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

A Report by the

Interagency Working Group on Emerging Contaminants

of the

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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About the Task Force on Emerging Contaminants

The Task Force on Emerging Contaminants (TF) was established in May 2018 under the Committee on Environment within the NSTC. The purpose of the TF was to provide OSTP with expertise from the Federal agencies about emerging contaminants in drinking water and resulted in the 2018 document.

About This Document

In response to direction given in Senate Report 115-139 to Public Law 115-141, OSTP, in collaboration with agency representatives, developed a 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. This document is an update to that plan, as requested by Senate Report 116-127 to Public Law 116-69, which asked OSTP to "update the implementation plan included in that report, including identifying budget resources required, by agency, for fiscal years 2019, 2020, and 2021."

About This Update

The report was initially updated in fall 2019, but was not released at the time. In spring 2021, the report underwent further review that includes additional agencies reporting on research and development activities. In addition, the report's language has been updated to highlight alignment with the Biden-Harris Administration's priorities on climate change and environmental justice.

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Abbreviations and Acronyms

AI	Artificial Intelligence
APHC	Army Public Health Center
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
CEC	Contaminant of Emerging Concern
CEA	Council of Economic Advisers
CEQ	Council on Environmental Quality
CPSC	Consumer Product Safety Commission
DHS	Department of Homeland Security
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOJ	Department of Justice
DOL	Department of Labor
DPC	Domestic Policy Council
DOT	Department of Transportation
ECOS	Environmental Council of the States
ED	Department of Education
EOP	Executive Office of the President
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EXP	Exposure
FDA	Food and Drug Administration
FS	Forest Service
FY	Fiscal Year
HH	Human Health
HHS	Health and Human Services
HUD	Housing and Urban Development
ID	Identification
IWG	Interagency Working Group

LSD Lysergic Acid Diethylamide

NCEH National Center for Environmental Health

NECRI National Emerging Contaminant Research Initiative

NEPC National Economic Policy Council

NIEHS National Institute of Environmental Health Sciences

NIFA National Institute of Food and Agriculture

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

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

R&D Research and Development

SDWA Safe Drinking Water Act

SERDP Strategic Environmental Research and Development Program

TF Task Force

Tox21 Toxicology for the 21^{st} Century

USACE United States Army Corps of Engineers

U.S.C. United States Code

USDA United States Department of Agriculture

USGS United States Geological Survey

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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 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.

OSTP and the NSTC TF sent Congress the *Plan for Addressing Critical Research Gaps Related to Emerging Contaminants in Drinking Water* in October 2018 (hereafter called the 2018 plan).[1] In 2019–2020, Congress asked OSTP to "update the implementation plan included in that report, including identifying budget resources required, by agency, for fiscal years 2019, 2020, and 2021."[2] OSTP added mission-related research programs and research and development activities that were new since the 2018 plan was published, as well as funding estimates for all Federal programs related to drinking water research. In accordance with this request, Table 3 in Appendix A has been updated, and Appendix B provides the funding estimates.[3] In 2020, the National Defense Authorization Act (NDAA) directed the Environmental Protection Agency (EPA) and the National Institutes of Health (NIH) to create an interagency working group on CECs (termed the Interagency Working Group on Emerging Contaminants). This working group succeeded the NSTC Task Force and provided subject matter expertise for this current update. Federal entities participating in the interagency working group (IWG) include the Agency for Toxic Substances and Disease Registry (ATSDR), the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health (CDC/NIOSH), the Department of Defense (DoD), the Department of Energy (DOE), EPA, the Food and Drug Administration (FDA), the National Institute of Standards and Technology (NIST), NIH National Institute of Environmental Health Sciences (NIH/NIEHS), the National Science Foundation (NSF), the United States Department of Agriculture Forest Service (USDA-FS) and National Institute of Food and Agriculture (USDA-NIFA), and the U.S. Geological Survey (USGS). These departments and agencies helped to provide information and subject matter expertise to OSTP to update this plan for Congress. The FY 2020 NDAA also directed OSTP to establish a National Emerging Contaminant Research Initiative to support the implementation of the Federal research strategy for Emerging Contaminants.[4] In addition to the updates listed above, the document has been revised to include other agencies' research and development activities as well as reflect the Biden-Harris Administration priorities in the areas of climate change and environmental justice.

[1] 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).

[2] House Conference Report 116-9, Making Further Continuing Appropriations for the Department of Homeland Security for Fiscal Year 2019, And For Other Purposes, 2019.

[3] *National Defense Authorization Act for Fiscal Year 2020*, Public Law 116-92. https://www.congress.gov/bill/116th-congress/senate-bill/1790

[4] *Id.*, sections 7341 and 7342.

Introduction

Drinking water contaminants of emerging concern (CECs) (also called emerging contaminants) are newly identified or reemerging manufactured or naturally occurring physical, chemical, biological, radiological, or nuclear materials that may cause adverse effects to human health or the environment and do not currently have a national primary drinking water regulation.[5,6] 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.[7] To address concerns about emerging contaminants in drinking water, Congress requested that OSTP develop a coordinated cross-agency plan to identify critical research gaps related to emerging contaminants in drinking water.

CECs are frequently categorized by their type and source, and the most common categories are personal care products, pesticides, pharmaceuticals and illicit drugs,[8] 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.[9] 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)[10] was passed by Congress in 1974 and amended in 1996 to protect the quality of drinking water provided by public water systems in the United States. Research across the Federal Government supports the SDWA requirements 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. CECs 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 and characterize contaminants in drinking water, new CECs that can cause public health concerns may be identified.

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5 This definition was developed by consensus of the Contaminant of Emerging Concern Interagency Working Group and is consistent with the *National Defense Authorization Act for Fiscal Year 2020*, Public Law 116-92, sections 7341 and 7342. https://www.congress.gov/bill/116th-congress/senate-bill/1790

6 Note that *national primary drinking water regulation* refers to the maximum contaminant level under the Safe Drinking Water Act. Additionally, per- and polyfluoroalkyl substances (PFASs) are subject to additional interagency research coordination statutory authorities, and PFAS are only briefly discussed in this report.

7 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.

8 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 Lysergic Acid Diethylamide (LSD)) to the effect that their use has been prohibited globally." International Encyclopedia of the Social & Behavioral Sciences (2001): 3877-3881.

9 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.

10 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.

