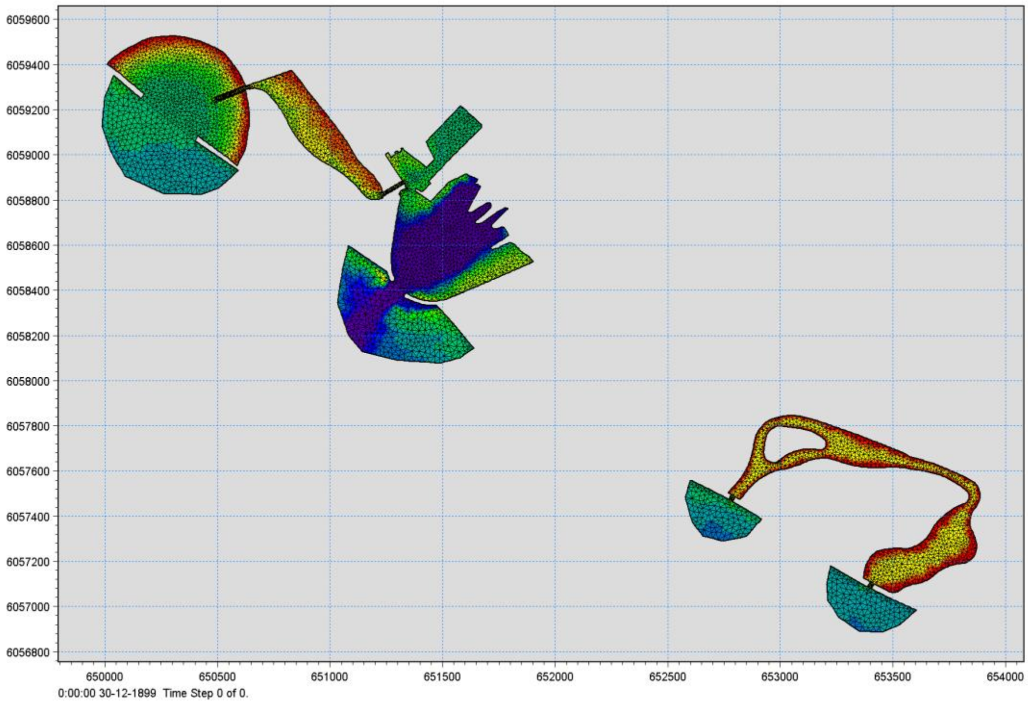
**Supplementary Report**

# FEHMARNBELT FIXED LINK
# Marine Biology Services (FEMA)

# Risk of TBT pollution of new recreational lagoons

**E2TR0032**




**October 2013**
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**Please cite as:**
FEMA (2013). Fehmarnbelt Fixed Link.
Risk of TBT pollution of new recreational lagoons

Report No. E2TR0032
Report: 19 pages

**October 2013**

**ISBN: 978-87-93074-01-9**



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

## Preface

The present note is a merge of two notes on Tributyltin (TBT) requested by Femern A/S as a supplement to the assessment made in the L2 report FEMA-FEHY (2013), Lolland reclamation lagoons, flushing and water quality E2TR0030. The note reports measurements of TBT in Rødbyhavn harbour and at a reference site in Fehmarnbelt and determines the modelling of the possible release and fate of the present TBT before and after establishing water exchange between the harbour and a new artificial recreational lagoon west of the harbour (as part of the land reclamation along the south-coast of Lolland). In addition to environmental concerns human health issues are also evaluated.

## *CONTENTS*

# 1 EXECUTIVE SUMMARY

As a part of the Fehmarnbelt Fixed Link it has been planned to design a number of artificial beaches and lagoons east and west of Rødbyhavn harbour. The recreational Inner Lagoon west of Rødbyhavn harbour is proposed to have a direct water connection to the harbour. This design would imply that water from the harbour basin can potentially influence the water quality of the lagoon and thereby also potentially the Pocket Beach Lagoon connected to the Inner Lagoon.

Since investigations of pollutants have shown that toxic organotins (e.g. TBT) can be found in high concentrations in sediment of the harbour and it is uncertain whether these organotin compounds are released to the water, a study of concentrations in mussels from the harbours has been conducted, followed by deterministic modelling of sediment release of TBT and spread of TBT to planned lagoons.

This report constitutes a risk assessment of the potential pollution of the lagoons with tributyltin compounds (TBTs) from the harbour area and the associated environmental impacts in the lagoons as well as health issues for recreational use of the lagoons.

The assessment of the environmental conditions in the new lagoons on the Lolland reclamations related to TBT released from Rødbyhavn harbour sediments and transported into the recreatiuonal lagoons west of Rødby has concluded the following for the provided layout with the developed depth specifications:

- Elevated levels of TBTs were measured in mussels collected in Rødbyhavn harbour which exceeded environmental assessment criteria (EAC) by a 10-factor

- Earlier investigation has documented elevated levels of TBTs in harbour sediment that approached the higher action levels set by the Danish authorities for handling dredged sediment

Assessments based on modelling of predicted concentrations in the Inner Lagoon documented that

- the environmental condition in the lagoons will not be degraded by TBT compounds released from the western harbour,

- TBT is only moderately toxic to humans and based on predicted concentrations in the Inner Lagoon human health effects will not occur.

The evaluations were based on a conservative assumption to estimate release from sediments. Using other literature data the release would have been 10 times lower.

## 2 INTRODUCTION

As a part of the Fehmarnbelt Fixed Link it has been planned to design a number of artificial beaches and lagoons east and west of Rødbyhavn harbour. The recreational Inner Lagoon west of Rødbyhavn harbour is proposed to have a direct water connection to the harbour. This design would imply that water from the harbour basin can potentially influence the water quality of the lagoon and thereby also potentially the Pocket Beach Lagoon connected to the Inner Lagoon.

Since investigations of different pollutants have shown that toxic organotins (e.g. TBT) can be found in high concentrations in sediment of the harbour and there is an uncertainty whether these organotin compounds are released to the water, a study of concentrations in mussels collected in the harbours has been conducted, followed by deterministic modelling of sediment release of TBT and spread of TBT to planned lagoons.

This report constitutes a risk assessment of the potential pollution of the lagoons with tributyltin compounds (TBT's) from the harbour area and the associated environmental impacts in the lagoons as well as health issues for recreational use of the lagoons.

## 3 TBT CONCENTRATIONS IN RØDBYHAVN HARBOUR

### 3.1 Rødbyhavn harbour and the Inner Lagoon

During the process of dredging the trench for the immersed tunnel for the Fehmarnbelt Fixed Link there will be a surplus of excavated soil. To make use of the soil it has been suggested to establish a number of beaches and lagoons at Lolland. One of the suggestions is to create an Inner Lagoon with a Paddling Beach immediately west of Rødbyhavn harbour with a connection to a Pocket Beach Lagoon (Figure 3.1). The Inner Lagoon will be directly connected to the marina basin of Rødbyhavn harbour by a channel in order to enhance flushing of the lagoon system (FEMA-FEHY 2013).

