Micropollutants in urban wastewater

Critical Review of the Impact Assessment accompanying the EU Urban Wastewater Treatment Directive (UWWTD)

Summary Report

April 2023

RAMBØLL

Bright ideas.
Sustainable change.

Ramboll Deutschland GmbH
Jürgen-Töpfer-Straße 48
22763 Hamburg
Germany

District Court Hamburg, HRB 168273
Managing Directors:
Stefan Wallmann, Hannes Reuter

BNP Paribas S.A. Branch Germany
IBAN: DE40512106004223034010
BIC: BNPADEFFXXX

ENVIRONMENT
& HEALTH

Micropollutants in Urban Wastewater

Critical review of the Impact Assessment accompanying the proposed recast of the EU Urban Wastewater Treatment Directive (UWWTD)

Project no.	**352004642**
Recipient	**Bundesverband der Arzneimittel-Hersteller e.V., Bundesverband der Pharmazeutischen Industrie e.V., Pro Generika e.V. and Verband forschender Arzneimittelhersteller e.V.**
Document type	**Summary Report**
Version	**Final**
Date	**20.04.2023**
Prepared by	**Anna Allberg, Anna Bylund, Nataliya Kitsera, Tilman Euler**
Checked by	**Nicklas Gustavsson**
Approved by	**Dr. Rudolf Wilden**

Content

Appendices

Appendix 1

Document List

Appendix 2

Document Review list incl. Guiding Questions

Executive Summary

OBJECTIVES

Ramboll Deutschland GmbH (Ramboll) was commissioned by Bundesverband der Arzneimittel-Hersteller e.V., Bundesverband der Pharmazeutischen Industrie e.V., Pro Generika e.V. and Verband forschender Arzneimittelhersteller e.V. to assess the data quality and assumptions in the Impact Assessment (IA) report by the European Commission, dated 26 October 2022, on which the planned recast of the EU Urban Wastewater Treatment Directive (UWWTD) is based. The IA report concluded that substances from pharmaceuticals account for the majority of micropollutants entering wastewater treatment plants, i.e. accounting for 59% of the input load and 66% of the total toxic PNEC load.

Ramboll reviewed the IA report including the main sources cited therein. Ramboll furthermore conducted an independent literature search and reviewed relevant studies and publications regarding micropollutants in urban wastewater.

KEY FINDINGS

- Wastewater comprises a complex mix of micropollutants such as active pharma & biocidal ingredients, artificial food sweeteners, and industrial chemicals such as PFAS, plasticizers and residual microplastics.
- The literature search conducted by Ramboll identified a significant number of additional studies which have not been considered in the IA report. Excluding new studies which have been published after the IA report had been drafted, still 22 relevant studies were identified which are not considered in the IA report.
- The IA report focusses on studies conducted on pharmaceutical micropollutants whereas consideration of the additional studies would have balanced the picture as these also focus on other micropollutants such as biocides, PFAS, microplastics or plastic additives, nanoparticles, metals or metalloids, detergents and cleaning products, or other household and industrial chemicals.
- The composition of urban wastewater reflects our current way of living as well as patient/customer choice, and the concentration of micropollutants varies significantly. Studies identified in the literature search conducted by Ramboll revealed much wider concentration ranges of micropollutants than what is described in the IA report. For example, a recent

peer review study[1] shows that micropollutants from pharmaceutical sources account for only 10% of the total micropollutant load. This emphasizes the importance of applying holistic sampling approaches to address the entirety of micropollutant load.

- When comparing the number of existing studies considering pharmaceuticals with the total number of studies on micropollutants, it appears that pharmaceuticals are the best studied group of micropollutants. This may lead to an unrepresentative focus on pharma micropollutants.
- The approach of the IA to calculate the micropollutant load is not transparent. The main micropollutant load percentages are taken from the report "Feasibility of an EPR system for micro-pollutant" (EPR[2] feasibility report) which does not have a clear description on how the data is calculated. Additionally, data partially stems from non-peer-reviewed and non-publicly available data sources.
- According to the EPR feasibility report the amount of certain analgesics sold in the EU is anticipated to continue to decrease in the future, as it has over the past decade, which will have an impact on the overall load of pharma micropollutants.

CONCLUSION

Overall, Ramboll found the IA report lacking in transparency in terms of how the share of the different sectors contributing to micropollutants was calculated. Additional studies identified by Ramboll show micropollutant concentrations related to the pharma industry in significantly smaller ratios than the data used in the IA report. Pharmaceuticals represent the best-studied group of micropollutants which may give them an unrepresentatively large share in the allocation of pollutant loads.

[1] Masoner et al., 2023, Contaminant Exposure and Transport from Three Potential Reuse Waters within a Single Watershed, Environmental Science & Technology 2023 57 (3), 1353-1365, DOI: 10.1021/acs.est.2c07372

[2] EPR: Extended Producer Responsibility

1. Introduction

1.1 Background

The chemical composition of river water varies considerably from the river source to the estuary. The pollution load of rivers and other water bodies depends mainly on substance inputs from their surroundings. Surface runoff from agricultural land, roads and cities, stormwater overflow from sewage treatment plants, and discharges of treated wastewater all have a significant influence. Trace substances, such as pesticides, pharmaceuticals, PFAS, or microplastics, play an increasingly important role in the public discourse.

The European Union's (EU) Urban Wastewater Treatment Directive (UWWTD) was introduced in 1991 and forms the legal basis on requirements for the collection, treatment and discharge of urban wastewater in the EU. While the positive impact on water quality since the introduction of the UWWTD is undisputed, micropollutants, among others, have been overlooked. However, the issue of micropollutants has grown considerably in recent years and has become a debated topic. The revision of the UWWTD proposed by the EU in 2022 is intended to close this gap.

1.2 Purpose and Objectives

Ramboll Deutschland GmbH (Ramboll) was commissioned by Bundesverband der Arzneimittel-Hersteller e.V., Bundesverband der Pharmazeutischen Industrie e.V., Pro Generika e.V. and Verband forschender Arzneimittelhersteller e.V. (the "Client") to provide scientific, technical, regulatory and strategic consulting services in the field of data collection and assessment concerning so-called micropollutants (MP) in wastewater in the course of the planned recast of the EU UWWTD. According to the associated Impact Assessment (IA), pharmaceuticals and personal care products are said to be responsible for a total of 92% of harmful micropollutants. Since pharmaceuticals for human use are said to be responsible for a total of 66% of harmful micropollutants, their manufacturers would have to make a substantial contribution to the construction and operation of the 4th treatment stage in all EU member states.

Ramboll conducted a literature search on the topic, and reviewed the IA and its main sources. The purpose of this data review was to assess the data quality and assumptions in the IA report and identify possible data gaps that could be relevant to the Client.

1.3 Limitations

Ramboll has relied on publicly available information and information provided by the Client and has made use of its own experience.

Due to the large amount of existing data and studies, Ramboll focused on studies from the last 5 years. Publicly available sources were selected according to Ramboll's own criteria and personal judgement.

2. Literature search

2.1 Methodology

Ramboll conducted a literature search using the following databases:

- PubMed, by the National Library of Medicine by the U.S. Department of Health and Human Services (HHS),
- Europe PubMed Central (Europe PMC) by the European Molecular Biology Laboratory-European Bioinformatics Institute, and
- Google Scholar.

The following search term was used:

("Micropollutant" OR "Micro-pollutant*") AND ("Urban Wastewater" OR "Domestic Wastewater" OR "Sewage Wastewater")*

Table 2-1: Number of hits for the defined search term per database

	PubMed	Europe PMC	Google Scholar
Total hits	112	78	6,390
Hits for articles published since 2018	66	55	4,320

The publications chosen for the review task were selected based on their title. The list of reviewed articles can be viewed in Appendix 1. As shown in Table 2-1 above, the search with Google Scholar resulted in thousands of hits. During the screening of the first hits, only a few were found relevant, all of which were duplicates to hits found in the other databases. Thus, the rest of the Google hits were disregarded.

Generally, there was a large overlap between the search hits identified in the databases PubMed and Europe PMC and most of the articles focused on different treatment technologies which were considered irrelevant for the review.

In total, 37 articles were reviewed and identified as key studies. Out of these, five articles are main reports used for the Impact Assessment.

2.2 Review

Ramboll reviewed all key studies, i.e. relevant database hits as well as five main reports of the *Impact Assessment,* considering the following key questions:

- Which micropollutants are considered?
- Is there an indication of quantity ratios (total share of micropollutants, subgroups of micropollutants, specific substances)?
- Which sources of the micropollutants are mentioned?
- Is there an indication on the toxicity/hazard of the micropollutants?
- What is the source of the data (e.g. measurements, other studies)?
- Uncertainties / validity of the data
- Other relevant information and comments

Detailed documentation of the review can be found in Appendix 2.

3. Results & Discussion

3.1 Literature Search

Wastewater comprises a complex mixture of pollutants in varying concentrations corresponding to the way of living of our societies. Pollutants occurring in (waste)water in concentrations below mg/L and having the potential to harm human health or the environment are called micropollutants (Fuchte et al. 2022, Bio Innovation Service 2022). Conventional WWTPs typically include mechanical, biological and chemical treatment steps but are not designed for the removal of micropollutants (German Environmental Agency, 2018).

