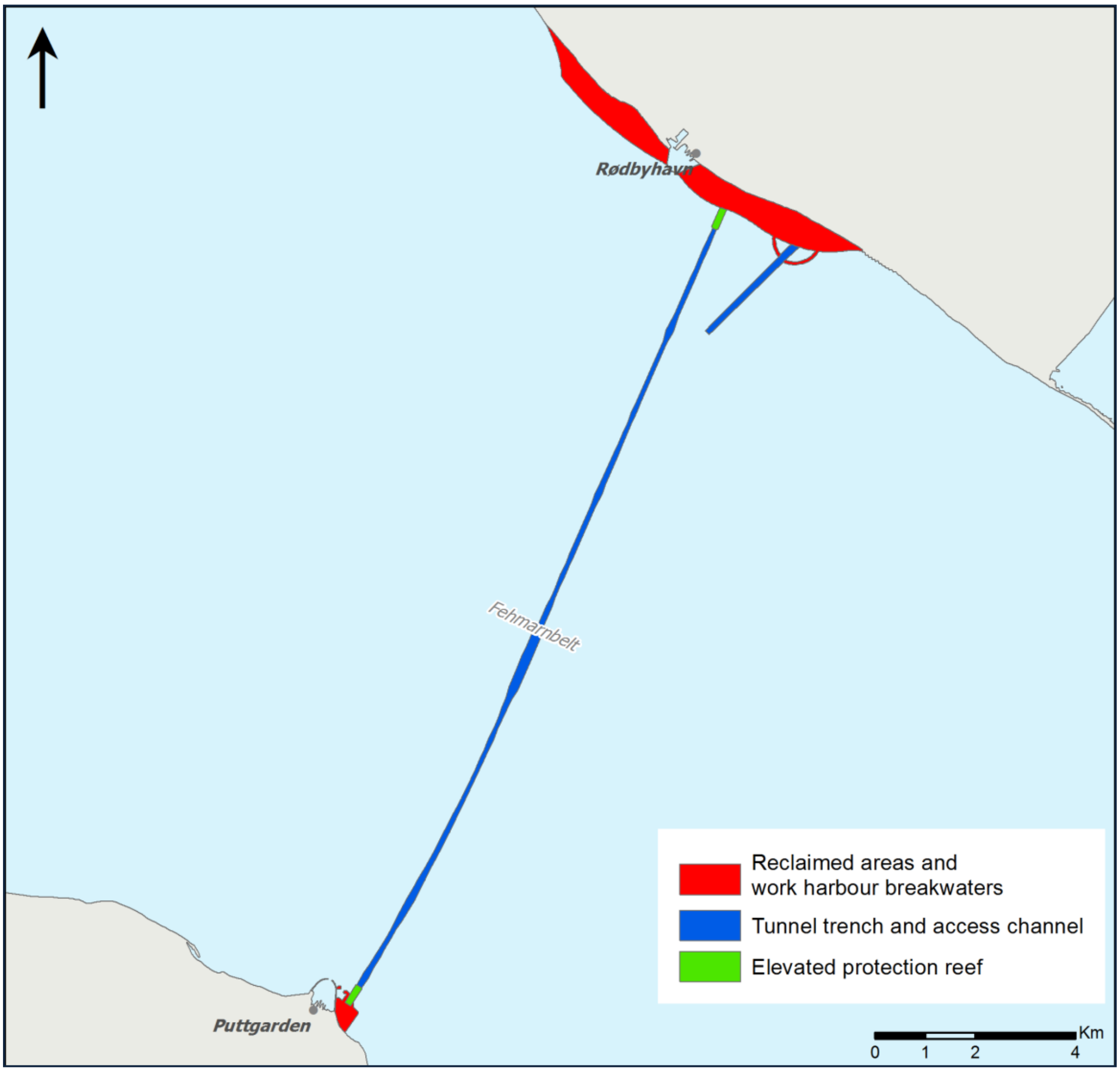


Fig. 6.2 Immersed tunnel elements in the construction period acting as pressure factors for the Central Baltic Sea assessment.

The construction activities also cause spill of dredging material, adding to the suspended sediment in the vicinity of the construction works. About half of this spilled sediment will enter the Central Baltic Sea. This pressure is described in detail in (FEHY 2013f).

An associated effect is a slight reduction of the plankton production in Fehmarnbelt because of shading from the suspended sediments. This impact is assessed in (FEHY & FEMA 2013) as being negligible and will not act as a pressure for the Central Baltic Sea.

Table 6.3 The dimensions of the additional immersed tunnel E-ME pressure elements during the construction period

Additional pressure element in the construction period	Dimension	Area (ha)
Tunnel trench	17500m * 110m	194
Work harbours outside permanent footprint		
Lolland	800m * 400m	26
Femern	400m * 200m	8

6.2.2 *Impact magnitude*

Hydrodynamics
The blocking of the exchange flow with the Central Baltic Sea in this phase of the construction period is -0.01% like the permanent conditions after the construction period (see Table 6.2). This shows that the work harbour and production facility effects on the water exchange are negligible. This also implies that there is no significant effect to the hydrography of the Central Baltic Sea from the tunnel scenario in the construction period.

Water quality
Modelling of sediment spill dispersion (FEHY 2013f) has documented that the suspended sediment concentration at Darss Sill at mid-depth will increase by about 0.1-0.2 mg/l during the construction period of six years. When the sediment spreads into the Central Baltic Sea it finally settles in the natural settling basins of the Arkona Basin. Thus the extra suspended sediment concentration in the Arkona Basin only appears at bottom waters and is very low compared to the naturally suspended sediment concentration at inflow events, when strong resuspension takes place. Therefore the effect is assessed as negligible.

6.2.3 *Loss and degree of impairment*
As there is no individual sub-component effect to the Central Baltic Sea for the immersed tunnel during the construction period, the aggregated permanent impacts for loss and degree of impairment in the Baltic Sea are negligible everywhere.

6.2.4 *Impact severity of loss and impairment*
In parallel to the above there will be no areas of any severity in the Central Baltic Sea with respect to construction period for the immersed tunnel alternative.

6.2.5 *Impact significance*
With no areas of impairment or loss in the Baltic Sea the assessment is that in the construction period does the immersed tunnel not have any significance for the hydrography, water quality and plankton in the Central Baltic Sea in any way.

6.3 Aggregation of impacts

In principle it is not relevant to aggregate impacts from the above two pressures, 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. Furthermore, both impacts are assessed to be negligible.

6.4 Cumulative impacts

Cumulative impact considerations are only relevant if there is a project impact (see Chapter 7.4 for bridge assessment).

6.5 Transboundary impacts

This issue is described above, as the Central Baltic Sea constitutes the area of transboundary impacts. In Kattegat and further outside of the Baltic transition area the impacts are also assessed to be non-existing.

6.6 Climate change

In this context climate change considerations are only relevant if there is a project impact (see Chapter 7.6 for bridge assessment).

6.7 Mitigation and compensation measures

In relation to the immersed tunnel mitigation measures do not seem to be relevant as there are no impacts to the Central Baltic Sea.

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 Central Baltic Sea will not sense the project leftovers after the decommissioning, in the same manner as it will not sense the project during the operation phase.

7 ASSESSMENT OF IMPACTS OF CABLE STAYED BRIDGE ALTERNATIVE

The following assessment for impacts to the Central Baltic Sea of 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 service), 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. Key results for the "bridge" scenario (without ferry service) are provided in Appendix A.

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 affected area off Fehmarn is slightly larger than at the Lolland coast, mainly because of the reclaimed area between the marine ramp and the Puttgarden eastern 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

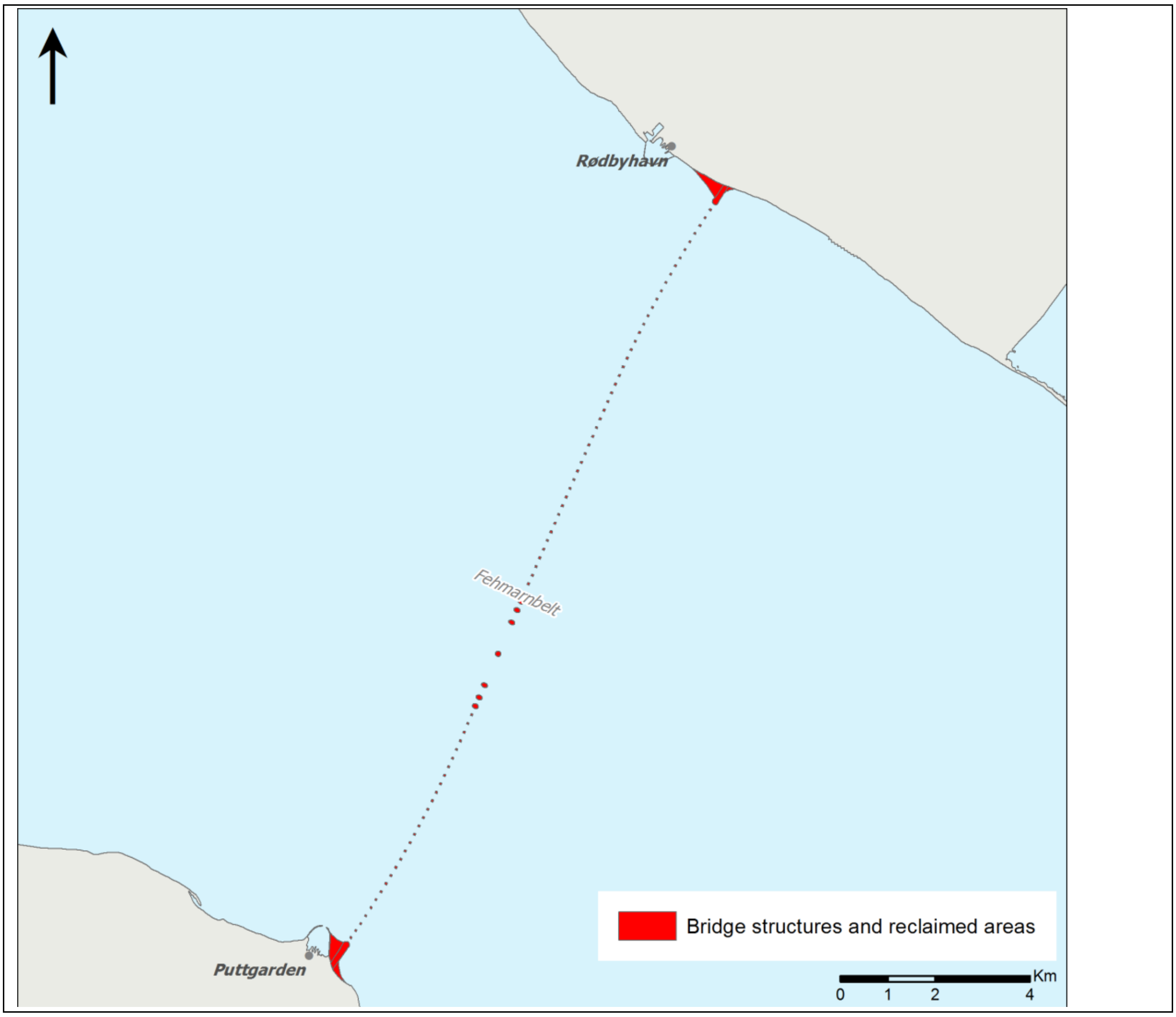


Fig. 7.1 Permanent cable stayed bridge Var. 2 B-EE (October 2010) elements acting as pressure factors for the Central Baltic Sea assessment

7.1.2 Impact magnitude

It should be noted that some of the below effects and impacts will take decades to build-up to a new semi steady-state, as described in Chapter 3.7.3. It may take up to 40 years to reach this new state.

