Water Joint Programming Initiative
Knowledge Hub on Contaminants of
Emerging Concern

Continuous increase of CECs in the anthroposphere as a stressor for water resources

STAKEHOLDER BRIEF

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Abbreviations

CECs (contaminants of emerging concern)
EQS (environmental quality standards)
DBPs (disinfection byproducts)
HRMS (highrresolution mass spectrometry)
MSFD (Marine Strategy Framework Directive)
NTS (non-targeted screening)
PFAS (polyfluoroalkyl substance)
PFCA (perfluoroalkyl carboxylic acid)
PFSA (perfluoroalkyl sulfonic acid)
PPCPs (pharmaceuticals and personal care products)
TPs (transformation products)
UWWTD (Urban Wastewater Treatment Directive)
WFD (Water Framework Directive)
WWTPs (wastewater treatment plants)

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Contents

"The protection of our environment and natural resources is very important in today's society. A major focus amongst the general public as well as in political programmes is on climate change and linked mitigation and adaptation strategies. A core issue in that discussion is both the availability and quantity, as well as the quality of our water resources - not only in regard to the protection of environmental waters for aquatic life and biodiversity, but also to ensure the demand for clean water in our daily life is met.

Our continued extraction of water together with a rise in the use of chemicals in modern society put increasing pressure on the quality of water resources.

This document emphasises that the quality of our water resources are under threat from new substances summarised under the term of contaminants of emerging concern (CECs). Experts within the Water JPI Knowledge Hub on CECs (KHCEC) have brought together information on CECs, including their sources, methods of detection and occurrence in our water cycle, to raise awareness within the broader public of the need to tackle the topic of CECs introduced by our society into the water cycle."

Norbert Kreuzinger,
Water JPI
KHCEC Scientific Coordinator

Document written by Norbert Kreuzinger, David Murphy and Eva Greene, with support from the Water Joint Programming Initiative Knowledge Hub on Contaminants of Emerging Concern (KHCEC) working group members.

Executive Summary

Sufficient scientific evidence has shown a massive and continuous increase in synthetic chemicals present in aquatic systems. Both the Urban Wastewater Directive (UWWTD), the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) were based on legacy as well as fundamental targets representing acute aquatic problems during the last decades of the last millennium. Today, there is a **pressing need to consider new policy and mitigation** in light of our rapidly changing society and environment.

The UWWTD stems from 1991 - a time when mobile networks were formed, and the first internet browsers were being developed. The pollution in water bodies was visible and a greater number of waterbodies in Europe were far from achieving a good environmental status (than today a qualitative description of the state of the water). However, some of the problems from the last century such as discolouration, foaming, fish deaths and eutrophication are still visible in some cases in Europe, and more frequently in other parts of the world.

Today, European water bodies have become polluted with complex mixtures of chemicals, including pesticides, biocides, pharmaceutical and industrial chemicals that - despite being present previously - were only recognized after the more severe problems were solved and chemical analysis was improved. The loads and diversity of pollutants are increasing due to population growth and the escalating introduction of new chemicals to the market. More than 4000 new substances are being added to the Chemical Abstracts Service (CAS)registry daily. The REACH Regulation (EC 1907/2006) places responsibility on industry to manage the risks from chemicals and to provide safety information on the substances – all registered in a central database. Figure 1 shows the rapid increase in the number of substances registered in the CAS registry over recent decades and highlights when the two most relevant directives were implemented, 19 (WFD) and 29 (UWWTD) years ago.

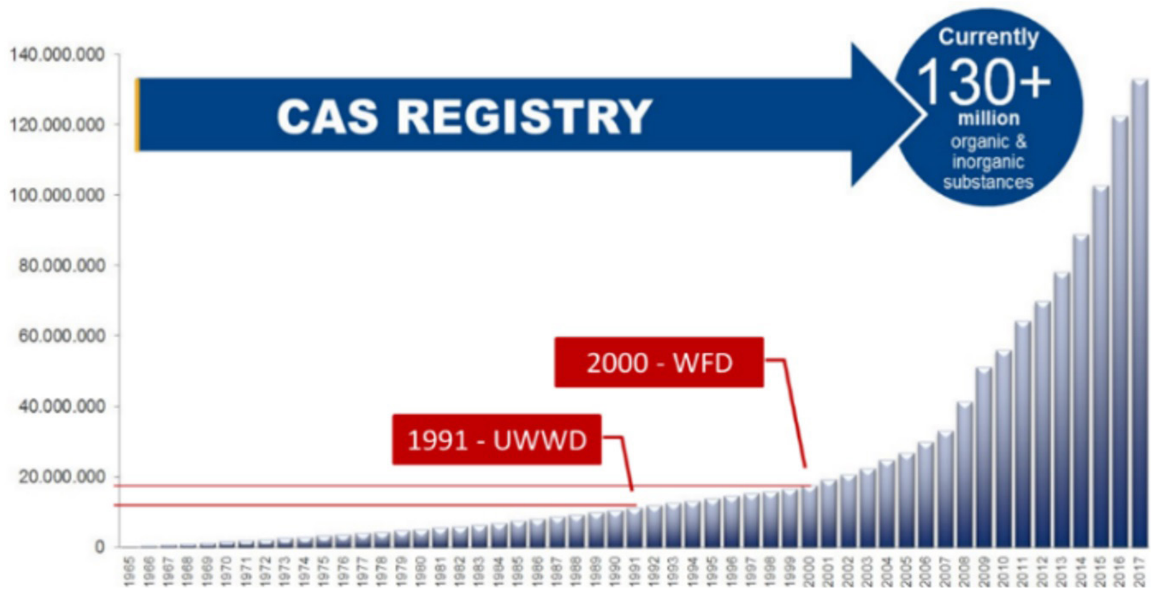


Figure 1. Increasing numbers of substances have been added to the CAS registry. X-axis shows progressive years, y-axis shows the number of registered organic and inorganic substances (Source: CAS resgistry).

