Safe and Sustainable Water Resources

National Research Program

Strategic Research Action Plan, 2019 – 2022

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List of Acronyms

A-E	Air and Energy
AMR	Antimicrobial resistance
AOPs	Adverse Outcome Pathways
ASDWA	Association of State Drinking Water Administrators
BCG	Biological condition gradient
CAA	Clean Air Act
CCL	Contaminant Candidate List
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act – "Superfund"
CSO	Combined Sewer Overflow
CSS	Chemical Safety for Sustainability
CWA	Clean Water Act
ECOS	Environmental Council of the States
EPA	Environmental Protection Agency
ERIS	Environmental Research Institute of the States
HABs	Harmful Algal Blooms
HHRA	Human Health Risk Assessment
HSRP	Homeland Security Research Program
MS4	Muncipal Separate Storm Sewer System
NARS	National Aquatic Resource Surveys
NEPA	National Environmental Policy Act
NGO	Nongovernmental Organization
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint Source
OAR	Office of Air and Radiation
OGWDW	Office of Ground Water and Drinking Water
OLEM	Office of Land and Emergency Management
ORD	Office of Research and Development
OST	Office of Science and Technology
OW	Office of Water
OWM	Office of Wastewater Management
PFAS	Per-and polyfluoroalkyl substances
SDWA	Safe Drinking Water Act
SHC	Sustainable and Healthy Communities
SSWR	Safe and Sustainable Water Resources
StRAP	Strategic Research Action Plan
SWAQ	Subcommittee on Water Availability and Quality
SWMM	Storm Water Management Model
SWC	National Stormwater Calculator
TMDL	Total Maximum Daily Load
UCMR	Unregulated Contaminants Monitoring Rule
WET	Whole Effluent Toxicity

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Executive Summary

The U.S. EPA's Safe and Sustainable Water Resources National Research Program (SSWR) helps ensure that when people turn on the tap for a glass of water, swim in a lake, use water at their farm, ranch, or business, or draw upon water in hundreds of other ways, they can count on the water being clean, safe, and reliable. Inextricably tied with that, SSWR also works to protect and restore the Nation's watersheds and aquatic ecosystems, now and for future generations.

Although tremendous accomplishments have been made, the challenges remaining are formidable. Solutions are more difficult to find, costlier to implement, and come with potential tradeoffs. New threats are emerging—such as per- and poly-fluoroalkyl substances (PFAS), accelerated antimicrobial resistance, and micro/nano plastics in the water—that potentially endanger human health and ecosystems. At the same time, persistent issues, including lead and disinfection byproducts in drinking water, excess nutrient loading, aging water infrastructure, demand for water supply, and contaminants in recreational waters and biosolids continue to pose problems for people, wildlife, and the economy.

To meet these challenges, SSWR will produce effective, efficient, and collaborative solutions. SSWR focuses on robust and innovative research that translates into practical, real-world solutions. Examples of this work include molecular methods to detect pathogens for safe water reuse and for microbial source tracking, satellite imagery for early detection of harmful algal blooms, aquatic ecosystem response trajectories, and non-regulatory, market-based incentives to reduce excess nutrient loading. The resulting products are data, tools, and capabilities that EPA programs and regions, states, tribes, local communities, utilities, and others need to protect water resources. SSWR has a long-term commitment to applying its research results through risk communication, technical support, and ongoing training.

SSWR's activities to ensure clean drinking water and to protect and restore watersheds and aquatic ecosystems adhere to the Congressional mandates found in the Safe Drinking Water Act, the Clean Water Act, and other legislation. SSWR does this work in partnership with other EPA programs, federal and state agencies, tribes, academia, nongovernmental agencies, public and private stakeholders, and the global scientific community. This crosscutting approach maximizes efficiency, transparency, interdisciplinary insights, and integration of results.

The broad scope of the SSWR research program activities will be guided by four overarching objectives:

- Research Objective 1: Improve Prediction and Early Accurate Detection of Contaminants — Continue advancements in environmental monitoring, modeling, methods, and other information that are needed to rapidly and reliably inform water quality decision-making at the national, state, tribal, and local levels.
- Research Objective 2: Assess Potential Impacts — Improve understanding of exposure pathways and effects of chemical and microbial contaminants on human health and aquatic ecosystems.
- Research Objective 3: Develop and Evaluate Approaches for Prevention and Mitigation — Expand solutions to prevent and mitigate water quality impairments using innovations in technology, market-based incentives, and other approaches.

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- Research Objective 4: Translate and Communicate Research – Provide practical solutions to water resource challenges through application of SSWR data, tools, and models, and disseminate this information through outreach activities.

To achieve these objectives, SSWR research is organized into three interrelated topics: watersheds, nutrients and harmful algal blooms, and water treatment and infrastructure. Each topic carries specific near- and long-term goals designed to yield practical tools and solutions for ensuring sustainable water resources. This *SSWR Strategic Research Action Plan 2019–2022* outlines these topics and the overall SSWR program design. The StRAP serves as planning guide for ORD's laboratories and centers to design specific research products that contribute to the identified outputs. SSWR's scientific results and innovative technologies will support the Clean Water Act objective to restore and maintain the chemical, physical, and biological integrity of the Nation's waters and the Safe Drinking Water Act to protect the quality of drinking water throughout the Nation.

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Introduction

Water is the molecule of life. Directly or indirectly, all life depends on it. Although the total amount of Earth's water is relatively constant, water dynamically moves through the hydrologic cycle, changing biologically, chemically, and geologically. The quality and availability of water, upon which human and ecosystem health and a robust economy depend, also change over space and time.

The U.S. Environmental Protection Agency (EPA) was established to protect human health and the environment, which includes safeguarding the Nation's waters together with states and tribal partners. To assist the Agency in meeting its goals and objectives, the Safe and Sustainable Water Resources National Research Program (SSWR), within EPA's Office of Research and Development (ORD), developed this Strategic Research Action Plan (StRAP) for fiscal years 2019–2022 (StRAP FY19-22). This StRAP outlines a four-year research strategy to advance the goals and cross-Agency priorities identified in the FY2018–FY2022 EPA Strategic Plan to provide clean and safe water (U.S. Environmental Protection Agency, 2018).

The SSWR StRAP is one of six research plans, one for each of EPA's national research programs in ORD. The six research programs are:

- Air and Energy (A-E)
- Chemical Safety for Sustainability (CSS)
- Homeland Security Research Program (HSRP)
- Human Health Risk Assessment (HHRA)
- Safe and Sustainable Water Resources (SSWR)
- Sustainable and Healthy Communities (SHC)

Research to Support EPA and ORD Strategic Plans

Each of ORD's six national research programs has developed a StRAP. Collectively, the StRAPs lay the foundation for EPA's research programs to provide focused research that meets the Agency's statutory requirements and the goals outlined in the EPA Strategic Plan (https://www.epa.gov/planandbudget/strategicplan) and the ORD Strategic Plan (https://www.epa.gov/research/epa-office-research-and-development-strategic-plan-2018-2022). The StRAPs are designed to guide an ambitious research portfolio that delivers the science and engineering solutions the Agency needs to meet its goals now and into the future, while also cultivating an efficient, innovative, and responsive research enterprise. The strategic directions and outputs identified in each StRAP serve as planning guides for ORD's laboratories and centers to design specific research products to address partner and stakeholder needs.

