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Technical BRIEF

INNOVATIVE RESEARCH FOR A SUSTAINABLE FUTURE

SAFE AND SUSTAINABLE WATER RESOURCES RESEARCH PROGRAM

Water Systems Research

Water systems challenged by limited resources, aging infrastructure, shifting demographics, climate change, and extreme weather events need transformative approaches to meet public health and environmental goals, while optimizing water treatment and maximizing resource recovery and system energy efficiency. EPA's water systems research aims to push forward the next generation of technological, engineering, and process advances to maintain safe and sustainable water resources for humans and the environment, while also augmenting and improving water resources. EPA's water system efforts focus on breaking down traditional barriers between drinking water and wastewater (now referred to as resource water) with an emphasis on research that encompasses the entire water cycle to improve the way we manage water.

Resource Water/Water Reuse

Scientists and engineers in EPA's Office of Research and Development (ORD) are conducting research on the evaluation of microbial and chemical contaminants in resource water treatment streams, safe and sustainable management of waste residuals, and advancing innovative technologies for water and resource recovery.

Pathogens and Chemicals

Scientists are conducting studies that will thoroughly characterize microbial pathogens and chemical contaminants, including contaminants of emerging concern (CECs), in resource water through a Regional Applied Research Effort (RARE) with EPA Region 6. These studies will help to refine risk assessment models for direct potable reuse in Texas and elsewhere. Building on the RARE effort, ORD researchers will conduct a comprehensive study on microbial communities and CECs in resource water effluents using high throughput gene sequencing to characterize bacterial, viral, and protozoan populations. The research effort will also monitor pathogen community dynamics throughout the treatment systems and provide data on effluent CEC concentrations for traditional wastewater treatment plants that are considering water reuse.

ORD researchers are also conducting research on antibiotic resistance in resource water. This work will provide data on the prevalence and human health impacts of antibiotic resistant bacteria (ARB) and the role of treatment on the

EPA/600/F-16/192 | August 2016

presence and persistence of ARB in water. The research will attempt to elucidate mechanisms and transfer rates of antibiotic resistant genes in bacterial populations encountered in resource water. The results of the study might help us to understand the potential impacts from ARB on human health and the environment in resource water that is reused or discharged.

Biosolids

Part 503 of the Biosolids Rule that provides guidance on the treatment requirements for land application of biosolids was most recently updated in 2003. Current research by ORD scientists assesses newer and more accurate methods for monitoring the microbial characteristics of residuals for land application. This research will provide support to EPA Program Offices for updating lists of methods for compliance monitoring. EPA researchers are also examining the transformation and fate of perfluorinated alkyl substances (PFAS) in resource water activated sludge systems and residuals to better understand the behavior of PFAS in the environment.

Resource Recovery

ORD research on anaerobic membrane bioreactors (AnMBR) examines the efficacy of AnMBR for resource water treatment for reuse and energy (methane) recovery. This research contains bench-scale experiments on methane recovery and a Net Zero field study in collaboration with the U.S. Army (Fort Riley, KS) using a pilot-scale AnMBR treating raw resource water effluents for non-potable reuse.

ORD scientists are also developing and advancing innovative membrane technologies for treating challenging water sources such as reverse osmosis concentrated brine streams. This research can improve management and lower costs for inland desalination facilities where brine management is a major contributor to high costs. Additionally research projects are examining the recovery and reuse of drinking water treatment residuals, bioaccumulation and recovery of phosphate from resource water, and the development of innovative packaged systems for small-scale water reuse.

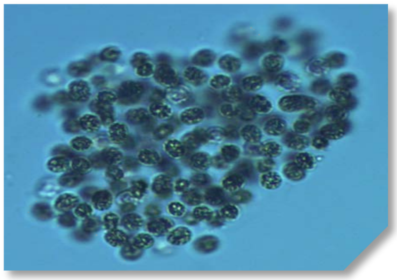
Water Management

ORD plans to integrate resource water/water reuse research results through the development of system-scale approaches to comprehensively manage water. ORD researchers are currently working with the City of San Francisco and the State of California to provide better risk assessment models for non-potable (and, in the future, potable) water reuse at building scales. ORD researchers are also conducting community-scale life cycle assessments on water resources to improve how we manage all water sources in a given community.

