PLAN FOR ADDRESSING CRITICAL RESEARCH GAPS RELATED TO EMERGING CONTAMINANTS IN DRINKING WATER

A Report by the

Task Force on Emerging Contaminants

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

October 2018

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About the Task Force on Emerging Contaminants

The Task Force on Emerging Contaminants (TF) was established on 8 May 2018 under the Committee on Environment. The purpose of the TF is to provide the Office of Science and Technology Policy (OSTP) with expertise from the Federal agencies about emerging contaminants in drinking water.

About this Document

This document is a response to Senate Report 115-139 related to Division B of Public Law 115-141 that states emerging contaminants are increasingly being detected at low levels in drinking water systems across the country. Prolonged exposure to unregulated drinking water contaminants may pose human health risks, and the lack of research on potential health effects has hindered Federal and State efforts to develop and strengthen the effectiveness of drinking water advisories or standards for these materials. In response, OSTP, in collaboration with agency representatives, has developed this coordinated cross-agency plan for addressing critical research gaps related to detecting, assessing exposure, and identifying potential adverse health effects of emerging contaminants in drinking water.

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Table of Contents

Executive Summary

Contaminants of emerging concern (CECs) have been detected at low levels in the drinking water systems that Americans rely upon across the Nation. Recent research has indicated that exposure to CECs under certain scenarios may pose risks to human health. To respond to these concerns, the Office of Science and Technology Policy (OSTP) established the 'Contaminants of Emerging Concern Research and Development Task Force' (TF) to develop a coordinated cross-agency plan to address critical research gaps as requested by Congress.

Improvements to existing coordination of Federal and State activities would enhance the research, tool development, and data translation to information necessary for CEC-related drinking water advisories, standards, and mitigation efforts that protect public health. The cross-agency plan presented here describes and integrates five elements: (1) identification of critical CEC research gaps, (2) alignment of agency missions with CEC research gaps, (3) thematic areas for collaboration and coordination, (4) timeline, and (5) actions to enhance research efficiency. Through this overarching framework, Federal agencies are able to identify shared interests in CEC research gaps, existing activities and programs related to the gaps, actions to enhance research efficiencies, and opportunities for strategic partnerships.

To develop the cross-agency plan, the TF reviewed the elements of the Safe Drinking Water Act applicable to CECs, current Federal and State research and development activities, and the state of scientific understanding regarding CECs. The following critical research gaps were identified in three areas, that when addressed, will enhance the ability of relevant State and Federal agencies to develop advisories and standards concerning CECs and help identify interventions needed to reduce risk.

Contaminant Identification

- Improve water sampling design
- Improve CEC monitoring technology
- Continue development of rapid analysis tools for contaminant identification in mixtures
- Accelerate development of computational tools, such as artificial intelligence (AI), that automate the incorporation and processing of CEC data

Exposure Characterization

- Conduct research on distribution system composition and integrity
- Develop models and collect data to assess exposure at the tap
- Study distribution-system-specific and source-specific exposure scenarios
- Investigate the influence of consumer behavior and demographics on exposure

Human Health Impacts

- Develop computational tools for rapid human health risk evaluation
- Advance tools to assess human health risks under realistic exposure scenarios
- Improve human health assessment methods for CEC exposure during sensitive developmental periods
- Build understanding of the psychology of CEC events
- Research methods to identify alternative safe chemicals

The elements of the plan presented in this report allow agencies to gauge progress on addressing the research gaps and are sufficiently flexible to allow for integration of new data and knowledge over time. The plan is also a tool to promote collaboration among stakeholders— Federal, State, local, Tribal, and private partners—who are directly involved in the development of safe drinking water advisories, standards, and mitigation strategies in communities across the country. By adapting and utilizing the elements of this plan for CECs now and in the future, communities will be better able to

proactively identify and address water contamination issues that may have otherwise led to exposure, thereby keeping water supplies safe and Americans healthy.

Introduction

Emerging contaminants, also called contaminants of emerging concern (CECs), are newly identified or re-emerging manufactured or naturally occurring physical, chemical, biological, or radiological materials that may be harmful to humans under certain exposure scenarios and do not have an applicable regulatory health standard. Numerous scientific papers have associated human exposure to some CECs in drinking water with public health impacts, and a lack of research on potential health effects has hindered Federal and State efforts to develop and strengthen the effectiveness of drinking water advisories or standards for these materials.[1] To address concerns about emerging contaminants in drinking water, Congress requested that the Office of Science and Technology Policy (OSTP) develop a coordinated cross-agency plan to identify critical research gaps related to emerging contaminants in drinking water.[2]

CECs are frequently categorized by their type and source, and the most common categories are personal care products, pesticides, pharmaceuticals and illicit drugs,[3] and industrial and consumer waste products. A 2017 nationwide study of CECs detected 121 different types of unregulated chemicals and microbes at least once in the output of 25 water treatment plants.[4] In many cases, advances in analytical technologies and instrumentation have made possible the identification of trace levels of contaminants. Concerns about potential human health impacts are fueled by the lack of toxicity information associated with individual CECs, mixtures of CECs, and cumulative exposure over time.

The Federal Safe Drinking Water Act (SDWA)[5] was passed by Congress in 1974 to protect the quality of drinking water provided by public water systems in the United States. Research across the Federal government supports the SDWA through assessments on the health effects of possible contaminants, and the likelihood they will occur in public water systems often enough and at levels that are a concern for public health. Contaminants of emerging concern pose a challenge because these occur at previously undetectable concentrations and can result from many different combinations of compounds, including chemical interactions with components of the drinking water treatment process and facilities. As advances in science and technology continue to improve the ability to detect

1 Villanueva CM, Kogevinas M, Cordier S, Templeton MR, et al. "Assessing exposure and health consequences of chemicals in drinking water: current state of knowledge and research needs." Environmental Health Perspectives 122, no 3 (2014): 213-221.

2 Senate Report 115-139, at 101 (July 27, 2017). U.S. Senate. Committee on Appropriations. Committee Report accompanying S. 1662, Departments of Commerce and Justice, Science and Related Agencies Appropriations Bill, 2018. Title III, Science, Office of Science and Technology Policy, Emerging Contaminants. Adopted by reference in the Explanatory Statement regarding the House Amendment to Senate Amendment on H.R. 1625, Consolidated Appropriations Act, 2018. Public Law 115-141. 164 Cong. Rec. H2094 (daily ed. March 22, 2018).

3 Illicit drugs are defined as "substances that either stimulate (such as cocaine or amphetamines) or inhibit (such as heroin or sedative-hypnotics) the central nervous system or cause hallucinogenic effects (such as marijuana or LSD) to the effect that their use has been prohibited globally." International Encyclopedia of the Social & Behavioral Sciences (2001): 3877-3881.

4 Glassmeyer, S.T. et al. "Nationwide reconnaissance of contaminants of emerging concern in source and treated drinking waters of the United States. Science of the Total Environment." *Sci. Total Environ.* 581-582 (2017): 909-922.

5 SDWA authorizes the U.S. Environmental Protection Agency (EPA) to set standards for drinking water quality for consumers receiving water from public drinking water supplies. See https://www.epa.gov/sdwa.

and characterize contaminants in drinking water, new CECs may be identified and cause public health concerns.

In response to the congressional request, OSTP convened an NSTC Task Force on Emerging Contaminants (TF) that assessed the state of CEC science to identify critical knowledge gaps and research needs. For the purposes of this report, CEC research is grouped into contaminant identification, exposure characterization, and human health impact, and the report focuses on the research gaps that are best met by the Federal Government, in full or through local, State, or private partnerships.