The FY2018–FY2022 EPA Strategic Plan has three overarching strategic goals with related objectives. The first goal is the Agency's core mission to provide the Nation with clean air, land, and water, and to ensure chemical safety. The SSWR StRAP primarily supports *objective 1.2: to provide for clean and safe water*.

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Research under SSWR also contributes to: 1) *objective 1.1: to improve air quality* through its atmospheric nitrogen and phosphorus work and wildland fires work; 2) *objective 1.3: to revitalize land and prevent contamination* through its biosolids and groundwater work; and 3) *objective 1.4: to ensure safety of chemicals* through its per- and polyfluoroalkyl substances (PFAS) and other contaminants research.

The Agency's second strategic goal addresses Cooperative Federalism for shared accountability, transparency, and participation with the public. ORD has made great strides in strengthening its relationship and engagement with states through the Environmental Council of the States (ECOS) and the Environmental Research Institute of the States (ERIS), and with tribes through the Tribal Science Council and other tribal organizations. The research priorities represented are primarily from EPA's Office of Water and regions; however, SSWR has worked closely with the states and tribes to understand their water resource challenges. Their input is reflected in this StRAP and reinforces the Agency's priorities (Appendix 1). ORD also recently implemented a Memorandum of Understanding with several health organizations (e.g., National Environmental Health Association and the Association of State and Territorial Health Officials) to support states in public health decision-making. SSWR has met with these groups to discuss its drinking water research for public health protection.

The third Agency goal, the Rule of Law and Process, has several objectives including prioritizing robust science. SSWR is committed to continuing to provide robust research and scientific analysis to inform policy and decision-making under the authorities of the Safe Drinking Water Act (SDWA) and Clean Water Act (CWA). The SSWR research aim is to develop and apply innovative, cost-effective solutions to current, emerging, and future water resource challenges.

Statutory and Policy Context

The objective of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" 33 USC12519a). The CWA attempts to accomplish this objective in part by authorizing or otherwise encouraging research in several areas. It should be noted that the CWA focuses on improving and protecting surface water resources and it does not specifically address contamination of groundwater resources. Groundwater protection and improvement is addressed by provisions in other statutes including g SDWA, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The SDWA directs EPA to set national health-based standards for drinking water to protect against naturally occurring and anthropogenic contaminants that may be found in drinking water. It also authorizes other regulatory programs (e.g., Underground Injection Control, Wellhead Protection), as well as funding and assistance, training, public information, and source water assessment programs, to foster the protection of many sources of drinking water.

Specific water research activities are either required or authorized under various provisions of these statutes, in addition to ORD's overarching research mandates (Environmental Research, Development and Demonstration Act, PL-95-155. 95th Congress, 1977). EPA's Office of Water, which has primary responsibility for implementing the provisions of the CWA and the SDWA, is a key partner for SSWR. For more information on EPA responsibilities under these statutes, see the links provided in (Appendix 2).

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Partner and Stakeholder Engagement

The SSWR StRAP FY19-22 guides ORD research to address the high-priority needs of the Agency and its partners and stakeholders. Accordingly, it was developed with considerable input from EPA's Office of Water and other program and regional offices. State and tribal priorities were integrated through engagement with the Environmental Council of the States (ECOS) and the Environmental Research Institute of the States (ERIS), and with tribes through the Tribal Science Council, the Tribal Science Water Council, and other tribal organizations. Federal partners, including the agencies represented on the Subcommittee on Water Availability and Quality (SWAQ) also informed the research planned in this StRAP. The SWAQ advises and assists the White House National Science and Technology Council on water-related issues and is comprises over a dozen federal agencies that facilitate effective outcomes of coordinated multi-agency, water-related activities. Coordination of international research strategies and expertise is facilitated by SSWR's participation on the Global Water Research Coalition and through memoranda of understanding or other mechanisms with Australia, Singapore, China, and other nations. Additionally, SSWR staff and researchers interact with academia, non-governmental organizations, and industry. These interactions help SSWR better understand the multi-sector needs for water research, leverage expertise and resources, and identify unique areas to which SSWR can make the greatest scientific contributions.

Environmental Problems and Program Objectives

Impairment of water quality and diminished water availability are concerns for human and ecosystem health, economic prosperity, and social well-being. Some of the most pressing challenges include:

- ***Water infrastructure and treatment***—The Nation's water treatment and distribution systems face increasingly greater challenges for delivering adequate supplies of safe drinking water. Legacy issues—such as 240,000 water main breaks every year across one million pipe miles that waste six billion gallons of treated drinking water every day—threaten water safety and availability (https://www.infrastructurereportcard.org/cat-item/drinking-water/). EPA's 6th Drinking Water Infrastructure Needs Survey and Assessment shows $472.6 billion is needed to maintain and improve the nation's drinking water infrastructure over the next 20 years (https://www.epa.gov/drinkingwatersrf/epas-6th-drinking-water-infrastructure-needs-survey-and-assessment). The American Society of Civil Engineers estimates the cost to maintain and expand service over the next 25 years is around $1 trillion (https://www.infrastructurereportcard.org/cat-item/drinking-water/). Lead (Pb) in service lines is another legacy issue, requiring advances in identifying lead service lines, improving lead sampling techniques, and furthering understanding of lead release under varying conditions. Balancing residual disinfectant levels in distribution systems remains a challenge to control pathogens without forming unacceptable levels of harmful byproducts from the disinfectants. Emerging issues, such as the treatment of PFAS in drinking water, are also high priorities. Innovative, cost-effective approaches are needed to optimize the efficacy and efficiency of water treatment and distribution, especially for small systems that often face greater technical, financial, and operational challenges to comply with new and existing standards.

- ***Excess nutrients and harmful algal blooms***—Excess levels of nutrients and sediment remain the largest impediment to the Nation's water quality. The rapid growth or bloom of phytoplankton,

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commonly referred to as harmful algal blooms (HABs), is triggered primarily by increased nutrient levels, but also low water flows, warmer temperatures, and other factors. In the United States, all 50 states are challenged in varying degrees by HABs. Impacts may be a nuisance (e.g., odor, aesthetics) or pose health risks to humans and animals. Economic impacts may include medical and veterinary expenses, increased cost of drinking water treatment, and decreased recreational revenue and property values. The capability to predict when, where, and what kind of bloom will occur; to prevent or rapidly treat the presence of algal toxins in drinking water; and to understand the adverse health outcomes from exposure to toxins, will advance the protection of human and animal health and minimize economic impacts.

- ***Microbial pathogens in recreational waters***—Surface water recreation, such as swimming, wading, fishing, and boating, is enjoyed by more than 60 percent of the U.S. population (Cordell 2012). Human exposure to pathogens associated with human and animal waste in some surface waters results in an estimated 90 million illnesses nationwide, costing between $2.2 billion to $3.7 billion annually—not including illnesses related to HABs (DeFlorio-Barker et. al. 2018). Added to the economic burden is lost revenue from beach closures. Although beach water monitoring is improving, rapid low-cost methods for same-day notifications of the presence of pathogens are needed to close and reopen beaches more quickly to prevent human illness and unnecessary lost revenue. Tools are also needed to identify the pathogen source(s) and to assess human health and exposure risk.

- ***Antimicrobial resistance (AMR) in surface waters***—Antibiotic-resistant bacteria and antibiotic-resistant genes have been detected in wastewater from municipal treatment plants and hospitals, as well as in drinking water, irrigation water, and recreational waters. The continued spread of antibiotic resistance throughout the environment is of public concern, and traditional water treatment methods vary in effectiveness. An integrated research approach is needed to evaluate AMR in surface waters, wastewater, biosolids, and water-reuse treatment systems by using methods and tools developed for AMR characterization, distribution, and hotspot identification, and by assessing potential health effects.

