Quantification of microplastic discharge from wastewater treatment plants, including sanitary sewer overflow events, to the Baltic Sea

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Description of work

Wastewater treatment plants (WWTPs) as a source for microplastics (MP) to the Baltic Sea have been investigated in Task 4.1. The work has been divided into two sub-tasks which results will be integrated into WP5. This sub-task includes:

(A) **Quantification of MP discharge from WWTP to the Baltic Sea** including compilation of wastewater treatment practices and technologies.

(B) **Estimation of sanitary sewer overflow as a source for MP to the Baltic Sea**. Sanitary sewer overflow (SSO) is a condition where untreated wastewater is discharged from a sanitary sewer into the environment, normally due to lack of process- or hydraulic capacity. Discharge of MP from SSO can be in the same magnitude as from treated wastewater (Magnusson et al., 2016), although the total flow is much lower than that of treated wastewater. SSO events frequently occur and are expected to increase due to climate change and urbanisation, unless infrastructure is rebuild. It is therefore important to gather information and increase knowledge on this matter.

Towards the end of the MICROPOLL-project, the current report will be revised and updated with more data that is planned to be gathered from project partners, updated data sources and actual tests at WWTPs. A number of data inconsistencies in the reported data have been identified during the present work and these require follow-ups to improve the MP-discharge calculations.

Method

Reported data on WWTPs in the Baltic Sea basin

The quantification of MP-discharge from WWTPs and SSO to the Baltic Sea is based on publicly accessible databases including WaterBase[1] , HELCOM data[2], Swedish data[3] and Danish data[4].

Unfortunately the HELCOM data did not include local WWTP-code or any other unique identifier that could be used to link it to data in WaterBase or local databases. While WaterBase included more plants in the HELCOM area than the HELCOM data (3 016 in relation to 2 749) the project decided to use WaterBase as main data source for the MICROPOLL database. We however complemented the MICROPOLL database with Russian plants from the HELCOM data and updated some plant parameters based on information in the Swedish and Danish databases.

The project also developed a Waste Water Survey, which has been sent to project members and other relevant organisations to retrieve missing plant level information about mainly total load on the plant [PE], wastewater treatment technology and information about overflow in WWTP and in the sewer system.

Reported data quality and quantity varies significantly between the various Baltic Sea countries which is illustrated by Figure 1 and Table 1 showing reported WWTPs for the different countries.

[1] https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-5
[2] http://maps.helcom.fi/website/mapservice/index.html
[3] https://smp.lansstyrelsen.se/
[4] Miljø- og Fødevareministeriet, 2017

