



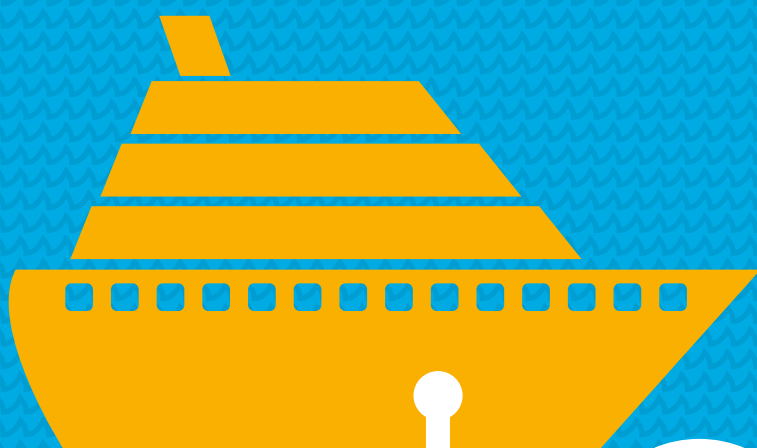
A Technical Guidance for the **Handling of Wastewater** in Ports of the Baltic Sea Special Area under MARPOL Annex IV


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Executive summary



The Baltic Sea, the biggest brackish sea worldwide, is a highly sensitive sea area and faces increasing maritime traffic at the same time. Connected with the Atlantic Ocean only via the Kattegat, a shallow strait, complete water exchange in the Baltic takes around 30 years. As a consequence, the constant input of hazardous substances and nutrients like nitrogen and phosphorus causes accumulation over time.

Eutrophication caused by the extensive input of nutrients leads to excessive algae growth and oxygen depletion. Although the amount of total nutrient input is decreasing, values are still too high to effectively combat eutrophication.

The HELCOM Baltic Sea Action Plan (BSAP) is an ambitious program to restore the ecological status of the Baltic marine environment by 2021. It includes measures to reduce the input of nutrients from various sources. With respect to maritime activities the BSAP has been a great success. In 2011, the International Maritime Organization (IMO) designated the Baltic Sea a Special Area for sewage discharges from passenger ships under Annex IV of the MARPOL-Convention. The proposal was submitted to IMO by the Baltic Sea riparian States, prepared and supported by the HELCOM Maritime Working Group as a result of a long process of negotiations and a common effort of all Contracting Parties to the Helsinki Convention.

The final decision was reached in April 2016 by the IMO Marine Environment Protection Committee (MEPC). The new regulations will take effect for all passenger ships on 1 June 2021 while new passenger ships built on or after 1 June 2019 will have to comply from that date on. For direct passages between St. Petersburg and the North Sea there is an exemption until 1 June 2023.

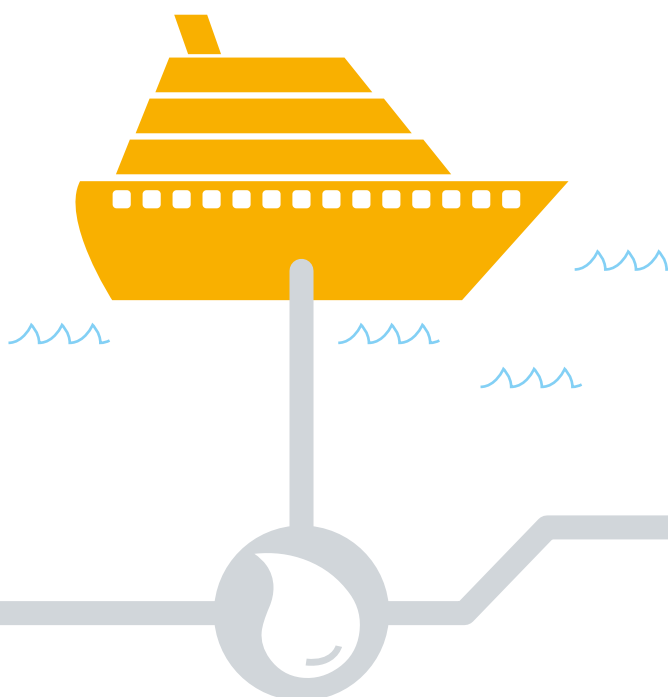
When the Special Area regulations come into force, passenger ships which carry more than 12 passengers¹ will be limited to either discharging sewage into Port Reception Facilities (PRF), or

alternatively at sea but only after treatment with advanced on-board sewage treatment plants capable of reducing the nutrient input into the sea according to Resolution MEPC.227(64), which stipulates a reduction of 70% nitrogen and 80% phosphorus levels.

Passenger ships not equipped with an on-board sewage treatment facility according to the specifications will have to discharge the sewage (black water) in a PRF.

The lack of experience with sewage handling in ports requires the development of new and innovative approaches to manage these new challenges. To support this process, this study document provides a “Technical Guidance” for the handling of wastewater in ports. Data from Baltic Sea ports and shipping companies on the composition and handling of sewage from passenger ships have been collected and evaluated. On the basis of this data and the results from our own studies, this paper offers recommendations to port operators and shipping companies, including

- information on how to avoid potential problems with the acceptance of the wastewater,
- and options for pre-treatment in ports and mobile solutions.



¹ Note that MARPOL Annex IV only applies to ships engaged in international voyage of 400 gross tonnages (GT) and above, or certified for more than 15 persons (including crew and passengers).



List of Abbreviations

ANF	Advanced Notification Form
AWN	Advanced Waste Notification
AOX	Adsorbable Organic Halides
ASCI	Alaska Cruise Ship Initiative
BW	Black water
BOD _n	Biological oxygen demand in n days
BSAP	Baltic Sea Action Plan
CLIA	Cruising Lines International Association
COD	Chemical oxygen demand
CSO	Combined sewer overflow
CSS	Combined sewer system
EPA	Environmental Protection Agency
FOG	Fat, oil and grease
GW	Grey water
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
H ₂ S	Hydrogen sulfide
IMO	International Maritime Organization
MARPOL	International Convention for the Prevention of Pollution from Ships
MWTP	Municipal Wastewater Treatment Plant
NH ₄ -N	Ammonia-Nitrogen
NO ₂ -N	Nitrite-Nitrogen
NO ₃ -N	Nitrate-Nitrogen
NSF	No Special Fee
N _{tot}	Total Nitrogen
p.e.	Population equivalent
PRF	Port Reception Facilities
P _{tot}	Total Phosphorus
SOB	Sulfur-oxidizing bacteria
SRB	Sulfur-reducing bacteria
STP	Sewage Treatment Plant
TA	Type Approval
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
Q _d	Dilution $(Q_d) = (Q_i) / (Q_e)$
Q _e	Effluent (Q _e)
Q _i	Influent (Q _i)





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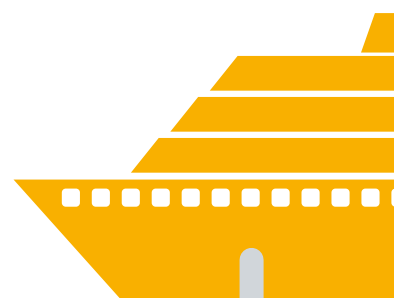
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1. Introduction

1.1. Background

The Baltic Sea is one of the most densely trafficked shipping areas of the world. Cargo, tanker, passenger and container ships are the most common ship types accounting for 80% of the traffic of International Maritime Organization (IMO) vessels in the Baltic Sea. Around 6% of these vessels are passenger ships.

Although the proportion of discharges from ships is small, when compared to other sources, wastewater discharges from ships contribute to marine pollution in the Baltic Sea in general and especially to the release of nutrients. Due to the slow water exchange with the North Sea these nutrients have accumulated over a long time period, leading to the Baltic's current eutrophication and oxygen deficiency issues.

In 2007, the Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM) adopted the Baltic Sea Action Plan (BSAP), which aimed to restore the Baltic Sea ecosystem to good health by 2021, including reducing sewage pollution from ships to a minimum.

With respect to maritime activities it was a great success. In 2011, IMO designated the Baltic Sea a Special Area for sewage discharges from passenger ships under MARPOL Annex IV. The proposal of the Baltic Sea riparian States to IMO was prepared and supported by the HELCOM Maritime Working Group as a result of a long process of negotiations and a common effort of all Contracting Parties.

In April 2016, a decision was reached by the IMO Marine Environment Protection Committee (MEPC). The new regulations will take effect for all passenger ships on 1 June 2021 while new passenger ships built on or after 1 June 2019 will have to comply from that date on. For direct passages between St. Petersburg and the North Sea there is an exemption until 1 June 2023.

When the Special Area regulations come into force, passenger ships which carry more than 12 passengers will be limited to either discharging sewage into Port Reception Facilities (PRF), or alternatively at sea but only after treatment with advanced on-board sewage treatment plants capable of reducing the nutrient input into the sea according to Resolution MEPC.227(64), which stipulates a reduction of nitrogen and phosphorus levels by 70% and 80% respectively.

It should be noted that MEPC defined the thresholds for phosphorus and nitrogen in re-

gards to sewage discharge in Annex IV. Sewage has to be distinguished from grey water. Both are human waste streams that are generated by vessels. Sewage specifically comes from toilets and medical facilities and is also known as black water. Grey water on the other hand consists of drainage from showers, washbasins, laundry facilities and galleys. Both waste streams contain nutrients and therefore contribute to eutrophication if discharged untreated into the sea. However, given that these waste streams are often mixed whilst at sea, it is necessary for them to be treated as 'sewage' together.

Passenger ships operating in the Special Area not equipped with an advanced on-board sewage treatment plant must store their sewage on board and discharge it to a PRF. It is the duty of ports to guarantee that vessels can discharge sewage without undue delay and that the PRF meets the requirements of the passenger ships when the Special Area is established. HELCOM has extensively promoted the reception of wastewater and other wastes in ports. However, there are still many challenges that must be overcome. A lack of experience with wastewater acceptance at present, especially in the case of smaller ports in communities with limited infrastructure means that flexible and sometimes innovative solutions will be required.

This "Technical Guidance" sets out these problems and presents possible solutions.

1.2. Material and Methods

The "Technical Guidance" has been developed based on the information from own surveys and additional literature research.

PIA ("Prüfinsitut für Abwassertechnik") has developed a questionnaire for port authorities and municipal wastewater treatment plants in order to determine the current state of PRFs and to identify problems linked to receiving sewage from passenger ships (Questionnaire template in Annex 8.5). The questionnaire served as a basis for a summary of the problems currently faced when handling cruise ship generated wastewater. Additionally, it has provided information of currently available and planned PRF infrastructure.

In addition to the questionnaire, a literature research was performed to help evaluate the results and identify possible solutions for the acknowledged problems.

Also included is data from the HELCOM Overview 2014 [3] and 2018 [38], the Cruise Baltic [2], and the CLIA Exercise 2016 [33].

An exercise by the Cruise Lines International Association (CLIA) in 2016 reported that of the 30 ports visited by 29 cruise ships, 46% faced PRF related problems; due to various reasons. The issues were considered together with the problems



mentioned in the PIA questionnaire in order to provide a comprehensive overview, including the perspective of the shipping industry. An effort was made to distinguish between problems in/for the port and problems for the ship. In addition, the results of the survey were compared with those of other studies on discharge and handling of wastewater in ports, such as N. Butt 2007 [36] and M. Wilewska-Bien *et al.*, 2018 [37] to name a few.