- ***Stormwater***—For many cities, stormwater management remains one of the greatest challenges to meeting water quality standards. Additional energy and funds are needed to treat stormwater-related pollutants; however, in some cases treatment is not even possible when surges in stormwater overwhelm systems that convey combined sewage and stormwater, resulting in direct discharge of untreated human, commercial, and industrial waste into surface waters. A shift in the approach to stormwater management to one that controls stormwater-related flooding and combined sewer overflows, and values stormwater as a resource, could offer multiple benefits. Better understanding of the potential health risks and cost effectiveness of stormwater reuse is needed.

- ***Diminished water availability***—Water shortages are occurring or expected to occur in the next ten years in 40 U.S. states, and some of the Nation's fastest-growing cities are in the most arid areas, such as the Southwest. Water reuse and fit-for-purpose treatment could reliably expand supplies of freshwater for ecosystems and potable and non-potable water for municipalities, agriculture, and industry. However, there remain uncertainties about potential health risks from exposure to chemical or microbial contaminants in alternative water sources.

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- ***Wetlands***— The Nation's wetlands provide numerous ecosystem benefits, such as water quality improvement, groundwater recharge, erosion and flooding protection, and habitats for commercially and recreationally valuable or imperiled species. Resourceful approaches that preserve wetlands, while also solving other challenges, such as stormwater and nutrient management, are needed.

These and other water resource challenges that encompass the water cycle guide SSWR's Problem Statement and Program Vision.

Problem Statement

The interrelated challenges of impaired watersheds and water quality collectively threaten the Nation's water resources that support human and ecosystem health and a strong economy. These challenges include persistent and new chemical and microbial contaminants, excess nutrients and harmful algal blooms, diminished water availability, aging water infrastructure, and knowledge gaps in the value of water quality.

Program Vision

SSWR's commitment to robust research and scientific analyses will support innovative scientific and technological solutions that ensure adequate supplies of clean water to protect people's health and livelihood, to protect and restore watersheds and aquatic ecosystems, and to strengthen the economy.

Program Objectives

The SSWR StRAP describes a four-year research plan to address the Agency's goals and objectives identified in the *FY 2018-22 EPA Strategic Plan* and focuses on the highest priorities identified by SSWR's partners and stakeholders. The SSWR research program's activities will be guided by four overarching objectives:

- Research Objective 1: Improve Prediction and Early Accurate Detection of Contaminants — Continue advancements in environmental monitoring, modeling, methods, and other information that are needed to rapidly and reliably inform water quality decision-making at the national, state, tribal, and local levels.
- Research Objective 2: Assess Potential Impacts — Improve understanding of exposure pathways and effects of chemical and microbial contaminants on human health and aquatic ecosystems.
- Research Objective 3: Develop and Evaluate Approaches for Prevention and Mitigation — Expand solutions to prevent and mitigate water quality impairments using innovations in technology, market-based incentives, and other approaches.
- Research Objective 4: Translate and Communicate Research – Provide practical solutions to water resource challenges through application of SSWR data, tools, and models, and disseminate this information though outreach activities.

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Research Topics and Research Areas

Topic 1: Watersheds

The Watersheds Topic will advance integrated water quality and watershed management tools to protect and restore water resources. Research in this topic will provide nationally- and regionally-consistent tools to assess ecological status and trends, set attainable goals, and monitor progress toward these goals. Research on the emerging issue of micro/nano plastics in water will provide innovative methods to identify and quantify micro/nanoplastics and their potential effects on human health and aquatic resources. In addition, research will refine and develop models, methods, and approaches to improve the management of water quality, watersheds, and aquifers for both regulatory and non-regulatory programs. Research on high-priority issues, such as microbial pathogens in recreational waters and chemical contaminants in surface and groundwater, will strengthen existing approaches for managing ambient water quality to protect human health and aquatic life. This research will integrate next-generation tools, such as "-omic" technologies and Adverse Outcome Pathways (AOPs), for screening mixtures of chemicals and evaluating antimicrobial resistance in surface waters. Research will refine and develop models, methods, and approaches to support improved aquatic resource mapping for both regulatory and non-regulatory purposes.

Research Area 1: Assessment, Monitoring, and Management of Aquatic Resources

To provide nationally consistent and scientifically defensible assessments of U.S. waters, EPA partners with states and tribes to implement the National Aquatic Resource Surveys (NARS, https://www.epa.gov/national-aquatic-resource-surveys). Science in this research area will support and advance NARS monitoring and assessment, and it will extend NARS data and approaches to support priority setting and management actions. Additionally, tools, indicators, methods, and models will be developed, improved, and applied to help decision-makers at multiple levels proactively and adaptively manage aquatic resources.

National Aquatic Resource Surveys

Program, regional, state, and/or tribal needs (for Outputs 1 and 2). The CWA requires EPA to periodically report on the condition of the Nation's water resources. The National Aquatic Resource Surveys (NARS) were developed and implemented as an EPA, state, and tribal partnership specifically to assess the quality of U.S. waters, track changes over time, and provide critical information for protecting and restoring water quality at national and regional scales. Continued research and technical expertise are needed to help improve and implement NARS by applying high-quality, innovative science and transferring expertise to EPA's OW and regions, states, and tribes. Planned work includes: 1) developing national statistical survey designs and specialized sampling designs for states/other organizations; 2) conducting and improving water resource analyses and assessments; 3) refining assessment benchmarks; 4) advancing innovations related to water quality monitoring methods, indicators, assessments, and data standards for issues of national concern, such as nutrients, algal toxins, habitat alteration, micro/nanoplastics, and antimicrobial resistance; 5) developing tools and products that facilitate the use of NARS and related outputs by OW, regions, states, tribes, and others; and 6) conducting analyses that

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extend use of NARS data to understand potential causal factors, estimate condition in unmonitored areas, and support regulatory program needs.

Output 1: Science to support NARS survey design, indicator development and assessment benchmarks, methods development, and data tools. This output will address the ecological condition of the Nation's waters, the changes in condition over time, and the data and tools critical to protect and restore these aquatic resources. ORD will provide the necessary science and support for designing NARS surveys, improving and expanding indicators and assessment benchmarks, and harmonizing datasets. ORD will also assist in developing national reports and will support states and tribes developing or implementing ecological assessment programs. The output will include training and workshops on new indicators (e.g., micro/nanoplastics, DNA monitoring) and analytes, data analysis methods, and assessment tools. Data analysis tools will provide for condition assessments and trend analyses at multiple spatial scales (e.g., national, state, regional).

Output Type: The Output will be delivered as training, workshops, and toolkits.

Output 2: Extended applications of NARS data and approaches to support priority setting and management actions. Continued research and technical expertise are needed to help implement and improve NARS. This output leverages and extends NARS data resources through integration with other data sources (e.g., geospatial data, state bioassessment data, loading and flow information, local data) to develop new tools and models for condition assessment, trends analysis, extrapolation to unmonitored waters, stressor identification, and causal analysis.

Output Type: Pilot studies will demonstrate the application and extension of NARS data at scales relevant to decision-making for important regional ecosystems, such as the Great Lakes and Chesapeake Bay. A synthesis document will describe the compilation of tools and models to support priority setting and management actions.

