

Office of Research and Development

# SAFE AND SUSTAINABLE WATER RESOURCES RESEARCH PROGRAM



## Water Systems

### Project 2: Next Steps: Technology Advances

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## Task 2A-Treatment, Monitoring and Risk Assessment for Water Reuse

1. Development of anaerobic membrane bioreactor (AnMBR) technologies for domestic resource water (RW) treatment combined with direct potable reuse (DPR)
2. Synthesis report on state of the science in membrane technologies for water recovery from challenging water sources such as brine streams
3. Water waste residuals: Strategies for valuable resource recovery product
4. Method development for key bacterial populations associated with phosphate bioaccumulation in low dissolved oxygen (DO) RW systems
5. Innovative packaged systems for water reuse and removal of contaminants.



# 1. Development of AnMBR technologies for domestic RW treatment combined with DPR

## FY16 Key Activities/Products/Impacts

- ❖ **AnMBR experiments for net positive energy recovery from domestic RW treatment**
  - ❖ Constitutes a large energy demand in the U.S.
  - ❖ Experiments investigating in-situ methane recovery from AnMBRs for use as an energy product are ongoing.
  - ❖ Conducting comparison of horizontal and vertical hollow fiber membrane module designs in order to achieve low energy fouling control.
  - ❖ An evaluation of downstream sorptive recovery of nutrients from AnMBR effluents in the planning stage.
  - ❖ Overall AnMBR technologies will be evaluated as components of direct potable reuse treatment trains.



## 2. Synthesis report on membrane technologies for water recovery from challenging water sources

### FY16 Key Activities/Products/Impacts

- ❖ **Conducting in-house experiments, process simulations, and literature reviews in preparation for FY19 product focusing on water and salt recovery from reverse osmosis brine-concentrates.**
- ❖ **Evaluating commercial and developmental membranes for water transmission and salt rejection in both membrane distillation and pervaporation modes of operation.**
  - The most promising membranes from that testing will be carried forward into salt crystallization tests.
- ❖ **Cooperative Research and Development Agreement (CRADA) with Aquatech International for membrane material development is in effect through May 2017.**
- ❖ **Currently preparing internal report for the Water Technology Innovation Cluster (WTIC) on the use of membrane distillation and pervaporation for salt crystallization from brines.**
  - WTIC provided seed funding for this project prior to inclusion in SSWR StRAP.



### 3. Water Waste Residuals: Strategies for Valuable Resource Recovery Product

#### FY16 Key Activities/Products/Impacts

- ❖ Review of the composition of residuals from a variety of historical EPA drinking water treatment plant studies.
- ❖ Development of a solid pelletizing protocol for producing media from drinking water treatment plant residuals.
  - Lime softening sludge.
  - Iron removal solids.
- ❖ **Evaluation of residual pellets for alternative uses:**
  - Neutralization of acidic waste streams.
  - Treatment of air pollutants.
  - Adsorption of multiple contaminants from various liquid streams.

Pathfinder Innovation Project:

- Water utility lime sludge- An environmental sorbent for power utilities
- Reuse landfill-bound lime sludge waste for removal of SO<sub>2</sub>, Hg, and metals from power plant air emissions.



## 4. Method Development for Key Bacterial Populations associated with Phosphate Bioaccumulation in Low-DO RW Systems

### FY16 Key Activities/Products/Impacts

- ❖ Completed the sequencing analysis of RW samples that remove nitrogen and accumulate phosphate at very high levels under low-DO conditions.
- ❖ Identified a denitrifying bacterial group (*Accumulobacter* sp.) that bioaccumulates phosphate under low-DO conditions.
- ❖ A manuscript describing the findings is currently under review.
- ❖ Developing genus- and function-specific qPCR assays to determine the relative abundance of the bacterial groups in different RW treatment samples and in environmental settings such as wetlands.