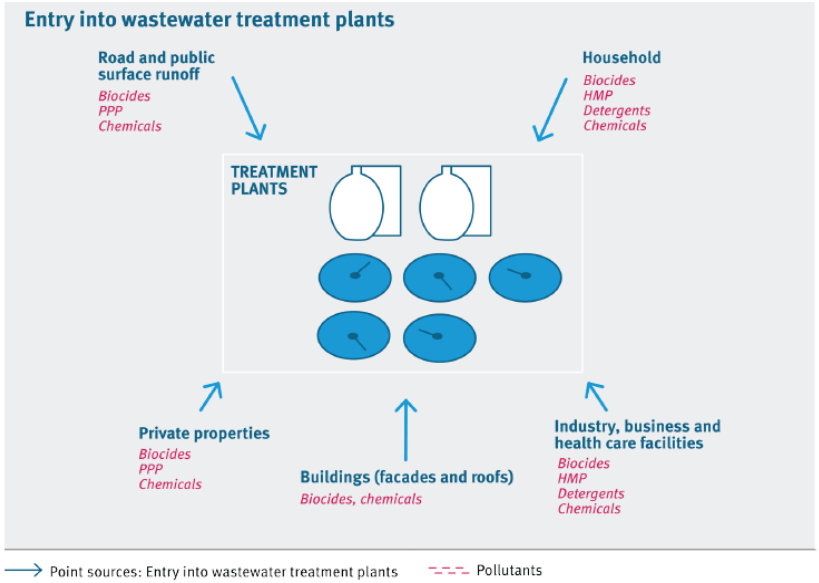

Figure 3-1: The fate of micropollutants into wastewater treatment plants (Source: German Environmental Agency, 2018).

Figure 3-1 shows important groups of micropollutants ending up in wastewater treatment plants (WWTPs) and their main point sources.

Most studies cluster micropollutants per product sector, such as pharmaceuticals (e.g. painkillers, antibiotics, hormones), personal care or cosmetic products (e.g. fragrances, cosmetics, sunscreens), pesticides and herbicides, industrial chemicals (e.g. flame retardants, plasticizer, surfactants), and poly- and perfluoroalkyl substances (PFAS). Figure 3-2 pictures how many of the reviewed reports considered each sector. Many reports discuss more than one sector.

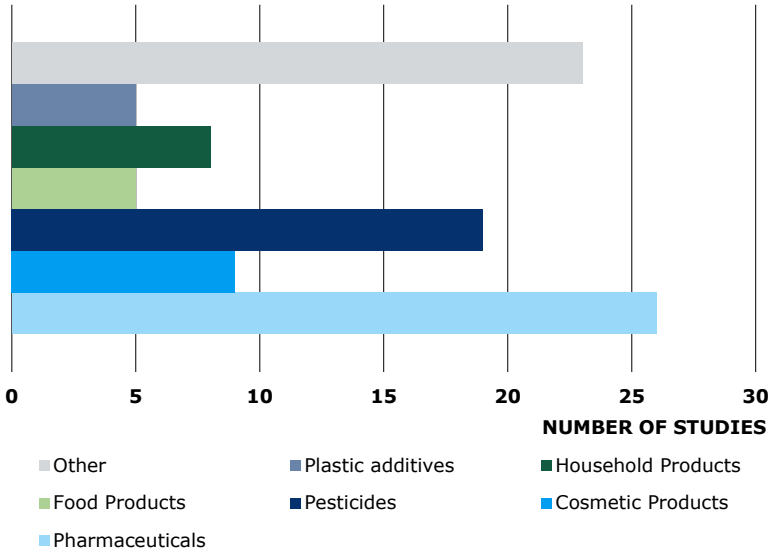

Figure 3-2: Sectors considered in the reviewed studies and number of reviewed studies per sector

Based on the screened hitlists and the reviewed studies, it seems that, in contrast to pharmaceuticals, many micropollutants have

scarcely been investigated. A keyword search in the abstracts of the PubMed Hitlist underlines this assumption, as shown in Table 3-1.

Table 3-1: Keyword search in PubMed Hitlist

keyword	hits *(one hit per substance and title out of 66 titles in total)*
pharmaceuticals	36
pesticides	8
disinfection	9
sweetener	2
plastic	2

Furthermore, the reviewed reports indicate that the pollutant loads in wastewater vary greatly, and study focus is essential for what is considered important. Below are some key information points Ramboll wants to highlight as they might be relevant for the Client:

- Masoner et al. (2022) describe in a recent study from the US, that **disinfection byproducts** accounted for 73 % of the total organic chemical concentration [3] whereas pharmaceuticals only accounted for 10 %.
- A study by the Danish Environmental Protection Agency (2014) showed that **biocides** used in cosmetics or leaching from construction materials, such as building facades and roofs are an important emission source in urban runoff which also ends up in WWTPs.
- Per- and polyfluoroalkyl substances (**PFAS**) are commonly found in wastewater. PFAS are proposed to be restricted.
- Hardly biodegradable **artificial sweeteners** are found in wastewater, surface water, groundwater and drinking water systems.
- Micropollutants in wastewater stem from **essential uses** (e.g. pharma) but equally **non-essential uses** (e.g. personal care products).

3.2 Data Sources used by the regulators

Ramboll reviewed the literature references of the Impact Assessment (Annex 10 of the IA). 22 main reports were used for the IA, five of which explicitly address one type of micropollutant, i.e. antibiotics, microplastics, mercury and nutrients. The main reports of the IA considered relevant for this assessment are listed in Table 3-2. All listed reports were reviewed by Ramboll following the same methodology as for the reports found within the literature search.

Table 3-2: Main source reports of the Impact Assessment accompanying the EUWWTD which have been considered in the review

#	authors	year	title	comment
1	Wood	2021	Study to support the Impact Assessment of the UWWTD	*not publicly available*

[3] The samples were analysed for concentrations of 643 organic chemicals, incl. 242 pesticides, 107 pharmaceuticals, 53 household/industrial chemicals, 46 hormones, 34 PFAS, 33 antibiotics, 22 disinfection byproducts and nonvolatile dissolved organic carbon.

#	authors	year	title	comment
2	Bio Innovation Service	2021	Feasibility of an EPR system for micro-pollutants	MP EPR
8	Obermaier, Pistocchi	2022	Plastics in European Wastewater Treatment Plants. Frontiers in Environmental Science, Sec. Water and Wastewater Management	microplastics
11	Manaia	2022	Framework for establishing regulatory guidelines to control antibiotic resistance in treated effluents, Critical Reviews in Environmental Science and Technology	antibiotics
12	Pistocchi et al.	2022	Screening of mercury pollution sources to European inland waters using high resolution earth surface data. Frontiers of Environmental Science	mercury (Hg)
14	Pistocchi et al.	2022	Treatment of micropollutants in wastewater: Balancing effectiveness, costs and implications, Science of The Total Environment, Volume 850, 2022, 157593, ISSN 0048-9697	MP treatment
15	Pistocchi et al.	2022	An assessment of options to improve the removal of excess nutrients from European wastewater	*not publicly available;* nutrients
16	Psomas	2021	Support studies on specific aspects of wastewater management: Individual or other Appropriate Systems (IAS). Brilliants Solutions Engineering & Consulting (BRiS)	*not publicly available - unable to find this source*

Three of the main reports were not publicly available at the time of Ramboll's Review (January 2023)[4]. Seven of the 22 main sources have been prepared with the collaboration of one single author (i.e. A. Pistocchi).

3.3 Data Gaps

The IA gives an overview on the contribution of each product sector for concentration and toxic loads of organic substances. These shares form the basis for financial contribution for the construction and operation of the fourth treatment stages which will be required after implementation of the EU UWWTD.

According to the feasibility report (Bio Innovation Service 2022), European Commission's Joint Research Centre (JRC) developed a "general chemical landscape of European waste water" from which the sectors were selected. Data on the input load and toxicity of the pharmaceutical substances are taken from a study conducted in Germany (Czichy, Oehlmann and Schitthelm, 2020) in which water tests were conducted for 151 trace substances. The detected substances were prioritized based on their harmfulness which was calculated by dividing the sum load with the environmental quality standard (EQS):

[4] WOOD (2021); Pistocchi et al. (2022); Psomas (2021)

$$\frac{1}{EQS} \times sum\ (mass)\ load = sum\ pollution\ units$$

The study revealed that five out of the top ten detected substances are Active Pharmaceutical Ingredients (API), see Table 3-3.

Table 3-3: Primary use of source of the top ten trace substances in North Rhine-Westfalia, Germany (Czichy, Oehlmann, Schitthelm, 2020)

#	Trace substance	Relative harmfulness	Primary use or source of the trace substance
1	Ibuprofen	30.24%	Pharmaceutical active ingredient
2	Perfluorooctanoic acid + derivatives (PFOS)	28.57%	e. g. impregnating products, fire extinguishing agents, electroplating
3	Diclofenac	22.42%	Pharmaceutical active ingredient
4	17ß-estradiol	5.92%	Pharmaceutical active ingredient
5	Imidacloprid	2.23%	Pesticides (insecticides)
6	Triclosan	1.60%	Antiseptic (e.g. disinfectant, cosmetic)
7	Carbamazepine	1.40%	Pharmaceutical active ingredient
8	Clarithromycin	1.25%	Pharmaceutical active ingredient
9	Selenium	0.96%	e. g. nutritional supplements, semiconductor
10	Flufenacet	0.56%	Pesticides (insecticides)
	Subtotal	95.16%	

Bio Innovation Service took amounts sold in 2019 of these five substances from the Danish Medstat database and extrapolated these data to the 27 EU member states based on population numbers and country-specific numbers for pharmaceutical consumption and sales. Where country-specific data was available, these data superseded the extrapolated data. In a next step, these numbers were used to calculate the mass being excreted, factoring in a share of 23% being unused and thus, disposed of and an excretion rate of 100%.