Tools to Inform Water Quality Goals

Program, regional, state, and/or tribal needs (for Output 3). States, tribes, and local decision-makers need better tools to promote healthy watershed assessments and support CWA 303(d), Total Maximum Daily Load (TMDL), and Non-Point Source (NPS) programs. These tools should facilitate setting attainable biological goals that are linked with quantified indicators of watershed condition, stressors, and stressor targets. Approaches will include evaluation of the watershed restoration potential and economic and social analyses to prioritize management actions based on predicted effectiveness, feasibility, and return on resource investment. Research needs include: 1) developing biological indicators and criteria for water body types that do not have nationally consistent and reliable methods and approaches; 2) developing biological condition gradient (BCG) approaches at regional and sub-regional scale; 3) piloting indicators and models for linking biological response to stressors and their sources at catchment and stream reach scales; 4) exploring applications of BCG or other biological measures in conjunction with physical, chemical, and landscape indicators and approaches to measure incremental changes in waters and their watersheds, and developing a menu of indicators of improvement, stability, and degradation; and 5) developing innovative approaches to merging large national data sets with local data sets and other information into a screening tool for states and counties to set goals, determine aquatic life use attainment, prioritize resources, and more efficiently implement CWA 303d, TMDL, and stormwater programs.

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Output 3: Tools, indicators, and information to inform water quality goals, assess biological condition, and support effective management of diverse water bodies. Tools, indicators, and technical information will be developed to assist state, tribal, and local decision-makers in setting goals and stressor targets, and in identifying management strategies to protect and restore aquatic resources across diverse water body types (e.g., low-gradient freshwater and tidal streams, streams with highly variable flow, large river systems, lakes, estuaries, coral reefs, wetlands). Tools may include innovative monitoring methods, advanced data interoperability protocols, and analytical approaches to advance integrated watershed assessments. Tools will help states, tribes, and local decision-makers optimize protection and restoration, including identifying and maintaining high-quality waters, evaluating recovery potential, assessing impacts from wildfires and drought on aquatic resources, and developing adaptive management strategies that recognize social, cultural, and economic contexts. The output will support adaptive management in characterizing stressor-response relationships, setting realistic biological targets, and providing tools to conduct causal analyses to inform development and implementation of management actions, such as TMDLs, National Pollutant Discharge Elimination System (NPDES) permits, NPS reductions, or habitat restoration. Adaptive management actions will link resource management activities to local, tribal, and state priorities.

Output Type: The output will be tools, indicators, and technical information, which will be delivered as training, workshops, toolkits, and a synthesis document.

Micro/Nanoplastics

Program, regional, state, and/or tribal needs (for Output 4)**.** The proliferation of plastics in marine and freshwater systems around the world has led to concerns for potential impacts on aquatic life and human health. Focused research efforts are needed to better understand the exposure to and potential effects of micro/nano plastic pollution in the aquatic environment to inform CWA regulatory programs and voluntary approaches. Standardized, reliable, reproducible, and environmentally representative methods are fundamental and of paramount importance for sample collection, extraction, characterization, and quantification. These methods will provide the foundation to investigate potential adverse health outcomes in humans and aquatic organisms exposed to micro/nanoplastics.

Output 4: Methods, models, and tools to evaluate the potential health effects from exposure to micro/nanoplastics. Research will address plastic pollution in the aquatic environment, including: 1) establishing reliable, reproducible, and environmentally-representative methods for applications in drinking water, surface water, sediment, and biosolids, including protocols for collection, extraction, characterization, and quantification of micro/nanoplastics; 2) investigating the potential health effects of micro/nanoplastics via water consumption in experimental models of human health; and 3) developing analytical approaches and standardized toxicity tests for representative aquatic species, including *in vitro* assays and multiple stressor interactions. Toxicity studies and dose-response relationships will address the role of micro/nanoplastic particles, as well as chemical and microbiological contaminants incorporated into or sorbed to the particles, on human health and aquatic life. Contingent upon recommendations produced by larger Agency-led efforts, research may support the evaluation of the current state and effectiveness of approaches, products, and technologies used to prevent macroplastics from entering aquatic systems.

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Output Type: This output will deliver recommendations for best practices and standardized methodologies and data relevant to human and aquatic life health risks. Presentations and publications will include webinars and website resources provided to program offices, regions, states, and tribes.

Water Quality Models for Decision-Makers

Program, regional, state, and/or tribal needs (for Output 5)**.** The Agency and states, tribes, and local decision-makers need improved modeling tools that enable science-based decisions necessary to achieve water quality goals. Tool development and support in water quality modeling are needed for TMDLs, permits, rulemaking, market-based incentives, and strategic foresight to address emerging issues and disasters, including extreme weather events. Integrated modeling and assessment of water quality and economics is needed to assess the impacts of water quality decisions. A consistent and transparent approach is needed for understanding the benefits of water quality improvement. OW and regional staff, through the EPA Water Modeling Workgroup, have highlighted tool development and support needs in water quality modeling. These needs include advancing methods and models for watershed and aquifer water quality management through regulatory and non-regulatory mechanisms and prioritizing short- and long-term methods development to incorporate new approaches and improved scientific knowledge into existing modeling tools.

Output 5: Water quality models and economic analyses to support science-based water quality decisions. Research conducted in support of this output will refine and/or develop models, methods, and approaches to improve water quality and watershed and aquifer management for both regulatory and non-regulatory needs of the stakeholders. Development of open-source versions of water quality, watershed, and socio-economic models, as well as training and technical support for these models, will be conducted to enable stakeholders to make effective, science-based water quality decisions. Research results provided by ORD and policy application by OW and the Office of Policy/National Center for Environmental Economics will expand the capacity of current models to include five main water body types, improve water quality-economic linkages, explore market-based incentives, and provide an updated toolkit for use in regulatory and non-regulatory programs.

Output Type: This output will include improved models, updated toolkits, training (webinars and workshops), case studies, and a synthesis report.

Animas-San Juan Watershed Water Quality

Program, regional, state, and/or tribal needs (for Output 6). The Animas-San Juan Watershed is impacted by decades of mining contamination, including heavy metals from mine tailings and discharges from abandoned mines on the upper Animas River in Colorado. In 2015, toxic wastewater from Gold King Mine was accidentally released into the Animas River watershed. In response, the U.S. Congress authorized appropriations of $4 million per year during 2017–2021 for a long-term water quality monitoring program for the San Juan watershed (referred to as the San Juan Watershed Program), which was established in 2017.

ORD's unique expertise gained from the intensive effort to monitor water quality conditions related to the Gold King Mine in the Animas-San Juan Watershed is critical to the success of the program. The development of the fate and transport and biological reports for the Animas and San Juan Rivers following the Gold King Mine Release, completed in the previous StRAP, were instrumental to the EPA in developing

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the San Juan Watershed Program in collaboration with states and tribes adjoining the watershed—Arizona, Colorado, New Mexico, Utah, the Navajo Nation, the Ute Mountain Ute Tribe, and the Southern Ute Indian Tribe. Implementing the San Juan Watershed Program requires targeted monitoring to track and evaluate chemical contamination and potential biological impacts from historical mining and other pollutants that affect water quality.

Output 6: Research support for the San Juan Watershed Program. SSWR will provide scientific expertise and research in support of new and ongoing collaborative monitoring projects designed to inform decision-makers about the source, transport, and fate of metals and other pollutants and their potential effect on the quality of water for domestic, agricultural, recreational uses, and aquatic ecosystem health. Research and monitoring will inform water quality criteria applied through the watershed, improve understanding of pollutant sources to inform restoration and protection activities, and assess the potential to expand fate and transport modeling in the watershed. An important element of the program will be to assist in finding innovative ways to communicate scientific research results to the public.