## 5. Innovative Packaged Systems for Water Reuse and Removal of Contaminants

### FY16 Key Activities/Products/Impacts

- ❖ **Conduct research on various types of granular activated carbon products and systems that will advance Safe Drinking Water Act compliance in small communities.**
- ❖ **The initial focus of the project will address compliance requirements for DBPs in a cost and operationally effective manner.**
- ❖ **Provide technical and analytical support for sample collection in Mississippi and Ohio and sample analysis at EPA's T&E Facility in Cincinnati, Ohio.**



## Task 2B – Novel Monitoring Technologies for Occurrence, Exposure and Effects for Individual and Groups of Contaminants

1. Adaptation of advanced methods for regulatory applications

2. Novel Grouping Methods to Improve Understanding the Effects of Groups/Mixtures of Chemicals

3. Advanced Technologies for Small Water Distribution Systems

Task Lead: Susan Glassmeyer



# 1. Adaptation of Advanced Methods for Regulatory Applications

## FY16 Key Activities/Products/Impacts

- ❖ **Determine protocols to utilize advanced technologies.**
  - Such as bioassays, for regulatory purposes.
- ❖ **The methods that will be evaluated using these protocols have been developed and are in use for non-regulatory purposes.**
  - A joint OW/ORD workgroup will be established to determine the data quality objectives required for regulatory purposes.
- ❖ **Proposed product- Next generation analytical and monitoring tools for regulatory compliance (FY 18).**
- ❖ **Product will directly support OW by broadening the tools used to ensure the public has safe drinking water.**



## 2. Novel Grouping Methods to Improve Understanding of the Effects of Groups/Mixtures of Chemicals

### FY16 Key Activities/Products/Impacts

- ❖ **Methodology developed to use adverse outcome pathways to group chemicals for mixtures risk assessment developed (Nelms, MD, Simmons, JE, Edwards, SW).**
  - Adverse Outcome Pathways to Support the Assessment of Chemical Mixtures (book chapter, in press).
- ❖ **Statistical technique to assess the contribution of component chemicals and subgroup mixtures to the toxicity of complex mixtures completed (journal article prepared).**
- ❖ **Survey of existing methods for grouping chemicals in progress (survey completed and manuscript to be written in FY17).**
- ❖ **Expected Component Contribution Score, a tool to discern the component chemicals responsible for the majority of mixture toxicity, applied to environmentally-realistic defined mixtures of the 5 regulated haloacetic acids (HAAs) and the 9 commonly measured HAAs.**
- ❖ **Screening-level mixture risk assessment approaches are being assessed for usefulness in prioritizing mixtures of water-borne chemical contaminants.**



## 2. Novel Grouping Methods to Improve Understanding of the Effects of Groups/Mixtures of Chemicals

### FY16 Key Activities/Products/Impacts

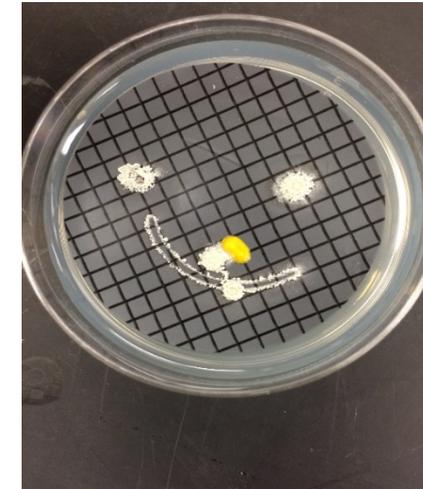
- ❖ **Monitoring of contaminants of emerging concern (CECs) in source water, treated drinking water, wastewater effluents, surface water and ground water.**
- ❖ **Develop tools to rapidly and efficiently prioritize individual contaminants for CCL and criteria development (FY16)-Six manuscripts are in press.**
- ❖ **Characterization of sources of contaminants of emerging concern to surface and ground waters (FY 18).**
- ❖ **Products will provide data to OW to develop future CCL and UCMR lists.**

### 3. Advanced Technologies for Small Water Distribution Systems

#### FY16 Key Activities/Products/Impacts

❖ **Apply advanced molecular methods for quantifying microbial contaminants in small, consecutive, DW distribution systems.**