A rise in the use of chemicals in everyday life can be seen as:

- Changes in sanitary, household and personal care products and use have led to a greater number of products being developed. Societies also tend to use more convenient products which can often contain more chemicals. This includes other goods and products e.g. materials for urban construction, electronics and textile chemicals.
- Advances in diagnostic and curative medicine and therapies have led to the development of new substances, particularly antibiotics and pharmaceutically-active compounds. Excessive application and misuse have led to contamination of water bodies at unsafe levels.
- A similar trend is seen in the food industry, with biocides, artificial sweeteners, plasticizers and antioxidants being readily seen in the aquatic environment. Rising food demand also puts pressure on intensive farming reliant on pesticide and antibiotic use.

While the growing economy provides wealth and innovation, it also introduces new exposure pathways for contaminants into the environment, as more new products appear on the market together with a greater desire from the public to use them. Contaminants of emerging concern (CECs) are substances/compounds that at present are not commonly monitored, but when present are suspected to have adverse ecological and human health effects. Most are substances that have entered the environment for many years, but their presence has been investigated only at the turn of the century. Frequently, industry responds to guidance for use of single substances by replacing them with similar, but non-regulated substances. For example, the endocrine-acting substance Bisphenol-A used in the production of plastic was replaced by Bisphenol-F, another substance with similar environmental impact. This trend can be mitigated by requiring the implementation of new holistic approaches complementing, or in some cases even replacing, single substance monitoring through techniques such as (untargeted) chemical screening and/or effect-based analyses that can detect cumulative effects caused by different substances. Some parameters are not new in water protection legislation (e.g. biological oxygen demand, chemical oxygen demand, dissolved organic carbon), but integrative effect-based bioassays are. Effect-directed analysis identifies those chemicals that might cause adverse effects. Such methods are recommended for monitoring to evaluate improvements of water quality.

CECs are transferred from products to the water matrix by application and use, with many ending up in wastewater. This includes those released from contaminated land and from stormwater runoff. The primary purpose of wastewater treatment plants (WWTPs) is to remove degradable carbon and nutrients. Some organic CECs are removed, or their chemical structures are partially modified. Even in these limited cases, removal is not always complete. As the existing WWTP infrastructure is not designed nor operated to remove residual concentrations of organic pollutants, they are instead released into receiving water bodies. The contaminated wastewater released into the environment can negatively impact aquatic organisms' habitats and freshwater resources. With the current strong focus on sustainability and the urban water cycle and water reuse, water quality preservation is essential.

A substantial step forward is required to revise the UWWTD towards redefining the goals. The UWWTD should introduce proactive measures to reduce the emissions of CECs discharged in WWTP effluents and stormwater runoff, to be applied together with the reduction of CECs at the source. The below steps should also encompass surface and ground water (WFD, MSFD) and drinking water.

- Effect-based approaches/assays should be implemented in water quality monitoring and assessment in combination with chemical-analytical screening methods to pinpoint potential stressors. For example, the whole effluent assessment for estrogenic effects (Fig. 2). The estrogenic value in effluents should be below the effect-based trigger value. Even the implementation of this as a first step would be sufficient to significantly improve effluent qualities as other effects are probably reduced in parallel.

- Single maximum concentrations are of relevance too; under the WFD there are the annual average environmental quality standards (EQS) and maximum allowable EQS values which are derived from toxicity considerations and must not be exceeded in any surface water sample, but only for a small number of chemicals.

- Further expanding priority substance lists to address persistent and mobile substance properties. Human and veterinary medicinal products are not yet defined as priority substances EU-wide. For some medicinal products, proposals for EQS are drafted at EU and national levels, but a more comprehensive approach should be considered. These approaches start from known contaminants but unravelling the knowledge about the unknowns (e.g. transformation products (TPs)) should not be neglected, by use of e.g. untargeted HRMS screening.

- New requirements for the UWWTD should be adapted: new requirements for non-sensitive areas should be the same as for previously sensitive areas. Sensitive areas include freshwater bodies, estuaries and coastal waters which are/may become eutrophic; Surface freshwaters intended for the abstraction of drinking water which contain more than 50 mg/l of