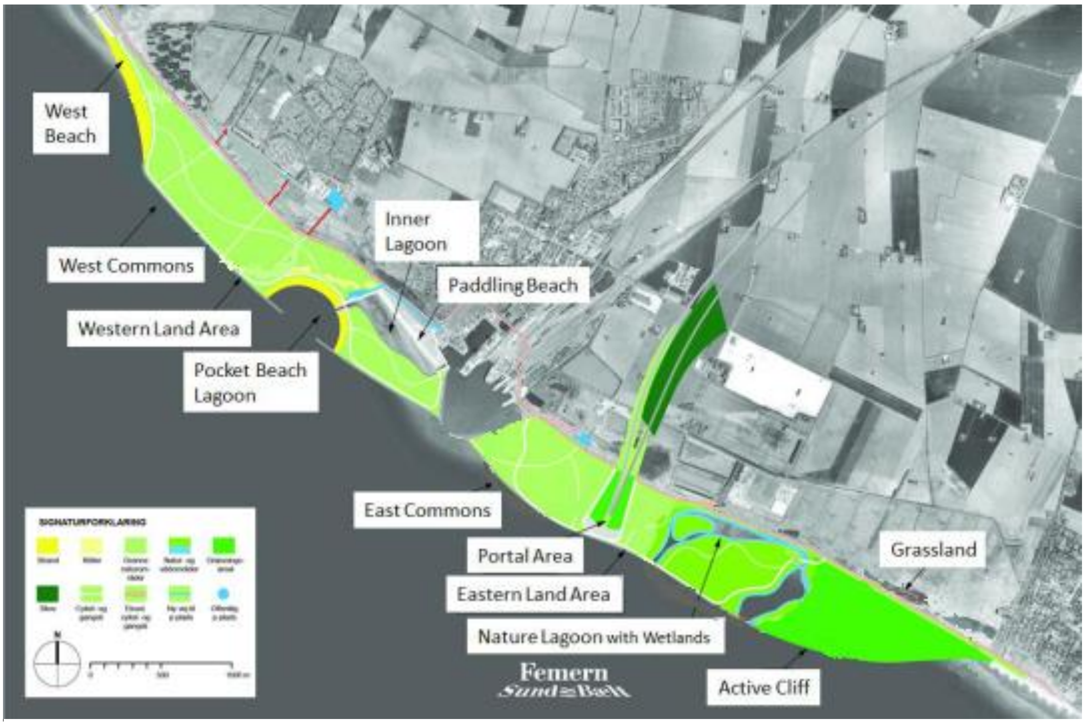



*Figure 3.1 Lolland land reclamation (figure modified from FEMA-FEHY 2013)*

Model results have shown that the flow direction of water in the Inner Lagoon will be from west to east in 34% of the time and from east to west in 66% of the time. Hence there will most likely be a transport of suspended and dissolved matter from the harbour into the lagoon (FEMA-FEHY 2013). Mean flushing time of the Inner Lagoon will be 0.9 days. Model results show that the water quality of the Inner Lagoon will be approximately identical to the water quality of the harbour basin (FEMA-FEHY 2013). Mean flushing time of Rødbyhavn harbour after construction of the lagoons and beaches is estimated at 4.3 days (FEMA-FEHY 2013).

### 3.2 Organotin compounds

The organotin compounds Tributyltin (TBT) and TriPhenyltin (TPhT) are considered to be two of the most toxic compounds released to the marine environment and are priority substances within OSPAR and the EU water frameworks directive. Both TBT and TPhT have been extensively used as antifouling agents on vessels and boats since the 1960'ies. Organotins accumulate in the seabed because of high affinity to sediments. In sediments organotin can persist for many years due to slow degradation under anaerobic conditions and protected from UV-radiation. Organotins can therefore be found in high concentrations in harbours and in areas with intensive ship traffic. Dibutyltin (DBT) and Monobutyltin are degradation products of TBT and are also of concern even though they are not as toxic as TBT.

Organotins are very harmful to marine organisms, and especially gastropods and bivalves are very sensitive to the compounds. Malformations such as impo- and intersex in marine gastropods at even very low concentrations (1-2 ng TBT-Sn $l^{-1}$) have been reported (e.g. in HELCOM 2012 and Svarvason et al. 2001). Furthermore, the compounds can bioaccumulate and be transferred through the marine food web to fish and marine mammals. TBT in humans comes primarily from the diet, in particular from fish and fish products. TBT can impact the immune system in mammals.

The use of TBT and TPhT as antifouling agents in paint has been totally banned in the European Union since 2008 and on recreational boats since 2003, but due to the large pool of organotins in the sediments, the compounds are still present in comparably high concentrations in the marine environment (Strand et al. 2006, Dahl et al. 2007), although the concentration in sediments and biota has decreased during the early 21st century (Knopf et al. 2012).

### *3.2.1 Mussels as Biomonitors*

TBT and TPhT dissolved in seawater degrade within a relative short period of time (weeks) or they absorb to particles and are thereby transferred out of the water column to the sediment. Because it is very difficult to measure the low concentration of the organotins in seawater, marine molluscs can be used as biomonitors for the presence and concentrations of the toxic substances. For example blue mussels (*Mytilus edulis*) that lack ability to degrade the compounds efficiently rapidly bioaccumulate TBT and degradation products in their soft tissue (Guéguen et al. 2011). As blue mussels are also stationary organisms they are excellent biomonitors and suitable for investigations of organic toxic compounds in the marine environment. High contamination levels have been found in mussels from areas with elevated but still in the nano-gram/L range of TBT in the water (Kim et al. 2008). Several studies indicate that the high concentrations are most likely due to resuspension of contaminated sediment and release of organotins from sediments (Devier et al 2005, Guéguen et al. 2011).

**Mussels in Rødbyhavn harbour**

In February 2013, a blue mussel sampling campaign was conducted in Rødbyhavn harbour. In total blue mussels were collected at five stations (Figure 3.2, Table 3.1). Stations RH-1, RH-2 and RH-4 were placed along a gradient out of the recreational harbour in the area where the channel to the Inner Lagoon is planned. Stations RH-3 and RH-5 were located in the outer part of the fishery harbour. It was not possible to find suitable reference stations in the vicinity of the harbour. Instead, two stations from a sampling campaign in 2011 in Fehmarnbelt (RH-6 and RH-7) have been used (Figure 3.2, Table 3.1).

*Table 3.1 Position and water depth of sampling stations*

| Station | Longitude | Latitude | Depth |
|---|---|---|---|
| | ***°N*** | ***°E*** | ***m*** |
| RH-1 | 54°39,312' | 11°20,713' | 1-3 |
| RH-2 | 54°39,273' | 11°20,742' | 1-3 |
| RH-3 | 54°39,307' | 11°20,911' | 1-3 |
| RH-4 | 54°39,254' | 11°20,798' | 1-3 |
| RH-5 | 54°39,364' | 11°20,851' | 1-3 |
| RH-6 | 54°37,850' | 11°20,850' | 9 |
| RH-7 | 54°38,610' | 11°19,125' | 9 |