Reducing critical CEC research gaps in the areas of contaminant identification, exposure characterization, and human health impacts supports broader local, State and Federal initiatives for risk assessment, communication, and mitigation (see Figure 1). The ability to identify and address potential risks to human health depends on the ability to identify contaminants early, characterize exposures, and prevent human health impacts from occurring. Too often in the past, human health impacts have been the first indication of a contaminant's presence in drinking water. Utilization of this framework will safeguard human health by providing the information needed to proactively perform risk assessment, communication, and mitigation among Federal, state, and local stakeholders.

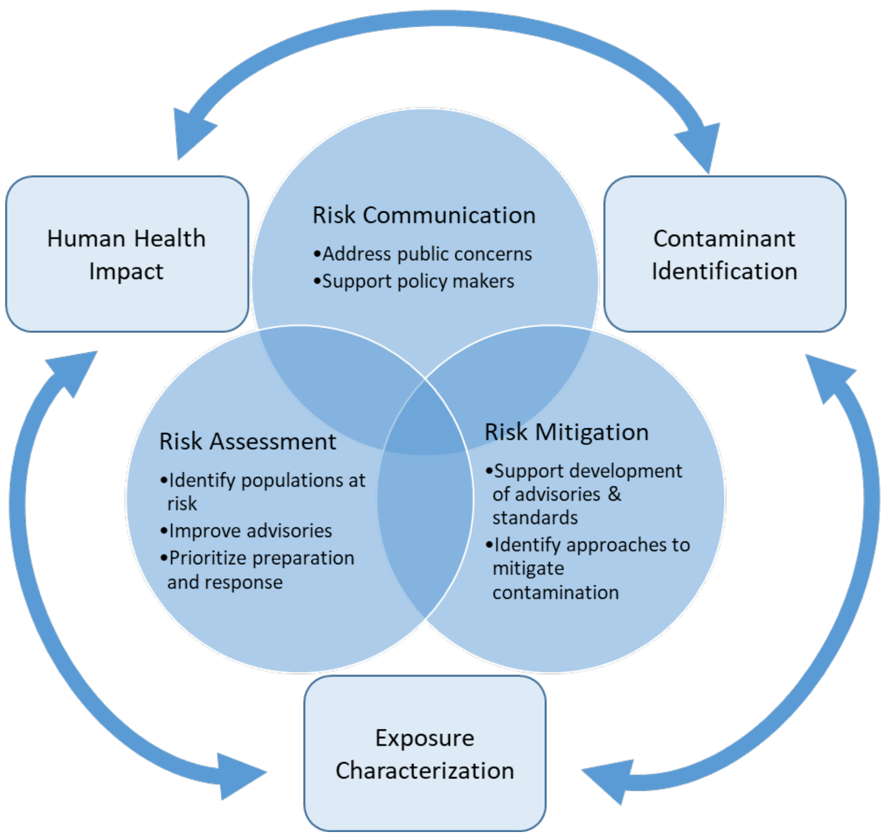

Figure 1. Research and development on CECs in the areas of Human Health Impacts, Contaminant Identification, and Exposure Characterization informs a policy framework that includes effective risk communication, risk assessment and risk mitigation.

Critical Research Gaps

A critical research gap is an activity or set of research activities essential to understanding and reducing human health risks related to CECs. This chapter groups these gaps into three areas: Contaminant Identification, Exposure Characterization, and Human Health Impacts.

1. Contaminant Identification

Research on contaminant identification determines the strengths and weaknesses of state-of-the-art approaches for identifying CECs in source and drinking water. The goal of such research is to enable rapid identification of CECs that pose the greatest potential risk to human health. Specific aims include identifying (1) new technologies and enhancements to existing techniques that enable more specific, sensitive, and accurate CEC identifications, and (2) affordable and potentially portable tools that allow CEC identification in real or near-real time, so that assessment decisions and response can be accelerated and tailored to the CECs of interest.

New techniques and tools are being developed to identify classes of chemicals that have historically proven challenging to detect and characterize. For example, new chemical extraction techniques have enabled chemists to analyze polar compounds with greater certainty.[6] High-resolution mass spectrometry, an analytical method used to characterize chemicals qualitatively and quantitatively, has enhanced the detection and quantification of byproducts of CECs undergoing environmental processes.[7] While reference libraries to aid in high-resolution chemical characterization still lack size and detail for many classes of CECs, they are improving and have the potential to accelerate chemical identification in the future.[8]

Current Federal and State research activities seek to identify the presence of CECs individually and in mixtures in numerous water types, including source and treated drinking waters, leachate, wastewater, organism tissues, and aquatic sediments. For example, research currently conducted to identify CECs includes targeted and non-targeted analyses, analytical method development, specialized data analysis tool development, and development of data resources. Multiple Federal agencies conduct research to develop: (1) reference standards for specific classes of CECs and (2) protocols and criteria to ensure quality assurance when CECs are measured by Federal and non-Federal entities. In collaboration with the States, academia, and industry partners, Federal agencies have also developed specialized tools to detect CECs in extremely low concentrations and to characterize CECs that have unique properties. Finally, agencies across the Federal Government have developed data resources to support the broader contaminant identification research community. Examples include the management of databases with chemical names, properties, and identifiers; naming conventions to standardize research efforts across institutions; and online mapping tools and fact sheets to document current scientific understanding of CECs. Additional research is needed in the following areas to address remaining research gaps:

Improve water sampling design: Data on CECs in drinking water is most often collected just after treatment at drinking water treatment plants but sampling data are needed for other relevant matrices, such as source water, wastewater, sediment, soils, and at the drinking water tap. The frequency and level of some CECs can change as the contaminant moves from source water, through

6 Aguera, A. and Lambropoulou, D. "New Challenges for the Analytical Evaluation of Reclaimed Water and Reuse Applications." in *Wasterwater Reuse and Current Challenges*, edited by Fatta-Kassinos, D., Dionysiou, D.D., and Kummerer, K., 7-47. New York: Springer International, 2016.

7 Hannemann, M., Zonja, B., Barcelo, D., et al. "HRMS Approaches for Evaluating Transformation of Pharmaceuticals in the Aquatic Environment." in *Assessing Transformation Products of Chemicals by Non-Target and Suspect Screening - Strategies and Workflows Volume 1*, edited by Drewes, J.E., Letzel, T., 25-44. Washington, DC: American Chemical Society, 2016.

8 Hollender, J., Schymanski, E., Singer, H. and Ferguson, P. "Nontarget Screening with High Resolution Mass Spectrometry in the Environment: Ready to Go?" *Environmental Science & Technology* 51 (2017): 11505-11512.

the treatment system and through the distribution system.[9] Therefore, information to better understand the fate and transport of CECs are needed to better understand exposure at the tap. Especially lacking are samples from tap water, which may be helpful for understanding the frequency of occurrence and concentrations of certain CECs at the point of use. While monitoring at the treatment plant is important, sampling in the distribution system and in tap water may better elucidate how water quality is affected across neighborhoods, and the effect of different plumbing systems. If CECs persist through treatment or are introduced during or after treatment, they may present human exposure concerns. Accordingly, developing and deploying sampling designs that extend beyond drinking water treatment plants to the tap would improve identification of potential CECs.