- Nontuberculous mycobacteria
- Mycobacterium avium complex
- Legionella pneumophila



❖ **Develop monitoring processes for small-scale distribution systems.**



## Task 2C-Water Treatment Technologies for Enhanced Reduction of Chemical and Microbial Risks

1. Biological drinking water treatment: Gaining acceptance and optimization to achieve desired treatment goals
2. Development of technologies to meet drinking water goals in small systems
3. Light-emitting diode (LED)/ultraviolet light (UV) systems for water disinfection
4. Effectiveness of current and innovative RW treatment operations for managing model compounds
5. Application of microelectrodes to optimize disinfection to control biofilms
6. Treating drinking water in buildings: A holistic approach to providing safe water to consumers

# 1. Biological Drinking Water Treatment: Gaining Acceptance and Optimization to Achieve Desired Treatment Goals

## FY16 Key Activities/Products/Impacts

- ❖ Develop a summary document on engineering design guidance for biological ammonia systems.
- ❖ CRADA and technology license agreement with AdEdge to develop EPA biological ammonia technology to full-scale application. Pilot currently being started in small system in Iowa.
- ❖ Development of innovative biological nitrate removal process.
- ❖ Pilot-scale system is under construction and innovative features (carbon source, oxygen removal strategy, etc) are being considered.
- ❖ Pathfinder Innovation Project: Treatment of emerging contaminants using UV light, percarbonate, and peracetic acid.





## 2. Development of Technologies to Meet Drinking Water Goals in Small Systems

### FY16 Key Activities/Products/Impacts

- ❖ Develop communication materials to educate small systems and their engineering firms on advances in small systems treatment options.
- ❖ Develop data sets demonstrating full-scale reduction of contaminants of concern or emerging contaminants of concern such as strontium at small systems.
- ❖ Report on the demonstration of water treatment technologies or approaches that can reduce multiple contaminants of concern in small systems.
- ❖ Re-evaluation of EPA arsenic demonstration study for small systems: where are they now?
- ❖ Manuscript on ion exchange for removal of ammonia in small systems.
- ❖ Development of basic analytical methods for monitoring PFAS in household DW samples.

#### FY16 Key Activities/Products/Impacts

##### ❖ Status update:

- Equipment has been purchased/ acquired for EPA laboratory.
- Initial wavelengths – 260nm and 280nm
- Developing experimental design based on previous UV-LED EPA/University of Colorado collaborative project (*E. coli*, *Adenovirus*, coliphage and *Bacillus* endospore inactivation).
- Compare to EPA laboratory results using medium- and low-pressure UV.



## **4. Effectiveness of Current and Innovative Resource Water Treatment Operations for Managing Model Compounds**

### **FY16 Key Activities/Products/Impacts**

- ❖ Develop standard operating procedures for sample collection, preservation and analysis for CECs in resource water and biosolids.**
- ❖ Conduct field studies/surveys at existing RW treatment plants.**



## 5. Application of Microelectrodes to Optimize Disinfection to Control

### FY16 Key Activities/Products/Impacts

- ❖ **Microprofiling experiments investigating free chlorine and monochloramine penetration into drinking water storage tank sediments were completed. Analysis of acquired microprofile data is ongoing.**
- ❖ **DNA extraction from sediments was conducted and analysis is ongoing.**
- ❖ **Presentation on the research has been accepted for the American Water Works Association's Water Quality Technology Conference in November, 2016.**
- ❖ **The research supports the periodic removal of sediments from storage tanks because disinfectants do not penetrate to a significant depth.**



## 6. Treating Drinking Water in Buildings: A Holistic Approach to Providing Safe Water to Consumers

### FY16 Key Activities/Products/Impacts

- ❖ **Demonstration of the effectiveness of monochloramine in reducing biofilm including Legionella in a hospital-data collection is nearly complete.**
- ❖ **Examine the secondary considerations (corrosion, nitrification, DBP's etc) when installing disinfection to a building such as a hospital to control Legionella.**
- ❖ **Apply hydraulic water quality model (EPANET) to household and building plumbing systems to identify areas of water quality degradation and provide recommendations to improve plumbing configurations during construction, additions, and changes.**