Research Grants

EPA's National Center for Environmental Research (NCER) Science to Achieve Results (STAR) grant program recently funded water reuse-related research to support the following studies:

- *Developing a framework for quantifying microbial risk and sustainability of potable reuse in the United States*
- *Assessment of stormwater harvesting via managed aquifer recharge to develop new water supplies in the arid West: the Salt Lake Valley example.*
- *Improving water reuse for a much healthier Potomac watershed.*
- *Enabling adaptive UV and solar-based disinfection systems to reduce the persistence of viral pathogens in wastewater for sustainable reuse.*
- *Reclaimed water irrigation: plant accumulation and risks from CECs.*



Analytical Methods and Monitoring

ORD researchers play a critical role in developing analytical methods for supporting regulatory processes in EPA's Office of Water (OW). Under the 1996 amendments to Safe Drinking Water Act (SDWA), Congress created an approach for determining which contaminants would become subject to drinking water standards. The approach includes three components: the Contaminant Candidate List (CCL), the Unregulated Contaminants Monitoring Rule (UCMR), and Regulatory Determination. EPA is currently drafting the fourth CCL. Analytical methods developed by ORD support OW by providing reliable, robust methods for analyzing contaminants listed on the CCL and standardized methods for water systems to use for monitoring contaminants under the UCMR.

Algal Toxins and Opportunistic Pathogens Methods

ORD researchers completed Method 544 for six congeners of microcystin and nodularin (cyanobacterial toxins) for use in the fourth cycle of the UCMR. Researchers continue to work on methods for saxitoxin and related cyanobacterial neurotoxins. In addition to chemical contaminants, ORD researchers are developing methods for *Legionella* and mycobacteria in support of the UCMR. These methods are currently undergoing verification by external participants in a multi-laboratory study. Lastly, a UCMR method for *Toxoplasma gondii* (protozoan) oocyst densities is under development.

Exposure Methods

In addition to research that supports the immediate needs of EPA's Program Offices and Regions, ORD researchers are looking to the future and developing new analytical methods for exposure risk assessment. ORD researchers conduct research on the use of salivary immunoassays to determine human exposure to opportunistic pathogens in drinking water distribution systems and recreational water. Research is also being conducted on the use of MS2 bacteriophage as an indicator organism for determining virus removal in water treatment systems.

Occurrence Studies on CECs, Pathogens, and Disinfection Byproducts

ORD researchers are finalizing one of the most comprehensive occurrence studies on CECs and pathogens in drinking water treatment systems affected by traditional wastewater plant discharges. ORD collaborated extensively with scientists in the U.S. Geological Survey for this occurrence study which provided frequency and concentration ranges for 247 analytes including pharmaceuticals, hormones metals, PFAS, viruses, bacteria, fungi and protozoa among other chemicals used in agriculture and commercial settings. The research also assessed potential human health impacts. This research concluded that for risks from chemicals in treated water was low; for pharmaceuticals, 70 percent were never detected in treated drinking water. Mycobacteria were detected in treated drinking water within the treatment plants which may serve as a source for mycobacteria colonization in distribution systems. The results also suggested that some of the elemental analytes (silicon, strontium, lithium, and manganese) will require additional investigation to determine potential human health impacts.

An additional branch of planned research aims to build on occurrence studies and related research on disinfection byproducts (DBPs) in drinking water systems in an effort to group contaminants for analytical methods and human exposure studies. This research will lead to the development of new and innovative approaches not only for prioritizing groups for monitoring and evaluation but also for developing groups for potential Agency action, including remediation and regulatory consideration.

Sensors and Monitoring

Lastly, ORD researchers are looking forward to the next generation of sensors and monitoring techniques. ORD scientists are developing sensors based on enzymatic response to contaminants for arsenic and plan to further develop this technology for other contaminants such as lead. ORD researchers are currently coordinating a sensor development "challenge" to facilitate the creation of biosensors based on adverse outcomes. These types of biosensors merge the latest cell-level bioassays with sensors that can potentially provide *in-situ* signals to warn a treatment system that there are contaminants in the system that are potentially harmful at the cellular level.