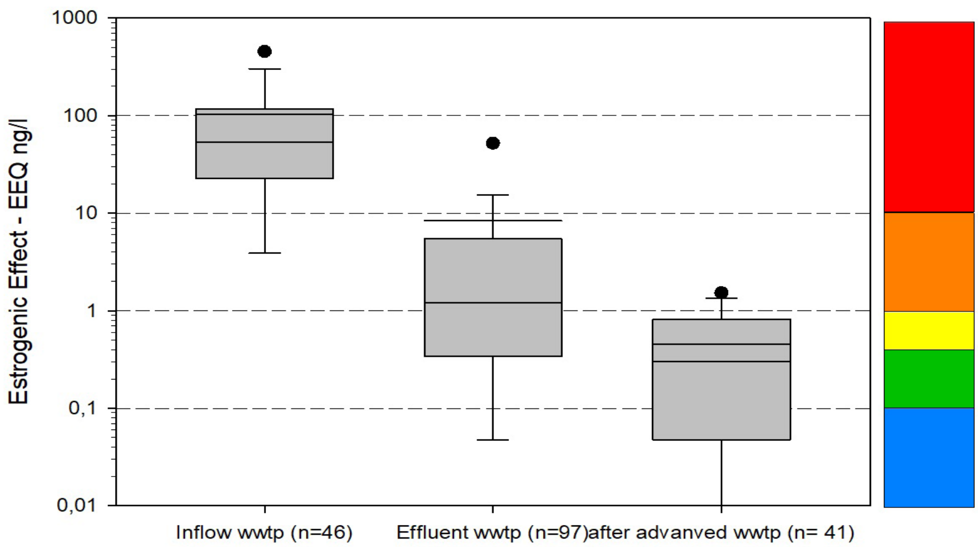


Figure 2. Improvements in water quality (specifically the concentration of estrogenic effects) following advanced wastewater treatment. Implementing advanced treatment would bring the effluent in the range of <10x the effect concentration. (Source: Norbert Kreuzinger)

of nitrates; and areas where further treatment is necessary to comply with other Council Directives such as the Bathing Water Directive. The parameters of the UWWTD should be extended to include more industrial branches.

Urgent action is required, as the establishment, revision and implementation of legislation takes time. Transition periods and reinvestment periods have to be considered. The reinvestment period of wastewater treatment plants (WWTP) is estimated to be 20-40 years. If new plants are built according to the old requirements, no change will be seen in the near future. The cost for advanced WWTP at the basic stage is approximately EUR 20 per person per year – this can be compared to the cost of 4-5 Big Macs a year. The upgrading can be done by re-designing existing treatment processes or by optimising operation conditions of the existing biological process. Adding a subsequent treatment step, such as ozonation and/or activated carbon filtration, can substantially reduce the discharge of compounds into the aquatic environment (Fig. 3). However, advancements in water treatment systems that prove effective in eliminating CECs are yet to be applied at full-scale to prevent further contamination.

While many more chemicals are becoming emerging contaminants, identification techniques are also being refined, and solutions are being sought that will create future-proof flexibility that ensures resilience to changing conditions due to demographic development and climate change.