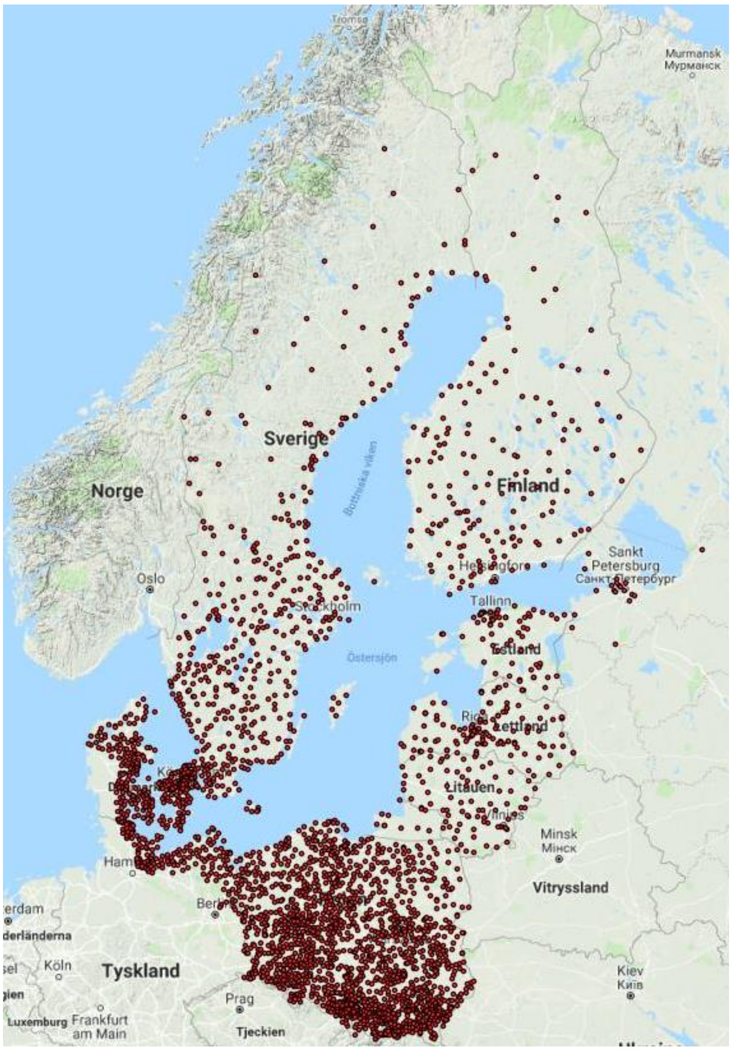

Figure 1. Overview of WWTP:s in the MICROPOLL database (HELCOM area definition).

Table 1. WWTP:s in the MICROPOLL database.

Country	Number of WWTP reported	used	Data source	WWTP Inflow [m³/yr]
Denmark	313	290	WaterBase+Helcom+Danish database	59 911 – 64 090 000
Estonia	68	62	WaterBase+Helcom	174 500[5] – 41 537 000
Finland	161	160	WaterBase+Helcom	220 - 93 200 000
Germany	184	168	WaterBase+Helcom	41 000 – 20 000 000
Latvia	123	89	WaterBase+Helcom	30 000 - 48 726 571
Lithuania	75	75	WaterBase+Helcom	200 - 41 190 000
Russia	28	27	Helcom	26 700 - 376 877 000
Sweden	421	399	WaterBase+Helcom+Swedish database	16 900 - 133 010 000
Poland	1 667	1 581	WaterBase+Helcom	600 - 67 910 075
Total	**3 040**	**2 851**		

[5] Inflow [m^3/yr] only reported to Helcome for 16 largest WWTP

Obviously, some countries report very detailed while other only report main WWTPs. Many of the WWTPs included in the databases were not considered in this work as necessary basic data were not available, they have been closed down or their receiving wastewater diverted to other WWTPs.

In addition, data quality differs significantly from state to state with some countries not providing any data on water flows [m^3/year] or total load [PE]. As the WWTP inflow of wastewater, however, is an important parameter for the calculation of MP discharge, water flows were estimated for WWTPs without such data reported. The estimation of flow was based on an average discharge of 100 m^3 per personal equivalent and year which is derived from Swedish average flows to WWTPs (Baresel *et al.,* 2017) and data on German WWTP inflow (StatA M-V, 2013).

Reported data on WWTPs treatment configuration, important for calculating the MP-removal efficiency of each WWTP was also derived from existing databases (mainly WaterBase). Even so, data was provided for all WWTPs a different understanding of the treatment technologies might imply data uncertainty. The option to report both secondary-and tertiary treatment, nitrogen and phosphorous removal at the same time does not support a clear technology definition. Sand filtration, for example, is considered as natural part of phosphorus removal or tertiary treatment by some WWTPs, while it is not for others.

The MICROPOLL survey aimed at collecting available data on SSO in the Baltic Sea countries resulted in few additional data, which visualizes the main problem of reporting such events. Reported data was often inconsistent and the project team therefore decided to use statistics and modelled data from Sweden (Länsstyrelsen Gävleborg, 2009; Sjörs, Å.B., 2014), which was judged the best data available. However, even this data is based on few reported and verified measurements and the actual amount of untreated wastewater released to the Baltic Sea by SSO may be much higher or much lower in case other countries actually having a better infrastructure avoiding SSO.