1. Identify potential exposure and effect posed by contaminants to manage their risk in source, drinking, waste and reused water through a tiered screening approach, which couples bioassays/bioactivity and analytical chemistry in an effect-directed analysis

2. Development of approaches to evaluate human health response to waterborne contaminants associated with drinking water quality



## 1. Identify Potential Exposure and Effect Posed by Contaminants to Manage their Risk in Source, Drinking, Waste and Re-used Water

### FY16 Key Activities/Products/Impacts

- ❖ **Developing the scientific basis for sound regulatory decisions on priority, unregulated waterborne contaminants**
  - Rapid in vivo screening assay (MicroTox) studies are in progress to examine relative potency of priority unregulated chemicals.
  - Preliminary prototype PBPK models in progress:
    - to understand the impacts of co-exposure on internal dosimetry.
    - to evaluate the potential for dermal absorption.
- ❖ **In vivo developmental toxicity screening of water contaminants for effects on pregnancy disruption and ocular development**
  - Screening of DBPs in progress; assays completed for iodoform and chloroform.
  - Narotsky et al. (2016) Assessment of iodoform effects on pregnancy maintenance and eye malformations in a developmental toxicity screen with F344 rats. Presented at Annual Meeting of Teratology Society.
  - Supports OW risk assessment; filling data gaps regarding developmental toxicity and endocrine disruption of DBPs.



## 1. Identify Potential Exposure and Effect Posed by Contaminants to Manage their Risk in Source, Drinking, Waste and Re-used Water through a Tiered Screening Approach which Couples Bioassays/Bioactivity and Analytical Chemistry in an Effect-directed Analysis

### FY16 Key Activities/Products/Impacts

- ❖ **Final report on publications detailing the utility of bioassays/bioactivity tools within an EDA framework**
  - Sampling, exposures and omics laboratory work has been completed in conjunction with considerable amount of targeted analytical characterization, as well as non-targeted characterization of field collected samples to determine the ability of omics-based profiles to characterize complex real world mixtures.
  - Exposures with real world samples, as well as spike in (positive control) samples have been completed to evaluate the ability of omics-based bioassays to identify exposures to targeted chemical classes. Transcriptional work is in progress.
- ❖ **Evaluation of a CEC indicator list to predict CEC's concentrations in environmental samples and develop extraction protocols and evaluate integrated exposure of environmental samples**
  - Research is on track through leveraging multiagency (ORD, Regions, USGS, USFW, NOAA, USACE, States, and academia) field sampling and laboratory experiments in SSWR, CSS, and SHC at impacted sites in the US. The large database of CECs will permit a statistical approach to identifying indicator chemicals for screening samples. If representative indicator CECs are detected, a decision can be made to do targeted analysis for classes of CECs detected.
  - The product will be a manuscript describing the approach and criteria for selecting a reduced number of indicator CECs.
  - This approach will be useful to utilities, state and federal regulators to manage the high cost of analytical chemistry for CECs and to more rapidly screen large numbers of samples.



## 2. Development of Approaches to Evaluate Human Health Response to Waterborne Contaminants Associated with Drinking Water Quality

### FY16 Key Activities/Products/Impacts

- ❖ **Application of innovative salivary immunoassays to link health effects with drinking water exposures**
  - Over 8,000 saliva samples from a Wisconsin community served by groundwater have been analyzed using novel immunoassay for antibodies against 10 waterborne pathogens; manuscript in preparation (FY17, Q2).
  - Analysis of saliva samples from rural communities in Puerto Rico to begin FY17, Q3.
  - Research findings expected to support Office of Water and Regions by developing innovative alternative methods for exposure assessment.
- ❖ **Development of improved biological markers to link health effects with drinking water exposures**
  - Identified several candidate proteins that may be indicative of acquiring toxoplasmosis through waterborne route of transmission.
  - Expanded list of assay targets to include other biomarkers of infection and immune status/health (cytokines, indicators of chronic diseases, etc.).
  - Results may support future drinking water regulations.