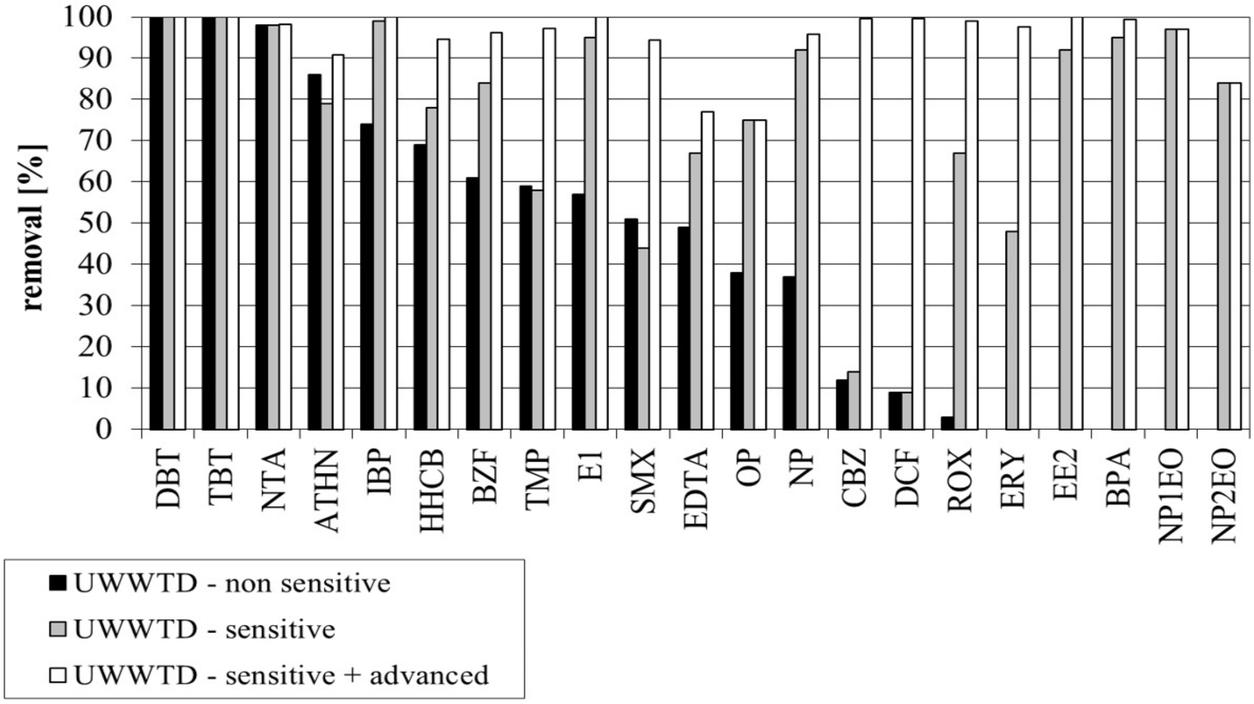


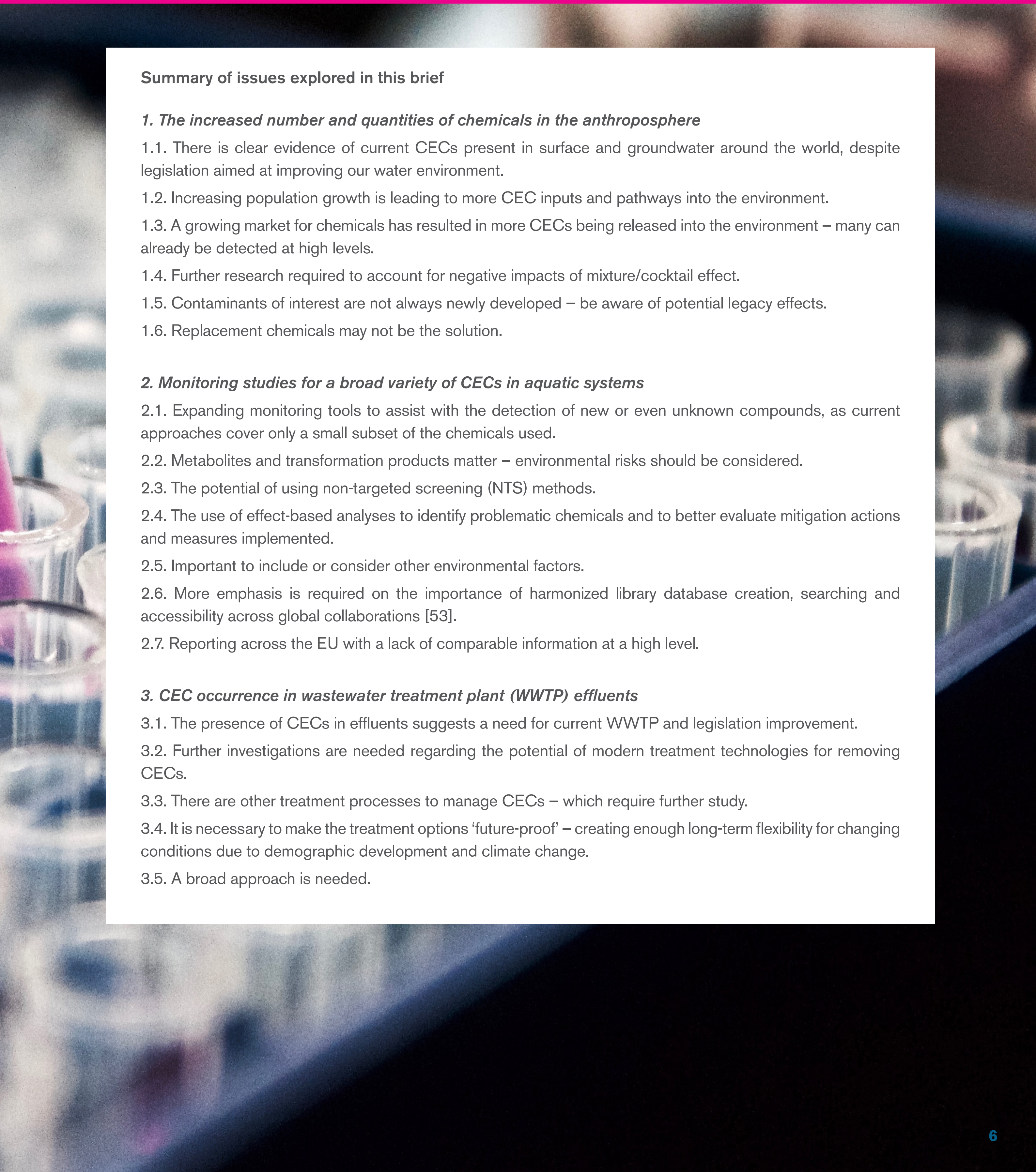
Figure 3. With the suggestion to adjust the UWWTD, the black bars (= requirements for non-sensitive areas now) would shift to the grey (= requirements for sensitive areas now) and the grey to white. The x-axis reads CECs found in non-sensitive to sensitive areas under the UWWTD. The y-axis shows the removal efficiency of CECs in WWTPs (%). (Source: Norbert Kreuzinger)

Introducing the Stakeholder Brief on CECs

Purpose

An expansion of ideas and analogies from the current literature, framed into issues related to three challenge statements. The following provides some context around the topic of the continued increase of contaminants of emerging concern (CECs) in the anthroposphere as a stressor for the quality of water resources, focusing on:

1. The increased number and quantities of chemicals in the anthroposphere
2. Monitoring studies for a broad variety of CECs in aquatic systems
3. CEC occurrence in wastewater treatment plant (WWTP) effluents



Summary of issues explored in this brief

1. The increased number and quantities of chemicals in the anthroposphere

1.1. There is clear evidence of current CECs present in surface and groundwater around the world, despite legislation aimed at improving our water environment.

1.2. Increasing population growth is leading to more CEC inputs and pathways into the environment.

1.3. A growing market for chemicals has resulted in more CECs being released into the environment – many can already be detected at high levels.

1.4. Further research required to account for negative impacts of mixture/cocktail effect.

1.5. Contaminants of interest are not always newly developed – be aware of potential legacy effects.

1.6. Replacement chemicals may not be the solution.

2. Monitoring studies for a broad variety of CECs in aquatic systems

2.1. Expanding monitoring tools to assist with the detection of new or even unknown compounds, as current approaches cover only a small subset of the chemicals used.

2.2. Metabolites and transformation products matter – environmental risks should be considered.

2.3. The potential of using non-targeted screening (NTS) methods.

2.4. The use of effect-based analyses to identify problematic chemicals and to better evaluate mitigation actions and measures implemented.

2.5. Important to include or consider other environmental factors.

2.6. More emphasis is required on the importance of harmonized library database creation, searching and accessibility across global collaborations [53].