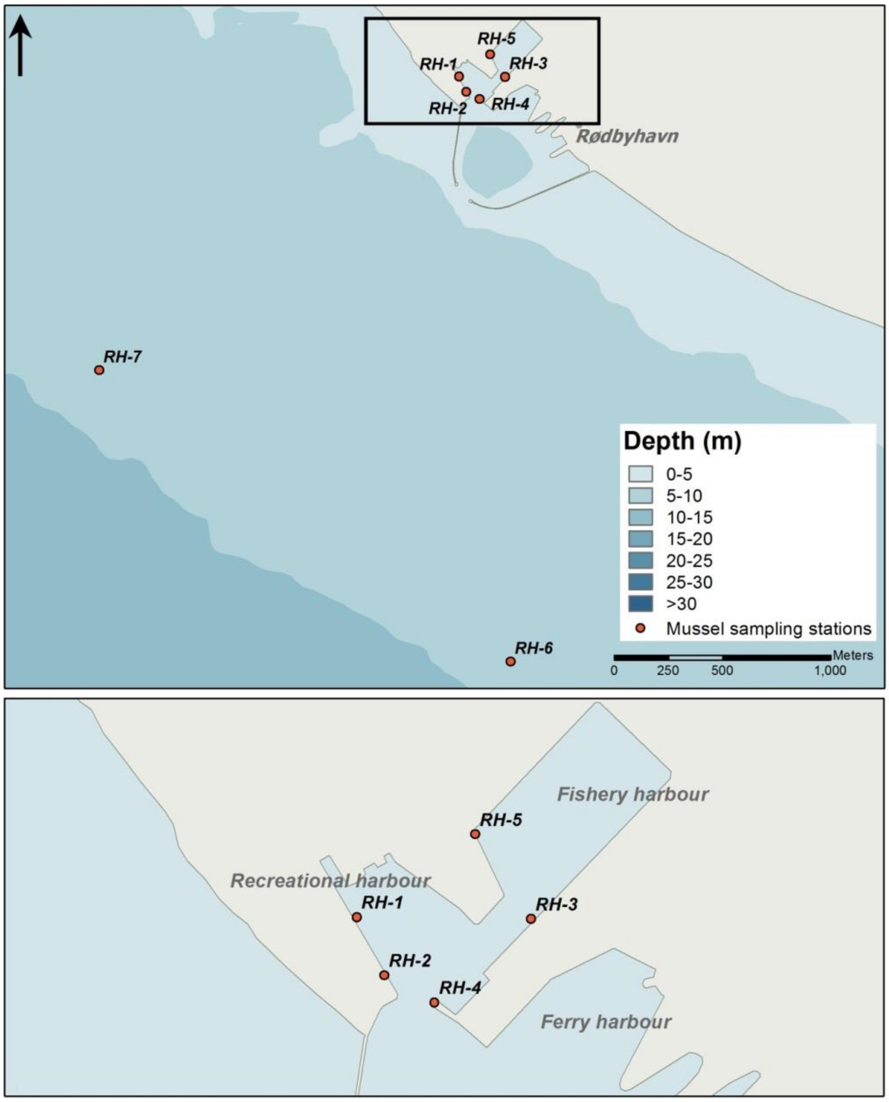



*Figure 3.2 Mussel sampling stations. Mussels at stations RH-1 to RH-5 were sampled in 2013. RH-6 and RH-7 are reference stations sampled in 2011.*

The size (shell length) of the mussels was measured and mussels were later analysed for organotins (TBT, DBT, MBT and TPhT) and dry matter. Analyses for TBT, DBT, MBT and dry matter are accredited (analysis report in appendix A). Each sample consisted of 21-22 mussels per station (appendix A).

In general only few specimens of blue mussels were found in Rødbyhavn fishery and recreational harbour. Mussels were not found in the ferry harbour and just outside the harbour area.

Size intervals of the sampled blue mussels are presented in Figure 3.3. The mussels were large with a dominating shell length between 50-60 mm. At station RH-3 the specimens were approximately 5 mm smaller than at the other stations.

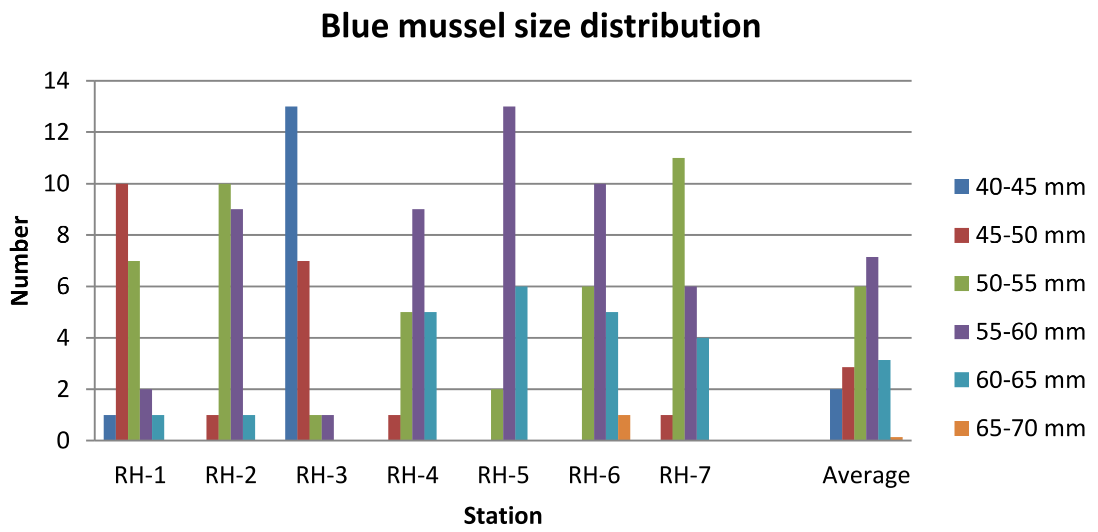



*Figure 3.3 Size distribution for blue mussels in the analysed samples. Sample size 21-22 mussels.*

The size of the mussels is correlated to the age of the mussels. Due to the large size it is evaluated that the specimens found in Rødbyhavn harbour and the reference sites were 7 years or older.

### Organotins in mussels from Rødbyhavn harbour

The concentrations of organotins in mussels are presented in Figure 3.4 and Table 3.2. The concentrations of all organotins (TBT, DBT, MBT and TPhT) were highest at station RH-1 with decreasing concentration along the gradient out of the recreational harbour (RH-1, RH-2 and RH-4). In the fishery harbour the concentrations were highest at RH-5.

At station RH-1 the concentration of TBT was 187.4 µg Sn/kg dry weight and approximately 13 times higher than at the reference stations (RH-6 and RH-7) in Fehmarnbelt, where the average concentration of TBT was 14.5 µg Sn/kg dry weight.

TPhT was only measurable at station RH-1 and was below detection level (<2 µg Sn/kg dry weight) at all other stations.

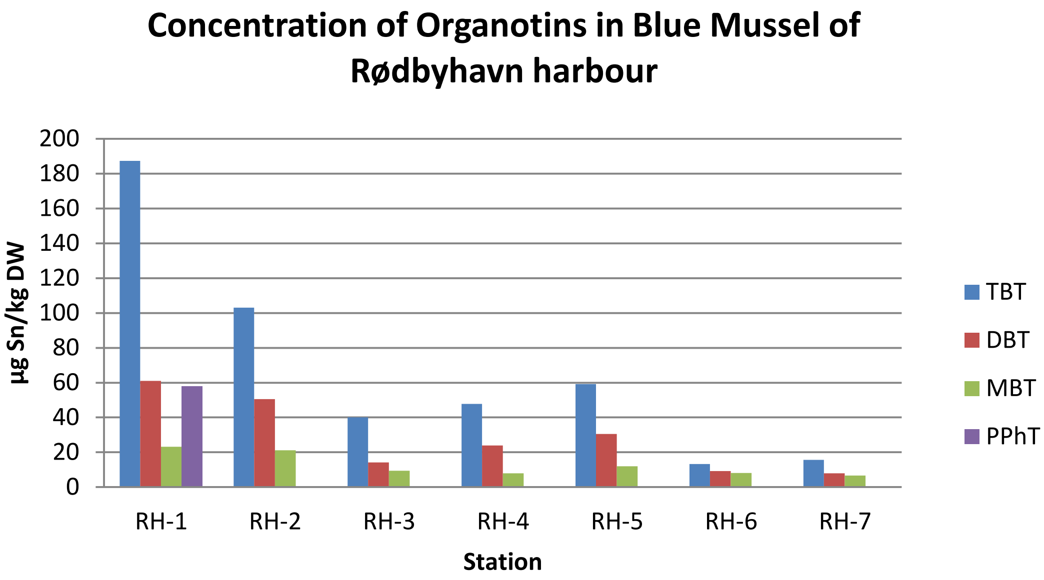



*Figure 3.4 Concentration of organotins in blue mussels from Rødbyhavn harbour (RH-1 to RH-5) and in Fehmarnbelt (RH-6 and RH-7).*

