Tackling persistent, mobile and toxic substances in the aquatic environment through prevention, prioritization and removal strategies

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Sammendrag

Håndtering av persistente, mobile og giftige substanser i akvatisk miljø gjennom strategier for beskyttelse, prioritering og fjerning. Rent drikkevann er avgjørende for menneskers liv. Imidlertid har en ny generasjon av miljøgifter økt i konsentrasjon i drikkevannskildene, i tillegg til å bli funnet oftere i menneskeblod. Disse miljøgiftene kalles persistente, mobile og toksiske (PMT) stoffer og veldig persistente og veldig mobile (vPvM) stoffer. Disse stoffer brytes ikke ned i miljøet selv over betydelige tidsskalaer og de kan bevege seg lange avstander med vann (persistent og mobil) og i noen tilfeller fører de til negative effekter på økosystemet og mennesker. Mange av oss kommer i kontakt med disse stoffene daglig, og vannindustrien sliter med å finne rense metoder for å fjerne dem fra drikkevannskildene. For øyeblikket utvikles europeisk kjemikalieregelverk for å være mer beskyttende og sikre rent vann. Det er forebyggende tiltak som er mer effektive enn retrospektive løsninger som tar tak i problemet etter at det har oppstått. Tilnærmingen skissert i europeisk kjemikalieregelverk gjenspeiles av den som ble tatt av det nye EU H2020 forsknings- og innovasjonshandlingsprosjektet ZeroPM: Zero pollution of persistent, mobile substansens. ZeroPM har satt seg som mål å være et veisøkende prosjekt som gjør at ambisjonene i EUs Green Deal-strategi om null forurensning av persistente og mobile stoffer kan bli en realitet på bakken.

Summary

Safe and clean drinking water is essential for human life. However, a new generation of pollutants have been increasing in concentration in the sources of drinking water as well as being found more commonly in human blood. These pollutants are called persistent, mobile and toxic (PMT) substances and very persistent and very mobile (vPvM) substances. By nature, these substances do not breakdown in the environment over appreciable timescales and can travel long distances with water (persistent and mobile) and in some cases cause negative effects on the ecosystem and humans. Many of us come in to contact with these substances on a daily basis and the water industry struggles to find remediation methods to remove them from the sources of drinking water. Currently, European chemicals legislation is developing to be more protective and safeguard clean water spearheaded by the Chemicals Strategy for Sustainability towards a Toxic Free Environment. It becomes

clear that preventative approaches are more effective than retrospective remediation solutions that address the problem after it has occurred. The approach outlined in the Chemicals Strategy is mirrored by that taken by the new EU H2020 research and innovation action project ZeroPM: Zero pollution of persistent, mobile substances. ZeroPM has set itself the goal to be the pathfinding project enabling the ambitions of the European Union's Green Deal strategy of zero pollution of persistent and mobile substances to become an on-the-ground reality.

Introduction

Safe and clean drinking water is essential for human life. Drinking water suppliers are tasked with ensuring that the water we drink is pollutant free. It has become clear over the past twenty years that a new generation of pollutants have been increasing in concentration in the sources of drinking water as well as being found more commonly in human blood. Regulators and scientists are referring to this new wave of pollution as persistent, mobile and toxic (PMT) substances and very persistent and very mobile (vPvM) substances. A solution is needed by regulators, industry, drinking water producers and scientists to ensure that future generations can enjoy safe and clean drinking water.

This article will highlight the current state of play related to persistent, mobile and toxic and very persistent and very mobile substances. Scientific aspects such as remediation methods, analytical gaps and current PMT/vPvM substances attracting attention will be detailed. The political arena as a mechanism for movement is also discussed. The need to focus on preventative strategies which minimise the production, use and release of these substances to the environment is highlighted. This is in contrast to retrospective solutions that tackle the pollution after it has occurred. Finally, the article presents the new Horizon 2020 Research and Innovation action project called ZeroPM: Zero pollution for persistent, mobile substances which aims to interlink prevention, prioritization and removal strategies to protect the environment and human health from persistent and mobile substances.