The quality and volume of wastewater from cruise ships have been investigated in order to distinguish between black and grey water. Data was collected mainly from studies performed by the US Environmental Protection Agency (EPA) and the Alaska Cruise Ship Initiative (ASCI). Other sources include reports authored by researchers at the University of Technology Hamburg (TUHH), cruise ship operators (E.g. TUIs and AIDAs Environmental Report) and manufacturers of ship sewage treatment plants like Scanship.

The US EPA provides data on the separate waste streams of grey water (e.g. accommodation, galley, laundry etc.). All information and data was summarized and used as a basis for calculating the reasonable scale and size of PRFs. In addition, the summarized data has been used to provide recommendations to improve the treatment and storage options whilst at sea and reduce problems within ports.

Furthermore, in order to estimate how much wastewater is produced it was necessary to gather information on cruise ships in the Baltic Sea and the profile of an “average ship” determined from cruise ships traveling the Baltic. This average was then used as the basis for calculations in order to ascertain the projected capacity needed for PRFs to fulfill the requirements that have been set out (see Chapter 4.1).

However, this “Technical Guidance” does not serve as a blueprint for planning a PRF. It is intended only to serve as a framework and must be adapted to port-specific infrastructure requirements.

2. Definitions

The terminology concerning wastewater handling and treatment is inconsistent in regards definitions used in political directives, legal regulations and technical standards. The definition for each term can often be different depending on source. In ports where both maritime and on-land regulations can apply, a clear common understanding of the different terminologies is essential.

The most significant difference is the meaning of “sewage”. In maritime regulations the term “sewage” has a different meaning than the term “wastewater” in on-land regulations which is used synonymously for “sewage”. As per definition in MARPOL Annex IV sewage means

- drainage and other wastes from any form of toilets and urinals
- drainage from medical premises (dispensary, sick bay, etc.) via wash basins, wash tubs and scuppers located in such premises
- drainage from spaces containing living animals; or
- other wastewaters when mixed with the drainages defined above.

If no other wastewater streams (e.g. grey water) are mixed in, sewage mainly consists of black water. By contrast the term “wastewater” (on-land used synonymously for “sewage”) covers all water polluted by the human life including all grey water streams as per normative standard EN 16323.

The most relevant definitions contained in maritime regulations, European directives and normative standards are listed in Annex I.



3. Legal basis

3.1. IMO MARPOL Annex IV

The International Maritime Organization (IMO) is a specialized agency of the United Nations and was established in Geneva in 1948. The IMO Convention entered into force in 1959. The original mandate was principally concerned with maritime safety and the prevention of oil pollution. In 1973, the IMO adopted the “International Convention for the Prevention of Pollution from Ships” (MARPOL 73), which has been amended by the Protocols of 1978 and 1997 and continues to be updated. MARPOL refers to – besides the prevention of pollution by oil – other pollution sources like noxious and harmful substances in bulk, garbage, exhaust emissions and sewage. The regulations concerning sewage are recorded in MARPOL Annex IV which is currently ratified by 142 member states and three associated members, which represent 96.25% of the world tonnage.¹ The Annex entered into force on 27 September 2003. A revised Annex IV was adopted on 1 April 2004 and applied from 1 August 2005.

For the discharge of sewage from ships, MARPOL Annex IV contains regulations regarding:

- definitions,
- the ships’ equipment,
- systems for the control of sewage discharge,
- the provision of PRF for sewage, and
- requirements for survey and certification.

As defined in Regulation 1 of MARPOL Annex IV, sewage is defined as:

- drainage and other waste from any form of toilets or urinals,
- drainage from medical premises (dispensary, sick bay, etc.) via wash basins, wash tubs and scuppers located in such premises,
- drainage from spaces containing living animals, or
- other wastewaters when mixed with the drainages above.

According to Regulation 9 of MARPOL Annex IV, every ship certified to carry more than 15 persons or

above 400 gross tonnage (GT) must be equipped with one of the following:

- a sewage treatment plant type approved by the Administration according to Resolution MEPC.227(64) as modified by Resolution MEPC.284(70),
- a sewage comminuting and disinfecting system including facilities for the temporary storage of sewage when the ship is less than 3 nautical miles from the nearest land,
- a holding tank of sufficient capacity for the retention of all sewage, in regard to the operation of the ship, the number of persons on-board and other relevant factors.

According to the provisions in Regulation 11 of MARPOL Annex IV the discharge of sewage from ships is prohibited when closer than 12 nautical miles to the nearest land unless the ship has an approved and functional sewage treatment plant. As an alternative the sewage can be comminuted and disinfected using an approved system and the distance to the nearest land is no more than 3 nautical miles. When discharging from a sewage holding tank the discharge must be at a moderate rate and the ship must be proceeding en-route at a minimum speed of 4 knots as defined in Resolution MEPC.157(55) (Recommendation on standards for the rate of discharge of untreated sewage from ships).

3.2. Special Areas

In general, global rules on ships’ sewage such as the MARPOL Annex IV, have typically addressed the sanitary concerns of sewage – rather than the nutrient content of sewage. At the same time the Baltic countries have applied increasingly stringent nutrient limits to sewage discharges from land. The considerable investments in sewage treatment on land increased public awareness and questioned the international maritime rules allowing sewage discharges from ships at sea. A recent major development resulting from over four decades work in addressing sewage from passenger ships as a pollution source has been the IMO declaring the Baltic Sea a Special Area for sewage in 2011.

This decision was based on a joint application

¹ IMO 2018; Status of Conventions; as at 12.06.2018



by the Baltic Sea countries and the dates for the enforcement of the regulations were decided by IMO in April 2016. The Baltic Sea was the first area in the world to receive this status and be enforced by the IMO.

The Special Area regulations will come into effect from 1 June 2021 for existing IMO-registered passenger ships. For new passenger ships, the regulations will apply from 1 June 2019. For direct passages between St. Petersburg and the North Sea, provisions have been made for a delay until 1 June 2023. The Special Area regulations will concern passenger ships which carry more than 12 passengers. They will be limited to discharging sewage into land-based PRFs, or whilst at sea provided that extensive treatment with an advanced on-board sewage treatment plant has taken place.

3.3. MEPC Guidelines on implementation of effluent standards and performance tests for sewage treatment plants

The second resolution of the sixth session of the MEPC provided the first international effluent standards and guidelines for performance tests for sewage treatment plants (Resolution MEPC.2(VI)). Although it was adopted in 1976, it

took 27 years to be fully ratified in 2003. Ongoing developments in the design and effectiveness of sewage treatment plants resulted in a revision to the guidelines to improve the protection of marine environments. The revised guidelines in Resolution MEPC.159(55) adopted in 2006 apply to equipment installed on board ships from 1 January 2010 (Table 3-1) and include more stringent effluent standards.

The sewage treatment plants are certified by the Administration to meet certain standards as provided for in the MEPC Guidelines on implementation of effluent standards and performance tests for sewage treatment plants in

- Resolution MEPC.2(VI)
- Resolution MEPC.159(55)
- Resolution MEPC.227(64) as amended by Resolution MEPC.284(70)

In section 4.2 of MEPC.227(64) additional effluent limits for nitrogen and phosphorus removal are set out. The requirements of MEPC.227(64), with the exception of the requirements in section 4.2, will apply to sewage treatment plants installed on or after 1 January 2016 on:

- ships, other than passenger ships, in all areas;
- and passenger ships outside MARPOL Annex IV Special Areas.

Table 3-1: Effluent standards during type approval

		MEPC.2(VI)	MEPC.159(55)	MEPC.227(64)
BOD₅	[mg/l]	50	25	25 Q _d /Q _e
COD	[mg/l]	-	125	125 Q _d /Q _e
TSS	[mg/l]	100*	35	35 Q _d /Q _e
Fecal coliforms	[cfu/100ml]	250	100	100
Residual Chlorine	[mg/l]	-	0.5	0.5
pH	[-]	-	6.0 – 8.5	6.0 – 8.5
N_{tot}	[mg/l]	-	-	20 Q _d /Q _e ** or 70% reduction
P_{tot}	[mg/l]	-	-	1 Q _d /Q _e ** or 80% reduction

*100 mg/l during type approval on board, 50 mg/l during type approval on land

**for passenger ships intending to discharge in Special Areas



The requirements of these guidelines, including those in section 4.2, will apply to sewage treatment plants installed on:

- new passenger ships² when operating in the Baltic Sea Special Area and intending to discharge treated sewage effluent into the sea on or after 1 June 2019;
- existing passenger ships, other than those specified in the sub-paragraph below, when operating in the Baltic Sea Special Area and intending to discharge treated sewage effluent into the sea on or after 1 June 2021; and
- from 1 June 2023 for existing passenger ships en route directly to or from a port located outside the Baltic Sea Special Area and to or from a port located east of longitude 28° 10' E within the Special Area that do not make any other port calls within the Special Area and intending to discharge treated sewage effluent into the sea.

Alternatively, the sewage needs to be discharged to PRFs.

Sewage treatment plants installed between 1 January 2010 and 1 January 2016 on ships other than passenger ships operating in MARPOL Annex IV Special Areas and intending to discharge treated sewage effluent into the sea should comply with the requirements in Resolution MEPC.159(55).

Sewage treatment plants installed prior to 1 January 2010 on ships other than passenger ships operating in MARPOL Annex IV Special Areas and intending to discharge treated sewage effluent into the sea should comply with the requirements in Resolution MEPC.2(VI).

An overview on the effluent standards is given in Table 3-1. A sewage treatment plant should meet the effluent standards when tested for its Certificate of Type Approval by the Administration. During the type approval test, which must last for at least 10 days, a minimum of 40 effluent samples are taken. For compliance with the standards for BOD₅, COD, TSS, fecal coliforms, N_{tot} and P_{tot}, the geometric mean of the 40 results must be below the established thresholds. However, no IMO regulation provides for effluent standards for compliance monitoring during operation of the sewage treatment plants.

3.4. EU Directive on Port Reception Facilities

At EU level, the Directive on Port Reception Facilities (Directive 2000/59/EC) is relevant to the issue of delivery and management of waste water from ships in ports. The Directive requires all EU member state to ensure that adequate port reception facilities are available to receive and manage the waste from ships normally visiting the ports. The legislators reached agreement on a new Directive on Port Reception Facilities ('PRF') for the delivery of waste from ships on 12 December 2018 (Directive 2019/XX/EU)[44].

The new Directive, which will repeal the current PRF Directive, aims at reducing discharges of waste from ships at sea by ensuring the availability and use of adequate port reception facilities, thereby protecting the marine environment.

The PRF Directive has a wide scope of application: it covers all types of vessels, including fishing vessels and recreational craft, and all the ports visited by those vessels. Besides covering oily waste, tank washings containing oil and noxious liquid substances, and garbage, the Directive also covers sewage from ships, as defined in the MARPOL Annex IV.

All waste from ships (including sewage) needs to be delivered to ports in accordance with the MARPOL discharge norms before departure from an EU port, unless the ship has sufficient dedicated storage capacity on board. The new Directive also requires ships the advance waste notification before arrival to an EU ports, as well as the information from the waste receipt. This information, which has to be electronically reported, is crucial for effective monitoring and enforcement.

The new Directive puts in place a dedicated inspection regime to check that ships comply with the mandatory delivery requirement. The inspection regime will be supported by a union based targeting mechanism to allow for risk-based approach for inspections.

The new rules also provide more guidance on what constitutes an 'adequate' PRF, distinguishing between both operational and environmental conditions in line with MARPOL Guidance, and strengthens the role of the waste reception and handling plans and the requirements for consulting all relevant stakeholders on the plans.