In response to the congressional request, OSTP convened the task force, which 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. In addition, lower-income and predominantly minority communities may be more frequently subject to contaminated drinking water.[11]

CEC research must also be conducted in anticipation of changes in conditions that may exacerbate the occurrence or health effects of CECs as a result of climate change.[12] Rising temperatures, sea level rise, and extreme weather events are increasingly expected to damage and disrupt the environment and infrastructure.[13] For example, climate change can increase the likelihood of natural disasters such as wildfires, which may change patterns in surface runoff and introduce new sediment and other contaminants to a watershed. The severity of droughts in geographic areas of the country will enhance the need for water reuse and recycling that may concentrate existing contaminants, increasing prevalence of extreme weather and climate-related events that may cause unintended industrial chemical releases, leading to potentially acute exposure scenarios.[14] Understanding the complex relationships between the hydrologic and drinking water cycles, CECs, and public health within the context of a changing climate will be a crucial step forward in ensuring clean drinking water for every person. Such work aligns with Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*.[15]

Implementation of the framework described below will safeguard human health by providing the information needed to proactively perform risk assessment, communication, and mitigation among Federal, State, and local stakeholders.

[11] National Academies of Sciences, Engineering, and Medicine, 2021. *Quality Water from Every Tap: Proceedings of a Workshop - in Brief*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26069

[12] U.S. Global Change Research Program, 2018. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Washington, DC: U.S. Global Change Research Program. https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf

[13] U.S. Global Change Research Program, 2018. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Washington, DC: U.S. Global Change Research Program. https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf

[14] Noyes, Pamela D., Matthew K. McElwee, Hilary D. Miller, Bryan W. Clark, Lindsey A. Van Tiem, Kia C. Walcott, Kyle N. Erwin, and Edward D. Levin. "The toxicology of climate change: environmental contaminants in a warming world." *Environment international* 35, no. 6 (2009): 971-986.

[15] Exec. Order. No. 14008, 86 Fed. Reg. 7619 (January 27, 2021), https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad.

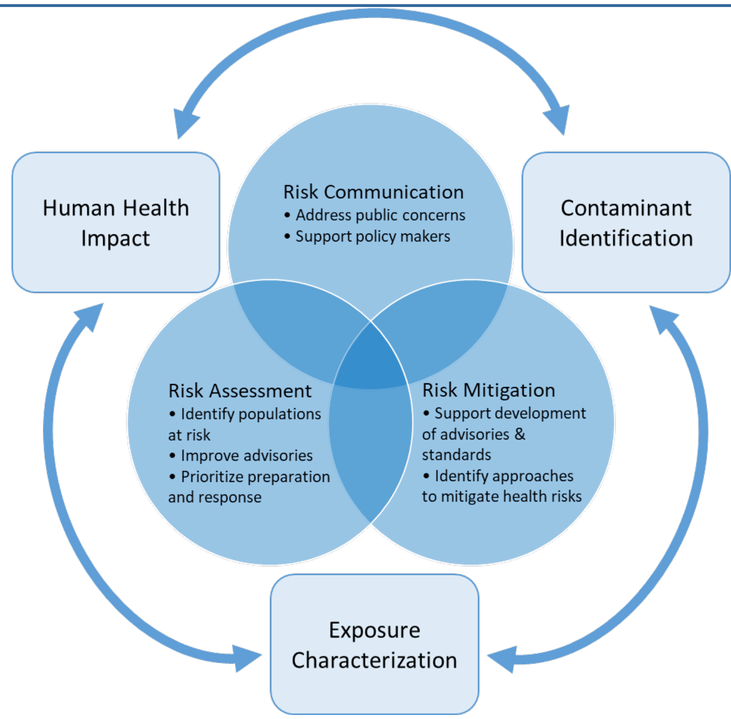

Figure 1. Research and development on CECs in the areas of Human Health Impacts, Contaminant Identification, and Exposure Characterization informs a policy framework that includes effective risk communication, risk assessment, and risk mitigation.

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.

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.[16] High-resolution mass spectrometry, an analytical method used to characterize chemicals qualitatively

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

and quantitatively, has enhanced the detection and quantification of byproducts of CECs undergoing environmental processes.[17] 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.[18]

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 the treatment system and through the distribution system.[19] Therefore, information to better understand the fate and transport of CECs is 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

[17] 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.

[18] 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.

[19] 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.

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, the Norman Early Warning System (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 hazards 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.

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 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.[20] *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.*

[20] 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.

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.[21] 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).[22] 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,[23] 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,[24] inhalation (e.g., breathing in aerosolized contaminants due to transfer from tap water to indoor air,[25] while showering, or using a humidifier[26]) and dermal absorption[27] (e.g., water and skin contact while bathing, hand washing, or cooking).[28] 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,[29] sub-chronic, and chronic exposure timeframes.[30] Additional

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

[22] 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.

[23] 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.

[24] 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.

[25] 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.

[26] Environmental Protection Agency, 2001. *Inhalation Exposure to Contaminants from a Water Distribution System.* Washington, DC: U.S. EPA Office of Research and Development. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=309585&Lab=NHSRC&fed_org_id=1253&subject=Homeland%20Security%20Research&view=desc&sortby=pubDateYear&showcriteria=1&count=25.

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

[28] 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.

[29] Centers for Disease Control and Prevention. "Norovirus." Last updated March 2021. Accessed August 6, 2021. https://www.cdc.gov/norovirus/index.html.

[30] Environmental Protection Agency. Last Updated September 11, 2018. "Report on the Environment - Drinking Water." Accessed September 9, 2021. https://www.epa.gov/report-environment/drinking-water

research has shown that susceptible subpopulations—such as pregnant women, nursing mothers, children, and the elderly—may be more vulnerable to certain CECs.[31]

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 per- and polyfluoroalkyl substances (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.

[31] 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)

PFAS are a group of human-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.[32] 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;[33] drinking water is one of multiple exposure routes.[34] 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. In addition, EPA has been monitoring fish tissue for PFAS in several national studies in rivers and Great Lakes to identify PFAS fish tissue occurrence. 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. In 2021, EPA released its PFAS Roadmap, which lays out a whole-of-agency approach to use every available tool to safeguard communities from PFAS contamination.[35] 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[36] and New Jersey,[37] 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. In addition, as the supply of drinking water to consumers is primarily a local government responsibility, inequalities in infrastructure and funding may lead to CEC exposure being exacerbated in lower-income and predominantly minority communities.[38] 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

[32] National Institute of Environmental Health Sciences (NIEHS). Last updated April 27, 2021. "Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)." Accessed August 6, 2021. https://www.niehs.nih.gov/health/materials/perflourinated_chemicals_508.pdf.

[33] 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.

[34] USEPA. Last updated April 8, 2021. "Basic Information on PFAS." Accessed August 6, 2021. https://www.epa.gov/pfas/basic-information-pfas.

[35] PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024 | US EPA.

[36] Minnesota Pollution Control Agency. n.d. "Perfluorochemicals (PFCs)."Accessed August 6, 2021. https://www.pca.state.mn.us/waste/perfluorochemicals-pfcs.

