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Guidance for a harmonized Emission Scenario Document (ESD) on Ballast Water discharge

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Guidance for a harmonized Emission Scenario Document (ESD) on Ballast Water discharge

by

Andreas Zipperle
BIS, Hamburg

Jos van Gils
DELTARES, Delft

Dr. Bert van Hattum
Institute for Environmental Studies, University of Amsterdam

Prof. Dr. Susanne Heise
BIS, Hamburg; Hamburg University of Applied Sciences

On behalf of the Federal Environment Agency (Germany)

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Study performed by:	BIS Eissendorfer Str. 40 21071 Hamburg(D)	DELTARES Rotterdamseweg 185 2629 HD Delft (NL)	IVM De Boelelaan 1087 1081 HV Amsterdam (NL)

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Federal Environment Agency (Umweltbundesamt)
Wörlitzer Platz 1
06844 Dessau-Roßlau
Germany
Phone: +49-340-2103-0
Fax: +49-340-2103-0
Email: info@umweltbundesamt.de
Internet: http://www.umweltbundesamt.de
http://fuer-mensch-und-umwelt.de/

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5. Autor(s), Family Name(s), First Name(s)
Dipl. Biol. Andreas Zipperle; Jos van Gils
Dr. Bert van Hattum; Prof. Dr. Susanne Heise

6. Performing Organisation (Name, Address)
BIS – Beratungszentrum für integriertes Sedimentmanagement
TuTech Innovation GmbH, Eissendorfer Str. 40, 21071 Hamburg, Germany

DELTARES
Rotterdamseweg 185, 2629 HD Delft, The Netherlands

IVM – Institute for Environmental Studies
VU University Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam
The NEtherlands

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16. Abstract

The present report provides guidance for a harmonized Emission Scenario Document (ESD) for the exposure assessment as part of the environmental risk assessment process which applicants seeking approval of a ballast water management system (BWMS) need to perform prior to notification and authorisation procedures. Despite the global variability of the marine environment, ballast water discharges and treatment methods, exposure assessments need to be comparable between different applications. In order to achieve this, this ESD points out the following aspects:

- Applicants should use **standardized scenarios** in order to predict mean exposure. These should reflect generic situations, independent of region or port so that results are widely applicable. In addition to a harbour scenario, a standardized shipping lane scenario should be considered,
- During or right after ballast water discharge, high concentrations may persist in a water body for a certain length of time until extensive mixing results in mean concentrations. Not taking exposure **to peak concentrations within gradients** into account could lead to an underestimation of risk, especially for rapidly degrading substances. Efforts have been made to approximate maximum exposure concentration with simple dilution factors. Their applicability was checked by near-field-evaluations.
- **Chemical properties** determine the environmental fate of substances. If they are ambiguous, selection of a specific set of data strongly influences the result of an exposure assessment. Guidance is given on what to do about lacking data.
- In order to harmonize the exposure assessments, reliable **chemical model software** should be used. A discussion on the requirements of suitable software and an evaluation of MAMPEC is given in this report.

17. Keywords

International Convention for the Control and Management of ships’ Ballast Water and Sediments, International Maritime Organization, ballast water, ballast water management system, active substance, relevant chemical, ballast water discharge, exposure assessment, emission scenario document, final approval procedure, guideline G9, MAMPEC, near-field analysis.

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5. Autor(en), Name(n), Vorname(n)

Dipl. Biol. Andreas Zipperle; Jos van Gils
Dr. Bert van Hattum; Prof. Dr. Susanne Heise

6. Durchführende Institution (Name, Anschrift)

BIS – Beratungszentrum für integriertes Sedimentmanagement
TuTech Innovation GmbH, Eissendorfer Str. 40, 21071 Hamburg, Germany

DELTARES
Rotterdamseweg 185, 2629 HD Delft, The Netherlands

IVM – Institute for Environmental Studies
VU University Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam
The NEtherlands

7. Fördernde Institution (Name, Anschrift)

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15. Zusätzliche Angaben

Angaben unter 11, 13, 14 beziehen sich auf den Bericht inklusive Annex I-IV

16. Zusammenfassung

Der vorliegende Bericht dient als Leitlinie für die Erstellung eines harmonisierten Emissionsszenario Dokumentes (ESD) für die Expositionsbewertung im Rahmen der zu erstellenden Umweltrisikobewertung wie sie im Zulassungsverfahren von Ballastwasserbehandlungsanlagen gefordert wird. Trotz der globalen Variabilität der marinen Umwelt, der Ballastwasserabgabe und der verwendeten Methoden muss die Bewertung der Exposition zwischen verschiedenen Zulassungsanträgen für Ballastwasserbahndlungstechniken vergleichbar sein. Dies setzt eine größtmögliche sinnvolle Harmonisierung voraus. Um dieses zu erreichen, werden in diesem Bericht folgende Empfehlungen gegeben:

- Antragsteller sollten **standardisierte Szenarien** verwenden, um eine **mittlere** Exposition im Voraus abzuschätzen. Die Szenarien sollten möglichst durchschnittliche Situationen widerspiegeln, die unabhängig von Region oder Hafen sind, damit die Ergebnisse einen möglichst großen Anwendungsbereich abdecken. Neben einem standardisierten „Hafenszenarios“ sollte ein zusätzliches „Schifffahrtswegszenario“ in Betracht gezogen werden.

- Während oder direkt nach der Ballastwasserabgabe kann es im Wasserkörper lokal zu temporären Höchstkonzentrationen kommen, die erst nach intensiver Durchmischung auf Durchschnittswerte sinken. Wird eine Exposition durch kurzfristig auftretende **sehr hohe Konzentration innerhalb** solcher **Gradienten** nicht berücksichtigt, würde das tatsächlich bestehende Risiko unterschätzt, insbesondere im Falle leicht abbaubarer Substanzen. Die Exposition kann anhand von Verdünnungsfaktoren abgeschätzt werden. Die Verwendbarkeit der Verdünnungsfaktoren wurde mit Hilfe eines „Near-field“ Bewertungsverfahrens überprüft.

- Die Verteilung von Substanzen in der Umwelt wird von ihren **chemischen Eigenschaften** bestimmt. Sind

	diese nicht eindeutig messbar, hängen die Ergebnisse der Expositionsbewertung stark von der Wahl der verwendeten Daten ab. Empfehlungen zum Umgang mit fehlenden oder mehrdeutigen Daten werden vorgestellt.
-	Im Sinne einer Harmonisierung sollte eine verlässliche **Software zur Ermittlung der Exposition** genutzt werden. Entsprechend enthält der Bericht eine umfassende Diskussion der Voraussetzungen, die solch ein Modellierungsprogramm erfüllen muss, sowie eine umfassende, analytische Bewertung des MAMPEC Models.

17. Schlagwörter

Internationales Übereinkommen von 2004 zur Überwachung und Behandlung von Ballastwasser und Sedimenten von Schiffen, Internationale Maritime Organisation, Ballastwasser, Ballastwassermanagement Anlage, Aktive Substanzen, Relevante Chemikalien, Ballastwasserabgabe, Expositionsabschätzung, Emissions Szenario Dokument, abschließendes Zulassungsverfahren, Richtlinie G9, MAMPEC, near-field Analyse

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LIST OF ABBREVIATIONS

AOX	Absorbable organic halogen compounds
BA	Basic Approval
BW	Ballast water
BWC	Ballast water convention
BWMH	Ballast water model harbour
BWMS	Ballast water management system
BWWG	Ballast Water Working Group
DELWAQ	Deltares Water Quality Model
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DWT	Dead Weight Tonnage
ECB	European Chemical Bureau
EHS	Working Group on the Evaluation of the Hazards of Harmful Substances Carried by Ship
EOX	Extractable organic halogen compounds
ERA	Environmental risk assessment
ESD	Emission Scenario Document
FA	Final Approval
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
HES	Human exposure scenario
IMO	International Maritime Organization
MAMPEC	Marine Antifoulant Model to Predict Environmental Concentrations
MEPC	Marine Environmental Protection Committee
LPUV	Low pressure ultra violet radiation
MPUV	Medium pressure ultra violet radiation
NIO	Non-indigenous organisms
OECD	Organisation for Economic Co-operation and Development
PAC	Poly Aluminium Chloride
PASA	Poly Acrylamide Sodium Acrylate
PEC	Predicted environmental concentration
PNEC	Predicted no effect concentration
POC	Particulate organic carbon
PoR	Port of Rotterdam
SPM	Suspended particulate matter
TBT	Tributyl tin
TOC	Total organic carbon
TRO	Total residual oxidants
UBA	Umweltbundesamt
WPI	World port index

0 ZUSAMMENFASSUNG

Die weltweite Verschleppung mariner Organismen in Ballastwasser von Schiffen kann zur Beeinträchtigung von Lebensräumen führen (z.B. Verdrängung oder Eliminierung ursprünglich heimischer Arten). Um diese weltweite Verschleppung mariner Organismen einzuschränken, verabschiedete die Internationale Maritime Organisation (IMO) im Jahre 2004 das „Internationale Übereinkommen zur Überwachung und Behandlung von Ballastwasser und Sedimenten von Schiffen“ (Ballastwasser-Konvention). Ziel der Ballastwasser-Konvention ist die präventive Behandlung von Ballastwasser durchzusetzen, um die weltweite Verbreitung mariner Organismen zu verhindern. In der Folge wurde eine große Bandbreite verschiedener Techniken entwickelt, um Organismen aus dem Ballastwasser zu entfernen, bevor dieses von den Schiffen abgelassen wird. Jede toxische Substanz, die in diesem Rahmen als Biozid eingesetzt oder während der Behandlung erzeugt wird, wird zwangsläufig mit den immensen Mengen an Ballastwasser in die Umwelt abgegeben. Aus diesem Grund muss für jede Ballastwasser-Behandlungsanlage eine Bewertung des Risikos für die Umwelt durchgeführt werden, bevor sie durch die zuständigen Behörden zugelassen werden kann. Die Risikobewertung sollte weltweit auf denselben Annahmen und Szenarien basieren und dabei die gleichen oder vergleichbare Hilfsmittel, wie z.B. Modelle verwenden.
Der vorliegende Bericht dient als Leitlinie für die Erstellung eines harmonisierten Emissionsszenario Dokumentes (ESD) für die Expositionsbewertung im Rahmen der zu erstellenden Umweltrisikobewertung. Dieser Text soll nicht nur für Antragsteller sondern auch für die bewertenden Behörden als Richtlinie dienen, weshalb kritische Gesichtspunkte, Datenlücken und Unsicherheiten in den möglichen Bewertungen dargelegt werden.

Diese Leitlinie kann für alle Ballastwasser-Behandlungsanlagen verwendet werden, die chemische oder physikalische Prozesse oder eine Kombination aus beiden einsetzen (Kapitel 1). Potenziell gefährliche Substanzen zur Beseitigung biologischer Aktivität im Ballastwasser können zugesetzt oder während des Prozesses erzeugt werden („Aktive Substanzen“), oder aber während der Behandlung als Nebenprodukte (Relevante Chemikalien) entstehen (Kapitel 2). Sie werden mit dem Ballastwasser in die Umwelt abgegeben. Kapitel 3 gibt einen Überblick über weltweit abgegebene Ballastwassermengen und die Variabilität der Umweltbedingungen, unter denen der Ballastwasserablass erfolgt

Trotz dieser Variabilität muss die Bewertung der Exposition zwischen verschiedenen Zulassungsanträgen für Ballastwasserbahndlungstechniken vergleichbar sein. Dies setzt eine größtmögliche sinnvolle Harmonisierung voraus. Um dieses zu erreichen, werden in diesem Bericht folgende Empfehlungen gegeben:

- Antragsteller sollten **standardisierte Szenarien** verwenden, um eine **mittlere** Exposition im Voraus abzuschätzen. Die Szenarien sollten möglichst durchschnittliche Situationen widerspiegeln, die unabhängig von Region oder Hafen sind, damit die Ergebnisse einen möglichst großen Anwendungsbereich abdecken.
- Während oder direkt nach der Ballastwasserabgabe kann es im Wasserkörper lokal zu temporären Höchstkonzentrationen kommen, die erst nach intensiver Durchmischung auf Durchschnittswerte sinken. Wird eine Exposition durch kurzfristig auftretende **sehr hohe Konzentration innerhalb** solcher

Gradienten nicht berücksichtigt, würde das tatsächlich bestehende Risiko unterschätzt, insbesondere im Falle leicht abbaubarer Substanzen.

- Die Verteilung von Substanzen in der Umwelt wird von ihren **chemischen Eigenschaften** bestimmt. Sind diese nicht eindeutig messbar, hängen die Ergebnisse der Expositionsbewertung stark von der Wahl der verwendeten Daten ab. Empfehlungen zum Umgang mit fehlenden oder mehrdeutigen Daten werden vorgestellt.
- Im Sinne einer Harmonisierung sollte eine verlässliche **Software zur Ermittlung der Exposition** genutzt werden. Entsprechend enthält der Bericht eine umfassende Diskussion der Voraussetzungen, die solch ein Modellierungsprogramm erfüllen muss, sowie eine umfassende, analytische Bewertung des MAMPEC Models.

Standardisierte Szenarien: Der Bericht empfiehlt die Verwendung eines auf einem „realistischen schlimmsten Fall“ beruhenden Szenarios, um die zu erwartende Expositionskonzentration in der Umwelt (predicted environmental concentration, PEC) und die Menge einer potentiell gefährlichen Substanz abzuschätzen, die von einer Ballastwasserbehandlungsanlage bei Betrieb erzeugt wird. „Realistische schlimmste Fällle“ sollen mögliche Extreme abbilden. Ihre Konzeption sollte nachvollziehbar sein und auf der Basis bestehender Statistiken erfolgen. Um ein derartiges Emissionsszenario abzuschätzen, wird ein Hafenszenario empfohlen bei dem der Hafen aus Hafenbecken mit beschränktem Austausch mit der offenen See besteht (Wasseraustausch pro Tidenzyklus: 30%; der Wert berücksichtigt die Entscheidung der GESAMP-BWWG für einen konservativeren Ansatz im Vergleich zur Vorlage des OECD-EU „kommerzieller Hafen“ Szenarios mit einer Austauschrate von 68% pro Tidenzyklus; siehe Kapitel 4.2.2). Die Menge des im Hafen emittierten Ballastwassers basiert auf der Annahme, dass alle Schiffe voll beladen den Hafen anfahren und vor Verlassen die maximale Menge an Ballastwassers abgeben, wobei zur Desinfektion des Ballastwassers auf allen Schiffe dieselbe Methode der Ballastwasserbehandlung eingesetzt wird. An Hand statistisch abgesicherter Daten über die maximal zu beobachtende Ballastwasserabgabe pro Stunde und dem durchschnittlichen Volumen eines solchen Hafenbeckens kann, unter der Annahme sofortiger Durchmischung des gesamten Wasservolumens, eine Durchschnittskonzentration für eine abgegebene Substanz abgeleitet werden. Es wird empfohlen, für solch einen Ansatz das GESAMP-BWWG Ballastwasser-Szenario zu verwenden.

Ergänzend zu dem Hafenszenario sollte zusätzlich das OECD-EU „Schifffahrtsweg“ Szenario in Betracht gezogen werden, da Schiffe häufig schon vor Ankunft in einem Hafen mit der Ballastwasserabgabe beginnen. In Anbetracht der Erfahrungen mit sehr hoher TBT Exposition entlang der meist befahrenen Schifffahrtswege in den 1980er Jahren, könnte sich die Berechnung der Exposition entlang von Schifffahrtsstraßen als Teil einer Risikobewertung als nützlich erweisen.

Hohe Konzentrationen in auftretenden Gradienten: Zurzeit können die räumliche und zeitliche Heterogenität der abgegebenen Ballastwassermengen und die daraus resultierenden grundsätzlichen Unterschiede zwischen mittlerer und (kurzzeitiger, lokaler) Maximalexposition mit dem gängigen für die Expositionsbewertung von Ballastwasser verwendeten und auf stationärem Verhalten des Systems beruhenden Modellprogramm (hier: MAMPEC) nicht dargestellt werden. Folglich wurde in diesem Bericht versucht, die maximal auftretende Exposition anhand einfacher Verdünnungsfaktoren abzuschätzen. Die Verwendbarkeit der Verdünnungsfaktoren wurde mit Hilfe eines „Near-field“ Bewertungsverfahrens überprüft. Die „Near-field“ Bewertung berücksichtigt unvollständige Durchmischung des Ballastwassers mit dem das Schiff umgebenden Wasserkörper und berechnet Maximalkonzentrationen für Substanzen am Rand der Ballastwasserfahne, also in dem Bereich, in dem Organismen im Umfeld einer Ballastwasserabgabe erhöhten Substanzkonzentrationen ausgesetzt werden. Dieser Ansatz berücksichtigt beispielsweise Salzgehaltsunterschiede zwischen Ballastwasser und dem umgebenden Wasserkörper, da sie eine Durchmischung auf Grund der Dichteunterschiede verzögern. Entsprechend der Berechnungsergebnisse aus Kapitel 4 wird für das standardisierte Hafenszenario ein Verdünnungsfaktor von 5 und für das standardisierte Schifffahrtsstraßenszenario ein Verdünnungsfaktor von 50 empfohlen. Hierbei sei darauf hingewiesen, dass dieser Ansatz eine Herausforderung für die anschließende Effektbewertung darstellt, da für die meisten Substanzen angemessene Wirkkriterien für kurzzeitige und variable Expositionssituationen (Zeitrahmen: Sekunden-Minuten-Stunden) höherer Organismen nicht verfügbar sein werden. Hierfür werden ersatzweise Wirkschwellen abgeschätzt und vereinbart werden müssen.

Chemische Eigenschaften: Für die Vorhersage von Umweltkonzentrationen sind Informationen über die Konstanten von Abbauraten oder über die Halbwertszeiten „Aktiver Substanzen“ und/oder relevanter Chemikalien notwendig. In vielen Fällen sind diese Daten mit großen Unsicherheiten behaftet, da sie aus einfachen, experimentellen Studien (z.B. „Die Away Tests“) abgeleitet werden und somit Angaben zwischen unterschiedlichen Datenbanken stark variieren können. Folglich wird eine Referenzdatenbank, wie sie von der GESAMP für Standardkomponenten beschlossen wurde, und die für die Verwendung in Expositionsszenarien verpflichtend ist zur Harmonisierung der Expositionsbewertung beitragen. Des Weiteren hat die Umgebungstemperatur einen großen Einfluss auf die Abbaurate, wobei Substanzen bei niedrigen Temperaturen im Allgemeinen langsamer abgebaut werden. Aufgrund der statistischen Auswertung globaler Sommer und Winter Wassertemperaturdaten in Häfen wird für die PEC Berechnung eine standardisierte Wassertemperatur von 6°C vorgeschlagen.

Chemische Modellierung: Das Model zur Bestimmung der Umweltkonzentrationen von Antifouling-Substanzen im marinen Milieu (Marine Antifoulant Model to Predict Environmental Concentrations; MAMPEC), welches ursprünglich für die Emission aktiver Substanzen aus Antifouling-Beschichtungen entwickelt wurde, wird als geeignetes Model für die Abschätzung von umweltrelevanten Konzentrationen potenziell gefährlicher Substanzen in abgelassenem Ballastwasser angesehen. Es wurde für die Verwendung im Bereich der Ballastwasser-Behandlung angepasst und wird derzeit von den meisten Herstellern solcher Anlagen für die Expositionsbewertung verwendet. In diesem Bericht wird an Hand einer eingeschränkten Sensitivitätsanalyse unter Einsatz dynamischer Modelle gezeigt, dass mit dem von MAMPEC verwendeten stationären Ansatz eine **Durchschnittsexposition** durch behandeltes Ballastwasser abgeschätzt werden kann. Solange die in diesem Bericht dargelegten Bedingungen eingehalten werden und Eingabeparameter sowie Szenarien nachvollziehbar abgeleitet oder spezifiziert werden, kann jede andere geeignete Software zur chemischen Modellierung verwendet werden.

0 EXECUTIVE SUMMARY

With ballast water in ships, marine organisms are transported around the globe and to environments on which they may have adverse effects (e.g. displacement or even elimination of indigenous species). In order to prevent this world-wide distribution, the International Maritime Organisation (IMO) approved the ‘International Convention for the Control and Management of Ships' ballast water and sediments’ (Ballast Water Convention) in 2004. This convention aims at a management of ballast water to avoid the transfer of organisms around the world. Consequently, a variety of technologies have been developed to remove living organisms from ballast water before it is discharged into the environment. Subsequently, any toxic substance that has served as biocide in the process or was formed during the treatment will be released to the environment when the large amounts of ballast water are discharged. Hence, before ballast water treatment measures are approved by the competent authorities, an assessment of the potential risk for the environment needs to be carried out. This assessment should be based on the same world-wide assumptions and scenarios, applying the same or comparable tools.
The present report provides guidance for a harmonized Emission Scenario Document (ESD) for the exposure assessment as part of the environmental risk assessment process which applicants seeking approval of a ballast water management system (BWMS) need to perform prior to notification and authorisation procedures. Next to applicants, it also intends to guide evaluating authorities, pointing out critical issues, lacking data and uncertainty in evaluations.

It applies to all ballast water management systems that make use of physical or chemical processes or a combination of both (Chapter 1). Potentially hazardous substances may be applied or produced on purpose in order to eliminate biological activity in ballast water (BW) (“active substances”) or may be formed as (unintentional) by-products (relevant chemicals) (Chapter 2). They are released to the environment when ballast water is discharged. Chapter 3 gives an overview over the global variability of discharge quantities of BW and of receiving environments.

Despite this variability, exposure assessments need to be comparable between different applications. Therefore, it has to be harmonized as much as possible and reasonable. In order to achieve this, this ESD points out the following aspects (Chapter 4):

- Applicants should use **standardized scenarios** in order to predict mean exposure. These should reflect generic situations, independent of region or port so that results are widely applicable.
- During or right after ballast water discharge, high concentrations may persist in a water body for a certain length of time until extensive mixing results in mean concentrations. Not taking exposure to **peak concentrations within gradients** into account could lead to an underestimation of risk, especially for rapidly degrading substances.
- **Chemical properties** determine the environmental fate of substances. If they are ambiguous, selection of a specific set of data strongly influences the result of an exposure assessment. Guidance is given on what to do about lacking data.

- In order to harmonize the exposure assessments, reliable **chemical model software** should be used. A discussion on the requirements of suitable software and an evaluation of MAMPEC is given in this report.

Standardized scenarios: This document proposes the use of a “realistic worst case scenario” to estimate the expected exposure concentrations in the environment (predicted environmental concentration, PEC) and the amount of potentially hazardous substances generated by BWMSs. Realistic worst case scenarios need to reflect reality as good as possible, need to be derived in a transparent way and preferably on the basis of statistical data where available.
For estimating the realistic worst case emission scenario, a harbour scenario is used, in which the port consists of basins with limited exchange with open sea (tidal renewal: appr. 30 % per tidal cycle; based on a decision of the GESAMP-BWWG for a more conservative approach compared to the original OECD-EU commercial harbour with 68% tidal exchange rate; see section 4.2.2). With regard to the amount of ballast water being emitted into such a harbour, it is assumed that all ships arrive at the port fully loaded with ballast water, leave the port after complete de-ballasting, and use the same ballast water treatment technique. From statistical data on the observed maximum of ballast water discharge per harbour basin and average water volume of such a basin, a mean concentration of released substances can be derived, assuming that instantaneous complete mixing of water volumes occur. For this type of approach, use of the GESAMP-BWWG ballast water scenario is recommended.
In addition to a harbour scenario, the OECD standardized shipping lane scenario should be considered, as ships often start de-ballasting before arrival at port. Based on the experience with TBT exposure in the 1980s that was very high along the most frequented shipping lanes, calculated shipping lane exposure data may prove useful as part of the risk assessment.