Improve CEC monitoring technology: As more CECs are detected in the water cycle, improved methods are needed to monitor the ever-expanding suite of analytes. Rapid miniaturization and improvements in traditional laboratory techniques, such as mass spectrometry, offer promise for routine monitoring of CECs. Ideally, new monitoring technologies would capture temporal and spatial differences in CEC concentrations. This would enable water managers and treatment plant operators to make better decisions on how to adjust treatment to minimize contaminant concentrations. In addition to methods for directly measuring chemicals, advances in tools that identify biological activity or effect are necessary. These tools are especially useful when results can be linked to chemical characterization and identification. Merged data arrays provide the ability to tie response to specific subsets of CECs and may help clarify causative links between identification, exposure, and health effects characterization.

Continue development of rapid analysis tools for contaminant identification in mixtures: While substantial progress has been made in the identification of mixtures of CECs, limitations remain in the ability to analyze water samples for the presence of chemical mixtures. To support effective risk characterization, multimodal approaches that can accurately determine constituents, effects, and other pertinent variables in drinking water, preferably in real time, are needed. The aim of such research is the development of non-targeted analysis tools, which have the potential to offer substantial qualitative and in some cases quantitative data for CECs, especially when integrated with conventional contaminant data. Ultimately, improvements in non-targeted analysis will best serve decision makers if they can contribute to an early warning system that identifies new contaminants that warrant further assessment. In Europe, NormaNEWS provides an example of such a system (see Box 1), but an emphasis on exposure through drinking water, coupled with consideration for potential biological effects, would provide a system more focused on potential human health outcomes.

Accelerate development of computational tools, such as AI, that automate the incorporation and processing of CEC data: As important data on CECs accumulates, gleaning insights from that data depends on the ability to aggregate and analyze it effectively. Development of computational tools will be instrumental to efficiently enhance the processing of CEC data. Application of AI techniques, such as machine learning and neural networks, will be key to identify the chemical properties of CECs that may be associated with human health hazard in large and complex datasets. In addition, developing and integrating novel and conventional contaminant data so both can be queried using automated AI approaches would assist in rapidly identifying the highest priority contaminants in source and drinking water.

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9 Craun, G. F.; Brunkard, J. M.; Yoder, J. S.; Roberts, V. A.; Carpenter, J.; Wade, T.; Calderon, R. L.; Roberts, J. M.; Beach, M. J.; Roy, S. L., Causes of outbreaks associated with drinking water in the United States from 1971 to 2006. *Clinical Microbiology Reviews* **2010,** *23*, (3), 507-528.

Box 1. The Norman Early Warning System (NormaNEWS)

When a new contaminant that is potentially harmful to human health is found in drinking water, it is often difficult to characterize the historical temporal and spatial distribution of exposure. This is especially difficult when the given contaminant is either found in low concentrations or has not been previously targeted in water analyses. To retrospectively characterize the historical distribution of the CEC, researchers have used non-targeted analyses and methods. The European Norman Early Warning System (NormaNEWS) provides a unique example of an approach and collaboration. The network of laboratories collects historical data, specifically high resolution and accurate tandem mass spectrometry, to examine the occurrence of contaminants that were not considered when the data was first collected and analyzed.[10] This demonstration project (using non-targeted methods) successfully developed models, methods, and software to conduct analyses that could be useful for evaluating U.S. drinking water.

2. Exposure Characterization

Exposure characterization research assesses exposure to CECs in drinking water, with the long-term goal of reducing health risks by minimizing the likelihood of exposure. This work includes assessments in distribution systems, drinking water treatment plants, and source water. To successfully identify and quantify exposure, data on the occurrence, transformation, fate and transport of CECs are needed across the lifecycle from source to tap.[11] Such data should be collected and communicated in a manner that is timely and informative to regulators, local decision makers, and the public.

CECs can be introduced into drinking water prior to, during, or after treatment. Research has sought to identify contaminant-specific parameters that govern the mobility of CECs through complex water systems (e.g., kinetics, biodegradation rate, and transformation reactions).[12] Other studies have endeavored to apply the state of the art in identification science and technology to model and identify the spatial and temporal distribution of the occurrence, transport and fate of specific CECs, such as pharmaceuticals,[13] in ground and surface waters sourced from industrial and municipal wastewater treatment plant discharge, sewer overflows, urban and agricultural runoff, and landfill leachate. Research has been conducted on tap water to understand how human exposure to CECs differs based on exposure pathways. Pathways include ingestion,[14] inhalation (e.g., breathing in aerosolized

10 Alygizakis, N.A., Samanipour, S., Hollender, J., et al. "Exploring the Potential of a Global Emerging Contaminant Early Warning Network through the Use of Retrospective Suspect Screening with High-resolution Mass Spectrometry." *Environmental Science & Technology* 52, no. 9 (2018): 5135-5144.

11 Fate and transport refers to the physical, chemical, or biological movement and end state of a CEC through water, air, and soil.

12 Tran, Ngoc Han, Martin Reinhard, and Karina Yew-Hoong Gin. "Occurrence and fate of emerging contaminants in municipal wastewater treatment plants from different geographical regions-a review." *Water Research* 133 (2018): 182-207.

13 Furlong, E.T., Batt, A.L., Glassmeyer, S.T., et al. "Nationwide Reconnaissance of Contaminants of Emerging Concern in Source and Treated Drinking Waters of the United States: Pharmaceuticals." *Sci. Total Environ.* 579 (2017): 1629-1642.

14 Krishnan, K., and Carrier, R. "The Use of Exposure Source Allocation Factor in the Risk Assessment of Drinking-water Contaminants." *Journal of Toxicology and Environmental Health, Part B* 16, no. 1 (2013): 39-51.

contaminants due to transfer from tap water to indoor air,[15] while showering, or using a humidifier[16]) and dermal absorption[17] (e.g., water and skin contact while bathing, hand washing, or cooking).[18] In addition to exposure routes, the timing and duration of an individual's exposure to CECs in drinking water has been studied to model and predict human health implications for acute,[19] sub-chronic, and chronic exposure timeframes.[20] Additional research has shown that susceptible subpopulations, such as pregnant women, nursing mothers, children and the elderly, may be more vulnerable to certain CECs.[21]

Current Federal and State research activities for characterizing exposure seek to understand the processes for CEC emergence and persistence in drinking water sources and distribution systems, and to inform mitigation efforts to reduce or eliminate human exposure. Research by both Federal and State entities is conducted to identify the degradation, sorption, mobility, biogeochemical reactivity, and transformation of CECs within source waters and drinking water distribution systems. Specifically, research is conducted to understand how CECs enter and move through water resources relative to other media such as soil, air, and sediments. These activities are augmented by State agencies and research institution efforts to identify the occurrence of CECs, such as PFAS (see Box 2). Further experimental and computational research is conducted by Federal agencies to understand the chemical and physical processes that influence the emergence and persistence of CECs in drinking water distribution systems; research includes risk model development, in vitro method development, and mixture studies. Federal research efforts help develop and inform evaluations to prevent, prepare for, recover from, and adapt to public health emergencies associated with CEC exposure.

15 Davis, M.J., Janke, R., and Taxon, T.N. "Assessing Inhalation Exposures Associated with Contamination Events in Water Distribution Systems." *PloS one* 11, no. 12 (2016): e0168051.

16 Environmental Protection Agency (EPA). (2001). "Inhalation Exposure to Contaminants from a Water Distribution System."

17 McCarley, K.D., and Bunge, A.L. "Pharmacokinetic Models of Dermal Absorption." *Journal of Pharmaceutical Sciences* 90, no. 11 (2001): 1699-1719.