Output Type: This Output will be delivered directly via technical support and collaborative engagement with EPA program offices and regions, states, and tribes.

Research Area 2: Improved Aquatic Resource Mapping

This research area will build upon long-standing ORD aquatic resource research and leverage existing research partnerships with other federal agencies, states and tribes, to improve mapping of aquatic resources. In addition to addressing one of OW's primary needs related to the use of such data to inform Clean Water Act jurisdiction determinations, the research will also support other regulatory and non-regulatory needs, contribute to ongoing or new ORD research, and leverage existing interagency research partnerships.

Methods, Tools, and Datasets to Support Aquatic Resource Mapping

Program, regional, state, and/or tribal needs (for Output 7). OW and other EPA programs/regions, states, tribes, and federal agencies need improved mapping of aquatic resources for a variety of regulatory and non-regulatory purposes. Transferrable methodologies, tools, and datasets are needed to improve the accuracy and the useful application of geospatial data to the definition of "waters of the United States." These products can also help states, tribes, local governments, and other federal agencies with the management of aquatic resources within their respective boundaries. This research supports OW rulemaking by helping to build state and tribal capacities and capabilities to map waters within their boundaries. This research will also assist EPA, the U.S. Army Corps of Engineers, and state and tribal co-regulators with day-to-day implementation of CWA programs.

Output 7: Improved accuracy and application of geospatially explicit aquatic resource data. For this output, ORD will partner with OW and the U.S. Army Corps of Engineers to engage other federal partners, as well as state and tribal stakeholders, to assess their needs and to help build their capacity for aquatic resource mapping, jurisdictional analysis, and decision support. ORD and partners will evaluate data gaps and conduct geospatial analyses and data collection in appropriate watersheds to quantify relationships between watershed attributes and stream or wetland characteristics that may be relevant for determining CWA jurisdiction consistent with the definition of "waters of the United States." ORD and partners will evaluate temporal and spatial resolution and accuracy of derived geospatial and modeling products, field-

based methodologies and sampling protocols, and assess uncertainty for partner and stakeholder decisions.

Output Type: This output will include improved models, metadata tools, standardized methodologies, geospatial products, training (webinars and workshops), and technical guidance.

Research Area 3: Human Health and Aquatic Life Criteria

The goal of this Research Area is to provide OW the science support they need to assist regions, states, and tribes with new or revised water quality criteria and their implementation. This work includes site-specific methodologies and science support to protect human health and aquatic life from pollutants in surface water. To address this goal, research will focus on: 1) human health protection from microbial contaminants in surface waters; 2) human health protection from chemical contaminants in surface waters; and 3) aquatic life protection from chemical contaminants in surface waters. This research area will provide stakeholders and decision-makers with scientific information and tools to more effectively assess and manage chemical and microbial contaminants associated with human health and aquatic life risks in surface waters, including recreational water bodies.

Microbial Contaminants in Surface Water

Program, regional, state, and/or tribal needs (for Output 8). Innovative research is needed to provide new and advanced tools, methods, and information relevant to revising Recreational Water Quality Criteria and its implementation by states, tribes, and local communities. OW will use this science to support the consideration of potential new or revised criteria in the next five-year review in 2022.

Output 8: Data and innovative tools to advance public health protection from microbial contaminants in surface water. This output will focus research in priority areas identified in the EPA 2017 Five-Year Review of the 2012 Recreational Water Quality Criteria (https://www.epa.gov/wqc/five-year-review-2012-recreational-water-quality-criteria) developed by OW in collaboration with ORD. Research will support new and revised criteria and implementation of criteria, including analyses of new and existing health studies, evaluation of new analytical methods for fecal indicators, and development and validation of analytical methods for microbial source tracking. Research will also be conducted to further develop fate and transport modeling with statistical and process models of indicators and pathogens for remediation and quantitative microbial risk assessment. Additionally, research will advance the development of integrated approaches to evaluate antimicrobial resistance (AMR) in surface waters and develop methods and tools for AMR characterization on national and regional scales, distribution in surface water, hotspot identification, and the assessment of health effects.

Output Type: This output will be delivered directly via technical support, training, and collaborative engagement with program offices, regions, states, tribes, and others.

Protecting Public Health from Consumption of Chemical Contaminants in Surface Waters and in Aquatic Organisms

Program, regional, state, and/or tribal needs (for Output 9). Screening and prioritizing the approximately 40,000 chemicals in commerce for human health criteria development remains a challenge. Additionally, states and other stakeholders want capabilities to explore probabilistic approaches for human health criteria development as an alternative to the deterministic approach presented in EPA's 2000 Human

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Health Methodology (https://www.epa.gov/wqc/fact-sheet-methodology-deriving-ambient-water-quality-criteria-protection-human-health-revised). To update several human health criteria, data gaps and modeling challenges related to developing bioaccumulation factors, particularly for metals, need to be resolved.

Output 9: Data and innovative tools to advance public health from consumption of chemical contaminants in surface waters and aquatic organisms. ORD will conduct research in several areas to support OW's development of new and revised human health water quality criteria for ingestion and consumption of chemical contaminants in surface water and in aquatic organisms. The research will address: development and validation of analytical methods for contaminants of concern in surface waters; development of bioaccumulation factors for the derivation of metals criteria for human health; innovative approaches for characterizing contaminant exposure; and development of harmful bioactivity metrics using approaches such as "-omic" technologies and AOP for screening mixtures of chemicals for adverse health outcome potential, in coordination with efforts in the HHRA and CSS research programs.

Output Type: This output will include validated methods, bioaccumulation factors, and bioactivity metrics, which will be delivered directly via technical support, training, and collaborative engagement with program offices, regions, states, tribes, and others.

Advancing the Methodology for Deriving Water Quality Criteria to Protect Aquatic Life from Toxic Chemicals

Program, regional, state, and/or tribal needs (for Output 10). The current methodology for deriving aquatic life criteria was published in 1985. Over the 30-plus intervening years, aquatic toxicology and modeling have significantly evolved. The 1985 methodology needs to be updated to incorporate the new science and leverage the data and analyses conducted under other statutes, FIFRA in particular, to provide appropriate guidance and science support to regions, states, and tribes.

Output 10: Science to advance the methodology for deriving water quality criteria to protect aquatic life from toxic chemicals. OW has developed a scoping document outlining their goals to revise the 1985 guidelines for deriving aquatic life criteria and to develop streamlined approaches to deriving regulatory guidance for chemicals lacking robust toxicological data. ORD will conduct research in several areas supporting OW goals to update the 1985 guidelines. Methods used in current criteria derivation, such as species sensitivity analysis and minimum taxonomic distributions, definition of averaging periods, quantification of effects, evaluation of plant data, and others, will be evaluated considering current understanding and advances where warranted. Additional research will focus on the development and use of inferential and predictive tools to extrapolate from existing data and make predictions for missing data to help the derivation of guidance values where data are limited. Next-generation toxicological tools, such as "-omic" technologies and AOP information, will be evaluated in coordination with the CSS research program for their applicability in the derivation of full and streamlined criteria. Finally, additional effort will address challenges presented by certain contaminants (or groups) that have unique characteristics or are of emerging interest. Examples include developing mixture-based approaches, evaluating methods to address bioavailability, and understanding new classes of chemicals whose toxicology may be incompletely understood. This new information will be integrated with the CSS research program's chemistry and ecotox dashboards.