Peak concentrations in gradients: Currently, the spatial and temporal heterogeneity of ballast water discharges that results in substantial differences between average exposure and (short term local) maximum exposure cannot be evaluated by the steady state approach of the current modelling software that is being used for exposure assessment with regard to ballast water (here: MAMPEC). Consequently, efforts have been made in this report to approximate maximum exposure concentration with simple dilution factors. Their applicability was checked by near-field-evaluations. Near-field evaluations take into account incomplete mixing of the discharged ballast water with ambient waters around the ship and assess the maximum concentrations at the edge of the plume, where organisms in the receiving environment are exposed to still high discharged concentrations. This approach accounts e.g. for salinity differences between the ballast water and the receiving environment, as these will delay mixing due to the different densities. Following the calculations laid out in chapter 4, a dilution factor of 5 is now recommended for the standardized harbour scenario and a dilution factor of 50 for the standardized shipping lane scenario. It should be noted, that this situation provides a challenge for the later effect assessment, as for most compounds suitable effect criteria for short time-varying exposure situations (duration: seconds-minutes-hours) will not be available for higher organisms and that for such an evaluation surrogate effect levels will need to be estimated separately and agreed upon.

Chemical properties: For predicting environmental concentrations, information on degradation rate constants or half-life of ‘active substances’ and/or relevant chemicals are essential. In many cases, environmental degradation rate constants may have a high uncertainty, as these data are derived from simple experimental studies (e.g. die away tests) and data may vary strongly among data bases. Hence, a reference data base as agreed upon by GESAMP for standard compounds, which is compulsory to use for the exposure scenarios, will add to the harmonization of the exposure assessments. Additionally, temperature has a strong influence on degradation processes, with usually higher persistence at low temperatures. Based on a statistical evaluation of winter and summer water temperatures in ports on a global scale, a standardized water temperature of 6 °C is suggested to be used in the PEC calculations.

Chemical model software: The Marine Antifoulant Model to Predict Environmental Concentrations (MAMPEC), originally developed for emissions of antifoulants, is considered a suitable model to assess environmental concentration of potentially hazardous substances after BW discharge. It has already been applied by most BWMS manufacturers and has been adapted to the field of ballast water treatment. Based on a limited sensitivity analysis with dynamic models, it is shown in this report that the average exposure from treated ballast water discharges can very well be estimated by the steady state approach of MAMPEC. Other suitable chemical software can also be applied as long as it can fulfil the requirements set out in this document and as input parameters and scenarios can be derived or specified in a transparent way.

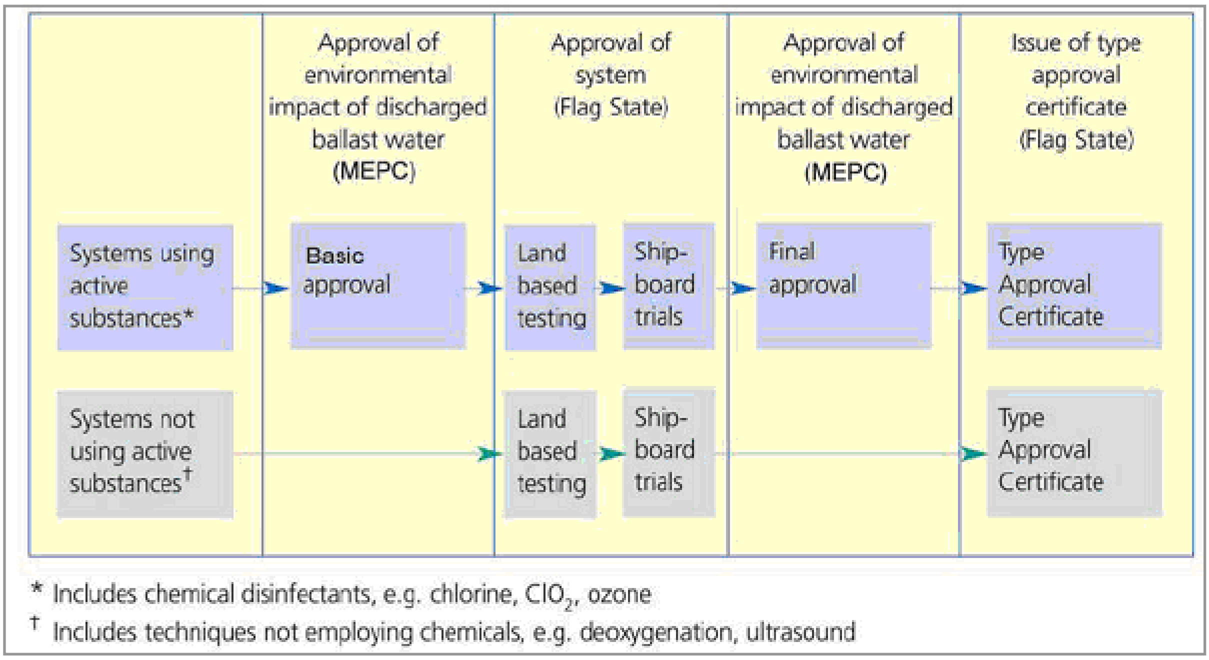
1 INTRODUCTION

1.1 Background to this document

Ballast water in vessels provides stability and is needed to adjust a vessel's trim, stress and torsion for optimal steering and propulsion. After the awareness spread that with BW, organisms had been transferred between different geographical regions and partly had become invasive to their new habitat, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (the Ballast Water Convention, BWC) was adopted in 2004, at a meeting of 74 members of the International Maritime Organization (IMO) and by 18 international Non-Governmental Organizations (IMO 2004). The convention comes into force one year after ratification by at least 30 IMO member states representing at least 35 % of the worlds tonnage. Stepping into force was expected by the end of 2010, but will most likely be time-delayed. The BWC requires ships to perform BW exchange during voyage and/ or the implementation of proper Ballast Water Management Systems (BWMS) onboard different classes of vessels between 2010 and 2017, depending on age, BW capacity and type of ship.

BWMS need to destroy organisms either while taking up BW (ballasting) and/ or during de-ballasting. At the same time, adverse effects after discharge of the treated BW to the receiving environment need to be prevented.

The potential environmental risk needs to be assessed for each technology in a multiple step process. These assessments need to be positively evaluated by the proper authorities in order to gain official approval (Fig. 1).



* Includes chemical disinfectants, e.g. chlorine, ClO_2, ozone
† Includes techniques not employing chemicals, e.g. deoxygenation, ultrasound

Figure 1: Summary of IMO approval pathway for BWMSs. (Dobroski et al. 2009)

An environmental risk assessment (ERA) always consists of two components: the evaluation of exposure and of effects. While information on the potential effects of a substance is often derived from laboratory studies, evaluation of exposure using models requires knowledge of e.g. the receiving environment, mixing and dilution rates, substances degradation rates and physico-chemical properties allowing the prediction of the environmental concentration (PEC). Monitoring data and experience with release of chemicals after BW treatment at this moment are scarce and knowledge of applicants of BWMSs is limited to emitted quantities of substances. Thus, guidance on estimating environmental concentrations is needed and this is done on the basis of analysing scenarios.

The purpose of an Emission Scenario Document is to help applicants and evaluating authorities with their exposure assessment in the approval application and authorisation procedures. It does, however, not contain information for an effect assessment, which is the complementary part of the risk assessment. It is also not intended to perform site-specific exposure assessments but to allow general evaluations in order to eventually contribute to an environmental risk assessment (ERA). The usefulness to have one ESD is to enable a similar analysis of different techniques with regard to their potential release of hazardous substances as well as – through its contribution to an ERA - to risk mitigation procedures. An ESD will therefore help to increase the level of environmental safety, independent of region or port. It is supposed to be a framework guiding users and raising their awareness towards critical issues, but also pointing out where data are lacking and uncertainty persists. Finally, it is an important step to a worldwide harmonised environmental risk assessment of BWMS.

1.2 Description of industry and use area

The transportation and introduction of unwanted non-indigenous organisms (NIO) by ships BW is one of the four major threats (pollution, overexploitation, habitat destruction, species invasions) to marine ecosystem today (Ruiz et al. 2000, Rilov and Crooks 2009). Aside from the ecological impact NIO might pose a threat to ocean based economy and public health (Hayes et al. 2005, Pimentel et al. 2005).

Ships carry BW to provide stability and adjust trim, stress and torsion for optimal steering and propulsion under various loading (empty to full) and weather conditions. Ballast water is used on:

- Oil platforms
- Sailing boats
- War ships
- Commercial ships[1]
    - Carriers (bulk, general cargo, gas, ore, combination)
    - Tankers (oil, chemicals)
    - Container ships
    - Passenger ships

In this document we focus on environmental emission scenarios for commercial shipping for several reasons. The `International convention for the control and management of ships' ballast water and sediments´ (IMO 2004) considers only commercial ships flying the flag of an IMO party and explicitly excepting war vessels. Most of world’s trade is transported by ships. Thus, commercial shipping together with bio-fouling is responsible for most marine NIO introductions (Hewitt et al. 2005).

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[1] **http://www.dnv.com/industry/maritime/shiptypes/**

Hence, the contribution of sailing boats to world wide BW transport might be negligible due to the limited range and the predominant return of BW to the area of origin. Ballast water used by oil platforms is always returned to the area of origin.

The BW convention (IMO 2004) requires proper BW management on different ship types according to the time table fixed in regulation B-3 (Annex I). Ballast water might be treated on board of the vessel or discharged to a land-based reception facility. Treated and discharged BW from vessels has to meet at least the BW performance standard fixing a maximum allowed organism load (regulation D-2 to the BW convention) and must not cause harm to humans and the environment. Discharge of BW to a proper land-based reception facility (IMO 2006) compensates for on board treatment of BW (regulation B-3.6).

Treatment of BW implies the removal or decimation of organisms. The BWMSs in the focus of this document apply ‘active substances’ directly or use techniques that generate “active substances” and/or relevant chemicals potentially harmful to humans and the environment (Chapters 1.3, 2.2). Ideally BWMS (according to regulation D-5):

1. comply with safety considerations of the ship
2. are environmentally sound
3. are easy to install and to use
4. are cost effective
5. comply to the D-2 performance standard

BWMS making use of ‘active substances’ and/or relevant chemicals (Chapters 1.3, 2.2) are subject to the approval procedure under the guideline to the convention G9 ‘Procedure for approval of BWMSs that make use of active substances’ (MEPC 169(57)) to assure compliance with the convention (e.g. ships’ safety regulations, the D-2 standard, environmental soundness) (Fig. 1).

A full environmental risk assessment is required for the application for Final Approval under G9. This should contain model calculations of environmental concentrations using defined emission scenarios. Maximum allowable discharge levels of both ‘active substances’ and the relevant chemicals in the treated BW as well as the eventual toxicity of the whole effluent sample are required.

So far no harmonized emission scenario document (ESD) exists especially dedicated to the process of BW treatment. However, administration and applicants currently attempt to model PEC values for exposure assessment by adapting existing model software. The Antifoulant Model to Predict Environmental Concentrations (MAMPEC) achieved acceptability by the administration and is recommended to applicants for G9 approval. The original MAMPEC exposure scenarios were developed as a basis for the ESD on anti-fouling paints (OECD 2005).

The current procedure is that manufacturers develop a worst case emission scenario for the BWMS under consideration mostly using different versions of MAMPEC. Different approaches for the exposure assessment have been summarized in Annex IIIA+B. The administration attempts to comprehend the results of the proposed emission scenario. From approval documents of BWMS, it becomes apparent, that free model choice and/or design by the applicant renders comparability among systems and consistency of the approval procedure impossible.

The purpose of this document is to identify the most suitable modelling approach to tackle the problem of environmental discharge concentrations of ‘active substances’ and relevant chemicals in treated BW in form of a harmonized ESD. The document will focus on the standardization of the discharge environment and temporal and spatial scales that need to be considered.

1.2.1 On board treatment of ships' ballast water

On board treatment of BW implies the installation of a BWMS that can provide the D-2 performance standard. Such a system can be either directly implemented in case of new construction of a ship or has to be retrofitted into the limited space and the existing pipe work on a ship.

In principle, BW can be treated upon uptake (ballasting) and/or prior to discharge (deballasting) applying a multitude of treatment options that in the considered cases pose a potential threat to humans and/or the environment (Chapters 1.3, 2.2). During ballasting water is taken in through the sea chest passing a rough grating to separate larger organisms (strainer) (1). A fine-filtration step is used in most cases to remove particles > 50 µm in order to increase BWMS performance (2). In case of treatment upon uptake the BW passes a BWMS (3) before entering the BW tank (4). After residing through the ship's voyage BW is discharged into the environment (Fig. 2). Treatment prior to discharge implies that water residing in ballast tanks (4) passes through a treatment system (3) and in some BWMS a neutralization unit immediately before the BW is discharged into the environment. Treatment options and available BWMS are discussed in chapter 1.3.

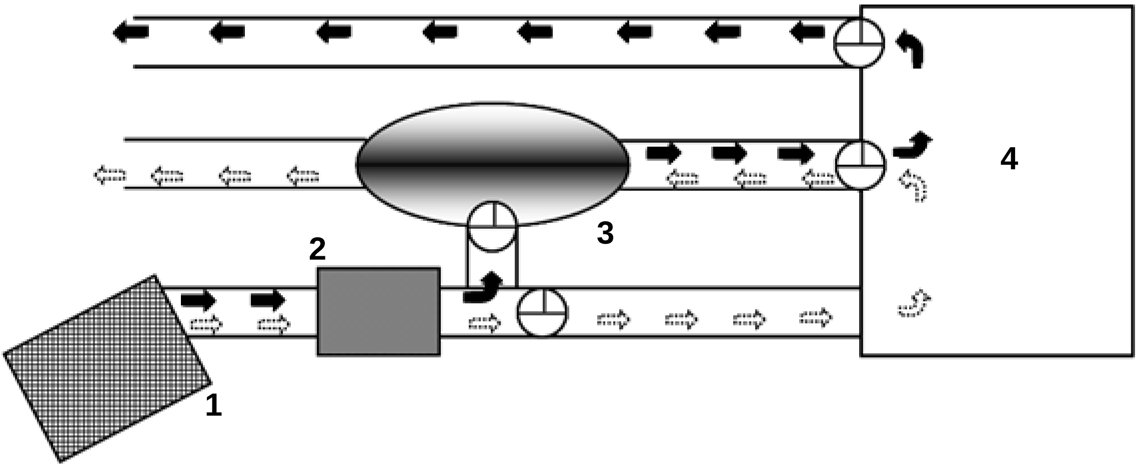

Figure 2: Conceptional ballast water treatment. Treatment upon uptake (bold arrows) and treatment prior to discharge (dotted arrows). 1 = Sea chest; 2 = Fine filtration; 3 = BWMS; 4 = Ballast water tank

1.2.2 Land-based ballast water reception and treatment facilities

Regulation A-2 of the International Convention for the Control and Management of Ships' ballast water and Sediments (IMO 2004) requires discharge of BW treated by proper BWMSs according to the conventions guidelines. According to regulation B-3.6 these requirements do not apply to BW discharged to a land-based reception facility designed according to the Guidelines for BW Reception Facilities (G5) (IMO 2006).

However, to date the development of land-based BW reception/treatment facilities and their implementation into ports is to large parts neglected although the same techniques could be applied as for on board treatment. The suitability and applicability is a point of current debate among experts (Raaymakers et al. 1999, Gollasch et al. 2007, Donner 2010). Table 1 summarizes the advantages and disadvantages of land-based reception facilities as discussed at the IMO-WMU Global R&D Forum on Emerging BWMS 2010 held in Malmö (Sweden).

Different options for land-based BW management facilities are currently under discussion. Oil industry ports (e.g. Valdez (USA), Scapa Flow (GB), Batumi (GE), Poti (GE), Middle East) have had land-based BWM facilities for oily BW e.g. from single-hull tankers with unsegregated BW tanks already for decades (Raaymakers 1999, PWSRCAC 2005a,b, David et al. 2008). The requirement for segregated ballast tanks was introduced in the MARPOL Convention in 1978 and the last single-hull tankers will be phased out within a few years[2] making land-based reception facilities for oily BW dispensable. A retro-fitting to BW management in the sense of the BW convention is considered possible and cost effective for such facilities (Raaymakers 1999, PWSRCAC 2005, Gollasch et al. 2007, Donner 2010).

The provision of mobile barges equipped with BWMS has been discussed and even tested. It has been argued, that this concept might only work in small harbours with limited berth (Gollasch et al. 2007). However, it would provide an alternative for city ports where the construction of a land-based BW reception facility is difficult due to limited space and/or prohibitive cost.

Table 1: Land-based BW treatment and reception. Identified advantages and disadvantages (PWSRCAC 2005, Gollasch 20017, Donner 2010).

Advantages	Disadvantages
Lower over all investment to equip few thousand ports compared to 50,000 ships	Construction and installation (facility and pipe work) expensive for e.g. inner city ports or not possible due to spatial constrains.
More economical than ship based treatment due to continuous operation.	One reception facility for several ports means delay for ships and incurs extra costs. Delay has to be avoided according to the Convention.
BWM totally under port state control. No compliance control for ships necessary.	Ships need to be equipped with connections for pipe work.
Specially trained personnel being expert on the system compared to ship personnel changing between different ships with varying BWM systems.	Facilities need to have connections for different ship types.
On reception of BW, it could provide freshwater for public use if coupled with desalination as treatment option and brine as BW.	
Could provide already disinfected BW to ships.	
Disinfection coupled with storage of ballast BW on shore time saving: a. BW exporting ports have disinfected water in stock. b. BW importing ports receive, store and treat later.	
Costs for installation could be amortised by increasing port fees. Operational costs could be passed on to the vessel directly.	
Creates jobs.	

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[2] http://www.imo.org/Safety/mainframe.asp?topic_id=155#double

The state government of Victoria (Australia) provides detailed cost estimation for the land-based reception concept for Victorian ports. Based on estimated costs for a land-based reception facility of $9-19 million excluding the acquisition of land and the costs for constructing of piping and an approximate cost of $21 million for a mobile treatment unit applying filtration, ultraviolet rays and chemicals to treat the BW with annual treatment costs of approximately $3 mil (at 70% utilisation) it was concluded that the installation of land-based reception was most likely too expensive for most ports in Victoria. However, treatment costs per ton BW were estimated to be as low as $ 0.34, which could be passed on directly to the vessel. Therefore, it was recommended, that the potential for the establishment of on-shore BW treatment facilities in Victoria should be further investigated[3].
Land based reception as an alternative BW management option is worth to be explored in the future and a strong leading nation is needed to promote in depth investigation considering the advantages. Points to consider are:

- Thorough up-to-date cost-benefit analysis.
- Consideration of distribution of costs between government, port authority and ship owners since all of them might have benefits from land-based BW reception.
- The mobile barge concept for ports where shore based reception is prohibitive or ports are small (barges with BWM units, retired tankers for BW reception and storage).

1.3 Ballast water management options and G9 treatment systems

A multitude of physical and chemical BW treatment options exist (Gregg et al. 2009, Tsolaki and Diamandopoulos 2009) and are briefly reviewed in this chapter. No stand-alone treatment option is able to provide the D-2 performance standard and therefore multiple treatment options usually are combined to multi component BWMS (Fig. 3). The Lloyd’s Register – Ballast Water Treatment Technology guide (Lloyd’s Register 2010) lists 46 BWMSs as approved, in the approval process or projected for approval combining a multitude of

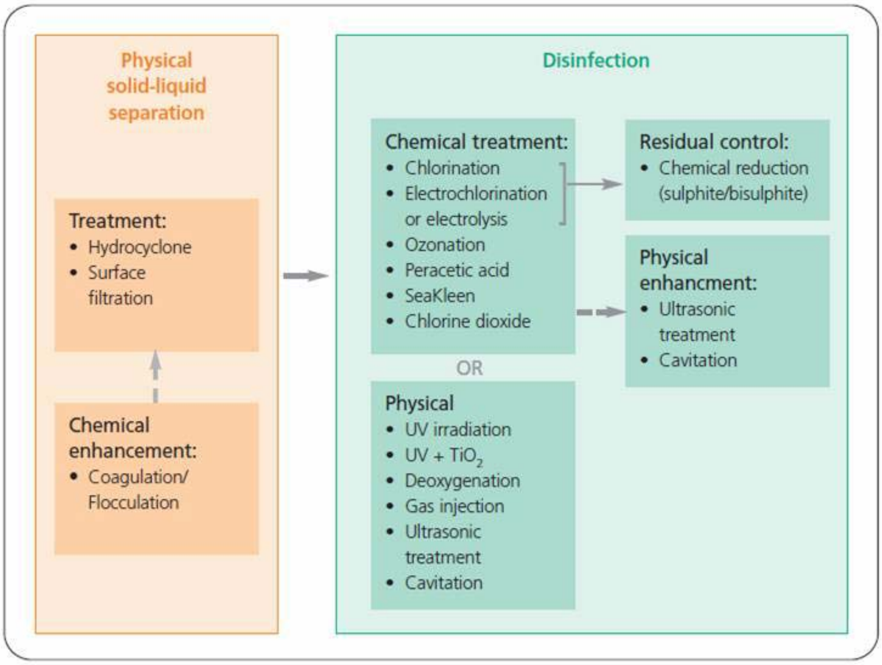

Figure 3: Schematic treatment options for ballast water disinfection (Lloyd´s Register 2008a)

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[3] http://www.parliament.vic.gov.au/enrc/inquiries/old/enrc/ballast/Ballast-59.htm#P3574_334475

different treatment options. Systems that have entered or completed the G9 approval procedure are listed in Table 2.

Table 2: Summary of BWMS currently in the G9 approval process or type approved after passing the G9 procedure.

System	Supplier	Submitting Country	Treatment process description	Basic Approval	Final Approval	Type Approval
SEDNA	Hamman AG	Germany	Hydrocyclone; Filtration (50 µm); PERACLEAN® (15% Peracetic acid (PAA) 14.3% Hydrogen peroxide (H_2O_2) 26.5% Acetic acid < 1% stabilizer (in total), e.g. phosphonic acid. Treatment upon uptake.	MEPC[4] 54/2/12	MEPC 57/2/5	06/ 2008
Electro Clean	Techcross Inc.	Republic of Korea	Seawater electrolysis. Treatment upon uptake.	MEPC 54/2/3	MEPC 58/2 (granted)	12/ 2008
Pure Ballast	Alfa Laval	Sweden	Filtration (50 µm); MPUV[2] + TiO2. Treatment upon uptake and discharge (filtration by-pass).	MEPC 55/2/1	MEPC 56/2/12	06/ 2008
Special Pipe Hybrid (Ozone version)	Mitsui Engineering & Shipbuilding	Japan	Filtration; Cavitation + shearing; Ozone (O_3); DWTT (activated carbon) post-treatment. Treatment upon uptake.	MEPC 55/2/16	MEPC 61/2/2 (granted)	
Special Pipe Hybrid (SPO-System)	Mitsui Engineering & Shipbuilding	Japan	Filtration; Cavitation + shearing; PERACLEAN® Ocean; DWTT (activated carbon) post-treatment. Treatment upon uptake.	MEPC 54/2/12; MEPC 55/2/16	MEPC 61/2/10 (pending)	
Clean Ballast	RWO	Germany	Filtration (50µm); Seawater electrolysis (EctoSys); (Neutralization[1] in high salinity waters). Treatment upon uptake and discharge (filtration by-pass).	MEPC 55/23	MEPC 59/2 (granted)	
Blue Ballast	NK Company, Ltd.	Republic of Korea	Oxygen concentration; Ozone (O_3) generation + injection; Neutralization ($H_2S_2O_3$). Treatment upon uptake.	MEPC 56/2/2	MEPC 59/2/3 (granted)	
Resource Ballast Technologies	Resource Ballast Technologies (Pty) Ltd.	South Africa	Filtration (40 µm); Cavitation + Ozone (O_3) + Seawater electrolysis. Treatment upon uptake.	MEPC 56/2/3	MEPC 59/2/10 (granted)	
Clear Ballast	Hitachi Plant Technologies, Ltd.	Japan	Triirontetroxide (Fe_3O_4) coagulation/ flocculationPAC/ PASA; Post-filtration. Treatment upon uptake.	MEPC 57/2/2	MEPC 59/2/5 (granted)	3/ 2010
GloEnPatrol	PANASIA Co., Ltd.	Republic of Korea	Filtration (50 µm); MPUV. Treatment upon uptake and discharge (filtration by-pass).	MEPC 57/2/4	MEPC 59/2/7	12/ 2009

Table 2: Continued.