[37] New Jersey Department of Environment Protection. Last updated August 5, 2021. "Site Remediation Program, Contaminants of Emerging Concern." Accessed August 6, 2021. https://www.nj.gov/dep/srp/emerging-contaminants.

[38] National Academies of Sciences, Engineering, and Medicine, 2021.

materials with drinking water disinfection byproducts, and assessments of the likelihood of pipe breaks and the potential for exposure to pathogenic microorganisms resulting from such infrastructure failures.

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. Modeling 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.

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.[39] 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.[40] 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 certain PFAS are associated with lower infant birth weights[41] and reduced effectiveness of childhood vaccines.[42]

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.*[43]

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

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

[40] Ibid.

[41] 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.

[42] 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.

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

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 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 National Toxicology Program's (NTP's) Toxicology for the 21st Century (Tox21) and EPA's Toxcast program seek to augment population and human clinical studies with in vitro and isolated molecular target analyses.[44] 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

[44] 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). More at: https://tox21.gov.

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 affects health outcomes of the exposed individual and their children. Toxicological models that better reflect other susceptible and underrepresented populations who may present with co-morbidities or have poor access to healthy food (unhealthy diet, food insecurity) should also be utilized. 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 exposure, as well as how those factors can be applied to develop more effective risk communication strategies, is needed.

Develop methods to identify alternative safer chemicals and their sustainable use: 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.

Additional Updates

Environmental Justice: Many environmental, physiological, social, and behavioral factors contribute to disproportionate exposure to CECs and disparities in CEC-related health effects. Many of these disparities are a result of a long and ongoing history of systemic racism, poverty, rural or urban locality, and other social and physical determinants of health inequities.[45] In addition, mitigation activities may also be hampered by underinvestment or disproportional neglect in

[45] HealthyPeople.gov. Last updated June 23, 2021. "Social Determinants of Health." Accessed August 6, 2021. https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants-of-health.

underserved communities. As such, CECs are an environmental justice issue. Environmental justice entails a clear commitment to addressing the disproportionate exposure to environmental pollution and its health effects and ensuring the protection and delivery of clean, safe water for all. An aspect of environmental justice is the meaningful involvement of impacted parties in decisions and communication on environmental hazards.[46]

Pre-existing burdens can contribute to more severe environmental health impacts in some populations despite similar levels of exposure.[47] These burdens include physiological diversity, pre-existing susceptibilities, a higher incidence of underlying health conditions, higher likelihood of exposure to multiple contaminants, and discrimination (e.g., inequity in treatment when seeking medical care).[48] These burdens may also mean fewer resources to mitigate exposure to contaminants or address any underlying health conditions. Climate change threatens to worsen these existing inequities by increasing exposure and worsening the underlying environmental factors in already-vulnerable areas such as floodplains, agricultural communities, areas with high fire risk, and in urban heat islands.[49] Approximately 40 million Americans in rural areas supply their own drinking water, where monitoring and treatment of water is the responsibility of property owners.[50] This contrasts with the majority of Americans who live in and near population centers served by public water utilities where they benefit from compliance monitoring and treatment of water as required under the Safe Drinking Water Act. Consequently, access to data and information about CECs in drinking water is out of the reach of many citizens in these underserved areas. Efforts should include meaningful engagement with these populations and enhanced transparences and action around water quality issues.

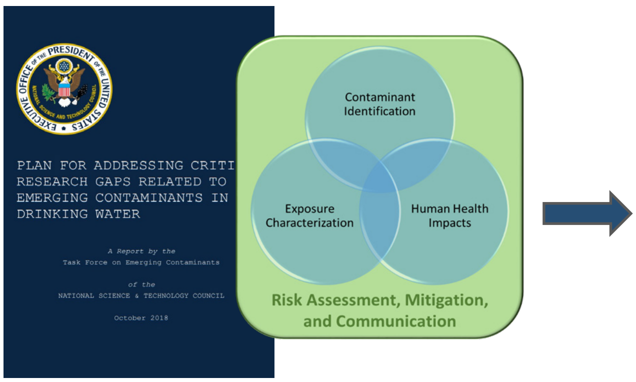
To better understand and address these inequities, specific effort needs to be made to enhance and modernize measures of exposures across populations and geographic areas. These efforts should focus on disparities and inclusion of affected communities at all levels and types of decision making, including working closely with stakeholders to facilitate two-way communications with communities.

Complementary CEC Efforts: The National Emerging Contaminant Research Initiative (NECRI)

This report identifies the three research themes of contaminant identification, exposure characterization, and human health impacts as key components of a coordinated cross-agency plan for modernizing tools and addressing critical research gaps related to detecting, assessing exposure, and identifying potential adverse health effects of CECs. This current update includes authors from all agencies on the initial 2018 Task Force. The update also includes additional authors from agencies that participate in the current Interagency Working Group on Emerging Contaminants (CEC IWG), co-chaired by the EPA and the Department of Health and Human Services (HHS). The CEC IWG was established in March 2020 in response to direction given in the National Defense Authorization Act for fiscal year (FY) 2020.[51] The CEC IWG works to coordinate CEC research activities of the Federal Government and identify and analyze the public health effects of

[46] EPA. 2016. *EJ 2020 Action Agenda*. Washington, DC: Office of Enforcement and Compliance. https://www.epa.gov/sites/production/files/2016-05/documents/052216_ej_2020_strategic_plan_final_0.pdf
[47] Healthpeople.gov, 2021.
[48] HealthyPeople.gov. Last updated August 27, 2021. "Disparities." Accessed September 9, 2021. https://www.healthypeople.gov/2020/about/foundation-health-measures/Disparities
[49] U.S. Global Change Research Program, 2018.
[50] Johnson, T. D., Belitz, K., Lombard, M. A., "Estimating domestic well locations and populations served in the contiguous U.S. for years 2000 and 2010," *Science of the Total Environ.* 687 (2019): 1261-1273. https://doi.org/10.1016/j.scitotenv.2019.06.036.
[51] *National Defense Authorization Act for Fiscal Year 2020, sections 7341 and 7342.*

drinking water CECs. The FY 2020 NDAA also outlined OSTP's development of a National Emerging Contaminant Research Initiative (NECRI) in order to improve the identification, analysis, monitoring, and treatment methods of CECs. To create the NECRI, OSTP and the CEC IWG are collaborating and expanding upon the CEC Plan's research themes, to include five CEC research areas: Exposure, Human Health and Environmental Effects, Risk Characterization, Risk Mitigation, and Risk Communication. The NECRI will identify areas of opportunity related to these five research themes, and help to facilitate Federal CEC research coordination by outlining guidance for a Federal R&D implementation plan that will incorporate the latest climate change information and address areas where communities are disproportionately impacted by water-related challenges. This document and the NECRI are synergistic with one another, and collectively provide a source of existing opportunities for Federal coordination and help to guide future areas of CEC research.