18 Villanueva, C.M., et al. "Assessing exposure and health consequences of chemicals in drinking water: current state of knowledge and research needs." *Environ Health Perspect.* 122, no. 3 (2014): 213-21.

19 Centers for Disease Control and Prevention. n.d. "Norovirus." Last updated April 2018. Available from https://www.cdc.gov/norovirus/index.html.

20 Villanueva, et al. (2014).

21 Mogensen, U.B., Grandjean, P., Heilmann, C., et al. "Structural equation modeling of immunotoxicity associated with exposure to perfluorinated alkylates." Environmental Health 14, no. 1 (2015):47.

Box 2. Developing Analyte Specific Methods for Per- and polyfluoroalkyl Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that have historically been used in a variety of consumer products to confer fire-, stain-, grease-, and water-resistant properties, and to reduce friction.[22] Though certain PFAS are no longer manufactured in the United States, some PFAS are resistant to degradation and have remained persistent in soils, waterways, and living organisms;[23] drinking water is one of multiple exposure routes.[24] Federal, State and municipal entities have conducted research to understand exposure and mitigate the health impacts of PFAS. For example, the U.S. EPA has worked alongside drinking water utilities to develop and evaluate treatment technologies that target PFAS. Through the U.S. EPA's 2018 PFAS National Leadership Summit and Community Engagements, EPA gathered ideas on near-term actions to address challenges facing states and local communities in preparation for developing a PFAS management plan. Further, research funded by Federal agencies including U.S. EPA, NIH, and others continues to characterize the impact of exposure to PFAS on human health and the environment. Such efforts have been augmented by local activities—the States of Minnesota[25] and New Jersey,[26] for example, have developed guidelines to identify the presence of PFAS in their drinking water systems, as well as evaluating exposure and water concentrations that may pose risk to human health.

The following objectives would help address remaining research gaps:

Conduct research on distribution system composition and integrity: The condition of water distribution systems in the United States has the potential to influence public exposure to CECs, yet these factors have not been systematically examined. For example, harmful by-products may result from the chemical interaction of water with piping material, and microbial contaminants can be introduced to drinking water following pipe breaks, but the risks associated with these possibilities have not been fully characterized. To help communities determine when and how to replace infrastructure to reduce exposure to CECs, additional research on water distribution systems and premise plumbing compositions is needed. Key research areas may include the effects of long-term contact of piping materials with residual chlorine from drinking water disinfection; and assessments of the likelihood of pipe breaks and the potential for exposure to pathogenic microorganisms resulting from such infrastructure failures.

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22 National Institute of Environmental Health Sciences (NIEHS). n.d. "Perfluorinated Chemicals (PFCs)." Accessed June 2018. Available from https://www.niehs.nih.gov/health/materials/perflourinated_chemicals_508.pdf.

23 Lynch, J. M., Ragland, J.M., Reagen, W.K., et al. "Feasibility of using the National Marine Mammal Tissue Bank for retrospective exploratory studies of perfluorinated alkyl acids." *Science of the Total Environment* 624 (2018): 781-789.

24 USEPA. n.d. "Basic Information on PFAS." Accessed August 2018. Available from https://www.epa.gov/pfas/basic-information-pfas.

25 Minnesota Pollution Control Agency. n.d. "Perfluorochemicals (PFCs)." Accessed August 2018. Available from https://www.pca.state.mn.us/waste/perfluorochemicals-pfcs.

26 New Jersey Department of Environment Protection. n.d. "Site Remediation Program, Contaminants of Emerging Concern." Last updated April 3, 2018. Accessed August 2018. Available from https://www.nj.gov/dep/srp/emerging-contaminants.

Develop models to assess exposure at the tap: Despite the numerous changes to the composition of water that can occur in a distribution system, no multifaceted approach currently allows the accurate measurement of contaminant-relevant variables in real time at the point of drinking water exposure. To enhance understanding of the biological, physical, and chemical processes that drive contaminant profiles at the point of exposure and thereby inform risk analysis, it is necessary to develop a robust and representative sampling design. It is not feasible to conduct a research study collecting samples at every tap in the United States, so ideally, knowledge gained through this approach would be transferrable and become part of a longer-term effort to develop models of exposure at taps. To provide the greatest impact, these occurrence studies should be designed to be combined with long-term environmental epidemiology studies, so the ramifications of a lifetime of exposure to CECs can be explored. Furthermore, to provide a comprehensive assessment of the identity, quantity, and exposure effects of CECs in drinking water, it will be necessary to develop the methodology to integrate datasets generated by a wide range of disciplines (e.g., engineering, environmental health science, microbiology, chemistry) and measuring techniques. Collected sampling data would need to be consolidated into a minimal set of variables to fully describe the complex behavior of these systems.

Study distribution-system-specific and source-specific exposure scenarios: Although research to date has shown that CEC concentrations are typically low in treated drinking water, these estimates may not adequately account for local conditions in individual communities or contaminant loads found in smaller drinking water treatment systems and private wells. To improve exposure assessments for the purposes of risk characterization, additional research on distribution-system-specific and source-specific exposure scenarios is needed. Model monitoring programs would include both targeted and non-targeted analyses. Novel chemicals and microbes identified in these studies would be used to inform the contaminant prioritization process. In turn, prioritization could lead to development of analyte-specific methods, which could be used in future occurrence studies to quantify contaminant concentrations. Modelling to extrapolate the findings in terms of both contaminant occurrence as well as fate and transport within the conveyance of water to the point of exposure is a component of this research area.

Investigate the influence of consumer behavior and demographics on exposure: Ultimately, exposure to CECs in drinking water is related to consumer behavior and demographics associated with drinking water, which are not fully understood. Research is needed to refine estimates of exposure to drinking water contaminants for the purposes of risk assessment. Specific areas for investigation might include the prevalence of point-of-entry or point-of-use technology for in-home water treatment and the relative proportion of daily water ingestion at home versus away from the home.

3. Human Health Impacts

Research on Human Health Impacts focuses on understanding the effects of exposure to CECs by (1) improving knowledge of whether and how contaminant exposure contributes to adverse health effects, and (2) identifying and characterizing factors that influence susceptibility. Relevant work spans a range of research disciplines, such as environmental health science, toxicology testing, and epidemiology. The ultimate goal is to inform risk mitigation strategies to protect public health.

Exposure to some CECs in drinking water has been associated with a number of adverse human health outcomes, from reproductive and developmental problems to neurotoxicity and cancer. In some cases, a causal relationship between contaminant exposure and adverse health effects has been established. For example, Federal drinking water risk evaluation determined that consumption of arsenic at levels above the Federal regulatory limits could result in increased risk of developing skin cancer.[27] In many cases, however, research has noted correlations between presence of a drinking water contaminant and an adverse human health effect but has failed to adequately establish underlying causality.

Characterizing human health effects of CEC exposure is challenging when scientific information is too limited to determine the exposure-response relationship, the biomolecular pathways that induce a response, and progression to disease. Other important considerations include dose magnitude, timing and duration of exposure, routes of exposure (ingestion, inhalation, or dermal absorption), timing of exposure relative to the exposed individual's life stage (e.g., exposure during windows of susceptibility), and characteristics of the exposed individual or population (See Box 3). It is also important to account for the fact that contaminants often occur in mixtures, which can influence absorption, distribution, metabolism, or excretion of mixture components.