Water Treatment

Water treatment continues to play a fundamental role in SSWR's research portfolio. ORD researchers conduct bench-, pilot-, and full-scale investigations to determine the best available treatment technologies and approaches for a variety of contaminants. Current research addresses issues such as regulatory compliance, distribution system corrosion, microbiological contamination, and challenges presented by emerging contaminants. Research in recent years has also focused on assisting small- and medium-sized systems in reaching compliance with current regulations.

Distributions Systems and Premise Plumbing

Distribution system and premise plumbing research plays an increasing role in the SSWR Research Program's portfolio. In addition to the development of analytical methods for opportunistic pathogens, ORD researchers are studying the occurrence and behavior of these pathogens in conveyance systems. Research results have been published on the presence of mycobacteria and *Legionella* from building taps and shower heads indicating that mycobacteria are ubiquitous in these systems and *Legionella* is common. Furthermore, ORD researchers have found that conditionally rare taxa in distribution systems can rapidly increase in number under favorable conditions.

ORD scientists have been developing microelectrodes to assess the role of biofilms in disinfectant decay on treated drinking water. The researchers aim to integrate the use of microelectrodes in water systems to optimize disinfectant levels for maintaining water quality in distributed water.

Lead: Technical Support and the Lead and Copper Rule

Over the past two years, ORD scientists and engineers provided critical technical support to EPA Program Offices and Regions. During the Flint, Michigan drinking water crisis, ORD engineers provided technical support to the regional office, state, and utility. ORD installed a pilot-scale pipe testing rig on site in Flint to test optimal water quality for maintaining disinfectant levels and minimizing lead release. ORD researchers continue this work on lead pipe samples from other communities with lead service lines.

ORD researchers are also developing a lead sampling protocol for identifying risks from lead pipe in distribution systems in support of OW's efforts on developing a household action level for lead. In addition to the sampling protocol, ORD modelers are integrating the Stochastic Human Exposure and Dose Simulation (SHEDS) model with the Integrated Exposure Uptake Biokinetic Model (IEUBK). Scientists employ the SHEDS-IEUBK model to predict lead levels in water that will lead to specific blood lead levels in infants, children, and adults. The model accounts for lead sources other than drinking water and results will be used in creating the household action level.

Algal Toxins

ORD engineers continue to provide technical support and perform research on the removal of cyanotoxins from source waters. Current research includes treatment optimization for drinking water plants located on Lake Erie and the impacts from treatment processes, such as permanganate addition, on the release of toxins from intact cyanobacterial cells.

PFOA/PFOS

ORD engineers also contributed to the development of OW drinking water health advisories for perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) through human health toxicity studies and the identification of best available technologies for PFOA/PFOS removal.

Small Systems

In addition to research that supports the immediate needs of EPA's Program and Regional Offices, ORD scientists are developing new, innovative, cost-effective methods for water treatment with an emphasis on small systems, which are defined in the SDWA as systems that serve fewer than 10,000 people. ORD engineers successfully installed and operated a biological drinking water treatment system in rural Palo, IA for removing ammonia from source waters. ORD engineers continue to work with small systems to develop affordable technologies for meeting drinking water goals. ORD scientists are assessing the effectiveness of UV systems that utilize light-emitting diodes (LED). LED-UV systems can potentially reduce costs due to lower energy needs for powering LED systems. ORD scientists are also working with hospitals and building-scale water treatment systems (consecutive water systems) to study the impacts of distal water treatment on water quality in buildings.

Ultraviolet Systems for Pathogen Removal

One of the main efforts involving innovative water treatment technology over the past two years has focused on the use of ultraviolet (UV) light treatment in drinking water and reuse settings. UV technologies are particularly attractive to small systems due to their ease of operation and effectiveness. However, establishing the proper dose (or fluence) of UV for inactivating organisms is not straight forward. ORD researchers are currently developing protocols to test UV systems for effectiveness in treating Adenovirus, which is resistant to many forms of treatment. Early results suggest that the use of MS2 bacteriophage may serve as an effective, conservative surrogate to its resistance to UV disinfection. This research also examines the differences in accounting for effective UV dose differences between low pressure and medium pressure UV treatment systems.