NECRI Technical Team Topic Areas:

- Exposure
- Human and Environment Effects
- Risk Characterization
- Risk Mitigation
- Risk Communication

Figure 2. This report will allow the interagency working group to pivot to the 2022 NECRI

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. Table 1 has been updated by CEC IWG participants to show which identified research gaps fall within the agencies' missions. Table 1 contains 3 parts (1.A, 1.B, 1.C), aligning with the three topic areas outlined in this plan. ATSDR, DoD, EPA, NIH, NIST, USDA, and USGS all report that the majority of identified research gaps fall within their agency missions. ATSDR, DoD, EPA, NIH, and USGS have responsibilities spread across the three topic areas, whereas NIST primarily focuses on contaminant identification and exposure assessment, and USDA primarily focuses on contaminant identification and human health impacts research. 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 A. Funding associated budgets with these research and development efforts may be found in Appendix B. Examples of State, Tribal, Territory, and non-government organizations research and development activities are also listed in Appendix A as potential examples of synergies and outreach.

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

Table 1A. Intersection of Agency Missions and Research Gaps Identified in This Plan for Contaminant Identification

Contaminant Identification (ID) Research Gaps	Water Sampling Design	CEC Monitoring Technology	Rapid Analysis Tools for Contaminant Identification in Mixtures	Computational Tools (e.g., AI) for Processing CEC Data
CDC/ATSDR	X	X		X
DoD	X	X	X	X
EPA	X	X	X	X
FDA	X (bottled water)			
NIH/NIEHS		X	X	X
NIST	X		X	X
NSF		X	X	
USDA-NIFA	X	X	X	
USGS	X	X	X	X

Table 1B. Intersection of Agency Missions and Research Gaps Identified in this Plan for Exposure Assessment

Exposure Assessment Research Gaps	Distribution System Composition and Integrity	Models to Assess Exposure at the Tap	Distribution-System- and Source-Specific Exposure Scenarios	Influences of Consumer Behavior and Demographics on Exposure
CDC/ATSDR		X	X	X
DoD		X	X	
EPA	X	X	X	
FDA		X (bottled water)		
NIH/NIEHS		X	X	X
NIST	X	X	X	
NSF				X
USDA-NIFA			X	X
USGS		X	X	

Table 1C. Intersection of Agency Missions and Research Gaps Identified in This Plan for Human Health Impacts

Human Health Impacts Research Gaps	Computational Tools for Rapid Human Health Risk Evaluation	Tools to Assess Human Health Risks under Realistic Exposure Scenarios	Human Health Assessment Methods for CEC Exposure During Sensitive Developmental Periods	Psychology of CEC Events	Methods to Identify Alternative Safe Chemicals
CDC/ATSDR	X	X	X	X	
DoD	X	X	X		X
EPA	X	X	X		
FDA		X	X		
NIH/NIEHS	X	X	X	X	
NIST					X
NSF					
USDA-NIFA		X	X	X	
USGS	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 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	

	Research Gap	Standards, Process, and Protocol Development	Data Management, Analytics, and Informatics	Cross-Government Coordination*	Outreach
	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:

1. **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 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.
2. **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.
3. **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.
4. **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

Clean drinking water has been a stated national priority since 1972 with the passage of the Clean Drinking Water Act, followed in 1974 with the passage of the Safe Drinking Water Act. As such, ensuring clean drinking water for all Americans remains a priority for better, safer, and more prosperous lives.[52,53] While most U.S. residents benefit from clean, safe water, industrial and agricultural releases coupled with a rapidly changing climate and aging infrastructure are challenging our ability to maintain equitable access to safe water. 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, avoid duplicative efforts and redundancies, leverage resources, and identify opportunities for strategic partnerships. Furthermore, the elements of the plan allow agencies to gauge progress individually and together on meeting performance goals, 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 effective implementation of this plan will require facilitated 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 United States is among the safest in the world, drinking water supply utilities wrestle with increasing concerns around emerging contaminants given deteriorating water infrastructure in the United States, which is beginning to exceed its life span of 75–100 years.[54] Significant infrastructure upgrades could be aligned with improved understanding of strategies to reduce risk from CECs. Small rural water utilities as well as low-income regions and historically marginalized and underserved communities may require special considerations because they are often challenged by economies of scale and financial, managerial, and technical capacity.[55,56] Individual homeowners in marginalized urban areas as well as those who supply their own drinking water in rural areas are particularly challenged in gaining access to information about CECs in their water and the resources to upgrade their own aging infrastructure, such as premise plumbing and point-of-use treatment.

[52] Exec. Order. No. 14008.

[53] Department of State and U.S. Agency for International Development. *U.S. Government Global Water Strategy*. 2017. Washington, DC: U.S. Agency for International Development. https://www.usaid.gov/sites/default/files/documents/1865/Global_Water_Strategy_2017_final_508v2.pdf.

[54] The American Society of Civil Engineers. 2017. *2017 Infrastructure Report Card - Drinking Water*. https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-Final.pdf.

[55] Department of State and U.S. Agency for International Development, 2017.

[56] Exec. Order. No. 13985, 86 Fed. Reg. 7009 (January 20, 2021). https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government

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, including changes and impact due to climate change. 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.

Appendix A: 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 nongovernmental 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
Department of Commerce (DOC)/NIST	Non targeted analysis https://www.nist.gov/programs-projects/method-assessment-non-targeted-analyses-manta-program Non-targeted analysis for ground water source apportionment (no website)	ID, EXP, HH
DOC/NIST	Metrology in Support of Exposure Science. https://www.nist.gov/mml/csd/biochemical-and-exposure-science-group	ID, EXP
DOC/NIST	Plastic Pollution Research https://www.nist.gov/programs-projects/plastic-pollution-measurement-science	ID, EXP
DOC/NIST	Nanomaterials Suspended in Liquids. https://www.nist.gov/programs-projects/environmental-leaching-nanoparticles-consumer-products	ID, EXP
DOC/NIST	Reference materials for human matrices. https://www.nist.gov/programs-projects/organic-contaminants-human-serum-milk-and-urine	ID, EX, HH
DOC/NIST	Measurement services for wildlife https://www.nist.gov/programs-projects/measurements-and-standards-contaminants-wildlife-matrices	ID, EXP
DOC/NIST	Quality assurance for metabolite detection	ID, EXP, HH