Box 3. Biological Factors and Susceptibility to CECs

The potential for an individual to experience health effects from the exposure to a CEC is influenced by a variety of biological factors. For example, exposure to CECs during certain life stages may present heightened risk. Notably, contaminants that interfere with reproduction and development may have health impacts on pregnant or lactating women and children. Other characteristics of exposed individuals may also impact their susceptibility to adverse health outcomes. For example, different genotypes may cause increased susceptibility to bladder cancer after exposure to potential carcinogens such as disinfection by-products.[28] Furthermore, Federal research programs funded by entities such as NIH's National Institute of Environmental Health Sciences have identified that exposure to CECs such as PFOS are associated with abnormal fetal growth rates[29] and reduced effectiveness of childhood vaccines.[30]

One promising approach to characterizing human toxicity following low-level exposures to CECs uses a weight-of-evidence approach based on *Toxicity Testing in the 21st Century*.[31] This approach relies on the use of high-throughput biochemical assays on human cells, which are combined with targeted testing to help identify dose levels where toxicity pathways are activated, increasing the possibility of disease progression. Other notable tools and methods under development include *in silico* (computer model) approaches and targeted analysis. Together, these tools, combined with other verified methods, can help develop data to improve chemical risk predictions.

Federal and State research activities conducted to identify the human health effects of CECs include systematic reviews of health-related topics, toxicological investigations using model organisms, epidemiological studies of residential and occupational cohorts, and clinical and in vitro toxicological

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27 Tseng W.P. "Effects and dose—response relationships of skin cancer and blackfoot disease with arsenic." *Environ. Health Perspect.* 19 (1977)*:* 109-119.

28 Ibid.

29 Jaacks, L.M., Barr, D.B., Sundaram, R., et al. "Pre-pregnancy maternal exposure to persistent organic pollutants and gestational weight gain: a prospective cohort study." *Int. J. Environ. Res. Public Health* 13, no. 9 (2016): 905.

30 Mogensen, U.B., Grandjean, P., Heilmann, C., et al. "Structural equation modeling of immunotoxicity associated with exposure to perfluorinated alkylates." *Environmental Health* 14, no. 1 (2015): 47.

31 National Research Council. *Toxicity Testing in the 21st Century: A Vision and a Strategy*. National Academies Washington, DC: National Academies Press, 2007.

assessments. These health effects data, combined with exposure information, can assist in the development of health standards and Federal and State guidelines to estimate the potential health risks associated with CECs. Health effects and exposure assessments are conducted through systematic review of epidemiological, clinical, animal and cell biology analyses. Programs such as the NTP's Toxicology for the 21st Century (Tox21) [32] and EPA's Toxcast program seek to augment population and human clinical studies with in vitro and isolated molecular target analyses. Based on the body of knowledge developed for the health effects of exposure to specific CECs, Federal agencies have developed health-based recommendations and standards, alongside toxicology profiles on contaminants, to inform public health professionals and regulatory authorities. On the State level, these standards and recommendations have been augmented based on regional priorities and exposure information.

The following objectives would help address remaining research gaps:

Develop computational tools for rapid human health risk evaluation: Emergency response situations often require rapid decision making, but the ability for first responders to make informed decisions may be hindered by a lack of information on risk. To aid the protection of public health, it is crucial to develop computational tools that can rapidly assess human health risks and provide insights to responders and key stakeholders on decision-relevant timescales. These tools will be most effective if they couple rapid toxicological assessment with thoughtful, site-specific exposure evaluation. One important goal of this research is the continued development and validation of computer models that can predict toxicity for substances and offer easily understandable results that can be used in emergency response situations where adequate toxicity data cannot be collected in time to allow decision makers to share critical health information with the public.

Build tools to assess human health risks under realistic exposure scenarios: Toxicological assessments may fail to account adequately for common characteristics of exposure to CECs, including exposure to low contaminant concentrations and chemical mixtures rather than as single chemicals. Moreover, these assessments are often conducted in animal models with very little genetic variability. To ensure that risk assessments provide meaningful results that can be applied to real-world settings, new tools need to be developed to assess combined risks at the point of exposure. Defining adverse outcomes using effects-based monitoring of contaminant specific and mixtures exposure provides an important tool for assessing toxicity of concurrent exposures to CECs. Advancements in the study of effects at the level of genetic changes (genomics) or disturbance of functional proteins (proteomics) may offer opportunities to rapidly understand the relative impact and mechanisms of toxicity caused by exposure to CECs in chemical mixtures. Additionally, better ways to understand the physiological interactions of chemical exposures and how one substance may affect the absorption, distribution, metabolism, and excretion of others are needed. The data can be used to develop predictive models, and once validated, these methods and models can be implemented to reduce uncertainty in a weight of evidence approach.

Improve human health assessment methods for CEC exposure during sensitive developmental periods: Exposures to CECs during susceptible life stages, such as during pregnancy, early infancy (e.g., through breastmilk or water mixed with formula), and childhood, may cause human health effects expressed immediately or in adulthood. Knowledge of the causes of heritable effects from exposure during sensitive developmental periods is limited, as is understanding of the potential reproductive and developmental effects of CECs. To protect the health of current and future generations, improved methods are needed to better understand how exposure to CECs during windows of susceptibility

[32] The Toxicology in the 21st Century (Tox21) Consortium is a federal collaboration between the U.S. Environmental Protection Agency (EPA), National Toxicology Program (NTP) headquartered at the National Institute of Environmental Health Sciences (NIEHS), National Center for Advancing Translational Sciences (NCATS), and Food and Drug Administration (FDA).

affects health outcomes of the exposed individual and their children. Such research must recognize the unique ethical limitations of conducting research on sensitive human life stages.

Advance understanding of the psychology of CEC events: The task of communicating human health risks of events involving exposure to CECs often falls on the shoulders of toxicologists, exposure scientists, environmental engineers, and public health officials, usually in the midst of ongoing emergency situations (e.g., during natural disasters or catastrophic water contamination events). This problem has been repeatedly identified as the most important issue facing decision makers and the public during environmental response actions. The social psychology surrounding events involving CECs should be explored to promote more effective risk communication. A more advanced effort to understand the perceptions, feelings, and psychological aspects involved in the ongoing or aftermath of a community exposures, as well as how those factors can be applied to develop more effective risk communication strategies, is needed.

Develop methods to identify alternative safe chemicals: Unexpected adverse effects have been identified for some chemicals believed to be less hazardous than the chemicals they replaced. The emerging field of alternatives assessment aims to establish processes that will guide the identification and use of less hazardous chemicals and products by identifying, comparing, and selecting alternatives to contaminants and CECs based on their hazards, performance, and economic viability. By focusing on obtaining and developing toxicity data in a phased manner, consistent with the relative effort devoted to product development, developers can use health information as a performance criterion to achieve the desired property, such as fire retardancy, stain resistance, or degreasing ability, while minimizing health hazards.

Integrated Cross-Agency Plan

The cross-agency plan contains five elements: (1) the critical CEC research gaps, (2) alignment of agency missions with CEC research gaps, (3) thematic areas to reduce the research gaps, (4) timeline, and (5) actions to enhance research efficiency. Together, the elements of the framework provide a guideline for the Federal research enterprise to engage in strategic planning to achieve a mix of research that is balanced between near-term results (0-3 years) and longer-term outcomes (>3 years) - especially longer-term efforts that build on near-term results.