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Output Type: The output will be delivered directly via technical support, training, and collaborative engagement with program offices, regions, states, tribes, and others.

Topic 2: Nutrients and Harmful Algal Blooms

The Nutrients and Harmful Algal Blooms (HABs) research topic will comprehensively address nutrient issues and one of the primary impacts of excess nutrients in water bodies—HABs. The HABs research (research area 1) will focus on detection, toxicity, impacts to humans and biota (e.g., pets, livestock, crops, aquatic organisms), and developing tools to mitigate exposure via predictive modeling and treatment technologies. The nutrients research (research area 2) will address ways to determine nutrient-related impacts in watersheds and water bodies across multiple scales, support water quality management goals, quantify ecosystem response and recovery rates, and identify those watersheds and water bodies that are optimally suited for management interventions. Additionally, assessment and management research (research area 3) will provide models and tools to apply best practices for nutrient management, develop approaches to monitor the effectiveness of those management practices, and evaluate the efficacy of these actions using an integrated, socio-economic, multi-media approach.

Research Area 1: Assessment and Management of Harmful Algal Blooms

Harmful algal blooms are increasing in frequency, intensity, and geographic range. Potential impacts of HABs and their toxins on human and animal health, and on ecological and economic systems, range from nuisance to catastrophic to fatal. Harmful algal blooms are complex ecological processes that are affected by various conditions (i.e., physical, chemical, biological, hydrological, and meteorological) and therefore are difficult to predict. Generally, eutrophication and increased temperatures set the stage for cyanobacteria dominance in freshwater systems, but there are also other factors (e.g., dissolved organic matter and iron). Much is unknown regarding the specific alignment of environmental drivers over varied spatial and temporal scales that result in toxin formation. This research area will provide stakeholders and decision-makers at the national (EPA OW), regional (EPA regional offices), state (primacy agencies), and local (water utility superintendents, beach managers, etc.) levels with scientific information and tools to: 1) more effectively predict and mitigate HABs formation and exposure through ecological and predictive modeling and treatment techniques, and 2) understand the health risks to humans and broader biota. All outputs will be developed in consultation with stakeholders and will be delivered through technical support, training, and direct engagement.

Program, regional, state, and/or tribal needs (for Outputs 11, 12, and 13). EPA, states, and tribes need tools to predict toxic bloom occurrence, characterize bloom development, increase effectiveness of cyanotoxin monitoring techniques, and understand the impacts of extreme weather effects on blooms. Research to evaluate management actions in watersheds and within source water reservoirs are needed to help prevent and mitigate HABs. Ambient water sensors could help determine which practices, in which combinations, and in which locations, are best suited to reduce nutrient loadings to ambient water and lead to reduced HABs. Economic analyses of HAB/cyanotoxin impacts and source water protection activities are needed. Research is needed to support guidance on drinking water treatment technologies for HABs/cyanotoxins. Toxicity and treatment methods for anatoxin *a* and saxitoxin toxicity are needed. Epidemiological and toxicological studies are needed on existing and emerging cyanotoxins, including cyanotoxins in biosolids, for both aquatic life and human health.

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Output 11: Data and tools to assess human and environmental adverse health outcomes from exposure to HABs and associated toxins. The toxicity and epidemiology of HABs across exposed biota are not fully understood. These knowledge gaps complicate the assessment of HABs-related risk in situations that include the exposure of humans, domestic pets, livestock, wildlife, plants, crops, and aquatic organisms. Impacts of toxins can range from acute and chronic individual effects to population, community, and system-level effects. SSWR will assess these impacts using multiple approaches, which may include whole organism toxicity studies, computational toxicology, pharmacokinetic studies, and epidemiological studies. The results of this work may be used to inform policy and response actions across a range of scales that include the formulation of health advisories and water quality criteria (OW, state primacy agencies), response and risk communication during HAB events (regional offices, state primacy agencies, and municipalities), design of drinking water treatment processes (local utilities and state primacy agencies), and the designation of aquatic life and environmental health thresholds (OW and state resource managers).

Output Type: Toxicity and epidemiological studies, webinars, and technical support to translate research results.

Output 12: Information for preventing, treating, and managing HABs and their impacts in water bodies, ambient water, and drinking water. Knowledge gaps in the areas of *in situ* bloom management and drinking water treatment have the potential to hinder the effective management of HABs risk. Development and dissemination of best practices to prevent, treat, and manage HABs are fundamental to reducing the risk of recreational exposure, ingestion exposure from contaminated drinking water, and potential ecosystem effects. Through a combination of bench-, pilot-, and potentially field-scale trials, ORD will investigate a range of strategies to prevent and manage HABs that could include emerging *in situ* bloom treatment techniques and the optimization of drinking water treatment process designs and operational practices. The results of this work may be used to inform management and response actions, including water body management plans (state primacy and natural resource agencies), design and purchasing of *in situ* treatment supplies and equipment (private vendors and natural resource agencies), and the design and selection of drinking water treatment processes (consulting engineers, drinking water utilities, and state primacy agencies). Human, animal, and ecosystem health risk information generated in Output 11 can help inform the application of best practices to prevent, treat, and manage HABs in source and finished waters.

Output Type: Webinars, tools, documents, and technical support to translate research results.

Output 13: Tools for HAB risk characterization and assessment. Uncertainty in existing HAB assessments makes it difficult to provide guidance or apply prevention and management strategies. HAB risk characterization utilizes basic ecological knowledge of how environmental drivers impact the development of biomass and the occurrence of toxins. Data sources range from high-frequency modern sensors to irregular discrete sampling, and from local sampling to satellite imagery. ORD will expand the current understanding of HABs ecology to identify and develop a range of monitoring and analytical approaches to be integrated with modeling tools. The results of this work can be used to characterize the development, intensity, and spatial extent of HABs in rivers, streams, lakes, and reservoirs. The information from Output 11 will help inform the implementation of tools to characterize HABs risk in source, finished, and recreational waters. Tools from Output 13 can inform the work in Output 12 by

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retrospectively identifying locations that require mitigation and prospectively evaluate the efficiency of mitigation approaches.

Output Type: Tools, models, webinars, documents, and technical support to translate research results.

Research Area 2: Science to Support Nutrient-Related Water Quality Goals

Nutrient pollution is the most widespread water quality problem facing the United States, with far-ranging consequences for environmental condition, economic prosperity, and human health and well-being. This work will advance the science to inform decisions related to nutrient and co-pollutant water quality goals of program offices, regions, states, and tribes. Outputs in this research area will: 1) provide information, methods, or approaches to determine nutrient-related impacts in watersheds and water bodies, which will help determine protective endpoints for aquatic life in different water body types, (2) relate the condition of watersheds and water bodies to nutrient loading, water quality, and aquatic life; and 3) link these results in approaches that identify areas that may most effectively respond to restoration and recovery.

Program, regional, state, and/or tribal needs. OW programs need scientific support as they develop new tools for states, tribes, and local decision-makers to establish and achieve water quality goals. This includes monitoring, modeling, and decision-support tools to inform recommendations to protect different types of waters and different designated uses (e.g., aquatic life, recreation, and drinking water source protection). OW helps regions, states, and tribes to develop their own numeric nutrient criteria, and scientific support for this work is also needed. Establishing nutrient-related water quality management goals requires an understanding of impacts to water bodies and aquatic life from excess nutrients, and the processes and rates at which they recover.