2.7. Reporting across the EU with a lack of comparable information at a high level.

3. CEC occurrence in wastewater treatment plant (WWTP) effluents

3.1. The presence of CECs in effluents suggests a need for current WWTP and legislation improvement.

3.2. Further investigations are needed regarding the potential of modern treatment technologies for removing CECs.

3.3. There are other treatment processes to manage CECs – which require further study.

3.4. It is necessary to make the treatment options 'future-proof' – creating enough long-term flexibility for changing conditions due to demographic development and climate change.

3.5. A broad approach is needed.

Challenge 1. The increased number and quantities of chemicals in the anthroposphere

Issue 1.1. There is clear evidence of current CECs present in surface and groundwater around the world, despite legislation aimed at improving our water environment.

- European water bodies are polluted with a complex mixture of chemicals including pesticides, biocides, pharmaceuticals and industrial chemicals [1].
- Trace organic contaminants, such as pharmaceuticals, personal care products and industrial chemicals are often found in all stages of the urban water cycle (wastewater, fresh and marine surface water, groundwater and drinking water) [2].
- For example, 125 substances were found in EU wastewater effluents in 2010, in concentrations ranging from low nanograms to milligrams per litre. The most abundant compounds with the highest median concentrations were organophosphate ester flame retardants and plasticizers, pharmaceuticals, antibiotics, an insect repellent, pesticides, per- and polyfluoroalkyl substances (PFASs), artificial sweeteners and food additives [3].
- Some of the world's best-known rivers are contaminated with antibiotics at unsafe levels – increasing the potential of developing and spreading antibiotic resistance in the environment [4].

Issue 1.2. Increasing population growth is leading to more CEC inputs and pathways into the environment.

- There is an increasing load and diversity of pollutants due to population growth and aging, as well as the escalating introduction of new chemicals to the market [5]. Due to changes in sanitary and personal care behaviour and to changes in nutritional behaviour, society now uses many more chemicals in everyday life: complex detergents, pharmaceuticals including antibiotics, artificial sweeteners, industrial and agro-chemicals, etc [6].
- The global population is expected to grow to nine billion by the mid-21st century. More pesticides will be used to intensify food production, so the contamination of the environment by pesticides will most likely further increase [7].
- The circular economy is a growing sector and can introduce new pathways for contaminants into the environment [8], highlighting the need for multi-stakeholder and multi-sector approaches to prevent, reduce, and manage CECs such as pharmaceuticals entering the environment (a new emerging policy issue under the Strategic Approach to International Chemicals Management) [9].

Issue 1.3. A growing market for chemicals has resulted in more CECs being released into the environment – many can already be detected at high levels.

- The global pharmaceuticals market is projected to increase by 3-6% annually between 2018-2022 [10]. For example, it was estimated that Irish General Medical Services expenditure alone would increase by 64%, from EUR 1.1 billion in 2016 to EUR 1.8 billion by 2026 [11]. With the world chemicals turnover valued at €3,475 billion in 2017 [12] - an increase in new chemicals entering the market and a growing volume of production can be expected [13].
- More than 100 million chemical substances are currently registered in the Chemical Abstracts Service and approximately 4000 new ones are registered every day [14].
- A study reviewing the exposure levels of CECs in surface waters across the globe stated that in the EU, 113 pharmaceuticals and personal care products (PPCPs), 201 pesticides, and 56 industrial chemicals were detected [15].
- Another review revealed that pharmaceuticals and their transformation products (TPs) were found in the environment of all 71 countries studied. In total, 631 different pharmaceutical substances were found above the detection limit of the respective analytical methods employed [16].
- A characterisation of wastewater effluents in the Danube River Basin discovered that pharmaceuticals were not only the most often detected compounds, but they also represented 25-67% of the total concentration of the target substances [17].
- Under the Water Framework Directive (WFD) watch

list, three new substances were proposed to be included in 2018 - one pesticide and two antibiotics [18]. Substances are included in this watch list to obtain sufficient high-quality monitoring data to assess the risk they pose at the EU level [19].

Issue 1.4. Further research required to account for negative impacts of mixture/cocktail effect.

- A study quantified the chronic and acute toxic pressure of mixture exposures for over 22000 water bodies in Europe for 1760 chemicals for both exposure and hazard data. The results showed the likelihood of mixture exposures exceeding a negligible effect level and of increasing species loss [20].
- Disinfection by products (DBPs) for example, and other (unknown) TPs) in general, formed when natural organic matter present in the water effluents reacts with a disinfectant. DBPs that formed from iodide, bromide, anthropogenic pollutants and PPCPs have also been reported. More than 600 DBPs have been identified to date and this number is expected to increase [21].

Issue 1.5. Contaminants of interest are not always newly developed – be aware of potential legacy effects.

- Most CECs are substances that have entered the environment for years, but their presence has been investigated only recently. Even banned substances are still detected in surface water. For example, the historical use and release of PFASs, resulting in environmental contamination of persistent perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs), is still dominating the PFAS class distribution and homologue pattern, even though decreasing environmental trends for some of these chemicals have been reported in recent years [22].

Issue 1.6. Replacement chemicals may not be the solution.

- Frequently industry responds to guidance for the use of single substances by replacing them with chemically structurally similar, unregulated substances or by a minor modification of regulated substances, such as the replacement of longer chained PFASs with structurally similar compounds as with the replacement of PFOA with GenX [23]. Compounds used to replace those which are statutory/regulation limited must be studied more to elucidate ultimate environmental fate and potential toxicity [24].
- Some replacements for precluded/banned chemicals may be similarly persistent in the environment as those they replace. The adsorption of potentially bioactive chemicals to micro- and nano-plastics is a significant topic with risks to aquatic organisms potentially greater than previously thought, as this reflects back on the fate of (replacement) chemicals in the environment [25].