Hydrodynamics

Results from the underlying numerical modelling with the MIKE and MOM regional models are displayed and discussed below for the various sub-components.

Water exchange

The effect to the exchange flows with the Central Baltic Sea is assessed both by the local model setups and the regional models, see Table 7.2 (and Table 7.2B in appendix A for "bridge" case without continued ferry service). The local models have the benefit of having a fine spatial resolution, but do not include effects of the Baltic Sea accumulation building up over decades after implementation of the fixed link. The regional models include this effect, but have a coarser resolution in the area where the link is implemented and are thus not as accurate regarding the basic representation of the fixed link.

In the local models the blocking of the flow is found to be -0.42 to -0.50% in the "bridge+ferry" case and slightly less in the "bridge" case. The regional MIKE model estimates the effect to -0.7% and the MOM regional model to -0.2%. It should be noted that the MOM results are underestimating the effect of the bridge pier by about a factor 3 as the current speed in this section of the MOM model is 40% too low, see Chapter 3.7.4.

The redistribution of net flow between Fehmarnbelt (Darss) and the Sound is estimated to be in the order of 40-70 m^3/s (after correction of MOM result). This should be compared to the total net outflow from the Central Baltic Sea of about 15,000 m^3/s.

Regarding the effect to net salt flux the models give opposite results with changes in the order of ±300-700 m^3*psu/s (after MOM scaling). MIKE model results indicate less salt outflow through Fehmarnbelt and more inflow via the Sound, and MOM oppositely. These net salt flux changes are very small and not important for the salt effects discussed below.

Table 7.2 Effect to water exchange conditions of the Baltic Sea for "Bridge+ferry" case.

"Bridge+ferry" compared to "ferry" case	**Local models (2005)**		**Regional models (18 years: 1990-2007 forcing)**	
	MIKE	GETM	MIKE	MOM[1]
Darss flow blocking	-0.50%	-0.42%	-0.70%	-0.22%
Net outflow effect Darss	(see regional models)	(see regional models)	-40m^3/s	-26m^3/s
Net outflow effect Drogden	(see regional models)	(see regional models)	+40m^3/s	+24m^3/s
Darss salt transport blocking	-0.52%	-0.37%	-0.95%	-0.20%
Net salt outflow effect Darss	(see regional models)	(see regional models)	+356m^3*psu/s	+70m^3*psu/s
Net salt outflow effect Drogden	(see regional models)	(see regional models)	-189m^3*psu/s	-233m^3*psu/s

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in Chapter 3.7.4.

Water levels

The fixed link will have a tendency to increase the mean water level marginally in the Central Baltic Sea. Fig. 7.2 shows the effect, which has a maximum increase in annual mean water level of less than 0.0006m all over the Central Baltic Sea.

The effects to the mean and maximum water level for the K04 position in the Arkona Basin are presented in Table 7.3. Regarding the effect to the maximum water level a very minor reduction is found for most of the Central Baltic Sea (down to -0.003m). The MIKE model gives slight increases of up to 0.0018m in the Arkona Basin station (see Fig. 7.2). These effects are a result of the combined general water level change and extra Fehmarnbelt resistance to water exchange during strong in- or outflows from the Central Baltic Sea.

Table 7.3   Water level effects for "Bridge+ferry" case, 1990-2007.

"Bridge+ferry" compared to "Ferry" case	**Arkona Basin (K04)**	
	MIKE	MOM[1]
ΔWl_{mean}	0.0005m	0.0002m
$\Delta(Wl_{max})$	0.0018m	-0.0002m

Note 1:   MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in Chapter 3.7.4.

All in all the water level effects are classified as being very marginal.

Salinity and temperature
The estimated effects to salinity and temperature for the "Bridge+ferry" case are shown in Fig. 7.3 and Fig. 7.4 based on the MIKE regional model.

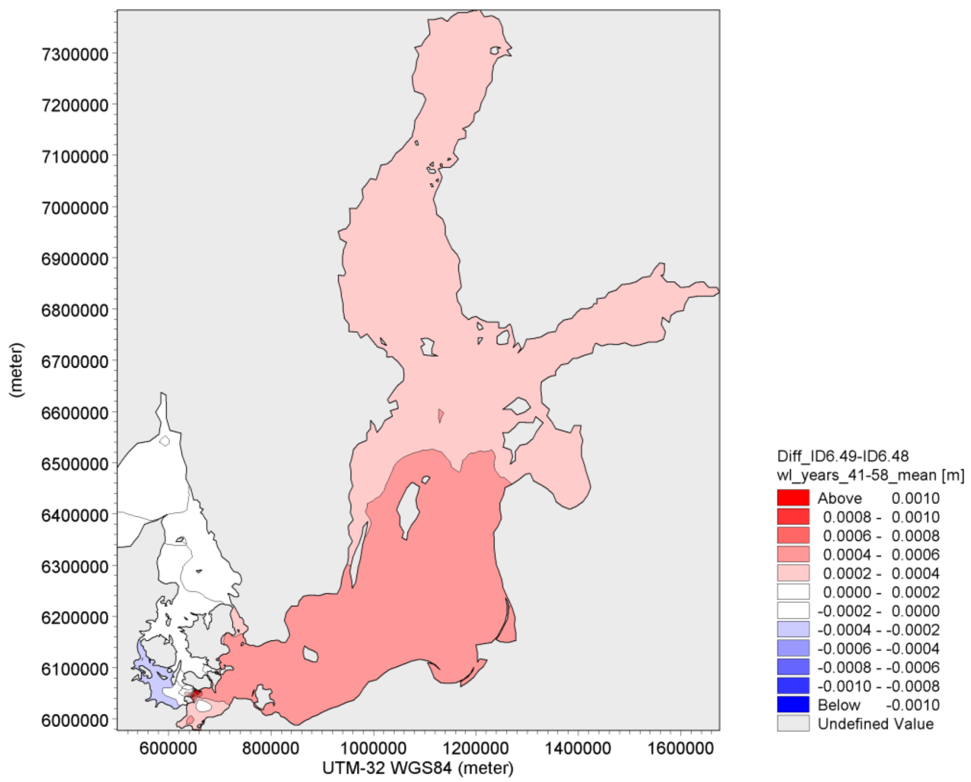
The mean surface salinity effect in the MIKE model is a slight reduction in the Arkona Basin (down to -0.08psu locally) and less (down to -0.03psu) in the rest of the Baltic Sea. In MOM reductions are generally lower (down to -0.001psu or -0.003psu after correction with factor 3), see also Table 7.4 for details for three key stations.

The mean bottom salinity effects are less than -0.06psu in the MIKE model and less than -0.02psu (or -0.06psu after correction) in the MOM model.

It should be noted that the MOM model seems to stabilise the effect faster than the MIKE model, where it did not reach a new equilibrium until after 40-60 years (see Fig. 3.12 versus 3.13).

The effects to surface temperatures are insignificant in both models. For bottom and other level temperatures the effects are also very small, except for a minor area where the MIKE model gives effect to bottom temperature of up to ±0.1ºC very locally. These MIKE effects are considered a model artefact.

The minor salinity and temperature effects potentially change the density and the vertical stratification. However, model results document that the general Central Baltic Sea density and stratification are affected everywhere less than 0.01 kg/m^3 and 0.02kg/m^3 in both models. The typical stratification within the Central Baltic Sea is about 5kg/m^3 with a temporal standard deviation of 0.8 kg/m^3 (estimated at K02 in Bornholm Basin).



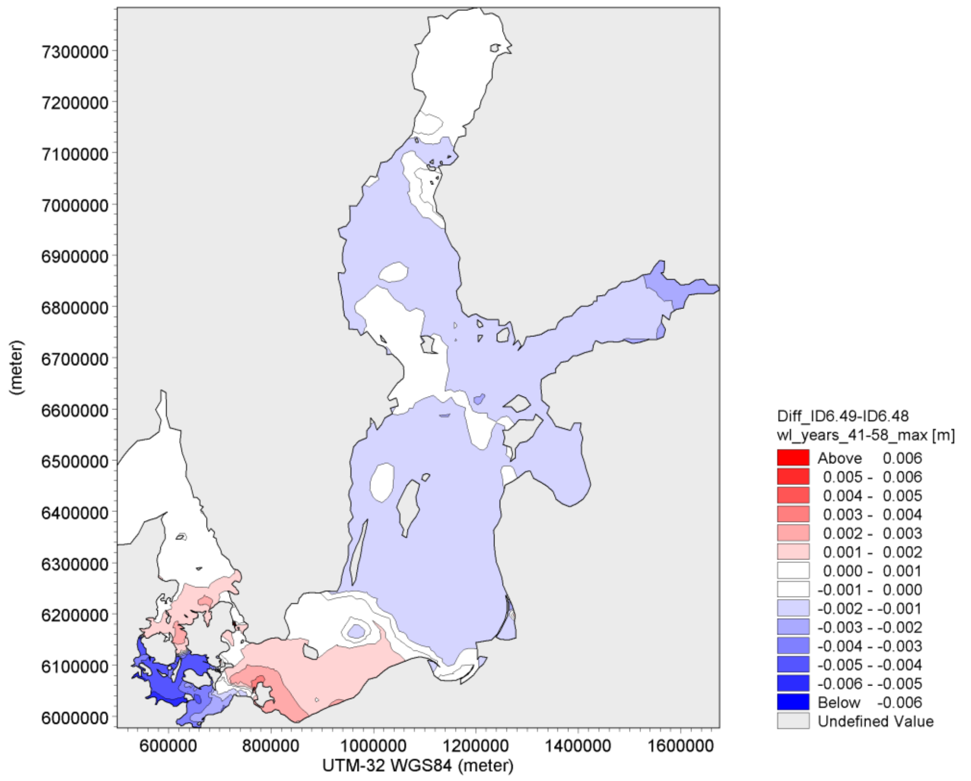


Fig. 7.2 Water level effects for "Bridge+ferry" case, 1990-2007 (MIKE model results). Top: effect to mean water level. Bottom: effect to max water level.

