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Advanced wastewater treatment – a proactive protection of the Baltic Sea

New times call for new measures. Advanced wastewater treatment can be part of meeting the challenges of society's ongoing chemical intensification. New water treatment techniques have the potential to significantly reduce emissions of both known and unknown substances to the aquatic environment and reduce the risk of marine pollution.

Innovations in the use and design of chemicals have had a profound impact on our society during the last century. Since 1930, global chemical production has increased from 1 million to 400 million tonnes per year[1], with a steep increase of for instance plastic, pesticide and pharmaceutical production since the 1950's[2–4]. Today, synthetic chemicals are components in virtually all industrial processes and products. More than 140 000 substances are currently pre-registered under the EU chemicals regulation REACH[5], while at the global level, more than 347 000 substances are present on various national inventory lists[6]. Never before have chemicals

Recommendations

- **Create legal incentives** to encourage implementation of advanced wastewater treatment. As is the case for nutrients and organic matter today, treatment efficiency requirements or threshold levels of concentration of chemicals could be included in new legislation related to wastewater such as the revision of the Urban Waste Water Directive or in legislation for water reuse. Increased demands can be put on large facilities where absolute emissions are high and costs per treated volume of water are lower due to upscaling effects.
- **Facilitate forerunners** by making financial instruments available for pilot studies and technical upgrading of WWTPs where there is a will to go beyond current legal requirements.
- **Ensure policy coherence and full implementation** of the Water, Marine and Urban Waste Water Directives. More measurements of the Priority Substances are needed to complete the assessments of Good Environmental Status. Further expansions of the risk assessment and monitoring of environmental pollutants should be included in future Programmes of Measures for the Water Directive.
- **Enable science based policy support** by investing in research to evaluate the importance of wastewater treatment plants as collection points for urban chemical flows to the aquatic environment. Innovative methods to monitor concentrations of a wide spectrum of chemicals and total effect of the chemical mixture are needed to go beyond the single chemical approach that is currently applied.

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been so prevalent in society and our daily lives. And the number of new substances and new usages is ever increasing[7,8].

Thousands of these chemical compounds are emitted to aquatic systems where they can accumulate and lead to negative effects on aquatic organisms[9]. This development has brought new challenges to chemicals management and the well-being of the Baltic Sea environment. Especially since the use pattern has also changed – from the previous use of few chemicals in large quantities, often from point sources, to today's use of many chemicals in small quantities, and from diffuse sources.

Chemicals' pathways to the sea

Chemicals reach the Baltic Sea via several different pathways: deposition from air, via surface runoff, eroded soil, rivers, direct emissions along the coast or at sea - and from outgoing water of wastewater treatment plants (WWTPs). From urban areas, thousands of these so-called micropollutants flow via WWTPs to surrounding waters making these facilities major collection points for chemical flows in society[10].

The micropollutants enter the sewage system for example when we wash clothes, rinse off personal care products or flush pharmaceuticals that have passed through our bodies. Today, conventional WWTPs are not designed to remove these chemicals. In particular pharmaceuticals are often poorly removed as many are by design highly water-soluble compounds that are resistant to biodegradation[11]. By upgrading conventional WWTPs with more advanced treatment technology, specifically designed to remove micropollutants, the chemical emissions to the Baltic Sea could be significantly decreased.

50% load reduction in coastal zone possible

Out of the 615 WWTPs close to the Baltic Sea coast, 45 plants receive wastewater from more than 100 000 connected persons and together treat wastewater from almost 70% of the coastal population[12,13]. Upgrading these large WWTPs with advanced treatment technologies would on average remove 70-80% of the micropollutants in outgoing water[14–20], reducing the total load from all coastal WWTPs by approximately 50%. This measure hence has potential to significantly lower concentrations of a wide range of micropollutants in seawater, thereby enhancing the protection of this sensitive water body.

A general reduction of the total chemical load to the Baltic Sea can be seen as a precautionary measure to lower the risk of what today remain unanticipated adverse effects. This is particularly important for persistent and water soluble chemicals since they easily escape conventional WWTPs[21], spread in waterways and accumulate in aquatic "end-stations" such as the Baltic Sea.

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Costs are lower for large treatment plants

Advanced wastewater treatment is today most commonly used for purification of drinking water and treatment of industrial wastewater. With the exception of forerunners found in Germany and Switzerland, this technology is rarely used in Europe to treat municipal wastewater[22].

There is a range of different available technologies that can be used to remove micropollutants from wastewater. Oxidation of chemicals with ozone or adsorption onto activated carbon are the two technologies mainly tested and implemented in full scale. The choice between the two is case dependent, depending on existing infrastructure, how sludge is to be treated, composition of the wastewater and which chemicals one wants to target. Removal efficiencies differ between them as some chemicals are best removed by ozonation and some by activated carbon. No technology is capable of removing all chemicals but full scale implementations of advanced treatment technologies show that, with reasonable costs (ca 0.1-0.3 euro/m3) and energy demand (ca 0.01-0.3 kWh/m3), chemical concentrations can on average be decreased by approximately 70-80%[22].

Costs and energy demand per cubic meter are lower for large facilities[22], and are also likely to decrease as technologies develop and prices drop with increasing market demand. The costs of additional treatment should be weighed against the benefit of removing chemicals from wastewater, as well as having the cost-effectiveness compared with that of other measures with the same goal.