Quantification of MP discharge from WWTP to the Baltic Sea

The quantification of MP-discharge from WWTPs to the Baltic Sea is based on the reported inflow to WWTPs and the specific treatment available at each specific facility. As measurements of MP-concentrations in the inflow to WWTPs only exists for a few WWTPs in the region of interest, those measurements have been used to define a realistic range of MP-concentrations in the WWTPs inflow (see Table 2). As most data is available for MP ≥ 20 µm particles smaller than 20 µm are not included in the following calculations. A WWTP-specific adjustment of MP-concentrations based on reported BOD-loads was not performed, as MP-concentrations generally do not follow traditional pollutant indications such as BOD, Total nitrogen (TN) or Total phosphorous (TP).

Table 2. MP-concentrations in WWTPs inflow (for MP > 20 µm].

MP concentration [> 20 µm particle/m^3]	Value	Reference
min	27 000	*Magnusson and Wahlberg 2014 (only including synthetic particles)* Prata 2018
average	250 000	*Magnusson et al., 2016a; Talvitie et al 2017;* Prata 2018
max	900 000	*Talvitie et al., 2017;* Prata 2018

As available studies on MP in WWTPs generally do not report weight of MP, a calculation based on Magnusson *et al.* (2016a) was done to derive an average weight of an MP-particle of 2.2 µg for MP > 20 µm. This rough approximation allows for calculation of discharges MP-weight. However, derived figures must be handles with care as MPs consist of many different plastics and depending on actual sources the composition in the wastewater can vary significantly between WWTPs.

In order to assess the individual MP-removal efficiency of each WWTP, reported data on related studies on treatment efficiency for MP using different technologies (e.g. Magnusson *et al.,* 2014; Prata 2018; Talvitie *et al.,* 2016, 2017) has been used in combination with data on incoming load to estimate MP discharge to the Baltic Sea from WWTP. Reported treatment technologies and defined removal efficiencies are provided in Table 3.

Table 3. WWTP treatment techniques and average MP removal efficiency [%].

Treatment technique	Removal efficiency [%]	Reference
Primary treatment	85	*Ziajahromi et al., 2016; Talvitie et al., 2016; grid (>5 mm) & sedimentation*
Secondary treatment	90	*Ziajahromi et al., 2016; Talvitie et al., 2016; grid (>5 mm) & sedimentation*
Tertiary treatment	95	*Ziajahromi et al., 2016; Magnusson and Wahlberg 2014; only post-clarifier, no extra polishing*
Sand filter	97	*Magnusson et al., 2016a; Magnusson and Wahlberg 2014; Talvitie et al., 2017*
Microfiltration	98	*Talvitie et al., 2016; Magnusson and Wahlberg 2014; e.g.discfilter (> 10 µm)*

Estimation of sanitary sewer overflow as a source for MP to the Baltic Sea

The total SSO volume from wastewater sewers in the Baltic countries and the associated total MP load on the sea from this pathway has been estimated based on mainly Swedish SSO statistics while this statistics has been defectively available in the other Baltic sea countries. Efforts made to gather this specific data in the various countries were without success. Detailed studies in e.g. Germany revealed that SSO in general is not a focus area and measurements or quantifications are almost completely absent. This is in spite of the fact that all contacted WWTPs and organisations have identified SSO as one important source of contaminant discharge to recipients, not only for MP.

When considering SSO three different kinds of overflows are considered.

1. **Technical SSO**
   Sewer overflows caused by technical failures of pump stations or other sewer installations. This kind of SSO is also common during reconstruction of sewer infrastructure. Technical SSO occur at no specific flow conditions such as the other two types of SSO.
2. **Storm event SSO**
   These events may be characterised as real SSO as they appear in the sewer network or at WWTPs when the hydraulic capacity of the sewer/WWTP is exceeded which is the case e.g. at heavy rainfall or snowmelt. Untreated wastewater is then discharged directly to the recipient.

While concentrations of traditional sewage pollutants such as BOD, TN and TP decrease due to dilution of wastewater during these events, this is not necessarily the case for MP as one of the main source of MP is storm water.