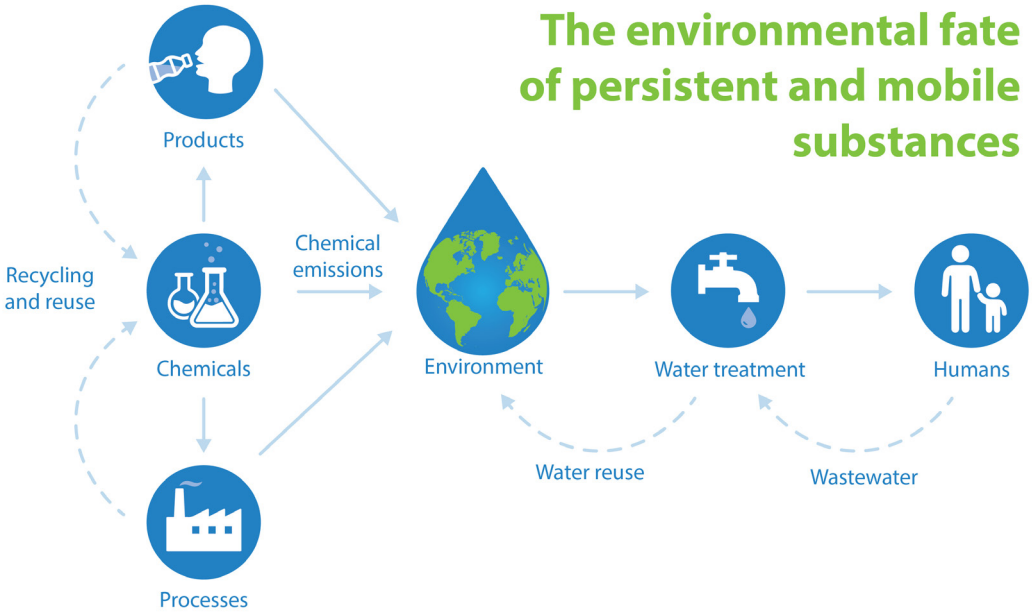

Figure 1. Fate of PM substances: Persistent and mobile substances do not break down and can be transported large distances with water ultimately reaching humans. Source: Maren Johnsen, NGI

Why PMT/vPvM substances are increasingly problematic

PMT/vPvM substances are problematic as once they enter the aquatic environment, they are able to spread very far over intergenerational time scales (Figure 1). They can reach the sources of our drinking water and once there, they cannot be removed without significant financial investment [1]. Current research about these substances indicates that they have been increasing in variety [2] and concentration [3] in the environment over the past decades. PMT/vPvM substances, are, as their name suggests, persistent in the environment, meaning they are not biodegraded over appreciable timescales. They are also mobile, which in this context means that they can travel long distances with water, becoming widely distributed spatially (Figure 2). If these persistent and mobile substances are also toxic, it means that they can exert negative effects on the environment and ecosystems.

Why are we only seeing this new generation of contaminants now? There are three reasons. The first is that the chemical industry is innovating all the time and as chemical synthesis is ever improving we are simply producing more chemicals than ever. Some of these chemicals enter drinking water and via uptake to humans can reach human blood. The second reason is related to the improvement of chemical regulations that has taken place over the last 50 years. The development of recent regulations, such as the Stockholm Convention on Persistent Organic Pollutants and the European Union's REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals, EC 1907/2006) which focus on Persistent, Bioaccumulative and Toxic (PBT) substances and very persistent and very bioaccumulative (vPvB) substances, has caused innovation to shift towards chemicals that are less hydrophobic (preferring lipids) and more hydrophilic (preferring water). The third reason is that we have started to look for these contaminants. With increasing regulatory focus comes more stringent monitoring requirements which have resulted in a general increase in the frequency of detection of these contaminants.

Current "hot" PMT/vPvM substances

Most of us own Teflon pans and, especially in Norway, it would be hard to find someone