Table 3-4: Masses of APIs and metabolites excreted to wastewater in the EU (Bio Innovation Service 2022)

API	Mass sold in EU-27 (kg)	Rate of use (%)	Rate of non-use (%)	Mass unused 2019 (kg)	Mass excreted to waste water 2019 (kg)	Mass excreted to waste water 2035 (kg)	Mass excreted to waste water 2050 (kg)
Ibuprofen (as parent compound)	4,601,906	77	23	1,067,452	3,534,454	2,654,478	1,618,307
Diclofenac (as parent compound)	61,698	77	23	14,311	47,387	17,832	7,152
Estradiol (as parent compound)	291	77	23	67	223	156	109
Carbamazepine (as parent compound)	76,647	77	23	17,779	58,868	29,792	15,326
Clarithromycin (as parent compound)	32,883	77	23	7,627	25,255	28,245	29,148

Still, the IA is not transparent on how the contribution per sector is calculated. The shares (see Table 3-5) are taken from the report "Feasibility of an EPR system for micro-pollutant" which also lacks a clear description on how the data is calculated.

Table 3-5: Contribution of the sectors to concentration and toxic loads of organic substances (Bio Innovation Service 2022).

Sector	% of input load to WWTP	% of input load to fourth treatment	%of total hazardous load (chronic)	% of total hazardous load (PNEC)
Pharma	59%	63%[113]	48%	66%
Cosmetic products	14%	9%	17%	26%
Pesticide	7%	8%	0%	2%
Household product	0%	0%	0%	0%
Food product	7%	4%	5%	1%
Plastic additive	4%	4%	28%	3%
Tobacco	0%	0%	0%	0%
Other	6%	6%	1%	0%
Uncategorized	3%	5%	0%	1%
Total	100%	100%	100%	100%

3.4 Extended Producer Responsibility (EPR)

The recast proposes that the manufacturers of the most toxic micropollutants shall form an EPR-fund. Costs are only being

charged for organic substances which need to be additionally treated with a fourth treatment stage, i.e. which do not biodegrade and mineralise during the conventional three treatment steps of a WWTP. Based on the calculated shares of the different sectors (see Table 3-5), the Impact Assessment proposes that the manufacturers of pharmaceuticals and those of personal care products, form the EPR fund. This would mean that these sectors alone would have to bear the costs of building and operating a fourth treatment stage in the envisaged wastewater treatment plants while all other sectors are exempted due to their comparatively low contribution.

Bio Innovation Service (2022) states that other sectors "could be asked to participate in a second stage, either in proportion to their contribution to the load or via a flat fee".

This could be important as the shares of the sectors´contributions to micropollution are likely to change, considering the projected sales to 2050 of the top five APIs being currently detected in wastewater, i.e. Ibuprofen, Diclofenac, Estradiol, Carbamazepine, and Clarithromycin. According to Bio Innovation Service 2022, the sold amounts of Ibuprofen and Estradiol are projected to be reduced in the EU by more than 50%, Carbamazepine by 74% and Diclofenac by 85% until 2050 compared to 2019. Solely for Clarithromycin the mass sold are estimated to slightly increase (by approx. 15%), see Table 3-4.

4. Conclusion

Overall, Ramboll found the Impact Assessment (IA) to be consistent with other studies with regards to main sectors contributing to micropollutants. The IA indicates that the input load and toxicity of micropollutants to wastewater treatment plants mainly stems from pharmaceuticals. This fits the general picture of the studies and reports reviewed by Ramboll. However, no concrete quantity statements were found to support the figures mentioned in the IA. In general, data on the quantities of micropollutants vary widely. This is in line with Ramboll's understanding that the pollutant load depends on many factors, such as location (population density, population habits, industrial, agricultural, or commercial use, traffic) or weather conditions. A uniform wastewater matrix for the whole of Europe as assumed in the IA is therefore not realistic.

The IA is not transparent on how the shares of the different sectors was calculated. Considering that these figures are decisive for the cost allocation of the expansion of all major wastewater treatment plants located in the European Union, the underlying calculation on the pollutant shares is insufficiently explained.

Furthermore, it does not seem to be farsighted to exempt other polluter and to focus only on the two main sectors. The data situation for most micropollutants is rather poor and the calculation for the comparably well studied pharmaceuticals is based on only five active pharmaceutical ingredients (APIs). Sales, and thus excretion into wastewater, of the four APIs that might contribute most in terms of volume, are projected to decline substantially by 2050. This will cause a complete change of the contribution per sectors and therefore change the basis for the entire financing concept which is currently foreseen by the European Commission.

In summary, the literature search confirmed many assumptions of the Impact Assessment but also revealed uncertainties in the underlying data. It is unquestionable that APIs contribute with a relevant share to micropollution, but it is questionable if their role is as distinctive as stated in the IA. This is especially relevant considering that the number of studies on APIs greatly exceeds that of any other group of micropollutants, including PFAS and biocides.

Appendices

APPENDIX 1
DOCUMENT LIST

Document List

List of key documents reviewed, including studies/publications/papers describing type/number/concentration/sources of micropollutants in urban wastewater.

Included documents listed as main report in the Impact Assessment: 9

No	Titel	Author	Date	Key word/message	source of IA?
1	Impact Assessment (Accompanying the document: "Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast)")	European Commission (WOOD)	26.10.2022	- Pharmaceuticals represent the majority of toxic micro-pollutant being discharged by the WWTPs: - remaining load of 264 millio p.e. on micropollutants sent to environment; - pharmaceuticals represent 59% of input quantities to wwtps; 48% toxic chronic load; and 66% of the total toxic load PNEC - a reduction of 50% of micro-pollutants is technically feasible - WWTPs need to be upgraded, costs are proposed to be allocated to the responsible producers (EPR)	main
2	Guideline for advanced API removal	Berlin Centre of Competence for Water, Aarhus University, German Environment Agency	December 2020	- An overview on how to plan start and operate advanced wastewater tretment Techniques for API elimination - Techniques; ozonation and activated carbon	
3	An alternative approach to risk rank chemicals on the threat they pose to the aquatic environment	Johnson et al.	17.05.2017	- A risk ranking study describing an alternative approach to rank chemicals. Focus on aquatic systems and exposure. - 71 different chemicals analaysed based on median environmental concentrations or and on median vs percentile of all ecotoxicity data. Chemical measurments from UK rivers. - The relative risk was highest for the metals copper, aluminium and zinc - Ethinylestradiol (hormone/pharma), linear alkylbenzene sulfonate (detergent/houshold chemical/personal care product) and triclosan (Personal Care Product) were in the top ten of posing a risk to the aquatic enivronment	general
4	Feasibility of an EPR system for micro-pollutants	Bio Innovation Service (European Commission)	04.03.2022	- pharmaceuticals represent the majority of toxic micro-pollutants (ibuprofen, diclofenac, 17β-estradiol, carbamazepine and clarithromycin) - calculation of masses of APIs excreted to ww page 41 (table 8) - pharmaceuticals represent 59% of input quantities to wwtps; 48% toxic chronic load; and 66% of the total toxic load PNEC	main
5	Screening-Level Estimates of Environmental Release Rates, Predicted Exposures, and Toxic Pressures of Currently Used Chemicals	Meent, Dik van de et al.	15.06.2020	Micropollutant are not mentioned, but emission estimations and toxic pressures for a typical European water body at steady state were predicted by using modelling for •REACH substances •Pharmaceuticals. •Pesticide For pharmaceuticals release fraction was assumed as 12% of the human consumption rate, which is assumed to be released entirely to sewage treatment plants	

6	Computational material flow analysis for thousands of chemicals of emerging concern in European waters	Gils, Jos van et al.	18.04.2020	- Aggregated emissions estimates (tons/year) over the total EU28Plus domain for selected substances (one pesticide, one pharmaceutical, one reach registered organic chemical) -All losses are to wastewater for pharmaceuticals (sulfamethoxazole), which is for the largest part routed to WWTPs -Removal at WWTPs: 11.75 tons/year	
7	Water quality in Europe: effects of the Urban Wastewater Treatment Directive	Pistocchi et al.	2019	•Agriculture and livestock not affected by currect Directive •Chemicals present in urban WW only significantly reduced by WWTPs when molecules either get removed in bioreactors or sorbed to solids treated as sludge •Some chemicals virtually unaffected by conventional WWTPs	
8	Micropollutants in urban wastewater: large-scale emission estimates and analysis of measured concentrations in the Baltic Sea catchment	Undeman E. et al	29 March 2022	- micropollutants from pharmaceuticals & hormones, pesticides, household & personal care products, industrial - compiled published data on substances analysed in effluentes from WWTPs in the Baltic Sea region (1090 substances analysed at 650 WWTPs) - no chemical category displayed concentrations that were consistently higher compared to those of other categories - Data for a specific substance were only available for one or a few countries, giving rise to uncertainty in the ranking of concentrations - Page 5, Fig 2; boxplot of median concentrations of individual substances with total concentration analysed in at least five WWTPs	
9	Micropollutants in European Rivers: A Mode of Action Survey to Support the Development of Effect-Based Tools for Water Monitoring	Busch et al.	08.08.2016	- Micropollutants: Pesticides, pharmaceuticals, biocides, by-products, food constitutents, illicit drugs, industrial chemicals, natural compounds, personal care products - The largest groups of compounds: pesticides (42%), pharmaceuticals & illicit drugs (34%), industrial chemicals (17%) -Possible biological effects: the largest category is the group of neuroactive compounds, mainly comprises pharmaceuticals, pesticides and illicit drugs	