3. **SSO treatment at WWTPs**
   This last category comprises overflows due to a hydraulic capacity limitation of the WWTP but where the discharged water at least undergoes a partial treatment. As this treatment often targets particulate phosphorous, a good removal effect is also achieved on MP.

It is important to point out that even the used Swedish data (Länsstyrelsen Gävleborg, 2009; Sjörs, Å.B., 2014) is not complete and reporting is limited by understanding of various SSO events. Technical SSO are for example often reported as normal SSO events. Overflow at WWTPs are often not characterised regarding if a treatment is applied or not. The used fractions for the various SSO-categories (see Table 4) are an approximation based on few reported data.

Table 4. Characteristics of different types of SSO.

SSO	Fraction of total WWTP Inflow [%]	MP concentration factor
Technical SSO	0.40	1
Storm event SSO	1.50	5.5
SSO treatment at WWTP	0.40	5.5

Table 4 further indicates that MP-concentrations at storm water events may be significantly higher than during normal flow conditions. There is rare data on this kind of measurements as sampling is challenging. However, Magnusson *et al.* (2016b) indicated significant higher MP-concentrations during storm water events in their measurements campaign. As scenario analyses show, this concentration factor has a significant impact on the overall discharge calculation and results are therefore provide for the reported factor as shown in Table 4 and if no increased concentration is assumed. More measurements, as planned in the MICROPOLL project, will provide a better understanding.

Result

MP discharge from WWTP to the Baltic Sea

For the calculation of MP discharge from WWTPs to the Baltic Sea, more than 2 800 WWTPs in the Baltic Sea catchment have been considered (Table 1). Which treatment that is used at these WWTPs was reported for all WWTPs. Except for some few smaller WWTPs especially in Russia (including Kaliningrad), all WWTPs considered have at least a secondary treatment installed. Only in a number of Russian facilities only primary treatment or no treatment at all was reported. Facilities without any treatment were considered as pumping stations only; with no effect on MP-removal. About 1 650 WWTPs have an extended treatment with phosphorous removal. 72 WWTPs have sand filtration as final polishing step but only 14 WWTP use microfiltration (MF) to treat their wastewater. Considering the total annual amount treated wastewater of about 6 000 Mm^3 per year discharged to the Baltic Sea from these WWTPs, and accounting for each treatment facilities' MP-removal efficiency, total MP discharge to the Baltic Sea is calculated and presented in Table 5.

Table 5. MP discharge >20µm from WWTP to the Baltic Sea not including SSO events.

	[Million particle/yr]	[ton/yr]
min	9 923 627	21.8
average	91 884 163	202.1
max	330 775 733	727.7

An average discharge of about 200 ton/yr to the Baltic Sea via WWTP effluent agrees with calculations by Magnusson *et al.* (2016b) for the total MP-discharge from Swedish WWTPs of < 40 ton/yr.

The average MP-removal efficiency of all considered WWTPs is determined to 94% based on the reported treatment processes used. While most countries have a better removal efficiency, Latvia archives only an average removal efficiency of 86% and Russia (incl. Kaliningrad) 91%, which lowers the total average.

Sanitary sewer overflow as a source for MP to the Baltic Sea

For the calculation of MP discharge from sanitary sewer overflows (SSO) to the Baltic Sea, the same 2 800 WWTPs in the Baltic Sea catchment have been used for calculations. With the factors for the different SSO-categories as presented in Table 4, a total SSO-flow of 24 Mm^3/yr was calculated for technical SSO and SSO after treatment at WWTP. Storm event SSO amount for about 90 Mm^3 per year. Considering no or specific concentration factor for various SSO-categories as presented in Table 4, total MP-discharge as presented in Table 6 are determined.

Table 6. MP discharge to the Baltic Sea from Sanitary Sewer Overflows (SSO).