## 2. Development of Approaches to Evaluate Human Health Response to Waterborne Contaminants Associated with Drinking Water Quality

### FY16 Key Activities/Products/Impacts

- ❖ **Animal model to address uncertainty surrounding the risk posed by aerosolization of waterborne pathogens**
  - Developing procedures for application of a new aerosol containment system at animal facility in Cincinnati.
  - Characterize survival and transmission of bacteria in aerosols.
  - Develop new methodology for measuring human health risks from pathogens in aerosols in drinking water.
- ❖ **Comparative toxicity of microcystin congeners found in United States freshwaters**
  - Five Microcystin congeners, MCLR, MCLA, MCRR, MCLF, and MCLY are currently being tested to confirm their identity, purity, and quantity prior to initiation of the definitive oral and intraperitoneal toxicology assessment studies.
  - Having these definitive toxicology studies on the microcystins are a high priority need by OW for making risk assessment decisions.



## FY16 Key Activities/Products/Impacts

- ❖ **Portfolio of grants (8 total) will end in 2016. Numerous articles have been published over the life of these grants.**
- ❖ **Research findings from four STAR Grantees contribute to EPA Summary Document: State of the Research on High-Priority Distribution System Issues, posted June, 2016.**
- ❖ **STAR researcher characterizes biofilm behavior within the Distribution System, University of Illinois.**
- ❖ **STAR researcher develops a mobile sensor device; allows real-time monitoring of water quality inside the distribution system, Purdue University**



## Task 2F-Research and Demonstration of Innovative Drinking Water Treatment Technologies in Small Systems (NCER-STAR)

### FY16 Key Activities/Products/Impacts

- ❖ Research portfolio is a combination of individual grants (11) and two National Research Centers.
- ❖ STAR research developed and demonstrated a hybrid ion-exchange (IX) catalytic treatment system for nitrate removal from drinking water, University of Illinois at Urbana-Champaign.
- ❖ STAR researcher uses nanoscale fibers to efficiently treat common waterborne contaminants in small drinking water systems, University of Iowa.
- ❖ STAR funded Case Study of small systems in rural Missouri results in recommendations on how to control DBP levels in their respective finished waters, Lincoln University – Missouri.
- ❖ Numerous articles have been published across the entire grant portfolio



### FY16 Key Activities/Products/Impacts

- ❖ **Joint Environmental Security Technology Certification Program Solicitation for Water Reuse Technology between EPA and DoD.**
- ❖ **Demonstration of anaerobic membrane bioreactor technology:**
  - Production of high quality re-usable water in an energy-neutral configuration.
  - Use of the technology in a treatment train that can effectively remove nitrogen and phosphorus nutrients in tandem with carbonaceous biochemical oxygen demand and total suspended solids.
  - Hollow-fiber gas transfer membrane technology can effectively recover dissolved methane from AnMBR permeate.
  - AnMBR minimizes sludge production and that the sludge that is produced can be used beneficially as biosolids.
  - AnMBR is a safe technology that is implementable at DoD installations and public utilities.

## Task 2A-RW

- AnMBR
- Brine treatment
- DWTP residuals recovery
- P recovery/Low DO Systems
- Treatability database
- Packaged systems

## Task 2B-Monitoring and Analytical Methods

- Advanced methods for regulatory applications
- Chemical groups/mixtures
- Advanced monitoring technologies for small systems

## Task 2C-Treatment

- Biological treatment
- Small systems support
- LED/UV
- CECs in RW/biosolids
- Microelectrodes/Distribution Systems
- Buildings/consecutive systems

## Task 2D-Health Effects

- Effects-directed analyses/bioassays
- New approaches to evaluate human health response