Federal Agency	Activity Description	R&D Areas
	https://www.nist.gov/programs-projects/metabolomics-quality-assurance-and-quality-control-materials-metqual-program https://www.nist.gov/programs-projects/development-nist-reference-materials-untargeted-metabolomics-lipidomics-and	
DOC/NIST	Steroid hormone measurement https://www.nist.gov/programs-projects/steroid-hormone-pathway-mapping https://www.nist.gov/programs-projects/development-reference-methods-and-reference-materials-determination-hormones-human	EX,HH
DOC/NIST/ EPA/NIH/FDA	Benchmarks for non-targeted analysis (BP4NTA) https://nontargetedanalysis.org/	ID, EX
DOC/National Oceanic and Atmospheric Administration (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.cf m	ID, EXP
DoD	Army Public Health Center- Toxicology Directorate. https://phc.amedd.army.mil/topics/labsciences/Pages/default.aspx	ID, EXP, HH
DoD	DoD Emerging Chemicals Program. https://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/NAMRUDayton/Pages/Home.aspx	HH

DoD	Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration	ID, EXP
DoD/United States Army Corps of Engineers (USACE)	Engineer Research and Development Center (ERDC) Program for Substances of Emerging Environmental Concern. Website in development.	ID, EXP
Department of the Interior (DOI)/USGS	Environmental Health Program (Contaminant Biology and Toxic Substances Hydrology) https://www.usgs.gov/ecosystems/environmental-health-program	HH
DOI/USGS	National Water Quality Program https://pubs.er.usgs.gov/publication/70204697	ID, EXP
DOI/USGS	Water and Wastewater Infrastructure Science Team. https://www.usgs.gov/ecosystems/environmental-health-program/science/water-and-wastewater-infrastructure-science-team?qt-science_center_objects=0#qt-science_center_objects	HH
EPA	Aggregated Computational Toxicology Online Resource System. https://actor.epa.gov/actor/home.xhtml	ID, HH
EPA	Analytical Methods Developed by EPA for Analysis of Unregulated Contaminants. https://www.epa.gov/dwanalyticalmethods/analytical-methods-developed-epa-analysis-unregulated-contaminants	ID
EPA	Contaminants of Emerging Concern including Pharmaceuticals and Personal Care Products. https://www.epa.gov/wqc/contaminants-emerging-concern-including-pharmaceuticals-and-personal-care-products	ID, EXP, HH
EPA	Determining the Prevalence of Contaminants in Treated and Untreated Drinking Water. https://www.epa.gov/water-research/determining-prevalence-contaminants-treated-and-untreated-drinking-water	ID, EXP, HH
EPA	Drinking Water Mapping Application to Protect Source Waters. https://www.epa.gov/sourcewaterprotection/drinking-water-mapping-application-protect-source-waters-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. https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-overview	EXP, HH
EPA	Emergency Response Research. https://www.epa.gov/emergency-response-research	EXP, HH
EPA	Fifth Unregulated Contaminant Monitoring Rule. https://www.epa.gov/dwucmr/fifth-unregulated-contaminant-monitoring-rule	ID, HH
EPA	Fourth Unregulated Contaminant Monitoring Rule. https://www.epa.gov/dwucmr/fourth-unregulated-contaminant-monitoring-rule	ID, 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 Program. https://ntp.niehs.nih.gov/whatwestudy/tox21/index.html	EXP, HH
EPA/Office of Research and Development (ORD)	Center for Public Health and Environmental Assessment's Integrated Risk Information System. https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system	EXP, HH
EPA/ORD	EPA Drinking Water Research Methods. https://www.epa.gov/water-research/epa-drinking-water-research-methods	ID, EXP
EPA/ORD	Center for Public Health and Environmental Assessment's Public Health and Environmental Systems Division. https://www.epa.gov/aboutepa/about-public-health-and-environmental-systems-division-phesd	EXP, HH

EPA/ORD	Center for Public Health and Environmental Assessment's Chemical and Pollutant Assessment Division. https://www.epa.gov/aboutepa/about-chemical-and-pollutant-assessment-division-cpad	ID, HH
EPA/ORD	Center for Environmental Solutions and Emergency Response's Water Infrastructure Division. https://www.epa.gov/aboutepa/about-water-infrastructure-division	EXP, HH
EPA/ORD	Safe and Sustainable Water Resources research program. https://www.epa.gov/sites/production/files/2021-03/documents/sswr_fy19-22_strap_final_2020.pdf	ID, EXP
EPA/Office of Water (OW)	Drinking Water Contaminant Candidate List and Regulatory Determination. https://www.epa.gov/ccl	ID, EXP, HH
EPA/OW	Monitoring the Occurrence of Unregulated Drinking Water Contaminants. https://www.epa.gov/dwucmr	EXP
EPA/OW	Method Development for Unregulated Contaminants in Drinking Water Meeting Materials. https://www.epa.gov/dwanalyticalmethods/method-development-unregulated-contaminants-drinking-water-meeting-materials	ID
HHS/ATSDR	Toxicological Profiles. https://www.atsdr.cdc.gov/toxprofiledocs/index.html	ID, EXP, HH
HHS/ATSDR	ATSDR's Partnership to Promote Localized Efforts to Reduce Environmental Exposure – State Cooperative Agreement Program	EXP, HH
HHS/ATSDR	Biomonitoring of Great Lakes Populations Program.	EXP, HH
HHS/ATSDR	Public Health Assessments and Health Consultations	EXP, HH
HHS/CDC	Health Studies Branch- Promoting Clean Water for Health. https://www.cdc.gov/nceh/hsb/cwh/research.htm	HH
HHS/CDC	National Biomonitoring Program https://www.cdc.gov/biomonitoring/index.html	EXP
HHS/CDC	National Health and Examination Survey. https://www.cdc.gov/nchs/nhanes/index.htm	EXP
HHS/CDC	National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/nhanes/index.htm	HH

HHS/CDC	NIOSH Health Hazard Evaluation (HHE) program. https://www.cdc.gov/niosh/hhe/default.html	EXP, HH
HHS/CDC, USDA, FDA, EPA	National Antimicrobial Resistance Monitoring System. https://www.fda.gov/animal-veterinary/antimicrobial-resistance/ national-antimicrobial-resistance-monitoring-system	ID
HHS/FDA	Total Diet Study-measure contaminants in food and bottled water https://www.fda.gov/food/total-diet-study/analytical-results-total-diet-study	ID
HHS/NIH	National Cancer Institute's Division of Cancer Epidemiology &Genetics. https://dceg.cancer.gov	HH
HHS/NIH	National Toxicology Program. https://ntp.niehs.nih.gov	ID, HH
HHS/ NIH/ NIEHS	NIEHS Superfund Research Program. https://www.niehs.nih.gov/research/supported/centers/srp	EXP, HH, ID
HHS/ NIH/ NIEHS	Time-Sensitive Research Opportunities in Environmental Health Sciences (R21) Exploratory/Developmental. https://www.niehs.nih.gov/research/supported/timesensitve/index.cfm	ID, HH
HHS/ NIH/ NIEHS	Environmental Health Sciences Core Centers. https://www.niehs.nih.gov/research/supported/centers/core/index.cfm	HH
HHS/NIH/ NIEHS	Environmental Health Disparities Strategic Focus Group. Environmental Health Disparities (EHD) (nih.gov)	HH
HHS/NIH/ NIEHS	Safe and Sustainable Alternatives Program. https://ntp.niehs.nih.gov/ntp/about_ntp/bsc/2021/august/meeting_materials/ssa_bsc_508.pdf	HH
HHS/NIH/ NIEHS	Disaster Research Response Program. Disaster Research Response (DR2) Program (nih.gov)	HH