- 2 A new passenger ship is a passenger ship:
- for which the building contract is placed, or in the absence of a building contract, the keel of which is laid, or which is in similar stage of construction, on or after 1 June 2019;
 - or the delivery of which is on or after 1 June 2021.



4. Background information

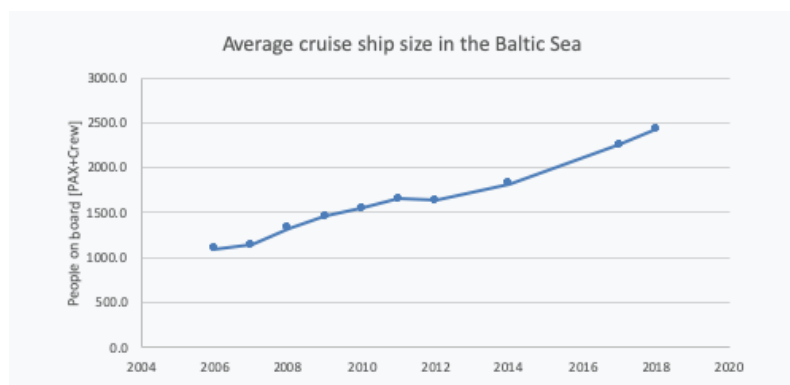


Figure 4-1. Average cruise ship size in the Baltic Sea over the years

4.1. Maritime traffic in the Baltic Sea

The Baltic Sea is a brackish inland sea with intense maritime traffic. More than 9% of the global maritime trade volume and 117 million ferry passengers called at Baltic Sea ports in 2012 [1]. Recently, cruise ship tourism has expanded and more than 4 million passengers were recorded in the Baltic Sea ports in 2015, compared to 1 million in 2000 [2]. Furthermore, ships traveling the Baltic Sea are increasing in size and passenger numbers (Figure 4-1).

The data used to calculate an “average cruise ship for 2018” derives from HELCOM [3] and Cruise Baltic [2]. As such, the average ship is able to carry 2431 passengers including crew, has a size of 65673 GT and a construction date of 2001. This ship serves as a basis for the calculations in this “Technical Guidance”.

4.2. Wastewater characteristics

Table 4-1: Composition of black water (BW)

Parameter	Unit	Average BW concentration on Cruise Ships ¹	Average BW concentration on Cruise Ships ²	Average BW concentration on Cruise Ships ³
COD	[mg/l]	1140	6325	7400
BOD ₅	[mg/l]	526	3475	3700
Alkalinity	[mg/l]	325	-	382
TKN	[mg/l]	111	-	620
Ammonia	[mg/l]	78.6	783	-
NO ₃ / NO ₂	[mg/l]	0.325	-	-
N _{tot}	[mg/l]	-	850	-
P _{tot}	[mg/l]	18.1	78.25	160
TSS	[mg/l]	545		3700

1) Based on data collected by the EPA in 2004 and 2005, when Black water is mixed with grey water

2) Based on data collected by the TUHH in 2015, 5 Ships 13 samples

3) Based on data collected by Ohle P. *et al.*, 2009

Table 4-2: Quantity of black water

	Unit	Min	Max	Mean
Black water	L/P*d	15	102	31

Based on data collected by the EPA, TUHH, ASCI, TUI, AIDA and Scanship.

4.2.1 Black water/sewage

Black water or sewage includes any waste contaminated by human excrement and other effluent (liquid waste), such as from urinals and toilets. Black water discharge from ships is globally regulated. Due to its high nutrient content, (Table 4-1), it contributes to eutrophication, as stated in the studies conducted by the US EPA [4-7] and scientific work by Köster *et al.*, 2016 [10] and Ohle *et al.*, 2008 [16].

The quantity of black water generated per day is dependent on the system used onboard the ship. E.g. a vacuum-system needs less water compared by a gravitational system (Table 4-2).

4.2.2 Grey water

The composition of grey water is dependent on the source of wastewater and the type of cruise ship (Table 4-3). For example, wastewater from the kitchen has the highest proportion of organic material in the grey water mix (Table 4-4). The pollutant levels in grey water are comparable to untreated municipal wastewater on land [8, 9].

The amount of grey water generated differs from vessel to vessel and depends on the activities offered on board of each individual vessel (Table. 4-5).

Table 4-3: Common sources and characteristics of grey water

Waste Source	Characteristics
Automatic clothes washer	bleach, foam, high pH, hot water, nitrate, oil and grease, oxygen demand, phosphate, salinity, soaps, sodium, suspended solids, turbidity
Automatic dish washer	bacteria, foam food particles, high pH, hot water, odor, oil and grease, organic matter, oxygen demand, salinity, soaps, suspended solids, turbidity
Sinks, including kitchen	bacteria, food particles, hot water, odor, oil and grease, organic matter, oxygen demand, soaps, suspended solids, turbidity
Bathtub and shower	bacteria, hair, hot water, odor, oil and grease, oxygen demand, soaps, suspended solids, turbidity

Based on data collected by the EPA 2008 p.68

Table 4-4: Grey water composition according to EPA, ASCI and TUHH

Parameter	Unit	Average conc. in GW of cruise ships ¹	Average conc. in GW of cruise ships ²	Average conc. in GW of cruise ships ³
Alkalinity	[mg/l]	53.8	57.8	
BOD ₅	[mg/l]	1140	354	865
COD	[mg/l]	1890	1000	1150
Chloride	[mg/l]	125		
Conductivity	[μS/cm]	427	2250	895
pH		67% between 6-9	7.67	8.05
Hexane extractable material	[mg/l]	54.5	-	-
TOC	[mg/l]	535	481	-
TSS	[mg/l]	704	318	-
Turbidity	[NTU]	224	-	-
Cadmium	[μg/L]	0.452	0.541	-
Chromium	[μg/L]	16.7	4.17	-
Lead	[μg/L]	12.3	19.3	-
Copper	[μg/L]	510	483	-
Nickel	[μg/L]	29.7	48.7	-
Zinc	[μg/L]	2540	790	-
Ammonia	[mg/L]	2.13	2.21	4.75
NO ₃ / NO ₂	[mg/l]	0.0872	0.009	-
TKN	[mg/l]	26.2	11.1	-
P _{tot}	[mg/l]	10.1	3.34	6.48
N _{tot}	[mg/l]	-	-	22

1) Based on data collected by the EPA in 2004

2) Based on data collected by the ASCI

3) Based on data collected by the TUHH

Table 4-5: Quantity of grey water

	Unit	Min	Max	Mean
Grey water	L/P*d	172	350	221

Based on data collected by the EPA, TUHH, ASCI, TUI, AIDA and Scanship.





4.3. Wastewater Treatment Systems (WTS)

4.3.1 Advanced Wastewater Treatment Systems (AWTS)

Ship sewage treatment plants have to be type approved. The type approval (TA) process follows MEPC guidelines on the implementation of effluent standards and performance tests for sewage treatment plants as mentioned in chapter 3.3 of this Guidance. Once the TA certificate has been issued the system is considered to be permanently functional. Compliance monitoring is therefore not an obligatory part of the operation of the sewage treatment plant on board. According to manufacturer specifications, the cleaning performance of a plant allows for 90.3% nitrogen reduction and 97.8% phosphorus reduction [11].

4.3.2 Municipal Wastewater Treatment Plant (MWTP)

The purification of wastewater involves using naturally occurring processes at a larger scale. A modern MWTP uses biological, chemical and physical purification stages.

The processes are optimized in order to comply with legal requirements for the discharge point of a MWTP (Table 4-6). These requirements concerning threshold values become increasingly stringent as more people are connected to the MWTP. In which 1 population equivalent (p.e.) corresponds to a 60 g biochemical oxygen demand (BOD₅) over five days [91/271/EEC].

Compliance monitoring is an obligatory part of the operation of the municipal sewage treatment plant on land. The EU has created an urban wastewater treatment directive [91/271/EEC] as a framework which can be further tightened by the individual member states (e.g. German Wastewater Regulation). The minimum annual number of samples for compliance monitoring shall be determined according to the size of the treatment plant and be collected at regular intervals during the year.

4.3.3 Port Reception Facilities (PRF)

For the handling of wastewater in ports there are three possible types of Port Reception Facilities (Figure 4-3):

- Fixed facilities (sewer connection)
- Floating facilities (barge)
- Mobile facilities (tank trucks)

Table 4-6: Wastewater requirements at the discharge point of a MWTP (Germany)

	Parameter				
	COD [mg/l]	BOD ₅ [mg/l]	NH ₄ -N [mg/l]	N _{tot} [mg/l]	P _{tot} [mg/l]
Class 1 MWTP <60 kg/d BOD ₅	150	40	-	-	-
Class 2 MWTP 60 – 300 kg/d BOD ₅	110	25	-	-	-
Class 3 MWTP 300 – 600 kg/d BOD ₅	90	20	10	-	-
Class 4 MWTP 600 – 6000 kg/d BOD ₅	90	20	10	18	2
Class 5 MWTP >6000 kg/d BOD ₅	75	15	10	13	1

Requirements for German MWTP from "Annex I of Wastewater Regulation"

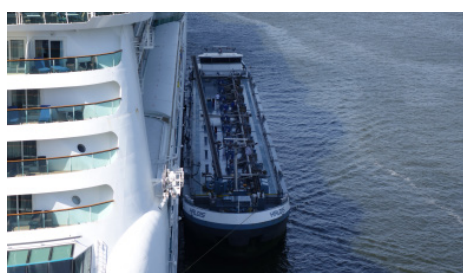
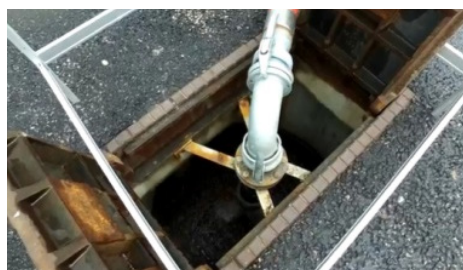


Figure 4-3: Different PRF types



5. Challenges and options

5.1. General capacity issues

5.1.1 Unavailability of PRF

▲ Challenges

In light of the new requirements mandated for a Special Area, all ports in the Baltic Sea at which cruise ships call that have no fixed-PRF installed face challenges. At EU level, also non-compliance with the new EU Directive may present a problem. Highly frequented ports, like Tallinn, Stockholm, Copenhagen and St. Petersburg have a combination of all types of PRFs. However, smaller ones like Wismar and Nynäshamn are only equipped with mobile and/or floating facilities. Receiving all sewage via a mobile PRF (tank trucks, barges) inevitably leads to problems with discharge speed and capacity for both ports and passenger ships. Due to the increasing demand for capacity faced by ports on the Baltic, these issues are expected to become increasingly exacerbated.

In smaller ports which can only provide tank trucks and/or barges for the reception of sewage, technical issues can cause more severe consequences. Capacity is limited and is often insufficient to accept the intended amount of wastewater. Furthermore, in case of mobile PRF usage, the equipment for discharge should be fully functional and well maintained in order to prevent spilling accidents and avoid contamination. Connecting and disconnecting multiple times increases the risks of accidents or damage to the ship. In addition, the unpleasant odors often negatively impact passengers.

The availability and deployment time depend on the respective tank truck or barge provider and can therefore lead to unforeseen delays. According to the CLIA-Exercise in 2016, during 565 port calls investigated, 220 issues were reported by the cruise ships:

- No facility available (12.7%)
- Use of facility technically not possible (5.9%)
- Undue delay (21.8%)

Limited discharge capacity results in longer service/deployment time. The constant provision of tank trucks and barges involves a high logistical effort.