*Table 3.2 Concentrations of TBT, DBT, MBT and TPhT in blue mussels at five sampling stations in Rødbyhavn harbour and two stations in Fehmarnbelt (Figure 3.2). Concentrations were normalised to dry weight (DW). ND= concentration is below detection limit.*

| Station | RH-1 | RH-2 | RH-3 | RH-4 | RH-5 | RH-6 | RH-7 |
|---|---|---|---|---|---|---|---|
| | ---------------- µg Sn/kg dry weight ------------------- | | | | | | |
| **TBT** | 187.37 | 103.03 | 40.00 | 47.79 | 59.26 | 13.27 | 15.73 |
| **DBT** | 61.05 | 50.51 | 14.12 | 23.89 | 30.56 | 9.18 | 7.87 |
| **MBT** | 23.16 | 21.21 | 9.41 | 7.96 | 12.04 | 8.16 | 6.74 |
| **TPhT** | 57.89 | ND | ND | ND | ND | ND | ND |
| | | | | | | | |
| %**DW** | 9.5 | 9.9 | 8.5 | 11.3 | 10.8 | 9.8 | 8.9 |

### *3.2.2 TBT assessment for Rødbyhavn harbour*

As it is likely that the water quality of the inner lagoon will resemble the water quality of Rødbyhavn harbour basin (future scenario), and because it is likely that suspended and dissolved matter will be transferred from the harbour to the lagoon (FEMA-FEHY 2013), it is necessary to assess the risk of impact on the marine environment (including biota). Two parameters are important to assess the risk of impact:

1. the expected water quality of the harbour (i.e. the concentration of TBT water and biota), and

2. the flushing of water in the harbour basin.

Evaluation of toxic compounds in biota can be based on the environmental assessment criteria (EAC) set by OSPAR (2010). EAC constitutes an assessment tool that represents the contaminant concentration in e.g. mussels below which no chronic effects are expected to occur in marine species, including the most sensitive species. Concentrations below EAC are considered as no-risk. As TBT is the most hazardous substance of the measured organotins and because the EAC is based on TBT, the assessment will be based on this compound.

The water quality can be assessed by using the water Environmental Quality Standards for priority substances (AA-EQS, Average Annual EQS for surface waters). EQS values are set to protect aquatic life and water concentrations below the EQS values are not considered to constitute a risk to the environment.

As the canal between the harbour and the Inner Lagoon is planned in the area between RH-1 and RH-2, the average concentration in mussels collected at the two sites are used for comparisons.

*Table 3.3 Concentrations of TBT in mussels collected in Rødbyhavn harbour and at a reference station in Fehmarnbelt (latter from FEMA-FEHY 2013) compared criteria for biota (from OSPAR 2010). DW = dry weight.*

| | Rødbyhavn harbour. Mussels<br>Average of<br>RH-1 and RH-2 | Reference Stations. Mussels.<br>Average of<br>RH-6 and RH-7 | Criteria for biota (mussels)<br>OSPAR<br>EAC | Criteria for water<br>EC (2008)<br>AA-EQS |
|---|---|---|---|---|
| | ---------- µg Sn/kg DW ----------- | | | µg Sn/l |
| **TBT** | 145.2 | 14.5 | 12 | 0.0002 |

The concentration of TBT in mussels sampled within the harbour area exceeds the EAC value set by OSPAR (Table 3.3), with the concentration at station RH-1 being almost 16 times higher than the EAC value. In contrast, concentrations at the reference stations in Fehmarnbelt are on the same level as the EAC value and as concentrations in mussels found in most areas of Danish waters (DCE 2012, Figure 3.5). For example, within the Danish monitoring programme it has been reported that more than 70% of analysed mussel samples exceeded the EAC set by OSPAR in 2007 (Dahl et al. 2007) and by 34% and 95% in 2009 and 2010 respectively (Gustavson et al. 2012). The concentration of TBT in mussels collected at RH-1 is higher than in most other observations in these studies. TBT concentrations at the reference stations (average 14.5 µg Sn/kg DW equivalent to 1.35 µg Sn/kg wet weight) are comparable to observations at Darßer Orth in the Baltic Sea in Germany, where the concentration of TBT was 0.6-0.7 µg Sn/kg wet weight (Knopf et al. 2012).

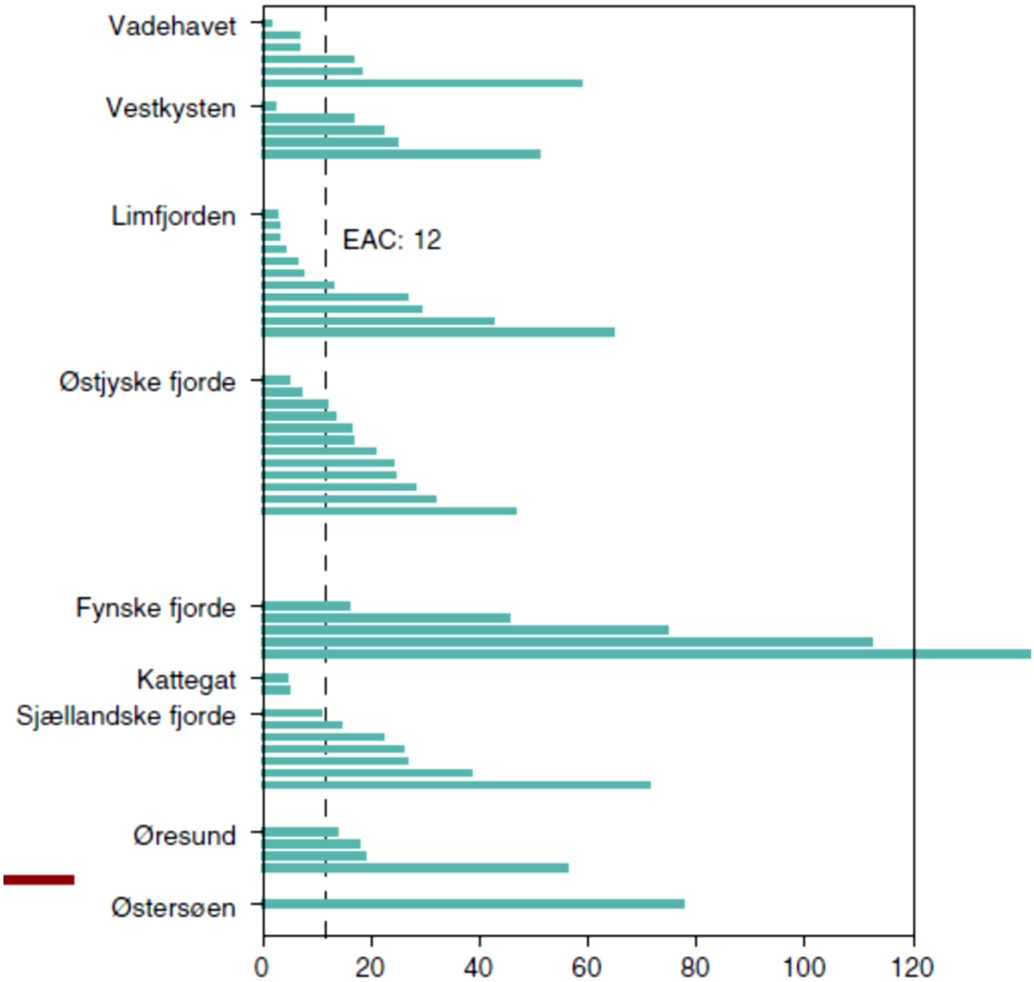



*Figure 3.5 TBT concentration in blue mussels in Danish waters. The dotted line indicates the EAC value set by OSPAR (2010). Unit: µg/kg dry weight. Figure from DCE (2012).*