10	Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures	Altenburger et al.	2019	The publication describes generally methods for identification of river basin specific pollutants and ecology directed analysis used within EU-funded SOLUTIONS project (http://www. solutions-project.eu/) .Advanced approaches for water quality monitoring and assessment were proposed.	
11	Pharmaceuticals in the Environment - global occurrences and perspectives	Beek, aus der, et al.	11.12.2015	Study provides a review of measured environmental concentrations for both human and veterinary pharmaceutical substances on a global scale. Pharmaceutical substances were foud: •Surface waters (47% of all database entries) •groundwater and drinking-water (8% of all database entries) •Wastewater (40% of all database entries) Detected pharmaceutical substances are reported with analysis of regional average and maximum concentrations for each UN region as well as on a global range. Source of emission: •Urban wastewater is the dominant emission pathway for pharmaceutical •hospitals (sewage effluent of health-care facilities) •commercial animal husbandry	general
12	Treatment of micropollutants in wastewater: Balancing effectiveness, costs and implications	Pistocchi et al.	19.07.2022	- Analyse scenarios of advanced wastewater treatment for the removal of micropollutans; activated carbon and chemical oxidation with ozone - pharmaceuticals, biocides and pesticides, and other industral chemical	main
13	Pesticides drive risk of micropollutants in wastewater-impacted streams during low flow conditions	Munz et al.	01.03.2017	- Samples were taken in connections to wastewater treatment plants. - Pesticides, pharmaceuticals and household chemicals were identified to have the highest load into the rivers. - The predicted toxic pressure was driven by pesticides. - Five singles substances explained much of the total environmental risk, with diclofenac, diazinon and clothianidin as the main drivers. -19 of the 26 top 5 substances of driving the toxicity are plant protection products.	
14	SIPIBEL observatory: Data on usual pollutants (solids, organic matter, nutrients, ions) and micropollutants (pharmaceuticals, surfactants, metals), biological and ecotoxicity indicators in hospital and urban wastewater, in treated effluent and sludge from wastewater treatment plant, and in surface and groundwater	Bertrand-Krajewski et al.		Brief report of the data collection on u micropollutants (pharmaceuticals, surfactants, metals), biological and ecotoxicity indicators in hospital and urban wastewater, in treated effluent and sludge from wastewater treatment plant, and in surface and groundwater No results are available. Only data collection. Data was used in other publication cited in this breif report.	
15	An assessment of options to improve the removal of excess nutrients from European wastewater.	Pistocchi, A., Grizzetti, B., Nielsen, P.H., Parravicini, V., Steinmetz, H., Thornberg, D., Vigiak, O.	submitted 2022	the study is focussed on nutrients removal solely. *"We quantify the potential to reduce the discharge of excess nutrients with European wastewater, by modelling pollution, greenhouse gas emissions and the costs of measures undequantify the potential to reduce the discharge of excess nutrients with European wastewater, by modelling pollution, greenhouse gas emissions and the costs of measures under various scenarios."*	main

16	A look down the drain: Identification of dissolved and particle bound organic pollutants in urban runoff waters and sediments	Fuchte HE, Beck N, Bieg E, Bayer VJ, Achten C, Krauss M, Schäffer A, Smith KEC.	01.06.2022	Runoff was collected and sampled in five street drains located in a medium sized town in Germany. Urban runoff waters: 187 polar organic micropollutants could be quantified using LC-HRMS: •Traffic derived micropollutants (corrosion inhibitors, rubber additives and the PAHs) •Industrial substances •Pesticides •Pharmaceuticals •Sweeteners	
17	Contaminant Exposure and Transport from Three Potential Reuse Waters within a Single Watershed	Masoner; Jason et al.	10.01.2023	-The surface water from discharge of three reuse water were analysed (wastewater effluent, urban stormwater and agricultural runoff). -140 organic chemicals were detected in the WWTP effluent including: pharmaceuticals, Industrial chemicals, household chemicals, PFAS, PAHs, pesticides, inorganic chemicals (e.g. chloride, nitrogen and bicarbonate), disinfection byproducts.	
18a	Mistra Pharma Annual report 2010	MistraPharma	2010	- Different projects in Sweden to identify and test pharmaceuticals of environmental concern, evaluating different wastewater treatments and ecotoxicological effects caused by pharmaceuticals. - Analysis of the wastewater of four constructed wetlands showed that other substances than pharmaceuticals were responsible for the observed toxicities (e.g. ammonium).	
18b	Mistra Pharma Annual report 2012	MistraPharma	2012	Identification and evaluation of active pharmaceutical ingredients of high concern in wastewater - Samples of wastewater to make mass balances of pharmaceuticals	
18c	Mistra Pharma Annual report 2013	MistraPharma	2013	- The result of water samples taken in the Baltic Sea show that pharmaceuticals are present in detectable concentrations in the Baltic, both at coastal and open sea locations.	
18d	Mistra Pharma Annual report 2014	MistraPharma	2014	- different projects to look at environmental effects posed by active pharmaceutical ingredients - Identification and evaluation of API's, based on the fish plasma model	
19	Identification and reduction of Environmental risks caused by human pharmaceuticals. MistraPharma Research 2008-2015 Final report.	MistraPharma	2015	pharmaceuticals (Active Pharmaceutical Ingredients; APIs) may pass sewage treatment plants (STPs) - Identification and evaluation of API's, based on the fish plasma model G29	
20	Gutachten zur Umsetzbarkeit der vom BDEW in die Diskussion gebrachten Fonds-Lösung zur Finanzierung der Spurenstoff-Elimination in Kläranlagen	IWW; Mocons GmbH & Co. KG	04.11.2021	•Higher urgency of micropollutants due to increasing amount of pharmaceuticals used •Financing of measures per Fonds recommended •Better than "end-of-pipe"-approach indirectly paid by public; is the EPR (fonds)	
21	Recommendations for reducing micropollutants in waters	German Environment Agency	01.04.2018	assessment of reduction measures for micropollutants (existant and possibilities) considering their sources, incl. Implementation possibility based on timeframe and costs Following pollutant were considered: •Radiocontrast agents •pesticides (plant protection products and biocides), •Medicinal products •Chemicals •Detergents, cleaning products and cosmetics Source of micropollutants German surface waters are discussed	

22	Ecotoxicological risk assessment of micropollutants from treated urban wastewater effluents for watercourses at a territorial scale: Application and comparison of two approaches.	Gosset A et al.		- pharmacuticals, personal care products, surfactants, plasticizers, heavy metals, pesticides -it has been demostrated that aquatic organisms exposed to a mixture of pollutants at low doses and individuelly not supposed to induce negative impacts, can lead significantly intoxicated. This joint effects have been for example observed with organism's exposure eo endocrine disruptors, pharmaceuticals, pesticides, or surfactants - research was performed at 33 urban WWTPs of a highly urbanized part of France	
23	Up-to-date monitoring data of wastewater and stormwater quality in Germany	Nickel JP et al	22.07.2021	-Montly sampling of wastewater for a period of 1-1.5 years at 49 different WWTPs in Germany, containing concentration values for 79 substances. - In WWTP effluents, high frequencies of values > LOQ were found for metals (≥68%), the plasticiser DEHP (100%), and the low-molecular-weight PAH fluorene (FL), phenanthrene (PHE), fluoranthene (Fluo), and pyrene (Pyr) (≥80%). For PFAS, biocides, and pesticides, the frequency of values >LOQ varied largely between the individual substances. The priority substances perfluorooctane sulfonic acid (PFOS), terbutryn (TBY), diuron (DIU), and isoproturon (ISO) could be quantified in ≥70% of the samples	
24	Micropollutants in treated wastewater	Rogowska et al.		•□harmaceuticals •s□weeteners •□anoparticles •□ndustrial chemicals (used as corrosion inhibitors, dishwasher detergents, and antifreezes) •□ersonal hygiene and household Lit review	
25	Fund-based solution as an economic instrument for a financing of trace element reduction measures according to the polluter-pays principle	Czichny, C., Oelmann, M., Schitthelm, D.	2020	biggest share of harmful trace substances/micropollutants in WW can be traced back to a small group of industries (primarily pharma and pesticides)	
26	Water driven leaching of biocides from paints and renders - Methods for the improvement of emission scenarios concerning biocides in buildings	The Danish Environmental Protection Agency	2014	Twelve biocides used in building materials were investigated for occurrence in storm water and 5 WWTPs (4 Danish and 1 Swedish). The results showed that some compounds (e.g. mecoprop) follow the storm water input into the combined sewer, while others (carbendazim, terbutryn, tebuconazole, propiconazole) either showed higher concentrations or were only detectable during dry weather periods.The concentration levels during dry weather were similar to the rainy weather samples with concentrations of up to several hundred ng L-1. Only for propiconazole, remarkably high concentrations were detected in one WWTP (Roskilde Bjergmarken) with up to 4.5 µg L-1. The authors deem it likely that it may be inappropriate disposal of pesticide formulation (propiconazole, tebuconazole) or of paint and render into the sewer that lead to biocide occurrence in the wastewater during dry weather. Only for a few compounds the usage as preservatives in personal care products (methylisothiazolinone), and washing off from painted bathroom-walls (octylisothiazolinone) might contribute as dry weather sources.	
27	Cosmetic preservatives: hazardous micropollutants in need of greater attention?	Nowak-Lange et al.	2022	This paper presents a review of the occurrence in different environmental matrices, toxico□ogical effects, and mechanisms of microbial degradation of four selected preservatives (triclocarban, chloroxylenol, methylisothiazolinone, and benzalkonium chloride)	