HHS/ NIH/ NIEHS/ NTP, EPA	NTP Rapid Evaluation and Assessment of Chemical Toxicity. No website available.	EXP, HH
NSF	Division of Chemical, Bioengineering, Environmental, and Transport Processes/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/ 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
NSF	Division of Chemical, Bioengineering, Environmental, and Transport Processes/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=SE S	EXP, HH
USDA-NIFA	Onsite Wastewater Treatment Systems: Assessing the Impact of Soil Variability and Climate Change (Multistate Committee) https://portal.nifa.usda.gov/web/crisprojectpages/1024140-onsite-wastewater-treatment-systems-assessing-the-impact-of-soil-variability-and-climate-change.html	ID, EXP

USDA-NIFA	Environmental Fate of Antibiotics Originating from Agricultural By-Products and Wastes https://portal.nifa.usda.gov/web/crisprojectpages/1023304-environmental-fate-of-antibiotics-originating-from-agricultural-by-products-and-wastes.html	EXP, HH
USDA-NIFA	Predictive Tools for Degradation of Chemicals of Emerging Concern in Livestock Manure by Anaerobic Digestion and Advanced Oxidation Processes PREDICTIVE https://www.journals.elsevier.com/environmental-research/editorial-board/huichun-zhang-phd	ID, EXP
USDA-NIFA	Beneficial Use of Residuals to Improve Soil Health and Protect Public, and Ecosystem Health (Multistate Committee) https://portal.nifa.usda.gov/web/crisprojectpages/1020675-beneficial-use-of-residuals-to-improve-soil-health-and-protect-public-and-ecosystem-health.html	ID, EXP, HH
USDA-NIFA	The Molecular Mechanisms Underlying Pollutant Bioaccumulation in Humans and Other Organisms https://etox.ucdavis.edu/nicklisch-sascha	ID, EXP, HH
USDA-NIFA	The Role of Polymer Structure and NCEO2 Addition on the Fate and Toxicity of Microplastic Additives in Agricultural Systems https://portal.nifa.usda.gov/web/crisprojectpages/1019943-the-role-of-polymer-structure-and-nceo2-addition-on-the-fate-and-toxicity-of-microplastic-additives-in-agricultural-systems.html	ID, EXP
USDA-NIFA	Bioaccessibility of Conjugated Plant Metabolites from Contaminants of Emerging Concern in Recycled Irrigation Water https://portal.nifa.usda.gov/web/crisprojectpages/1025074-bioaccessibility-of-conjugated-plant-metabolites-from-contaminants-of-emerging-concern-in-recycled-irrigation-water.html	ID, EXP
USDA-NIFA	Fate and Mitigation of Pharmaceuticals and Personal Care Products in Subsurface Tile-Drained Fields Irrigated with Rural Sewage Effluents https://www.istc.illinois.edu/cms/One.aspx?portalId=427487&pageId=1482344	ID, EXP

USDA-NIFA	Veterinary Antibiotics Influencing the Biogeochemical Cycling of Boron: Evaluating the Role of Abiotic Surface Interaction Mechanisms on Soil Minerals https://portal.nifa.usda.gov/web/crisprojectpages/1018918-veterinary-antibiotics-influencing-the-biogeochemical-cycling-of-boron-evaluating-the-role-of-abiotic-surface-interaction-mechanisms-on-soil-minerals.h	EXP
USDA-NIFA	Linking Human Behavior and Hydrological Processes Towards Improved Understanding of Spatio-Temporal CEC Prevalence Across Agroecosystems https://portal.nifa.usda.gov/web/crisprojectpages/1015116-linking-human-behavior-and-hydrological-processes-towards-improved-understanding-of-spatio-temporal-cec-prevalence-across-agroecosystems.html	ID, EXP, HH
USDA-NIFA	Anthropogenic Contribution of Contaminants of Emerging Concern and Their Foodweb Implications in Waishkey Bay, Michigan: With an Investigation of Freshwater Mussels as a Sentinel https://portal.nifa.usda.gov/web/crisprojectpages/1013658-anthropogenic-contribution-of-contaminants-of-emerging-concern-and-their-foodweb-implications-in-waishkey-bay-michigan-with-an-investigation-of-freshwater-mussels-as-a-sentinel.html	ID, EXP
CPSC, USDA, ED, DOE, HHS, DHS, DOL, HUD, DOJ, DOT, EPA, EOP, CEA, CEQ, DPC	Federal Action Plan to Reduce Childhood Lead Exposure and Associated Health Impacts. https://www.epa.gov/lead/federal-action-plan-reducechildhood-lead-exposure	EXP, HH

Table 4. Examples of State, Tribal, Territory, and NGO R&D Activities Related to CECs in Drinking Water

Organization	Activity Description	R&D Areas
Alaska Community Action on Toxics	Contaminants in Alaska. https://www.akaction.org/tackling_toxics/alaska/	ID, EXP, HH
Alliance for the Great Lakes	Legacy Campaign: Emerging Contaminant Threats and the Great Lakes. https://cdn.ymaws.com/www.productstewardship.us/resource/collection/FFDF28A1-9926-46E7-87F9-70C7BBD95491/Emerging_Contaminant_Threats_and_the_Great_Lakes.pdf	ID, EXP, HH
Arizona Department of Environmental Quality	Advisory Panel on Emerging Contaminants. https://azdeq.gov/advisory-panel-emerging-contaminants-apec	ID, EXP
Association of Clean Water Administrators	Recommendations Report: Contaminants of Emerging Concern Workgroup. https://www.acwa-us.org/wp-content/uploads/2019/05/ACWA-ASDWA-CEC-Report.pdf	ID, EXP, HH
CalEPA	Office of Environmental Health Hazard Assessment. https://oehha.ca.gov/water	EXP, HH
California Ocean Protection Council	Emerging Contaminants Program. https://www.opc.ca.gov/programs-summary/marine-pollution/emerging-contaminants/	ID, EXP, HH
California Water Boards	Safe Drinking Water Plan. https://www.waterboards.ca.gov/drinking_water/safedrinkingwaterplan/	ID, EXP, HH
Chesapeake Progress	Toxic Contaminants Research. https://www.chesapeakeprogress.com/?/clean-water/toxic-contaminants-research	ID, EXP, HH
Clean Colorado River Sustainability Coalition	Threats: Other contaminants. http://www.cleancoloradoriver.org/threats.php	ID, EXP
Connecticut Department of Energy and Environmental Protection	Contaminants of Emerging Concern. https://portal.ct.gov/DEEP/Remediation--Site-Clean-Up/Contaminants-of-Emerging-Concern/Contaminants-of-Emerging-Concern	ID