The high concentration of organotins in the mussels collected within the harbour area indicates that there is a pool of TBT and other organotins in the harbour sediments which becomes available for the mussels either by re-suspension of sediments or by passive release from the sediments to the water column. The high load of TBT within the recreational harbour in Rødbyhavn is confirmed by high concentrations in sediment collected in 2012 (NST 2012). Excluding one sample above upper action level at 268 µg/kg dry weight, TBT in sediments averaged 36 µg/kg dry weight and is thus above the lower action level, regulating dredging and disposal options for marine sediment (BLST 2008). Sediment analyses of TBT in the Fehmarnbelt area (FEMA 2013) show that the concentrations of TBT is very low and well below sediment quality guideline (SQG) values set by OSPAR (see OSPAR 2010). The TBT in the mussels from the reference stations does therefore reflect bioaccumulation of TBT from other sources, e.g. from passing vessels still with TBT-paint on the hull.

Because of the old age of the mussels, it cannot be ruled out that some of the bioaccumulated organotins are due to previous pollution levels in the harbour. As the measurements carried out for Scandlines (NST 2012) are from 2012, it is however likely that the pool of organotins in the harbour sediment is "active" and gradually becomes bioavailable for the biota.

The current water quality can be calculated from the mussel Bio-Concentration Factor (BCF). The BCF is based on a relatively simple concept of a linear relationship between the concentration of a substance in an organism and the concentration of the same substance in the surrounding water (Polikarpov 1960, Kim et al. 2008). The BCF for TBT was estimated by Guéguen et al. (2011) in transplanted blue mussels in a harbour area. Their calculated BCF values of $2.8*10^5$ to $1.3*10^6$ are among the highest ones found in the literature (e.g. compared to BCF = $5*10^4$ found by Kim et al. 2008). Back-calculating from concentration of TBT in mussel tissue and BCF values indicates that the average (and approximate) concentration of TBT in the water is 0.0002 µg Sn/l using the Guéguen et al. (2011) data. This value equals the EQS value set by EU (Table 3.3). Using the BCF calculated by Kim et al. (2008) water concentration could be 10-15 times higher at 0.003 µg Sn/l and thus exceeding the EQS value of 0.0002 µg Sn/l.

As the water quality in the Inner Lagoon will resemble the water quality in the harbour (FEMA-FEHY 2013) it is necessary to assess the water quality in the harbour after establishment of the lagoon system. To this end robust information is established on the dilution of TBT released from Rødbyhavn harbour after the new Harbour-Lagoon design and on to what extent this dissolved TBT is transported into the Inner Lagoon. Such information was provided using numerical modelling.

## 3.3 Modelling TBT concentration in Rødbyhavn harbour and Lagoon system

In the previous study, the flushing rate of the combined harbour-lagoon system was estimated, but not flushing in the present harbour (FEMA-FEHY 2013), which is required in order to estimate the release of TBT from polluted sediments in the western harbour.

In the present study, circulation and spread of TBT from a hypothetical sediment source in the western harbour was estimated based on the previous model set-up applied in FEMA (2013) excluding and including connection between the Lagoon systems and the western harbour.

There are three potential sources to TBT pollution in the planned lagoon system west of Rødbyhavn Harbour:

1. Sediment from the tunnel trench used for landfill and constituting the bed of parts of the new lagoon system, but in some parts the old seabed is maintained

2. TBT in water in the Fehmarnbelt

3. TBT originating from the TBT-contaminated sediments in the western harbour

Ad. 1 Surface sediments from the Fehmarnbelt used for land reclamation has a content of TBT that is 6-7 times below the Lower Action level (7 ng TBT-Sn/kg) set by the Danish authorities. Hence, environmental impacts are not expected. Being a recently introduced pollutant, TBT concentration reaches 0 (i.e. background concentrations) below 10 cm sediment depth (FEMA 2013). With a typical excavation depth of 12-14 m, less than 1% of the material for infill will contain TBT and if so in a low non-harmful concentration. Therefore, infill material will not constitute a source for dissolved TBT in the western lagoons. On the contrary, newly exposed intact soil will act as a trap for dissolved TBT until equilibrium between dissolved and sediment-bound TBT is approached.

Ad. 2. Concentration of dissolved TBT is unknown in the Fehmarnbelt, but concentration in mussels from the Fehmarnbelt is at the level of the environmental assessment criterion (EAC) set by the Oslo-Paris commission (OSPAR 2010) to define the upper boundary of TBT concentrations in mussels considered unproblematic for the marine environment. The exact relation between the water-based criterion at 0.2 ng TBT-Sn/l set by EU (Environmental Quality Standard, EQS) and the EAC in mussels is not clear, but presumably they equilibrate to some extent. Therefore, although presence of dissolved TBT in Fehmarnbelt cannot be excluded the concentration is most presumably below the EQS-value.

Ad. 3. Concentration of dissolved TBT in the sediments of the western harbour is as mentioned previously rather high exceeding the lower action level set by the Danish authorities for handling dredged sediments.

Based on present conditions in the western harbour, release of TBT from sediments in the western harbour and transport with currents is evaluated as being the most important source for TBT in the Inner Lagoon. The risk of unacceptable levels of TBT in the new lagoon was therefore investigated further.

The magnitude of the sediment source and the resulting concentration of TBT in the Inner Lagoon were estimated using numerical modelling of spread of TBT after release from sediments.

The model was run using the present condition of harbour layout (i.e. no lagoons) to predict the rate of TBT release from sediments in the western harbour and rerun using the planned layout of reclamation of the recreational area to predict future TBT concentration in Inner Lagoon.

### *3.3.1 Model approach*

The magnitude of this source and the resulting concentration of TBT in the Inner Lagoon were estimated using numerical modelling of spread of TBT after release from sediments.

The model was run using the present condition of the harbour layout (i.e. no lagoons - baseline) to predict the rate of TBT release from sediments in the western harbour and rerun the model using the planned layout of reclamation of the recreational area to predict future TBT concentration in the Inner Lagoon.

### *3.3.2 Methodology*

Modelling of the distribution of dissolved TBT for existing conditions (Baseline) and the future conditions with the Inner Lagoon connected by a channel to the western harbour was carried out using the same three periods applied in FEMA-FEHY (2013):

- Period 1: 9 -19 November 2005: Starting with varying flow directions and finalizing with westward flow
- Period 2: 14 – 24 November 2005: Starting with varying to eastward flow and finalizing with westward flow
- Period 3: 17 – 27 November 2005: Starting with westward flow and finalizing with eastward to varying flow.

The periods were selected to represent flow conditions in the Fehmarnbelt. The first 3 days of each model period were used for model spin-up to reach quasi-stationary concentration of TBT in the western harbour. Average concentrations in the following 7 days were assumed to be representative of concentrations for the 3 periods selected.