28	Investigating options for reducing releases in the aquatic environment of micro-plastics emitted by (but not Intentionally added in) products: Final report	EC/Eunomia	2018	- microplastics from automotive tyres, road markings, pre-production plastics, washing of synthetic clothing, building paint, artificial turf, automotive brakes, fishing gear, marine paint	main
29	Plastics in European Wastewater Treatment Plants	Obermaier,N.; Pistocchi, A.	2022		main
30	Framework for establishing regulatory guidelines to control antibiotic resistance in treated effluents	Manaia, C.M.	2022	- Antibiotic resistance bacteria - Antibiotic resistance genes - Advanced treatment	main
31	Screening of mercury pollution sources to European inland waters using high resolution earth surface data	Pistocchi, A., Cinnirella, S., Mouratidis, P., Rosenstock, N., Whalley, C., Sponar, M., Pirrone, N.	2022		main
32	Möglichkeiten einer verursachergerechten Finanzierung von Maßnahmen zur Reduktion von Spurenstoffen	Oelmann, M., Czichy, C.	2019	comprehensive report and baseline for the article "Fund-based solution as an economic instrument for a financing of trace element reduction measures according to the polluter-pays principle"	
33	EU-wide monitoring survey on emerging polar organic contaminants in wastewater treatment plant effluents	Loos, R. et al.	2013	- report based on an analysis of 90 european WWTPs for 156 polar organic chemical contaminants - results showed 125 substances present in ww effluents - most relevant compounds (highest median concentration levels) were artificial sweeteners acesulfame and sucralose, benzotriazoles (corrosion inhibitors), several organophosphate ester flame retardants and plasticizers (e.g. tris(2-chloroisopropyl)phosphate; TCPP), pharmaceutical compounds such as carbamazepine, tramadol, telmisartan, venlafaxine, irbesartan, fluconazole, oxazepam, fexofenadine, diclofenac, citalopram, codeine, bisoprolol, eprosartan, the antibiotics trimethoprim, ciprofloxacine, sulfamethoxazole, and clindamycine, the insect repellent N,N'-diethyltoluamide (DEET), the pesticides MCPA and mecoprop, perfluoroalkyl substances (such as PFOS and PFOA), caffeine, and gadolinium.	
34	IKSR-Empfehlung-Empfehlung zur Reduktion von Mikroverunreinigungen in Gewässern	Internationale Kommissuin zum Schutz des Rheins (IKSR)	2019	Miccropollutants are considered based on there fate into the environment: -public WWTsystems (pharmaceutical residues, x-ray contrast); - agricultur (PSM); - industry (industry chemics)	general