Organization	Activity Description	R&D Areas
Delaware River Basin Commission	Contaminants of Emerging Concern Program. https://www.state.nj.us/drbc/programs/quality/cecs.html	ID, EXP, HH
Environmental Business Council New England, Inc.	Environmental Business Council New England, Inc. Toxic Substances Control Act and Emerging Contaminants Committee. https://ebcne.org/calendar/cat_ids~157/	ID, EXP
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-812-08-endorsed-9-21-08.pdf	ID, EXP, HH
Environmental Defense Fund	Protecting Groundwater Quality in California. https://www.edf.org/sites/default/files/documents/groundwater-contaminants-report.pdf	ID, EXP, HH
Environment and Natural Resources Trust Fund	Chemicals of emerging concern in subsistence species used by Minnesota Chippewa. https://www.lccmr.leg.mn/projects/2017/work_plan_drafts/_2017_04g.pdf	ID, EXP, HH
Groundwater Foundation	Using Technology to Conduct a Contaminant Source Inventory. https://www.groundwater.org/action/	ID
Florida Department of Environmental Protection	Regulated Drinking Water Contaminants and Contaminants of Emerging Concern. https://floridadep.gov/comm/press-office/content/regulated-drinking-water-contaminants-and-contaminants-emerging-concern	ID, EXP
Hawai'i Department of Health	Groundwater Protection Program. https://health.hawaii.gov/sdwb/files/2020/04/HI.2018GroundwaterStatusReportWithAppendices.pdf	ID, EXP
Idaho Department of Environmental Quality	Contaminants in Drinking Water. https://www.deq.idaho.gov/water-quality/drinking-water/contaminants-in-drinking-water/	ID, EXP, HH
Massachusetts Department of Environmental Protection	Emerging Contaminants. https://www.mass.gov/info-details/emerging-contaminants	ID, EXP, HH
Milwaukee Riverkeeper	Emerging Contaminants. https://www.milwaukeeriverkeeper.org/emerging-contaminants/	ID, EXP

Organization	Activity Description	R&D Areas
Minnesota Department of Health	Contaminants of Emerging Concern Program. https://www.health.state.mn.us/cec	ID, HH
Minnesota Pollution Control Agency	Contaminants of emerging concern. https://www.pca.state.mn.us/water/contaminants-emerging-concern	ID, EXP, HH
New England Interstate Water Pollution Control Commission	Nonpoint Source Pollution Program: Emerging Contaminants. https://neiwpcc.org/our-programs/nps/emerging-contaminants/research/	ID, EXP, HH
New Hampshire Department of Environmental Services	Interim Best Management Practices for Emerging Contaminants in Certified Biosolids. https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/web-29.pdf	ID, EXP
New Jersey Department of Environmental Protection	Division of Science and Research: Drinking Water Research. https://www.nj.gov/dep/dsr/dw/dw.htm	ID, EXP
New Jersey Drinking Water Quality Institute	New Jersey Drinking Water Quality Institute. https://www.state.nj.us/dep/watersupply/g_boards_dwqi.html	ID, EXP, HH
New Mexico Environment Department	Water Resources & Management: Cleanups & Monitoring for Water Resource Protection. https://www.env.nm.gov/water/	ID, EXP
New York City Department of Environmental Protection	Emerging Contaminants Monitoring Project. https://www1.nyc.gov/assets/dep/downloads/pdf/water/water-monitoring/monitoring-for-contaminants/2019-q3-emerging-contaminants-monitoring-project.pdf	ID
New York State Environmental Facilities Cooperation	Water Infrastructure Improvements on Long Island. https://www.efc.ny.gov/press-releases/governor-cuomo-announces-more-178-million-grants-water-infrastructure-improvements	EXP
NORMAN Network	NORMAN Network. https://www.norman-network.net	ID, EXP, HH
Northern Kentucky Water District	Emerging Contaminants. https://nkywater.org/pdfs/NKWD%20Emerging%20Compounds%20rev%20November%2013%202019.pdf	ID, EXP

Organization	Activity Description	R&D Areas
NSF International	Consumer Resources and Drinking Water. https://www.nsf.org/knowledge-library/topic/consumer-resources/drinking-water	ID
North Carolina Department of Environmental Quality	Emerging Compounds. https://deq.nc.gov/news/key-issues/emerging-compounds#:~:text=The%20emerging%20compounds%20known%20as,wide%20range%20of%20consumer%20products.	ID, EXP
Ohio River Valley Water Sanitation Commission	Source Water Protection Program. http://www.orsanco.org/programs/source-water-protection/	ID, EXP
Oregon Department of Environmental Quality	Water Quality Toxics Monitoring Program. http://www.oregon.gov/deq/wq/Pages/WQ-MonitoringStatewide.aspx	ID, EXP
Oregon Health Authority	Groundwater & Source Water Protection: Unregulated Contaminants https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/SOURCEWATER/Pages/unreg.aspx	ID, EXP
Pennsylvania Department of Environmental Protection	Water Quality: Contaminants of Emerging Concern. https://www.dep.pa.gov/Business/Water/CleanWater/WaterQuality/Pages/CECs.aspx	ID, EXP
Potomac River Basin Drinking Water Source Protection Partnership	Contaminants of Emerging Concern Workgroup. https://www.potomacdwspp.org/about-us/emerging-contaminants-workgroup/	ID, EXP, HH
Rhode Island Department of Environmental Management	Nonpoint Source Management Program. http://www.dem.ri.gov/programs/benviron/water/quality/nonpoint/pdfs/npsmanplan.pdf	ID, EXP
San Francisco Estuary Institute & The Aquatic Science Center	Contaminants of Emerging Concern Strategy. https://www.sfei.org/projects/contaminants-emerging-concern-strategy	ID, EXP
South Dakota Department of Environment & Natural Resources	Drinking Water Program. https://denr.sd.gov/des/dw/UCMR.aspx	ID, EXP