System	Supplier	Submitting Country	Treatment process description	Basic Approval	Final Approval	Type Approval
Ocean Saver	OceanSaver AS	Norway	Filtration (50 µm or less); Cavitation; N_2-supersaturation (deoxygenation); Seawater electrolysis. Treatment upon uptake and discharge (filtration by-pass).	MEPC 57/2/6	MEPC 58/2/8	04/ 2009
TG Ballast Cleaner	TG Corporation group	Japan	Filtration (50 µm); TG Ballastcleaner (NaClO); TG Environmentalguard neutralization (Na_2SO_3). Treatment upon uptake.	MEPC 57/2/8	MEPC 60/2/2 (granted)	
EcoChlor	Ecochlor	Germany	Filtration (40 µm); PURATE (ClO_2). Treatment upon uptake.	MEPC 58/2/2	MEPC 61/2/8 (pending)	
SEDINOX	Greenship Ltd.	The Netherlands	Multi-hydrocyclone; Seawater electrolysis. Treatment upon uptake.	MEPC 58/2/7	MEPC 59/2/6 (granted)	
SiCURE	Siemens AG	Germany	Filtration (40µm); Seawater electrolysis. Treatment upon uptake.	MEPC 59/2/11 (granted)		
EcoBallast	Hyundai Heavy Industries Co., Ltd.	Republik of Korea	Filtration (50µm); Helix UV (LPUV[3]/ MPUV). Treatment upon uptake and discharge (filtration by-pass).	MEPC 59/2/4	MEPC 60/2/1 (granted)	
AquaTriComb	Aquaworx ATC GmbH	Germany	3 MicroSintFilters (35 µm); LPUV; low-frequency ultrasound. Treatment upon uptake and discharge (filtration by-pass).	MEPC 59/2/8 (granted)		
ATLAS DANMARK BWTS	ATLAS DANMARK	Denmark	Filter (50 µm); Electrolysis of artificial salt water (ANOLYTE/ CATHOLYTE). Treatment upon uptake.	MEPC 60/2 (rejected)		
Blue Ocean Shield	China Ocean Shipping	China	Filtration (50µm); LPUV. Treatment upon uptake and discharge (filtration by-pass).	MEPC 60/2/2 (granted)		
BalClor	Sunrui Corrosion and Fouling Control Company	China	Filter (50 µm); Seawater electrolysis; Neutralization ($Na_2S_2O_3$). Treatment upon uptake.	MEPC 60/2/3	MEPC 61/2/4 (granted)	
DESMI Ocean Guard	DESMI Ocean Guard A/S	Denmark	Filtration (20; 40 µm)); LPUV + Ozone (O_3). Treatment upon uptake and discharge (filtration by-pass).	MEPC 60/2/4 (granted)		

Table 2: Continued.

System	Supplier	Submitting Country	Treatment process description	Basic Approval	Final Approval	Type Approval
ARA Ballast (Blue Ocean Guardian)	21st Century Shipbuilding Co., Ltd.	Republik of Korea	Filtration (50µm); Plasma pulse module; MPUV. Treatment upon uptake and discharge (filtration by-pass).	MEPC 60/2/5	MEPC 61/2/5 (granted)	
Hi-Ballast (HHI)	Hyundai Heavy Industries Co., Ltd.	Republik of Korea	Filter (50 µm, optional); Seawater electrolysis; Neutralization ($Na_2S_2O_3$; $NaHSO_3$). Treatment upon uptake.	MEPC 60/2/6 (granted)		
EnBallast	Kwang San Co., Ltd	Republic of Korea	Filtration (50 µm); Seawater electrolysis; Neutralization ($Na_2S_2O_3$). Treatment upon uptake.	MEPC 60/2/7 (granted)		
Ocean Guard	Qingdao Headway Technology Co., Ltd.	Norway	Filtration (50 µm); Electrocatalysis + ultrasound. Treatment upon uptake and discharge (filtration by-pass).	MEPC 60/2/8 (granted)	MEPC 61/2/7 (pending)	
BalPure	Severn Trent DeNora	Germany	Filtration (40µm); Seawater electrolysis; Neutralization ($NaHSO_3$). Treatment upon uptake.	MEPC 60/2/9 (granted)	MEPC 61/2/9 (pending)	
PuriMar	Techwin Eco Co., Ltd.	Republik of Korea	Filtration (50 µm); Seawater electrolysis; Neutralization ($Na_2S_2O_3$). Treatment upon uptake.	MEPC 61/2 (pending)		
AquaStar	AQUA Eng. Co., Ltd	Republik of Korea	Smart Pipe (row of filter compartments 30 - 50 µm); Seawater electrolysis; Neutralization ($Na_2S_2O_3$). Treatment upon uptake.	MEPC 61/2/1 (pending)		
Fine Ballast	MES	Japan	Pre-Filtration (100-200 µm); Membrane filtration; hydrogen peroxide (H_2O_2) membrane cleaning; H_2O_2 removal by MnO_2 ($KMnO_4$). Treatment upon uptake.	MEPC 61/2/3 (pending)		
MICROFADE (Kuraray)	Kuraray Co., Ltd.	Japan	Ca(ClO)2; Ca(OH)2; Na5P3O10; NaCl; CaCl2; Ca(ClO3)2; CaCO3; Neutralization (Na2S2O3). Treatment upon uptake.	MEPC 61/2/6 (pending)		
ERMA FIRST	ERMA FIRST E.S.K. Engineering Solutions S.A.	Greece	Pre-filtration (500 µm); Hydrocyclone (20 µm); Seawater electrolysis; Neutralization ($NaHSO_3$). Treatment upon uptake.	MEPC 61/2/11 (pending)		
BlueSeas	Envirotech and Consultancy Pte. Ltd.	Singapore	Filtration (50 µm); Seawater electrolysis; Neutralization ($Na_2S_2O_3$); Treatment upon uptake.	MEPC 61/2/12 (pending)		

Table 2: Continued.

System	Supplier	Submitting Country	Treatment process description	Basic Approval	Final Approval	Type Approval
Venturi Oxygen Stripping	NEI treatment system (US)	Marshall Islands	Filtration; Inert gas (low-sulfur marine diesel combust exhaust) injection. BW tank kept in hypoxia with combust gas. Treatment upon uptake.	N.R.[5] (G8)	N.R. (G8)	10/ 2007
Hyde Guardian	Hyde Marine	UK	Filtration (50 µm); MPUV. Treatment upon uptake and discharge (filtration by-pass).	N.R. (G8)	N.R. (G8)	4/ 2008
OBS	Optimarin AS	Norway	Filtration (40 µm); MPUV. Treatment upon uptake and discharge	N.R. (G8)	N.R. (G8)	11/ 2009

[1]Neutralization = removal of excess chlorine species; [2]MPUV = medium pressure UV light; [3]LPUV = low pressure UV light; [4]MEPC = Marine Environmental Protection Committee document; [5] N.R. = Not Required at that time

1.3.1 Pre-treatment Filtration / Hydrocyclone

Filtration and Hydrocyclone technologies are usually applied prior to the actual treatment system in order to improve water quality and treatment system performance (Table 2). Filtration/ Hydrocyclone technology does not use or produce ‘active substances’ and/ or relevant chemicals, but the majority of multi component systems apply one or the other (as combination in one system) prior to the actual treatment. Hence, technologies are described for completeness.

Screen filter

Screen filter use a rigid or flexible screen to separate sediments and fine particles out of a liquid phase. The filtration unit usually consists of a housing containing a filter screen cylinder (Fig. 4). Water is pumped into the cylinder, passes the screen and is transported out. These are generally not recommended for filtering organic matter such as algae, since these types of contaminants can be extruded into spaghetti-like strings through the filter if enough pressure drop occurs across the filter surface. Typical screen materials include stainless steel (Mesh), polypropylene, nylon and Polyester. Self-cleaning screen filters incorporate an automatic backwash cycle to overcome clogging. Similar screens with larger openings designed only to segregate large objects are called strainers (e.g. covering a ship’s sea chest).

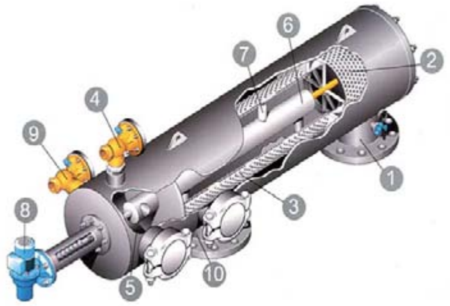

Figure 4: Screen filter. 1 Inlet; 2 Coarse screen; 3 Fine screen; 4 – 9 Backflushing system; 10 Outlet. (http://www.process-controls.com/ Pelmar/Pelmar_SE_Series.html)

Disk filter

Disc filters provide the same positive two dimensional filtering surface as a screen filter with the added dimension of depth filtration. A disk filter consists of a filter cartridge that consists of a number of disks stacked on top of each other. The water passes through the small grooves in between and the impurities are trapped behind. Some disk filters can be backflushed by succinct disk separation and spin during the cleaning cycle (Fig. 5).

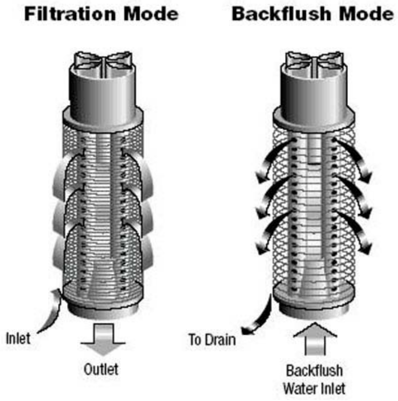

Figure 5: Disc filtration. Principle of filtration (left) and backflushing

Tube filter

A tube filter is a vertical tank filter with tubes suspended from a tube sheet. Liquid is sucked in through the porous tube surface. A filter cake is formed on the outside of the tube and filtrate flows up through the tube into the head and out. The tubes are cleaned by high rate backwashing often assisted by a hydraulic "pump".

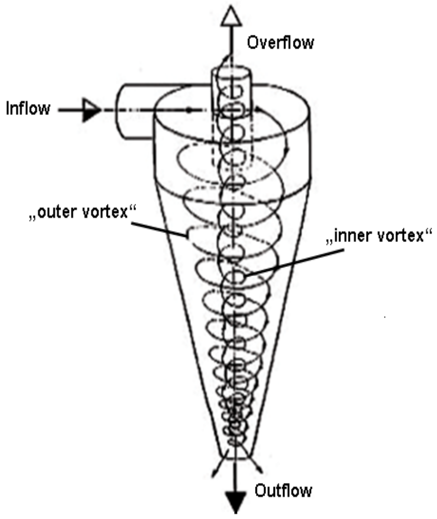

Figure 6: Hydroclone working principle

Hydrocyclone separation
Hydrocyclones are an important device for the separation of solid-liquid suspensions (Svarovsky 1984). By centrifugal sedimentation, the particles in a suspension are exposed to centrifugal forces. A hydrocyclone makes use of relative density differences for solid/ liquid or liquid/ liquid separation (Petty and Parks 2001, Vieira et al. 2005). Due to the tangent feeding the fluid acquires a spiralling motion urging the higher density agent against the wall of the hydrocyclone where it subsequently is dragged to the underflow while the less dense agent proceeds to the overflow. Hence, a free vortex (outer vortex) and a forced vortex (inner vortex) are formed (Fig. 6).

1.3.2 Chemical disinfection

Most chemical disinfection techniques use the strong biocidal effect of chemical oxidants which inactivate viable organisms in BW by irreversibly damaging cell membranes. A short introduction to the most common disinfection techniques is given below. The numbers in brackets refer to the number of existing BWMS applying the particular technique.

Coagulation/ Flocculation (1 System)
In the coagulation technique a magnetic powder (e.g. Triirontetroxide) and a organic or inorganic coagulant (e.g. Poly Aluminium Chloride; Poly Acrylamide Sodium Acrylate) are added to the incoming BW. Suspended particles (sediment, organisms) and the magnetic powder are aggregated in flocs by the coagulant (Fig. 7). The treated water is passed through a magnetic separator to remove the flocs. To secure the removal of all flocs the treated water then passes a filter before entering the ballast tank. Flocs are separated in a sludge tank and need to be disposed of to shore.

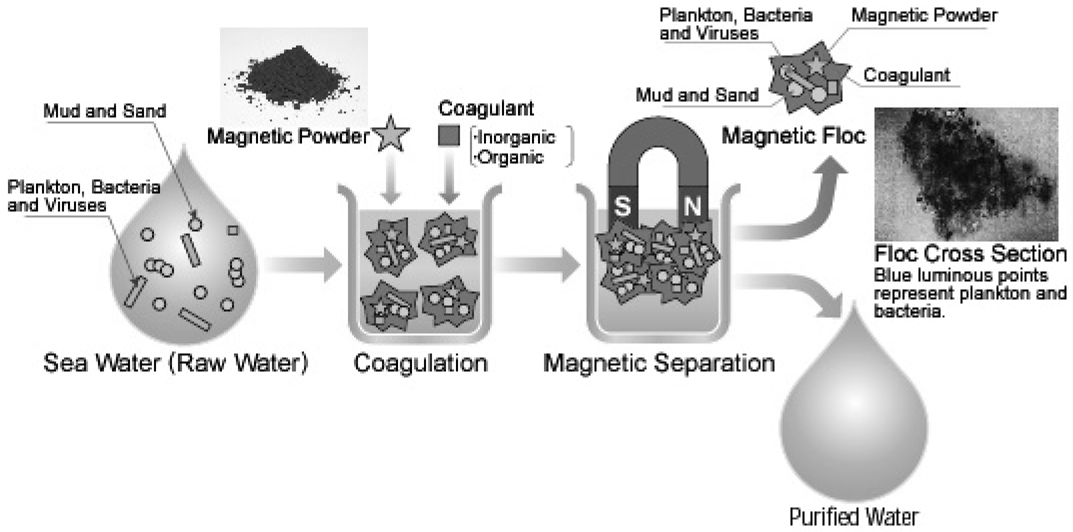

Figure 7: Schematic overview of the coagulation/ flocculation process.

Chlorination (3 Systems)
Chlorination is known to remove organisms and pathogens from water and widely applied in water treatment technologies. Chlorine usually is dosed to the incoming BW in a variety of forms including liquefied chlorine gas, sodium hypochlorite or calcium hypochlorite. Residual chlorine remains in the BW tank and is often

neutralized in-line during the deballasting process. Most common neutralizers are sodium thiosulfate ($Na_2S_2O_3$) and sodium bisulfite ($NaHSO_3$). The toxicity of chlorine is a function of several factors including chlorine concentration, pH, exposure time, type and quantity of chlorine compounds formed, organism and organic matter concentration (Gregg et al. 2009).
The biggest drawback of chlorination is the formation of toxic organochlorides and subsequent environmental impacts at the port of ballast discharge. A shipboard assessment of the use of chlorine for BW treatment found that chlorine concentrations above 3 ppm should not be used due to the formation of high concentrations of toxic by-products (e.g. trihalomethanes; haloacetic acids) (Vianna da Silva and da Costa Fernandes 2004).
Chlorine dioxide (ClO_2) is applied alternatively. It does not involve or create free available chlorine, reacts less with organic matter, and creates less chlorinated by-products, chlorate being the most important.

Electrolysis/ electrochlorination (15 systems)
Electrochlorination is based on the electric generation of a weak chlorine solution by electrolysis of an artifical salt solution or natural seawater. In most cases a quantity of incoming BW is by passed through an electrochlorination unit and the generated chlorine solution is then mixed into the ballast pipe for disinfection. Naturally occurring bromine in seawater undergoes a comparable reaction. The wealth of reactions is complex, but the key reactions are:

$NaCl + H_2O$ + energy ---> $NaOCl + H_2$

$NaBr + H_2O$ + energy ---> $NaOBr + H_2$

Resulting in the hypochlorite/ hypobromite anion (OCl^-) forming hypochlorous/ hypobromous acid as the main disinfecting agents. The formation of by-products is comparable to chlorination and hence, a chlorine neutralization step is often applied (see Chlorination) (Tsolaki and Diamandopoulos 2009).

Ozonation (4 systems)
Ozone (O_3) is one of the most powerful chemical oxidants used for disinfection and like chlorine has a long tradition as disinfection technology. Ozone usually is generated on board in an ozone generator from air and ozone gas is injected into a side stream of the regular ballast pipe during the ballasting process. Since O_3 is gaseous and readily decomposes into oxygen, the germicidal effect is mostly attributed to the production of hypobromous acid/hypobromite, which are generally measured as total residual oxidants (TRO’s) (Perrins et al. 2006).
The high reactivity with bromine in seawater leads to the formation of unwanted toxic by-products (e.g. brominated organics, bromoform, bromate, bromamines). Thus, to keep toxic by-products minimal ozone is often combined with other treatment options or a neutralization step is applied (Table 2).

Peracetic acid (2 system)
Peracetic acid ($C_2H_4O_3$) is a mixture of acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2) in a watery solution and is produced by a reaction of hydrogen peroxide and acetic acid. Peracetic acid is a broad range biocide with an oxidising potential outranging chlorine and chlorine dioxide with the advantage of any by-product formation. However, the biocidal effect strongly depends on pH (Sagripanti

and Bonifacino 1996) and degradation is slowed down in freshwater and under cold conditions setting limits to the application in BW treatment (de Lafontaine et al. 2008a,b).

Hydrogen peroxide (3 systems)
Although a strong oxidant and a well known disinfectant hydrogen peroxide so far is used only as auxiliary chemical in BWMSs, either for cleaning of filter membranes or for the generation of the Active substance (see *Peracetic acid*).
Hydrogen peroxide potentially is a viable disinfectant for BW, but high concentrations and long exposure are required for effective treatment (Smit et al. 2008). Hydrogen peroxide could theoretically be produced on board in an electrochemical reactor from dissolved oxygen in seawater (Gregg et al. 2009).

1.3.3 Physical disinfection

The numbers in brackets refer to the number of existing BWMS applying the particular technique

UV irradiation/ Advanced Oxidation Processes (8 systems)
UV radiation as disinfection is well known for almost hundred years and is utilized widespread in public and private water disinfection. In contrast to most chemical treatment options UV light does not change the chemical composition ph-value, temperature, salinity, taste, smell and colour of the treated water. Photochemical inactivation by UV light is very effective and the required dosage mainly depends on organism size. The dosage is a function of lamp intensity and exposure time which are directly affected by water quality limiting the transmission of UV light. Two types of lamps are used to generate UV light: Low Pressure UV (LPUV) and Medium Pressure UV (MPUV). LPUV emits light especially at the UV-C wave length of 254 nm (UV_{254nm}) matching the DNA absorption maximum. MPUV lamps in contrast emit light over a broad wave length spectrum from UV to visible light. The basic process of disinfection with UV light is photolysis, the decomposition of a molecule by light. LPUV specifically targets the DNA molecule causing partly irreversible damage to the molecule itself and its repair mechanism. Generation of free radicals plays a minor role. Disinfection with MPUV is explicitly based on the generation of short lived free radicals causing direct oxidative cell damage and the production of secondary disinfectants e.g. HOCl/OCl-, $HOBr/OBr^-$. The DNA damaging effect of UV_{254nm} contributes to the germicidal effect of MPUV. To increase the free radical yield MPUV is sometimes used in conjunction with catalysts (e.g. TiO2) in a so called advanced oxidation process (AOP). Free radicals potentially generate unwanted halogenated by-products from chlorine and bromine naturally occurring in seawater. Increasing loads of organic matter also increase the chance for by-product formation. Hence, initial filtration of BW upon entry is essential to increase water clarity for UV treatment and reducing by-product formation. Water then is treated upon entry in a UV module consisting of a set of lamps in varying arrangements and is stored in the ballast tank. Usually a second UV treatment is conducted prior to discharge in order to remove potentially regrown organisms due to photoreactivation and dark repair.

Ultrasound (2 systems)
Ultrasound has a long tradition in drinking and waste water disinfection e.g. in German water treatment plants ultrasound is used to remove viable plankton organisms (Mason & Peters 2002).

The basic mechanism for disinfection is the generation and subsequent collapse of cavitation bubbles. The concentration of ultrasound energy makes cavitation bubbles micro-reactors with estimated temperatures of ~1800 K (~1500 °C). Therefore, collapsing bubbles mechanically destroy organisms by shear forces and by the release of free radicals generated from water inside the bubble. Radicals immediately react with organisms or compounds in the water (Riesz et al. 1985). Radical reactions are unspecific and thus can generate unwanted halogenated by-products. Radical generation strongly depends on ultrasound frequency. The higher the frequency the more cavitation bubbles and consequently the more radicals are generated (Thompson and Doraiswamy 1999, Abu-Hassan et al. 2006).
For BW treatment ultrasound is used as auxiliary technique for either cleaning of filter and other treatment devices (e.g. UV lamps) or the support of electrocatalysis by increasing the radical yield.

Cavitation (4 systems)
Hydrodynamic cavitation uses the same mechanism described for ultrasound. Slit plates or venture pipes are used to generate cavitation bubbles with a high local energy release upon collapse. The shock wave damages and destroys organisms contained in the water (Gogate and Kabadi 2009). To aid the process additional gas (air, ozone etc.) is added to the flowing water increasing the amount of cavitation bubbles.

Deoxygenation/ Inert gas injection (2 systems)
The principle mechanism for deoxygenation is inert gas introduction directly or via a venture injector into BW as it is drawn into the vessel (Gregg et al. 2009). The venturi injector creates a micro-fine bubble emulsion where dissolved oxygen quickly diffuses out of the water into the gas. Either nitrogen supersaturation is used to force out dissolved oxygen in BW or an inert gas is produced by combusting low-sulfur marine diesel (generating mostly nitrogen with small amounts of carbon dioxide and only trace levels of oxygen). Carbon dioxide in solution forms both carbonic and carboxylic acid, reducing the pH of treated water (Tamburri et al. 2003).

Plasma pulse technology (1 system)
Pulse plasma technology uses short bursts of energy to kill organisms in water. High voltage in current is applied between two electrodes in the reactor that creates an ionization field. The field produces a high-energy plasma arc, which causes an extremely rapid rise in pressure, temperature and density flow and generates extensions resulting in a shock-wave as primary mechanism to kill organisms. Destruction is also achieved by direct reaction of hydrated electrons and free radicals due to the release of soft X-rays and high-energy UV radiation from the energized plasma (PWSRCAC 2005c).

Membrane filtration (1 system)
After pre-filtration incoming BW passes a membrane filter with a uniform micro-pore size removing all organisms in the water. A filter module consists of a cylinder of alternating layers of micro-porous membranes and spacer sheets wrapped around a pipe. Incoming BW is pumped through the membrane filter for organism removal and organisms are returned to sea in regular intervals. Water enters the central pipe and is transported into the ballast tank. The membrane filter requires cleaning after ballasting with e.g. hydrogen peroxide to prevent clogging.

2 ‘ACTIVE SUBSTANCES’ AND RELEVANT CHEMICALS – PRODUCTION, DEGRADATION AND DISCHARGE

According to guideline G9 to the `International convention for the control and management of ships' ballast water and sediments´ (IMO 2004) definitions of ‘active substance’ and relevant chemical are:

“Active substance” means a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens.

“Relevant Chemicals” means transformation or reaction products that are produced during and after employment of the BWMS in the BW or in the receiving environment and that may be of concern to the ship’s safety, aquatic environment and/or human health.

2.1 ‘Active substances’ and relevant chemicals produced by ballast water management systems

Thorough characterization of ‘active substances’ and relevant chemicals is mandatory under the G9 approval procedure. From a multitude of approval documents, several lists of the most frequent and environmentally critical chemicals have been extracted: The GESAMP-BWWG issued two lists ranked by frequency and environmental risk (MEPC 58/2/7, MEPC 59/2/13). In addition, the German Federal Environment Agency (Umweltbundesamt, UBA) attempted to identify all ‘active substances’ and relevant chemicals in the accessible approval documents and extracted them in a separate list. Furthermore, in the approval document for the AquaTriComb-BWMS (receiving basic approval in MEPC 59), the manufacturer provides an extensive list of tested by-products. Table 3 provides a comparative overview of those identified chemical compounds.