SSO		MP-concentration factor at SSO (Table 4) [Mill particle/yr]	MP-concentration factor at SSO (Table 4) [ton/yr]	MP- no concentration factor [Mill particle/yr]	MP- no concentration factor [ton/yr]
Technical SSO	min	647 354	1.4	647 354	1.4
	average	5 994 014	13.2	5 994 014	13.2
	max	21 578 451	47.5	21 578 451	47.5
Storm event SSO	min	12 137 879	26.7	2 427 576	5.3
	average	112 387 765	247.3	22 477 553	49.5
	max	404 595 956	890.1	80 919 191	178.0
SSO treatment at WWTP	min	485 515	1.1	97 103	0.2
	average	4 495 511	9.9	899 102	2.0
	max	16 183 838	35.6	3 236 768	7.1

The result clearly indicate the relevance of SSO to the total discharge of MP to the Baltic Sea despite the relatively small share of total water flows. Technical SSO contribute only with minor MP-amounts as extend of these events is limited and assumed to happen mostly under normal flow conditions. This also implies that discharged amounts do not change in the two scenarios shown in Table 6.

SSO events at WWTP where the overflow is partly treated stand for an even lower contribution despite the same flow fraction as technical SSO. This is explained by the assumed relatively good removal efficiency of this partial treatment.

Discussion

Presented results indicate a considerable discharge of MP to the Baltic Sea from WWTPs despite relatively good removal efficiency in existing facilities. Even so, there is room for improvements in some countries, an average removal efficiency of 94% has to be considered as very good and that even so MP has not been a target group in conventional WWTP operation. However, due to the extreme water quantity treated in today's WWTPs, also few MP in the effluent add up to vast numbers; a problem not unknown when handling other contaminants.

Table 7 shows the different contribution of each Baltic Sea country to total wastewater effluent and MP-discharge to the Baltic Sea. It can be seen that while Poland, Russia and Sweden are the countries with the largest wastewater discharge to the Baltic and account for the highest MP-discharges, Latvia, Russia and Poland are the countries that have the highest amount of MP-discharge per discharged wastewater unit. This is explained by the poorer MP-removal efficiency in the counties as indicated in Table 7.

Table 7. Estimated contribution of Baltic Sea countries to total MP-discharge.

Country	WWTP flow [m^3]	% of total contribution Flow	MP discharge share	MP-removal efficiency [%]
Denmark	637 593 800	11%	9%	95%
Estonia	110 619 659	2%	2%	95%
Finland	634 930 000	11%	9%	95%
Germany	179 676 039	3%	2%	96%
Latvia	95 438 171	2%	4%	86%
Lithuania	145 872 271	2%	2%	95%
Russia	732 829 996	12%	17%	91%
Sweden	1 081 266 221	18%	12%	96%
Poland	2 375 839 000	40%	44%	93%
Total	**5 994 065 157**	**100%**	**100%**	**0.94%**

SSO is a category often neglected in conventional wastewater handling, as pollutant concentrations normally are much lower due to dilution with storm water. For MP, however, this does not have to be the case. Table 8 shows total contribution of the different SSO categories and WWTPs to the total MP-discharge to the Baltic Sea. Considering an increase of MP-concentrations in wastewater at SSO events as reported by Magnusson *et al.* (2016b; Table 4); storm event SSO contribute substantially to total MP-discharge, here with more than 50%. Even if no changed concentration is considered, real SSO events account almost for 1/5 of the total MP-discharge to the Baltic Sea.

Table 8. MP discharge distribution for different sources.

MP source	Share of total MP-discharge: MP - Concentration at SSO (Table 4)	MP – No changed concentration assumed
WWTP effluent	42.8 %	75.8 %
Technical SSO	2.8 %	4.9 %
Storm event SSO	52.3 %	18.5 %
SSO treatment at WWTP	2.1 %	0.7 %

As the presented calculation are based on few data and reported date for WWTPs that may include errors, conclusion drawn from this must be handled with care! Total discharged might as well been overestimated as underestimated. Nevertheless, the importance of SSO has been clearly shown.

These results also indicate that storm water discharge directly to the water environment is a highly important transport route for microplastics from the urban environment that needs to be addressed.

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