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Source control is key

The key principle for reducing chemical emissions in wastewater is to regulate use of harmful chemicals already at the production stage[23]. This source control approach protects all environmental compartments and enables enforcement of the polluter-pays-principle. It also facilitates the transition to a circular economy, enabling optimal recycling of materials, and safe reuse of sludge as fertiliser and wastewater for irrigation and aquifer recharge.

Several treaties, directives and regulations are in place to manage chemical risk, but the speed and scope of regulation, success of implementation and extent of compliance are unfortunately insufficient. There is neither adequate information on environmental levels and effects of the majority of chemical substances used, nor cost efficient measures to manage risks[24–28].

A number of fundamental challenges still have to be met before effective and satisfactory source control is achieved (see box). Even if these challenges are met, measures for regulating production and use may still be insufficient in protecting the aquatic environment since:

- the realistic emission reduction potential may not suffice to reduce environmental levels below relevant toxicity thresholds, such as Environmental Quality Standards[29].
- there are difficulties in regulating and reducing use of environmentally concerning substances with invaluable benefits for humans such as pharmaceuticals and efficient firefighting foams[30,31].
- several banned chemicals, such as PCBs and DDT, are still circulating in the environment, despite the fact that primary emissions of these chemicals have already been radically reduced[32].

Current limitations of source control

- Regulation of chemicals is done one- by-one and usually takes several years. The regulated substances are often substituted by compounds exhibiting similar properties.
- Regulation is reactive and clear adverse impact must be observed in the environment before decisions are made.
- Risks due to combination effects and effects of unknown degradation products are not considered.
- Chemicals cross national borders via import/export of products, as well as moving air and water masses. Current EU regulation of hazardous substances in imported products is insufficient and global treaties have limited scope and compliance.
- Criteria for identifying hazardous substances are not appropriate to protect the environment from unanticipated effects or emerging pollutants with unusual properties. This makes the prioritisation of which chemicals to assess and the balancing of protective thresholds with socioeconomic values difficult.

These circumstances mean end-of-pipe measures, such as advanced wastewater treatment, are required to sufficiently reduce environmental levels of many hazardous substances.

Avoiding future pollution of a sensitive sea

The Baltic Sea is often described as a vulnerable environment. The long residence time of water[33], combined with sensitive marine organisms and the wide spectrum of pollutants emitted from the ca 85 million inhabitants[34,35] in the Baltic Sea catchment area, put the ecosystem under high environmental pressure[36].

History has taught us that chemical contamination can have catastrophic and long lasting consequences. For PCBs and DDT, two legacy pollutants largely banned in the 1970s, levels still exceed toxicity thresholds in many parts of the Baltic Sea, some 40 years after the emissions peaked[37,38].

This detrimental pollution occurred in an era of weak or non-existing chemicals legislation and low awareness of chemical threats. Chemicals management has developed over time, many hazardous substances have been identified and point sources rectified. Today, few adverse effects observed in field studies can be linked to specific chemical contaminants or combinations of these in the Baltic Sea[36]. However, the general lack of data on concentrations of contaminants, and the lack of assessments of ecotoxicological effects, combined with obscuring effects of multiple stressors – including eutrophication, overfishing and climate related changes – make it difficult to assess the true chemical status of the Baltic Sea[39].

In fact, thousands of chemical compounds are emitted to the aquatic system[9]. The exact number and identity of man-made substances present in this system is unknown because monitoring of micropollutants is expensive and time consuming. For example, the Water Directive and the Marine Directive include a list of 45 priority substances with defined Environmental Quality Standards (EQS), i.e. concentration thresholds that should not be exceeded in the aquatic environment. The levels of several of these priority substances exceed EQS, indicating that Good Chemical Status is not achieved for several water bodies. However, even for this limited set of chemicals, existing monitoring data is not sufficient to evaluate the chemical status in many water bodies and the majority of assessments are based on only a few indicator substances[40].

More than 1000 chemicals that are rarely monitored, but known or suspected to cause adverse ecological effects, have been identified in European waters[41]. Almost half of the European freshwater bodies have been identified as likely threatened by chronic long-term effects on sensitive aquatic organisms, but due to a lack of data this is likely an underestimation[42]. Numerous laboratory studies show negative effects for many chemicals widespread in our aquatic environment, but the consequences for populations in the wild are difficult to predict[43]. Therefore, the magnitude of the environmental impact is largely unknown.

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Putting water treatment on the EU agenda

This circumstance calls for precaution and proactive protection of water resources. WWTPs are one of few collection points for chemical flows in our society providing an opportunity to remove a broad range of chemicals emitted from human activities from the water cycle. The limited knowledge about major entry routes to water bodies, of current levels and effects of most chemicals on the market – as well as mixture effects – hinders evaluation of the benefit associated with reduction of this multitude of substances in wastewater by updating WWTPs with new and often costly technology. The benefit of removal of known and unknown substances has previously been estimated e.g. by measuring peoples' willingness to pay for protection of water resources or the estimated socioeconomic value of these resources[44–46]. These assessments indicate that economic benefits exceed the costs of additional treatment. The actual value of this precaution is however impossible to estimate.

Increasing water scarcity and recent examples of contamination of drinking water reservoirs has put the issue of protecting water resources, and the safe reuse of those already available, on the European agenda. Past experiences show that remediation of polluted environments can be nearly impossible and costs substantial. This gives an indication of the potential price of inaction.

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