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Biological impacts of emerging contaminants in wastewater effluent and treatment processes to reduce risk:

Considerations for Arizona's communities and rivers

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To develop a better understanding of the issues and best practices related to the use of treated effluent to help maintain river flows and habitat, the Conservancy commissioned a study to summarize the state of the science. The use of treated wastewater effluent is becoming a more prominent factor in Arizona's overall water management strategy. Treated effluent contains a wide array of chemical and pharmaceutical compounds referred to as emerging contaminants. Because many of the individual compounds in wastewater persist through the treatment process and can cause damage to biological systems, careful consideration must be given to the design of treatment systems and use of treated wastewater effluent. As the state strives to achieve sustainable use of water, treated effluent is one option to supplement human and environmental needs.

Understanding tradeoffs between water quantity, quality and the cost of alternative treatment strategies will require access to the best available information for those working to maintain the conservation, economic and cultural values of our rivers. The Conservancy recognizes that treated wastewater effluent is a valuable resource, but also has associated risks.

The literature was summarized in a report by Dr. Catherine Propper and Dr. David Quanrud that examines the biological impacts of exposure to municipal wastewater effluent and ways to reduce exposure through conventional, natural and advanced treatment processes, including a comparison of costs. This summary provides an overview of the report's major findings, including the best practices identified in the scientific literature for treating effluent.

The full report is available for download at the Conservancy's science website, www.azconservation.org.

Emerging Contaminants—What are they and where do they come from?

Recent research has widely documented the presence in the environment of a wide array of commonly used chemical compounds including:

· prescription and non-prescription pharmaceuticals
· personal care products
· flame retardants
· antimicrobials
· detergents
· pesticides
· natural and synthetic hormones
· other industrial compounds

Most of these compounds originate from consumer use and industrial processes. The discharge of municipal wastewater, either untreated or treated, is a common source of these contaminants to the environment. These compounds have been referred to as emerging contaminants. A subset of emerging contaminants are Endocrine Disrupting Compounds (EDCs)—naturally occurring and synthetic organic compounds that have the ability to alter the normal functioning of the endocrine system, which is responsible for growth, development and general physiological function in vertebrates.

In a 2002 U.S. Geological Survey study of 139 streams across the United States, 80% contained trace organic contaminants including steroids, non-prescription and prescription drugs, antibiotics, hormones, and personal care

EDCs are entering our waterways through direct sources such as wastewater and industrial plant discharges and indirect sources such as runoff from concentrated animal feeding operations and municipal sludge/biosolids applied to land.

Biological Effects

The literature documents effects of wastewater exposure on survivorship, health and reproduction of exposed organisms. Outcomes of exposure range from overt toxicity and increased mortality to impacts on development of reproductive organs and behavior. Fish populations in streams sampled above and below effluent discharge points showed altered ratios of male to female fish and impaired reproductive potential within individuals. There are complex interactions among species exposed to wastewater effluent. Understanding which compounds are causing these effects and how mixtures of compounds influence physiological function and community dynamics is challenging. Studies have shown that toxicity and reproductive disruption occurs in wildlife populations exposed to the complex mix of chemicals in wastewater effluent even when it is diluted to 10 percent of its full strength.

In addition to the complexity of endocrine physiology and species differences, each wastewater effluent mix is different, which makes straightforward predictions about outcomes difficult. Many of these compounds accumulate in commercial and sport fish used for human consumption, leading to human exposure. Few studies have addressed the complex ecosystem consequences of exposure to wastewater effluent. Such studies are critical to gaining a full understanding of the potential long-term effects these compounds may have on people and the environment.

Municipal Wastewater Treatment Systems

The fate of EDCs and other emerging organic contaminants during municipal wastewater treatment has received considerable scientific attention in recent years. Studies have shown EDC removal during conventional wastewater treatment is incomplete; EDCs remain present to some degree in treated effluent and in biosolids. Removal efficiencies correlate roughly to overall process efficiency. That is, the better the removal of conventional water contaminants during treatment, the better the removal of trace organic constituents.

Advanced wastewater treatment technologies such as granular activated carbon, ozonation, advanced oxidation processes, or membrane treatment are capable of removing EDCs to below detection levels. But capital, operational and energy costs of advanced treatment are significant and may prove to exceed what communities are willing to pay. Currently, wastewater regulation focuses on reduction of common pollutants entering the environment, such as nitrates, phosphates, and pathogens. However, some communities may choose increased costs as a tradeoff for increased protection from contaminants entering a river that provides drinking water and/or important aquatic wildlife habitat.

Studies have shown that EDC removal efficiency can be improved within the conventional treatment processes. The most important design parameter in the conventional treatment process is the solids retention time (SRT), also known as sludge age. A longer SRT allows for enrichment of more slowly-growing bacteria and broader treatment capabilities. If a critical sludge retention time can be determined for removal of a specific EDC then increasing SRT to meet or exceed that critical value should result in complete degradation of the contaminant.