2.2 Production rates for ‘active substances’ and relevant chemicals

The demand for ‘active substances’ and relevant chemicals used by chemical treatment systems depends on the oxidant demand which is directly linked to the total organic carbon (TOC) concentration of untreated water. Likewise the concentration of relevant chemicals that will result from disinfection is based on the ‘active substance’ dose as well as the parameters of the untreated water (e.g. TOC, pH, temperature), with TOC being of significant influence. Hence, the more TOC in the water, the more ‘active substance’ is needed for proper treatment and the higher the chance for relevant chemical formation.
Disinfection techniques not applying ‘active substances’ per se mostly generate short lived radicals (UV, ultrasound, plasma pulse, cavitation) which can promote reactions of the dissolved organic matter (DOM) with chlorine and bromine naturally occurring in seawater to form harmful relevant chemicals. Hence, relevant chemical formation again depends on the characteristics of the untreated water.

Table 3: Comparative overview of potentially harmful substances in treated ballast water. Non-hazardous substances or dissociation products are given in light gray.

Active Substances	**Molecular formula**	**CAS number**	**GESAMP** MEPC 58/2/7	**GESAMP** MEPC 59/2/13	**UBA**	**AquaTriComb BWMS**
[4]TRO (Freshwater)					x	
TRO (Saltwater)					x	
AOX			x			x
EOX			x			x
Chlorine	Cl_2	7782-50-5				x
Hypochlorous acid	HOCl	7790-92-3			x	
Hypochloride Ion	NaOCl	7681-52-9		x	x	
Hyperbromate/ Hypobromous acid	HOBr	13517-11-8			x	x
Bromate Ion	$NaBrO_3$	7789-38-0		x	x	x
	$KBrO_3$	7758-01-2		x		
Chlorine Dioxide	ClO_2	10049-04-4			x	
Ozone	O_3	10028-15-6			x	x
Peracetic acid	CH_3 OCOOH	79-21-0			x	
Hydrogen peroxide	H_2O_2	7722-84-1			x	x
Acrolein	C_3H_4O	107-02-8			x	
Silver Ions	Ag^{2+}				x	
Copper Ions	Cu^{2+}				x	

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[4] TRO is included as 'Active substance' in the UBA list. TRO is comprised of chlorine and bromine based oxidants and used as a measure of such products in systems applying Chlorine or Chlorine dioxide as 'Active substance'. In other systems TRO would solely include reaction by-products. Hence, it could be both 'Active substance' and/or 'Relevant chemical'.

Table 3: Continued.

Relevant chemicals (Disinfection by-products)	**Molecular formula**	**CAS number**	**GESAMP** MEPC 58/2/7	**GESAMP** MEPC 59/2/13	**UBA**	**AquaTriComb BWMS**
Halogenated Methanes						
Trichloromethane	$CHCl_3$	67-66-3	x	x	x	x
Tetrachloromethane	CCl_4	56-23-5				x
Tribromomethane	$CHBr_3$	75-25-2	x	x	x	x
Dibromochloromethane	$CHBr_2Cl$	124-48-1	x	x	x	x
Dichlorobromomethane	$CHBrCl_2$	75-27-4	x	x	x	x
Halogenated Hydrocarbons						
1,2-Dibromoethane	$C_2H_4Br_2$	106-93-4	x			x
1,1,1-Trichloroethane	$C_2H_3Cl_3$	71-55-6				x
Tetrachloroethene	C_2Cl_4	127-18-4				x
1,2,3-Trichloropropane	$C_3H_4Cl_3$	96-18-4	x	x		x
1,2-Dibromo-3-chloropropane	$C_3H_4Br_2Cl$	96-12-8	x			x
Halogenated Aromatics						
2,4-Dibromophenol	$C_6H_4Br_2O$	615-58-7	x			x
2,6-Dibromophenol	$C_6H_4Br_2O$	608-33-3	x			x
2,4,6-Tribromophenol	$C_6H_3Br_3O$	118-79-6	x			x
2-Chlorotoluene	C_7H_7Cl	95-49-8	x			x
4-Chlorotoluene	C_7H_7Cl	106-43-4	x			x
1,2,3-Tribromobenzen	$C_6H_3Br_3$	n.a.	x			x

Table 3: Continued.

Halogenated Acetic Acids	**Molecular formula**	**CAS number**	**GESAMP** MEPC 58/2/7	**GESAMP** MEPC 59/2/13	**UBA**	**AquaTriComb BWMS**
Monochloroacetic acid	$CH_2ClCOOH$	79-11-8		x	x	x
Dichloroacetic acid	$CHCl_2COOH$	79-43-6		x	x	x
Trichloroacetic acid	CCl_3COOH	76-03-9		x	x	x
Monobromoacetic acid	$CH_2BrCOOH$	79-08-3	x	x	x	x
Dibromoacetic acid	$CHBr_2COOH$	631-64-1	x	x	x	x
Tribromoacetic acid	CBr_3COOH	75-96-7	x	x	x	x
Bromochloroacetic acid	$CHClBrCOOH$	5589-96-8	x	x	x	x
Dibromochloroacetic acid	$CHBr_2ClCOOH$	5278-95-5	x			x
Bromodichloroacetic acid	$CHBrCl_2COOH$	71133-14-7	x			x
Halogenated Acetonitriles						
Chloroacetonitrile	CH_2ClCN	107-14-2			x	
Dichloroacetonitrile	$CHCl_2CN$	3018-12-0			x	
Trichloroacetonitrile	CCl_3CN	545-06-2			x	
Monobromoacetonitrile	CH_2BrCN	590-17-0	x	x	x	x
Dibromoacetonitrile	$CHBr_2CN$	3252-43-5	x		x	x
Tribromoacetonitrile	CBr_3CN	75519-19-6			x	
Bromochloroacetonitrile	$CHBrClCN$	83463-62-1	x		x	x
Halogenated Amines						
Monochloramine	NH_2Cl	10599-90-3		x	x	
Dichloramine	$NHCl_2$	3400-09-7			x	
Inorganics						
Chlorite Ion	$NaClO_2$	7758-19-2			x	
Chlorate Ion	$NaClO_3$	7775-09-9			x	
Nitrite Ion	$NaNO_2$	7632-00-0			x	x
Nitrate Ion	$NaNO_3$	7631-99-4			x	

Table 3: Continued.

Neutralization	**Molecular formula**	**CAS number**	**GESAMP (MEPC 58/2/7)**	**GESAMP MEPC 59/2/13**	**UBA**	**AquaTriComb**
Sodium Bisulfate	$NaHSO_4$	7681-38-1			x	
Sodium Sulfite	Na_2SO_3	7757-83-7			x	
Sodium Thiosulfate	$Na_2S_2O_3$	7772-98-7	x	x	x	
Sodium Sulfate	Na_2SO_4	7757-82-6			x	

Due to changing seawater characteristics around the globe, estimation of general production rates for ‘active substances’ and relevant chemicals is difficult. According to guideline G9 concentrations of ‘active substances’ and relevant chemicals in treated BW have to be evaluated by the applicant in an approval process controlled by the competent authorities (Fig. 1). For Basic Approval (BA) only bench scale tests are required. For Final Approval (FA) concentrations in treated BW have to be determined in effluent from a land-based test system fulfilling the criteria prescribed in the G8 guidelines (MEPC 58/3/4 ANNEX Part 2, Chapter 2.3).
Results from chemical testing of the effluent directly after treatment can give an approximation for the concentration of ‘active substances’ and relevant chemicals generated in treated BW by a BWMS. Concentrations of ‘active substances’ and relevant chemicals in treated BW change over time due to biotic and abiotic degradation. In case a neutralization step is applied, residual oxidants might be completely removed prior to BW discharge. However, a multitude of environmentally and toxicologically critical relevant chemicals (disinfection by-products) are unaffected by the common neutralization agents applied.

Annex II summarizes ‘active substances’ and relevant chemicals detected and the measured concentrations in water treated by BWMSs (reviewed from approval documents). These concentrations are generally used by applicants as input for environmental concentration modelling (Annex IIIB).

2.3. Degradation of active and relevant substances in the tank and in the environment – treatment during uptake or before deballasting?

Abiotic and biotic transformation of ‘active substances’ and relevant chemicals determines their persistence in BW tanks and in the environment. Abiotic processes comprise photolysis, hydrolysis, oxidations and reductions, and ß-eliminations. Their efficiency varies with the ambient conditions such as UV-light exposure, concentration of organic matter, salinity etc. Biotic processes depend on the number, diversity and physiological activity of (micro-) organisms being present. They may lead to alkylation of metals, de-halogenation and/or breakdown and/or mineralization of organic substances. Overall, degradation rates are difficult to predict, but ranges could be given and the specific ambient conditions be taken into account. In general, oxidizing substances such as hydrogen peroxide, ozone, chlorine, and bromine are biocides that disrupt cell membranes and are highly reactive. Accordingly decomposition rates are significantly related to the amount of organic matter present.
Relevant chemicals, that are produced as disinfection by-products, on the other side, often are halogenated compounds with reduced degradation rates and half-lives of days to months. Trihalomethanes such as chloroform and bromoform are in principle degraded under aerobic conditions (methane-utilizing bacteria) and under anaerobic conditions (by methanogenic bacteria), however not to an extent which would characterize e.g. chloroform as readily biodegradable (Anonymous 2007). Hydrolysis, adsorption, photo-oxidation, photolysis, hydraulic processes, and bioaccumulation do not appear to reduce chloroform concentrations in water substantially. Among haloacetic acids, trifluoroacetic acid seems to be extremely persistent (no degradation measurable within a year). Residence times often vary with the numbers of substituted halogen atoms: from the chloroacetic acids, trichloroacetic acid had the longest half-life with 40 days, monochloroacetic acid with 14 days an intermediate and dichloroacetic acid the

shortest half-life (4 days) (Ellis 2001). Biodegradation of trichloro-, dichloro-, and monochloroacetic acids leads primarily to the formation of chloride and oxalic, glyoxalic, and glycolic acids, respectively.
As BW can be treated during ballasting or before deballasting, or to some extent at both stages, e.g. using different systems (see 1.2), the following aspects with regard to transformation processes have to be taken into account when designing and assessing the treatment procedure:

1) Since BW in the tanks is not sterile, organisms will multiply during the ship's travel. Especially bacteria will form biofilms on immersed surfaces which will be difficult to remove at a later stage. Bacterial biofilms develop within hours on submerged artificial surfaces (see e.g. Lee et al, 2008 for experiments in coastal waters). Once formed, their destruction is difficult as they show increased resistance to chemicals that tend to kill free-living bacteria (e.g. Lewis 2001 for review). As biofilms within BW tanks are known to potentially contain pathogenic organisms (McCarthy & Khambaty 1994), their persistence with occasional sloughing off of the biofilm should be prevented. In addition, biofilms can build up anaerobic zones and thus allow for anaerobic bacterial transformation processes. Potential emissions of contaminants from biocide-based coatings of BW tanks, which prevent or limit the formation of biofilms, have not been addressed further in this report.

2) Treatment of BW during uptake could lead to chemical degradation of 'active substances' and/or relevant chemicals with time and thus to decreased concentration of contaminants in the BW. However, this decreased concentration may also lead to reduced efficiency in biomass control in the tanks.

3) Treatment before deballasting directly releases the formed substances into the environment. Depending on the mixing depth and the location of discharge pipes, photolysis may enhance degradation of organic substances.

3 SETTING THE SCENE FOR THE EXPOSURE ASSESSMENT

3.1. Introduction

The exposure assessment is based on a realistic scenario which considers reasonable worst-case circumstances that are exceeded by a small percentage of cases over the whole possible range of likely circumstances of use. By using a “worst case” scenario, exposure concentrations should rather be over- than underestimated, leading to conservative calculations of the amount of potentially hazardous substances released through BW treatment. By applying a “realistic” or “reasonable worst case”-scenario, exposure conditions under normal use are considered, excluding extreme situations such as accidents, malfunction or deliberate misuse (ECB, 2003a). From a statistical point of view, use of the 90th percentile of possible exposure concentrations has been suggested to define a realistic worst case, but this requires extensive data sets which are often unavailable and is not necessarily in line with the above definition. Available measured and modelled data and qualifying information should provide the basis for setting the boundaries of a realistic worst case scenario, which will - to some degree – be prone to interpretation and expert judgement (ECB, 2003). The following chapters will present and explain the use of boundaries in the used realistic worst-case scenarios.

3.2. Harbour discharges

Whether the discharge of treated BW in harbours leads to a high or low exposure depends on a number of different factors: How much BW is discharged per time (Chapter 3.2.1)? What type of harbour is the BW discharged to (Chapter 3.2.2)?

3.2.1. Discharge quantities

Ballast water carried by different ship types

Ballast water capacity varies as a function of cargo carrying capacity and ship type as discussed in Endresen et al. (2003). The annual uptake of BW can be estimated as a function of the total cargo transported annually (Endresen et al. 2004). Endresen et al. (2003) estimated the BW uptake as 36% of the dead weight tonnage (DWT) or 40% of the transported cargo, and arrive at an estimated annual uptake of BW of 3500 Mton. This is shared between international≈(2200 Mton) and national (1300 Mton) trade.
Internationally, oil tankers account for some 37% of the BW annually transported, while Dry bulk cargo carriers account for 39% (coal, iron ore, grains and other bulk commodities). The remaining 24% includes General Cargo, Container vessels, Ro-Ro, Chemical tankers and LNG tankers. The contribution of the latter group may be lower since General Cargo and Container vessels rarely operate return voyages in ballast condition and mainly use ballast for adjusting trim and heel. A more detailed estimate of the relation between DWT and BW volumes is provided by the Globallast Partnerships website (http://globallast.imo.org/). In the remainder of this report we will use the overall estimates by Endresen et al. (2004) as representative estimates.
The abovementioned quantities of BW are transported around the world according to international ship traffic, loading and unloading patterns. As an illustration, the international sea borne cargo statistics indicate that the US, Europe and Japan are the

main export regions of BW by crude oil carriers. The main importing regions are the Middle East, the Caribbean and Africa (Fig. 8).

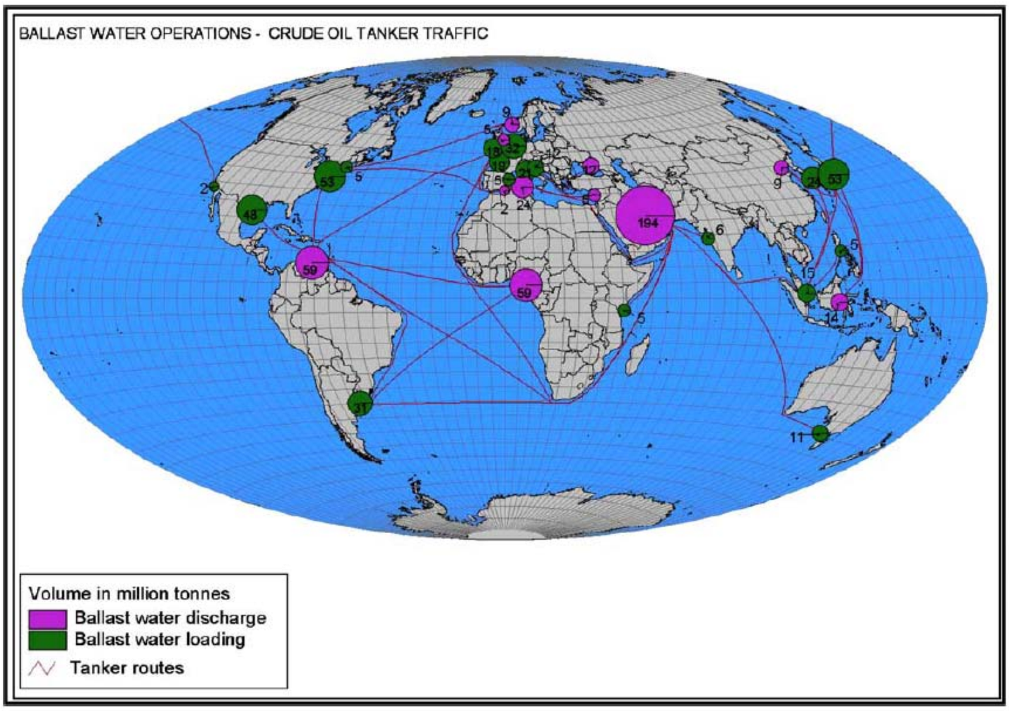

Figure 8: Export (loading, red) and import (discharge, blue) areas of ballast water by large crude oil carriers in 1996 (Endresen et al. 2004).

Figure 9: Open ocean exchange of ballast water. A. Ship undergoing mid-ocean ballast water exchange; B. Ballast water is forced out an opening at the top of the ship in flow-through exchange. (photos: Marine Invasions Research Laboratory, Smithsonian Environmental Research Centre. http://www.serc.si.edu/labs/marine_invasions/index.aspx)

It is recommended to limit the introduction of non-indigenous species by BW by carrying out open ocean exchange of BW (IMO, 2003). Open ocean exchange of BW involves replacing coastal water with open ocean water during a voyage, either by emptying and refilling ballast tanks (sequential exchange) or by flow-through dilution (three times tank volume) (Fig. 9). Endresen et al. (2004) however argue that BW exchange is not always possible to perform due to safety issues (Fig. 10) as well as to geographical constraints. In addition, it is not always biologically efficient, thus providing motivation for the development of BW treatment technologies.

Figure 10: Loss of stability of MV Cougar Ace during open ocean exchange of ballast water on 23 July 2006 (photo: http://en.wikipedia.org/wiki/MV_Cougar_Ace).

Discharge estimation/ modelling

The BW load carried by ships can be derived from cargo transport statistics, as discussed above. These amounts present the potential maximum BW discharge quantities. Some case studies exist where BW discharges in harbours have been directly derived from local inventories. This information is collected in Table 5.

Table 5: Daily BW discharge, unit discharge and number of discharge events recorded in different ports.

Port	**BW discharges (m^3/d)**	**Average volume of one BW discharge (m^3)**	**Average nr. of discharges (1/d)**	**Reference**
Rotterdam (NL)	95200	2582	36.9	van Niekerk, 2008
Kharg (IR)	65383	37026	1.8	Clarke et al. 2003a
Sepetiba (BR)	7981	7567	1.1	Clarke et al. 2003c
Saldanah Bay (ZA)	20310	22687	0.9	Awad et al. 2003
Dalian (CHN)	1490	2150	0.7	Clarke et al. 2003b
Odessa (UA)	12391	3673	3.4	Alexandrov et al. 2003

Note 1: Except for the Rotterdam case, the BW discharges reported may be inaccurate due to the fact that the total ballast water discharge volume was clearly reported, but not the total period during which discharges were monitored.
Note 2: Except for the Rotterdam case, the volume of a single discharge is probably overestimated, since vessels are expected to have submitted in many cases a single, total discharge volume covering all their BW tanks.
Note 3: The Rotterdam data clearly show that the volume of individual discharges varies within a wide range (according to ship size and type), by at least two orders of magnitude.

The rule-of-thumb for maximum BW discharges as a function of total exported cargo discussed by Endresen et al. (2004) is theoretically a worst case number. It holds for a situation that all ships arrive at the port fully loaded with BW and leave the port without

BW. Table 6 shows data evaluating the ratio between the annual BW discharges and the annual cargo throughput. The results are variable, between <1% and 28%, which demonstrates that 40% is indeed a worst case estimate. The results for Saldanah and Kharg ports are the closest to the estimated maximum of 40%, which can be expected for these ports, in view of the fact that both are primarily exporting harbours (Saldanah: Iron ore; Kharg: Crude oil) (Fig. 8). Thus, maximum possible BW discharge volumes are connected to cargo volumes. Consequently, high volumes of BW discharges are connected to areas with a high cargo transport density. In areas with a lower cargo transport density, BW discharges are expected to be relatively smaller, but also more irregularly distributed both in time and space (as witnessed by the nr. of discharge events in the various ports, Table 5).

Table 6: Annual BW discharge, annual cargo throughput and ratio between the two.

Port	BW discharges (Mm^3/y)	Annual cargo (Mt/y)	Ratio (%)	Reference
Rotterdam (NL)	34.7[1]	421[2]	8%	[1]Royal Haskoning (2008) [2]Havenbedrijf Rotterdam N.V. (2008)
Kharg (IR)	22.5[3]	130[4]	17%	[3]Clarke et al. (2003a) [4]http://www.irandaily.com/1388/3378/html/economy.htm
Saldanah Bay (ZA)	14[5]	50.3[6]	28%	[5]Clark et al. (2009) [6]http://ports.co.za/saldanha-bay.php
Dalian (CN)	0.5[7]	90[8]	<1%	[7] Clarke et al. (2003b) [8]http://www.worldportsource.com/ports/CHN_Port_of_Dalian_238.php
Odessa (UA)	3.1[9]	31.6[10]	10%	[9] Alexandrov et al. (2003) [10]http://www.port.odessa.ua/main.php?lan=en&page=4002

According to the US National Research Council (1996), typical BW pumping rates vary between 5,000 and 20,000 m^3/h for BW replacing cargo. With an average unit discharge volume of several thousand m^3 (Table 5), the average duration of a single discharge is in the order of an hour or smaller. We note that for large ships, this number is expected to be higher (up to about 5 hours for a 100,000 m^3 tank emptied at 20,000 m^3/h).

A final important aspect is the salinity of the discharge. For vessels using open ocean exchange of BW, the BW salinity is expected to be close to open ocean values. Endresen et al. (2004) indicate that this holds for about 60% of the total BW uptake. For the remaining 40%, open ocean exchange of BW is for practical reasons considered impossible. For this share of the BW volume, the salinity is determined by the area of uptake. In view of the large variety of ambient salinities observed in ports all over the world (Fig. 11), a density difference between the BW discharge and the receiving ambient waters must be anticipated.

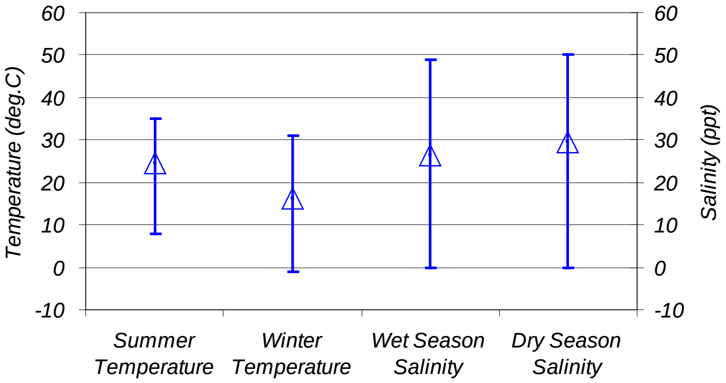

Figure 11: **Range and mean of seasonal values of water temperature and salinity in 357 larger ports all over the world (Clarke et al. 2003).**

3.2.2 Types of harbours:

There are different categorizations of harbours that differ slightly: The world port index (WPI), maintained by the National Geospatial-intelligence Agency differentiates 8 major harbour types: (Information from Rodrigue, J-P et al. 2009), which are shown with their worldwide distribution in figure 13. The 8 harbour types are coastal natural harbour, coastal breakwater, coastal tide gates, river natural, river basins, canal or lake, river tide gates, and open roadstead. A list of harbours and their environmental parameters by GLOBALLAST uses a different categorization into 6 categories (open water T-jetty or mooring, in bay – natural harbour, breakwater harbour, in tidal creek, in estuary, in river) which in its assignment of ports is only roughly comparable to the one from WPI. To the largest extent the class “breakwater harbour” corresponds with “coastal breakwater”.
For exposure assessment, the WPI categories seem to be more useful, as they give a better indication on the water exchange within the harbour and with open water.

Coastal natural harbour represents a sheltered site, the outcome of a natural profile of the coast, creating a natural barrier such as a cape, a reef or an island. About 2,100 (46.0%) ports are in this category, underlining that the selection of a port site is dominantly influenced by the quality of the harbour. As shown in figure 13 which depicts the harbour of Kingston, Jamaica, in coastal natural harbours few boundaries would hinder the mixing of discharged BW and open water.