APPENDIX 2

DOCUMENT REVIEW LIST INCL. GUIDING QUESTIONS

No	Titel	Author	Date	Which micropollutants are considered?	Is there an indication of quantity ratios (total share of micropollutants, subgroups of micropollutants, specific substances)?	Which sources of the micropollutants are mentioned?	Is there an indication on the toxicity/hazard of the micropollutants?	What is the source of the data (measurements, other studies which, ...)?	Uncertainties / validity of the data	Other relevant information and comments
1	Impact Assessment (Accompanying the document: "Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast)")	European Commission (WOOD)	26.10.2022	The Impact Assessment distinguish between micro-pollutants and micro-plastics Micro-pollutants •Pharmaceuticals and personal care products (PCP) represent the majority of micro-pollutants inputs and toxicity in wwtp Micro-plastics •Biggest amount in domestic ww comes from textiles, i.e. micro fibres emitted during washing of clothes •Smaller amounts from tyres on the road and uncontrolled use of plastic pellets in plastic production (when rain water is mixed with ww •Expected to be significantly reduced due to new textile strategy and upcoming EU initiative on micro-plastics	• Pharmaceuticals represent 59% of input quantities to wastewater treatment plants (14% for PCPs) • Remaining loads from urban sources: 264 million p.e. micro-pollutants 191 million p.e. Nitrogen 149 million p.e. Phosphorus 71 million p.e. E. coli 66 million p.e. BOD	Many products in households containing micro-pollutants which end up via centralised wwtps in the environment	•Toxic load corresponding to 264 million p.e. is emitted to the environment (158 million p.e. from centralised treatment plants) •Pharmaceuticals represent 48% of the toxic chronic load (17% for PCPs) and 66% of the total toxic load PNEC (26% for PCPs)	other studies - key studies included in the doc. list	•Lack of data on the actual toxicity of micro-pollutants, as well as their removal efficiency by standard techniques •Simplifying assumptions made for modelling, i.e. oChemical mixture of ww is constant across the EU and in time oAssumed concentrations of individual mico-pollutants, on basis of available measurements, are representative	•PCPs and the Pharmaceutical industry will have to set up new 'Producer responsibility' organisations and finance their operations. •These sectors should be financially responsible for the additional costs related to additional treatment needed to treat the pollution they generate (€ 1.186 million/year for all micro-pollutants) •These industries will have the choice to either pass these new costs in the price of their products (max increase of 0.59%) or reduce their profit margins on these products (average maximum impact of 0.7). •Micro-pollutants and pharmaceuticals are nearly used synonymously (p.21); or actually only pharmaceutical studies are mentioned to evidence the occurrence of micro-pollutants
2	Guideline for advanced API removal	Berlin Centre of Competence for Water, Aarhus University, German Environment Agency	December 2020	- Pharmaceuticals	- not applicable	- API	- not applicable	- not applicable		- Looking on how du reduce the load of APIs entering the aquatic environment; ozonation and application of powdered and granular activated carbon - only focus on the technique
3	An alternative approach to risk rank chemicals on the threat they pose to the aquatic environment	Andrew C. Johnson et al.	17.05.2017	•Pharmaceuticals (13) •Nano particles (2 •Metals (12) •Pesticides (23) •Persistent organic pollutants (11) •Surfactants and similar compounds (10)	•Not applicable	•The selection of chemicals was based on the degree of concern that was expressed in the scientific literature and to some degree by their prevalence in water •Pharmaceuticals were selected based on the frequency of reporting in pharmaceutical prioritisation papers •Micropollutants that are present and measured in UK rivers at or after year 2000.	•Some metals such as Cu, Zn and Al, the insecticides Methomyl and Chlorpyrifos as well as Triclosan, linear alkylbenzene sulfonate and ethinylestradiol are ranked to have a high concern and pose a threat to the aquatic environment	•Web of science to identify scientific journals. Scientific literature and grey literature reports to retrieve studies on the effects of a chemical on aquatic organisms and the concentration of a chemical in the UK aquatic environment. Other European measurements were included if the data was very limited and for nanoparticles, modelled values were used. •Risk ranking based on all ecotoxicity data (lethal and sub-lethal) versus only sub-lethal ecotoxicity data	•The study is ranking the potential risk of chemicals, but it is not known if any of the chemicals are harming the wildlife in UK rivers •Not considering mixture effects of chemicals •Some chemicals have low detection limits, consequently the monitoring networks are not fit enough to the report concentrations of these chemicals •Not clear if all chemicals that are analysed have ended up in the river due to wastewater •Other factors can influence the toxicity, e.g., water may not be a relevant route for hydrophobic substances	
4	Feasibility of an EPR system for micro-pollutants	Bio Innovation Service	04.03.2022	- pharmaceuticals - cosmetic products - pesticides - food products - household products - plastic products - other (e.g., illegal drugs, industrial solvents and heavy mentals)	- pharmaceuticals represent 59% of input quantities to wwtps - pharmaceuticals represent the majority of toxic micro-pollutants (ibuprofen, diclofenac, 17β-estradiol, carbamazepine and clarithromycin)	Pharmaceuticals, plant protection products, biocides, cosmetic products, household products, plastic produts, heavy metals, dyes, illegal drugs etc. pharmaceuticals were included because the presence of pharmaceuticals residues is a known environmental problem	Presence of pharmaceutical residues described to be a known environmental problem. Cosmetic products have a high level of persistence. pharmaceuticals: 48% toxic chronic load and 66% of the total toxic load PNEC	Databases and other studies. - tests conducted at waterbodies in north Rhine-Westphalia	One substance can have several CAS numbers that adds complexity to map a substance to a product/sector. Sometimes chemicals were present in several sectors and then they were refered to as their main usage domain. Thus, it does not account for the full amount of that chemical.	
5	Screening-Level Estimates of Environmental Release Rates, Predicted Exposures, and Toxic Pressures of Currently Used Chemicals	Dik van de Meent et al.	15.06.2020	Micropollutant are not mentioned, but emission estimations and toxic pressures for a typical European water body at steady state were predicted by using modelling for •REACH substances •Pharmaceuticals. •Pesticide	For pharmaceuticals release fraction was assumed as 12% of the human consumption rate, which is assumed to be released entirely to sewage treatment plants Median concentration in European Union water is presented for REACH: 1.0E 09 g/L-1 Pharma: 5.0E 12 g/L-1 Pesticide: 4.0E 09 g/L-1 Expected steady state concentrations of chemical substances in a "typical European Union water body are reported for •Organic •Pharma •Pesticides	•REACH: European Union tonnages from registration dossier data •Active ingredients of medicines: Amounts of individual pharmaceuticals sold (public data) •Active ingredients of crop protection products: harvested area approach	The predicted mixture toxic pressure EC50 was estimated as 3.7% in the typical EU water body, with a dominant contribution of the REACH chemicals (which also represented by far the largest relative mass) Expected aquatic toxic pressures (TPs) for pharma is low then for other chemicals.	Modelling		
6	Computational material flow analysis for thousands of chemicals of emerging concern in European waters	Jos van Gils et al.	18.04.2020	- Pharmaceuticals - one group of "REACH registered" substances with multiple use types - plant protection products	- all losses are to wastewater for pharmaceuticals, which is for the largetst part routed to WWTPs	- not applicable	- not applicable	- A computational material flow analysis to predict the occurrence of thousands of man-made organic chemicals on a European scale		
7	Water quality in Europe: effects of the Urban Wastewater Treatment Directive	Alberto Pistocchi et al.	2019	•Chemicals polluting drinking water which may origin from wastewater, including metals, nitrate, household or industrial chemicals in total 54 representative micropollutants (24+8+1+21others) •28 focus substances Anthracene, Brominated diphenylethers, Chloroalkanes C10-13; Dichloromethane, DEHP, Fluoranthene, Hexachlorobenzene, Hexachlorobutadiene, Naphtalene, Octylphenols,Pentachlorobenzene, Tributyltin compounds, Trichlorobenzenes, Trichloromethane, Hexabromocyclododecanes, benzene, Cd, Pb, Hg, Ni, PAHs, PFOs, Nonylphenols, 1,2-Dichloroethane •Medicines: Ibuprofen, Carbamazepine, Ciprofloxacin, Fluoxetine, Sertraline, Atorvastatin, Simvastatin, antibacterial Triclosan •Cosmetics: Octamethylcyclotetrasiloxane (D4)	no	•Study focuses on chemicals associated with ww •Others originated from urban runoff or agriculture are disregarded	•Yes, table with ecotox data on the specific substances	•Different data bases, and modelling results	Modelling of chemical fate extremely complex and uncertain	•So-called metachemicals have been virtually designed to cluster chemicals according to their "treatability" in conventional WWTPs