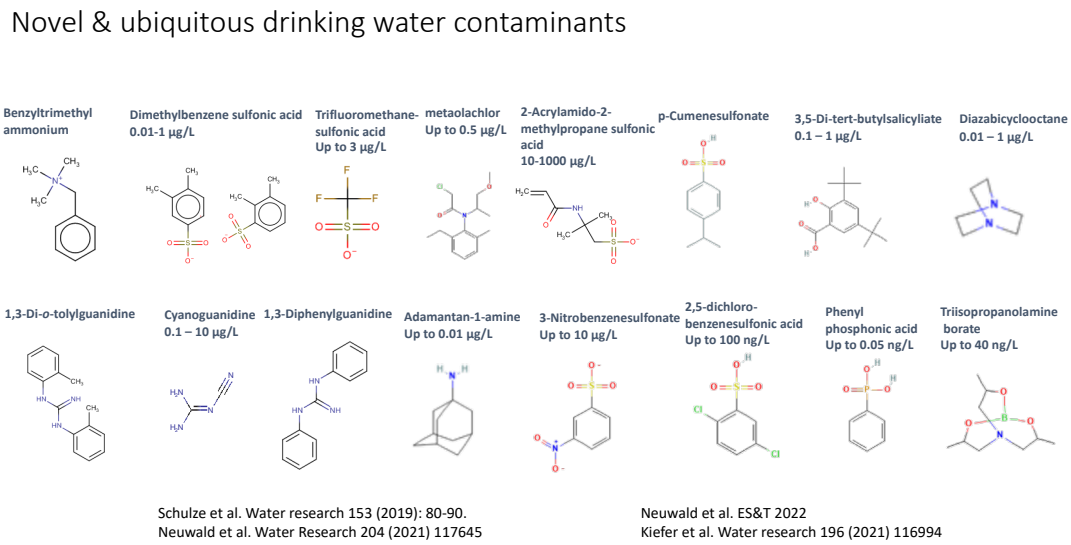

Figure 2. Novel and ubiquitous drinking water contaminants: Many recent monitoring studies have reported the presence of never before detected PMT/vPvM substances. Source: authors own

without a Gore-Tex jacket. What most people probably do not know is that these products can contain and release PMT/vPvM substances, specifically mobile per- and polyfluoroalkyl substances (PFAS). PMT/vPvM substances are used in a wide range of products, several of which can be found in kitchens, offices and outdoors. Dishwashing and clothing detergents can often contain benzotriazole which is a corrosion inhibitor. Plates and cups that are made of bamboo might also contain melamine which is added as a resin to prevent scratching and cracking. 1,4-dioxane is found in makeup, shampoo and certain soaps. Another highly profiled PMT/vPvM substance is trifluoracetic acid, which is a by-product of many refrigerants, agricultural chemicals and pesticides. Occurrence and concentrations of trifluoracetic acid have been found to be increasing in drinking water and even in arctic water dramatically over the past 20 years [4,5]. All of these PMT/vPvM substances are examples that we come into contact with on a daily basis and emit into the environment, where they can eventually reappear in our drinking water.

As the chemical industry innovates, remediation methods fall behind

The number of substances on the global market is ever increasing as the chemical industry innovates. The current estimate is around 350 000 and the proportion of these which are PMT/vPvM substances is still unknown [6]. With the increasing number of substances, it is important to consider whether changes to chemical and water resources management need to be made in order to safeguard water resources from PMT/vPvM substances.

This is especially pertinent as there is no single current remediation solution that can be used to remove all of the known PMT/vPvM substances, let alone the novel substances that will be placed on the market in the future. One of the most widely used advanced remediation methods relies on adsorptive removal via the use of activated carbon. However, because many

Figure 3. Waterworks for PFAS treatment: Remediation of PMT/vPvM substances is extremely difficult. Source: Marcel Riegel, DVGW-TZW

PMT/vPvM substances are not aromatic and/or ionizable or ionic, this method may fail. It is possible to use reverse osmosis and nanofiltration methods to purify drinking water, but these techniques are energy intensive and produce a waste concentrate which has to be disposed or remediated itself. Ultimately, they are extremely expensive [1] (Figure 3).

It is interesting to ask ourselves – what happens if there is no action? This question has been answered for perhaps the most well-known group of PMT/vPvM substances, PFAS in a report aptly entitled "The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS" [7]. Costs related to identification, screening and remediation of sites contaminated with PFAS across Europe is estimated to be around €10-20 billion per annum. This cost only covers immediate interventions and does not account for costs related to, for example, increased healthcare demands, ecological damage, property loss and impacts on the agricultural sector. In such cases, the overall cost to the EEA could be in the region of €52-84 billion per annum. It is therefore imperative that we act now.

The case of "regrettable substitution" and "regrettable remediation"

There are two central dilemmas related to PMT/vPvM substances. One is "regrettable substitution" and the other is "regrettable remediation". Regrettable substitution occurs when one substance is banned or restricted and replaced with a substance that has a similar or a different kind of hazard, but where the hazard is of the same or worse degree than the original substance. An example can be seen for the replacement of many long chain PFAS which were restricted and banned because they were PBT and vPvB substances. However, they were replaced with shorter chain PFAS that are PMT and vPvM substances. Regrettable remediation occurs when remediation efforts are put into place that are extremely costly, non-sustainable, or ineffective, leading to "the cure being worse than the disease". This is an issue with many PMT/vPvM substances due to the environmental and economic costs that are associated with removing them. It becomes questionable whether billions of Euros of tax payer's money should be used to remove the very last few nanograms of a PMT/vPvM substance if, for example, there is no exposure to the environment and humans from the substance in question. A holistic approach is needed in order to weight costs against benefits and assess such dilemmas.