Issues related to the available treatment capacity of the municipal wastewater treatment plant (hydraulic and pollution load capacity) are addressed in chapter 5.2.1 and 5.2.6.

✓ Solutions

Improvement of discharge options in ports

Ideally, both types of PRF (fixed and mobile) should be available to meet the needs of passenger ships. A combination of fixed, floating and mobile PRFs allows for a flexible response in case of issues with individual PRFs.

This said, based on results from the CLIA-Exercise 2016, the most effective ports are always those which can allow the discharge of the wastewater via fixed PRF at the pier. Good examples of this are the ports of Helsinki and Stockholm. However, due to the different infrastructural conditions of the ports the installation of fixed PRFs is not always feasible.

In order to achieve better discharge efficiency, a continuous optimization process of the available PRFs in the Baltic Sea region should be sought. Table 5-1 summarizes the potential solutions.

Operators for discharge

Based on the CLIA-Exercise 2016 there are only a small number of providers for the discharge of wastewater via barges and/or tank trucks in Baltic Sea ports. Table 5-2 shows the average of existing providers in ports.

The limited number of providers inevitably leads to monopolies and a lack of competition and thus, to high prices. This is especially relevant

Table 5-1: Solutions for better discharge options in ports

Type 1 Installation of a fixed PRF	— High discharge rate — Low vulnerability to failures — High capacity
Type 2 Combination of all types of PRFs	— High flexibility — Low vulnerability to failures — Highest discharge rate
Type 3 Optimization of existing PRF	Optimization of: — Pump capacity — Storage capacity — (dis)connection time — Higher number of barges & tank trucks in service

Table 5-2: Number of mobile PRF providers to select from (CLIA-Exercise 2016)

How many PRF providers can the ship select from in the port? (maximum)	Amount reported by participating ships
1	12
2	5
3	1
Average:	1.39

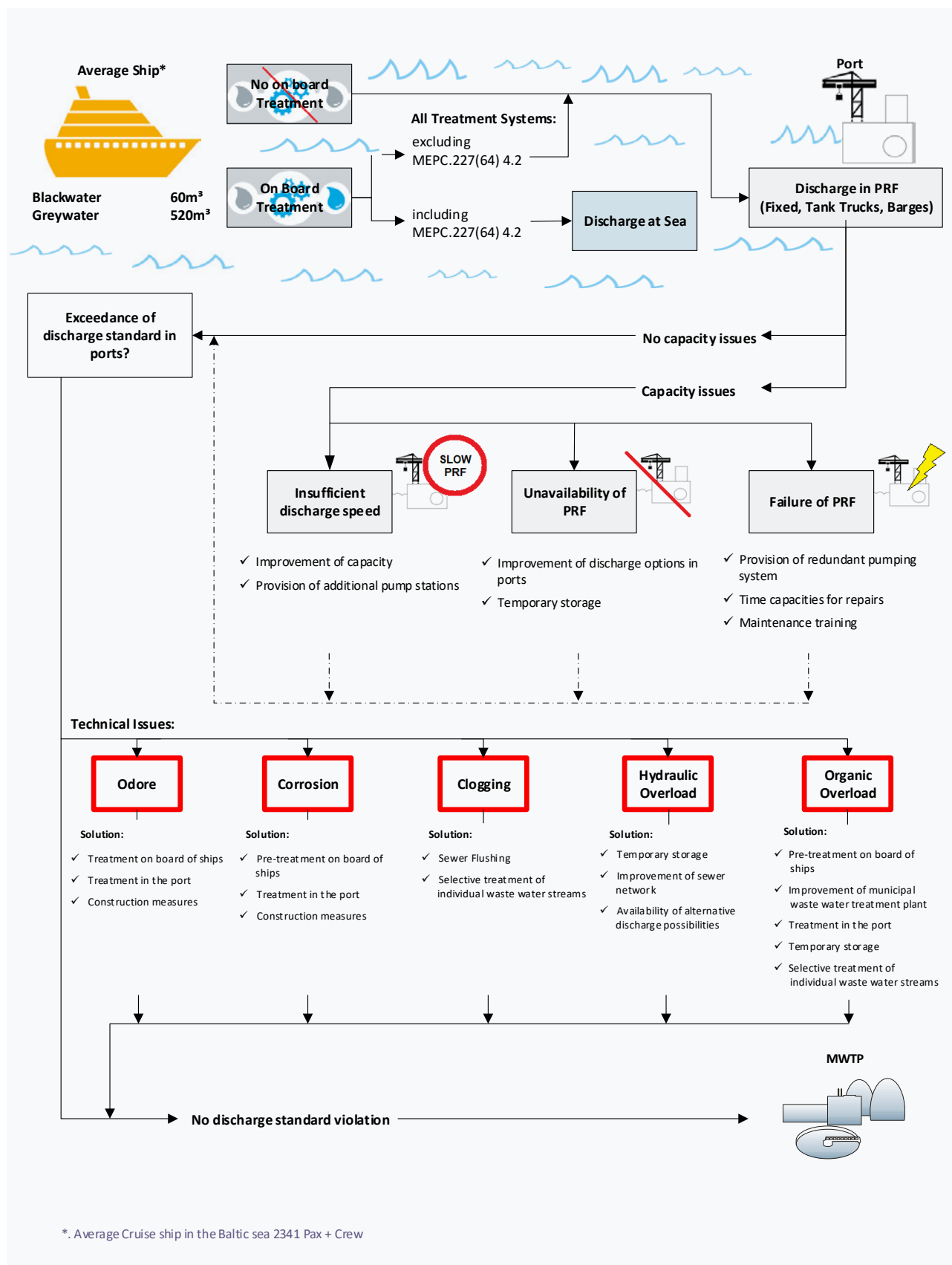


Figure 5-1: Flow chart of wastewater discharge in PRFs with special attention on associated problems and challenges



for cruise ships when calling at a port that does not have a no-special-fee (NSF) system. Ideally, the cruise ship industry should have the opportunity to choose between different providers. The resulting competition between providers should lead to an adjustment of prices and an overall improvement of services. It would be advisable to develop “key-indicators” for each provider so as to make it possible for their performance to be measured and compared.

Temporary storage

In the event of technical problems, it would be recommendable for a port to be able to fall back on alternative solutions/PRFs. In addition to the availability of tank trucks and barges, temporary storages could be an option to offset the impact of any issues. These would mitigate technical failures and bolster storage capacity in ports for short periods. The temporary storages should be designed in a way that minimizes the impact on the environment and human health e.g. odors (see technical solution 5.2.2).

5.1.2 Insufficient discharge speed

▲ Challenges

A critical aspect of the delivery of wastewater from passenger ships is ensuring a sufficient discharge speed. According to the CLIA-Exercise 2016, undue delay caused by discharge problems was reported in 21.8% of the calls. This proportion is also confirmed by the PIA-Questionnaire with 27%. The reasons for insufficient discharge speed can depend on various factors, though the main

causes are insufficient pumping capacity and lacking communication between port authorities and ship operators.

✓ Solutions

Improvement of discharge/pump capacity

Based on the HELCOM Overview 2014/17, cruise ships spend between 8 and 11 hours at berth. Insufficient discharge/pumping capacity resulted in a disproportional delay mainly in ports working with tank trucks and barges.

In order to reduce discharge time, each port should have at least a fixed PRF (see also previous chapter). In an ideal scenario, the combination of all types of PRF leads to significantly shorter discharge periods. Improving discharge capacity is best achieved by combining barges and fixed facilities so long as the ship is able to provide the required additional discharge hoses and pumps.

Provision of additional pump stations

By providing additional pump connections on both sides (ship and port), the pumping capacity, and thereby the discharge capacity, can be increased.

Longer discharge period / time for discharge

Should it not be possible to implement the solutions mentioned above and upgrade the PRFs and ship facilities, longer service times in the respective ports must be considered and integrated into both short term and long term planning.

5.1.3 Failure of pumping system

▲ Challenges

According to the PIA Questionnaire, in 18% of the port calls, pumping systems failures were reported. This leads to delays in the discharge of wastewater and thus, to prolonged stays in the port. Furthermore, if discharge is temporarily impossible (see also previous chapter) alternatives must be available as quick as possible.

✓ Solutions

Provision of additional pumping system

In case of a failure in the pumping system there should be provision for a redundant replacement. Thereby, in case of failure, the exchange is easier to handle and faster for both sides (ship and port).

Provision of spare parts

All spare and wearing parts which are integral to the discharge process like pumps, valves, pipes should be readily available for replacement.

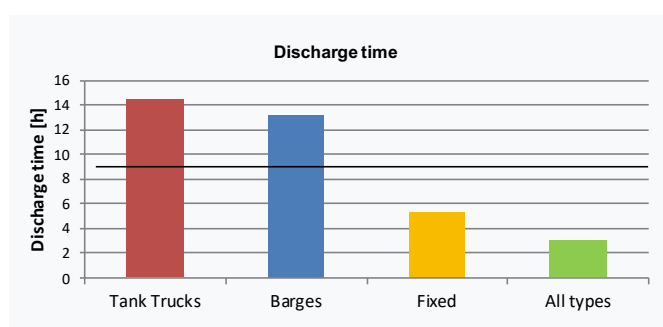


Figure 5-2: Discharge period depending on type of PRF used (Data from PIA Questionnaire)



Availability of alternative discharge possibilities (e.g. tank trucks)

According to the CLIA Exercise most ports offer a “Plan B” if the discharge in to the sewer system is temporary impossible. Tank trucks are most common method because of their high flexibility.

Staff training

The staff should be trained on the exchange of the installed pumping system in case of failure. This should lead to shorter downtimes and can be further enhanced by the adequate availability of spare parts.

5.2. Technical issues

5.2.1 Additional discharge standards

▲ Challenges

A port's acceptance of sewage is dependent on the respective discharge standard and the quality of the sewage. This can lead to challenges if a discharge standard is exceeded. The lack of a clear description as to what constitutes sewage in MARPOL is problematic for on-shore treatment, because as there is no definitive information about its composition and thus, exactly how discharge standards apply to it. This is partly because MARPOL Annex IV black water can be anything from pre-treated wastewater, to various undefined additives of grey water, to untreated and poorly stored wastewater.

Table 5-3: Ammonia concentration in mixed black- and grey water influent

	Unit	Ammonia-Nitrogen
Black water + 50 % of accommodation grey water	[mg/l]	150
Black water + 100% accommodation grey water	[mg/l]	82
Black water + 100% accommodation grey water + 100% laundry water	[mg/l]	68
Black water + 100% accommodation grey water + 100% laundry + 100% galley grey water	[mg/l]	50

Source: W. Chen, Hamworthy 2010 [13]

Some municipal treatment plants are designed to receive sewage mainly from households and are mainly equipped for reducing carbon and nutrients. They are not prepared to treat sewage mixed with oil and other substances like chlorine (see Annex IV, information on sewage treatment). Therefore, sewage from ships will most likely be classified as industrial waste and not as household sewage once it is discharged in the port. As a result, ports are forced to find other, likely more expensive, solutions to treat such mixed sewage from ships. The increased costs of treatment will likely have to be reflected in harbor fees. [12]

Each port's specific waste management plans dictate their discharge standards. As such, they may vary from port to port. The port specific discharge standards of the port of Kiel are shown in Annex II as an example.