Coastal breakwater harbours lie behind an artificial breakwater construction, built from scratch or built to add to an existing natural shelter. About 810 ports (17.6%) are in this category. As shown in Figure 13 depicting the port of Cherbourg, France, as an example, the breakwater can restrict water movement within the port and mixing of water bodies. Other examples are the ports of Saldanha (South Africa) and Odessa (Ukraine). Due to the fact that breakwaters are built when harbours are exposed to dominant winds, waves or the sea currents, the exchange of harbour water with open water will still be significant.

Coastal tide gates and River tide gate. A harbour behind a set of locks or other mechanical devices built to insure sufficient water levels in the port for all tide levels. In many cases ships can enter or exit the port only at certain times of the day when water levels are adequate. Such harbours tend to be located close to the ocean, in a river delta or estuary. Only 86 (1.8%) such ports exist, such as Mumbai, India (Fig. 13, example for coastal tide gate) or Bremerhaven, Germany. Mixing of BW with open water would occur only when tide gates are opened. This is presumably the most confined situation in which BW is discharged.

River natural. A harbour located along a river where water is not retained in any artificial means. In these types of harbours, exchange of BW and open water is maximal even though often quays or wharves exist parallel to the river banks. Piers may also extend into the river. About 850 (18.5%) such ports exist.

River basins describe a river harbour where basins have been excavated to accommodate ships, often parallel to the flow of the river. This confers the advantage of additional berth space without impeding fluvial navigation. 77 (1.6%) such ports exist. The ports of Bremen and Rotterdam are examples of river basins ports.

Canal or lake. A harbour located along an artificial canal or by a river accessible through a navigable waterway. 67 (1.4%) such ports exist. The port of Hamburg is given as an example for this harbour type by the World Seaports Catalogue. This category does not provide useful information in terms of BW exposure, as little can be deduced from this definition in terms of water mixing in the port.

Open roadstead. A harbour without natural or artificial protection. They are often built to accommodate very large ships (such as oil tankers) or are in a setting where there are limited tides, implying that sheltering infrastructure is much less required (Persian Gulf, Red Sea, Gulf of Mexico). 580 (12.5%) ports are in this category, one of which is the port of Kharg Iran. Mixing will depend on strength of the hydrodynamic regime (currents, tides, turbulences. dispersion), but most likely mixing effects will be high in this harbour type.

Different types of harbours dominate in different parts of the world. Based on information from the world seaports catalogue, figure 12 depicts the distribution of different kinds of harbours on the different continents, whereby only harbours with an anchorage depth of more than 9.4 meters[5] were considered. Those harbour types with least expected dilution of BW discharge, tide gates and river basins ports, are mainly found in Europe. Of 2292 world seaports, only 47 are either coastal or river tide gates and 37 of those are in the UK[6].

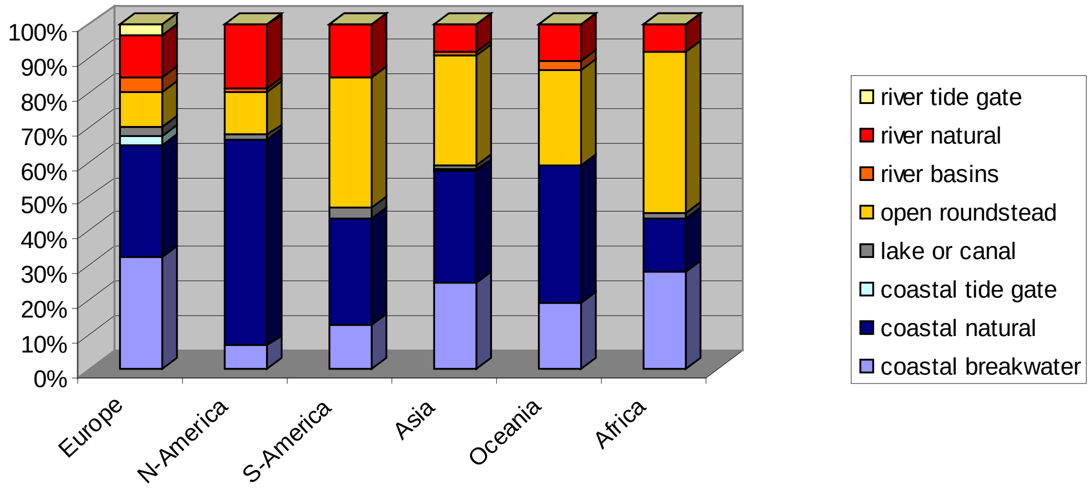

Figure 12: Harbour type distribution by continent.

As hydrodynamics and mixing processes vary with port morphology, a realistic worst case scenario would be a simplified river basin-like structure with reduced mixing with outside waters.

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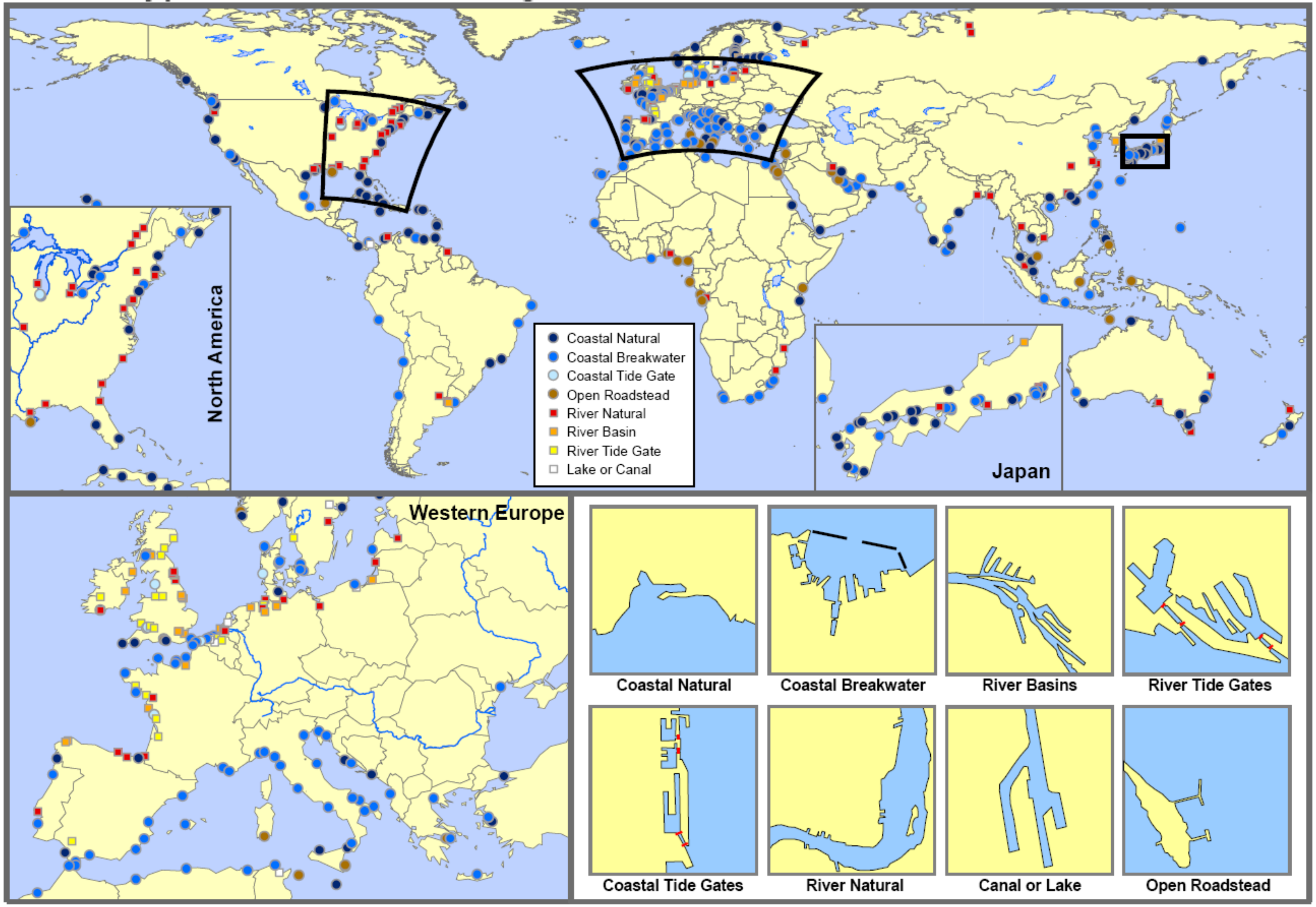
[5] **Container ships of the first generation had a draft of 9 m, so a minimal anchorage depth of 9 m is considered a precondition for a harbour with significant ballast water discharge**.

[6] **Data from the World seaports catalogue, www.ports.com**



Source: adapted from National Geospatial-intelligence Agency (2005) World Port Index, Eighteenth Edition.

Dr. Jean-Paul Rodrigue, Dept. of Economics & Geography, Hofstra University, October 2005.

Figure 13: Harbour type categories for the world's large and medium sized ports (by courtesy of J.-P. Rodrigue, Hofstra University)

3.3 Shipping lane discharges

Depending on the weather and geographical conditions, de-ballasting may occur before the ships enter the port. This may be due to the necessity to allow the ship's keel to clear a shallow channel or in order to safe time when reaching the port. Information is not sufficient to quantify how much BW is discharged before arrival, but in order to retain the ship’s stability it can be assumed that this is a process carried out in short distance of the port.
Especially in the case of ports that are frequented a lot, this may lead to increased exposure of the environment to relevant substances from treated BW even though mixing can be assumed to be extensive along shipping lanes. The case of tributyl tin (TBT), however, showed that specific substances can accumulate along busy shipping lanes despite dilution and degradation processes and induced effects (Ten Hallers-Tjabbes et al, 1994, 2003). In order to account for this possibility, we included a worst-case shipping lane scenario in this document (4.2.3).

3.4 Human exposure

In this document we focus on the environmental exposure. Occupational activities on or close to ships discharging BW or recreational activities in coastal areas may lead to significant human exposure. This may include skin contact with (diluted) BW, swallowing (in case of swimmers), as well as inhalation of volatile compounds from BW. A special task group within GESAMP BWWG is concerned with the definition of relevant human exposure scenarios and the evaluation of suitable modelling tools for exposure assessment. For this reason human exposure is not further addressed in this document.

3.5 Factors determining chemical fate

The final exposure concentrations are determined by the intensity of the emissions in combination with environmental conditions, such as e.g. the hydrodynamic exchange, sedimentation, and water characteristics, as well as compound-related properties, such as evaporation, (bio) degradation, and sorption to suspended particulate matter (SPM) and sediment. Most existing screening type chemical fate models for water systems are based on a similar central mass balance equation, describing the main transport and fate processes. As an example the mass balance equation of MAMPEC (Van Hattum et al., 2002) for the water column is described as:

emission + inflow - outflow - settling - volatilisation - decomposition = 0

$L + Q_i.C_i - Q_o.C_t - Fs.P.f_{df}.C_t - rv.f_{df}.C_t.V_w - r_w.f_{df}C_t.V_w = 0$ [1]

with:

$Fs = v_s.S_s.f_{oc}.A_w$ for organic compounds [1a]

$Fs = v_s.S_s.A_w$ for metals [1b]

in which:

A_w = surface area of the compartment (m^2)
C_t = total concentration in the water column ($g.m^{-3}$)
f_{df} = freely dissolved fraction (-)
f_{oc} = fraction organic carbon in suspended solids (-)
Fs = settling load of suspended organic carbon (g $OC.d^{-1}$); for metals: in $g.d^{-1}$
L = load (emission) of compound ($g.d^{-1}$)
P = for organic compounds : K_{oc} partition coefficient (10^{-6} $l.kg^{-1}$ OC)
= for metals: Kd partition coefficient ($l.kg^{-1}$)
Q_o = total outgoing flow rate ($m^3.d^{-1}$)
Q_i = total ingoing flow rate ($m^3.d^{-1}$)
C_i = total concentration at ingoing flow ($g.m^{-3}$)
rv = volatilisation rate (d^{-1})
r_w = overall first order decomposition rate constant in the water column (d^{-1}) from hydrolysis, photolysis, and biodegradation
S_s = concentration of suspended solids ($g.m^{-3}$)
v_s = net settling velocity ($m.d^{-1}$)
V_w = water volume (m^3)

The volatilisation rate rv is a function of substance related parameters (Henry's constant) and compartment specific variables (depth, temperature, gas-water mass transfer coefficients).

The overall decomposition rate constant r_w is a summation of the contributions of abiotic degradation (hydrolysis, photolysis) and biodegradation and are substance and compartment specific. The photolysis rate constant is determined by both compound-related properties (spectral absorption, quantum yield) and factors determining the light penetration in the water column (e.g. average meteorology and water properties, DOC, SPM, Chlorophyll). For a number of parameters a temperature correction is in place (rate constants for biodegradation and hydrolysis, Henry's constant).

Based on exercises with MAMPEC it can be shown that the major processes affecting the final fate are the hydrodynamic exchange, degradation processes, sorption properties and evaporation. For a number of different antifouling substances and ballast water related compounds in combination with different standard MAMPEC environments the significance is indicated in table 7.

Note that the relative share of the loss due to hydrodynamic exchange depends not only on the % exchange per tide, but also on the intensity of other removal or decay processes. A substance undergoing very rapid biodegradation will always have a very high share of loss due to biodegradation and consequently a low share of loss due to other processes, including hydrodynamic exchange.

Table 7: Importance of fate processes in MAMPEC for the different standard environments. Indicated are % of emissions disappeared from the harbour area due to the different processes.

Compound	OECD-EU standard Environment % Exchange per tide	% of emissions lost from harbour due to :					
		Hydro-dynamic exchange	Sedimen-tation	Photo-lysis	Biode-gradation	Hydrolysis	Evaporation
TBT	Com. Harb. 68%	93%	0.6%	-	6%	-	0.02%
Dichlofluanid	Com. Harb. 68%	6%	-	-	27%	68%	-
Dichlofluanid	Marina 307%	27%	-	-	21%	52%	-
Zn Omadine	Com. Harb. 68 %	50%	0.04%	38%	7%	5%	-
Bromoform	Com. Harb. 32%	50%	-	-	-	11%	39%

The results in table 7 briefly demonstrate the importance of standardisation of the evaluative environments, with respect to dimensions, hydrodynamic exchange, sediment settling, and water characteristics (SPM, POC, and DOC concentrations, chlorophyll content, temperature) and the importance of reliable compound property data (especially the degradation rate constants, organic carbon absorption coefficients, and Henry's constant).

4 EVALUATION OF THE MOST MEANINGFUL APPROACHES FOR EXPOSURE ASSESSMENT

4.1 Introduction

The approach for the assessment of the exposure as a result of treated BW discharges is determined by different factors. In the first place, there are various ‘active substances’ and other relevant chemicals, such as disinfection by-products, which all show their own specific behaviour in the aquatic environment, which leads to different levels of persistency. Typically, the half-life times of the substances to be assessed vary within a wide range of several hours to a few months. It is therefore noted, that there are substances which are expected to undergo a rapid decay.

The BW discharge volumes are clearly connected to cargo volumes, and therefore the amount of BW discharged within a certain area is connected to the cargo transport density in that area. BW discharges typically show an intermittent pattern, both in space and in time. In areas with a high transport density, several BW discharges may be taking place in the same time and close to each other, thus providing a more constant and homogeneous overall discharge pattern. In areas with a low transport density, BW discharges are expected to be relatively smaller, but also more irregularly distributed both in time and space.

Finally, the receiving environment is important. Depending on the local geometry and hydrology, flushing may be stronger or weaker, leading to different degrees of accumulation of more persistent substances (chapter 3.2.2). The environmental conditions may also affect the behaviour of the assessed substances.

Recent applications for approval of BWMS under the IMO G9 procedure are partly based on calculations with MAMPEC (Marine Antifoulant Model to Predict Environmental Concentrations).

MAMPEC is a steady-state 2D integrated hydrodynamic and chemical fate model, developed for the exposure assessment of antifouling substances (Van Hattum et al., 2002, 2006). The first version of the model was developed in 1999 with support of the the Antifouling Working Group of the European Paint Makers Association (CEPE / CEFIC) and co-sponsored by the European Commission (DG XI). Since then updates have been released in 2002 (v1.4) [1], 2005 (v1.6), 2008 (v2.5) compatible with changing requirements of common operating systems (Win9X-NT-2000-XP-VISTA-Win7) and requirements of users and competent authorities. The model has been distributed freely via the internet[7] .

The model predicts concentrations of antifoulants in generalised ‘typical’ marine environments (open sea, shipping lane, estuary, commercial harbour, yachting marina, open harbour). The user can specify: emission factors (e.g., leaching rates, shipping intensities, residence times, ship hull underwater surface areas), compound-related properties and processes (e.g., Kd, Kow, Koc, volatilisation, speciation, hydrolysis, photolysis, biodegradation), and properties and hydrodynamics related to the specific environment (e.g. currents, tides, salinity,

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[7] http://delftsoftware.wldelft.nl

DOC, suspended matter load, port dimensions). MAMPEC includes options for advanced photolysis modelling, and incorporation of wind-driven hydrodynamic exchange and other non-tidal exchange processes important for areas without tidal action, or inland freshwater environments. Included are also service-life emission and other scenarios developed by an OECD-EU working group (OECD, 2005) and adopted by EU as the standard environmental emission scenarios, to be used for evaluation of the biocides under the Biocidal Products Directive. The model has been validated for a number of compounds and is today recognized by regulatory authorities in EU, USA, Japan, and other OECD countries. MAMPEC is currently being adapted sponsored by IMO to include the standard environment and emission scenarios for ballastwater as recommended by GESAMP.

As explained in the ESD for Antifouling products (OECD, 2005), MAMPEC provides a User Interface allowing non-experts to use the underlying specialist software. In this case, we have used the specialist software directly (DELWAQ, Postma & Hervouet, 2006), without its User Interface, to perform more comprehensive simulations in order to carry out a sensitivity analysis. The sensitivity analysis focuses on the specifics of BW discharges, in particular:

- the heterogeneity of the BW discharges, both in space and time;
- the variable persistence of the relevant substances.

Furthermore, the sensitivity assessment takes into account the variability of the flushing characteristics of the environment. The sensitivity analysis was carried out for a harbour environment, and consisted of 4 different BW discharges, 3 different decay rates and 3 different flushing rates (4x3x3 = 36 simulations), and is further specified in Table 8.

Figure 14A shows the mean concentrations (over space and time) obtained from the 36 simulations. The simulated mean concentrations appear not to depend significantly on the heterogeneity of the BW discharges. The mean concentrations obtained while neglecting this heterogeneity (marked “MAMPEC” in Figure 14) can be considered a good approximation of reality. These results of the sensitivity analysis constitute a justification of the use of MAMPEC to assess mean exposure as a result of treated BW discharges.

Figure 14B shows the maximum concentrations obtained at any location at any time from the 36 simulations. As expected the steady state approach of MAMPEC and other screening type models is not capable to mimic the temporal variability. Due to the 2D nature of MAMPEC the scenarios part of the spatial heterogeneity is approached only for conservative compounds. Figure 14C shows the results from the sensitivity assessment as expressed by the ratio between the simulated maximum concentration and the mean concentration. These results show that the spatial and temporal heterogeneity of the BW discharges will result in substantial differences between average exposure and maximum exposure (the examples presented here show differences up to two orders of magnitude). If the spatial and temporal heterogeneity of the BW discharges is neglected, the maximum exposure can not be properly assessed. The difference between maximum and average exposure is expected to increase if the substance life time is decreasing (or if the decay rate is increasing).

Table 8: Specification of variables combined in the sensitivity analysis. Variable combinations always consist of a BW discharge x substance decay x environment/ flushing characteristic in varying combinations (4x3x3; 36 in total).

Alternative BW discharges (n=4)	All spatial and temporal heterogeneity is neglected (just as in the regular MAMPEC simulations)	Strong spatial heterogeneity but no temporal heterogeneity (constant average discharge rate, with randomly distributed individual discharges with a duration of 2 hours)	Both spatial and temporal heterogeneity (maximum discharge rate is 4x the average discharge rate, with randomly distributed individual discharges with a duration of 2 hours)	Both spatial and temporal heterogeneity (maximum discharge rate is 12x the average discharge rate, with randomly distributed individual discharges with a duration of 2 hours)

X

Alternative substance decay (n=3)	No decay (rate constant = 0 d^{-1})	Half-life time is 1 day (rate constant = 0.693 d^{-1}) ("medium decay")	Half-life time is 4 hours (rate constant = 4.16 d^{-1}) ("fast decay")

X

Alternative environment / flushing characteristics (n=3)	Standard OECD Commercial Harbour scenario, with the parameter *Mouth Width* reduced from 2500 m to 1000 m ("slow flushing")	3x stronger flushing ("medium flushing")	10x stronger flushing ("fast flushing")

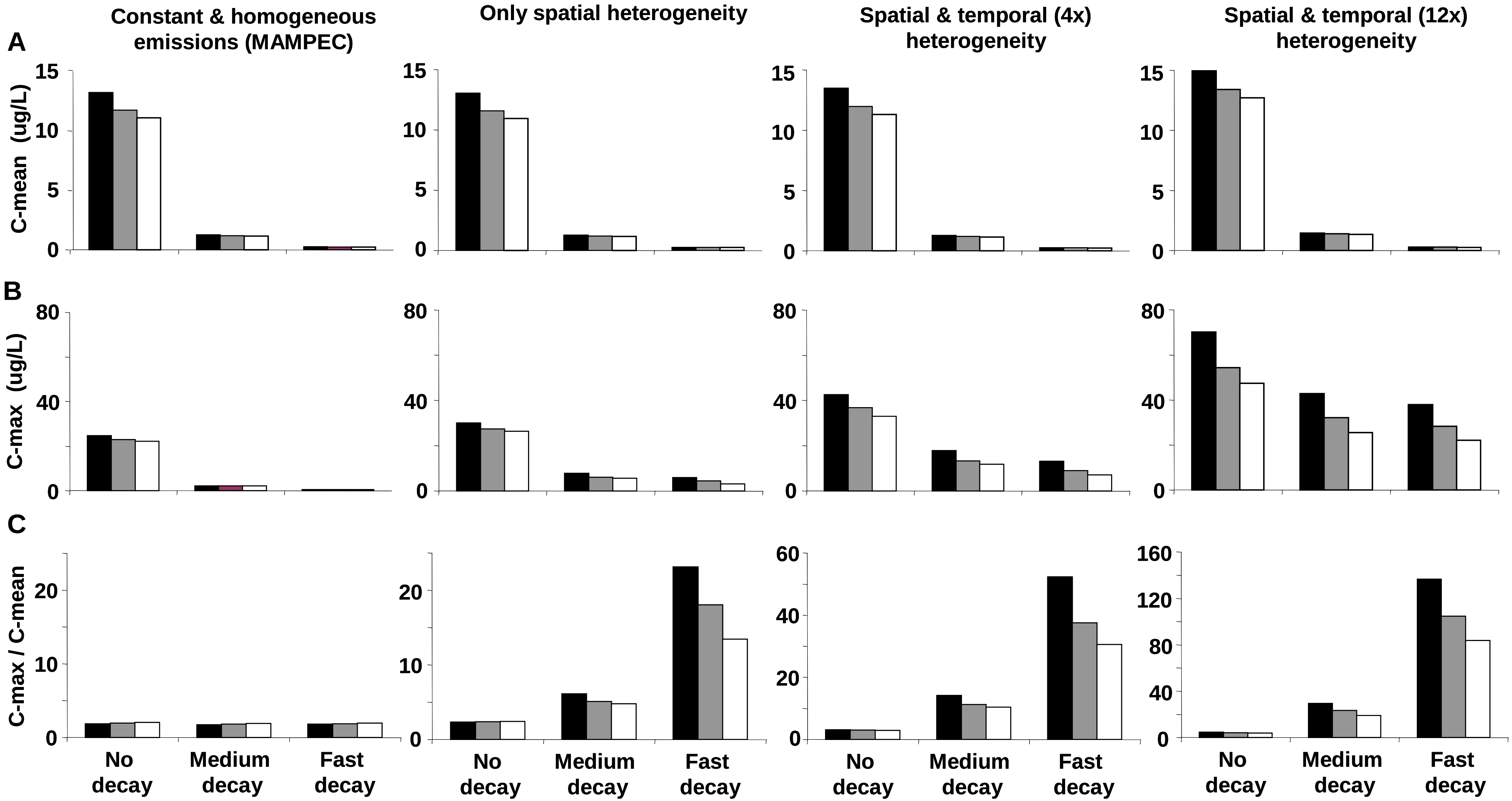

Figure 14: Sensitivity assessment. A Mean concentrations, B Maximum concentrations, C Ratio between maximum and mean concentrations obtained during the sensitivity analysis, for different BW discharge patterns, different flushing conditions (black, grey and white bars) and different substance decay rates (note variable scale on Y-axis).

