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Treatment of emerging pollutants in water using bioremediation technology

The development of new products for human use has led to the use of more chemicals, many of these unregulated and under researched. These include agricultural compounds, pharmaceuticals, personal care products and endocrine disrupting compounds that end up in our waterways and are known as Emerging Pollutants (EP). Without the proper infrastructure in Wastewater Treatment Plants (WWTP) to filter them out of our water or sufficient government regulations to control industrial effluents containing these pollutants, they will inevitably end up in the environment. Atrazine is an herbicide known to cause reproductive harm in humans and other organisms. Ethinylestradiol (EE2) is a synthetic estrogen capable of feminizing male fish, hinder reproductive development and overall damage reproductive success in aquatic species. Polyfluoroalkyl Substances (PFAS) are a group of "forever" chemicals connected to developmental delay, certain cancers, liver toxicity, and other health effects in humans and other organisms. All of these chemicals are considered emerging pollutants that have made their way into the environment. Due to their threat on human and environmental health, the need to treat water for emerging pollutants is urgent. These chemicals can be eliminated from our water through bioremediation techniques such as using microbial bacteria, algae and phytoremediation strategies, which have the potential to become environmentally and economically sustainable solutions that could provide clean water to both humans and wildlife.

Emerging pollutants, which can also be known as emerging contaminants, are defined as chemicals that present potential threats to human and environmental health, have not yet been regulated, and lack public health standards. These chemicals can also be considered "emerging" because of the discovery of new sources and effects that were not known before (Murnyak et al. 2011). Many chemicals known to be emerging pollutants are also Endocrine Disrupting Compounds (EDCs), that alter hormonal function in aquatic organisms and can cause concerning reproductive effects even when exposed to low concentrations (US EPA 2025). Atrazine, ethinylestradiol, and PFAS are three types of chemicals that can be considered emerging pollutants due to the developing concern regarding their effects on human and environmental health as well as lack of corresponding regulations and procedures to keep them out of public waterways.

Atrazine is a chlorinated triazine herbicide used to control broadleaf and grassy weeds, it is used for agricultural purposes in corn and sugarcane crops as well as non-agricultural, in ornamental, nursery and turf vegetation (US EPA 2025). Application of atrazine itself can result in some loss of product into the soil and atmosphere, where it can deposit in the water. It can also enter water through runoff onto surface water and percolate into groundwater (Agency for Toxic Substances and Disease Registry (US) 2003). This is concerning because Atrazine can affect hormone function, cause birth defects, reproductive tumors, and weight loss in amphibians (Ma et. al. 2017). It also has long-term endocrine disrupting and reproductive effects and is a probable human carcinogen (El-Bestawy et al. 2013). Regarding the regulations on Atrazine in the US, as of July of 2024, the EPA has set a limit of 9.7 µg/L of Atrazine in drinking water (EPA 2024). Atrazine is also on the EPA's restricted use pesticide list, meaning only certified pesticide applicators can use them (US EPA 2025).

External application is not the only way chemicals can reach Public Water Systems (PWS). Ethinyl estradiol is a synthetic steroid that is usually combined with other drugs for contraception, treatment of premenstrual dysphoric disorder, acne, menopausal symptoms and postmenopausal osteoporosis (National Center for Biotechnology Information 2025). The main source of EE2 in water is through WWTP effluents, since it is primarily used in oral contraceptives, the unmetabolized hormones are excreted in the form of feces or urine (Atkinson et. al. 2012). Current WWTP are not designed to remove synthetic estrogens from wastewater, but are able to remove 67-80% (Guerrero-Gualan et. al. 2023). However, this is not enough to prevent EE2 from harming wildlife, since even extremely small traces of synthetic estrogens can cause reproductive harm in aquatic species. EE2 hinders enzyme production in copepod crustaceans (Souza et. al. 2013), and it is also capable of skewing female to male sex ratios in freshwater killifish (Jackson & Klerks 2020). In one study, male gulp pipefish showed traits of feminization, lacked reproductive success, were unable to mate, and showed abnormal brood pouch morphology when exposed to EE2. These effects persisted up to four days after their removal from the EE2 contaminated environment (Rose et. al. 2013). Even the smallest amount of synthetic estrogens in the aquatic environment could cause the collapse of populations of species. Despite this, in the United States there are no federal regulations regarding the

Maximum Contaminant Levels (MLC) of ethinyl estradiol in PWS, however, EE2 became part of the EPA's Unregulated Contaminants Monitoring Rule list in 2013 for Screening Survey monitoring, requiring PWS to test for its presence (US EPA 2024). EE2 is also part of the EPA's Endocrine Disruptor Screening Program (EDSP), used to monitor, screen and research potential endocrine disruptors in drinking water, and is required by the Safe Drinking Water Act (US EPA 2025).