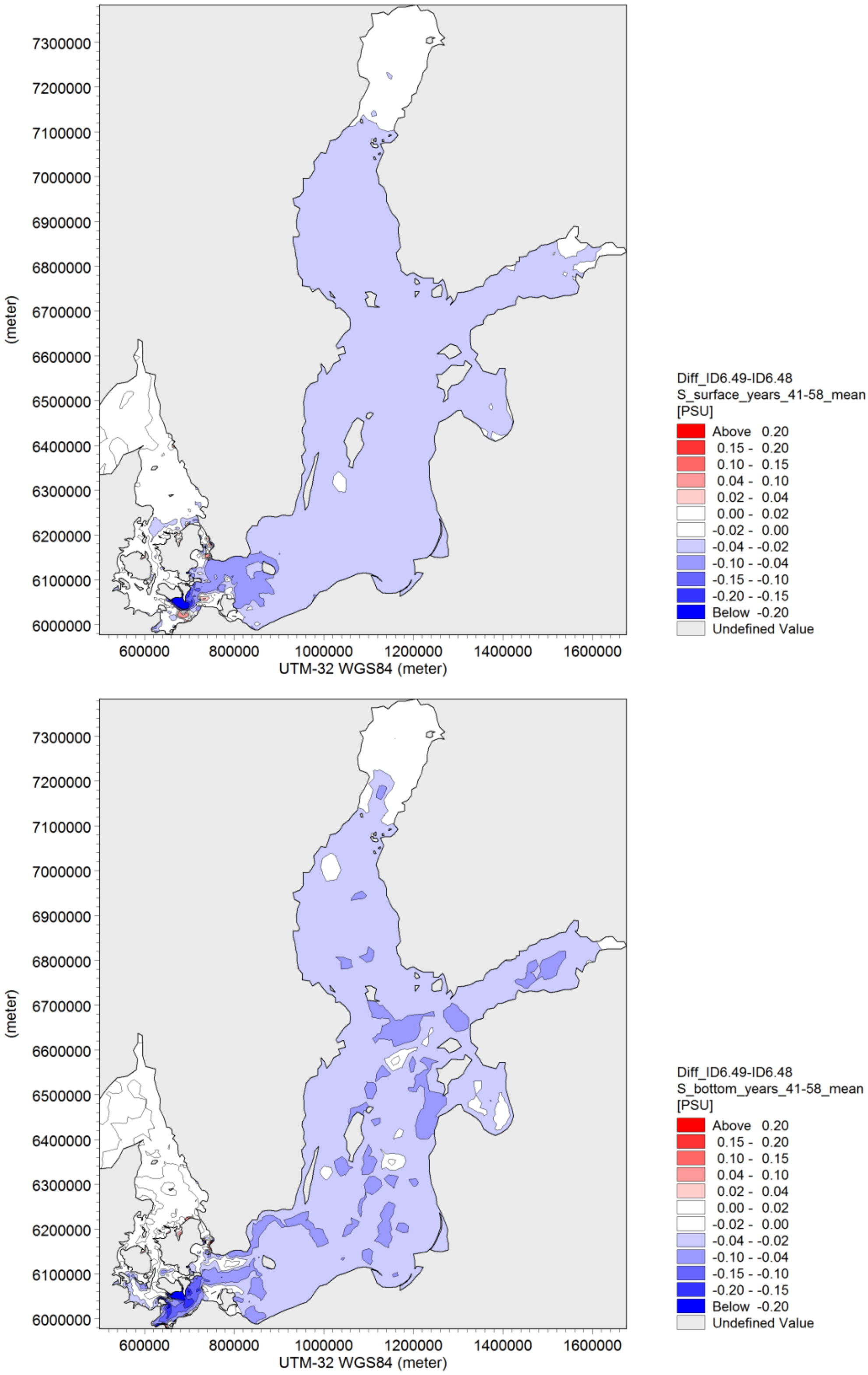


Fig. 7.3 Change in mean salinity for the "bridge+ferry" scenario (MIKE regional model, forcing data 1990-2007). Top: surface salinity change. Bottom: Bottom salinity change.

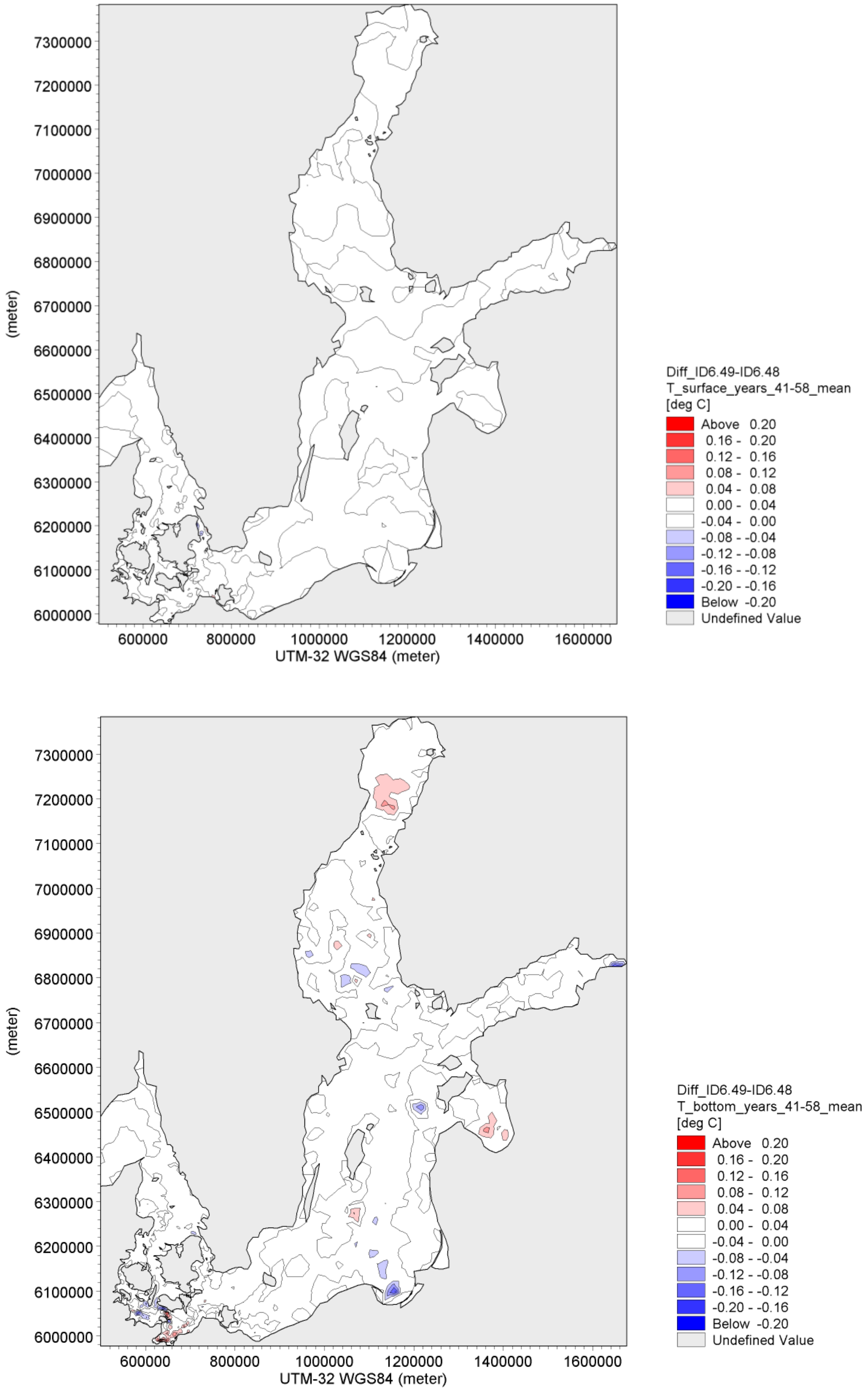


Fig. 7.4 Change in mean temperature for the "bridge+ferry" scenario (MIKE regional model, forcing data 1990-2007). Top: surface temperature change. Bottom: Bottom temperature change.

Table 7.4 Effect to mean salinity and temperature for various positions in the Central Baltic Sea for "Bridge+ferry" case, 18-year period (1990-2007 forcing).

"Bridge+ferry" vs. "Ferry" case	**Arkona Basin (K04)**		**Bornholm Basin (K02)**		**Gotland Basin (J01)**	
	MIKE	MOM[1]	MIKE	MOM[1]	MIKE	MOM[1]
$\Delta S_{mean,\ surface}$ $\Delta S_{mean,\ bottom}$	-0.052psu -0.053psu	-0.001psu -0.003psu	-0.026psu -0.034psu	-0.001psu -0.002psu	-0.027psu -0.016psu	-0.001psu -0.010psu
$\Delta T_{mean,\ surface}$ $\Delta T_{mean,\ bottom}$	-0.002°C +0.024°C	+0.001°C +0.013°C	-0.002°C +0.033°C	+0.001°C +0.029°C	-0.001°C -0.009°C	+0.001°C +0.015°C

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in Chapter 3.7.4.

Fig 7.5 illustrates that the changed salinity over the depth varies somewhat from the surface and bottom values provided in Table 7.4. However, the changes are limited. The associated change in the level of maximum salinity gradient (halocline level) is 0.1-0.4m.

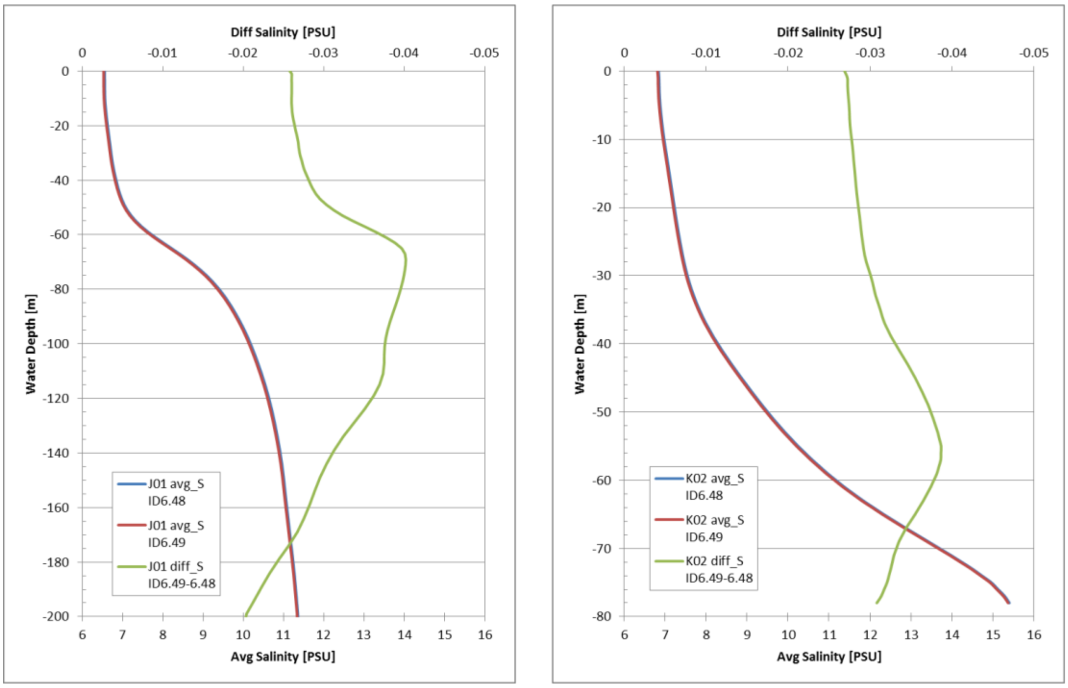
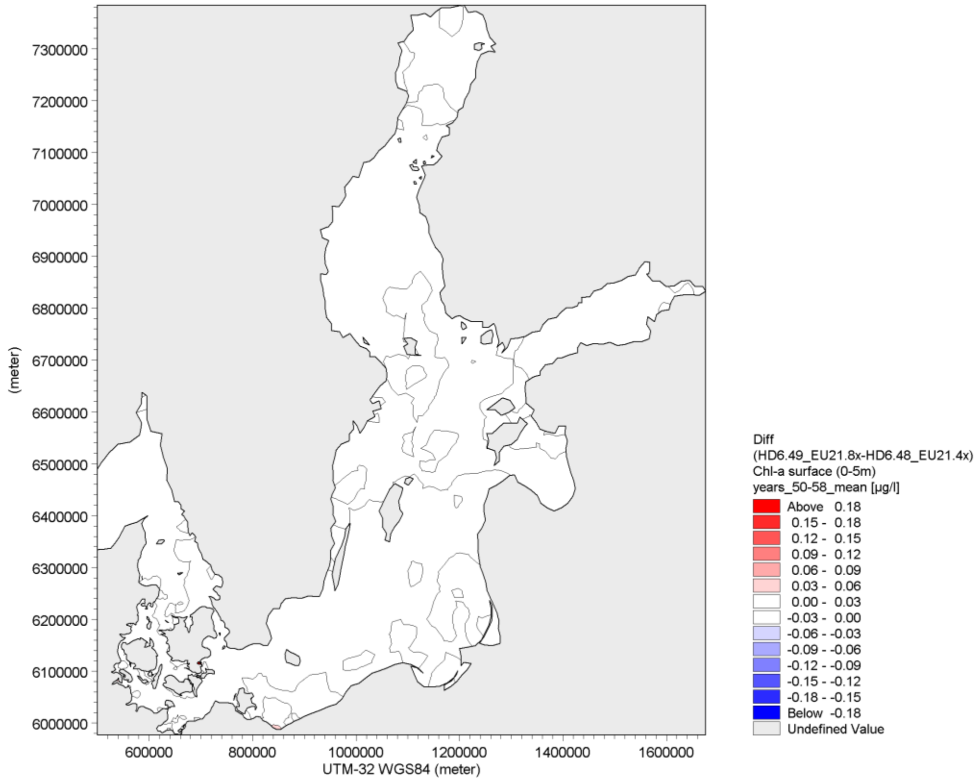


Fig. 7.5 Average salinity profile at two positions from MIKE regional model (left: JO1 Gotland Basin; right: KO2 Bornholm Basin) and salinity change modelled for the 18-year period (1990-2007 forcing)

Water quality parameters and plankton
The estimated effects on Chlorophyll, blue-green algae, dissolved oxygen and transparency (Secchi depth) for the "Bridge+ferry" case are shown in Figures 7.6 to 7.9 for the MIKE 3 regional model and the MOM regional model.