The sensitivity analysis allows two clear conclusions:

1. the average exposure from treated BW discharges can very well be estimated by the MAMPEC approach (or other suitable steady state models);
2. the spatial and temporal heterogeneity of the BW discharges will result in substantial differences between average exposure and maximum exposure; such differences are most relevant for rapidly decaying substances; they can not be evaluated properly by steady state models such as MAMPEC.

The remainder of this chapter will develop an approach which accounts for both the mean (Chapter 4.2) and the maximum exposure (Chapter 4.3).

4.2 Standardized scenarios for mean exposure

4.2.1 “Realistic worst case” scenarios

With respect to the assessment of the mean exposure, the objective is to define a *realistic worst case scenario*. The starting point for this study is that all waters need to be protected from unacceptable environmental impacts, including the harbour environments. This implies that an approach where environmental impacts inside the harbour are a priori accepted and the environmental concentrations are only assessed outside harbours is not considered in this report. Along this line of reasoning, harbour environments are expected to show the highest environmental concentrations, because of the relatively high ship traffic density and because of their semi-enclosed character which leads to relatively poor flushing.

Another observation is that the registration of BWMSs is done at the international level. Therefore, we would look for worst cases on a world scale. Developing alternative “local scenarios” does not make sense, since there is no country-specific BWMS registration.

The environmental characteristics are important as indicated in section 3.5. The local dilution capacity or flushing rate has a distinct impact on the PECs, and therefore, care should be taken that a relatively low flushing rate is adopted. Similarly, the ambient water quality may have an impact on the decay of the target substances, see Section 2.3. Also the temperature is relevant in this respect, since most PEC assessment methods (including MAMPEC) explicitly account for the relation between the water temperature and the decay rate and evaporation: specifying a lower temperature will result in lower decay rates. As described in 3.5 other water characteristics (SPM, DOC, Chlorophyll) affect sorption, sedimentation, and photolysis. In most risk assessment procedures applicants are supposed to account for these effects in the selection of appropriate decay rates.

4.2.2 The standardised harbour scenario as recommended by international authorities

The GESAMP-BWWG has discussed the Risk Assessment Model to be applied within the G9 application process, and has come up with clear recommendations.

(GESAMP-BWWG, stock taking meetings January and October 2009). For reference, we quote the respective GESAMP-BWWG[8] reports:

> January 2009 GESAMP-BWWG meeting:
> ..The MAMPEC-model has incorporated several standard harbour scenarios. Looking at the definition of these scenarios the most feasible harbour would be the OECD-EU commercial harbour scenario. This scenario was meant to represent and average sized European commercial harbour and was extrapolated from shipping characteristics and measured data of the Port of Rotterdam but may not be considered the same as the harbour of Rotterdam. It has been adapted in the discussions to a hypothetical harbour that would serve it purpose mostly. The Group decided that indeed the scenario of the OECD-EU harbour would be best suited to serve also as the basis for the harbour scenario of the Group. In discussing the tidal renewal, the Group felt a need for a more worst-case approach and defined a tidal renewal of about 30% as more appropriate than the almost 70% in the original OECD-EU harbour….
>
> October 2009 GESAMP-BWWG meeting:
> ..The Group decided
> - not to take into account the market share of BW management systems (% of ships with a specific treatment system) when calculating emissions of chemical by-products produced during the BW treatment, bearing in mind that some ports are highly specialized and may receive only a certain type of ships using a certain type of BWMS……;
> - and to set up a volume of 100,000 m^3 BW discharge for the BW model harbour (BWMH), which is believed to be more realistic in relation with the dimensions previously agreed for the model harbour;

On the basis of the information provided in this report, the selection of a harbour environment with high cargo traffic intensity is a sensible choice. Furthermore, the selection of a harbour of the “river basins” type like Rotterdam, with reduced mixing with outside waters (see Section 3.2) makes perfect sense as well. The selected daily volume of BW discharges (100,000 m^3/d) can be seen in a wider perspective. The data presented in Table 6 demonstrate that the observed Rotterdam Port BW discharges are relatively far away from the maximum possible BW discharges volume: 10% of annual cargo volume, where literature provides a maximum potential BW volume of 40% and the maximum value observed for other ports is 28%. This is no doubt connected to the fact that Rotterdam is not specifically a BW importing port (van Niekerk, 2008).

A more specific measure for the relevance of BW discharges is the ratio between BW discharges and the harbour water volume. Table 9 calculates this ratio for the Rotterdam harbour under different assumptions. The ratio of BW discharge volume and total water volume in the GESAMP proposal amounts to 0.13%. This is more than double the value that would result for the maximum potential BW discharge in the Rotterdam Harbour as a whole, and about equal to the maximum ratio observed for individual sub-basins in the Rotterdam Port according to van Niekerk

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[8] **Reports not publicly available**

(2008). Consequently, we consider the proposed 100,000 m^3/d a realistic worst case. Furthermore, it is assumed that all ships use the BWMS under investigation (100% application rate).
The volume of BW discharges relative to the total harbour water volume is small. It is therefore acceptable that the volume of the BW discharges is neglected while estimating the flushing rate of the harbour.
Finally, the selected environmental conditions should not lead to an overestimation of decay rates. This refers in particular to the water temperature. For the water temperature, the GESAMP proposal uses a value of 15 °C. An inventory by Globallast provides the average winter temperature in 357 of the world's ports (Figure 11, Clarke et al. 2003a). In view of the reported values, a temperature of 15 °C leads to an overestimation of the winter decay rates in a significant number of cases. From a worst case perspective, we propose to modify the water temperature in the ESD scenario to 6 °C, being the 10%-value in the available data set of port winter temperatures (Table 10).

Table 9: BW discharge volumes related to cargo throughput and water volume, Rotterdam harbour.

	cargo volume (Mt/y)	BW discharges (Mm^3/y)	BW discharges (m^3/d)	BW discharges / cargo volume (%)	water volume (Mm^3)	BW discharges / water volume (%/d)
Rotterdam port - maximum potential BW discharges	421	168	461370	40%	800	0.06%
Rotterdam port - observed BW discharges (van Niekerk, 2008)	421	37	100000	9%		
GESAMP proposal	n.a.	37	100000	n.a.	75	0.13%
Observed maximum per sub-basin (van Niekerk, 2008)						0.12%

A similar standardization can not be performed for other water quality parameters used for PEC assessment (POC, DOC, chlorophyll, salinity, pH), since comparable systematic data for a large number of ports are missing for such parameters. We do not further address standardization of other water quality parameters in this document for three reasons:

- the lack of appropriate data;
- the fact that most PEC prediction models neglect the dependency of the decay rate on ambient water quality;
- the temperature effect discussed earlier is probably the dominating effect,.

The recommended Commercial Harbour Scenario is presented in Table 11.

Table 10: List of coldest ports (10% of 357 harbours in the Globallast inventory, Clarke et al. 2003).

Port	**Winter Temp. (°C)**	**Port**	**Winter Temp. (°C)**
Sept-Iles (Pointe Noire) Quebec (CA)	-1.0	Ilyichevsk (UA)	2.6
Tianjin (CN)	-0.1	Vancouver (British Columbia) (CA)	3.0
Boston Massachusetts (US)	0.5	Roberts Bank (British Columbia) (CA)	3.0
Anchorage Alaska (US)	1.0	Yantai Shandong (CN)	3.0
Portland Oregon (US)	1.0	Hamburg (DE)	3.0
Vancouver Washington (US)	1.0	Hafnarfjörður (IS)	3.0
Dnepro-Bugsky (Ochakov) (UA)	1.3	Straumsvik (IS)	3.0
Nicolayev (UA)	1.3	Enstedvaerkets Havn (DK)	3.5
Come By Chance (CA)	2.0	Fredericia (DK)	3.5
Halifax Nova Scotia (CA)	2.0	Wilhelmshaven (DE)	4.0
La Havre (FR)	2.0	Qinggdao Shandong (CN)	4.2
New York New York (New Jersey) (US)	2.0	Midia (RO)	4.5
Philadeplhia Pennsylvania (US)	2.0	Constanta (RO)	4.9
Wilmington Delaware (US)	2.0	Antwerpen (BE)	5.0
Dalian Liaoning (CN)	2.2	Ghent (Gent) (BE)	5.0
Vladivostok (RU)	2.5	Mangalia (RO)	5.7
Baltimore Maryland (US)	2.5	Varna, Bulgaria (BG)	5.9
Odessa (UA)	2.6	Amsterdam (NL)	6.0

Table 11: Recommended Commercial Harbour Scenario

Variable	Unit	Value
Dimensions		
Distance from river mouth	[m]	1,000
Width of river	[m]	500
Length of harbour	[m]	5,000
Width of harbour	[m]	1,000
Depth of harbour	[m]	15
Harbour entrance width	[m]	1,000
Harbour entrance depth	[m]	10
Height dam harbour entr.	[m]	0
Width dam harbour entr.	[m]	0
Latitude	[°N]	50
Water quality		
Silt concentration	[g.m^{-3}]	35
Temperature	[°C]	6
Salinity	ppt	34
Particular organic carbon	[g.m^{-3}]	1
Dissolved organic carbon	[g.m^{-3}]	2
pH	[-]	7.5
Chlorophyll	[µg.l^{-1}]	3
Hydrology		
Tidal period	[h]	12.41
Tidal difference	[m]	1.5
River flow velocity	[m.s^{-1}]	1.0
Non-tidal water level fluctuation	[m]	0
Density difference	[kg.m^{-3}]	0.4
Flush in harbour	[m^{3}.s^{-1}]	0
Density difference of flush	[kg.m^{-3}]	0
Wind speed	[m.s^{-1}]	0
Fraction of time wind perpendicular	[-]	0
Emission		
BW discharge	[m^{3}.d^{-1}]	100,000
Concentration of active substance	[g.m^{-3}]	defined by applicant

4.2.3 A standardised shipping lane scenario

As all waters need to be protected from unacceptable environmental impacts, harbour environments are expected to show the highest environmental concentrations, because of the relatively high ship traffic density and because of their semi-enclosed character which leads to relatively poor flushing. Developing a scenario for open sea environments is therefore of less importance from an environmental perspective (chapter 3.3)

Nevertheless, in order to provide a standardised exposure assessment approach for cases where the exposure in a semi-enclosed harbour environment is not decisive, this chapter discusses a standardised shipping lane scenario.

The ESD for antifoulants (OECD, 2005) provides a summary and evaluation of shipping lane scenarios existing at that time, and proposes a standardised shipping lane scenario. This “OECD Shipping Lane” scenario is based on the Eastern section of the main shipping lane along the Dutch coast. The choice is based on the fact that the area has one of the highest shipping densities of the world (Van Hattum et al. 2002). In view of the fact that the cargo transport density is a factor determining the BW uptake, we consider this scenario suitable for BW exposure assessments as well.

The calculation of the (maximum potential) daily transport of BW along the shipping lane is summarized in Table 12. This (maximum potential) transport of BW turns out to be about 1.8 Mt/d, which is approximately equivalent to 1.8 Mm^3/d. It is noted that this volume is based on the assumption that all ships passing carry a full BW load while passing the shipping lane. To arrive at an emission scenario, the fraction of that (maximum potential) total volume being discharged needs to be established. To arrive at a realistic worst case, we propose to assume that the actual BW transported along the shipping lane is 50% of the maximum potential transport of BW, and that 20% of the actual BW transported is actually discharged along the 20 km shipping lane section under investigation. This implies a total daily discharge volume of 10% of 1.8 Mm^3/d, being 180,000 m^3/d.

Table 12: Calculated transport of BW along the OECD shipping lane.

Ship classes	Length range (m)	Representative length (m)	Nr of ships moving at any time of the day (-)[9]	Sailing speed (km/h)[10]	Nr of ships passing (1/d)[11]	Calculated total DWT[12] (t/d)	Calculated BW load (t/d)[13]
Cat 1	50-100	75	3.9	28	130	586,631	211,187
Cat 2	100-150	125	1.7	28	57	549,521	197,828
Cat 3	150-200	175	1.6	28	53	1,111,453	400,123
Cat 4	200-250	225	0.4	28	13	597,126	214,965
Cat 5	250-300	275	0.5	28	17	1,604,026	577,450
Cat 6	300-350	325	0.1	28	3	689,409	248,187
Total			8.2		273	5,138,166	1,849,740

For the same reason as argued in the harbour scenario, we propose to modify the water temperature in the OECD Shipping Lane scenario to 6°C.

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[9] As reported by the OECD (2005).

[10] Estimated to be 15 knots.

[11] Calculated as nr of ships moving at any time of day divided by time needed for passage; time needed for passage is calculated as length of shipping lane section (20 km) divided by sailing speed.

[12] Using a relation presented by van Hattum et al. (2002): DWT = 1432.3 $e^{0.0153\ \mathrm{Length}}$.

[13] Using a conversion factor of 36% from DWT to BW uptake (Endresen et al. 2004, see also Chapter 2.4).

The recommended Shipping Lane BW Scenario is presented in Table 13.

Table 13: Recommended Shipping Lane Scenario

Variable	Unit	Value
Dimensions		
Length	[m]	20,000
Width	[m]	10,000
Depth	[m]	20
Latitude	[°N]	50
Water quality		
Silt concentration	$[g.m^{-3}]$	5
Temperature	[°C]	6
Salinity	ppt	34
Particular organic carbon	$[g.m^{-3}]$	0.3
Dissolved organic carbon	$[g.m^{-3}]$	0.2
pH	[-]	8
Chlorophyll	$[\mu g.l^{-1}]$	3
Hydrology		
Tidal period	[h]	12.41
Tidal current	$[m.s^{-1}]$	1
Emission		
BW discharge	$[m^3.d^{-1}]$	180,000
Concentration of active substance	$[g.m^{-3}]$	defined by applicant

4.3 Temporal and spatial scales; maximum exposure

4.3.1 Whole harbour vs. individual ship approach

With respect to the assessment of the maximum exposure, the objective is to define a realistic worst case scenario. In the Introduction to this chapter, it was demonstrated that maximum exposure temporally and locally can exceed the mean exposure by several orders of magnitude, depending on the conditions. This maximum exposure is taking place during short periods of time, typically for the duration of a typical BW discharge event (0.5 to several hours).

The approach used in Section 4.1 to assess maximum exposure is not suited to obtain reliable results, because several relevant factors are neglected, and the model does not have sufficient spatial resolution. Instead, we propose to derive the maximum exposure from a so-called "near-field" analysis. In such an analysis, an individual discharge and ship are addressed rather than a whole harbour.

The "near-field" is defined as:

'*The region of the receiving water where the initial BW discharge characteristics (momentum flux, buoyancy flux and discharge channel geometry) influence the trajectory and mixing of the discharged BW*.'

We propose to use the concentration at the end of the "near-field" zone as representative for the maximum exposure. We note that next to BW discharge points, inside the near-field, effectively undiluted BW will be present. We also note that very close to the discharge point in the BW plume, the dilution factor will be smaller than at the end of the near-field zone. These very low dilution values occur at relatively small spatial or temporal scales only (i.e. during the actual BW discharge operation), and are considered irrelevant for the risk assessment.

The “end of the near-field zone” is determined by a mathematical process which quantifies all factors determining the fate of the BW discharge. It is noted that generally applied models which deal with the near-field zone, such as CORMIX (Doneker and Jirka 2001[14]), can clearly indicate the end of the near-field zone.

The near-field behaviour of the discharged plume of BW depends on a number of factors, which include details of the BW discharge itself. Relevant factors include:

- the discharge characteristics:
    - discharge rate (m^3/s);
    - duration of an individual discharge (s);
    - location of the discharge (m above or below water level);
    - initial velocity of the discharges (m/s);
    - temperature (°C) and salinity (ppt) of the discharge (kg/m^3);
- the environmental characteristics:
    - ambient velocity (m/s);
    - water depth (m);
    - ambient temperature (°C) and salinity (ppt), optionally as a function of depth.

It is noted that depending on the conditions, the discharged BW may not mix over the whole water column, but stay confined to a thin layer. For example, if ships discharge BW from mid-ocean in the Arabian Gulf, the BW may have a significant lower density than the receiving water and may initially create a “floating” layer, which does not (completely) mix with the receiving water.

The near field assessment leads to a dilution factor at the end of the near-field zone *S*. Once this dilution factor is known, the maximum exposure concentration can be derived from the concentration of chemicals in the BW (C_{BW}) and from the average exposure as calculated from the scenarios discussed in Section 4.2 (C_{mean}):

BOX 1:

$$C_{\max} = \frac{C_{BW} + (S-1)\cdot C_{Mean}}{S}$$

4.3.2 Dispersion/ dilution upon discharge

In this chapter, we discuss realistic ranges for the factors determining the near field behaviour of the BW plume. From these ranges we will develop a realistic worst case that can be used to assess the maximum exposure. We assume at this point that the discharge characteristics are independent of the applied BWMS. Should this assumption not be valid, applicants may choose to carry out their own near-field assessment, taking into account, however, the remaining assumptions listed in Table 14.

The difference between the BW discharge density and the ambient density depends on the location where BW has been taken in or exchanged and on the

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[14] http://www.cormix.info/

ambient conditions. Data to carry out a systematic assessment of such differences taking into account shipping routes statistics, BW management statistics and sea water temperature and salinity data (Fig. 15) are missing. Therefore, we propose to consider two realistic extreme cases only, Case A and Case B. These cases have been derived from an inventory by Globallast which provides seasonal averages of the water temperature and salinity in 357 of the world's ports (see Figure 11, Clarke et al. 2003a).

Table 14: Realistic ranges for factors affecting the near field behaviour of a BW discharge plume.

Variable/parameter	**Value/range**	**Remarks**
Discharge characteristics:		
discharge rate (m^3/h)	up to 20,000	different openings, up to 5,000 per opening (see Section 3.2.1)
duration of an individual discharge (h)	0.5-5	(see Section 3.2.1)
location of the discharge (m above or below water level)	middle of water column	assumption, discharge at lower part of ship, ship's position varies during deballasting, ship depth relative to harbour depth also variable
initial velocity of the discharges (m/s)	negligible	(expert judgement[15])
density difference between BW and ambient water (kg/m^3)	case A, case B	see text
Environmental characteristics:		
ambient velocity (m/s)	0.02-0.10 3	for harbour scenario for shipping lane scenario (ship's speed) (expert judgement)
water depth (m)	9-20 m	(minimum value: see Section 3.2.2, maximum value: expert judgement)
optional vertical water density profile	n.a.	proposed to be neglected, in view of other uncertainties

- Case A is based on the consideration that many harbours are situated in an estuarine or riverine environment and have a salinity which is significantly lower than that of the open ocean (Table 15).
  For Case A, we assume a ship taking in BW in open sea (salinity 35 ppt) and discharging BW in a low salinity environment (0 ppt), a situation which according to Table 15 occurs in a number of places all around the world. In this case the BW discharge is heavier than the ambient water. As witnessed by Table 15, this salinity difference is to be evaluated over a range of temperatures. We select a range of 5-25°C.

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[15] **In the sense of section 3.1**

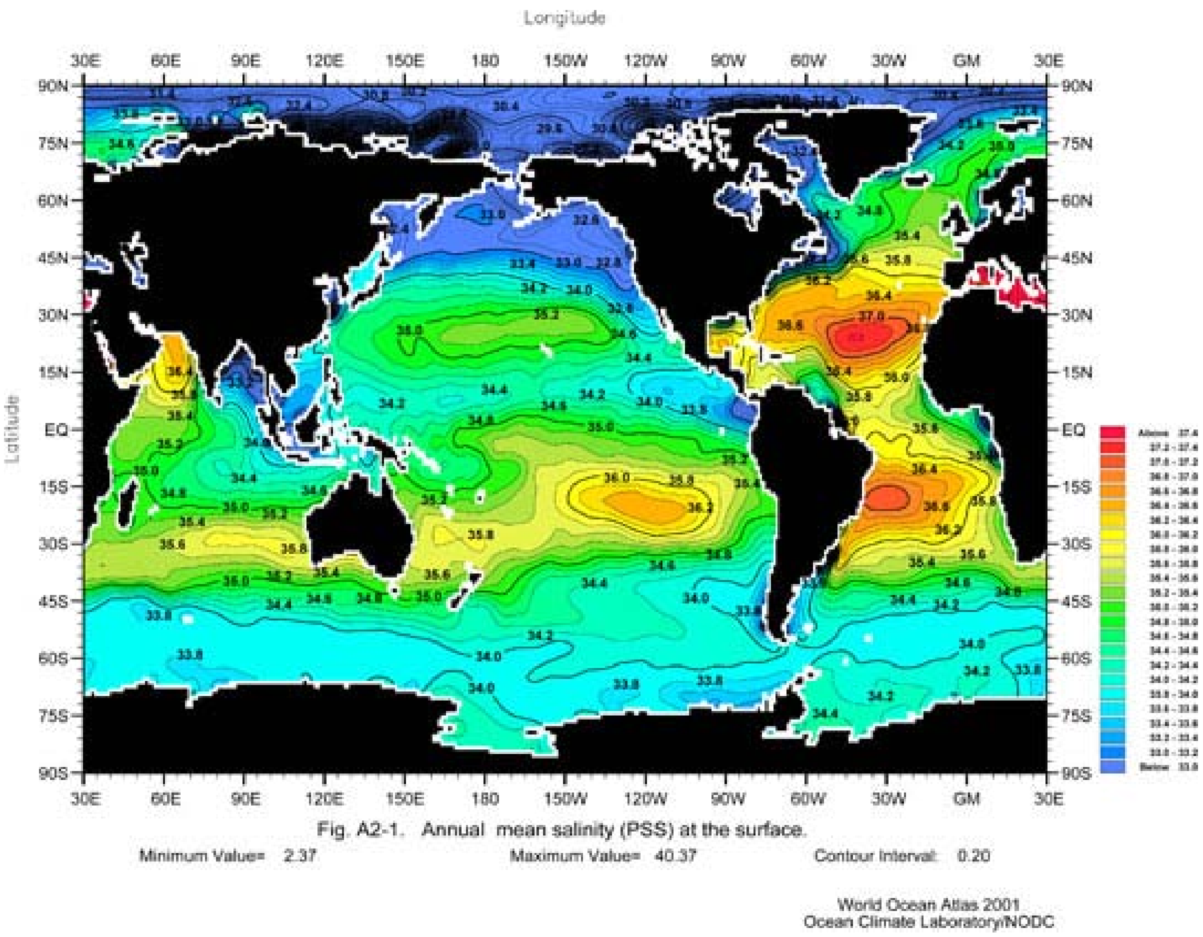

Figure 15: Annual mean surface salinity of the world's oceans.

- Case B is based on the consideration that many harbours are situated in an environment with a high natural salinity, which is significantly higher than that of the open ocean, for example in the Red Sea, Arabian Gulf or Mediterranean (Table 16).
  For Case B, we assume a ship taking in BW in open sea (salinity 35 ppt) and discharging BW in a high salinity environment (40 ppt), a situation which according to Table 16 occurs in a considerable number of ports. In this case the BW discharge is lighter than the ambient water. As witnessed by Table 16, this salinity difference is to be evaluated over a range of temperatures. We select a range of 20-30°C.

Table 15: Globallast inventory (Clarke et al. 2003a): harbours with low salinity.

