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Passive ecosystem services, juxtaposed with engineered processes, can democratize wastewater treatment

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Due to technological, economic and environmental constraints, contemporary treatment plants cannot treat all wastewater. In particular, the very high amount of agricultural and urban runoff to be treated is increasingly concerning, especially with more erratic – and unpredictable – rainfall events. Combining passive ecosystem services with engineered processes can be used to create hybrid, locally adapted, inexpensive, and sustainable technologies to more feasibly treat runoff and wastewater globally.

Globally, an estimated 80% of wastewater is discharged into aquatic ecosystems untreated.[1] The amount of untreated wastewater discharged in the environment is variable among economies, with a trend toward less treatment in lower-income economies and more treatment in higher-income economies. In some economies, as much as 95% of wastewater goes untreated,[1] whereas in others the number is as little as 4%.[2] The term "wastewater" can be used to include municipal and industrial wastewater, as well as agricultural and urban runoff. When treated, wastewater is generally processed using dedicated infrastructure (i.e., wastewater treatment plants), where eliminated contaminants end up in a sludge that must be dewatered, landfilled, or incinerated. Mechanical, engineered, and closely monitored processes, such as aggregation, settling, filtration and disinfection, are essential to comply with government regulations that protect public health and aquatic ecosystems. However, wastewater treatment plants are expensive and have a considerable carbon and energy footprint. Moreover, wastewater treatment plants are expected to be subjected to great pressure owing to increasing water consumption, intensive urbanization, impermeabilization of cities, and erratic rainfall events associated with climate change.[3,4] In most geographies where treatment plants exist, they are only used for municipal sewage and industrial wastewater, as agricultural and urban runoff are often considered to be "not contaminated enough" to justify the treatment cost and footprint, and therefore are not systematically treated even though they release several contaminants into aquatic ecosystems.[5] Moreover, because (as mentioned above) a large fraction of municipal and industrial wastewaters are minimally treated or not treated at all due primarily to high costs, the need for widely available treatment technologies has become urgent.

We argue that to reduce the load on existing wastewater treatment plants and treat waters that are currently left untreated, more passive custom-made processes that use low-cost materials, such as *in situ* decentralized interceptors acting as a smaller contaminant retention unit (e.g., passive aggregation-settling system, infiltration area, bioretention cells) should be universally adopted.[6,7] Unlike engineered and centralized water treatment plants, interceptors locally isolate contaminants within strategically selected environmental compartments rather than removing, accumulating, and concentrating them as a residue (e.g., in water treatment plant sludge). Consequently, such interceptors would not require sludge management (or would require minimal sludge management), and the contaminants would be locally sequestered and/or (bio)degraded via ecosystem services.[7] Interceptors can be strategically placed to avoid unwanted ecotoxicological effects within vulnerable ecosystems and to protect natural waters and drinking water sources downstream.

Interceptors can be a low-cost processing option for effectively treating agricultural and urban runoff, most of which enters our environment untreated today.[1] As an example, passive riparian zones intercept several contaminants from agricultural runoff, such as pesticides, fertilizers, manure, heavy metals, salts, and pathogens.[8] Combining the advantages of efficient engineered systems and low-cost passive interceptors, such as functionalizing soil in riparian zones (Fig. 1c and d) with metal (hydr)oxides to increase interactions with the most challenging contaminants (e.g., adsorb soluble phosphorus, organic matter, and pesticides via electrostatic affinities) can enhance interception and agricultural sustainability. Other examples of engineered (eco)interceptors to limit the transport of contaminants from agricultural runoff in groundwater and surface water are presented in Fig. 1.

Passive ecosystem services can be standalone water decontamination units or used as catalysts for engineered processes, i.e., common engineered water treatment processes could be rethought and reconfigured as passive (eco)interceptors to be democratized and implemented at a low cost globally. Biological filtration and other biodegradation processes (e.g., using specific indigenous and locally available microorganisms), photooxidation, photodegradation, and inactivation (e.g., with redirected natural UV light), aerobic oxidation (e.g., by aeration via sparging systems, Fig. 1a), sequestration by aggregation/settling (e.g., using natural polysaccharide-based flocculants, Fig. 1b), and adsorption on natural surfaces or functionalized soils (e.g., soil grafted with metal (hydr)oxides, Fig. 1c and d) could all be used as natural/ecosystem services and intensified in a dedicated infrastructure *in situ*. Passive/engineered (eco)interceptors presented in Fig. 1 are tunable and could consequently be adjusted to treat or partially treat several types of industrial and municipal wastewaters as well as urban runoff[9] – not only agricultural runoff. Existing and future physical barriers fragmenting or rerouting rivers such as weirs, dams, urban reservoirs, sluice gates, channels, waterways, and culverts (> 1,200,000 barriers in Europe)[10] present opportunities for implementing (eco)interceptors (via settling, flotation, coarse screening, vortexing, infiltration, bioretention, etc.), rather than being designed only for water transit or storage. Such (eco)interceptors may also provide habitat for wildlife, and also restore groundwater supply – which is expected to reach new critical levels due to heavy pumping and climate change.[11-13] In the near future, this synergistic combination of natural services and engineering could provide a techno-economically balanced, tunable, and holistic approach democratizing *in situ* water decontamination for industrialized and, more importantly, developing countries.