✓ Solutions

Pre-treatment of sewage on board / in port (without chlorination) or dilution

Sewage treatment (on board): To comply with the required discharge standard at the port, the vessel should perform pre-treatment of the sewage. The on-board treatment system should be tested according to IMO Resolution MEPC 227 (64) excl. section 4.2 and should not chlorinate the wastewater.

Sewage treatment (in port): Alternatively, in order to meet the required discharge standard the port can carry out a pre-treatment process before the sewage is discharged into the sewer system or the MWTP. Treatment options are dependent on the size of the port and the amount of sewage received.

Dilution of sewage with less concentrated wastewater: The sewage can be mixed with wastewater from less concentrated wastewater streams. Grey water drawn from accommodation sources is well suited for this purpose. Table 5-3 shows the ammonia-nitrogen concentration of black water mixed with different volumes of grey water. The mixing of the waste water can, for example, be carried out in a mixing tank on board.

Monitoring of critical parameters

In wastewater processes, the following parameters are recommended to be analyzed. Total Organic Carbon (TOC), Chemical Oxygen Demand (COD), Biological Oxygen Demand in five days (BOD₅), Total Phosphorus (P_{tot}), Total Nitrogen (N_{tot}), Total Kjeldahl Nitrogen (TKN), Nitrite-Nitrogen (NO₂-N), Nitrate-Nitrogen (NO₃-N), and for industrial waste additionally Adsorbable Organic Halides (AOX), heavy metals and situational parameters.

According to our survey, 73% of the ports use only a monitoring system for the flow rate and volume of the received wastewater. Other parameters

**Table 5-4:** Parameters analyzed in the port

Parameter	Unit	Laboratory/Online	Application (% of ports monitoring the parameter)
Flow	[m³/h]	Online	73%
Temperature	[°C]	Online	45%
pH	[-]	Online	55%
Conductivity	[mS/cm]	Online	27%
TOC	[mg/l]	Online	9%
COD	[mg/l]	Laboratory	45%
BOD ₅	[mg/l]	Laboratory	18%
P _{tot}	[mg/l]	Online	18%
N _{tot}	[mg/l]	Laboratory	18%
TKN	[mg/l]	Laboratory	9%
NO ₂ -N / NO ₃ -N	[mg/l]	Laboratory	9%
AOX	[µg/L]	Laboratory	27%
Chlorine	[mg/l]	Online	9%
Heavy metals	[µg/L]	Laboratory	18%

Source: PIA Questionnaire 2017 [Annex V]

Table 5-5: Impact of increasing H₂S concentrations on humans

Concentration of H ₂ S [ppm]	Effect on humans
0,001	Odor threshold
0,1	Minimum Inhibitory Concentration (=MIC)
3-5	Explicit odor nuisance
10	Maximum Allowable Concentration (=MAC)
20	Intolerable odor nuisance
50-100	Irritation of the respiratory tract
100-200	Loss of olfactory sense
500	Headache, uncoordinated movements, vertigo

Source: <https://www.ncbi.nlm.nih.gov/books/NBK219913/>**Table 5-6:** Compilation of relevant parameters, pH-value, sulfide and temperature in comparison with their respective thresholds and the demand for action in order to avoid H₂S generation

Parameter	Threshold	Sewage from ships	Demand for action
pH-value	6,5 - 10	4,7 – 6,3	increase pH
sulfide	max. 2,0 mg/L	0,3 – 3,7 mg/L	reduce sulfide
temperature	max. 35°C	max. 27°C	no demand for action

Source: UniTechnics [17] threshold values for the Port of Kiel

for the chemical characterization, as listed in Table 5-4 are usually not part of the current wastewater monitoring. For selecting the right additional parameters to be monitored, the connected wastewater treatment plant should be consulted. This is important in order to react on discharge standard exceedance and to inform the MWTP.

5.2.2 Hydrogen sulfide (H₂S) and odor

▲ Challenges

According to the PIA Questionnaire 45% of the ports face odor problems when handling sewage from ships. The odor is caused by substances in the wastewater. Of these substances, H₂S is of particular importance, due to its characteristic odor of rotten eggs. The odor nuisance of H₂S arises even at minor concentrations in the air [14]. With larger concentrations health risks emerge for humans and animals in the area (Table 5-5).

Hydrogen sulfide is a component of the natural sulfur cycle and is produced endogenously in mammals, like humans [15]. It is then excreted through the faeces in the form of proteins and organic matter. These substances are then reduced to H₂S under anaerobic conditions by microorganisms (*Acidithiobacillus spp.*). This process can start on board of the vessel if the stored wastewater is not kept properly aerated. Outside of sufficient oxygen exposure there are other parameters that must be managed (Table 5-6).

✓ Solutions

The biological production of H₂S, like many biological processes, depends on the surrounding environment. For example, there are thresholds that need to be adjusted to reduce the H₂S production. The following table shows thresholds, values for typical sewage from ships and demand for actions (Table 5-6).

Separation of sewage streams to minimize H₂S (food waste and galley water)

Food waste and galley water contain high concentrations of organic matter which demand oxygen when degrading. As a result, the oxygen concentration decreases in the storage tank and anaerobic conditions develop. These conditions may increase the formation of H₂S within in the storage tank. By separating this wastewater stream anaerobic conditions can be reduced.

Chemical and/or technical solutions on board or in port (aeration, closed systems, additives, precipitation, biofilter)

Aeration: Aerobic biological degradation processes result in oxygen consumption in the wastewater until an anaerobic environment is created.



This leads to anaerobic biological degradation processes and the formation of odor noxious substances as product. By aeration of the storage tank/treatment tank the wastewater remains aerobic and the formation of odor noxious substances is reduced. This is important for long journeys and the resulting long storage times for wastewater.

Dosage of additives

Chemical oxidation: Additives like chlorine, ozone, hydrogen peroxide, and potassium permanganate are used to oxidize the odor compounds chemically. These chemicals are not odor compound specific and will react with other constituents in the wastewater. Therefore, more oxidative chemicals have to be added than stoichiometrically required. It should be noted that the use of chlorine can be problematic. This is particularly the case for ports with AOX limits.

Oxidation inhibitor: By adding oxidation inhibitors, the oxygen content in the wastewater can also be regulated. The application of nitrate salts is a widely used method of sulfide control. The nitrate creates anoxic conditions and prevents fermentation, so H_2S is not formed. In the process Nitrate serves as an electron acceptor for biological actions, very similar to aeration, in the collection system.

Precipitation: Chemical precipitation in order to precipitate sulfides from odor compounds using iron and other metallic salts. Iron salts (e.g. FeCl_3) are commonly used with the benefit, that iron salts precipitate sulfide without significantly altering the wastewater chemistry.

pH adjustment: One technique used to keep odor noxious substances like H_2S in solution is pH control. Maintaining a pH above 9 will keep most of the H_2S in ionized form and prevent its release in the gaseous phase. Possible chemicals to increase the pH are lime milk or Lye (e.g. caustic soda).

Technical solutions

A closed design of the system or the storage tank prevents odor noxious substances like H_2S from escaping into the air. Alternatively, a filter system is also possible.

Standard filter cartridges for the manhole odor eliminator contain activated carbon-based filter media. Other options can be installed depending on what gases are present. Another option is the sealing of the manhole. After this, the air from the manhole can be pumped through a bio filter or activated carbon filter.

5.2.3 Corrosion

▲ Challenges

Sewage contains various ingredients with corrosive effects on concrete and steel like:

- H_2S
- $\text{NH}_3 / \text{NH}_4$
- HCl

Since sewer systems are often built from the aforementioned materials, corrosion may occur. According to DWA (German Association for Water Management, Wastewater and Waste) [18], concrete pipes make up 38% of all existing sewer pipelines in Germany, this is comparable to other countries. In Poland, concrete pipes account for more than half of the operating sewers in some cities [19].

The rate of sulfide formation is dependent on several factors such as pH, temperature, nutrients, hydraulic retention time, pipe surface, and biofilm [20]. Concrete corrosion after both short and long-term exposure to sulfuric acid can increase the risk of catastrophic structural failure in concrete sewers. Likewise, important infrastructure like pumps and storages suffer from the effects of corrosion as well.

✔ Solutions

No direct discharge into existing sewer

If the sewer system is not resistant to corrosion, direct discharge should be avoided. Upgrading the sewer with a chemically resistant material (e.g., stoneware or plastics) would also have a positive effect.

Additional treatment in the port

To control biogenic production of corrosive substances (e.g. H_2S), additional treatment in the port is necessary.

Oxygen injection: Oxygen injection is often used to control biogenic production of H_2S in sewers, since oxygen reduces the growth of the anaerobic sulfur-reducing bacteria (SRB). For these bacteria the atmospheric oxygen is toxic since the SRB lack the enzymes superoxide dismutase and catalase for detoxing the oxygen superoxide radical. They can only proliferate in anaerobic environments.

Caustic shock-loading (= e.g. NaOH): Periodic caustic shock-loading is a commonly used method for controlling sulfide levels in sewers. Caustic



shock-loading relies on raising the sewage pH to ≥ 10.5 for several hours (0.5 - 6.0 h), thereby removing sewer pipe biofilms as well as deactivating SRB activity in the remaining biofilm. Laboratory studies demonstrated that the sulfide production rate of the laboratory sewer biofilm was reduced by 70 - 90% upon the completion of the pH shock, while the methane production rate decreased by 95 - 100% [35].

Free nitrous acid (FNA): FNA treatment is a cheap and effective technology to limit corrosion. Since FNA has an antimicrobial effect and can be used to reduce the number of SRB and SOB (sulfur oxidizing bacteria) in the biofilm of the sewer. This lowers the production of corrosive substances [34].

Iron salts: The addition of iron salts is one of the most commonly used strategies for sulfide control in sewers. Metal salts such as ferric chloride

precipitate the sulfide from water as ferric sulfide salts. Beside the formation of sludge, handling of the iron salts can be a corrosion problem of its own due to the formation of HCl.

Ozone: Ozone is used to control the production of H_2S either via oxidation that destroys SRB or by air stripping, another common method to remove H_2S odors from water. UniTechnics has built a system for the port of Kiel to strip of corrosive substances from the wastewater (Figure 5-3).

pH adjustment: The specification of sulfur, as H_2S , HS^- or S^{2-} depends on the pH-value in the wastewater. The more acidic the environment, the more the equilibrium shifts in the direction of hydrogen sulfide, which then escapes in gaseous form from the water phase. Therefore, an adjustment of the pH to an alkaline-value is appropriate (Figure 5-4).