The strength of the TBT source in the western harbour sediment was regulated by trial and error to obtain an approximate dissolved TBT concentration of 2 ng TBT-Sn/l in the western harbour under baseline conditions. The target concentration of 2 ng TBT-Sn/l was estimated from TBT concentrations in mussels collected in the western harbour (FEMA-FEHY 2013). The same strength of TBT source was used in all 6 simulations, including 3 periods with baseline conditions and 3 periods with planned harbour-lagoon layout.

## *3.4 Results*

*Period 1:* Concentration of dissolved TBT in the western harbour varies between 2.0 and 4.8 ng TBT-Sn/l when lagoons were not connected to the harbour (baseline) and between 0.6 and 1.8 ng TBT-Sn/l when lagoons are connected to the harbour (Figure 3.6). The concentration in the major central part of the Inner Lagoon ranges between 0.2 and 0.4 ng TBT-Sn/l and is thus 10-12 times lower (i.e. (0.2 to 0.4) /(2.0 to 4.8) than in the western harbour under present (baseline) condition.

*Period 2*: Concentration of TBT in the western harbour varies between 3.0 and 4.5 ng TBT-Sn/l when lagoons were not connected to the harbour (baseline) and between 0.8 and 1.8 ng TBT/l, when lagoons are connected to the harbour (Figure 3.7). The concentration in the major part of the Inner Lagoon ranges between 0.2 and 0.4 ng TBT-Sn/l and is thus ca. 10-15 times lower (i.e. (0.2 to 0.4) /(3.5 to 4.5)) than in in the western harbour under the present (baseline) condition.

*Period 3*: Concentration of TBT in the western harbour varies between 3.5 and 4.0 ng TBT-Sn/l when lagoons were not connected to the harbour (baseline) and between 1 and 1.6 ng TBT-Sn/l when lagoons were connected to the harbour (Figure 3.8). The concentration in the major part of the Inner Lagoon ranges between 0.2 and 0.6 ng TBT-Sn/l and is thus 8-15 times lower (i.e. (0.2 to 0.6) /(3.5 to 4.0) than in the western harbour under the present (Baseline) condition.

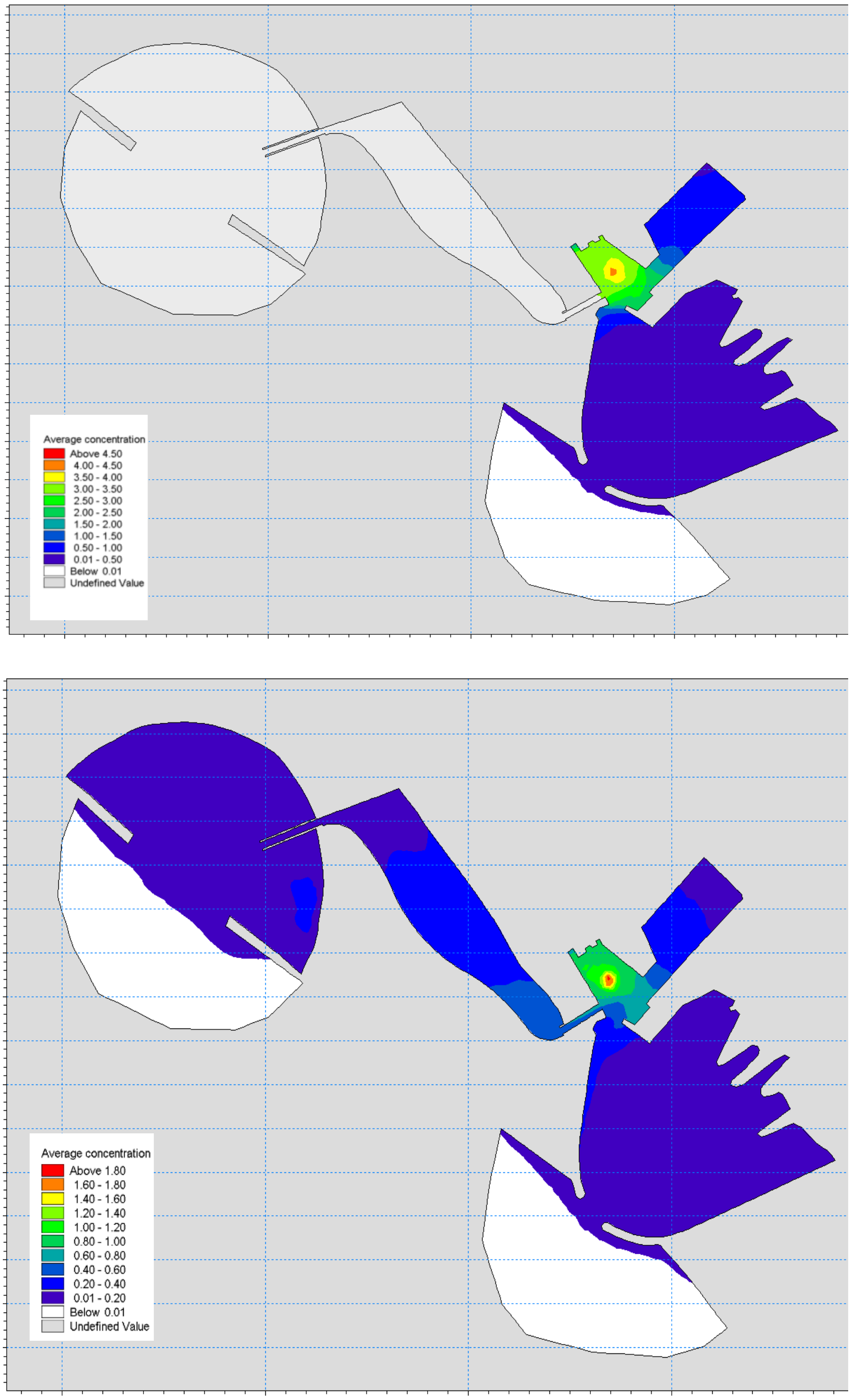



*Figure 3.6* *Modelled concentration of dissolved TBT in the Rødbyhavn harbour and lagoon system during model period 1. Upper figure: no connection between western harbour and Inner Lagoon (≈ present situation, baseline); lower figure: future harbour-lagoon layout with a channel connection western harbour to Inner Lagoon.*