Polyfluoroalkyl Substances (PFAS) are a group of synthetic chemicals that have been used to create many products for human use such as cookware, anti-stain clothing and carpets as well as firefighting foam (National Institute of Environmental Health Sciences 2025). They can enter drinking water through industrial effluents, WWTP effluents, land applied with contaminated sludge, landfill leachate and firefighting foams (New Jersey Department of Health 2024). Due to their carbon-fluoride bonds, PFAS are resistant to decomposition, withstanding WWTP treatment methods (Coulson 2024). Certain levels of PFAS may cause reproductive effects and high blood pressure in pregnant women, developmental delays in children such as low birth rate, accelerated puberty, bone changes and behavioral changes. PFAS are also linked to cancers such as kidney, prostate, and testicular cancer. Reduced vaccine response, interference with the endocrine system, and increased cholesterol are also health risks associated with PFAS exposure (US EPA 2024). PFAS also decrease microbial diversity in sediments (Sun et. al. 2016). Less diversity of microbial communities in sediments can affect soil functioning and Nitrogen cycling (Saghaï et. al. 2022). In a study done regarding the effect of PFAS on zebra fish, significant reduction of body length and weight as well as accumulation of lipids in the liver was observed in male fish after being exposed to PFOS (Du et. al. 2009). As for US regulations of PFAS in water, in 2024 the EPA announced the final National Primary Drinking Water Regulations. Etsablishing MCLs for six types of PFAS. Monitoring of these PFAS in PWS must be completed by 2027. Those currently exceeding MCL have until 2029 to implement solutions to lower levels. By 2029, PWS exceeding MCL must take corrective action and notify the public of the violation (US EPA 2025). This regulation only covers 6 of more than 12,000 types of PFAS that exist, and not all can be detected under current tests (USGS 2023).

The development of methods to remove these pollutants from the environment is crucial. No human or animal should have their health compromised due to contaminated water. These methods should be clean, economically feasible, scalable, and effective. Promising solutions to remediate PWS of these chemicals include using certain types of bacteria, algae and plants to decompose or absorb them. Specific strains of bacteria are capable of degrading Atrazine in water or soil, which have the potential to be harnessed for large-scale treatments that would be cost efficient and would require minimal waste management procedures (Rostami et. al. 2021). CX-T is a naturally occurring bacterial strain found in riverside soil. It can degrade Atrazine in 30 hours and mineralize it into non-toxic cyanuric acid, even using the acid as a nitrogen source, allowing full biodegradation (Ma et. al. 2017). Another method to treat Atrazine in water is using the properties of algae *Cladophora* and bacteria phylum *proteobacteria*. The algae and bacteria work synergistically to degrade Atrazine and were capable of degrading it to levels below EPA regulations in 25 days. The algae was able to buffer the chlorine and ammonia produced by the bacteria during Atrazine degradation, which otherwise would hinder the ability of bacteria to further degrade the chemical (Xu et. al. 2023).

Atrazine isn't the only chemical that can be removed by bioremediation. Sustainable solutions for synthetic estrogen remediation also demonstrate promising results. White rot fungus (*Pleurotus ostreatus*), also known as abalone, oyster, or tree mushrooms, is a popular edible mushroom. Spent straw substrate containing this fungus sourced from an oyster mushroom farm was capable of significantly biodegrading EE2 in a wastewater bioreactor along with other EDCs. The availability of this type of mushroom and the inexpensive materials show that this method is both financially feasible and effective (Křesinová et. al. 2018). Bacteria can also be used to treat EE2 contaminated wastewater. Microorganism strains *R. zopfii* Y 50158 and *R. equi* Y 50155, Y 50156, and Y 50157 degraded EE2 by 80% in 24 hours. These bacteria strains could be cultured in bulk and introduced into bioreactors in WWTP (Yoshimoto et. al. 2004).

PFAS may seem difficult to remove due to their title of "forever chemicals", but there is also a natural, sustainable solution to rid PWS of them. Phytoremediation is a form of bioremediation using the natural ability of plants to absorb, accumulate, and degrade pollutants (US EPA 2012). Plants are capable of uptaking PFAS from contaminated water or soil and distributing them within the plant body. They can also secrete enzymes in the rhizosphere that can degrade PFAS through enzyme-catalyzed oxidative humification reactions (ECOHRs). Using phytoremediation, wetland plants such as *Carex rostrata* can be used to purify contaminated water. These plants could be mounted on rafts as "floating wetlands" in contaminated water bodies, absorb PFAS and then be harvested (Greger & Landberg 2024).

As more is learned about the effects of emerging pollutants present in drinking water sources and aquatic environments, more is the urgency to develop ways to remove them. Man made chemicals are present in many products and leach into the environment through industrial and WWTP effluents, runoff from agricultural crops, landfills, and many other sources. Current wastewater treatment plants were not designed and built to handle these pollutants, allowing them to enter sources of drinking water and the aquatic habitats of other organisms. This presents a threat to human and environmental health, mainly to the endocrine and reproductive systems of organisms living in and humans consuming contaminated water. Although the United States government regulates a few of these chemicals, this is not enough to prevent them from entering the environment and becoming available to humans and wildlife. Development of methods using the principles of bioremediation is the most promising way to rid water of EPs. Bacteria, algae, and fungus capable of naturally degrading chemicals along with plants that can absorb and degrade them are the pathway to cost-effective, waste-free, and effective solutions that will provide clean water for all.

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