Gaps in analytics, monitoring and regulation

Even though there are now more monitoring requirements and we are finding an increasing variety of PMT/vPvM substances in our water resources, there are still very few of these substances that are regulated [2]. Many recent monitoring studies have reported the presence of never before detected PMT/vPvM substances.

Without legislative pressure, companies have no incentive to monitor and demand for analysis is not present. Without demand, analytical method development is stalled and thus the cycle continues. If the correct regulatory tools were in place, demand would increase and so would method development. Certain laboratories can measure the concentration of many PMT/vPvM substance using chromatographic techniques. Combined these factors should collectively address the analytic, monitoring and regulatory gaps [1]. However, given the huge number of PMT/vPvM substances in the environment and that fact that many of these remain unknown and undetected, a paradigm shift is needed. Luckily this is now arguably underway.

The political future is bright

The EU has one of the most comprehensive and protective regulatory frameworks for chemicals in the world, with the REACH regulation and the CLP regulation (Classification, Labelling and Packaging) aiming to provide a high level of protection to the environment and human health. In October 2019 the European Commission released the Chemicals Strategy for Sustain-

ability Towards a Toxic free Environment (referred to here as the Chemicals Strategy [8]) (Figure 4). The document outlines the new long-term vision for the EU's chemical policy and is part of the European Green Deal where the overarching objective is for the EU to become the first climate neutral continent by 2050. The Chemicals Strategy strives for a toxic-free environment, where chemicals are produced and used in a way that maximises their contribution to society including achieving the green and digital transition, while avoiding harm to the planet and to current and future generations.

The Chemicals Strategy presents bold new action points that reflect the challenge associated with certain PMT/vPvM substances, and particularly focuses PFAS. Specific points include proposing new hazard classes and criteria in the CLP regulation for PMT/vPvM substances and adding PMT/vPvM substances to the list of Substances of Very High Concern (SVHC) under Article 57 of the REACH regulation. Additionally, it seeks to define the criteria for "essential use" to ensure that the most harmful chemicals are only allowed if their use is necessary for health, safety or is critical for the functioning of society and if there are no alternatives that are acceptable from the standpoint of environment and health. Finally, it seeks to restrict all PFAS in a broad manner to ensure a PFAS phase out for "all but essential uses".

Prevention is better than cure

Improvements to the current regulatory framework is one form of upstream, proactive measure that can be taken to protect the environment and human health from PMT/vPvM substances. By preventing the production, use and release of PMT/vPvM substances, downstream, reactive measures will be needed less. Preventative actions could also include stimulating change via the development of safe and sustainable alternatives to harmful PM substances. This then paves the way for green innovation. The Chemicals Strategy calls for a transition towards a new approach for how we use and assess substances. This new approach should increase the ability to generate goods in ways that minimize harm from chemicals along lifecycles of the chemicals and the products they are used in over the long term. The approach is referred to as Safe and Sustainable by Design [9]. Steps can be

Figure 4. Chemicals Strategy for Sustainability Towards a Toxic free Environment: The EU have proposed an ambitious plan for chemicals management over the years to come. Source: European Commission

taken to develop safe and sustainable alternatives for harmful PMT/vPvM substances, but it is important to decide which harmful PMT/vPvM substances should be focused on first.

Deciding how to prioritize

Prioritization could be based on exposure and toxicological hazards. Exposure levels of certain PMT/vPvM substances can be approximated by identifying uses of the substances and looking into production volumes and monitoring studies. The main exposure route of PMT/vPvM substances to humans is long term exposure via drinking water consumption. Toxicological data in this area is lacking. A key way to avoid regrettable substitution is to prioritize groups of PMT/vPvM substances, rather than individual substances. This helps avoid the substitution of one hazardous substance with another in the same group (e.g. one PFAS for another PFAS, or one bisphenol for another bisphenol). Both the European Commission and the European Chemicals Agency (ECHA) are currently working on grouping approaches. Substances can be grouped based on similar uses (e.g. flame retardants, pigments), similar chemical structure (e.g. PFAS, bisphenols), or based on common environmental degradation products (e.g. precursors of melamine). One way to avoid regrettable remediation is to group by transformation products, as several remediation methods can enhance or catalyse reactions that lead to hazardous transformation biproducts. These remediation methods should, therefore, be avoided. In addition, there are some remediation methods that may be more effective for some substances within a hazardous group, than for others.