8	Micropollutants in urban wastewater: large-scale emission estimates and analysis of measured concentrations in the Baltic Sea catchment	Emma Undeman et al	29 March 2022	- pharmaceuticals & hormones - pesticides - household & personal care products - industrial	- no chemical category displayed concentrations that were consistently higher compared to those of other categories	- WWTPs are collecting points for chemicals present in our homes, workplaces, public buildings and industries which eventually end up in the sewers	- the concentration tip-list is populated by a diverse range of substance from different chemical categories	- compiled published data on substances analysed in effluents from WWTPs in the Baltic Sea region - 1090 substances analysed at 650 WWTPs	- In most cases, data for a specific substance were only available for one or a few countries, giving rise to uncertainty in the ranking of concentrations	
9	Micropollutants in European Rivers: A Mode of Action Survey to Support the Development of Effect-Based Tools for Water Monitoring	Wibke Busch et al.	08.08.2016	- pharmaceuticals - pesticides - industrial chemicals	- pesticides (42%) - pharmaceuticals and illicit drugs (34%) - industrial chemicals (17%)		- Possible biological effects: the largest category is the group of neuroactive compounds, mainly comprises pharmaceuticals, pesticides and illicit drugs.			
10	Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures	Altenburger et al.	2019	River basin specifc pollutants: Pesticides Pharmaceuticals Complexing agents Surfactants Polyaromatic compounds	No. The publication describes generally methods for identification of river basin specific pollutants and ecology directed analysis used within EU-funded SOLUTIONS project (http://www. solutions-project.eu/) . Advanced approaches for water quality monitoring and assessment were proposed.	Compounds and products for pesticidal, biocidal, pharmaceutical, industrial and other	Yes	SOLUTIONS project (http://www. solutions-project.eu/)		
11	Pharmaceuticals in the Environment - global occurrences and perspectives	Tim aus der beek et al.	11.12.2015	Pharmaceuticals	Only pharmaceuticals	•Urban wastewater is the dominant emission pathway for pharmaceutical •Hospitals (sewage effluent of health-care facilities) •Commercial animal husbandry	yes, ecotoxicological effects--> however ecotoxicologically derived no-effect concentra-tions have not yet been established	Literature review identified 1016 original publications reporting unique MEC data for human and/or veterinarypharmaceutical substances worldwide and 147 review articles.		
12	Treatment of micropollutants in wastewater: Balancing effectiveness, costs and implications	A. Pistocchi et al.	19.07.2022	- pharmaceuticals - biocides and pesticides - other household and industrial chemicals	- not applicable	- not applicable	- not applicable	- Analyse scenarios of advanced wastewater treatment for the removal of micropollutants; activated carbon and chemical oxidation with ozone		
13	Pesticides drive risk of micropollutants in wastewater-impacted streams during low flow conditions	Nicole A. Munz et al.	01.03.2017	389 organic substances screened for, in which 57 substances were prioritized. Those includes: 28 plant protection products, 3 biocides, 22 pharmaceuticals/personal care products and 2 corrosion inhibitors	Of the micropollutants identified in the streams, pesticides and pharmaceuticals dominated. Substances of highest maximum concentrations were terbutylazine for plant protection products, iopromide and gabapentin for pharmaceuticals. 95 % of the detected substances consisted of equal parts of pesticides and pharmaceuticals.	Pesticides, pharmaceuticals, heavy metals, corrosion inhibitors	The toxicity data for the pharmaceuticals were limited. Nevertheless, the toxicity distribution of the available data shows that the majority of the pharmaceuticals are less toxic compared to the pesticides. Five single substance were the main drivers of toxicity, in which diclofenac, diazinon and clothianidin were the most substantial drivers. 19 of the 26 top 5 substances of driving the toxicity were plant protection products.	Samples were taken upstream, downstream and at the effluent of 24 Swiss wastewater treatment plants		
14	SIPIBEL observatory: Data on usual pollutants (solids, organic matter, nutrients, ions) and micropollutants (pharmaceuticals, surfactants, metals), biological and ecotoxicity indicators in hospital and urban wastewater, in treated effluent and sludge from wastewater treatment plant, and in surface and groundwater	Bertrand-Krajewski et.al.		Micropollutants: 15 pharmaceuticals and 14 transformation products, 9 metals or metalloids, surfactants (anionic, cationic, alkylphenols, LAS…), AOX, PAHs, organohalogenic compounds	no	pharmaceuticals, surfactants, metals	No stated in this publication	The results of a 7-year study (2011-2017) at the Bellecombe pilot site – (SIPIBEL) - that aims at the characterisation, treatability and impacts of hospital effluents in an urban wastewater treatment plant		
15	An assessment of options to improve the removal of excess nutrients from European wastewater.	Pistocchi, A., Grizzetti, B., Nielsen, P.H., Parravicini, V., Steinmetz, H., Thornberg, D., Vojak, O.	submitted 2022	none, study only on nutrients	n.a.	n.a.	n.a.			
16	A look down the drain: Identification of dissolved and particle bound organic pollutants in urban runoff waters and sediments	Fuchte HE, Beck N, Bieg E, Bayer VJ, Achten C, Krauss M, Schäffer A, Smith KEC.	01.06.2022	Urban runoff waters: 187 polar organic micropollutants could be quantified using LC-HRMS: •Traffic derived micropollutants (corrosion inhibitors, rubber additives and the PAHs) •Industrial substances •Pesticides •Pharmaceuticals •Sweeteners	•Industrial substances (8–27% of the total polar organic micropollutant loads) •Pesticides (low concentrations ,medians of 4 µg/kg in sediment (DW), 13 ng/L in water and 2 µg/kg in silicone). •Pharmaceuticals: water (6–11 ng/L), sediment (13–36 µg/kg DW) and/or the PS (2-8 µg/ kg silicone). •Sweeteners (1–2 µg/L) •Caffeine and cotinine	•Traffic derived micropollutants (corrosion inhibitors, rubber additives and the PAHs) •Industrial substances •Pesticides •Micropollutants from other urban sources: Pharmaceuticals, Sweeteners, caffeine and cotinine	yes, PAH-->carcinogenicity	Field sampling was carried out in the center of Aachen, (Germany)		
17	Contaminant Exposure and Transport from Three Potential Reuse Waters within a Single Watershed	Masoner; Jason et al.	10.01.2023	•Pharmaceuticals, Industrial chemicals, household chemicals, PFAS, PAHs, pesticides, inorganic chemicals (e.g. chloride, nitrogen and bicarbonate)	•82 different prescription pharmaceuticals and seven nonprescription pharmaceuticals were detected in wastewater effluent •Pharmaceuticals were the most frequently detected chemical in wastewater effluent, but only accounted for 10 % of the total target organic concentration. Disinfection byproducts (DBPs) accounted for 10% of total detections but 73% of the total concentration. •12 household chemicals detected in the wastewater effluent. •8 PFAS detected •11 pesticides detected	•Results document substantial and varying organic-chemical contribution to surface water from effluent discharges (e.g.,DBP, prescription pharmaceuticals, industrial/household chemicals), urban storm water (e.g.,polycyclic aromatic hydrocarbons, pesticides, non-prescription pharmaceuticals),and agricultural runoff (e.g.,pesticides).	•Many of the chemicals are known carcinogens (e.g. PAHs), designed bioactives (e.g. pesticides and pharmaceuticals) or hormonally active (e.g., PFAS and hormones). •The chemical benzophenone is a concern for human health and to aquatic organisms	•Measurement of a wastewater treatment plants' effluent in Oklahoma		
18	Mistra Pharma Annual reports 2010, 2012, 2013, 2014	MistraPharma		Pharmaceuticals	A chemical map of active pharmaceutical ingredients (APIs) covering 899 drugs. 46 API from the priority list selected to perform studies on - the result of water samples taken in the Baltic Sea show that pharmaceuticals are present in detectable concentrations in the Baltic, both at coastal and open sea locations	Active pharmaceutical ingredients (APIs)	Constructed wetlands were shown to hava a capactity to remove a variety of micropollutants, including APIs. The effects evident in the ecotoxicological studies of the outgoing and incoming water of the constructed wetlands could not be assigned to either pharmaceuticals or metals. - Progestin levonorgestres (contraceptive) was shoen to be a potent developmental toxicant in female frogs. Lowest tested concentration is approaching evenironmentally measured concentrations of levonorgestrel.	Experimental studies at various locations in Sweden		Different experiments in Sweden to identify pharmaceuticals in wastewater, aquatic life and on how to better separate pharmaceuticals from wastewater.
19	Identification and reduction of Environmental risks caused by human pharmaceuticals. MistraPharma Research 2008-2015 Final report.	MistraPharma		Pharmaceuticals	Not applicable	API		Experimental studies at various locations in Sweden		