Natural Treatment Systems

Natural treatment processes including rapid infiltration (soil-aquifer treatment) and constructed wetlands can remove EDCs and may be useful as part of a multi-barrier treatment system. Infiltration processes that contribute to soil-aquifer treatment have a significant beneficial effect on water quality. At the Tucson Sweetwater Recharge Facility, infiltration through 100 feet of unconsolidated sediment from infiltration basins to monitoring wells at the water table produces significant reductions in both dissolved organic carbon and total estrogenic activity. The loss of estrogenic activity during infiltration is on the order of 90%. The degree of emerging contaminant removal will depend on sediment hydraulic characteristics. Fractured or highly porous sediment might produce limited removal of EDCs. Soil-aquifer treatment can be an important component of a multi-barrier treatment system for restoring wastewater to near-potable quality. However, the ability of estrogenic contaminants and other trace organics in municipal effluent to partially survive conventional wastewater treatment and soil-aquifer treatment suggests the need for continued groundwater quality monitoring during artificial recharge.

Reducing Input

Another option available to communities that are interested in reducing release of trace organic compounds to the environment is source control. Strategies that local governments can undertake that do not require wastewater treatment facility upgrades or changes in operational procedures include pharmaceutical take-back programs and education on proper disposal of unused medications and household products.

Monitoring and Research

Further study of optimization strategies for improving conventional wastewater treatment and nutrient removal processes for EDC removal is warranted. Increasing the solids retention time (and/or hydraulic residence time) and sequential anaerobic/aerobic sludge digestion plus managed recharge of treated effluent at appropriate locations may prove the most viable approach for reducing contaminant concentration and risk to the environment, at less cost than advanced treatment technologies.

Given the thousands of different trace organic compounds in wastewater present at concentrations of nanograms to micrograms per liter, a comprehensive chemical monitoring program is cost prohibitive. But, monitoring is essential to provide quantitative information pertaining to the fate and transport of contaminants in the environment and to assess impacts to wildlife. A new approach gaining increased attention by researchers is to identify and monitor an appropriate set of "indicator" trace organic compounds or surrogates that are then used to predict the fates of other trace compounds that are more difficult and expensive to monitor. Coupling testing of different treatment processes to studies of impacts on a defined suite of indicators may facilitate understanding of how to achieve removal efficiencies that will minimize biological impacts. These studies should be tied to biological assays for evaluating low level contaminant activity on biological systems. Research should consider the effects of complex mixtures of compounds, not just on individual organisms but also at a population scale and on overall ecosystem function.

Summary of Best Practices

Arizona's rivers provide drinking water, recreation and other uses for people as well as important habitat for fish, birds and other wildlife. Treated wastewater effluent discharged to streambeds has created or increased surface flow downstream from a number of cities. In areas with growing populations and important biological resources—such as the Verde and San Pedro river basins—treated effluent is being considered to fulfill future water needs of rivers and riparian areas. Recharged effluent already is being used to maintain regional groundwater levels as a strategy for maintaining surface flows in the San Pedro River near the City of Sierra Vista.Research has shown impacts to biological systems from exposure to even very low levels of certain emerging contaminants. For effluent that will be used to support river flows and associated habitats, the major findings of this report include the following "best practices" that can reduce risk:

Source Reduction: city- and community-sponsored pharmaceutical take-back programs and education on proper disposal of unused medications and household products. *Cost:* Low. This strategy works with other approaches because it reduces the problem.

Increased solids retention time: increased holding time for sewage sludge during secondary treatment at traditional wastewater treatment plants has been shown to increase removal of emerging contaminants. *Cost:* Moderate, requires increasing the storage capacity of wastewater treatment plants.

Natural treatment systems: wetland treatment and/or recharge at appropriate locations have been shown to further reduce the concentration of emerging contaminants. *Cost:* Moderate, depends on land prices and distance from treatment plant.

Advanced treatment systems: the highest removal efficiencies are accomplished using advanced methods such as ozonation and advanced oxidation or membrane treatment and activated carbon. However, these methods are expensive and have high energy consumption; thus, a high level of risk reduction must be required for cost effectiveness. *Cost:* High, for both capital and operational costs.

There remains considerable uncertainty regarding this complex topic. However, we cannot discount treated effluent as an important part of the overall water supply. Thus, we can work to reduce risk while maintaining the benefit of treated effluent in supporting water needs for people and the environment.

About the Authors

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Catherine R. Propper, PhD. Dr. Propper is a Professor of Biological Sciences at Northern Arizona University. She has been investigating the impact of environmental contaminants on development, reproduction and behavior of aquatic vertebrates for the past 15 years. Dr. Propper received her PhD in Zoology with an emphasis on Environmental Endocrinology from Oregon State University.

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