Organization	Activity Description	R&D Areas
Southern California Coastal Water Research Project	Research Theme: Emerging Contaminants. https://www.sccwrp.org/about/research-areas/emerging-contaminants/	ID, EXP, HH
State Library of Iowa	The Iowa Well Survey 2017 Survey Report. http://publications.iowa.gov/32915/	ID, EXP, HH
State of Washington Department of Ecology	Contaminants of Emerging Concern in wastewater. https://ecology.wa.gov/Water-Shorelines/Water-quality/Wastewater/Contaminants-of-Emerging-Concern	ID, EXP, HH
Vermont Agency of Natural Resources	Residuals Management & Emerging Contaminants Program. https://dec.vermont.gov/waste-management/residuals-management	ID, EXP
Washington State Department of Health	Contaminants. https://www.doh.wa.gov/communityandenvironment/contaminants	ID, EXP
Water Quality Research Foundation	Ongoing Water Quality Research Foundation Research (on contaminants). https://www.wqrf.org/ongoing-studies.html	ID, EXP
Water Research Foundation	Compounds of Emerging Concern. https://www.waterrf.org/research/topics/compounds-emerging-concern-cecs	ID, HH
Wisconsin Department of Natural Resources	Wisconsin Groundwater Coordinating Council Report to the Legislature 2020. https://dnr.wi.gov/topic/Groundwater/documents/GCC/gwQuality/EmergingContaminants.pdf	ID, EXP, HH

Appendix B: Funding Estimates for Federal CEC Research Programs and Activities

In response to the December 2019 congressional request, OSTP asked the agencies to provide funding estimates for FY 2019, 2020, and 2021 for their CEC research and development activities.[57] FY 2019 and 2020 estimates are *actual* or *enacted* investments, while FY 2021 estimates are consistent with enacted appropriations. Note that funding levels for the agencies are estimates due to many CEC research and development activities being embedded within larger programs and activities. In addition, due to agency differences in accounting, the methods used to derive the numbers vary between agencies. The process by which agencies derived their numbers is described in the footnotes. Please note that despite these differences, the numbers serve as a reasonable estimated baseline for research and development activities.

[57] House Conference Report 116-9, 2019.

Table 5. Estimated Funding for CEC Research by Agency[58]

Organization	FY19 Actual (Million USD)	FY20 Actual (Million USD)	FY21 Actual (Million USD)
DOC/NIST[59]	$0.7	$0.95	$1.2
DoD[60]	$5.81	$8.57	$5.5
EPA[61]	$12.0	$13.2	$15.8
HHS/ATSDR[62]	$12.3	$11.7	$11.9
HHS/NIH/NIEHS[63]	$9.5	$11.5	$11.0
NSF[64]	$18.31	$20.05	$21.05

[58] Note that some agencies reporting research activities did not report associated funding levels due to the level of funding < $1 million.

[59] All figures (actual and estimated) were computed based on funding allocations among the NIST groups for measurement science, measurement services, and metrological support in areas related to detection, quantitation and characterization of emerging contaminants in water.

[60] Funding levels provided by DoD include funding from USACE-ERDC, the Army Public Health Center (APHC) Toxicology Directorate, and the Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program (SERDP/ESTCP). The ERDC allocation is a compilation of all DoD direct funded research for the USACE-ERDC (in-house dollars only) on emerging contaminants (e.g., PFAS) and assessment of alternatives, including fluorine-free firefighting foam, relating to ID, EXP, and/or HH for 2019, 2020, and 2021. APHC Toxicology funding is compilation of funds characterizing new Army chemicals that may have drinking water relevance. SERDP and ESTCP funding levels are a compilation of work for the multi-lab validation study, FY19 sampling and analysis projects, ESTCP project for the mobile lab, and the FY20 passive sampler projects.

[61] Funding estimates were developed by the Office of Research and Development's budget staff in collaboration with EPA's research centers. Estimates include ORD allocations out of enacted appropriations for contaminants identification research, exposure characterization research, and human health research. Contaminant identification research focuses on (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. Exposure characterization research considers (1) identification and quantification of exposure, and (2) the occurrence, transformation, fate and transport of CECs across the lifecycle, from source to tap. Human health research fosters (1) knowledge of whether and how contaminant exposure contributes to adverse health effects, and (2) identification and characterization of factors that influence susceptibility. Resources include payroll estimates for Full Time Equivalents. PFAS research is not included.

[62] ATSDR included funding for staff, contracts and grants involved in toxicological profiles and human health studies.

[63] NIEHS supports translational science on environmental hazards. As such, NIEHS's activities are usually broadly applicable to exposure route and related adverse outcomes. In response to this inquiry, NIEHS has limited its estimates to the subset of studies specifically related to contaminants from drinking water. Other NIEHS activities, specifically research that may be relevant from a health effects perspective but not limited to drinking water, are not included in these estimates. There have been no major changes to the CEC-related activities in NIEHS or NTP since the previous reporting in 2019 prior to this update.

[64] NSF CEC funding estimates (in millions) were reported on award search and review method. Estimates include funding from the Directorate of Mathematical and Physical Sciences-Division of Chemistry, the Directorate for Engineering-Division of Chemical, Bioengineering, Environmental, and Transport Processes, and the Directorate for Social, Behavioral, and Economic Sciences-Division of Behavioral and Cognitive Sciences and Division of Social and Economic Sciences. Programs in Biological and Environmental Interactions of Nanoscale Materials, Environmental Engineering, and Environmental Sustainability are included within ENG-Division of Chemical, Bioengineering, Environmental, and Transport Processes. The Directorate of Social, Behavioral, and Economic Sciences does not have a dedicated program for CECs in either the Behavioral

Organization	FY19 Actual (Million USD)	FY20 Actual (Million USD)	FY21 Actual (Million USD)
USDA-NIFA[65]	$4.1	$4.0	$4.0
USGS[66]	$23.545	$23.745	$23.745

and Cognitive Sciences or Social and Economic Sciences divisions; however, based on the merit of proposals submitted, it may fund individual research awards related to CEC.

[65] USDA's estimated funding level for 2021 is based on FY 2019 and 2020 peer-reviewed project proposals that were awarded by peer review panels in the USDA-NIFA Agriculture and Food Research Initiative Bioenergy, National Resources, and Environment Water Quantity and Quality and Soil Health programs.

[66] The Environmental Health Program (Contaminant Biology and Toxic Substances Hydrology) supports integrated natural science expertise and capabilities across the USGS related to environmental contaminants and pathogens. This science informs stakeholder decisions to manage fish and wildlife health and provides environmental exposure information to partners in public health. USGS estimates for research on CECs is tracked as a crosscutting collaborative activity jointly funded by Toxic Substances Hydrology and Contaminant Biology within the Ecosystems Mission Area. The funding reported considers: 1) the costs to collect water samples; 2) the lab costs for analyses; 3) the cost for data analysis; and 4) the associated management, quality assurance/quality control, and publication costs.