Treatment Database

ORD maintains and updates EPA's Drinking Water Treatability Database which provides utilities with recommendations on effective technologies for removing a wide range of chemical, microbiological, and radiological contaminants. The treatability database will be merged with OW cost models to provide stakeholders the ability to include cost factors when selecting treatment processes. iaspub.epa.gov/tdb/pages/general/about.do

Technology Cluster

Many of the innovative water treatment technology projects are supported by the Water Technology Innovation Cluster (WTIC) program. The WTIC seeks to identify new and innovative water treatment technologies and barriers in the acceptance of new technologies. It will be critical to accelerate the acceptance of new technologies as pressures on water resources increase.

Research Grants

NCER funding through the STAR and National Priorities grants has supported to following treatment-related research:

1. *Studies on advancing public health protection through water infrastructure sustainability*
   - Biofilm behavior within distribution systems.
   - Development of real-time mobile sensor device for monitoring distribution system water quality.
   - Development and demonstration of a hybrid ion exchange catalytic treatment system for nitrate removal from drinking water.
   - Development of nanoscale fibers for treating waterborne contaminants in small drinking water systems.
   - Case studies of small systems in rural Missouri for controlling DBP levels in finished water.

1. *National small systems drinking water research centers*
   - Design of Risk Reducing, Innovative Implementable Small System Knowledge (DeRISK) Center
   - Water Innovation Network for Sustainable Small Systems (WINSSS)

2. *Distribution systems studies*
   - National Priorities: Impacts of water conservation on water quality in premise plumbing and water distribution systems

3. *Drought resiliency studies*
   - Consequences of watershed management practices against wildfire on the exports of dissolved organic matter from forested watersheds and associated biogeochemical processes and impacts on water supplies.
   - Innovative methods for improving water management by reducing risks from inadequate drought preparedness, including pre-drought planning and emergency response.

Health Impacts

ORD's SSWR researchers are studying human health risks posed by contaminants (microbial, chemical, and radiological) associated with water systems, including those contaminants found in finished water that are either not removed by treatment, are formed or altered during water treatment and then later affected by residence time in water systems, or those impacted by wastewater treatment processes. Research in this area will improve estimates of human health risk and inform risk management.

Impacts of Disinfection Byproducts

ORD scientists continue to provide immediate support to Program Office decisions on water contaminants through technical support for the six-year DBP rule process. Health effects research currently focuses on DBP (regulated and non-regulated) consequences to human health. ORD researchers are re-examining regulated DBPs effects on bladder cancer. They are also performing studies on DBP exposure and colon cancer using human colonocyte cytotoxicity assays. These cellular assays afford a higher throughput than tradition toxicity methods. This work will eventually use the assays for testing individual DBPs and environmentally realistic mixtures of DBPs.

ORD scientists are using physiologically-based pharmacokinetic (PBPK) models for assessing human health impacts from DBPs. The models emphasize the need to consider alternative (to ingestion) exposure routes such as dermal and inhalation exposure which may significantly contribute to internal doses for internal organs. Health impacts research also currently includes studies on integrated exposure assessments that focus on varying halogen (e.g. bromine, iodine) concentrations' impacts on DBP formation and the toxicity of the mixtures formed during chlorination and chloramination.

Toxicity Screening

ORD researchers are also looking to the future in developing innovative toxicity screening methods that involve tiered screening approaches that couple bioassays with analytical chemistry for effects-directed analysis. In addition to bioassay methods, immunological salivary assays can be used to screen for exposure to contaminants in drinking water. Research is also being conducted on *in-vivo* developmental toxicity screening methods for water contaminants and effects on pregnancy disruption and ocular development. ORD research will fill in knowledge gaps in risk from aerosolization of waterborne pathogens in order to gain a more realistic understanding of internal doses from sources other than ingestion. ORD researchers are conducting studies to compare the toxic effects of different microcystin congeners in freshwaters of the U.S.

Waterborne Diseases

ORD researchers currently collaborate with scientists from the Centers for Disease Control and Prevention to develop methods to characterize waterborne diseases through outbreak surveillance and identify waterborne diseases associated with distribution systems. Lastly, ORD is examining the role of waterborne and environmental pathogens as triggers for Type 1 diabetes.

Additional Information

EPA's Safe and Sustainable Water Resource Research: epa.gov/water-research

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