Challenge 2. Monitoring studies for a broad variety of CECs in aquatic systems

Issue 2.1. Expanding monitoring tools to assist with the detection of new or even unknown compounds, as current approaches cover only a small subset of the chemicals used.

- There is a distinct possibility of current and future hazardous micropollutants going undetected [26]. Many efforts in the development of early warning methods for detecting changes in source/drinking water quality are based on measures such as DOC or turbidity using sensors for on-line monitoring or with high time resolution. These methods are not always able to detect CECs. As more sophisticated tools become available, exponential growth in the scientific literature on the identification of previously unknown CECs and TPs is expected.
- Several research studies have included HRMS to screen for several hundred substances in individual environmental samples [27].
- Target (priority) substance lists by definition overlook unknown compounds, yet unknowns can substantially contribute to toxic effects observed in environmental samples [28].
- Since all possible pollutants in any water body cannot be entirely known, bioassays can be used to assess the hazard and toxicity derived from unknown CECs. Bioassays are able to quantitatively capture the predicted non-interactive, additive combined effect of bioactive compounds against a background complex mixture of other chemicals [29].
- Batteries of bioassays, that span the full breadth of the adverse outcome pathways, can be applied for effect-based monitoring of micropollutant risks in surface waters for the interpretation of the harmful effects of all chemicals present in surface waters without individual identification of the causing compounds [30].
- A more holistic approach to environmental monitoring including innovative sampling and analytical methodologies is required. Traditional targeted screening with low-resolution mass spectrometry results in numerous chemicals, such as transformation products (TPs) (with often similar toxicity) going undetected; hence it is necessary to use an integrated analytical approach that combines chemical and effect-based analyses to predict environmental impacts [31].

Issue 2.2. Metabolites and transformation products matter – environmental risks should be considered.

- Knowledge on the effects of chemical cocktails (mixtures of chemicals) in the environment is lacking. There is a need to investigate the chronic impact of multiple CECs synergistically at low concentrations and to assess the ecological impact to organisms of different trophic levels [32]. Transformation of CECs into other products can reduce contaminant loadings, but some TPs have been found to be more toxic than their parent compounds. It will be important to also assess the ecological risks of TPs [33]. Progress has been made in the development of advanced analytical tools, and effect-based tools [34]
- It will be critical with respect to mixtures in the environment to overcome the isolated consideration of chemicals according to their use pattern and to start assessing coincidental mixtures from a holistic perspective. What matters is the overall chemical mixture that an organism is exposed to, and a sound assessment whether the overall ecotoxicological pressure is at an acceptable level, or not [35].
- Studies have combined chemistry and toxicology as well as using effect-directed analysis to find the active compounds in a complex environmental mixture [36]. Using chemical and bioanalytical monitoring tools to identify chemicals that drive a specific mixture effect [37] gives a comprehensive picture of the micropollutant load, which can be used for risk assessment and management [38].

Issue 2.3. The potential of using non-targeted screening (NTS) methods.

- Non-targeted unknown analysis uses detailed software workflows to handle the data instead of manually interpreting it for thousands of unknown compounds and spectral features.
- There are several limitations to NTS as the chemistry of the CECs in question are unknown, and their identification can be a time-consuming process. Chemical analyses need to be further supported with novel bioanalytical techniques [39] and big-data processing tools, and the results depend on background knowledge, the focus area and the

availability of chemical databases [40].

- A study has shown that using these techniques, 11 chemicals were identified, of which two have not been previously reported as environmental pollutants [41]. Other examples in the literature are also available [42].
- A prerequisite for NTS is the use of high-resolution mass spectrometry technology and the sharing of information. There is a need to optimize and harmonize terminology and analytical and validation procedures [43]. NTS cannot replace dedicated target methods in sensitivity and specificity, but it has proven to be an important tool for the detection and/or identification of still-unknown CECs [44].

Issue 2.4. The use of effect-based analyses to identify problematic chemicals and to better evaluate mitigation actions and measures implemented.

- Effect-directed analysis can be used to identify chemicals that might cause adverse effects. Multiple bioassays on specific and reactive toxicity that direct toxicant identification are available and ready for use [45]. With the calculated risk of potential acute and chronic (sub)lethal effects increasing with the number of ecotoxicologically relevant chemicals analysed [46], new testing protocols and new toxicity endpoints can be used to better assess the effects of CECs on representative organisms [47].
- Effect-based methods are recommended for WFD monitoring to cover the major modes of action of environmentally relevant chemicals in order to evaluate improvements of water quality upon implementation of the measures [48].
- More research and monitoring data are needed for persistent and mobile organic compounds. The present process of ranking and selection of priority substances and development of EQS does not adequately address persistent and mobile substance properties [49].
- As a result of the application of management measures, prioritized chemicals tend to be replaced by non-prioritized (non-regulated) ones that often have similar effects. The use of bioassays can overcome the limitation of priority lists by incorporating all bioactive compounds and help to address multiple substances with comparable effects. This process increases the relative contribution of non-prioritized chemicals to the overall determined risk [50].

Issue 2.5. Important to include or consider other environmental factors.

- Input of chemicals from agriculture and urban environments and their fate and transport are affected by changing environmental conditions like quantity of the receiving waters, temperature, pH value, organic matter also. It is important to monitor these to assess the likely increase in chemical risks to human and ecosystem health following from changing

environmental conditions (e.g. climate change) [51].