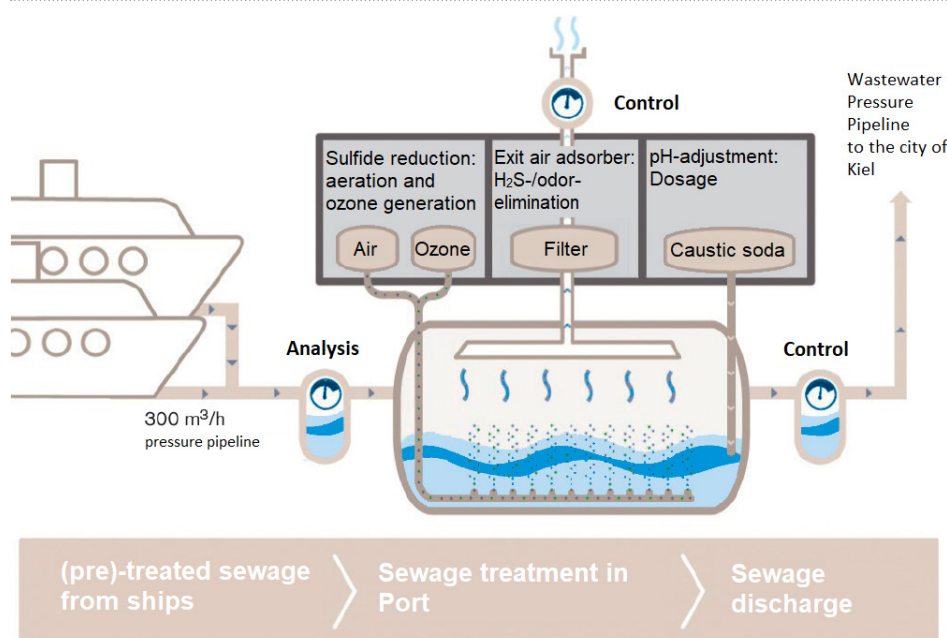


Figure 5-3: System used by UniTechnics to control the H_2S formation in the Port of Kiel

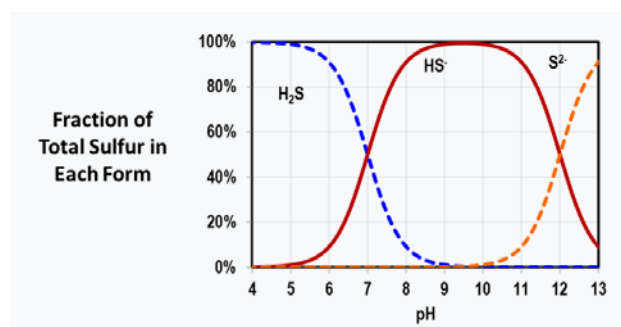


Figure 5-4: Specification of sulfur in different pH values



5.2.4 Sewer overflow

▲ Challenges

When the port discharges the received sewage into the sewer the hydraulic design of the sewer plays an important role. According to the PIA questionnaire, sewer systems can become overloaded when heavy rains occur. A similar occurrence can take place when a combined sewer connects the port with the MWTP combined sewer system (CSS). An overload may occur when the system is not sufficiently dimensioned to receive sewage from larger cruise ships (>3000 Pax). Moreover, peak loads (days with multiple calls) can also lead to the hydraulic capacity of the sewer systems being exceeded. This event is called a combined sewer overflow (CSO) [21] [22] [23] [24].

The impact of a CSO on the receiving water body is an issue of increasing concern, as it may lead to environmental hazards and restrictions in the use of the receiving body, such as bathing or recreational area closures, fish and shellfish consumption restrictions, and the contamination of drinking water resources (Figure 5-5). Recent investigations have mainly referred to the occurrence and loads of suspended solids, organic compounds and micro pollutants.

✓ Solutions

Temporary storage of sewage in the ports

When the port is connected to a CSS, a temporary storage of wastewater in the port should be offered. Thereby, the sewer system can e.g. be relieved until any heavy rain diminishes. The size of the storage tank should be adapted to the number and size of passenger ships calling the port.

Improvement of sewer network (pressure pipeline, separate sewer, capacity)

The average distance from the port to the wastewater treatment plant in the Baltic Sea region is 7.7 km according to the PIA questionnaire. If a CSS cannot be used and a storage tank is not a viable option due to a lack of space, construction measures should be considered.

Pressure pipeline: Pressurized sewers differ from conventional gravity collection systems. They use pumps instead of gravity to transport wastewater. The primary effluent is delivered to the collection tank by gravity where it is ground (pressed) before being transported into the pressurized system by pumps. A pressure pipeline requires little water, only for transporting the excreta. Moreover, deposits in the pipeline are removed by pressure and cannot build up.

Separate sewer: Separate sewer systems are designed to convey wastewater and storm water in separate pipes, which reduces the risk of a potential sewage overflow. Additionally, there are no issues related to discharging industrial wastewater when the risk of a sewage overflow is eliminated. A disadvantage of a separate sewer is the dependency on a reliable supply of piped water. Low flow speeds create deposits that can build up, and which in time may potentially clog the sewer system (See 5.2.5).

Sustainable sewer system: A sustainable sewer system can be used to relieve the hydraulic load on wastewater treatment plants in case of storm water events or first flush events through technical solutions. “Parameter specific discharge control” and “pump control regulation” are to be mentioned as examples.

For parameter specific discharge the contaminated effluents in storm water are detected with a photometer probe in the sewer system. Turbidity and total suspended solids are defined as indicator parameters. By continuously measuring the

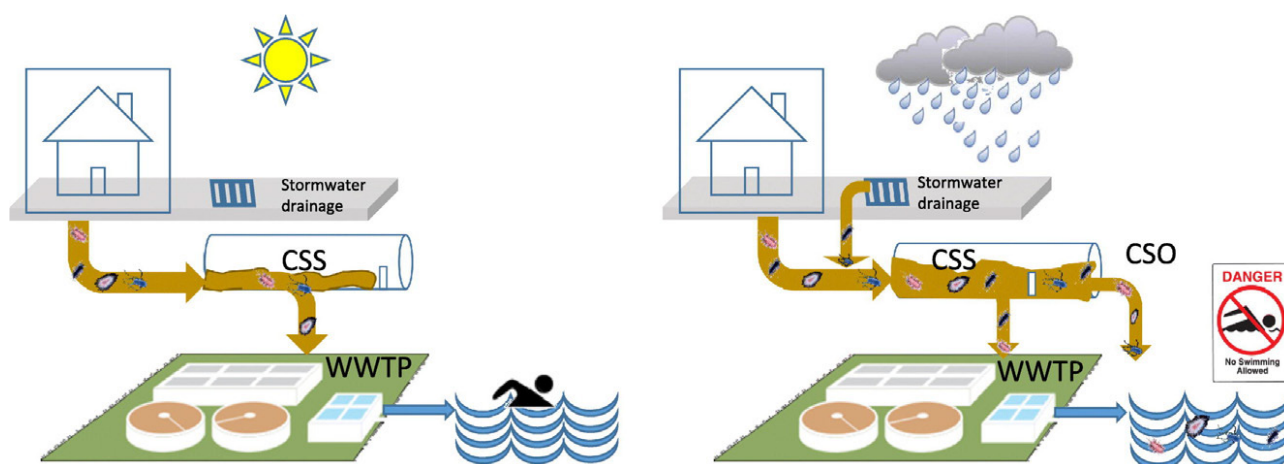


Figure 5-5: Effect on receiving waters when a CSO event occurs [25]



wastewater stream, the effluent portion requiring treatment is fed to the sewage treatment plant and the less polluted part is discharged into the receiving water.

Pump control regulation can be used in the case of point discharges of heavily polluted waste water. Significantly higher concentrations of pollutants may be present in certain areas of the sewer system. In these cases it is conceivable to influence throttle discharges in a way that relief takes place mainly in areas where the wastewater is less heavily polluted.

Improvement of capacity: Larger diameters in the sewer system ensure higher capacity. In addition, relief buildings can be built to counteract any hydraulic overloads.

Availability of alternative discharge possibilities (e.g. tank trucks)

According to the CLIA exercise most ports offer a “Plan B” if the discharge in the sewer system is temporarily impossible. Tank trucks are most often used because of their high flexibility.

Table 5-7: Pollution load of different Wastewater streams

Parameter	Unit	BW ¹		GW ²		BW+GW ³	
Flow	m³/ship	75.4		534.8		610.2	
		36.5	248	418.1	850.9	454.6	1098.9
COD	kg/Ship	476.9		615.0		1091.9	
		157.0	2442.8	320.9	3339.8	477.8	5782.6
BOD ₅	kg/Ship	262		462.6		724.6	
		61.1	1382.6	302.1	1042.4	363.2	2425.0
N _{tot}	kg/Ship	64.1		11.8		61.7	
		25.0	1643	3.8	18.7	28.8	1661.7
NH ₄ -N	kg/Ship	59.0		2.5		61.5	
		19.8	236.8	0.4	28.9	20.2	265.8
P _{tot}	kg/Ship	5.9		3.5		9.4	
		2.0	151.3	2.1	5.5	4.1	156.8
						Average	
						Min	Max

1) Black water Pollution Load for an Average ship in the Baltic Sea in 2017 (2431 Pax+Crew)

2) Grey water Pollution Load for an Average ship in the Baltic Sea in 2017 (2431 Pax+Crew)

3) Black water + Grey water Pollution Load for an Average ship in the Baltic Sea in 2017 (2431 Pax+Crew)

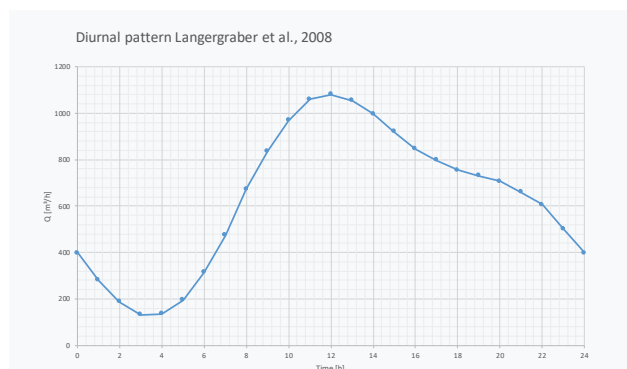


Figure 5-6: Diurnal pattern of a Wastewater treatment plant [29]

5.2.5 Logging of sewer systems

Challenges

Due to the low flow velocity in some sewer networks and the unfavorable composition of sewage, blockages in sewer systems may occur, caused by the mineralization of organic material (= special fats) [26-28].

Solutions

Flushing of sewer system at regular intervals

Continuous flushing of the sewer system can be used to remove deposits. To flush the sewer system either domestic water or slightly polluted grey water should be used. The use of sea water is not recommended as the salt content has a negative effect on the purification performance of the MWTP and has corrosive properties.

Separation of food waste and galley water (see odor (5.2.2))

Wastewater containing a high proportion of food waste, pulper and galley water should be treated separately. This is due to their high percentage of fats, oil, and grease (FOGs). As such they should not be channeled through the sewer system into the treatment plant. An alternative solution is the transportation via tank trucks.

5.2.6 Exceedance of hydraulic and/or organic load capacity of municipal treatment plant (MWTP)

Challenges

The PIA questionnaire showed that 38% of the surveyed ports had problems with the connected MWTP. If a port has a fixed PRF and directs its discharges into the sewer, problems may arise. In particular small ports with poor infrastructure are affected. Major ports may have problems when it comes to a “bottleneck” (several ships start to discharge at the same time). After being discharged in port, the sewage passes through the sewer network into the inlet building of the sewage treatment plant. It is important to ensure that the local discharge standards (Annex II Table 8-1) are not exceeded when discharging in the sewer network. Not only are large quantities of wastewater generated, but also pollution dependent on the origin and treatment of the wastewater (Table 5-7).

A wastewater treatment plant has a diurnal pattern with shock peaks where the most wastewater arrives (Figure 5-6). When a cruise ship discharges on-shore the amount of wastewater can increase significantly.

