Reinventing Urban Water Systems

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The water and wastewater treatment systems that serve modern cities were developed during a time when urban population densities were lower, energy was less expensive and society paid less attention to the environment. As a result, most cities are served by centralized systems that import water from long distances and discharge wastewater that adversely impact aquatic life. These aging systems also consume large amounts of energy and are expensive to operate. Current concerns about energy consumption and climate change coupled with rapidly growing populations provide an opportunity to reinvent urban water infrastructure using modern technologies to make them more sustainable and resilient.

Most current efforts to reinvent urban water infrastructure focus on increasing the reuse and recycling of municipal wastewater effluent (i.e., sewage) for industrial processes and irrigation. Over the past thirty years, considerable progress has been made on centralized treatment systems that produce water that is safe for non-potable applications. However, the potential for further expansion of centralized systems is limited because they require an independent pipe network for distributing water to locations not immediately adjacent to the treatment plants. Decentralized systems, consisting of modular biological treatment plants that can be operated remotely, have the potential to overcome this problem, provided that they can be made cost-effective and reliable.

Another important opportunity associated with the reinvention of urban water infrastructure involves the recovery of nutrients and energy from wastewater. In terms of energy consumption, urban water systems in the US consume approximately 17.5 W/person of energy, mainly for pumping water over long distances. If the waste heat and energy associated with organic matter in the wastes were effectively captured, the energy consumption could be reduced by approximately 30%. Furthermore, nutrients present in wastewater, which are partially responsible for the expansion of “dead zones” along populated coastal areas, could be recovered and reused in agriculture, reducing energy use for nitrogen fixation and environmental damage from phosphate mining.

Reuse of wastewater as a drinking water supplies also is a potentially viable option for water-stressed cities. Advanced wastewater treatment plants, equipped with reverse osmosis followed by disinfection with ultraviolet light have been used to recharge depleted groundwater aquifer and replenish drinking water reservoirs in California and Singapore. While these systems can be built and operated in a cost effective manner, concerns have been raised about potential public health risks from chemical contaminants that are capable of passing through reverse osmosis membranes. The use of multiple barriers, consisting of treatment technologies that employ different approaches for contaminant removal, can produce water of exceptional purity, but the public remains skeptical about the practice. Therefore, it is critical for engineers to maintain and build public confidence by paying careful attention to the removal of contaminants that pose risks to public health or compromise the aesthetics of drinking water.

While all of these engineered treatment systems offer potentially significant improvements over current practices, they require considerable energy and oversight to operate. Tapping into the ability of natural systems to purify and store water offers a complimentary approach that may be particularly important to the sustainable reinvention of urban water infrastructure. Historically, cities located on rivers downstream of wastewater discharges have relied upon processes that occur in natural systems to purify water. However, a lack of understanding of how natural systems can be managed to maximize their assimilative capacity hinders their expanded application in modern water infrastructure. Therefore, additional research is needed to understand how natural systems can be managed to enhance treatment efficiency.

Over the past few years our research group has studied the transformation of wastewater-derived organic contaminants in rivers and wetlands. We have learned that many of the compounds that pose the greatest threats to humans and aquatic organisms can be removed by photolysis (i.e., transformation reactions initiated by sunlight) or by biotransformation. By understanding the conditions that control the rates of these transformation reactions, it may be possible to manipulate natural systems to improve treatment efficacy. For example, microbes in wetlands are adapted to break down organic matter (i.e., decaying plants) using nitrate as a terminal electron acceptor. The ability of the microbes to transform low concentrations (i.e., <1 μg/L) of wastewater-derived contaminants will depend upon the similarity between the compounds and the decaying organic matter in the wetland. Therefore, manipulation of the types of plants growing in the wetland may provide a basis for improving the effectiveness of wetland treatment.

The reinvention of urban water infrastructure will require further refinement in water treatment technologies using advanced materials and natural systems to remove contaminants and recover nutrients and energy from wastewater. Society also will have to become more comfortable with the idea that drinking water does not always come from pristine sources that are unaffected by human activities. The acceptance of this concept will require better education and more research to quantify the potential risks associated with contaminant exposure during water reuse.