Output 14: Research for characterizing nutrient-related impacts across multiple spatial scales. This research will produce scientific information, data, models, and tools to describe the potential for nutrient-related impacts across water bodies and watersheds. This will help determine protective endpoints for aquatic life in different water body types, specifically reservoirs, estuaries, turbid waters, and tannin-rich waters. In partnership with states and tribes, OW can use this information to develop numeric nutrient criteria or pursue other nutrient-related water quality management goals.

Output Type: Technical support, training, and collaborative engagement with program offices (mainly OW), regions, states, tribes, and others.

Output 15: Trajectories of aquatic ecosystem responses to and recovery from nutrient pollution. This research will generate scientific information, data, models, and tools to describe and quantify aquatic ecosystem responses to nutrient pollution, as well as the processes and time to recover from nutrient pollution impacts. This will be provided to OW to help the program provide technical advice to states and tribes on water body and aquatic life recovery rates from nutrient pollution impacts.

Output Type: Technical support, training, and collaborative engagement with program offices (mainly OW), regions, states, tribes, and others.

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Output 16: Scientific approach for identifying which watersheds and water bodies may most efficiently attain water quality goals. This work will incorporate information, data, models, and tools developed in

Outputs 14 and 15 to identify watersheds and water bodies that may most effectively respond to restoration and recovery efforts. This will help program offices (mainly OW), regions, and partner agencies identify where specific nutrient management actions, which are addressed in Research Area 3, would be most effectively targeted to achieve a given policy objective.

Output Type: Technical support, training, and collaborative engagement with program offices (mainly OW), regions, states, tribes, and others.

Research Area 3: Nutrient Reduction Strategies and Assessment

While EPA, states and tribes have made great efforts toward reducing nutrient pollution nationwide, it is still a challenge to consider the appropriate spatial and temporal context for reductions and best practices for tracking interventions to meet nutrient reduction goals in a comprehensive manner. To address the problem, this research area is comprised of three broad components for nutrient reduction strategies: 1) application of state-of-the-science; 2) effectiveness monitoring; and 3) whole-system integrated nutrient science, engineering, economics, and stakeholder engagement.

Program, regional, state, and/or tribal needs. EPA, states, and tribes need to plan, implement, and track the effectiveness of nutrient reduction strategies at multiple spatial and temporal scales, including watersheds affected by HABs or other nutrient-related water quality issues. More generally, once the states and tribes establish a goal related to nutrient reduction, for example from the efforts in Research Area 2, the tools and techniques developed from this effort could be used to design and implement nutrient reduction strategies and track the progress toward meeting the goal.

Output 17: Provide tools, technologies, and best practices to predict, monitor, and reduce nutrients in surface water and groundwater *(application of state-of-the-science for nutrient management).* In collaboration with SSWR partners, this output will deliver methods, models, and prediction tools that will help stakeholders design and track nutrient reduction activities at watershed scales. Effective strategies will be assessed for both point and nonpoint sources of nutrients, including legacy nutrients, to surface water and groundwater. Design evaluations will be developed and delivered to help determine which source control practices, in which combinations, and in which locations are best suited to reduce nutrient loading to ambient water. Lessons learned from successful stakeholder engagement activities will be disseminated. Synthesis of existing information and defining research gaps will be a significant component. For example, the information provided in this output could allow a stakeholder to consider the application of constructed wetlands as a system of practices in a large watershed to reduce nutrient pollution to a drinking water reservoir.

Output Type: Technical support for the application of nutrient management.

Output 18: Information for assessing the effectiveness of restoration and conservation systems and practices *(nutrient reduction effectiveness monitoring).* In collaborations with partners and stakeholders, programs will be designed to monitor and track the effectiveness of nutrient reduction strategies, including evaluating low-cost ambient monitoring technologies for assessment of nutrient reduction activities, approaches, and strategies (e.g., application of nutrient sensors to capture real-time nutrient reduction or changes in temporal dynamics). For example, groundwater-monitoring networks can track

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changes in nutrient characteristics or evaluate the effectiveness of EPA's 319 Grant Program for states and territories. Tracking the progress of nutrient reduction strategies will likely require partnering with land grant universities, soil and water conservation districts, businesses, NGOs, and other federal and state agencies. A key aspect of this research area will be information, models, and tools developed under the nutrients translational science pilot project to address the problem of nonpoint nutrient pollution using nontraditional approaches.

Output Type: Seminars, webinars, or workshops that demonstrate good practices for monitoring the effectiveness of nutrient reduction programs and activities.

Output 19: Best practices for integrated nutrient management programs *(whole system integrated nutrient science, engineering, economics, and stakeholder engagement*). This output will develop, translate, and deliver research and evaluations of nutrient reduction actions in watersheds at multiple scales and within source waters for prevention and mitigation of nutrient pollution. Economic analyses of nutrient reduction programs (e.g., market-based mechanisms) will be conducted, including socio-economic aspects of nutrient reduction practices that influence adoption and maintenance, while evaluating water quality and multi-media modeling. These efforts will include user feedback to inform adaptive management strategies, incorporate legacy nutrient issues, temporal lags, and water body recovery rates into the planning and implementation of nutrient reduction programs. Overall, this work will provide a means of considering non-traditional participants in nutrient reduction.

Output Type: A series of fact sheets and accompanying webinars that can easily be made web accessible to demonstrate the processes and procedures needed for integrated nutrient reduction strategies.

Topic 3: Water Treatment and Infrastructure

The Water Treatment and Infrastructure topic includes research on drinking water, wastewater, water reuse, and stormwater management. Research will provide innovative methods for assessing and treating water from source to tap and back to the source. The focus will be on the assessment and control of opportunistic pathogens and disinfection byproducts, analytical methods development, optimization and application of tools for improving drinking water infrastructure, and augmentation of reliable water sources through water reuse research and stormwater capture for enhancing water supplies. High-priority issues, such as characterization, assessment, and mitigation of lead in drinking water, will be emphasized, while keeping an eye toward future challenges facing water treatment and infrastructure. This SSWR research will integrate with the SHC (e.g., lead exposure from drinking water, PFAS in biosolids) and CSS (e.g., application of bioassays, PFAS analytical method development) research programs.

SSWR research will continue to apply research results through workshops, webinars, training sessions, and printed materials. Research results will play a role in statutory/guidance decisions by OW by providing peer-reviewed, transparent research results in a timely manner. This research will also make every effort to provide direct support on regional/state-specific issues affecting drinking water through communications with organizations such as ECOS and the Association of State Drinking Water Administrators (ASDWA).

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Research Area 1: Drinking Water/Distribution Systems

This research area will provide essential results and tools to the program offices, primarily OW's Office of Ground Water and Drinking Water (OGWDW), states, tribes, and communities to manage existing and future drinking water needs. Specifically, it focuses on areas of recent concern that require novel solutions. This includes addressing legacy issues (e.g., removing lead from leaded materials in distribution systems and identifying cost-effective infrastructure improvements), managing distribution system operation (e.g., balancing disinfection and disinfection byproducts, and controlling opportunistic pathogens in premise plumbing), and identifying contaminants of emerging concern and treatment processes (e.g., algal toxins). Specific emphasis will be given to addressing issues for small water systems, or other systems that lack technical, managerial, and financial capability.