The research gaps serve as a unifying theme for agency missions and research opportunities. In Table 1, relevant agencies identified gaps that fall within their mission. The EPA and NIH have mission alignment with all gaps, with the exception of social-behavioral research for EPA and water distribution systems for NIH. DoD and USGS have more targeted responsibilities in all three topic areas, whereas NIST focuses primarily on contaminant identification and exposure assessment. NSF, as a fundamental research agency, identifies tool and methods development and consumer behavior as topics within their mission. This information allows the agencies to identify shared mission responsibilities across the research gaps. To extend the potential to build collaborations based on existing programs, align current research to avoid duplication, and plan future programs, the agencies reported their major current activities and programs in Appendix C.

Four thematic areas provide an opportunity for coordination and collaboration (Table 2). The first two areas—standards, process, and protocol development; and data management, analytics, and informatics—are areas in which collaboration would expedite progress in addressing CEC research gaps. Standards, process, and protocol development refers to the creation of uniform approaches and methods that can be deployed across the drinking water science and technology enterprise. Data management, analytics, and informatics includes the methods and processes necessary to collect, curate, integrate, and analyze datasets and to translate these findings to information. The final two areas—cross-government coordination and outreach—promote the sharing of information about CECs with stakeholders. Cross-government coordination includes interagency coordination, as well as coordination between the Federal government and State, local, and Tribal entities, and outreach refers to activities that engage or inform the public.

Table 2 also identifies the timescale—near-term, defined as less than 3 years (light blue), and mid- to long-term (darker blue), defined as greater than 3 years—on which efforts to reduce the gaps are possible to achieve. Notably, research gaps associated with contaminant identification could be reduced in the near-term and rely heavily on methodological standardization and process and protocol development as well as data management. Those gaps associated with exposure and health tend to be longer term and efforts to reduce them depend more heavily on cross-government coordination and outreach.

Table 1. Intersection of Agency Missions and Research Gaps Identified in this Plan

Research Gap		EPA	DoD	NIH	NIST	NSF	USGS
Contaminant Identification	Improve water sampling design	X	X		X		X
	Improve CEC monitoring technology	X	X	X		X	X
	Continue development of rapid analysis tools for contaminant identification in mixtures	X	X	X	X	X	X
	Accelerate development of computational tools, such as AI, that automate the incorporation and processing of CEC data	X		X	X	X	X
Exposure Assessment	Conduct research on distribution system composition and integrity	X			X		
	Develop models and collect data to assess exposure at the tap	X	X	X	X		X
	Study distribution-system-specific and source-specific exposure scenarios	X	X	X	X		X
	Investigate the influence of consumer behavior and demographics on exposure		X	X		X	
Human Health Impacts	Develop computational tools for rapid human health risk evaluation	X		X			X
	Build tools to assess human health risks under realistic exposure scenarios	X	X	X			X
	Improve human health assessment methods for CEC exposure during sensitive developmental periods	X	X	X			X
	Build understanding of the psychology of CEC events			X			
	Develop methods to identify alternative safe chemicals	X	X	X	X	X	

Table 2. Thematic Areas that Support Collaboration to Reduce Research Gaps Identified in this Plan

Research Gap		Standards, Process, and Protocol Development	Data Management, Analytics, and Informatics	Cross-Government Coordination*	Outreach
Contaminant Identification	Improve water sampling design	X	X	X	
	Improve CEC monitoring technology	X	X	X	
	Continue development of rapid analysis tools for contaminant identification in mixtures	X	X	X	
	Accelerate development of computational tools, such as AI, that automate the incorporation and processing of CEC data	X	X	X	
Exposure Assessment	Conduct research on distribution system composition and integrity				X
	Develop models and collect data to assess exposure at the tap	X	X	X	X
	Study distribution-system-specific and source-specific exposure scenarios	X	X	X	X
	Investigate the influence of consumer behavior and demographics on exposure			X	X
Human Health Impacts	Develop computational tools for rapid human health risk evaluation	X	X	X	
	Build tools to assess human health risks under realistic exposure scenarios	X	X	X	X
	Improve human health assessment methods for CEC exposure during sensitive developmental periods	X	X	X	
	Build understanding of the psychology of CEC events				X
	Develop methods to identify alternative safe chemicals			X	

*This coordination refers to research involving three or more agencies or involving coordination between the Federal Government and State, local, and Tribal entities.

Anticipated Timeline to reduce research gap	
(light blue)	Near term (0-3 years)
(dark blue)	Mid- to long-term (>3 years)

The following four actions could enhance research efficiency through data sharing and partnerships:

- **Optimization and integration of current data collection processes**: Some knowledge gaps related to CECs in drinking water require enhanced data management rather than additional data collection. To ensure effective utilization of data, a clearinghouse for information stored in individual Federal or State databases, such as those associated with private wells and other databases on public information systems and public water systems, and to encourage systematic review of this information would be useful. Collecting and structuring data can enable the identification of national trends and locations where testing may be insufficient.
- **Alignment of data collection and regulatory requirements**: Regulatory requirements inform the types and magnitude of data collected. For example, when the needs and timelines of the regulatory community are considered in the design of research conducted by Federal agencies, generated information can be directly integrated into efforts. Additionally the integration of new technology into existing policies and/or regulations can improve the quality, credibility, and use of data with little additional resource burden.
- **Development of nationally consistent identification criteria for characterizing and prioritizing pharmaceutical, industrial, and agricultural chemicals:** There are gaps in the present approach to coordinating methods for characterizing, prioritizing, and cataloging knowledge about the effects of CECs. To leverage knowledge on the effects of CECs for the protection of public health, criteria to compare and integrate identification, exposure, and toxicological findings across scientific disciplines and industries would be useful.
- **Local, State, Tribal, and private partnerships**: The supply of drinking water is largely a local responsibility regulated at the State and Federal level. As a result, an effective coordinated plan to reduce critical research gaps requires strong Federal, State, Tribal, local government, and where relevant, private sector partnerships. These partnerships require an ability to share information and facilitate collaboration. For example, the sampling of CECs in tap water would likely be led by the relevant local utilities. However, State and Federal agencies may lead on regional or national assessment of trends and patterns of risk to human health and exposure from these CECs and the use of AI to support data analysis. Moreover, some utilities may need assistance to participate. The role of the private sector is also strategic in such partnerships—73 million Americans receive their water from private water utilities and over 2,000 utilities are operated in public-private contract agreements.

Conclusion

President Trump has stated that water may be the most important issue we face as a nation for the next generation, and as such it is a priority to ensure clean water for better, safer and more prosperous lives.[33] The critical research gaps and the cross-agency plan outlined in this report respond to these concerns and fulfill the congressional request for a Federal response to concerns about emerging contaminants in drinking water to reduce risk to human health. These identify and coordinate critical research areas in identification and exposure to CECs, and human health impacts from CECs where science and technology activities and programs would provide essential data for the risk assessment, mitigation, and communication that underlie public health advisories and standards.

The cross-agency plan provides an overarching framework and integrated elements through which Federal agencies are able to identify shared interests, existing activities and programs related to CECs, actions to enhance research efficiencies, and opportunities for strategic partnerships. Furthermore, the elements of the plan allow agencies to gauge progress on achieving gains in both knowledge and research, and are sufficiently flexible to allow for integration of new data and knowledge growth over time. The provision of safe drinking water is largely a local responsibility, and thus the plan facilitates collaboration and dialogue across stakeholders—Federal, State, local, Tribal, and private partners—who contribute to the development of safe drinking water advisories, standards, and mitigation strategies in communities across the country.