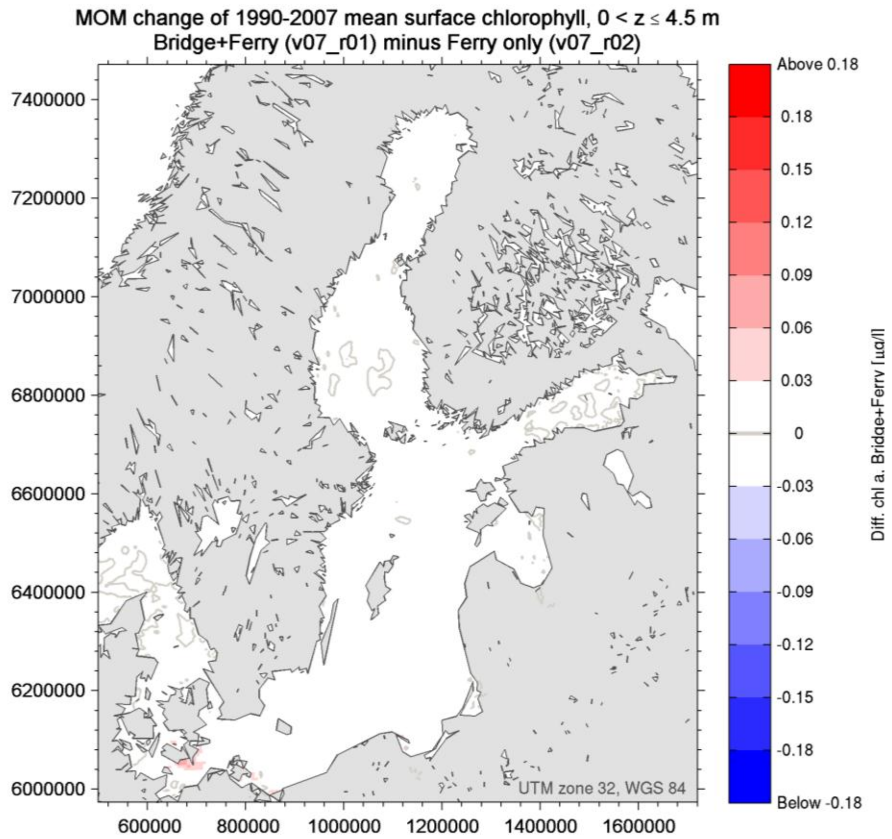
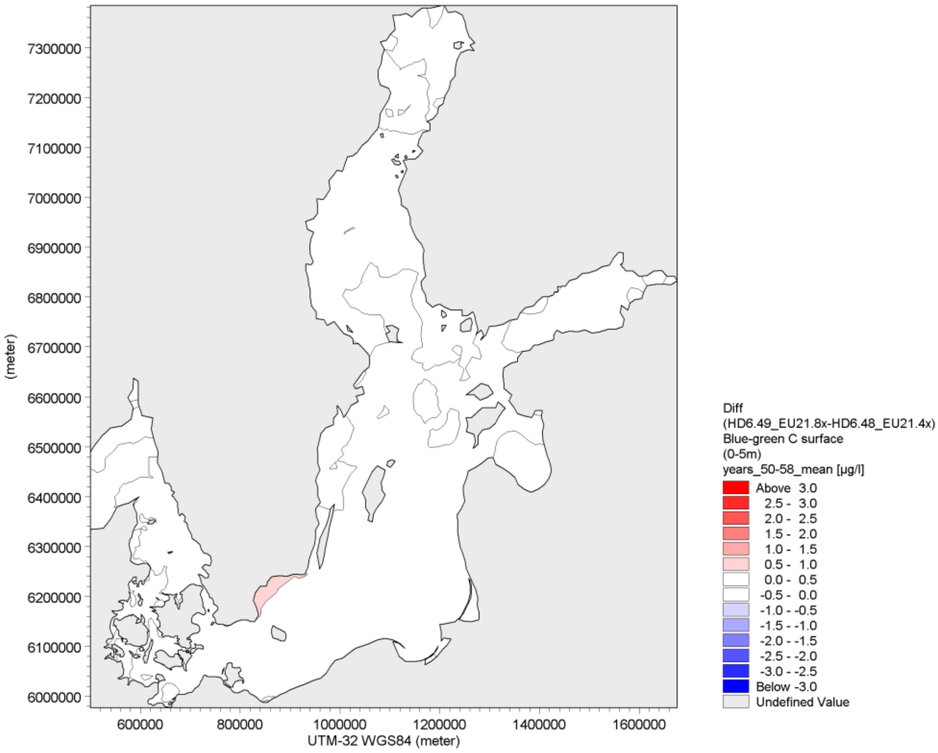


Fig. 7.6 Change in mean surface Chlorophyll-a for the "bridge+ferry" scenario (Top: MIKE model; Bottom: MOM model; forcing data 1990-2007).



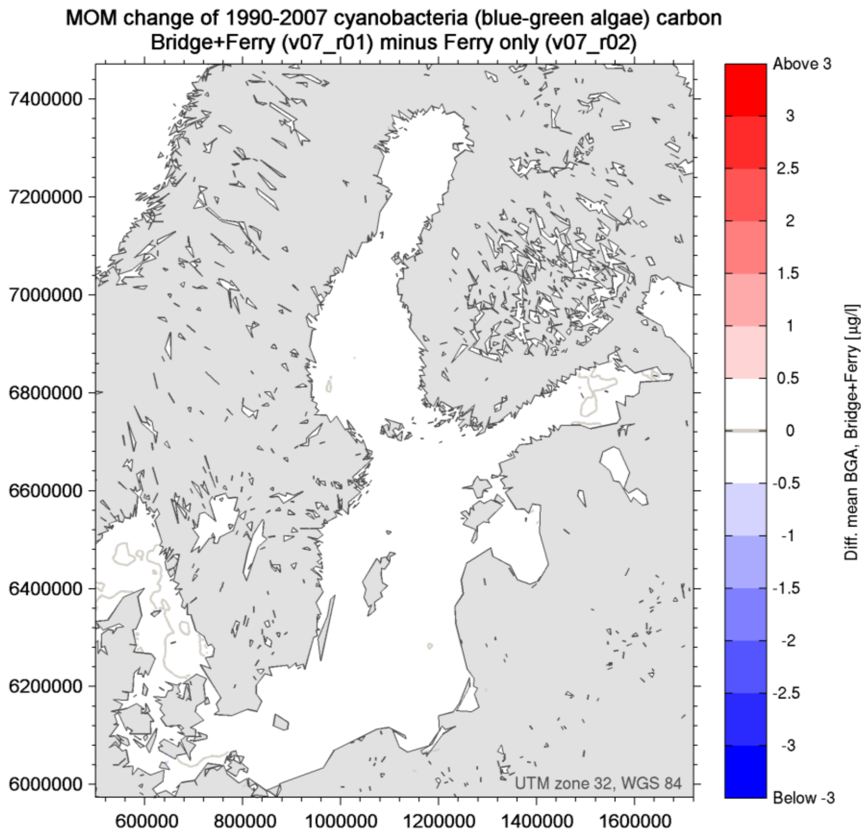
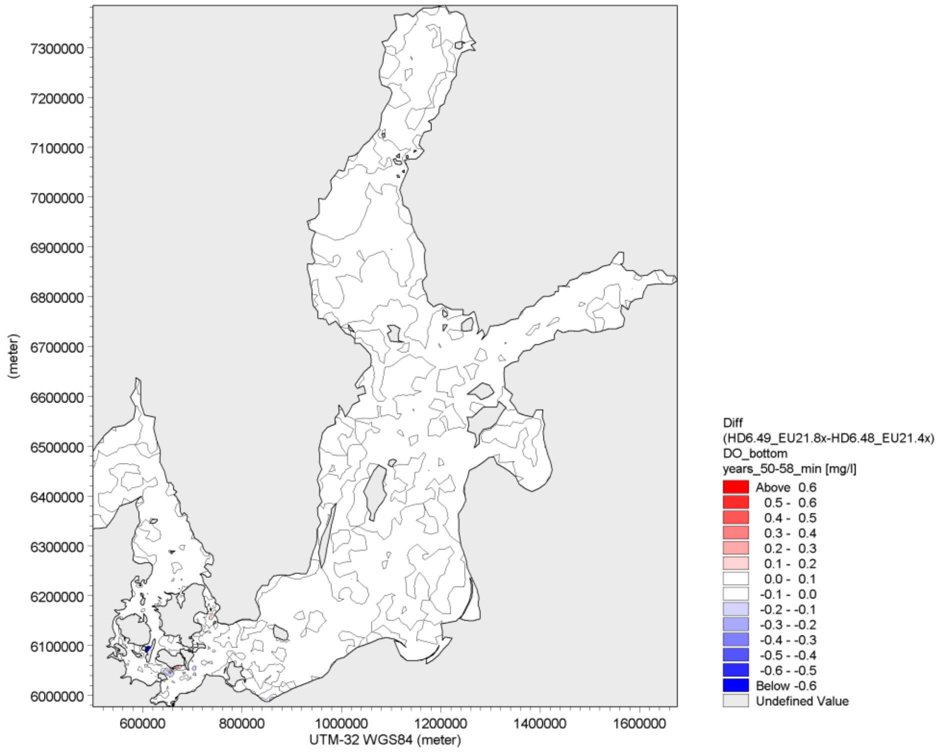


Fig. 7.7 Change in mean surface blue-green algae concentration (carbon content) for the "bridge+ferry" scenario (Top: MIKE model; Bottom: MOM model; forcing data 1990-2007).