- Constructing an environmental matrix (soil, surface water, groundwater, wastewater, drinking water, marine environment, air) to evaluate CECs by their behaviour and mode of action can help to categorise contaminants by environmental behaviour and modes of action. Changes in the physical environment due to climate change (e.g. extreme weather events) can impact CECs behaviour and toxicity. Long term multi-generational studies are needed at different trophic levels which can simulate environmental conditions and CEC concentrations to gain insight in chronic effects with changing environmental conditions but are very ambitious [52].

Issue 2.6. More emphasis is required on the importance of harmonized library database creation, searching and accessibility across global collaborations [53].

- Unique datasets are needed to change the current paradigm, which is based on tracing individual environmental pollutants when they become regulated, to simultaneous screening and retrospective assessment of knowns and unknowns in complex matrices.
- The lack of tools for archiving data from various studies in a harmonized way reduces their potential for use in regulation and limits the ability to perform in-depth investigations into environmental contamination [54].
- Background information on CECs, such as physical-chemical characteristics, toxicity and legislative frameworks, water cycle entrance pathways and a database with associated possible mitigation methods are important to understand the full picture. Monitoring data should be uploaded centrally to assess environmental and human health risks in a specific water database system [55].
- More powerful global datasets will enable the evaluation of differences in chemical policies, use patterns and efforts to reduce releases [56].

Issue 2.7. Reporting across the EU with a lack of comparable information at a high level.

- It is a challenge to characterise chemical pollution in a comprehensive way with limited resources [57], but the timely provision of validated chemical analytical and bioanalytical tools, improved knowledge, and useful decision support instruments are vital to improve practices [58].
- There is a need to synthesise key information on validated analytical and sensitive test methods for ecological effects [59].
- It is important to create incentives to extend the monitoring basis of chemical contamination across Europe and to improve links across member states [60], and even expanding to a global approach in order to better understand the environmental occurrence, fate, behaviour and dispersion of CECs as well as to define appropriate management and treatment strategies to minimise their discharge and effects in the environment.
- Standardised methods, that combine effect-based tools with advanced chemical analysis, should be described and implemented in the WFD. Only when authorities are required to monitor according to these novel methods will sufficient funds and resources be made available to generate comprehensive datasets of toxicants causing adverse environmental effects at the local, river basin, and national and European scales.

Challenge 3. CEC occurrence in wastewater treatment plant effluents

Issue 3.1. The presence of CECs in effluents suggests a need for current WWTP and legislation improvement.

- Priority substances or other organic compounds are not regulated in WWTP effluents, but they are in surface waters under the WFD [61]. There is a need for the UWWTD to introduce specific measures to address CECs and/or their effects in wastewater systems, and to address the trend of the increasing load and diversity of pollutants due to population growth and the continued synthesis of new chemicals [62].
- Conventional wastewater treatment infrastructure is not designed or operated to remove CECs and they are only partially effective in CEC removal or degradation, resulting in their accumulation in the receiving water bodies [63,64].
- Studies have shown that WWTPs contribute significantly to the release of contaminants into the environment [65]. The removal efficiency of contaminants is strongly dependent on the physical-chemical properties of the CECs and on the WWTP technology used [66].
- Many pharmaceuticals are found in effluents from WWTPs with basic secondary or no treatment, as well as from those with advanced treatment technologies [67,68].
- WWTPs can also act as collection points for antibiotics and antibiotic-resistant microorganisms, becoming sources for environmental dissemination of antibiotic resistance [69].

Issue 3.2. Further investigations are needed regarding the potential of modern treatment technologies for removing CECs.

- Several processes, such as adsorption to activated carbon, ozonation or other advanced (oxidation) technologies, can be adopted for the removal of CECs [70]. Studies have shown that the discharge of investigated compounds from WWTPs into the aquatic environment could be substantially reduced by ozonation, followed by granular activated carbon filtration [71].
- In an appropriately equipped WWTP, a reduction of 80% is possible for many organic micropollutants. However, the degree of elimination is substance-specific and depends on the applied treatment technology used. A study has shown that by upgrading 230 WWTPs of a particular size, 50% of the total amount of wastewater in Germany could be further treated and the release of micropollutants significantly reduced [72].
- Advanced treatment technologies in general have a relatively high energy consumption. The addition of advanced WWT leads to a 5–30% increase in energy consumption on average, depending on the size of the plant, the wastewater quality and methods used [73]. Hence the ecological footprint of advanced wastewater treatment technologies remains an important consideration.

Issue 3.3. There are other treatment processes to manage CECs – which require further study.

- Further improvements could be made to upgrade plants by re-designing the existing treatment processes and/or by optimising the design and operational conditions of the existing biological process. This can include membrane-based processes, biological processes such as conventional activated sludge, natural-based systems, membrane bioreactors and bio-electrochemical systems.
- By adopting the requirements outlined in the UWWTP, a significant improvement with regards to CEC removal could be achieved as WWTPs fulfilling requirements for sensitive areas show significantly improved CEC removal compared to plants operated in non-sensitive areas. New requirements for sensitive areas should be the same with regards to nutrients and the estrogenic activity in effluents should be below the effect-based trigger value. By reducing estrogenic effects by advanced wastewater treatment, not only would estrogenic substances be removed, but also other organic CECs.
- A study estimated the cost of advanced WWT techniques for the elimination of micropollutants in