Although drinking water quality in the U.S. is one of the safest in the world, drinking water supply utilities wrestle with increasing concerns around emerging contaminants given deteriorating water infrastructure in the U.S., which is beginning to exceed its life span of 75-100 years.[34] Significant infrastructure upgrades could be aligned with improved understanding of strategies to reduce risk from CECs. Small rural water utilities may require special considerations because they are often challenged by economies of scale and financial, managerial and technical capacity.[35] In effect, the Administration seeks to improve the quality of life in rural America through the modernization of rural utilities to include water.[36]

Progress in the areas described here should be revisited at regular intervals so that adjustments can be made for new and emerging technologies, tools, and knowledge. Ultimately, research should keep pace with the needs of an ever-changing world in order to inform advisories, standards, and actions at the local level to safeguard human health now and in the future.

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33 Department of State and U.S. Agency for International Development. *U.S. Government Global Water Strategy*. 2017.

34 The American Society of Engineers (ASCE). *2017 Infrastructure Report Card - Drinking Water*. https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-Final.pdf.

35 *U.S. Government Global Water Strategy*, 25.

36 Department of Agriculture. *Report to the President of the United States from the Task Force on Agricultural and Rural Prosperity*. 2018. https://www.usda.gov/sites/default/files/documents/rural-prosperity-report.pdf.

Appendix: Federal and State Research Activities and Programs

The following is a selection of intramural and extramural Federal R&D activities and programs that are relevant to CECs in drinking water (Table 3) for identification (ID), exposure (EXP), and human health (HH). Though not meant to be comprehensive, a selection of programs from State and non-governmental actors are also provided to illustrate research and development activity currently being conducted outside the Federal Government (Table 4).

Table 3. Current Federal R&D Activities Related to CECs in Drinking Water

Federal Agency	Activity Description	R&D Areas
DOC/NIST	Metrology in Support of Exposure Science. https://www.nist.gov/mml/csd/environmental-chemical-sciences-group	ID, EXP
DOC/NOAA	Ecotoxicology and Environmental Physiology Program. No website available.	EXP, HH
DOC/NOAA	Environmental Chemistry Program. https://www.nwfsc.noaa.gov/research/divisions/efs/envchem/index.cfm	ID, EXP
DoD	Air Force Total Exposure Health (TEH). No website available.	EXP, HH
DoD	Army Corps of Engineers Environmental Laboratory (Environmental Chemistry Branch). http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/485738/environmental-chemistry-branch	ID, EXP
DoD	Army Public Health Center - Health Effects Division. https://phc.amedd.army.mil/organization/tox/Pages/HealthEffects.aspx	HH
DoD	Army Public Health Center - Toxicology Division. https://phc.amedd.army.mil/Pages/default.aspx	ID, EXP, HH
DoD	DoD Chemical and Biological Defense Program / DTRA Joint Science and Technology Office/ Diagnostics and Detection Program; US Army Institute for Chemical Defense. http://www.dtra.mil/Research/Chemical-Biological-Technologies	ID
DoD	DoD Environment, Safety and Occupational Health Network and Information Exchange (DENIX) Emerging Contaminants Program Basics. https://www.denix.osd.mil/cmrmp/ecmr/ecprogrambasics	ID, EXP, HH
DoD	Military Operational Medicine Research Program. https://momrp.amedd.army.mil	EXP, HH
DoD	Naval Medical Research Unit- Dayton Environmental Health Effects Laboratory. https://www.med.navy.mil/sites/nmrc/Dayton/Directorates/Admin/Pages/Enviornmental-Health-Effects.aspx	HH
DoD	US Army Center for Environmental Health Research. http://usacehr.amedd.army.mil	EXP, HH
DOI/USGS	Contaminant Biology Program. https://www2.usgs.gov/envirohealth/cbp/index.php	HH
DOI/USGS	National Water Quality Assessment (NAWQA) Project. https://water.usgs.gov/nawqa	ID, EXP
DOI/USGS	Toxic Substances Hydrology Program (TSHP). https://toxics.usgs.gov/index.php	ID, EXP

Federal Agency	Activity Description	R&D Areas
DOI/USGS	Water Infrastructure Science Team. https://www2.usgs.gov/envirohealth/science_teams/dw_and_mw/index.php	HH
EPA	Aggregated Computational Toxicology Online Resource system. https://actor.epa.gov/actor/home.xhtml	ID, HH
EPA	Drinking Water Mapping Application to Protect Source Waters (DWMAPS). https://www.epa.gov/sourcewaterprotection/dwmaps	ID
EPA	Emerging Contaminants and Federal Facility Contaminants of Concern Fact Sheets. https://www.epa.gov/fedfac/emerging-contaminants-and-federal-facility-contaminants-concern	ID, HH
EPA	Endocrine Disruptor Screening Program (EDSP). https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-overview	EXP, HH
EPA	Homeland Security Research Program (HSRP). https://www.epa.gov/homeland-security-research	EXP, HH
EPA	Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report). https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990	ID, EXP
EPA	USEPA Region 8 Emerging Contaminants Project. https://www.epa.gov/sites/production/files/2013-08/documents/r8_emergingcontaminantsprojectsummaryaug2013.pdf	ID, EXP
EPA, NIH, FDA	Toxicology in the 21st Century (Tox21) Program. https://www.niehs.nih.gov/research/programs/tox21/index.cfm	EXP, HH
EPA/ORD	National Center for Environmental Assessment (NCEA)'s Integrated Risk Information System (IRIS). https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system	EXP, HH
EPA/ORD	National Exposure Research Laboratory's EPA Drinking Water Research Methods. https://www.epa.gov/aboutepa/about-national-exposure-research-laboratory-nerl-exposure-methods-and-measurement-division	ID, EXP
EPA/ORD	National Health and Environmental Effects Research Laboratory's The Environmental Public Health Division (EPHD). https://www.epa.gov/aboutepa/about-environmental-public-health-division-ephd-epas-national-health-and-environmental	EXP, HH
EPA/ORD	National Health and Environmental Effects Research Laboratory's Toxicity Assessment Division (TAD). https://www.epa.gov/aboutepa/about-toxicity-assessment-division-tad-epas-national-health-and-environmental-effects	ID, HH
EPA/ORD	National Risk Management Research Laboratory (NRMRL)'s Water Systems Division (WSD). https://www.epa.gov/aboutepa/about-water-systems-division-wsd-epas-national-risk-management-research-laboratory-nrmrl	EXP, HH
EPA/ORD	Safe and Sustainable Water Resources research program. https://www.epa.gov/research/safe-and-sustainable-water-resources-strategic-research-action-plan-2016-2019	ID, EXP
EPA/OW	Contaminant Candidate List. https://www.epa.gov/ccl	ID, EXP, HH
EPA/OW	Six-Year Review. https://www.epa.gov/dwsixyearreview	ID, EXP, HH
EPA/OW	Unregulated Contaminant Monitoring Rule. https://www.epa.gov/dwucmr	EXP