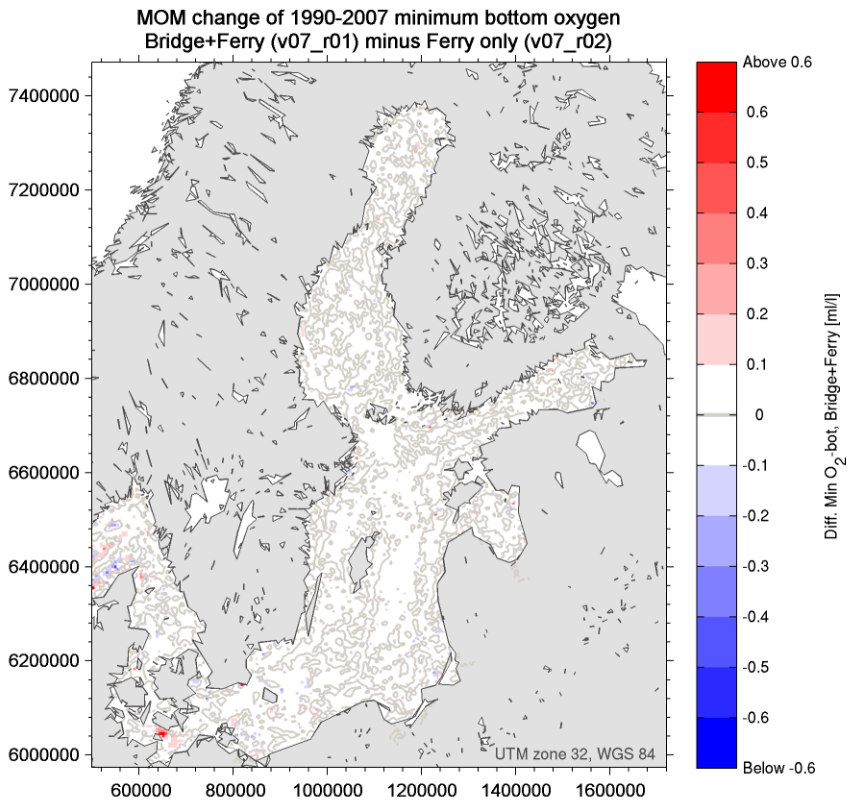


Fig. 7.8 Change in minimum oxygen concentration at bottom for the "bridge+ferry" scenario (Top: MIKE model; Bottom: MOM model; forcing data 1990-2007).

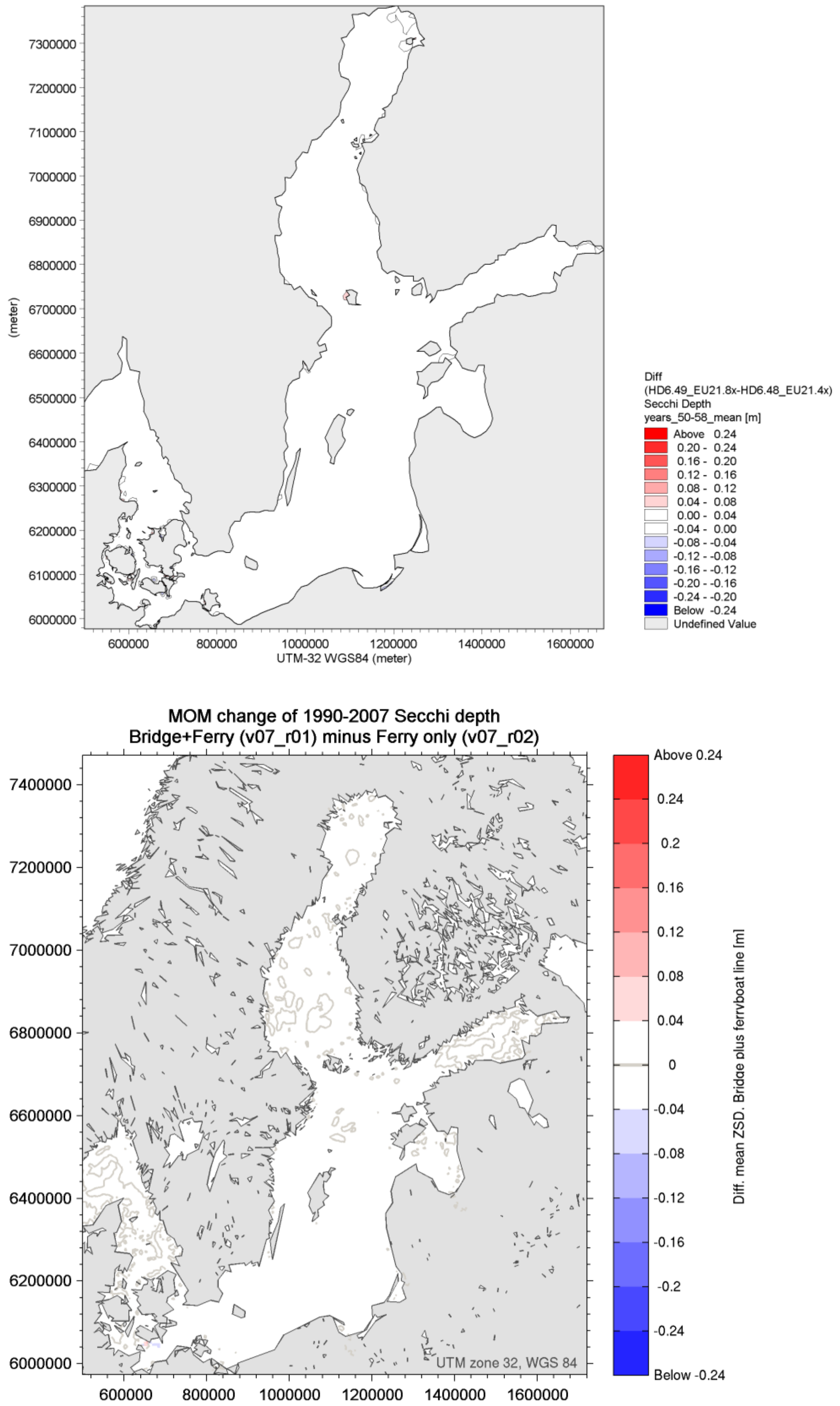


Fig. 7.9 Change in mean transparency (Secchi depth) for the "bridge+ferry" scenario (Top: MIKE model; Bottom: MOM model; forcing data 1990-2007).

The estimated chlorophyll effect is a slight increase of 0.003-0.004µg/l in annual mean for the MIKE model and up to 0.01µg/l in the MOM model (after correction by factor 3), see Table 7.5 for details for three key positions.

Table 7.5 Effect to key WQ parameters for various positions in the Central Baltic Sea for "Bridge+ferry" case, 18-year period (1990-2007 forcing)

"Bridge+ferry" compared to "Ferry" case	**Arkona Basin (K04)**		**Bornholm Basin (K2)**		**Gotland Basin (J01)**	
	MIKE	MOM[1]	MIKE	MOM[1]	MIKE	MOM[1]
$\Delta DO_{min,\ bottom}$ (mg/l)	-0.002	-0.031	0.015	-0.027	0.000	-0.016
$\Delta Chl_{mean,\ surface}$ (µg/l)	0.003	0.004	0.003	0.004	0.004	0.003
ΔBluegreen-$Carbon_{mean,surface}$ (µgC/l)	0.22	0.10	0.15	0.11	0.14	0.11
ΔSecchi depth mean (m)	0.017	-0.002	0.018	-0.001	0.017	-0.002

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in Chapter 3.7.4.

For blue-green algae the MIKE regional model gives an increase of up to 0.2µgC/l in annual mean concentration for the MIKE model and up to 0.3 ugC/l (after correction by a factor 3) in the MOM model. Locally along the Swedish coast of Ystad the increase in the MIKE model exceeds 0.5ugC/l. For reference the annual mean concentration in the two regional models is from 20 to more than 70ugC/l for the Central Baltic Sea.

Everywhere the effect to minimum bottom oxygen is well below ±0.1mg/l. At the Arkona station the two models both give a reduced minimum oxygen concentration (MIKE: -0.002mg/l, MOM -0.09mg/l (after correction by factor 3)), while the changes are opposite at the two other key stations in Bornholm Basin and Gotland Basin.

Transect plots (see Fig. 7.10) confirm that there are no large dissolved oxygen changes at other levels of the water column. The largest changes occur at 60-100m depth in the Eastern Gotland Basin and are up to ±0.05 mg/l. In the areas with reduced oxygen the baseline value for mean oxygen concentration is 3-5 mg/l.

The transparency (Secchi depth) of the two models is changed marginally but oppositely. The MIKE model gives a slight improvement in the annual mean Secchi depth of up to 0.02m, while the MOM model predicts reductions of up to -0.006m (after correction with a factor 3) at the three key stations.

The two model predictions of the effects for the "Bridge+ferry" scenario vs. the present "Ferry" case show many similarities but also some differences in statistical properties for specific positions. Generally the MIKE model provides the largest changes in conditions for most state variables, except dissolved oxygen and chlorophyll.

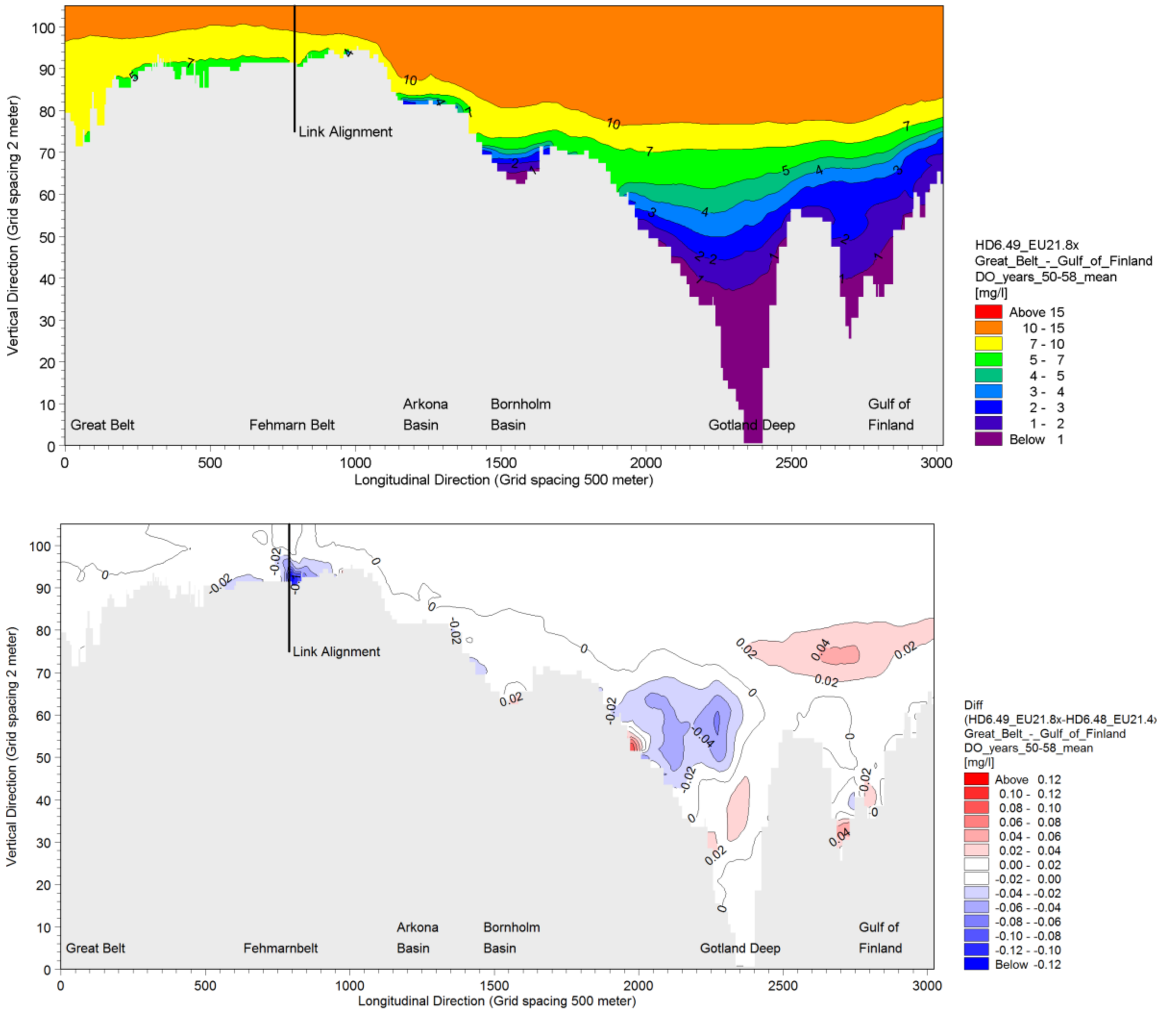


Fig. 7.10 Mean oxygen (top) and change in mean oxygen(bottom) along a longitudinal transect from the Great Belt to the Gulf of Finland for the "bridge+ferry" scenario (MIKE regional model, forcing data 1990-2007).