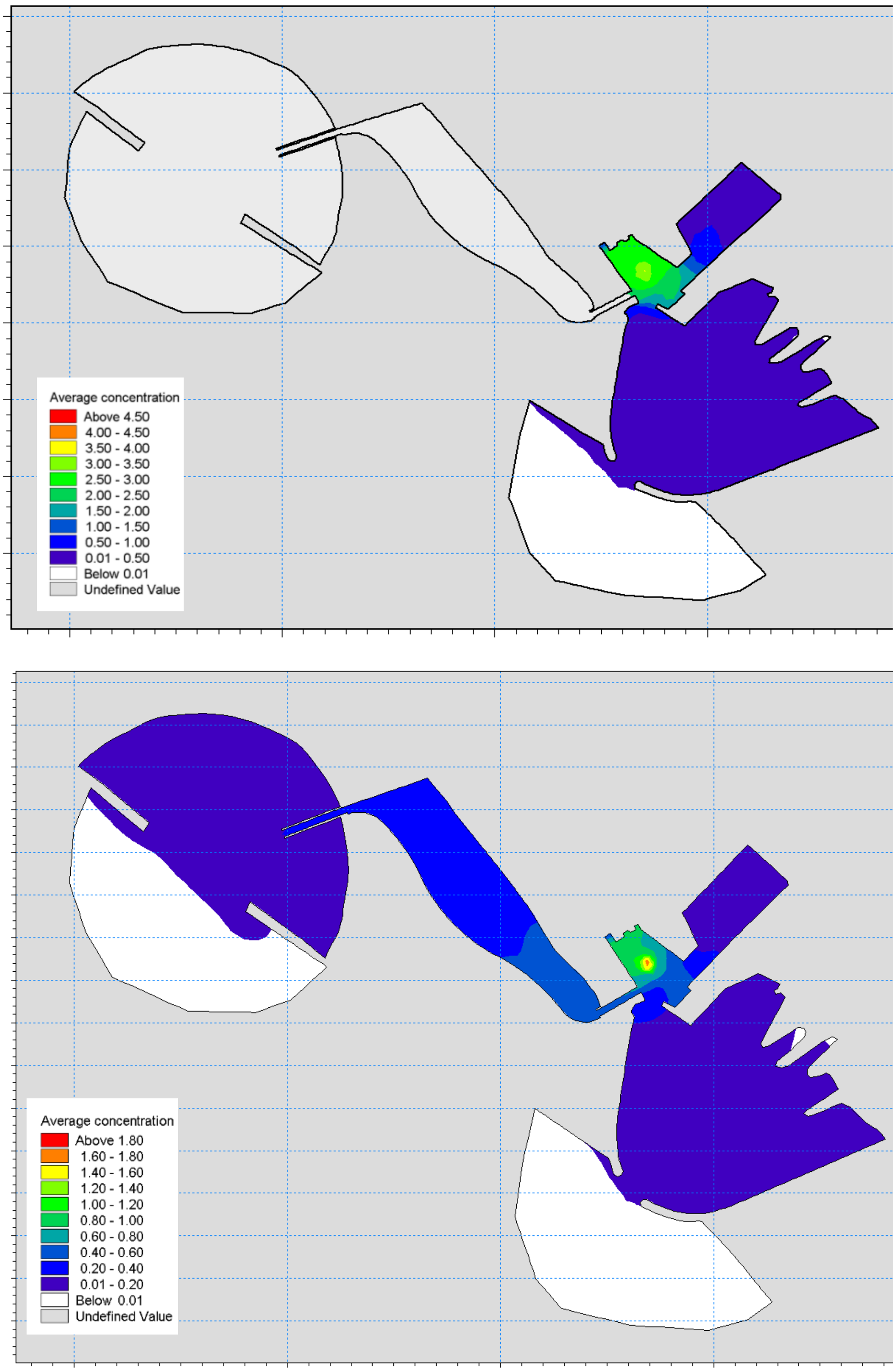
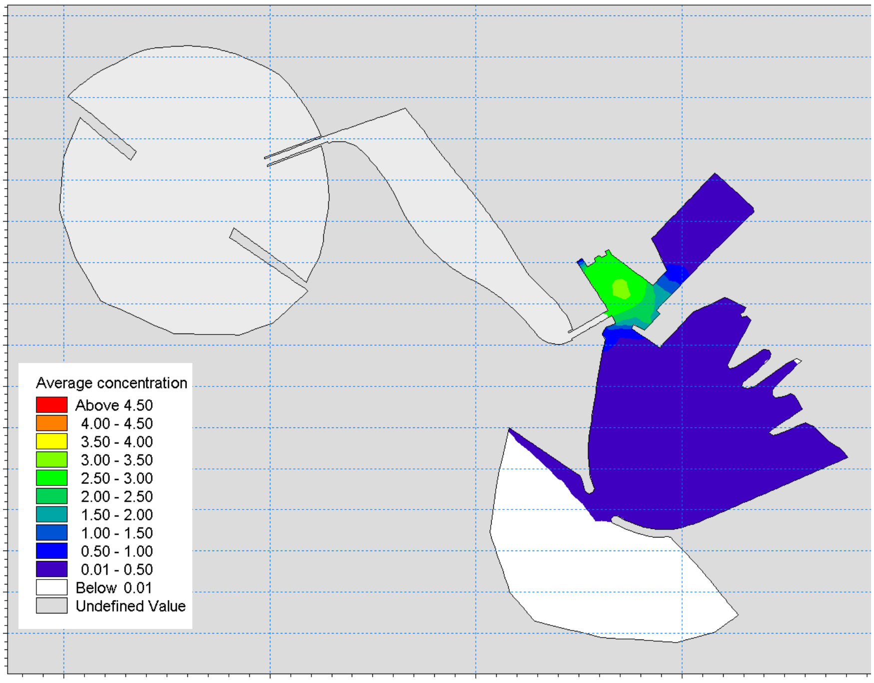



*Figure 3.7* *Modelled concentration of dissolved TBT in the Rødbyhavn harbour and lagoon system during model period 2. Upper figure: no connection between western harbour and Inner Lagoon (≈ present situation, baseline); lower figure: future harbour-lagoon layout with a channel connection western harbour to Inner Lagoon.*



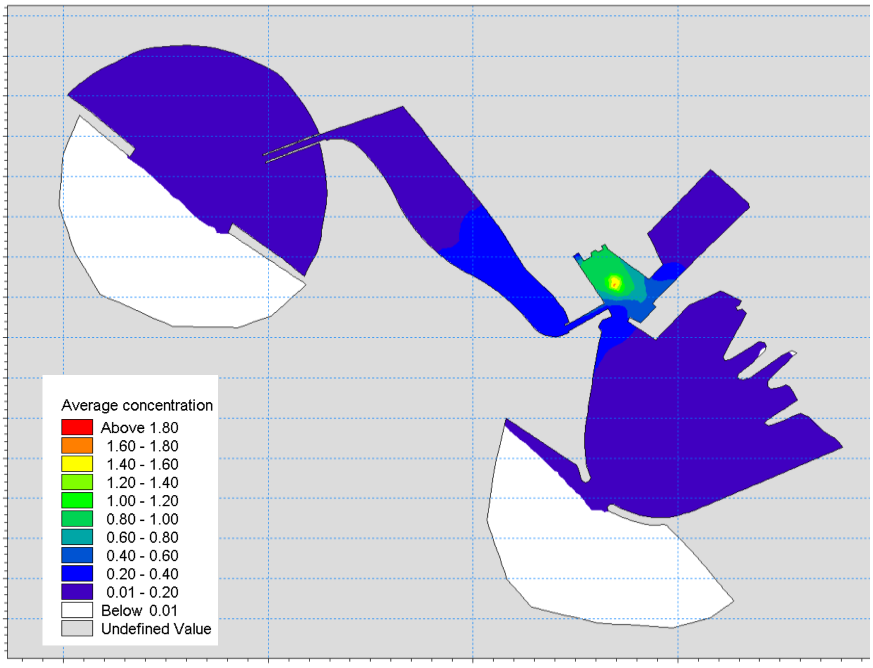




*Figure 3.8* *Modelled concentration of dissolved TBT in the Rødbyhavn harbour and lagoon system during model period 3. Upper figure: no connection between western harbour and Inner Lagoon (≈ present situation); lower figure: future harbour-lagoon layout with a channel connection western harbour to Inner Lagoon.*

### 3.4.1 *Environmental assessment of TBT in lagoons*

The modelled dilution of dissolved TBT in the Inner Lagoon was rather similar in the three model periods indicating that predictions are rather robust under varying flow speed and direction in Fehmarnbelt currents. Averaged over the 3 modelling periods the concentration of TBT in the Inner Lagoon originating from sediment release in the western harbour is expected to be 10-15 times lower than the present (baseline) concentration in the western harbour. Concentrations of TBT in mussels from the western harbour suggest that the present dissolved concentration in this part of the harbour is ca. 2 ng TBT-Sn/l implying that release from sediments in the polluted western harbour will lead to an elevated TBT concentration of 0.15-0.2 ng TBT-Sn/l in the Inner Lagoon compared to the Fehmarnbelt. The increase in TBT concentration will add to the unknown (but presumably low) background concentration already present in the Fehmarnbelt water.