**Table 5-8:** Population equivalent of different ship sizes with untreated black- and grey water

Parameter	Unit		Small Cruise Ship ¹	Large Cruise Ship ²	Average Cruise Ship ³
Flow	p.e.flow	$\frac{1}{0.150 \text{ m}^3}$	2510.0	6693.3	4067.9
COD	p.e.COD	$\frac{1}{0.12 \text{ kg COD}}$	5613.4	14969.2	9097.5
BOD ₅	p.e.BOD ₅	$\frac{1}{0.06 \text{ kg BOD}_5}$	7450.6	19868.3	12075.0
N _{tot}	p.e.N _{tot}	$\frac{1}{0.0011 \text{ kg N}_{\text{tot}}}$	4253.2	11341.8	6893.0
P _{tot}	p.e.P _{tot}	$\frac{1}{0.0018 \text{ kg P}_{\text{tot}}}$	3208.5	8556.1	5200.0

1) Small Cruise Ship with 1500 Pax+Crew

2) Big Cruise Ship with 4000 Pax+Crew

3) Average Cruise Ship with 2431 Pax+Crew

This temporary shock load may exceed the capacity of the MWTP, resulting in a reduction of the cleaning performance. The problem with low capacity designs is mainly relevant for smaller ports.

Solutions

Improvement of MWTP

If the design capacity of the MWTP has been exceeded, it is advisable to examine the possibility of improvements. A big cruise ship (4000 Pax+Crew) discharging increases a wastewater treatment plant load by a population equivalent for biological oxygen demand p.e.BOD₅ of almost 20000, if the sewage is untreated (Table 5-8).

Treatment in the port

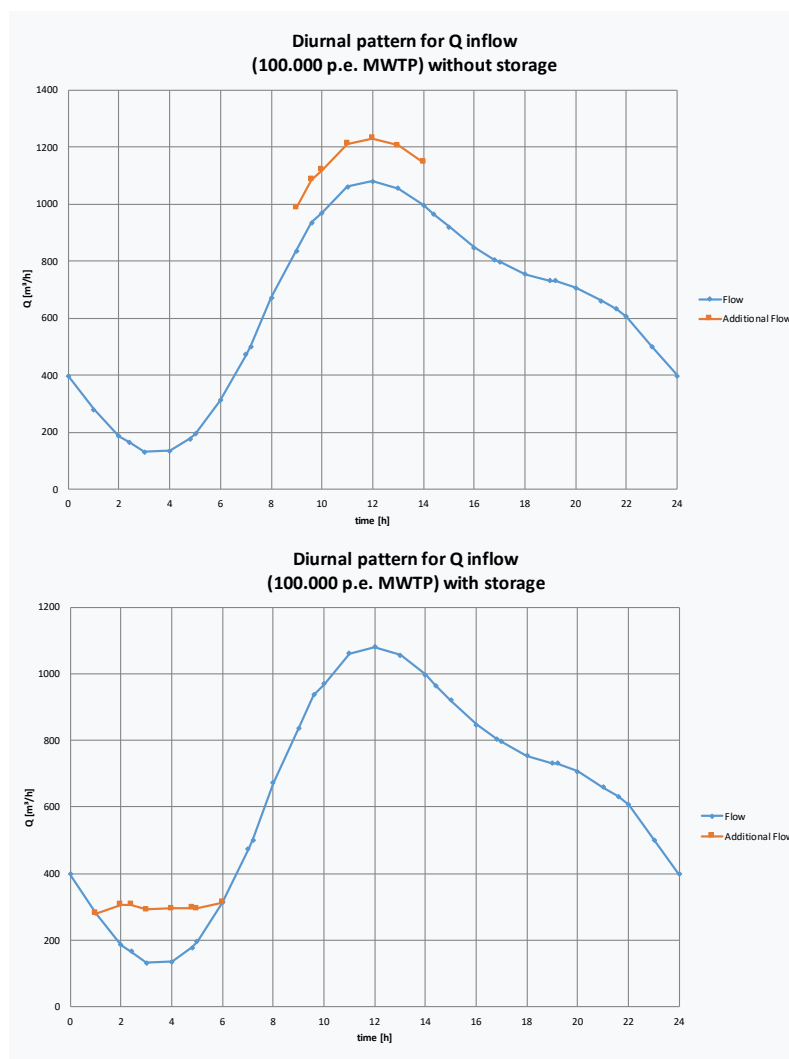
In order to achieve a reduction in pollution loads, the wastewater can be pre-treated in the port. The use of a pre-settling tank for smaller ports is advisable. This results in a reduction of the BOD₅ and TSS values by up to 30%. Priority ports can also provide a biological purification stage with additive supplementation for phosphate reduction in addition to pre-treatment. These steps should reduce transgression.

Temporary storage

The diurnal pattern of the MWTP has high peaks and low peaks. The low peaks present an excellent opportunity to discharge stored sewage into the system. This will produce two benefits (Figure 5-7).

Peak loads of wastewater can be buffered.

Low peaks can be compensated with stored sewage.

**Figure 5-7:** Diurnal pattern for Q inflow without and with temporary storage

**Table 5-9:** Daily food waste stream on an average cruise ship

Parameter	Unit	Food waste ¹	
Flow	m ³ /Ship	7.4	
COD	kg/Ship	192.6*	
		145.9	372.0
BOD ₅	kg/Ship	222.5	
		126.2	230.5
N _{tot}	kg/Ship	1.4	
		0.7	1.4
NH ₄ -N	kg/Ship	0.13	
		0.13	0.13
P _{tot}	kg/Ship	1.4	
		0.2	2.2
		Average	
		Min	Max

* COD_{filtered}

1) Data were gathered from NAUTEK and refers to an average cruise ship in the Baltic Sea (2431 Pax + Crew)

Waste stream controlling

A cruise ship produces different sources of wastewater. Each stream is different, depending on the origin, volume and pollution load. Food waste is heavily polluted but has only a small volume (Table 5-9). Furthermore, sewage treatment plants in the EU can refuse food waste if it is food from outside the EU and the sewage treatment plant uses sewage sludge for agriculture.

By separating the food waste stream from the other wastewater streams, the pollution load can be reduced by 222.5 kg BOD₅ per ship. This corresponds to a BOD₅ reduction of approximately 30%. Working on the basis that 60g BOD₅/d corresponds to a single person, the separation of food waste removes a load of 3708 p.e. BOD₅. [30]

A separation of the food waste stream is beneficial for both cruise ships and ports:

Improvement of storage and treatment conditions

- Reduction of BOD₅ in the black water by 30%
- Reduction of FOGs in the black water
- Easier to store when separated
- Better treatment potential on board (no load peak when food waste is added)

Possibility for separate disposal

- Direct anaerobic treatment for biogas production in MWTP
- Reduction of clogging through FOGs (in Black water) in the sewer system
- Incineration, if food comes from outside the EU
- Possible phosphate-recovery if the food comes from the EU and the MWTP uses sewage sludge for an agricultural purpose



5.3. Other issues

5.3.1 Improvement of communication between ports and ships (process definition)

▲ Challenges

The information on PRFs for sewage should be included in the waste reception and handling plans in each port. The content of the plans is regulated by both IMO MARPOL and, in the case of EU Member states, in the current and new PRF Directive, which both include in their article 5, Annex 1 detailed requirements. Also ships should according to IMO rules, and, when EU regulations apply, are required to provide the ports with some information via prior notification. However, in practice, communication gaps still exist.

✓ Solutions

In order to rectify the information gaps that currently exist between ports and cruise ships, the waste reception and handling plans and prior notifications by the ships should include all important reference information related to the discharge of wastewater. Based on the PIA questionnaire, the following key information for both sides (port and ship) should be included:

- Type of wastewater (separated grey-, oil- and black water)
- Compatibility between MWTP demands on sewage composition and the composition of sewage from ships should be studied in more detail, and if feasible on a port-by-port basis.
- Pre-treatment on board (including which type)
- Pump capacity (port and ship related)
- Connection types
- Any restrictions set out by service providers
- PRFs availability
- When (24/7, business time: 5-7 hrs./d)
- Costs (special fee, no costs)
- Where (all/one/specific berths)
- Maximum receiving capacity
- Contamination with other waste or products

The information should be exchanged as early as possible and not less than 24 hours in advance via initial notification of the ship.

As an EU member state, also note the requirement of article 5(2) of the new PRF Directive on making publicly available the information listed in article 5¹, as well as reporting this information electronically into SafeSeaNet, which is part of the information, monitoring and enforcement system referred to in article 13 of the new PRF Directive.

Also take note of the Advanced Waste Notification (AWN) according to article 6, annex 2 of the new PRF Directive. In addition the new Directive will require a Waste Delivery Receipt (WR) to be delivered to the ship after the delivery (see article 7). The ship will need to electronically report both the information from the AWN and the WR into SafeSeaNet, to allow for proper monitoring and enforcement. Also sufficient storage capacity of the ship then needs to be reported via the AWN (article 6, Annex II), and will be a pre-condition for allowing a ship to depart from the port without having delivered (all) its waste.

Finally, in this context also the use of online services could be helpful. The IMO offers a Global Integrated Shipping Information System (GISIS) where cruise operators can evaluate the availability of PRFs (<https://gis.imo.org/Public/Default.aspx>). Moreover, cruise ship operators can report cases of PRFs that they find to be inadequate. This allows ports to engage with feedback to make improvements to their PRFs.

Also, the HELCOM Cooperation Platform on Special Area According to MARPOL Annex IV aims to promote dialogue and an exchange of experiences concerning good practices in planning, implementing and operating PRFs for sewage. The platform's website provides publications relevant to the work of the PRF cooperation platform; relevant workshops, projects and other information.

(<http://www.helcom.fi/helcom-at-work/groups/maritime/prf-cooperation-platform>)

¹ See Article 5 Paragraph 2 of the new PRF Directive:
(a) location of port reception facilities applicable to each berth, and, where relevant, their opening hours;
(b) list of waste from ships normally managed by the port;
(c) list of contact points, the port reception facility operators and the services offered;
(d) description of the procedures for delivery of the waste;
(e) description of the cost recovery system, including waste management schemes and funds as referred to in Annex 4, where applicable.



6. Conclusions

The new requirements of the Special Area represent a challenge not only for the maritime industry, but also for the ports of the Baltic Sea region.

There is not a 'one size fits all' solution. Each port faces unique challenges according to its specific location, size, frequency of port calls, connection/distance to the local municipal wastewater treatment plant, design capacity of the MWTP, regulatory environment etc.

Therefore, the lists of recommendations for ports and ships below only represent possible options, apart from those that are legal requirements for EU member states under the current and future PRF Directive.

The solutions presented concern different aspects: infrastructural, technological and planning and communication.