Thus, grouping emerges as a key tool to support effective prevention and removal strategies for PMT/vPvM substances. As an additional example to PFAS, one can consider the triazine group, which is characterised by an aromatic ring with three carbon atoms and three nitrogen atoms. Many trazines are high production chemicals and they have now been ubiquitously detected in the environment. Examples include melamine and several plant production products, including the recently banned atrazine. Grouping triazines will support better protection of the environment and human health.

Prevent – prioritize – remove

The approach outlined in the Chemicals Strategy is mirrored by that taken by the new EU H2020 research and innovation action project ZeroPM: Zero pollution of persistent, mobile substances. ZeroPM has set itself the goal to be the pathfinding project enabling the ambitions of the European Union's Green Deal strategy of zero pollution of persistent and mobile substances to become an on-the-ground reality. ZeroPM will interlink and synergize three strategies to protect the environment and human health from persistent, mobile substances: Prevent, Prioritize and Remove (Figure 5). To Prevent, ZeroPM will develop scientific, policy and market tools for the substitution and mitigation of prioritized persistent and mobile substances to safer and sustainable alternatives. To Prioritize, ZeroPM will identify the groups of persistent and mobile substances requiring the most urgency to act upon; considering the sustainability aspects of removal. To Remove, ZeroPM will explore real-word scale remediation solutions, and find the limits of their sustainability. ZeroPM will integrate the Prevent, Prioritize and Remove strategies through an evidence-based multilevel framework. The framework will guide policy, technological and market incentives to minimize use, emissions and pollution of entire groups of persistent and mobile substances. Through this systemic approach to chemical pollution, the EU will be better able to avoid regrettable substitution and regrettable remediation.

ZeroPM started in October 2021 and will run for 5 years. The project brings together 15 partners with diverse backgrounds and is led by the Norwegian Geotechnical Institute and Project Coordinator Sarah Hale and Deputy Coordinator Hans Peter Arp. More information about the project can be found at www.zeropm.eu.

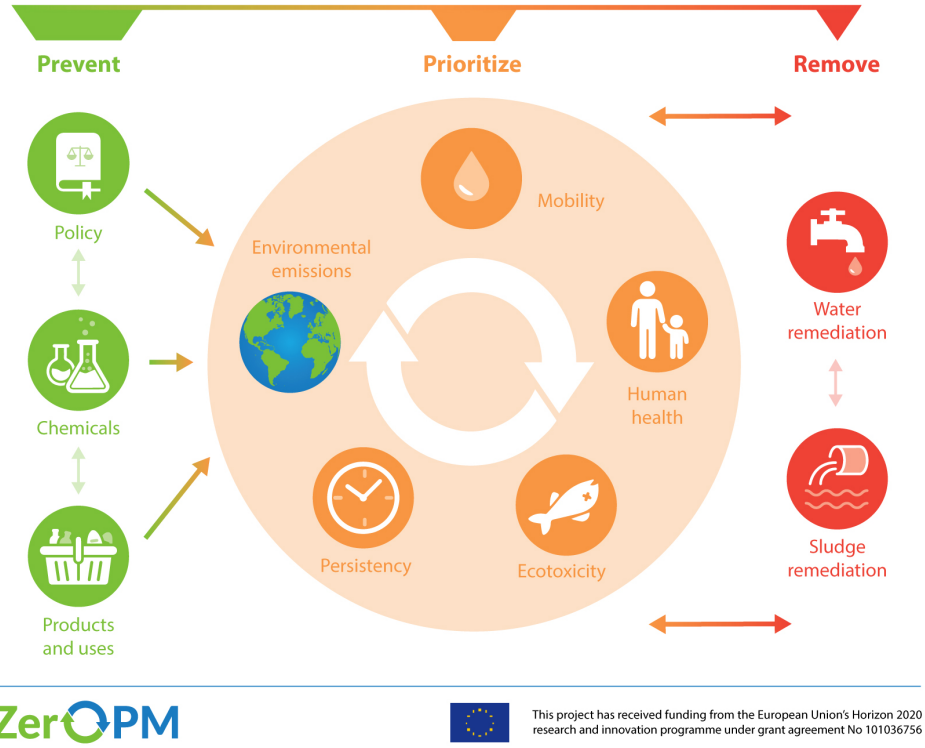

Figure 5. ZeroPM concept: ZeroPM will interlink prevention, prioritization and removal strategies to protect the environment and human health from persistent and mobile substances. Source: Maren Johnsen, NGI

Acknowledgement

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