Smaller *in situ* (eco)interceptors can be strategically placed to manage localized sources of pollution entering fragile aquatic ecosystems and/or drinking water sources, for example, i) between a busy road and a river to retain tire wear particles and oil from cars; ii) at the intersection of agriculture drainage systems and rivers to trap pesticides, nutrients, and pathogens; and iii) around cities to retain litter, road salt or other anthropogenic stressors in untreated urban runoff.[9] A low-cost approach via passive aggregation and settling could also be implemented by industries to treat wastewater from industrial processes, for example, textile and plastic manufacturers. Although more extensive research and a proper evaluation of the advantages (performance vs. cost) provided by tunable passive/engineered (eco)interceptors would be necessary, it is reasonable to expect that such hybrid and flexible processes could be adjusted for different wastewaters and for specific needs, flow rates, contaminants, and landscape.

Clean water is critical for human health and prosperity, as well as to protect global biodiversity. Low-cost and sustainable (eco)interceptors – if properly engineered – could democratize water treatment and increase the quality of water globally. Environmental authorities must exert more pressure for the development and implementation of passive (eco)interceptors to accelerate drinking water accessibility and protect natural waters.

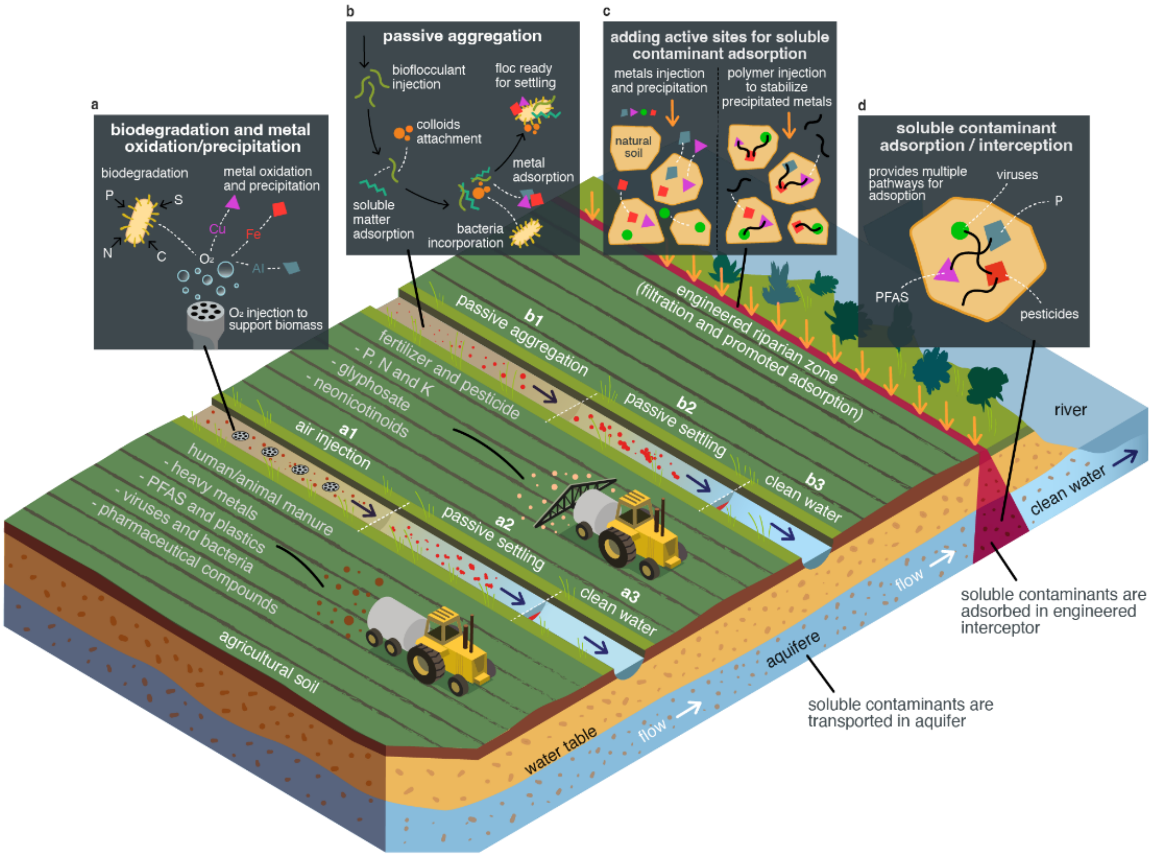

Figure 1 │Flow pattern and examples of passive (eco)interceptors to sustainably treat agricultural runoff, *in situ*. Several contaminants coming from commercial fertilizers (P and N), biosolids and manures used for agriculture are currently released in surface water and groundwater, and are accumulating in agricultural fields: pesticides, heavy metals, viruses, bacteria, pharmaceutical compounds, plastics debris and perfluorinated compounds.[14,15] **a**, Contaminants biodegradation and oxidation/precipitation via air/O_2 sparging (a1) followed by passive settling (a2). **b**, Particulate and soluble matters passive aggregation via biosourced flocculant (b1) followed by passive settling (b2). **c**, Metals injected, precipitated, and polymer-stabilized in soil to add active sites for soluble contaminants adsorption. **d**, Soluble contaminants adsorption on functionalized soil grains. Other than runoff, tunable passive/engineered (eco)interceptors could be used to (partially) treat several types of industrial and municipal wastewaters.

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Competing interests

The authors declare no competing interests.

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