6.1. For ports

1. Provision of a waste reception and management plan suited for IMO Annex IV waste (and for EU member states according to article 5, annex 1 of new PRF Directive, as well as a Waste Delivery Receipt (WR) according to article 7 of the new PRF Directive for improved monitoring and enforcement)
2. Sufficient pump capacity even for large ships
3. A selection of PRF types
 - Fixed and mobile
 - Tank trucks are available as a "Plan B"
4. Online measurement of parameters with thresholds/standards
5. Storage tanks for sewage
6. Pretreatment
 - Aeration
 - pH-adjustments
 - Odor control
7. Adequate pipeline from the storage tank to the MWTP
 - Pressure pipeline
 - Separate sewer system
8. Sufficient design capacity of the MWTP

6.2. For cruise ships

1. Advanced Notification Form (ANF) or for EU member states Advanced Waste Notification (AWN) according to article 6, annex II of the new PRF Directive with additional information for the port and the MWTP:
 - Is the wastewater treated on board and how efficient is the treatment on board?
 - Is grey water and black water separated?
 - Is food waste part of the waste stream?
 - What are the wastewater volumes of all waste streams?
2. A (pre-)treatment system on board, including reduction of organic matter (BODs) by biological treatment
3. Aeration of the storage tanks to prevent anaerobic conditions
4. No disinfection of wastewater through the use of chlorine (for AOX regulated ports)
5. Partitioning and separate storage for individual wastewater streams
6. Provision of individual discharge connections for the individual wastewater streams
7. Provision of discharge pumps with sufficient pumping capacity
8. Analysis of crucial wastewater parameters to meet thresholds/standards in ports
9. Provision of sufficient storage capacity for each waste stream
10. Route planning with all participating ports (e.g. that smaller ports can be relieved by larger ports if needed)



7. References

- [1] Lilja, Tina, and Sundblad. Sjöfarten kring Sverige och dess påverkan på havsmiljön. Göteborg: Havsmiljöinstitutet, 2014. Print. http://havsmiljoinstitutet.se/digitalAssets/1488/1488843_sjofart_och_havsmiljo.pdf Access at 10.09.2018
- [2] Cruise Baltic, Cruise Baltic Market Review 2017, Copenhagen, 2018. <https://api.cruisebaltic.ovdal.dk/media/4160/cruise-baltic-market-review-2000-2018-pdf.pdf> (Access at 10.09.2018)
- [3] Baltic Sea Sewage Port Reception Facilities - HELCOM Overview 2014. ISBN: 978-952-67205-9-3 <http://www.helcom.fi/Lists/Publications/Baltic%20Sea%20Sewage%20Port%20Reception%20Facilities.%20HELCOM%20overview%202014.pdf> (Last Access 10.09.2018)
- [4] U.S. Environmental Protection Agency, public hearings 2000
- [5] U.S. Environmental Protection Agency, Sampling Report 2004
- [6] U.S. Environmental Protection Agency, Cruise Ship Discharge Assessment Report 2008 (EPA842-R-07-005).
- [7] Alaska Department of Environment Conservation (ADEC) 2012. Cruise Ship Wastewater Science Advisory Panel
- [8] United States' Submission to the 44th Session of the Marine Environment Protection Committee of the International Maritime Organization. "Interpretations and Amendments of MARPOL 73/78 and Related Codes; Proposed Amendments to MARPOL Annex IV" (December 1999).
- [9] Meyer Werft (2011). Cruise ship wastewater Science Advisory Panel (SAP) 22th September 2011, Basic information on system integration waste water treatment in ship building and data collection for the report. http://dec.alaska.gov/water/cruise_ships/sciencepanel/documents/binder/meyer-werft-presentation.pdf (Access 10.09.2018)
- [10] S. Köster, L. Westhof, L. Keller Stand der Technik der Abwasserreinigung an Bord von Kreuzfahrtschiffen gwf, 157 (2016), pp. S. 528-S. 537. https://www.gwf-wasser.de/fileadmin/GWF/01_fb_Koester.pdf (Access at 10.09.2018)
- [11] Scanship Testing of Norwegian Breakaway 2013, https://www.conservationfund.org/images/programs/files/2017_AIW_presentations/1505_Lars_Rohold_Scanship_Solutions_Aquaculture_Nov_New02.pdf (Access at 10.09.2018)
- [12] Baltic Marine Environment Protection Commission - HELCOM, Interim guidance on technical and operational aspects of delivery of sewage by passenger ships to port reception facilities 2013. http://www.helcom.fi/Documents/Ministerial2013/Ministerial%20declaration/Adopted_endorsed%20documents/Interim%20Guidance%20PRF.pdf (Access at 10.09.2018)
- [13] W. Chen, Hamworthy 2010
- [14] Budavari, S., editor; , M.J. O'Neil, editor; , A. Smith, editor; , and P.E. Heckelman, editor. , eds. 1989. Hydrogen sulfide. P. 761 in The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals, 11th Ed. Rahway, NJ: Merck.
- [15] Weil, E.D., S.R. Sandler, and M. Gernon. 2006. Sulfur compounds. Pp. 621-701 in Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 23, J.I. Kroschwitz, editor; and A. Seidel, editor. , eds. Hoboken, NJ: Wiley-Interscience.
- [16] Ohle P, Keutgen H, Noble J, 2009. Wastewater treatment on ships with ZeeWeed MBR technology 3rd, International symposium SOWOS 3; 2009; Hamburg, Germany. 219 p. 12/1-12/18 ISBN: 9783938996256
- [17] Obermayer A, Magdeburg F, 2017. Modere Abwasserbehandlung im Hafen <https://www.wwt-online.de/sites/default/files/fachartikel/wwt0917-sp-obermayer.pdf> (Access 10.09.2018)
- [18] Christian Falk (Dortmund), Friedrich Hetzel (Hennef), Johannes Pinnekamp, Silke Roder und Jan Ruppelt (Aachen) Christian Berger (Hennef). (2016). Zustand der Kanalisation in Deutschland. Zustand Der Kanalisation in Deutschland, 2016(6), 498–508. <https://doi.org/10.3242/kae2016.06.001>
- [19] Kuliczowska, E. (2016). Risk of structural failure in concrete sewers due to internal corrosion. Engineering Failure Analysis, 66, 110–119. <https://doi.org/10.1016/j.engfailanal.2016.04.026>
- [20] Delgado, S., Alvarez, M., Rodriguez-gomez, L. E., & Aguiar, E. (1999). H₂S generation in a reclaimed urban wastewater pipe. case study: Tenerife (Spain). Water Research, 33(2), 539–547. [https://doi.org/10.1016/s0043-1354\(98\)00223-1](https://doi.org/10.1016/s0043-1354(98)00223-1)
- [21] Mailhot, A., Talbot, G., & Lavallée, B. (2015). Relationships between rainfall and Combined Sewer Overflow (CSO) occurrences. Journal of Hydrology, 523, 602–609. <https://doi.org/10.1016/j.jhydrol.2015.01.063>



- [22] Tavakol-Davani, H., Goharian, E., Hansen, C. H., Tavakol-Davani, H., Apul, D., & Burian, S. J. (2016). How does climate change affect combined sewer overflow in a system benefiting from rainwater harvesting systems? *Sustainable Cities and Society*, 27, 430–438. <https://doi.org/10.1016/j.scs.2016.07.003>
- [23] Riechel, M., Matzinger, A., Pawlowsky-Reusing, E., Sonnenberg, H., Uldack, M., Heinzmann, B., ... Rouault, P. (2016). Impacts of combined sewer overflows on a large urban river – Understanding the effect of different management strategies. *Water Research*, 105, 264–273. <https://doi.org/10.1016/j.watres.2016.08.017>
- [24] Madoux-Humery, A.-S., Dorner, S., Sauvé, S., Aboulfadl, K., Galarneau, M., Servais, P., & Prévost, M. (2013). Temporal variability of combined sewer overflow contaminants: Evaluation of wastewater micropollutants as tracers of fecal contamination. *Water Research*, 47(13), 4370–4382. <https://doi.org/10.1016/j.watres.2013.04.030>
- [25] Al Aukidy, M., & Verlicchi, P. (2017). Contributions of combined sewer overflows and treated effluents to the bacterial load released into a coastal area. *Science of The Total Environment*, 607–608, 483–496. <https://doi.org/10.1016/j.scitotenv.2017.07.050>
- [26] Mattsson, J. (2015). Impacts on sewer performance due to changes to inputs in domestic wastewater (PhD dissertation). Retrieved from <http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-18086> (Access at 10.09.2018)
- [27] Mattsson, J., Hedström, A., Ashley, R. M., & Viklander, M. (2015). Impacts and managerial implications for sewer systems due to recent changes to inputs in domestic wastewater – A review. *Journal of Environmental Management*, 161, 188–197. <https://doi.org/10.1016/j.jenvman.2015.06.043>
- [28] Martin, S. (2017). Tackling the impact of FOG in drainage systems. *Filtration + Separation*, 54(2), 42–44. [https://doi.org/10.1016/s0015-1882\(17\)30086-1](https://doi.org/10.1016/s0015-1882(17)30086-1)
- [29] Langergraber, G., Alex, J., Weissenbacher, N., Woerner, D., Ahnert, M., Frehmann, T., ... Winkler, S. (2008). Generation of diurnal variation for influent data for dynamic simulation. *Water Science and Technology*, 57(9), 1483–1486. <https://doi.org/10.2166/wst.2008.228>
- [30] Long, J. H., Aziz, T. N., Reyes, F. L. de los, III, & Ducoste, J. J. (2012). Anaerobic co-digestion of fat, oil, and grease (FOG): A review of gas production and process limitations. *Process Safety and Environmental Protection*, 90(3), 231–245. <https://doi.org/10.1016/j.psep.2011.10.001>
- [31] HELCOM, HELCOM Recommendation 19/8. Application of the no-special-fee system in the Baltic Sea Area, in: HELCOM (Ed.), 1998
- [32] European Commission, Ex-Post Evaluation of Directive 2000/59/EC on Port Reception Facilities for Ship-generated Waste and Cargo Residues. Final report, Brussels, 2015
- [33] CLIA 2016, CLIA Europe Baltic Exercise on Sewage 2016 https://portal.helcom.fi/meetings/CP%20PRF%207-2017-463/MeetingDocuments/Document%201_CLIA%20Europe%20Baltic%20Exercise%20on%20Sewage%202016.pdf
- [34] Sun, X., Jiang, G., Bond, P. L., Keller, J., & Yuan, Z. (2015). A novel and simple treatment for control of sulfide induced sewer concrete corrosion using free nitrous acid. *Water Research*, 70, 279–287. <https://doi.org/10.1016/j.watres.2014.12.020>
- [35] Gutierrez, O., Sudarjanto, G., Ren, G., Ganigué, R., Jiang, G., & Yuan, Z. (2014). Assessment of pH shock as a method for controlling sulfide and methane formation in pressure main sewer systems. *Water Research*, 48, 569–578. <https://doi.org/10.1016/j.watres.2013.10.021>
- [36] Butt, N. (2007). The impact of cruise ship generated waste on home ports and ports of call: A study of Southampton. *Marine Policy*, 31(5), 591–598. <https://doi.org/10.1016/j.marpol.2007.03.002>
- [37] Wilewska-Bien, M., & Anderberg, S. (2018). Reception of sewage in the Baltic Sea – The port's role in the sustainable management of ship wastes. *Marine Policy*, 93, 207–213. <https://doi.org/10.1016/j.marpol.2018.04.012>
- [38] HELCOM (2018), Baltic Sea Sewage Port Reception Facilities, HELCOM Overview 2018. 123 pp. https://portal.helcom.fi/meetings/CP%20PRF%207-2017-463/MeetingDocuments/Document%202_2017%20HELCOM%20Overview%20on%20PRF.pdf
- [39] Cruise Baltic, Port Reception Facilities in the Baltic Sea Region, 2016. www.cruisebaltic.com.
- [40] Port of Aarhus, Terms of business in force as of January 1, 2014. Conditions and prices for the Port's activities, Aarhus, 2014
- [41] Port of Aalborg, Business Conditions. General 2015, Aalborg, 2015
- [42] AIDA Zahlen und Fakten ABWASSER [G4-EN22] <https://www.aida.de/aida-cruises/nachhaltigkeit/aida-cares-2017/erfolge/aida-in-zahlen.34517.html>
- [43] TUI Environmental Report 2016 p.20 https://www.tuigroup.com/damfiles/default/tuigroup-15/de/nachhaltigkeit/berichterstattung-downloads/2017/TUI-Cruises_Environmental-Report-2016.pdf-bfde65f94864f85f8020724fbd7ae223.pdf
- [44] Directive (EU) 2019/883 of the European Parliament and of the Council of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU and repealing Directive 2000/59/EC (Text with EEA relevance); Published: OJEU L 151, 07 June 2019 p. 116. <http://data.europa.eu/eli/dir/2019/883/oj>