20	Gutachten zur Umsetzbarkeit der vom BDEW in die Diskussion gebrachten Fonds-Lösung zur Finanzierung der Spurenstoff-Elimination in Kläranlagen	IWW; Mocons GmbH & Co. KG	04.11.2021	•Pesticides, animal pharmaceuticals, industrial chemicals (PFC)		•Runoff (pesticides, animal pharma); •Wwtp (human pharma, industrial chemicals)	UQN if not available, PNEC shall be used			•Financing of advanced treatment tech. through fond (manufacturers, importers) •Advantages: •Elimination rate of advanced treatment never 100% (depending on technology, amount of additives, type of micropollutant, amount dissolved organic) , thus, reduction at manufacturers (sustainable products) better •Runoff water-borne micropollutants which are currently measured in water bodies could be significantly reduced when treated in "ordinary" wwtp (i.e. third treatment step reduces PAK very good), better than 4th treatment step is,, increasing volume of rainwater basins (Regenrückhaltebecken); 99.5% of emissions in rainwaters can be traced back to combustion residues, i.e. higher GHG prices recommended
21	Recommendations for reducing micropollutants in waters	German Environment Agency	01.04.2018	- human medicinical products, - veterinary medicinical products, - plant protection products, - biocides, - REACH-chemicals, - detergents, cleaning products and cosmetics - radiocontrast agents	-threshold for pesticides (plant protection products and biocides) of 0.1µg/l was exceeded by plant protection products and biocides -the annual entry of chemicals into wastewater resulting from private household detergents is approximately 530,470 tonnes (2015): -Surfactants (including soap): 184,419 tonnes Phosphates/phosphonates: 19,444/4,673 tonnes Perfumes: 9,027 tonnes Enzymes: 5,513 tonnes Optical lighteners: 434 tonnes Dyes and pigments: 109 tonnes -in Germany, there are currently 1,200 potentially environmentally relevant active substances from human medicinal products, at an annual consumption of around 8,100	primary sources: - urban ww (HMP, biocides, chemicals, detergents, cleaning products) - combined sewer overflow (biocodes, chemicals, PPP, HMP, detergents) - rainwater from separate sewer system (chemicals, biocides, PPP) - surface runoff (PPP; Manura, Fermentation residues, sewage sludge; - directly entering into surface waters (antifouling agents9	-radiocontrast agents can break down into transformation products of high toxic potential (e.g. products of iopamidol due to chlorination) -EU-wide environmental quality standards have been exceeded by pesticides (plant protection products and biocides), namely: Diuron, TBT, Bifenox, Cybutryn, Cybutryn, Isoproturon and for industrial chemicals (PAH).	Data from research projects		
22	Ecotoxicological risk assessment of micropollutants from treated urban wastewater effluents for watercourses at a territorial scale: Application and comparison of two approaches.	Gosset A et al.		- pharmaceuticals, personal care products, surfactants, plasticizers, heavy metals, pesticides				research was performed at 33 urban WWTPs of a highly urbanized part of France		
23	Up-to-date monitoring data of wastewater and stormwater quality in Germany	Nickel JP et al	22.07.2021	100 different substances considered, mainly priority substances according to Directive 2013/39/EU, substances with national Environmental Quality Standards according to the German ordinance on the protection of surface waters and biocides. 40 biocides and pesticides, 16 PAH, 16 PFAS, 12 metals, 8 pharmaceuticals, 3 benzotriazoles, 2 phenols, acesulfame (ACE), di-(2-ethylhexyl)phthalate (DEHP), and hexabromocyclododecanes (HBCDD)	In WWTP effluents, high frequencies were found for metals, the plasticiser DEHP, and the low-molecular-weight PAH fluorene (FL), phenanthrene (PHE), fluoranthene (Fluo), and pyrene (Pyr)	Metals, PAH, Phenols, PFAS, biocides and pesticides, Pharmaceuticals and other organic substances	Not applicable	Measurements		Includes stormwater
24	Micropollutants in treated wastewater	Rogowska et al.		•Pharmaceuticals •Sweeteners •Nanoparticles •Industrial chemicals (used as corrosion inhibitors, dishwasher detergents, and antifreezes) •Personal hygiene and household	Highest concentration determined (lg/L) for substances reported		polychlorinated biphenyls (PCBs), bisphenol A, phthalates, pesticides, some pharmaceuticals, brominated flame retardants, and organic tin compounds Endocrine disrupting chemicals (EDC)	Lit revision	Although the number of studies on the determination of target pollutants in the treated wastewater is constantly increasing, there are few reports in literature on the identification of non-target compounds present in the treated wastewater	
25	Fund-based solution as an economic instrument for a financing of trace element reduction measures according to the polluter-pays principle	Christoph Czichny, Mark Oelmann, Dietmar Schittlehm	2020	tests were analysed for 151 trace substances, the ones with the highes harmfullness were mainly used as active pharmaceutical ingredients (Ibuprofen, Diclofenac, 17ß-estradiol, Carbamazepine, Clarithromycin), pesticides (Imidacloprid, Flufenacet), impregnating products/fire extinguishing agents/electroplating (PFOS), antiseptic and nutritional supplements/semiconductor (Selenium)	only of the 10 most harmfulness substances: sum load Selenium 2481.47; Diclofenac 964.17; Carbamazepine 603.40;Ibuprofen 260.14;Clarithromycin 139.59; Triclosan 27.53; Flufenacet 19.29; PFOS 15.98;Imidacloprid 3.84; 17ß-estradiol 2.04	APIs, impregnating products, fire extinguishers, electroplating, disinfectants, cosmetics, pesticides, nutritional supplements, semiconductors	EQS values mentioned, and multiplied with sum load = relative harmfulness	water analysis/measurements of 4 ww associations in Germany, North Rhine-Westphalia (Emschergenossenschaft, Lippverband, Niersverband, Ruhrverband)		- 5 out of 10 substances are pharmaceutical ingredients (and 8 out of the top 20) - 2 out of 10 substances are pesticide agents, i.e. herbicides or insecticides (and 6 out of 20) - 14 out of 20 top substances are contained in products of two industrial sectors: pharmaceutical and pesticides
26	Water driven leaching of biocides from paints and renders - Methods for the improvement of emission scenarios concerning biocides in buildings	The Danish Environmental Protection Agency	2014	The study covers 12 biocides used in building material: cybutryn (Irgarol 1051), terbutryn, diuron, isoproturon, methylisothiazolinone, benzisothiazolinone, octylisothiazolinone, dichlorooctylisothiazolinone, carbendazim, tebuconazole, propiconazole and mecoprop	In addition to measurements of concentrations in storm water, measurements of biocides were performed for 5 WWTPs in different waether conditions.	For measurements during rain, the assumption was that the major contribution was facade render and paint. Since high levels were found for certain biocides during dry weather conditions, and especially during day/evening hours rather than than during the night, this indicates human activity. The most likely explaniation for most biocides was stated to be the inappropriate disposal of paints and renders into the sewer for example when washing used paint brushes and other equipment.	Some compounds (especially cybutryn, terbutryn and mecoprop) were present in storm water in levels sometimes exceeding receiving water quality standards set in regulations such as the water framework directive or the surface water directive	Analysis		
27	Cosmetic preservatives: hazardous micropollutants in need of greater attention?	Nowak-Lange et al.	2022	Cosmetic Preservatives (organochloride compaunds, Isothiazolinones, Quaternary Ammonium Compounds)	**Sewage and Sludge**: The concentrations of preservatives significantly ranged from below the limit of quantification (LOQ) to a few tens of micrograms per liter or kilogram dry weight. **Surface Waters:**The deficient removal of preservatives from WWTPs and the following discharge of effluents lead to the contamination of the receiving environments. Concentrations of selected preservatives in surface waters range from ng L−1 to tens of µg L−1	Soaps, shower gels, toothpastes, disinfectant products, makeup products	**Aquatic Toxicity:** Histopathological alterations, modification of proteins, neurotoxicity and genotoxicity, reproduction and structural abnormalities, embryotoxicity, and endocrine disturbance have been observed as a result of preservative toxicity in aquatic organisms. **Soil Toxicity** ;reduced the variety of soil microbial communities and caused an increased quantity of Crenarchaeota and Proteobacteria;decrease the abundance of soil bacteria and reduce the degradation level of pesticides in soil resulting in their persistence in the environment ;inhibition of soil microflora.	Lit revision	peer reviewed publications was used in the review	
28	Investigating options for reducing releases in the aquatic environment of micro-plastics emitted by (but not Intentionally added in) products: final report	EC/Eunomia	2018	microplastic		automotive tyres, road markings, pre-production plastics, washing of synthetic clothing, building paint, artificial turf, automotive brakes, fishing grar, marine paint				
29	Plastics in European Wastewater Treatment Plants	Obermaier,N.; Pistocchi, A.	2022	Microplastic	a preliminary european budget of MP in wastewater is calculated, but values from stormwater is also included	tire wear particles		The article quantify the emissions associated with urban wastewater based on the range of observed concentrations in wastewater treatment plants (WWTPs) effluents, and the emissions from tire wear particles (TWP) by assuming that a percentage of the particles generated on roads eventually reaches surface waters.	Large variation of data. Data available for MP consist only of spot measurements since there is no harmonized reporting of monitoring data as for other polluntants	Includes both wastwater and stormwater.
30	Framework for establishing regulatory guidelines to control antibiotic resistance in treated effluents	Manaia, C.M.	2022	antibiotics		Antibiotic resistance bacteria, Antibiotic resistance genes				
31	Screening of mercury pollution sources to European inland waters using high resolution earth surface data	Pistocchi, A., Cinnirella, S., Mouratidis, P., Rosenstock, N., Whalley, C., Sponar, M., Pirrone, N.	2022	Mercury and its compounds, e.g. methyll mercury	Hg is released to water and soil from many wastewater treatment plants above a capacity of 100,000 Population Equivalents. Although, the E-PRTR does not include industrial activities below a certain threshold and many plants do not report Hg systematically, which means that there is likely a data gap.	Total releases of Hg to water are estimated to be 45.59 t year across the EU. Of these, 24.49 t year (53.7%) are represented by direct deposition. The second largest contribution (10.45 t year or 22.9%) is urban runoff while leaching from soil is the third contribution with 5.21 t year (11.4%), followed by treated effluents (6.1%, 2.79 t year), industrial releases (4.8%, 2.17 t year) and combined sewer overflows (CSO: 1.1%, 0.49 t year).	Hg and its compounds are identified as Priority Hazardous Substances (PHS) in Annex X to the Water Framework Directive (WFD, 2000/60/EC), and pose a concern in particular due to the potential of MethylMercury (MeHg) to bio-accumulate and bio-magnify in organisms.	Data based on European Pollutant Release and Transfer Register (E-PRTR).	Study based on estimations by a model: Steady state mass balance model to estimate the mass flow of Hg	The calculations in this study highlights that direct deposition to permanent and temporary inland water surfaces is a dominant source of pollution. We also show that an important source is the washout of impervious urban surfaces, while releases from soil and industrial and urban wastewater play a lesser, albeit sizable role
32	Möglichkeiten einer verursachergerechten Finanzierung von Maßnahmen zur Reduktion von Spurenstoffen	Oelmann, M., Czichy, C.	2019	151 analyzed trace substances 51 substances enter water bodies via wastewater treatment plants. Ibuprofen, Perfluorooctane sulphanic acid + Derivate (PFOS) and Diclofenac.	20 top micropollutants with relative Harmfulness: •Ibuprofen 30,24 % •PFOS 28,57 % •Diclofenac 22,42 % •17-ß Östradiol (Estradiol) 5,92 % •Imidacloprid 2,23 % •Triclosan 1,60 % •Carbamacepin 1,40 % •Clarithromycin 1,25 % •Selen 0,96 % •Flufenacet 0,56 % •ESulfamethoxazol 0,55 % •Rcosulfuron 0,39 % •Cadmium und Cadmiumverbindungen 0,37 % •Terbutryn 0,37 % •Thallium4 0,35 % •Mecoprop 0,33 % •Nonylphenol (4-Nonylphenol) Nonylphenol (4-Nonylphenol) 0,32 % •Diflufenican 0,23% •17-α Ethinylöstradiol 0,23 % •Erythromycin 0,21 %	Information not available	20 top micropollutants with relative Harmfulness: •Ibuprofen 30,24 % •PFOS 28,57 % •Diclofenac 22,42 % •17-ß Östradiol (Estradiol) 5,92 % •Imidacloprid 2,23 % •Triclosan 1,60 % •Carbamacepin 1,40 % •Clarithromycin 1,25 % •Selen 0,96 % •Flufenacet 0,56 % •ESulfamethoxazol 0,55 % •Rcosulfuron 0,39 % •Cadmium und Cadmiumverbindungen 0,37 % •Terbutryn 0,37 % •Thallium4 0,35 % •Mecoprop 0,33 % •Nonylphenol (4-Nonylphenol) Nonylphenol (4-Nonylphenol) 0,32 % •Diflufenican 0,23% •17-α Ethinylöstradiol 0,23 % •Erythromycin 0,21 %	Example study area (four-legal associations from North Rhine-Westphalia)		
33	EU-wide monitoring survey on emerging polar organic contaminants in wastewater treatment plant effluents	Loos, R. et al.	2013	156 polar organic chemical contaminants. Compounds were selected by previous experience, their environmental and toxic relevance and by available analytical procedures.	The results show the presence of 125 substances (80% of the target compounds) in European wastewater effluents, in concentrations ranging from low nanograms to milligrams per liter. The most relevant compounds in the effluent waters with the highest median concentration levels were the artificial sweeteners acesulfame and sucralose, benzotriazoles (corrosion inhibitors), several organophosphate ester flame retardants and plasticizers (e.g. tris(2-chloroisopropyl)phos-phate; TCPP), pharmaceutical compounds such as carbamazepine, tramadol, telmisartan, venlafaxine, irbesartan, fluconazole, oxazepam, fexofenadine, diclofenac, citalopram, codeine, bisoprolol, eprosartan, the antibiotics trimethoprim, ciprofloxacine, sulfameth-oxazole, and clindamycine, the insect repellent N,N0-diethyltoluamide (DEET), the pesticides MCPA and mecoprop, perfluoroalkyl substances (such as PFOS and PFOA), caffeine, and gadolinium	Target microcontaminants were pharmaceuticals and personal care products (PPCPs), veterinary (antibiotic) drugs, perfluoroalkyl substances (PFASs), organophosphate ester flame retardants, pesticides (and some metabolites), industrial chemicals such as benzotriazoles (corrosion inhibitors), iodinated x-ray contrast agents, and gadolinium magnetic resonance imaging agents	Estrogenicity and dioxin-like toxicity analyzed by in vitro reporter gene bioassay. Activity detected in several of the WWTP effluents. Cytotoxicity : 1 out of 3 WWTP effluents that caused cytotoxicity to yeast and diatom contained diuron. Diuron is suggeted to likely be one of the major toxicants in the effluent, although it could only explain 10-20% of the observed effects. Most of the compound are present at low concentrations but still raise toxicological concern, especially in mixtures.	Sampling from 90 different WWTPs in Europe. The result is compared with available literature and some in vitro tests performed to test the toxicity.	Not so clear or very broad explanation on how the specific compunds were selected	
34	IKSR-Empfehlung-Empfehlung zur Reduktion von Mikroverunreinigungen in Gewässern	Internationale Kommissuin zum Schutz des Rheins (IKSR)	2019	•Pharmaceutical residues •(X-ray contrast media), •Pesticides •Industrial chemicals •Household chemicals, •Biocides •Flame retardants	no information	**X-ray contrast media** (RKM) are developed as biologically inactive substances and are hardly degraded in wastewater treatment plants due to their stability. RKM are mainly used in hospitals and radiology practices. The majority of these RKM enters the wastewater within 24 hours where they are administered, or into the household wastewater of patients at home	Active pharmaceutical ingredients are sometimes measured in concentrations above the EU proposals for environmental quality standards (EU EQS proposals). X-ray contrast media were measured partly above the precautionary values of the International Working Group of the Waterworks in the Rhine Basin (IAWR) and the health orientation values (GOW)	Field measurements (Rheinmessprogramm Chemie 2015 bis 2020, Sondermessprogramm 2017 , reported in IKSR-Fachbericht Nr. 246)		

Bright
ideas.
Sustainable
change.

RAMBØLL