Port	Summer Tempera-ture (°C)	Winter Tempera-ture (°C)	Wet Season Salinity (ppt)	Dry Season Salinity (ppt)
Campana (AR)	24.0	15.0	0.0	0.0
Antwerpen (BE)	17.0	5.0	0.0	0.0
Ghent (Gent) (BE)	17.0	5.0	0.0	0.0
Amsterdam (NL)	18.0	6.0	0.0	0.0
Davant (US)	27.0	12.0	0.0	0.0
New Orleans (US)	27.0	17.5	0.0	0.0
Portland Oregon (US)	12.0	1.0	0.0	0.0
Vancouver Washington (US)	12.0	1.0	0.0	0.0
Calcutta (IN)	29.0	25.0	0.0	0.0
Nicolaev (UA)	21.4	1.3	0.1	0.2
Philadeplhia Pennsylvania (Port Richmond) (US)	18.0	2.0	0.0	1.0
Wilmington Delaware (US)	18.0	2.0	0.0	3.0
Port Harcourt (NG)	29.0	26.0	0.0	4.0
Baltimore Maryland (US)	20.0	2.5	0.0	4.0
Beaumont (US)	28.5	16.0	0.0	5.0
Shanghai Baoshan (CN)	25.5	7.0	0.5	5.0
Shanghai (CN)	26.4	6.5	0.8	4.9
Lake Charles Louisana (US)	27.0	20.0	0.0	7.0

Table 17 provides a summary of these two cases. On the basis of the information collected in Table 14 and Table 17, the dilution factor at the end of the near-field zone is estimated based on some indicative computations with the CorMix expert system (Doneker and Jirka 2001). Although only very generalised and schematic cases could be assessed, a general indication of the expected dilution factors could be obtained.

The assessment of the two different cases showed a negatively buoyant plume (i.e. sinking) for Case A (higher salinity and excess density of about 27 kg/m^3) and a positively buoyant plume (i.e. rising) for Case B (lower salinity and excess density of about 4 kg/m^3). Furthermore, the different parameters (ambient current velocity, depth and discharge) influence the near field behaviour of the plume and with that the dilution factor at the end of the near field. It should be noted that *the end of the near field* can be significantly far away from the vessel in case of large ambient current velocities (3 m/s in case of moving vessel). Therefore, the dilution factor is also assessed at around 100 m from the vessel if the end of the near field was not reached yet.

This assessment has shown that the dilution factor increases with increasing ambient current velocities, smaller BW discharges and larger discharge depths. The ambient temperature (assumed that the BW has approximately the same temperature) has no significant influence on the initial discharge plume behaviour.

The assessed cases and ranges have shown that the dilution factor at the end of the near field or at about 100 m from the vessel (whichever is governing) ranges from about 7.5 – 10 to >1000 in high ambient current velocities. In very stagnant conditions (ambient current velocity ~0 m/s), the dilution factor can decrease below 5 at the end of the near field.

Consequently, our realistic worst case recommendation is to assess the maximum exposure using a dilution factor $S = 5$ for the standardised harbour scenario, and S

= 50 for the standardised shipping lane scenario. This recommendation constitutes a more specific approach as compared to the factor of 10 proposed by the ECB (ECB 2003b, Chapter 4) for the marine environment.

Table 16: Globallast inventory (Clarke et al. 2003a): harbours with high salinity.

Port	Summer Temp. (°C)	Winter Temp. (°C)	Wet Season Salinity (ppt)	Dry Season Salinity (ppt)
Larnaca (CY)	25.6	18.2	38.6	39.2
Limassol (CY)	25.6	18.2	38.6	39.2
Aspropyrgos (GR)	23.0	17.0	38.6	39.2
Elefsis (Eleusis) (GR)	23.5	17.0	38.6	39.2
Chios (GR)	24.4	15.5	38.8	39.1
Volos (GR)	24.2	14.6	38.8	39.1
Mina Al Ahmadi (KW)	33.0	17.0	38.9	39.0
Dortyol Oil Terminal (TR)	26.2	18.5	38.8	39.1
Mersin (TR)	26.2	19.0	38.8	39.1
Shuaiba (KW)	33.0	17.5	39.0	39.0
Port Rashid (AE)	30.5	23.0	38.5	40.0
Dubai (AE)	30.5	23.0	38.5	40.0
Jebel Ali (AE)	30.5	21.0	38.5	40.0
Jebel Dhanna (AE)	30.0	22.5	39.0	39.5
Ruwais Oil Terminal (AE)	30.0	22.5	39.0	39.5
Sharjah (AE)	30.5	23.0	38.5	40.0
Doha (QA)	31.0	17.0	38.5	40.0
Yanbu (SA)	30.0	22.0	39.0	39.5
Um Al Qiwain (AE)	30.5	21.0	38.5	40.5
Umm Said (Mesaieed) (QA)	31.0	17.0	39.0	40.0
Ras Al Ghar (SA)	32.0	17.0	39.0	40.0
Bandar Mushar (Mushahr) (IN)	34.9	16.5	38.2	40.9
Khark Island (IR)	34.2	18.2	38.9	40.9
Bushehr (IR)	34.5	18.0	38.5	41.5
Bandar Imam Khomeyni (IR)	34.9	16.5	38.2	42.0
Ras Al Tannura (SA)	31.0	16.8	40.0	40.5
Sitra (Bahrain) (BH)	32.0	17.0	40.0	42.0
Mina Sulman (Al Manamah) (BH)	32.0	17.0	40.0	42.0
Al Juaymah Terminal (SA)	31.0	16.8	40.0	42.0
Suez (El Suweis) (EG)	29.0	20.0	40.5	42.0
Ain Sukhna (EG)	29.0	20.0	41.0	42.0
Dammam (SA)	32.0	17.0	41.0	43.0
Jubail (SA)	32.0	16.0	49.0	50.0

Table17: Specification of realistic worst case for density difference between BW and receiving waters.

	Salinity	Temperature
Case A	BW: 35 ppt, receiving waters: 0 ppt	range of 5-25 °C
Case B	BW: 35 ppt, receiving waters: 40 ppt	range of 20-30 °C

4.4 Standardisation of chemical properties

For most ‘active substances’ and relevant chemicals, a broad range of data exists for some environmental properties such as degradation rate or half-life in the environment, but most are not available for marine conditions. Differing selections of available data accordingly lead to different outcomes of the exposure assessment. Hence, a standardized data base for 'active substances' and relevant chemicals of physico-chemical and environmental properties to be used by applicants for exposure assessment is highly desirable. Such a data base could also be implemented in the modelling software.

Such a data base currently is under development by the GESAMP-BWWG and GESAMP-ESH, although this includes at this stage only a limited number of compounds (personal communication J. Linders). The special MAMPEC-BW version (commissioned by IMO) will be available in 2011and will include this compound property database if available.

4.5 Evaluation of existing model software

An inventory of existing models is provided by different authors, for example Van Hattum et al. (2006), included in Annex IV, and Laane et al. (in prep.).

For the calculation of representative PECs as a result of treated BW discharges, the modelling does not need to be very detailed. It needs to be done for generic harmonised emission scenarios as described above. The modelling is not intended to support or replace impact assessments for specific study areas. It is necessary that the following phenomena are properly represented in the model:

- realistic representation of the harbour geometry;
- realistic representation of the processes causing renewal of the harbour water masses;
- realistic representation of (average) treated BW emissions;
- realistic representation of the fate of relevant substances, including processes like decay, exchange with the atmosphere and net exchange with aquatic sediments.

The modelling of harmonised emission scenarios is the most effective and the least error-prone if the modelling software is dedicated to the problem at hand and if the required model input directly corresponds to the emission scenarios. This observation has been derived from the existing practice with the ESD for Antifouling Products in OECD countries, where the dedicated model MAMPEC provides easy and reproducible assessments. For an assessment of MAMPEC's strengths and weaknesses in relation to other models used for Antifouling Products we refer to OECD (2005), the technical documentation of the software[16] and the paper of van Hattum et al. (2006). It is noted that investments in revisions of MAMPEC continued since the first release in 1999 and that the software has been further improved and modernised.

The current practice is that different producers of BWMSs already use MAMPEC for the PEC calculations in their approval for registration. This report has demonstrated that this practice is well justified for assessing mean PECs. In view of this, and given the significant and ongoing investments in MAMPEC as well as

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[16] **Available at http://delftsoftware.wldelft.nl**

the international recognition for the approach, we recommend the use of MAMPEC to calculate mean PECs as a result of treated BW discharges. There is no objection though to using other software (see Annex IV), as long as the requirements of this document can be met, and as long as the phenomena listed above can be well represented.

On top of using MAMPEC or a similar model for calculating mean PECs, this document also specifies the assessment of maximum PECs from a near-field assessment using recommended initial dilution values. Optionally, BWMS registration applicants may use their own near field assessment modelling software (such as CorMix, Visual-Plumes) to elaborate the recommended initial dilution values, using the conditions as specified in this document.

5 RECOMMENDATIONS

Considering the heterogeneity of the BW discharges, both in space and time, and the variable persistence of relevant substances, we recommend to distinguish between the assessment of maximum exposure (at a typical time scale of 2 hours) and mean exposure.

As all waters need to be protected from unacceptable environmental impacts, harbour environments are expected to show the highest environmental concentrations, because of the relatively high ship traffic density and because of their semi-enclosed character which leads to relatively poor flushing. For assessing the mean exposure, we recommend to use the existing GESAMP Ballast Water scenario. We recommend to modify this scenario slightly by assuming a water temperature of 6°C. An overview of the resulting scenario is given in Table 11.

For cases where the exposure assessment in a semi-enclosed harbour environment is not considered decisive, we developed an optional standardised shipping lane scenario for assessing the mean exposure. This scenario is based on the equivalent OECD Shipping Lane scenario developed for the assessment of antifoulants, with an emission calculation added and a water temperature of 6°C. An overview of the resulting scenario is given in Table 13.

For the assessment of mean exposure an approach like the one used by MAMPEC (Marine Antifoulant Model to Predict Environmental Concentrations) is recommended.

For the assessment of maximum exposure, we recommend to use a so-called “near-field” assessment. The dilution factor S at the end of the near-field zone is considered representative for the maximum exposure. The maximum exposure should then be calculated by the formula listed in BOX 1 in Chapter 4.3.1. We recommend using a set of standardised assumptions for the near-field assessment, as collected in Table 11. Based on an assessment for different geographic regions, we recommend including two realistic extreme cases for possible density differences between the discharged BW and the environment as listed in Table 17. Assuming that the BW discharge characteristics are independent of the applied BWMS, we recommend the use of a factor S= 5 for a harbour environment and a factor S= 50 for a shipping lane environment. Should this assumption not be valid, applicants may choose to carry out their own near-field assessment, taking into account however the remaining assumptions listed in Table 12 and Table 17.

A standardized data base of compound properties and especially the degradation rate (since degradation is one of the most sensitive parameters in exposure models) is highly desirable.

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ANNEX I

Regulations to the BWC mentioned in this document.

Regulation A-2 *General Applicability*

Except where expressly provided otherwise, the discharge of Ballast Water shall only be conducted through Ballast Water Management in accordance with the provisions of this Annex.

Regulation B-3 *Ballast Water Management for Ships*

1 A ship constructed before 2009:

.1 with a Ballast Water Capacity of between 1,500 and 5,000 cubic metres, inclusive, shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2014, after which time it shall at least meet the standard described in regulation D-2;

.2 with a Ballast Water Capacity of less than 1,500 or greater than 5,000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2016, after which time it shall at least meet the standard described in regulation D-2.

2 A ship to which paragraph 1 applies shall comply with paragraph 1 not later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date of delivery of the ship in the year of compliance with the standard applicable to the ship.

3 A ship constructed in or after 2009 with a Ballast Water Capacity of less than 5,000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.

4 A ship constructed in or after 2009, but before 2012, with a Ballast Water Capacity of 5,000 cubic metres or more shall conduct Ballast Water Management in accordance with paragraph 1.2.

5 A ship constructed in or after 2012 with a Ballast Water Capacity of 5000 cubic metres or more shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.

6 The requirements of this regulation do not apply to ships that discharge Ballast Water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities.

7 Other methods of Ballast Water Management may also be accepted as alternatives to the requirements described in paragraphs 1 to 5, provided that such methods ensure at least the same level of protection to the environment, human health, property or resources, and are approved in principle by the Committee.

Regulation D-2 *Ballast Water Performance Standard*

1 Ships conducting Ballast Water Management in accordance with this regulation shall discharge less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension and less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations described in paragraph 2.

2 Indicator microbes, as a human health standard, shall include:

.1 Toxicogenic Vibrio cholerae (O1 and O139) with less than 1 colony forming unit (cfu) per 100 millilitres or less than 1 cfu per 1 gram (wet weight) zooplankton samples ;

.2 Escherichia coli less than 250 cfu per 100 millilitres;

.3 Intestinal Enterococci less than 100 cfu per 100

Regulation D-5 *Review of Standards by the Organization*

1 At a meeting of the Committee held no later than three years before the earliest effective date of the standard set forth in regulation D-2, the Committee shall undertake a review which includes a determination of whether appropriate technologies are available to achieve the standard, an assessment of the criteria in paragraph 2, and an assessment of the socio-economic effect(s) specifically in relation to the developmental needs of developing countries, particularly small island developing States. The Committee shall also undertake periodic reviews, as appropriate, to examine the applicable requirements for ships described in regulation B-3.1 as well as any other aspect of Ballast Water Management addressed in this Annex, including any Guidelines developed by the Organization.

2 Such reviews of appropriate technologies shall also take into account:

.1 safety considerations relating to the ship and the crew;

.2 environmental acceptability, i.e., not causing more or greater environmental impacts than they solve;

.3 practicability, i.e., compatibility with ship design and operations;

.4 cost effectiveness, i.e., economics; and

.5 Biological effectiveness in terms of removing, or otherwise rendering not viable, harmful aquatic organisms and pathogend in ballast water.

ANNEX II

Identification of 'active substances' and relevant chemicals in treated ballast water from non-confidential approval dossiers of BWMS manufacturers.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)	Treated water (µg/L)	Treated water after neutralization (µg/L)	Testing conditions
SEDNA	AOX (solid phase extraction)	< 0.2	28	N.A.	G8 (marine waters)
	Dibromochloromethane	< 0.1	0.2		
	Tribromomethane	< 0.1	1.5		
Electro Clean	Trichloromethane	0.2	0.12	0.13	G8 (marine waters)
	Dibromomethane	N.D.	0.07	0.06	
	Bromodichloromethane	0.02	0.31	0.12	
	Dibromochloromethane	0.02	14.35	8.04	
	Tribromomethane	0.1	481.67	373.96	
	Dibromoacetonitril	0.16	36.84	21.49	
	2,4-Dibromophenol	0.01	0.02	0.02	
	2,6-Dibromophenol	0.01	0.02	0.01	
	2,4,6-Tribromophenol	0.01	0.28	0.38	
	Monochloroacetic acid	0.19	1.31	1.26	
	Monobromoacetic acid	N.D.	26.33	22.98	
	Dichloroacetic acid	0.06	0.88	0.74	
	Bromochloroacetic acid	N.D.	11.59	7.87	
	Dibromoacetic acid	N.D.	270.96	163.38	
	Tribromoacetic acid	N.D.	289.67	183.41	
	Sodium thiosulfate	N.A.	N.A.	1633	
Pure Ballast	AOX	0.45	0.57 (n.s.)	N.A.	G8 (marine waters)
Special Pipe Hybrid	AOX	12 - 16	-	20 - 37	G8 (Ranges given in approval document from chemical analysis in brackish and marine waters).
	TRO (as O_3)	230 – 900	900 – 1250	420 – 960	
	Generated TRO (O_3 treatment)	N.A.	550 – 1000	< 150 – 690	
	Bromate Ion	< 10	22 – 100	17 – 30	
	Bromoform	< 0.1	76 – 170	0.1 – 6.8	
	Dibromochloromethane	< 0.1	< 0.1 – 4.2	< 0.1	
	Phenole	0.4 - 0.5	-	0.3 – 0.7	

G8 = Samples drawn from the G8 land-based tests for final approval; BA = Basic Approval; N.A. = Not Applicable; n.s. = Not Significant; N.D. = Not Detected; psu = Practical Salinity Units; TRO = Total Residual Oxidants; AOX = Adsorbable Organic Halogen Compounds; EOX = Extractable Organic Halogen Compounds; FAC = Free Active Chlorine; FRO = Free Residual Oxidants; Tx = holding time in days.

Table 5: Continued

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)	Treated water after neutralization (µg/L)			Testing conditions
Clean Ballast	AOX	100; <10; 12			140; 60; 50	N.A.			G8 (Concentrations in: fresh; brackish; marine water)
	EOX	N.A.; < 10; < 10			N.A.; 10; 30				
	TRO (as Cl_2)	120; 60; 80			220; 400; 110				
	Bromate (BrO_3)	<1; < 0.1; <1			2.6; 26; 9.9				
	Trichloromethane	0.32; N.D.; N.D.			0.38; N.D.; N.D.				
	Dichlorobromomethane	<0.1; N.D.; N.D.			0.38; N.D.; N.D.				
	Dibromochloromethane	N.D.; N.D.; N.D.			0.82; 6; 5.3	N.A.			G8 (Concentrations in: fresh; brackish; marine water). Averaged over 3 replicates
	Tribromomethane	N.D.; 1.05; 1.43			1.44; 147; 135				
	Monochloroacetic acid	N.D.; N.D.; N.D.			0.21; N.D.; N.D.				
	Dichloroacetic acid	0.14; N.D.; N.D.			0.87; N.D.; N.D.				
	Trichloroacetic acid	0.08; N.D.; N.D.			0.5; N.D.; N.D.				
	Monobromoacetic acid	N.D.; N.D.; N.D.			0.15; N.D.; N.D.				
	Dibromoacetic acid	N.D.; <0.47; <0.22			1.28; 22; 5				
	Bromochloroacetic acid	N.D.; N.D.; N.D.			1.07; 0.6; <0.17				
Blue Ballast		T_0	T_2	T_5		T_0	T_2	T_5	
	TRO	N.D.; N.D.	N.D.; N.D.	N.D.; N.D.		2500 - 3040; 4010 - 4230;	N.D. - 180; N.D.	N.D.; N.D.	G8 (Concentrations in: brackish; marine water). Ranges from two replicates per holding time.
	Tribromomethane	N.D.	N.D.	N.D.		5.33 - 7.76; 15.6 - 24.3	78.5 - 106; 38.3 - 145	58.6 – 78.6 ; 76.6 - 152	
	Dibromoacetic acid	N.D.- 6.36; N.D.	N.D. - 3.1; N.D. - 4.5	N.D. - 3; N.D. - 2		6.77 - 7.43 4.21 - 5.5	5.44 – 7.94; 4.5 - 11.6	6.37 – 6.56; 3.5 - 14.1	
	Trichloroacetic acid	N.D.; N.D. - 1.1	N.D.; N.D. - 58.4	N.D.; N.D. - 55.5		N.D.; N.D. - 43	N.D.; N.D. - 51.4	N.D.; N.D. - 50.1	
	Monochloroacetic acid	N.D. - 5.83; N.D.	N.D. - 2.67; N.D. - 3.5	N.D. - 1.11; N.D. - 2.1		N.D.; 1.52 - 11.4	N.D. - 4.11; 4.96 - 2.1	N.D. - 2.29; 2.5 - 4.45	
	Dichloroacetic acid	N.D.	N.D.	N.D.		N.D.	N.D.; N.D.-1.1	N.D.	

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)			Treated water after neutralization (µg/L)	Testing conditions
Resource Ballast Technologies	TRO	47; N.D.; 17			67; 600; 740			N.A.	G8 (Concentrations in: fresh; brackish; marine water). Drinking water (fresh); Seawater diluted with municipal drinking water (brackish) ; Natural seawater (marine). Averages from 3 replicates. Selected results shown.
	FRO	20; N.D.; 27			43; 430; 540				
	Bromate (BrO_3)	<10			<10				
	Bromoform	N.D.; <1; N.D.			N.D.; 1.3; N.D.				
	Dibromochloromethane	N.D.; 1.3; N.D.			N.D.; 1.7 (ns); N.D.				
	Bromodichloromethane	5.5; 3; N.D.			1.7; 4 (ns); N.D.				
	Chloroform	21; 12.7; N.D.			5.7; 15.3 (ns); N.D.				
	Dibromoacetic acid	<0.5; <0.5; <0.5			2.4; 1.5; 8.7				
Clear Ballast	Aluminum	48			22			N.A.	G8 (marine water)
	Iron	50			N.D.				
GloEnPatrol		T_0	T_3	T_5	T_0	T_3	T_5	N.A.	G8 (Concentrations in: brackish; marine water). Natural river water (brackish, 21 psu); Natural seawater (marine, >32 psu). Ranges from 2 replicates for marine water.
	Fluoride (Fl^-)	725; 1240-1390	442; 1170-1920	299; 1170-3410	555; 410-2130	423; 1180-1840	402; 317- 513		
	Nitrate (NO_3^-)	345; N.D.	274; N.D.	370; N.D.	528; N.D.	268; N.D.	N.D.; N.D		
	Sulfate (SO_4^{2-}) (g/L)	1.45; 2.31-3.05	1.49; 2.51-2.87	1.55; 2.68-2.77	1.48; 2.58-3.24	1.54; 2.72-2.84	1.52; 2.68-2.78		
	Dibromoacetic acid	4.36; N.D	N.D.	N.D.	3.87	3.61	N.D.		
	Chloroacetic acid	5.62; N.D	N.D.	N.D.	3.06; N.D	N.D.	N.D.		
	Trichloroacetic acid	19.6; N.D	N.D.	N.D.	19.6; N.D	N.D.	N.D.		
	TOX	4.18; 85-100	4.05; 77-100	3.68; 97-260	6.99; 61-97	2.14; 93-260	2.21; N.D.-66		
	Hydrogen peroxide (H_2O_2)	N.D.	N.D.	N.D.	0.21; 47-48	N.D.	N.D.; N.D.-18		
Ocean Saver		T_0		T_5	T_0		T_5	N.A.	G8 (Concentrations in: brackish; marine water).
	AOX	3.48; 1.63		0.75;3.74	0.64; 2.9		5.04; 0.84		
	Dibromochloromethane	<0.5; <0.5		<0.5; <0.5	17; 4.6		15; 5.5		
	Dichlorobromomethane	<0.5; <0.5		2.6; <0.5	0.93; 0.51		1; <0.5		
	Tribromomethane	<1; <1		2.5; <1	200; 110		230; 120		
	Trichloropropane	2.6; 2.1		1.5; 4.1	2.2; 2.5		1.5; 2.3		

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)	Treated water (µg/L)	Treated water after neutralization (µg/L)	Testing conditions
TG BallastCleaner	Bromate (BrO_3)	-	-	18; 46	G8 (Concentrations in: brackish; marine water). Maximum values of 4 replicates.
	Bromodichloromethan			0.88; 0.7	
	Dibromochloromethane			16; 6.6	
	Bromoform			330; 180	
	Bromochloroacetic acid			0.47; 0.43	
	Bromoacetic acid			N.D.; 5.7	
	Dibromoacetic acid			47; 8.7	
	Tribromoacetic acid			N.D.; 0.1	

EcoChlor		T_0	T_1	T_5	T_0	T_1	T_5	N.A.	G8 (Concentrations in: brackish; marine water).
	Chlorine dioxide (mg/L)	N.A.	N.A.	N.A.	>2.5; >2.5	0.67; 0.85	N.D.		
	Chlorite (mg/L)	<0.1	<0.1	<0.1	3.18; 3.83	3.12; 3.11	2.8; 2.26		
	Chlorate (mg/L)	<0.1	<0.1	<0.1	1.24; 2.24	1.07; 1.46	0.98; 1.27		
	Bromoacetic acid	<1	<1	<1	<1	<1; 3	<1; 2		
	Dibromoacetic acid	<1	<1	<1	21; 23	21; 23	12; 25		