Two mechanisms not accounted for in the modelling will tend to reduce the dissolved TBT concentrations in lagoons further compared to the modelling results. Firstly, the bed in the constructed lagoons will primarily consist of dredged infill material (fine sand, till and clay) with close to zero content of TBT, and over time the lagoon bed will adsorb TBT from the water column until an equilibrium determined by the partition coefficient, Kd, is reached. Secondly, because the Inner Lagoon is shallow, UV light will penetrate almost to the bottom (Vantrepotte and Mélin 2006) and accelerate the degradation of TBT dissolved in the water by photo-oxidation (Fletcher and Lewis 1999).

Since the ban of TBT use for antifouling paints the concentration in sediments from harbours and coastal waters has been decreasing due to degradation, burial and release to the water column. Therefore, the TBT concentration will decrease in the western harbour sediments resulting in lower release rates and ultimately even lower concentrations in the Inner Lagoon in future.

### 3.4.2 *Human Health*

Besides environmental concern human exposure and health effects of TBT *could* be an issue especially for small children. The main route of TBT into the human body is by oral intake, not through skin (EFSA 2004, Antizar-Ladislao 2008). Hence, in the Inner Lagoon small children may be exposed to TBT by drinking water or eating sediment. Based on chronic exposure studies and applying a safety factor of 100 the Tolerable Daily Intake (TDI) of organic tin compounds is set at 0.25 µg/kg body weight (EFSA 2004). Therefore, a 10 kg toddler would need to drink 8 $m^3$ of water (with a concentration of 0.3 ng/l TBT) from the Inner Lagoon per day or swallow 2.5 kg of sediment (with an assumed high concentration of 10 ng TBT/kg) per day to exceed TDI. These figures demonstrate that human hazards related to TBT in the Lagoons are non-existing.

# 4 CONCLUSION

The potential impact of flushing the recreational lagoons including the Inner Lagoon with water from the TBT-contaminated Rødbyhavn harbour, especially the western harbour, was assessed based on dedicated modelling of spread of TBT released from the western harbour sediments and information in literature.

Using a very conservative assumption for Bioconcentration Factor (lowest BCF published) to calculate release of TBT from harbour sediments the spread of TBT from the harbour would theoretically increase the concentration of TBT in the Inner Lagoon by 0.15 to 0.2 ng TBT-Sn/l compared to Fehmarnelt water, but uptake in seabed and UV-degradation would reduce the concentration of dissolved TBT in the lagoons.

It is thus evaluated that the environmental condition in the lagoons will not be degraded by TBT released from the western harbour.

TBT is only moderately toxic to humans, and based on predicted concentrations in the Inner Lagoon human health effects will not occur.

# 5 REFERENCES

Antizar-Ladislao B (2008). Environmental levels, toxicity and human exposure to tributyltin (TBT)-contaminated marine environment. A review. Environment International 34: 292–308.

BLST (2008). Vejledning fra By- og Landskabsstyrelsen: Dumpning af optaget havbundsmateriale – klapning; Vejledning nr. 9702 af 20. Oktober 2008. (Guidelines from the Danish Ministry of Environment: Dumping of dregded seabed material – disposal; Guideline No. 9702, 20 October 2008. https://www.retsinformation.dk/Forms/R0710.aspx?id=121680.

Dahl K and Josefson AB (red.) (2009). Marine områder 2007. NOVANA. Tilstand og udvikling i miljø- og naturkvaliteten. Danmarks Miljøundersøgelser, Aarhus Universitet. 113 s. - Faglig rapport fra DMU nr. 707, pp. 113. http://www.dmu.dk/Pub/FR707.pdf

DCE (2012). http://naturogmiljoe.dmu.dk/hav/44/.

Devier MH, Augagneur S, Budzinski H, Le Menach K, Mora P, Narbonne JF and P Garrigues (2005). One-year monitoring survey of organic compounds (PAHs, PCBs, TBT), heavy metals and biomarkers in blue mussels from the Arcachon bay, France. J Environ Monit 7:224-240.

EC (2008). Directive 2008/105/EC of the European Parliament and the Council of 16 December 2008. On environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EC, 83/513/EEC, 84/156/EEC, 84/491/EEC and amending Directive 2000/60/EC of the European Parliament and the Council.

EFSA (2004). Opinion of the Scientific Panel on Contaminants in the Food Chain on a request from the Commission to assess the health risks to consumers associated with exposure to organotins in foodstuffs. EFSA answer to Question N° EFSA-Q-2003-110. The EFSA Journal 102: 1-119

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

FEMA (2013). Fehmarnbelt Fixed Link EIA. Marine Soil - Baseline.

Seabed Chemistry of the Fehmarnbelt Area. Report No. E1TR0056 Volume II, pp.46.

Fletcher LE and JA Lewis (1999). Regulation of shipyard discharges in Australia and the potential of UV oxidation for TBT degradation in washdown waste water, Proceedings of Oceans '99 Congress: 27 – 35.

Gustavson K, Larsen MM and J Strand (2012). Faglig karakterisering af forekomst og udbredelse af miljøfarlige stoffer, herunder biologiske effekter, i de danske farvande. Notat til Naturstyrelsen.

Guéguen M, Amiard J, Arnich N, Badot P, Claisse P, Guérin T and J Vernoux (2011). Shellfish and Residual Chemical Contaminants: Hazards, Monitoring, and Health Risk Assessment Along French Coasts. Reviews of Environmental Contamination and Toxicology, 213: 55-111.

HELCOM (2010). Hazardous substances in the Baltic Sea – An integrated thematic assessment of hazardous substances in the Baltic Sea. Balt.Sea Environ. Proc. No. 120B.

Kim SN, Shim WJ, Yim UH, Ha SY and PS Park (2008). Assessment of tributyltin contamination in a shipyard area using a mussel transplantation experiment. Mar Pollut. Bull 57; 883-888.

Knopf B, Klawonn T, Köster I, Rüdel H, Klein R and C Schröter-Kermani (2012). Verification of the success of recent use restrictions for tributyltin by retrospective monitoring of archived biological samples from North and Baltic Seas. Poster

NST (2012). Klaptilladelse til Rødby Havn. http://www.naturstyrelsen.dk/Annonceringer/Klaptilladelser/klaptilladelser_2012/ros_klap_rodby_280612.htm

OSPAR (2010). Agreement on CEMP Assessment Criteria for the QSR 2010. Agreement number: 2009-2.

Polikarpov GG (1960). Absorption of short-lived radioactivity by sea organisms. Priroda 49:105-7.

Strand J, Larsen MM, Næs K, Cato I and I Dahllöf (2006). TRIBUTYLTIN (TBT) - Forekomst og effekter i Skagerrak. Forum Skagerrak II. Projektgruppe: Arbejsgruppe WP2 - Miljøfremmede stoffer, affald og oliespild. Uddevalla, Sweden: Forum Skagerrak II, pp. 39.

Svavarsson J, Granmo Å and R Ekelund (2001). Occurrence and effects of tributyltin (TBT) on common whelk (*Buccinum undatum*) in harbours and in a simulated dredging situation. Mar Poll Bull 42: 370-376.

Vantrepotte V and F Mélin (2006). UV penetration in the water column. Report from Institute for Environment and Sustainability. EUR 22217, p. 67.