Furthermore, it is noted that the two models are different with respect to spin-up period duration for the Baltic Sea to reach a new equilibrium after the implementation of the link in the models. MOM seems to reach the new equilibrium within the first 20 years (Fig. 3.13), but has afterwards some oscillations in effects. The MIKE model has a slower but steadily increasing response to the link (Fig. 3.12), and does not reach the new equilibrium until after about 40 years.

The differences may be attributed to the two basic models and their solution technique and to some extent probably also to spatial resolution, particularly in the Fehmarnbelt section, whereas the forcing conditions and the drag/lift/mixing specifications for the tested bridge are the same for the two models.

The predicted increase in average biomass of blue-green algae is very small between 0.11 and 0.22 µgC/l depending on the subarea and the model applied. Assuming a carbon/chlorophyll ratio (weight) of 40 the very small modelled increase in chlorophyll can be fully explained by the increase in blue-green algae. The modelled increase in blue-green algae is probably due to slight reductions in salinity as the dominating species (Nodularia and Aphani-zomenon) have an optimum growth between 2 and 4psu and lower growth rates at lower and higher salinities (MIKE model). Compared to the modelled variation (SD, see Table 3.3) and measured variation in biomass between years since 1977 (Wasmund et al. 2011) the predicted changes are insignificant.

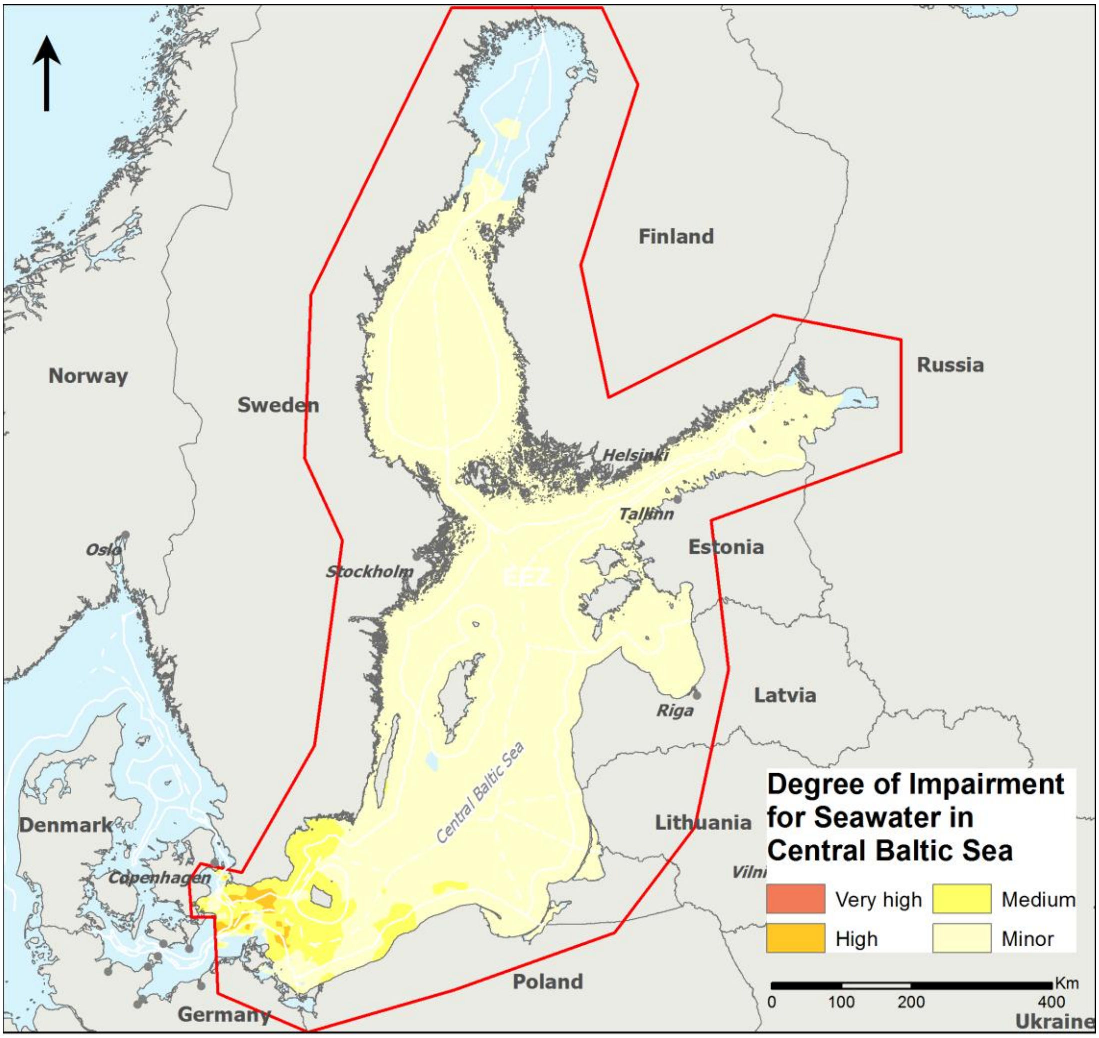
In Table 7.6 a comparison of predicted changes for the Baltic Sea with standard deviation and mean value of the baseline parameters is provided. The baseline parameters are quoted for the station K02 in the Bornholm Basin as a station representing the typical conditions in the Baltic Sea. The comparison is performed focussing on the upper limit of the estimated effects, taking both spatial variation and the results from the two regional models into account.

Table 7.6 Summary of magnitude for key effects in the Baltic Sea for "Bridge+ferry" case, 18-year period (1990-2007 forcing). The table is also a valid approximation for the "Bridge" only case.

"Bridge+ferry" compared to "Ferry" case	Upper limit for estimated change in the Central Baltic Sea	Monitoring data K02 Bornholm Basin (1990-2007)	
		Standard deviation	**Mean value**
Mean water level (annual mean)	Locally up to 0.0006 m, typically much less	0.2m (MIKE3 results)	-
Max water level (18 years)	Locally up to 0.003 m	0.2 m (MIKE3 results)	-
Blocking of instantaneous flow across Darss	0.5% (0.4-0.7%)	-	-
Redistribution of flow from Darss to Drogden	25-40 m^3/s	111,500m^3/s (MIKE3 at Darss)	10,400m^3/s (MIKE3 at Darss)
Surface salinity (annual mean)	Arkona Basin down to -0.05 to -0.08 psu, remaining Baltic Sea down to -0.03 psu	0.34psu (mean for Baltic Sea stations)	7.5psu
Bottom salinity (annual mean)	Everywhere down to -0.05 psu	1.1psu	16.3psu
Surface temperatures (annual mean)	Less than ±0.005 ºC	5.8°C	10.5°C
Bottom temperature (annual mean)	Bornholm Basin locally up to +0.09 ºC, elsewhere typically below ±0.05 ºC	1.5°C	6.5°C
Stratification (annual mean)	In Arkona Basin up to 0.08kg/m^3 locally, elsewhere about -0.014kg/m^3	0.8kg/m^3	5.3kg/m^3
Bottom Oxygen (minimum)	MIKE down to -0.002mg/l, MOM larger effects (max ±0.09mg/l after scaling)	2.3mg/l	1.6mg/l
Surface Chlorophyll (annual mean)	Up to 0.01 µg/l	1.8µg/l	2.3µg/l
Blue-green Carbon (annual mean)	Locally +0.5µgC/l, typically below +0.2µg/	30-60µg/l (MIKE3 and MOM)	17-35µgC/l (MIKE3 and MOM)
Secchi depth (annual mean)	Up to +0.02m	3.2m (1910-1999)	9.8m (1910-1999)

7.1.3 Loss and degree of impairment

The aggregation of the degree of impairment for the individual sub component indicators for the bridge results in the distribution of degree of impairment shown in Fig. 7.11. The size of the affected areas is given in Table 7.7.



Bridge Var.2 B-EE (October 2010): Permanent impacts

Fig. 7.11 The estimated degree of impairment distribution for permanent Central Baltic Sea impacts of the cable stayed bridge Var. 2 B-EE (October 2010).

Table 7.7 The degree of impairment area for permanent Central Baltic Sea impacts to hydrography, water quality and plankton after implementation of the cable stayed bridge Var. 2 B-EE (October 2010)

Component	**Central Baltic Sea impacts for Bridge Var. 2 B-EE (October 2010)**										
	Total area [km²]	Various subpart areas (km²)									
		DK	D	POL	RUS	LT	LV	EST	FIN	S	EEZ
Loss area	0	0	0	0	0	0	0	0	0	0	0
Impairment area											
Very high	0	0	0	0	0	0	0	0	0	0	0
High	2,310	247	206	0	0	0	0	0	0	716	1,141
Medium	22,213	3,657	1,259	1,820	0	0	0	0	0	4,920	10,558
Minor	320,584	1,883	1,622	7,743	15,049	2,317	12,796	25,872	46,891	57,600	148,811
Total impairment	**345,108**	**5,787**	**3,087**	**9,562**	**15,049**	**2,317**	**12,796**	**25,872**	**46,891**	**63,235**	**160,510**
Total permanent	**345,107 (90.6%)**	**5,787**	**3,087**	**9,562**	**15,049**	**2,317**	**12,796**	**25,872**	**46,891**	**63,235**	**160,509**
Reference area[1]	380,976										

Note 1: Area of the Baltic Sea out to the Drogden and Darss Sills

The degree of impairment reaches the "High" level in subparts of the Arkona Basin. This is dominantly due to surface salinity changes. The associated surface salinity effects are in Chapter 7.1.2 found to be up to -0.08psu. When compared to the standard deviation of surface salinity of about 0.34psu this gives a change of about 25% of the standard deviation for these subparts and therefore the "High" impairment (20-100% of standard deviation). This change in mean salinity implies that the distribution of salinity at the surface with and without the bridge scenario will still overlap by 92-60%.

In the Bornholm Basin "medium" impairment is found in subparts. This again is due to surface salinity ("Medium" impairment range is 10-20% of standard deviation or 96-92% overlap of distributions).

The remaining part of the Central Baltic Sea reaches "minor" degree of impairment, except for negligible impairment in the Bothnian Sea and innermost part of Gulf of Finland.

7.1.4 *Impact severity of loss and impairment*

A full importance mapping has not been established on the Baltic Sea scale. Instead an assumption of general importance everywhere is applied.

When combining the degree of impairment in the Baltic Sea with the importance, the result becomes as displayed in Fig. 7.11, with large areas of "minor" severity, except for parts of the Arkona and Bornholm Basins where the severity reaches "Medium". Table 7.8 provides the quantification of the severity areas.