SEDINOX		C	T_0	$T_{0.5}$	T_2	T_4	T_{12}	T_{48}		G8 (Concentrations in: fresh; brackish water).
	FAC (mg/L)	<0.01	0.38; 1	0.2; 0.4	<0.01; 0.1	<0.01	<0.01	<0.01		
	Trichloromethane	<0.1	0.3; <0.1	0.4; <0.1	0.5; <0.1	0.6; <0.1	0.8; <0.1	0.9; <0.1		
	Tribromomethane	<0.5	11; 47	14; 70	15; 80	15; 73	16; 82	16; 84		
	Bromodichloromethane	<0.5	2.6; <0.5	3.6; <0.5	4.0; <0.5	4.3; <0.5	4.7; <0.5	4.9, <0.5		
	Dibromochloromethane	<0.5	9.9; 3.8	13; 5.2	13; 5.9	14; 5.4	15; 6	16; 6.3		
	Chloroacetic acid	<1	7; <1	5.3; <1	7.1; <1	4.5; <1	4.1; <1	1.3; <1		
	Dichloroacetic acid	<1	5.1; <1	5.5; <1	5.4; <1	3.8; <1	3.6; <1	6.4; <1		
	Bromoacetic acid	<1	17;24	16; 72	15; 77	12; 59	9.9; 86	12; 5.8		
	Dibromoacetic acid	<1	39; 40	40; 76	40; 64	31; 47	32; 69	30; 3.6		
	Bromochloroacetic acid	<1	24; 4.1	23; 6.7	22; 5.8	18; 4.5	17; 6.2	17; <1		
	Bromodichloroacetic acid	<1	<1; 2.2	<1; 3.2	<1; 2.3	<1; 2.4	<1; 3.1	<1; 2.8		
	Tribromoacetic acid	<1	<1; 9.9	<1; 14	<1; 12	<1; 12	<1; 13	<1; 12		

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)				Treated water after neutralization (µg/L)	Testing conditions
SiCURE		-			T_0	T_1	T_3	T_5	N.A.	Basic approval bench scale testing. North Sea water. Averaged over 3 replicates (own calculations).
	TRO (mg/L)				1.01	0.36	0.3	0.1		
	FAH (mg/L)				0.64	0.17	0.09	0.067		
	Bromate				-	-	56.67	53.67		
	Tribromomethane						48.8	19.2		
	Dibromochloromethane						1.4	0.2		
	Dibromoacetic acid						23.87	17.2		
	Tribromoacetic acid						43.67	41.3		
	Dichloroacetic acid						1.47	1		
EcoBallast		T_0	T_1	T_5	T_0	T_1	T_5		N.A.	G8 (Concentrations in: brackish; marine water).
	AOX	0.45; 0.51	0.76; 0.45	0.68; 0.24	0.39; 0.51	0.36; 0.48	0.29; 0.29			
	Tribromomethane	0.003; 0.015	0.003; 0.016	0.004; 0.01	0.002; 0.008	N.D.; 0.008	N.D.; 0.004			
AquaTriComb	-	-			-				N.A.	Basic approval bench scale testing.
ATLAS Danmark	-	-			-				N.A.	Basic approval bench scale testing.
Blue Ocean Shield		0 mJ/cm²			156 mJ/cm²	406 mJ/cm²	1990 mJ/cm²		N.A.	Basic approval bench scale testing. Influence of increasing UV dosage on chemicals in seawater. Max. dosage of the system 300 mJ/cm²
	Nitrite (mg/L)	0.04			0.046	0.043	0.051			
	Phosphate (mg/L)	0.028			0.11	0.14	0.042			
	Trichloromethane	N.D.			2	3	6			
	Dichloroacetic acid	2			2	2	8			
	Trichloroacetic acid	2			N.D.	N.D.	4			
	Bromodichloroacetic acid	2			N.D.	N.D.	4			
	Bromochloroacetic acid	8			10	8	12			
	Bromoacetic acid	2			N.D.	N.D.	4			
BalClor	Tribromomethane	-			-				42.21	Maximum concentration measured in treated seawater after neutralization.
	Dibromochloromethane								2.15	
	Monobromoacetic acid								2.89	
	Dibromoacetic acid								8.98	
	Tribromoacetic acid								4.09	
	Bromochloroacetic acid								0.46	
	Dibromochloroacetic acid								2.96	
	Dibromoacetonitrile								5.58	
	Sodium thiosulphate								870	

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)			Treated water after neutralization (µg/L)	Testing conditions
DESMI Ocean Guard	Nitrite (mg/L) AOX (mg/L) TRO (as mg Cl_2/L)	0.28; <0.005 0.05; 017 <0.04; 0.35 0.05; 0.07			0.33; <0.005 0.04; <0.01 <0.04; <0.04 0.06; 0.08			N.A.	Basic approval bench scale testing (fresh; marine water). Lake at Aalborg University (freshwater); Aalborg harbour (marine/ brackish water)
ARA Ballast (BlueOceanGuardian)		T_0	T_1	T_5	T_0	T_1	T_5 (de-ballasting)	N.A.	G8 (Concentrations in: brackish; marine water).
	Bromide (mg/L)	36.9; 63.5	62.4; 36.8	65.5 37.5	64.2; 37.4	63.2 37.1	63.5 36.9		
	1,2,3-Trichloropropane	N.D.	N.D.	N.D.	N.D.; 0.45	N.D.; 0.3	N.D.		
	1,1-Dichloroethene	N.D.; 0.01	N.D.	N.D.	N.D.	N.D.; 0.02	N.D.; N.D.		
	4-Chlorotoluene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.; 0.1		
	Bromobenzene	N.D.	N.D.;	N.D.	N.D.; 0.32	N.D.; 0.21	N.D.; 0.18		
	Chlorobenzene	0.32; N.D.	0.17; N.D.	0.04; 0.14	0.21; 0.16	0.18; 0.15	0.06; 0.13		
	Dichlorobromomethane	0.83; 0.3	N.D.; 0.27	N.D.; 0.18	0.51; N.D.	N.D.	N.D.		
	Trichloromethane	3.85; 1.23	2.95; 0.89	0.85; 0.63	1.13; 1.02	0.92; 0.68	0.45; 0.49		
	Chloral hydrate	0.25; N.D.	0.17; N.D.	0.08; N.D.	0.19; N.D.	0.15; N.D.	0.07; N.D.		
	Dichloroacetonitril	0.35; N.D.	0.21; N.D.	0.19; N.D.	0.3; N.D.	0.1; N.D.	0.04; N.D.		

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)			Treated water after neutralization (µg/L)	Testing conditions
Hi-Ballast (HHI)	Sodium bromate	-			-			32.1; 26.6	Basic approval bench scale testing (brackish; marine water). Substances measured on day 5 after treatment and neutralization.
	Bromochloromethane							0.25; N.D.	
	Dibromochloromethane							6.96; 0.75	
	Dibromomethane							0.73; 3.37	
	Dichlorobromomethane							0.51; 0.15	
	Dichloromethane							1.57; 0.16	
	Trans-1,2-dichloroethene							N.D.; 0.01	
	Trichloromethane							0.1; 0.2	
	Tribromomethane							111; 0.25	
	Trichloroacetonitril							N.D.; 0.02	
	Dichloroacetonitril							0.14; 0.04	
	Dibromoacetonitril							0.32; 0.01	
	Chloral hydrate							0.01; 0.02	
	Chloropicrin							1.54; 0.45	
	2-Bromoacetic acid							6.35; 5.66	
	2,2-Dibromoacetic acid							32; 55.1	
	2,2,2-Tribromoacetic acid							13.8; 14.9	
EnBallast		T_0	T_1	T_5	T_0	T_1	T_5	T_5	Basic approval bench scale testing (brackish; marine water).
	TRO (mg/L)	N.D.; N.D	N.D.; N.D.	N.D.; N.D.	5.2; 4.1	1.8; 2.3	0.25; 1.4	N.A.; <0.2	
	FRO (mg/L)	N.D.; N.D.	N.D.; N.D.	N.D.; N.D.	2.8; 3	1; 1.4	0.15; 0.8	N.A.; <0.05	
	Bromate (mg/L)	N.D.; N.D.	N.D.; N.D.	N.D.; N.D.	45.7; 50.9	1.85; 40.2	1.37; 2.17	-	
	Bromide (mg/L)	31.6; 40.2	32.3; 41.2	31.3; 42.5	30.7; 42.4	30.5; 43.7	31.8; 45.6	-	
	AOX	0.46; 0.52	0.48; 0.85	0.79; 0.68	0.43; 0.46	0.7; 0.77	-	0.77; 0.84	
	1,1,1-Trichloroethane	N.D.; 0.01	N.D.; N.D.	N.D.; N.D.	N.D.; 0.01	N.D.		N.D.	
	1,1-Dichloroethane	0.85; N.D.	N.D.	N.D.	N.D.; 0.25	N.D.; 0.13		N.D.	
	1,2,3-Trichlorobenzene	N.D.; 0.25	N.D.	N.D	N.D.; 0.18	N.D.; 0.02		N.D.	

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)			Treated water after neutralization (µg/L)	Testing conditions
EnBallast		T_0	T_1	T_5	T_0	T_1	T_5	T_5	Basic approval bench scale testing (brackish; marine water).
	1,2,4-Trichlorobenzene	N.D.; 0.27	N.D.	N.D.	N.D.; 0.21	N.D.		N.D.	
	1,1-Dichloroethene	0.42; N.D.	0.15; N.D.	N.D.; N.D.	0.52; N.D.	0.38; N.D.		0.2; N.D.	
	4-Chlorotoluene	N.D.; 0.05	N.D.	N.D.	N.D.; 0.04	N.D.		N.D.	
	Bromochloromethane	N.D.; N.D.	N.D.; N.D.	N.D. N.D.	0.41; N.D.	0.11; N.D.		0.02; N.D.	
	Chlorobenzene	0.21, 0.27	0.23; 0.2	0.2; 0.16	0.29; 0.24	0.24; 0.21		0.15; 0.15	
	Dibromomethane	N.D.	N.D.	N.D.	5.11; 0.7	1.29; 0.62		0.48; 0.41	
	Dichloromethane	N.D.	0.47	0.42	4.83; 0.17	0.99; 0.26		0.66; 0.33	
	Dibromochloromethan	3.86; N.D.	3.78; N.D.	2.27; N.D.	6.25; 1.65	9.11; 4.75		2.6; 8.75	
	Dichlorobromomethane	3.57; N.D.	3.16; N.D.	N.D. 1.06	3.82; 5.14	0.42; 0.29		N.D.; 0.19	
	Trichloromethane	3.61; N.D.	3.37; N.D.	1.78; N.D.	4.83; N.D.	4.08; N.D.		4.17; N.D.	
	Tribromomethane	2.57; 0.47	1.93; 0.44	1.85; 0.37	55.7; 41.1	127; 120		205; 232	
	Dichloroacetonitril	0.47.; 0.13	0.41; 0.14	0.43; 0.19	3.15; 0.3	2.32; 0.21		0.14; 0.09	
	Dibromoacetonitril	0.14; 0.14	0.04; 0.13	0.05; N.D.	30.1; 2.2	29.5; 1.19		22.1; 1.03	
	Chloral hydrate	0.21; N.D.	0.25; N.D.	0.23; N.D.	0.08; 0.12	0.13; 0.09		0.13; 0.02	
	Chloropicrin	0.28; 0.01	0.25; 0.01	0.23; 0.01	3.62; 3.61	4.81; 3.23		2.83; 0.34	
	2-Monochloroacetic acid	20.8; 4.83	18.5; 4.77	18.6; 3.41	41.9; 27.4	38.4; 48.7		20.7; 42.9	
	2,2-Dichloroacetic acid	N.D.	N.D.	N.D.	1.25; 6.78	N.D.; 6.13		N.D.; 5.41	
	2,2,2-Trichloroacetic acid	7.85; 1.14	2.07; 1.27	0.58; 1.53	8.5; 14.7	5.88; 0.65		4.9; 0.51	
	2-Monobromoacetic acid	2.95; N.D.	2.72; N.D.	N.D.; N.D.	10.5; 2.45	3.04; N.D.		1.6; N.D.	
	2,2-Dibromoacetic acid	1.09; 0.75	1.08; 0.77	1.05; 0.78	18.3; 4.74	15.7; 2.03		11.6; 1.79	

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)			Treated water (µg/L)			Treated water after neutralization (µg/L)		Testing conditions
EnBallast		T_0	T_1	T_5	T_0	T_1	T_5	T_5		Basic approval bench scale testing (brackish; marine water).
	2,2,2-Tribromoacetic acid	10.9; 1.13	N.D.	11; N.D.	12.2; 13.3	11; 1.32		5.41; 1.29		
	2,2-Bromochloroacetic acid	20.5; 27.1	27.2; 26.3	32.1; 26.1	40.1; 22.2	42.9; 23.5		47.3; 20.6		
	2,2,2-Bromodichloroacetic acid	3.56; 6.76	3.31; 5.56	3.28; 5.29	4.66; 5.45	4.32; 1.43		3.87; 1.25		
	Dalapon acid	15.1; 10.2	8.86; 11.4	8.54; 12.8	108; 292	24.8; 113		10.3; 50.3		
	2,3-Dichlorophenol	0.58; 1.26	N.D.; 0.76	N.D.	0.81; 0.5	N.D.; 0.61		N.D.		
	2,5-Dichlorophenol	3.62; 3.82	3.54; 3.12	2.22; 2.15	2.25; 2.65	2.36; 2.44		1.94; 1.54		
OceanGuard	AOX (mg/ L)	-			0.1; 0.02			N.A.		Basic approval bench scale testing (fresh; marine water). Substances measured on day 5 after treatment.
	Bromate				3.5; 1					
	Dibromochloromethane				5; 1.7					
	Tribromomethane				150; 44					
	Dibromoacetic acid				5.9; 0.66					
	2,4,6-Bromophenisic acid				0.1; <0.1					
BalPure					T_0	T_2		T_5	T_{10}	Basic approval bench scale testing (fresh; brackish; marine water).
	TRO (mg/L)	-			6.7; 9.1; 4.3	2.3; 6.3; 3.6		1; 4.8; 3.1	0	
	Trichloromethane				21.6; 0; 0	42.2; 0.5; 0		52.9; 0.6; 0	43.1; 0.5; 0	
	Dichlorobromomethane				33.2; 2.4; 0	70.8; 6.4; 0		90.2; 6.3; 0	73.6; 4.6; 0	
	Chlorodibromomethane				71.8; 13.4; 0.7	127; 42.8; 2.7		157;45.7; 3.4	123.7; 34.1; 2.2	
	Tribromomethane				69.7; 209; 32.6	92.1; 854; 106.9		100; 1046; 117.9	95; 782.8; 90.1	
	Bromochloroacetic acid				23.4; 11.2; 0	49.7; 7.8; 0		38.8; 9.4; 0	44.2; 7.1; 0	
	Chloroacetic acid				3.9; 7.4; 5.3	2.5; 12.1; 12.8		2.7; 15.3; 9.9	2.8; 0; 0	
	Dichloroacetic acid				18.4; 2.9; 0	38.8; 1.2; 0		33.7; 2.4; 0	39.5; 3.7; 0	
	Trichloroacetic acid				33; 0; 0	42.2; 1.5; 0		47.7; 1.5; 0	56.3; 0.7; 0	
	Bromoacetic acid				2.4; 8.4; 0	3.3; 8.4; 1.4		3.3; 6.1; 2.2	2.1; 3.5;0	
	Dibromoacetic acid				36; 117.9; 12.5	51.1; 219; 19.6		47.4; 156.3;24.7	54; 193; 19.3	

Table 5: Continued.

System	Active substance/ Relevant chemical	Untreated control water (µg/L)	Treated water (µg/L)	Treated water after neutralization (µg/L)	Testing conditions
PuriMar	Not available	Not available	Not available	Not available	BA
AquaStar	TRO (as Cl_2) (mg/L)	0; 0	8.78; 2.54	0; 0.1	Basic approval bench scale testing (brackish; marine water). Substances measured on day 5 after treatment and neutralization.
	AOX	0.42; 0.36	0.78; 0.96	0.82; 1.02	
	1,1-Dichloroethane	N.D.	0.13; N.D.	N.D.	
	1,2-Dichloroethane	0.23; N.D.	0.4; N.D.	0.39; N.D.	
	Trichloromethane	3.17; N.D.	6.64; N.D.	5.71; N.D.	
	Dibromomethane	N.D.	N.D.; 4.13	N.D.; 3.17	
	1,2-Dichloropropane	N.D.	N.D.; 0.04	N.D.	
	Dichlorobromomethane	3.5; N.D.	6.34; 0.34	5.92; 0.27	
	Dibromochloromethane	2.55; N.D.	15.2; 13.5	14.4; 12.9	
	Tribromomethane	1.96; N.D.	290; 592	280; 585	
	Dichloroacetonitril	0.62; N.D.	3.98; N.D.	1.04; N.D.	
	Chloropicrin	0.1; N.D.	1.94; 0.49	1.74; 0.4	
	Dibromoacetonitril	N.D.	19.5; 16.8	17.4; 16.5	
	Monochloroacetic acid	46.8; 3.23	292; 513	289; 430	
	Monobromoacetic acid	N.D.	N.D.; 18.6	N.D.; 16.2	
	Dalapon	N.D.	22.4; 9.51	18.2; 4.2	
	Trichloroacetic acid	N.D.; 4.86	3.41; 8.36	1.85; 2.61	
	Bromochloroacetic acid	N.D.; 12.5	205; 409	184; 390	
	Dibromoacetic acid	N.D.; N.D.	2.63; 160	2.11; 45.8	
	Tribromoacetic acid	N.D.	192; 166	174; 140	
Fine Ballast	Chloroform	N.D.	N.D.	N.D.; 0.09	Basic approval bench scale testing (brackish; marine water).
MICROFADE (Kuraray)	FAC	-	-	20; 20	Basic approval bench scale testing (brackish; marine water).
	Tribromomethane			2; 10.1	
	Dibromochloromethane			N.D.; 0.2	
	Dichloromethane			0.4, 6.2	
	Monobromoacetic acid			0.3; N.D.	
	Dibromoacetic acid			1.9, 4	
	Tribromoacetic acid			5; 4	
	Dibromochloroacetic acid			0.3; 0.3	
	Dibromoamine (as Chloramine)			20; 20	

ANNEX III

A Exposure assessment software and standardized environments applied by applicants under G9 approval.

System	Exposure assessment software	Standardized environment
AquaStar	MAMPEC (V.2.0)	OECD Commercial harbour[17]
BalClor	MAMPEC (V.2.0)	OECD commercial harbour
Blue Ballast	MAMPEC (V.2.0)	Default marina type (Port of Busan)
ARA Ballast (BlueOceanGuardian)	MAMPEC (V.2.0)	OECD Commercial harbour
CleanBallast	MAMPEC (V.2.0); MIKE3 + ECOLAB plume and fate model	OECD commercial harbour Esbjerg port basin (ECOLAB)
ClearBallast	MAMPEC (V. 1.6)	OECD Commercial harbour
DESMI Ocean Guard	MAMPEC (V.2.0)	OECD Commercial harbour
EcoChlor	MAMPEC (V. 2.5 beta); Delft 3-D	OECD Commercial harbour ; Delft-3D (Maashaven)
ElectroClean	MAMPEC (V. 1.6)	OECD Commercial harbour
EnBallast	MAMPEC (V.2.0)	OECD Commercial harbour
FineBallast	MAMPEC (V.?)	Port of Tokyo (Ranges for degradation rates)
Hi-Ballast (HHI)	MAMPEC (V.2.0)	OECD Commercial harbour
MICROFADE (Kuraray)	MAMPEC (V.2.0)	OECD Commercial harbour (Port of Tokyo)
OceanGuard	MAMPEC (V.2.0)	OECD commercial harbour
OceanSaver	MAMPEC (?); DREAM model; Visual plumes model	Commercial harbour scenario; Mongstad + Fredrikstad ports (DREAM)
PuriMar	MAMPEC (?)	Default marina (Port of Busan) 2 case calculations
ResourceBallast Technologies	MAMPEC (V.2.0)	Commercial harbour scenario
SEDINOX	MAMPEC (V.2.0)	Commercial harbour scenario
SiCURE	MAMPEC (V.?)	OECD commercial harbour and Port of Rotterdam several case scenarios (1,10, 80 ships)
SpecialPipeHybrid	MAMPEC (V.2.0)	Tokyo Bay
TGBallastCleaner	MAMPEC (V.?)	Commercial harbour scenario

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[17] The OECD-EU Commercial Harbour is derived from the Port of Rotterdam with similar hydrodynamics and water characteristics and mimics only well exchanging harbour sections (68% exchange per tide; the surface area is approximately 25% of the Port of Rotterdam.

B Existing standardized harbour scenarios for environmental exposure assessment using MAMPEC generated by applicants in their non-confidential approval dossiers which gained acceptance by the GESAMP.

BWMS System	Special Pipe Hybrid	BlueBallast/ NK BWMS	HI-Ballast
Scenario	Port of Tokyo (J) (Modified OECD commercial harbour)	Port of Busan (ROK) (Modified default marina)	OECD-Commercial Harbour
Length x_1 (m)	350	-	2,000
x_2 (m)	3,500	3,500	10,000
Width y $(m)_1$	1,400	6,500	2,000
y_2 (m)	140	-	500
Depth (m)	10	15	20
Mouth width (m)	3,500	580	5,000
Flow velocity (m/s)	0.35	1.0	1.5
Exchange Volume (m^3/tide; %/tide)	1.08^{E+7}; 22.04	Not specified (tidal range 1-1.5m)	2.59^{E+08}; Not specified
Tidal period (h)	12	Not specified (12)	12.41
Silt conc. (mg/ L)	35	6.48 (as SS)	35
POC (mg/ L)	1	-	1
DOC (mg/ L)	2	-	2
Chlorophyll (mg/ L)	3	4.6	3
Salinity (psu)	34	32.95	30
Temperature (°C)	15	15.27	15
Latitude	35	35	50
pH	8	7.92	7.5
Depth mixed sediment layer (m)	2.3	-	0.2
Sediment density (kg/ m^3)	2,800	-	1,000
Fraction organic C in Sediment	0.032	-	0.03
Net sediment velocity (m/d)	1.2	-	1

ANNEX IV

Characteristics of models available for chemical fate assessment of antifoulants reported in Van Hattum et al. (2006)

	C/f	Nr. of Media	Hydro Dynamics	Emiss. from ships	Skills required	Effect of S,T,pH	Generic	Spatial resolution	Steady state / Dynamic	Ref.
Screeningtype models										
EUSES	c	4	-	-	low	-	g	1D	s	[35,46]
EQC-based models	f	> 4	-	-	low	-	g	1D	s	[37]
Simplebox	c	> 4	+	+	high	(+)	g	2D	s/d	[36]
2D/3D type models										
QWASI	f	> 4	+	+	high	(+)	l	2D	s/d	[39]
TOXFATE	f	> 4	+	+	high	(+)	l	2D	s/d	[40]
EXAMS	c	> 4	+	+	high	(+)	g	2/3D	s/d	[2]
ECOS 2.1	c	> 4	+	+	high	+	g	3D	s/d	[38]
Delft3D/DELWAQ	c	> 3	++	+	high	+	g	3D	s/d	[29]
Mike-3.	c	> 4	++	+	high	+	g	3D	s/d	[31]
Telemac-3D	c	> 4	++	+	high	+	g	3D	s/d	[32]
Models developped for antifoulants										
Simple spreadsheet models	c	3	-	+	low	-	g	1D	s	[16,47]
REMA	f	4	+	+	low	(+)	l	2D	s	[4]
Mam-Pec	c	4	++	++	low	(+)	g	2D	s	[5]

Explanation: C/f: concentration or fugacity based model; Nr. of Media: number of abiotic main and sub-compartments included (water column, sediment, air, soil, particulate matter); Hydrodynamics: ability to cope with more complex marine hydrodynamic features; Emiss. from Ships: ability to include (+) or estimate (++) typical emission patterns of antifoulants. Generic: generic model (g) or location specific (l). Other categories: -: missing; +: available as user editable option; ++: integrated in model; (+): option is partly available. Adapted from Van Hattum et al. (2006).