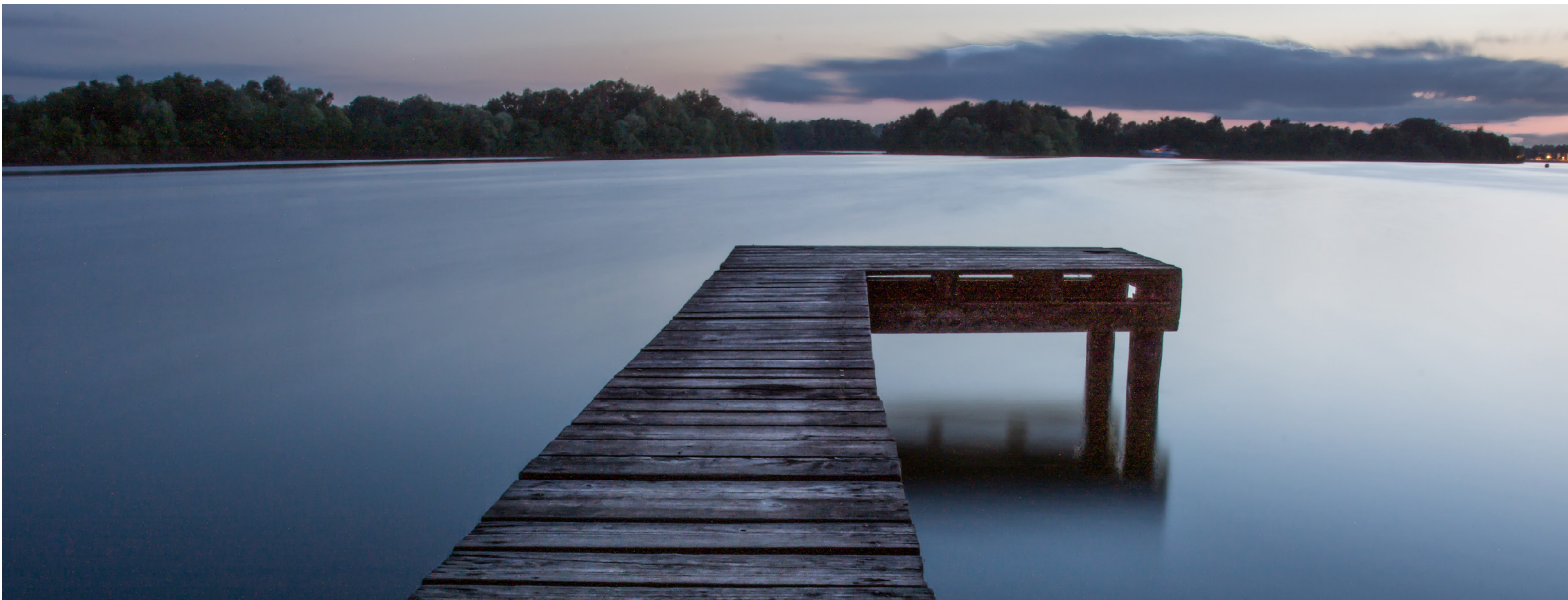
large treatment plants to be about €0.1 - 0.15/m^3, but this varies depending on the method of calculation. In any case, advanced techniques are not yet applied on a regular basis [74]. Alternatives should be explored for the next generation of treatment plants.

Issue 3.4. It is necessary to make the treatment options 'future-proof' – creating enough long-term flexibility for changing conditions due to demographic development and climate change.

- Treatment efficiency should be adaptable to concentrations in the wastewater and should be targeted towards a specified effluent water quality [75]. It connects to the water-fit-for-use principle which will become even more relevant in the circular economy where water re-use for different applications will require different qualities.
- There are patterns of use with chemicals, particularly those related to personal care and medication. A study found the increased occurrence of metabolites of recreational drugs at weekends, hospital dispensed chemicals at weekdays, antihistamines and sunscreen in summer and medications to treat cold symptoms in winter [76]. The increase in highly polar compounds that can pass through WWTPs also requires the development of treatment technologies that address such persistent and mobile organic pollutants [77].
- Treatment technology should be efficient in energy and chemicals demand and have a low environmental impact. The growing trend of improving sustainability and reducing energy demand of WWTPs will see an increase in the application of novel treatment methods. E.g. the potential of using algae ponds for secondary effluent polishing which indirectly produce energy through the production of biogas. Further studies are needed to monitor their performance for CEC removal [78].
- The treatment of CECs should not hinder but foster the development of circular economy principles of recovering water and valuable resources from the treated wastewater. Future wastewater treatment technologies have to consider both of these core challenges. Considering the escalating population growth and increased water stress, reuse of treated water and wastewater recycling are becoming more important [79].

Issue 3.5. A broad approach is needed.

- There are high uncertainties due to the diversity of contaminants, their sources and inputs, unknown contaminants, the impact of chemical mixtures, and the constant engineering of new chemicals. CEC removal also depends on the treatment conditions and the physicochemical properties of the individual compounds. Treatment technologies should cover a broad spectrum of CECs with different properties. However, it is difficult to assess the potential ways in which removal of all CEC classes identified (organic trace pollutants with different physico-chemical behaviour; antibiotic resistance bacteria and genes; etc.) can be enhanced.
- Further investigations on processes to maximize CEC removal while successfully removing conventional parameters are needed to promote a safer reuse of treated wastewater [80]. Advancements in water treatment systems that prove effective and efficient in controlling/eliminating CECs will need to be demonstrated at a full scale to prevent further contamination [81].
- The UWWTD should introduce proactive measures to reduce the emissions of CECs discharged in WWTP effluents and stormwater runoff. Monitoring schemes are also required to discriminate between normal WWTP effluent and specific emissions requiring source-related measures according to the polluter pays principle [82].
- Other options beyond WWTP upgrades include water quality standards, extended producer responsibility, watch lists, environmental labelling schemes, precision medicine, green pharmacy and education campaigns [83].



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