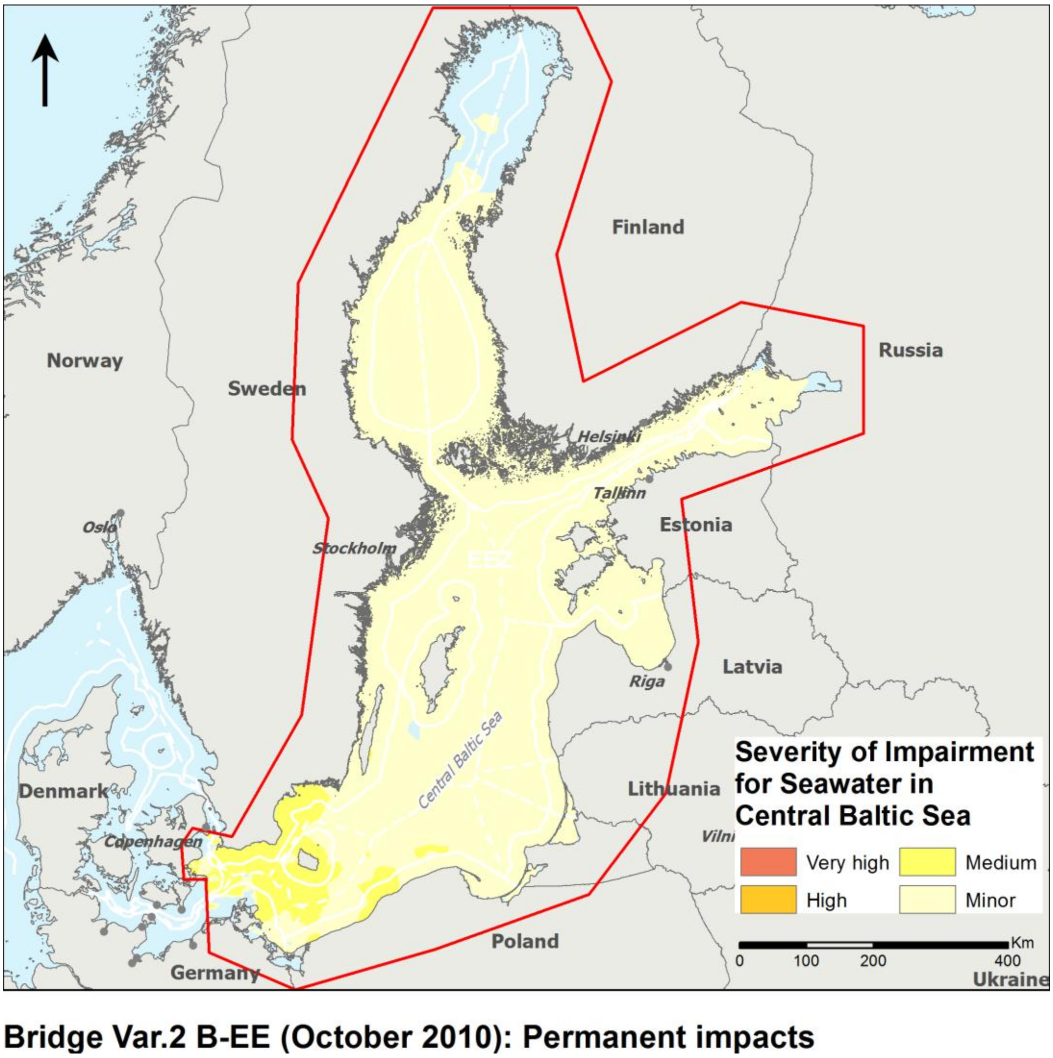


Fig. 7.12 The impact severity distribution for permanent Baltic Sea impacts of the cable stayed bridge Var. 2 B-EE (October 2010)

Table 7.8 *The impact severity area size for permanent Central Baltic Sea impacts to hydrography, water quality and plankton after implementation of the cable stayed bridge Var. 2 B-EE (October 2010)*

Component	Central Baltic Sea impacts for Bridge Var. 2 B-EE (October 2010)										
	Total area [km^2]	Various subpart areas (km^2)									
		DK	D	POL	RUS	LT	LV	EST	FIN	S	EEZ
Severity of loss	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Severity of impairment											
Very high	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0
Medium	24,523	3,903	1,465	1,819	0	0	0	0	0	5,635	11,699
Minor	320,584	1,883	1,622	7,743	15,049	2,317	12,796	25,872	46,891	57,599	148,811
Total	**345,107 (90.6%)**	**5,787**	**3,087**	**9,562**	**15,049**	**2,317**	**12,796**	**25,872**	**46,891**	**63,235**	**160,509**
Reference area[1]	380,976										

Note 1: Area of the Baltic Sea out to the Drogden and Darss Sills

7.1.5 Impact significance

The permanent impact area size is summarised in Table 7.8. In total the areas affected by "Minor" to "Medium" severity add to 345,000km^2 or 91% of the Central Baltic Sea area. The "Minor" and "Medium" severity areas add to 6% and 84%, respectively. There are no areas of "High" or "Very High" severity.

The overall assessment of effects to the hydrography, water quality and plankton conditions for the cable stayed bridge is that it has no significance for the general Central Baltic Sea conditions. The identified effects of a non-negligible level according to the established impact criteria is dominated by the reduced salinity of about 0.03psu, which for the upper layer causes the areas of minor/medium severity. The other indicators (bottom salinity, temperature, oxygen, plankton and transparency) come out with negligible effects except for minor areas. As a changed salinity of the order of 0.03psu not itself can be claimed to be significant for the Baltic Sea system, the overall assessment is that effect is of no significance to Baltic Sea hydrography, water quality and plankton.

The reduction in upper layer salinity of 0.03psu corresponds to about 9% of the standard deviation for the surface salinity in the Central Baltic Sea. It will hardly be possible to measure this in practice - not even over a very long time span.

Furthermore, within the same time span climate changes will probably cause salinity changes which are much larger, see Chapter 7.6.

Other Central Baltic Sea parameters related to hydrography, water quality and plankton will not to any significant degree be impacted.

The effect of the cable stayed bridge to the water exchange with the Central 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% flow effect is compensated by dredging (DHI/LIC JV 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 JV 2000).

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

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. 7.13 are present. The size of these temporary structures are summarised in Table 7.9.

Table 7.9 The dimensions of the extra pressure elements during the construction period for cable stayed bridge Var. 2 B-EE (October 2010) in relation to Central Baltic Sea impacts.

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

The construction activities also cause spill of dredging material, adding to the suspended sediment in the vicinity of the construction works. About half of this spilled sediment will enter the Central Baltic Sea. This pressure is described in detail in (FEHY 2013f) and is so limited that it is not considered relevant to assess in relation to the Central Baltic Sea.

Also the associated effect with a minimal reduction in plankton production in Fehmarnbelt because of shading from the suspended sediments is assessed as being insignificant in relation to being a pressure for the Central Baltic Sea.

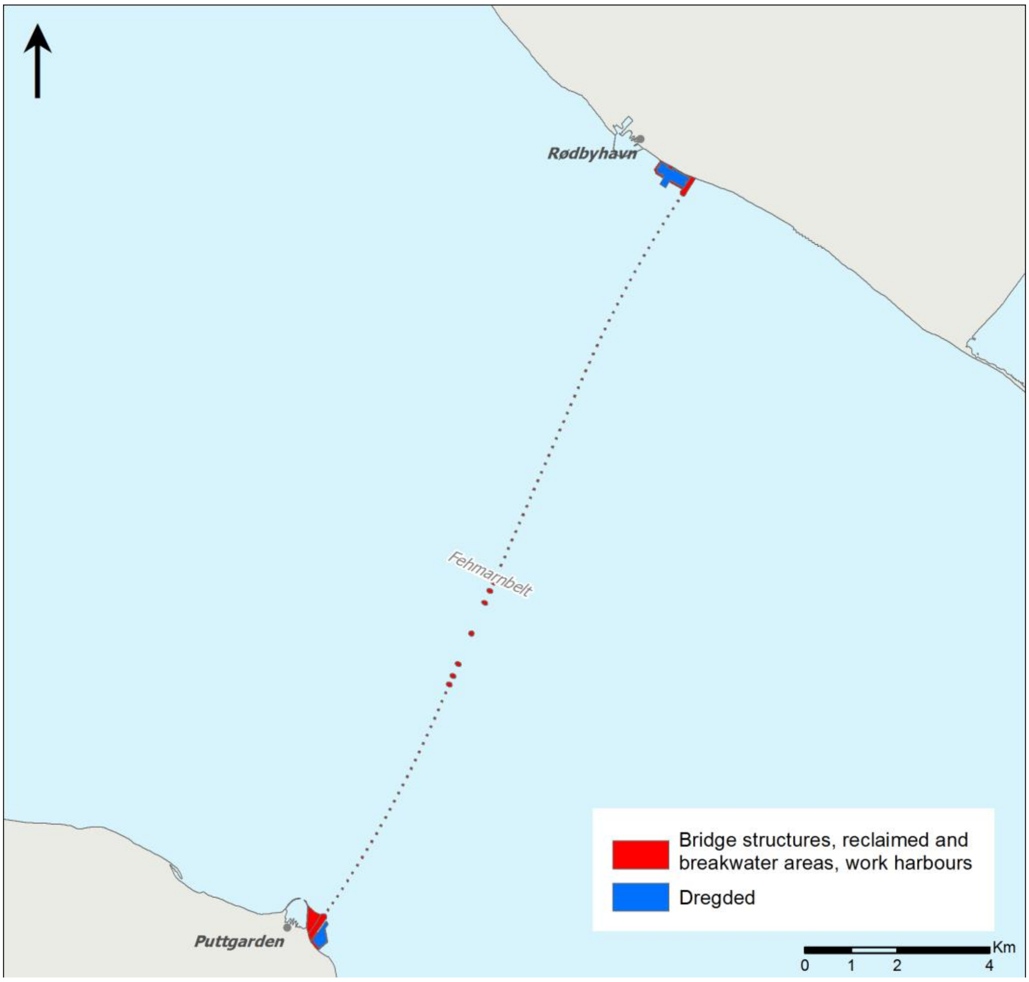


Fig. 7.13 Cable stayed bridge Var. 2 B-EE (October 2010) elements in the construction period acting as pressure factors in the Central Baltic Sea assessment.

7.2.2 Impact magnitude

Both work harbours with associated excavations are constructed in lee of the marine ramps. And at a short distance eastwards of the present harbour breakwaters at Rødbyhavn and Puttgarden.

The detailed hydrodynamic and water quality modelling has not specifically covered this stage of the cable stayed bridge project. However, with the position in lee of the existing and new structures, no effect to the water exchange with the Central Baltic Sea is foreseen.

Thus the impacts to the Central Baltic Sea in the construction period will slowly build up during the compensation period. However, it will not reach the permanent impacts even when both marine ramps and all pier and pylon structures are in place, because of the long response time of e.g. the Central Baltic Sea salinity to flow blocking effects. Thus the construction period impacts to the Baltic Sea will not at any stage exceed the permanent impacts described in Chapter 7.1.2. It is evaluated that in reality the impairment will only have reached about 20-35% of the permanent impacts within the short 5-year construction period.

7.2.3 Loss and degree of impairment

The degree of impairment for the construction period has not been assessed specifically, but due to the long response time of the Central Baltic Sea it will be less than the permanent impacts.