Federal Agency	Activity Description	R&D Areas
HHS/ATSDR	Toxicological Profiles. https://www.atsdr.cdc.gov/toxprofiles/index.asp.	ID, EXP, HH
HHS/ATSDR	Division of Community Health Investigations: Public Health Assessment and Consultation http://intranet.cdc.gov/nceh-atsdr/dchi/dchi_health-access.htm	ID, EXP, HH
HHS/ATSDR	Division of Community Health Investigations: Exposure Investigations http://intranet.cdc.gov/nceh-atsdr/dchi/dchi_exposure_inv.htm	EXP
HHS/ATSDR	Division of Community Health Investigations: State cooperative agreement program http://intranet.cdc.gov/nceh-atsdr/dchi/dchi_coop_agree.htm	ID, EXP, HH
HHS/ATSDR	Division of Community Health Investigations: Dose reconstruction/data analysis and visualization: http://intranet.cdc.gov/nceh-atsdr/dchi/dchi_dose_recon.htm and http://intranet.cdc.gov/nceh-atsdr/dchi/dchi_data_analysis.htm	ID, EXP
HHS/ATSDR	Division of Toxicology and Human Health Sciences: Computational Toxicology and Methods Development Lab http://intranet.cdc.gov/nceh-atsdr/dthhs/branch_comptox.html	HH, EXP
HHS/ATSDR	Division of Toxicology and Human Health Sciences: Environmental Epidemiology Branch http://intranet.cdc.gov/nceh-atsdr/dthhs/branch_eeb.html	EXP, HH
HHS/ATSDR	Division of Toxicology and Human Health Sciences: Substance Priority List program https://www.atsdr.cdc.gov/spl/index.html	ID
HHS/ATSDR	Division of Toxicology and Human Health Sciences: Environmental Medicine Branch https://www.atsdr.cdc.gov/emes/	HH
HHS/ATSDR	Division of Toxicology and Human Health Sciences: Geospatial Research, Analysis, and Services Program http://app-v-atsd-web2/grasp_intranet/default.aspx	EXP, HH
HHS/ATSDR	Division of Toxicology and Human Health Sciences: GRASP; Environmental Burden Index Water Module http://app-v-atsd-web2/grasp_intranet/default.aspx	EXP
HHS/ATSDR	Division of Toxicology and Human Health Sciences: GRASP; CDC PHOENIX (Public Health Operations for Emergency Information Integration and Exchange) System http://app-v-atsd-web2/grasp_intranet/default.aspx	EXP, HH
HHS/ATSDR	Division of Toxicology and Human Health Sciences: GRASP Social Vulnerability Index (SVI) http://app-v-atsd-web2/grasp_intranet/grasp_svi.aspx	HH
NSF	Division of Chemical, Bioengineering, Environmental, and Transport Processes (CBET) / Environmental Sustainability Program. https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505549&org=CBET&from=home	ID, EXP
NSF	Division of Chemical, Bioengineering, Environmental, and Transport Processes (CBET) / Biological and Environmental Interactions of Nanoscale Materials Program. https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505553&org=CBET&from=home	ID, EXP, HH

Federal Agency	Activity Description	R&D Areas
NSF	Division of Chemical, Bioengineering, Environmental, and Transport Processes (CBET) / Environmental Engineering Program. https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505551&org=CBET&from=home	ID, EXP, HH
NSF	Division of Chemistry. https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505568&org=CHE&from=home	ID, EXP
NSF	Social, Behavioral and Economic Sciences Directorate / Division of Behavioral and Cognitive Sciences. https://www.nsf.gov/div/index.jsp?div=BCS	EXP, HH
NSF	Social, Behavioral and Economic Sciences Directorate / Division of Social and Economic Sciences. https://www.nsf.gov/div/index.jsp?div=SES	EXP, HH

Table 4. State and NGO R&D Activities Related to CECs in Drinking Water

Organization	Activity Description	R&D Areas
CalEPA	Office of Environmental Health Hazard Assessment (OEHHA). https://oehha.ca.gov/water	EXP, HH
California Water Boards	Safe Drinking Water Plan. https://www.waterboards.ca.gov/drinking_water/safedrinkingwaterplan	ID, HH
Environmental Council of the States (ECOS)	ECOS-DoD Sustainability Work Group, Emerging Contaminants Task Group. https://www.ecos.org/wp-content/uploads/2016/05/Resource-Triggers-Paper-finalized-8-12-08-endorsed-9-21-08.pdf	ID, EXP, HH
Environmental Working Group	EWG's Tap Water Database. https://www.ewg.org/tapwater/index.php	ID, EXP
Interstate Chemicals Clearinghouse	Chemical Hazard Assessment Database. http://www.theic2.org/hazard-assessment	ID
Interstate Technology and Regulatory Council	PFAS project. https://www.itrcweb.org/Team/Public?teamID=78	ID, EXP
Michigan	Michigan PFAS Action Response Team. https://www.michigan.gov/pfasresponse	ID, EXP
Minnesota Department of Health	Contaminants of Emerging Concern Program. http://www.health.state.mn.us/divs/eh/risk/guidance/dwec/index.html	ID, HH
New Jersey Department of Environmental Protection	Division of Science, Research and Technology. http://www.state.nj.us/dep/dsr/contaminants-dw.htm	ID, EXP
New Jersey Drinking Water Quality Institute	Maximum Contaminant Level Recommendation for Perfluorooctanoic Acid in Drinking Water. http://www.nj.gov/dep/watersupply/pdf/pfoa-recommend.pdf	ID, EXP, HH
NORMAN Network	NORMAN Network. https://www.norman-network.net	ID, EXP
NSF International	Standard NSF/ANSI 401: Emerging Contaminants/Incidental Compounds. http://www.nsf.org/consumer-resources/water-quality/drinking-water/nsf-ansi-401-testing-emerging-contaminants	ID
Oregon Department of Environmental Quality	Toxics Monitoring Program. http://www.oregon.gov/deq/wq/Pages/WQ-Monitoring-Statewide.aspx	ID, EXP
Southern California Coastal Water Research Project	Research Theme: Contaminants. http://www.sccwrp.org/ResearchAreas/Contaminants.aspx	ID, EXP, HH
Water Research Foundation	Holistic Strategies for Managing Contaminants of Emerging Concern (CECs) in Water (Completed in 2014). http://www.waterrf.org/the-foundation/research-programs/focus-area-program/Pages/contaminants-of-emerging-concern-.aspx	ID, HH

Organization	Activity Description	R&D Areas
World Health Organization	Joint FAO/WHO Expert Committee on Food Additives (JECFA). http://apps.who.int/food-additives-contaminants-jecfa-database/search.aspx#	ID, EXP

List of Acronyms

AI	Artificial Intelligence
ANSI	American National Standards Institute
ATSDR	Agency for Toxic Substances and Disease Registry
CCL	Contaminant Candidate List
CDC	Centers for Disease Control and Prevention
CEC	Contaminant of Emerging Concern
DOC	Department of Commerce
DoD	Department of Defense
DOI	Department of the Interior
DTRA	Defense Threat Reduction Agency
ECOS	Environmental Council of the States
EPA	Environmental Protection Agency
EWG	Environmental Working Group
EXP	Exposure
FDA	Federal Drug Administration
HH	Human Health
HHS	Department of Health and Human Services
ID	Identification
LSD	Lysergic Acid Diethylamide
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NormaNEWS	Norman Early Warning System
NPDWR	National Primary Drinking Water Regulations
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTP	National Toxicology Program
OMB	Office of Management and Budget
ORD	Office of Research and Development
OSTP	Office of Science and Technology Policy
OW	Office of Water
PFAS	Per- and Polyfluoroalkyl Substances
SDWA	Safe Drinking Water Act
TF	Task Force
Tox21	Toxicology for the 21st Century
UCMR	Unregulated Contaminant Monitoring Rule
U.S.C.	United States Code
USGS	United States Geological Survey
WHO	World Health Organization