Using the above estimate of construction period impacts having developed to only 20-35% of the permanent impacts, the Central Baltic Sea will dominantly have “Negligible” degree of impairment during the construction period. Furthermore, it is noted that there will not be any loss areas.

7.2.4 Impact severity of loss and impairment

The severity mapping for the Central Baltic Sea impacts to hydrography, water quality and plankton in the construction period would come out as having mainly “Negligible” severity of impacts. The map has not been processed specifically, because the severity will be less than the permanent impacts building up over several decades.

7.2.5 Impact significance

During the construction period the impact to Central Baltic Sea will be assessed as being insignificant, due to the relatively short construction period compared to the response time for most changes in the Central Baltic Sea.

7.3 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.

7.4 Cumulative impacts

The present pressures for the Central Baltic Sea according to the baseline assessment (FEHY 2013e) include:

- Major constructions: Like large offshore and onshore constructions. The bridges across the Danish Straits are all designed as zero solutions and are thus not supposed to affect the hydrography of the Baltic Sea directly. While it has been shown in the QuantAS study (HELCOM 2009c) that the effect on the hydrography and ecology of the Baltic Sea of offshore wind farms is negligible in shallow waters, the impact of future offshore wind farms that may comprise up to 1,000 turbines is yet unclear.

- Ship and ferry traffic: One effect is due to high-speed ferries affecting nearby coasts due to the wakes they produce while sailing with full speed. The other effect is the general increase of shipping. A risk occurs in certain areas like the Great Belt or in the Gulf of Finland where traffic of oil tankers is ever more increasing. Collisions or grounding of oil tankers pose a threat of severe oil spills that will affect the Baltic Sea ecosystem for decades due to the slow exchange of water masses in the Baltic.

- Eutrophication and hazardous substances: Only the open waters of the Bothnian Bay and the Swedish parts of the north-eastern Kattegat are classified as areas not affected by eutrophication according to (HELCOM 2009a). In the coastal zone, 161 areas show signs of eutrophication, only 11 have a good ecological status. Consequently, HELCOM comes to the conclusion that eutrophication is still a major concern despite measure undertaken so far. There the so-called Baltic Sea Action Plan which was adopted 2007 by all Contracting Parties of the Helsinki Commission, aims at further reducing nutrient input.

The Baltic Sea has been exposed to an extensive use of chemicals since the beginning of industrialization in the area, and its marine environment has a long history of contamination. With the exception of the north-western Kattegat, all open-sea areas of the Baltic Sea were classified as being disturbed by hazardous substances (HELCOM 2010c). 98 of the 104 coastal assessment units were classified as being disturbed by hazardous substances.

- Expected climate change

Besides the plans for shallow water wind mill parks at Krieger's Flak and some minor wind parks around Fehmarn, there are no other firm plans for large structures in the Baltic Sea. The wind mill parks at Rødsand are already established and thus part of the baseline.

The likely substantial 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.

7.5 Transboundary impacts

Most of the estimated impact areas in the Baltic Sea should be regarded as transboundary impacts. It is estimated that outside the Baltic Sea and its transition area to the Skagerrak and North Sea impacts will all be very marginal and not exceed the negligible threshold level.

7.6 Climate change

The warming trend for the Baltic Sea basin in the last century is in the order of 0.08°C/decade and therefore larger than the global trend of 0.05°C/decade. A pronounced warming started around 1990 which is related to the accelerating global warming trend.

For the Baltic Sea basin Regional Climate model (RMC) simulations show a positive temperature trend. In winter and spring the temperature increase is stronger compared to summertime in the north-eastern part of the Baltic Sea basin, and in the south-western part the increase is stronger in summer. Furthermore, daily maximum temperature in summer will increase from 3°C to 10°C. For precipitation the simulations show an increase in winter, while in summer projections show an increase in the northern part and a decrease in the southern part. Extreme precipitation events generally show an increase in winter. The sea ice season will decrease by 1-2 months in the northern part and 2-3 months in the central part of the Baltic Sea. The sea surface temperature will increase by 2-4°C and would be strongest in May and June and in the southern and central basins.

Global sea level rise will propagate into the Central Baltic Sea as well. The most recent projections are up to +1m at the end of the 21th century according to a dedicated Fehmarnbelt climate change effect workshop (FEHY 2009).

The combined effect of the increased precipitation, increased evaporation due to temperature increase and a sea level rise of up to 1 m on the salinity of the Central Baltic Sea are not yet known.

The bridge project impacts under such a new climate setting are assessed as being similar to the estimated impact found above for the present climate setting. The bridge structures will have a tendency to reduce the exchange flow with the Central Baltic Sea by about 0.5%, and the associated effect to stratification etc. will approximately be as described above.

However, it should be mentioned that isolated each of the climate pressures may cause much larger change to the Central Baltic Sea than the bridge project.

Tentative model calculation undertaken with the MIKE modelling tool thus indicated that the present sea level rise of 0.003m per year within eight years will result in an increased water exchange with the Central Baltic Sea of the same magnitude as the bridge project. And this sea level rise is assumed to continue and even accelerate in the coming decades.

Therefore it seems unlikely that it will even be possible to verify the impacts of the bridge to the Baltic Sea by measurements e.g. of surface salinity, as climate caused changes will be much larger within few decades.

7.7 Mitigation and compensation measures

In general the impacts of the bridge project to the Central Baltic Sea hydrography, water quality and plankton composition are evaluated being insignificant, and therefore mitigation is less relevant.

It has earlier been assessed (Feasibility Study 2006) whether 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 also 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 central Baltic Sea during the decommissioning period is evaluated as being small. After decommissioning the minor Central Baltic Sea impacts will slowly regenerate over some decades to the state which the Baltic Sea would have developed into without the blocking effect from the bridge.

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 Central Baltic Sea conditions very differently. Table 8.1 summarises the impairment area. While the total permanent impact area for the immersed tunnel is 0% of the Central Baltic Sea area, about 90% are affected to a minor degree of impairment by the cable stayed bridge alternative.

Table 8.1 The degree of impairment area for the situation for Central Baltic Sea 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 (km^2)[1]	**Total area (km^2)[1]**
Construction period impairment	**0**	**0 (impacts typically about 40 years to develop**
Permanent impairment		
Very high	0 (0.0%)	0 (0.0%)
High	0 (0.0%)	2310 (0.6%)
Medium	0 (0%)	22,231 (6%)
Minor	0 (0%)	320,600 (84%)
Total permanent impairment	**0 (0%)**	**345,100 (90%)**

Note 1: Relative to area of Baltic Sea out to the Drogden and Darss Sills

None of the areas in Table 8.1 relates to loss, as there is no project footprint inside the Central Baltic Sea.

Based on this comparison Table 8.2 and 8.3 summarises the impacts and relative ranking of the alternatives with respect to potential impacts to the Central Baltic Sea.

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

Assessed theme	**Immersed tunnel**	**Cable stayed bridge**
Conditions in the Central Baltic Sea	No significant impacts	Minimal permanent change of the salinity (also assessed as insignificant)

Tabel 8.3 Relative comparison of impacts of the immersed tunnel and bridge alternatives to the Central Baltic Sea. For each factor is 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
Conditions in the Central Baltic Sea	(+)		Tunnel gives no impacts to the Baltic Sea compared to minimal changes in salinity 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 Baltic Sea impacts for the two fixed link alternatives as versus the situation with continued ferry service. 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 Fehmarnbelt 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 calibration 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 hydrology. It is noted that the difference in modelled effect to the water exchange through Fehmarnbelt in the high resolution local models is low (GETM -0.42%, MIKE -0.5%). For the coarser regional models the blocking is -0.7% (MIKE) and -0.2% (MOM), however with a known underestimation in the MOM model of about a factor 3, due to 40% too low current speeds in the Fehmarnbelt section in the coarse MOM mesh. This means that after correction of the MOM results the regional models are close to the local models' blocking results.

The detailed impact impairment and severity assessment for the Central Baltic Sea are based mainly on the MIKE regional model results, as it is not fully clear if the MOM results can be scaled proportionally. At the same time the MIKE regional model in general has impacts exceeding the MOM (and the scaled MOM) results. Thus the approach is a conservative approach with respect to impacts in the Central Baltic Sea.

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

Thus the uncertainty of the assessments is assessed as being relatively low with a tendency to be conservative.

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Tables of impacts for the bridge case (without ferry service)

Table 7.2A Effect to water exchange parameters for the Central Baltic Sea for "Bridge" case.

"Bridge" compared to "ferry" case	**Local models (2005)**		**Regional models (18 years: 1990-2007 forcing)**	
	MIKE	GETM	MIKE	MOM[1]
Darss flow blocking	-0.49%	-0.40%	-0.70%	-0.25%
Net outflow effect Darss	(see regional models)	(see regional models)	-40 m^3/s	-24 m^3/s
Net outflow effect Drogden	(see regional models)	(see regional models)	+40 m^3/s	+23 m^3/s
Darss salt transport blocking	-0.49%	-0.39%	-0.94 %	-0.27%
Net salt outflow effect Darss	(see regional models)	(see regional models)	+326m^3*psu/s	-64m^3*psu/s
Net salt outflow effect Drogden	(see regional models)	(see regional models)	-177m^3*psu/s	+199m^3*psu/s

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in section 3.7.4.

Table 7.3B Water level effects for "Bridge" case, 1990-2007.

"Bridge" compared to "Ferry" case	**Arkona Basin (K04)**	
	MIKE	MOM[1]
ΔWl_{mean}	0.0005m	0.0002 m
$\Delta(Wl_{max})$	0.0010m	-0.0008m

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in section 3.7.4

Table 7.4B *Effect to mean salinity and temperature for various positions in the Central Baltic Sea for "Bridge" case, 18-year period (1990-2007 forcing)*

"Bridge" vs. "Ferry" case	**Arkona Basin (K04)**		**Bornholm Basin (K02)**		**Gotland Basin (JO1)**	
	MIKE	MOM[1]	MIKE	MOM[1]	MIKE	MOM[1]
$\Delta S_{mean,\ surface}$ $\Delta S_{mean,\ bottom}$	-0.053psu -0.044psu	-0.009psu -0.013psu	-0.024psu -0.029psu	-0.001psu -0.002psu	-0.026psu -0.017psu	-0.001psu -0.002psu
$\Delta T_{mean,\ surface}$ $\Delta T_{mean,\ bottom}$	-0.001°C +0.017°C	+0.000°C +0.001°C	-0.002°C +0.029°C	-0.001°C +0.022°C	-0.001°C -0.013°C	-0.003°C +0.013°C

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in section 3.7.4.

Table 7.5A *Effect to key WQ parameters for various positions in the Central Baltic Sea for "Bridge" case, 18- year period (1990-2007 forcing)*

"Bridge" compared to "Ferry" case	**Arkona Basin (K4)**		**Bornholm Basin (K2)**		**Gotland Basin (JO1)**	
	MIKE	MOM[1]	MIKE	MOM[1]	MIKE	MOM[1]
$\Delta DO_{mean,\ bottom}$ (mg/l)	0.004	-0.031	0.006	-0.027	0.000	-0.016
$\Delta Chl_{mean,\ surface}$ (µg/l)	0.002	0.005	0.001	0.004	0.002	0.004
ΔBluegreen-Carbon$_{mean,surface}$ (µg/l)	0.19	0.10	0.10	0.11	0.08	0.11
ΔSecchi depth $_{mean}$ (m)	0.016	-0.003	0.017	-0.002	0.016	-0.003

Note 1: MOM results need to be scaled up by a factor evaluated as being about 3 to account for low current speeds in the alignment section, see comment in section 3.7.4.