Program, regional, state, and/or tribal needs. The EPA, states, tribes, and utilities need technical support for guidance on the assessment and treatment of contaminants and management of drinking water and distribution systems. Additionally, the Agency requires research support for a variety of regulatory actions, including: The Contaminant Candidate List (CCL), Unregulated Contaminants Monitoring Rule (UCMR), National Primary/Secondary Drinking Water Regulatory process, Long Term Surface Water Treatment Rules, Disinfection Byproduct Rules, and Revisions to the Lead and Copper Rule.

Output 20: Resources and tools for characterizing and mitigating lead and copper release in drinking water distribution systems and premise plumbing. This output will provide research on source contributions from lead-containing plumbing materials under varying water quality conditions and scale properties. This output will also develop improved sampling and detection strategies, including those to identify lead service lines, and will include corrosion control strategies for minimizing copper pitting and release in water-delivery systems. This research will be integrated into models that estimate lead exposure and into remediation strategies to protect public health. Results from this research will inform the Federal Lead Strategy and will help states and utilities reduce human exposure to lead.

Output Type: Sampling protocols/guidance improved lead exposure models, guidance on optimizing lead mitigation strategies.

Output 21: Best practices, tools, and information for assessing and controlling pathogens, managing disinfectant residuals, and minimizing disinfection by-products in drinking water systems. This output involves research on the types and populations of opportunistic and other pathogens (*Legionella*, *Mycobacterium*, *Amoeba*, viruses) and understanding the impacts of their presence in drinking water delivery systems. Results will include improved strategies for controlling pathogens and maintaining disinfectant levels while controlling disinfection byproduct formation, with an emphasis on small systems. Research results will also help utilities optimize disinfection practices and manage water quality in distribution infrastructure.

Output Type: Reports and tools for assessing and controlling opportunistic pathogens in distribution and premise plumbing systems.

Output 22: Analytical methods, occurrence, health effects, and treatment assessments for emerging contaminants. This output will involve research on the detection and removal of Agency priority chemicals (e.g., those listed on the 5th CCL and other emerging contaminants (both chemical and microbial) to support the evaluation of these contaminants by program offices and to provide tools to states, tribes, and communities in their efforts to protect public health. The PFAS work will be conducted separately

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under Research Area 2: Per- and Poly-Fluorinated Alkyl Substances. Research will also be conducted to fill any health effects data gaps for drinking water contaminants. Research results will help inform OW's decision-making for unregulated contaminants in accordance with SDWA.

Output Type: Analytical methods for future CCL/UCMR contaminants in drinking water, and guidance for optimal treatment. Technical support for future OW decisions related to SDWA.

Output 23: Resources and tools toward a systems approach for maintaining drinking water infrastructure performance and integrity. This output will involve research on meeting multiple competing objectives that are encountered in the operation, maintenance, and renewal of drinking water systems. This will include developing approaches to protect human health, while minimizing the current and long-term costs of supplying water to all end users. Researchers will prepare modeling and management tools by utilizing analytical and geospatial data to assess system conditions, hydraulics, water quality, and resilience, from source water to the consumer's tap.

Output Type: Improved models (e.g., EPANET) and guidance for optimizing the efficiency of distribution systems.

Research Area 2: Per- and Poly-Fluorinated Alkyl Substances (PFAS)

PFAS are a complex class of chemicals, some of which are very persistent in the environment and human body. Other unknown and undiscovered PFAS likely exist within the environment as impurities or byproducts of chemical production, or as a result of environmental degradation and transformation processes. The SSWR PFAS research area will focus on developing analytical methods, treatment, and remediation of priority PFAS sources.

Program, regional, state, and/or tribal needs. States and utilities need robust analytical methods for measuring a wide variety of PFAS in environmental samples including water, soil, sediment, biosolids, and plant and animal tissues. Data are needed on effective treatment strategies for multiple PFAS compounds in drinking water and wastewater systems. Additionally, PFAS sources, fate, and transport must be addressed to provide more effective remediation strategies to protect water resources.

Output 24: Validated analytical methods for PFAS in environmental samples. This research will provide EPA program offices and regions, states, tribes, and utilities with robust analytical methods for analyzing PFAS in water, solid, and tissue samples. Method development efforts will coordinate closely with OW, OLEM, other federal agencies (e.g., the Department of Defense), and states to ensure that analytical needs are met. This output will also include research on new approaches for PFAS analysis, including non-targeted analyses, total organic fluorine, and total oxidizable precursors.

Output Type: Centralized website for accessing analytical methods for PFAS.

Output 25: Treatment technologies and processes for removing PFAS from water. This output will focus on testing and evaluating treatment processes for removing PFAS from drinking and wastewaters. Bench-, pilot-, and, where possible, full-scale treatment processes will be tested. Cost information, including operation and maintenance costs, will be evaluated and presented. Emphasis will be placed on treatment technologies for small systems and processes (e.g., decentralized and point-of-use/point-of-entry treatment systems) for addressing PFAS compounds that have been shown to be challenging to remove from source waters (e.g., shorter chained PFAS, such as the GenX chemical HFPO-DA).

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Output Type: Updated information for the OW/ORD Drinking Water Treatability Database, which provides compound-specific cost and treatment efficacy data for PFAS and other contaminants. Centralized website for treatment and pre-treatment recommendations for wastewater and water-reuse treatment strategies.

Output 26: Characterization of PFAS sources and remediation options for protecting drinking and agricultural water resources, wastewater, biosolids, and landfill leachates. Research will be conducted on impacts to water resources from biosolids and land application of industrial waste, wastewater discharge, and landfill leachate sent to wastewater treatment systems. Treatment and pre-treatment technologies will be evaluated for removing PFAS at the source to minimize consequences to downstream treatment or disposal operations. Research will focus on the characterization of PFAS in biosolids, wastewater, landfill leachates, and rural and agricultural water supplies with an emphasis on pre-treatment strategies for minimizing PFAS contamination in water resources.

Output Type: Guidance report on characterization and pretreatment options for PFAS sources. Webinar series on PFAS in rural and agricultural water supplies.

Research Area 3: Wastewater/Water Reuse

Demand is increasing for sufficient quantities of high-quality water. An integrated water resource management approach may facilitate meeting this demand by enhancing the availability and quality of reused water for drinking, agriculture, irrigation and other purposes. This research will support the Agency in deploying its new Water Reuse Action Plan, in collaboration with other federal agencies, states, tribes and water sector stakeholders. This research area has three outputs that aim to: 1) develop, evaluate, and validate new and existing analytical methods for emerging contaminants (e.g., antibiotic resistant microbes, *Legionella*, etc.) in wastewater and reused water; 2) develop new methods and further enhance existing methods for exposure and effects assessment (e.g., enhanced and additional Whole Effluent Toxicity [WET] methods, quantitative microbial risk assessment); and 3) assess new treatment strategies for wastewater and fit-for-purpose water reuse for emerging contaminants and endocrine disrupting compounds. This research area will provide support for guidance on new and existing treatment technologies, develop analytical methods for emerging contaminants in relevant matrices, and develop methods to better assess risks posed by individual and groups of contaminants, with the overall goal of improving the quality and quantity of treated water. The research will provide essential information for OW's Office of Wastewater Management (OWM), Office of Science and Technology (OST), OGWDW, regions, and states for meeting statutory requirements under the CWA and SDWA.

Program, regional, state, and/or tribal needs. Methods and tools are needed to characterize and assess microbial populations in wastewater treatment processes and for fit-for-purpose water reuse. New and enhanced methods are needed to assess exposure and effects from exposure to chemical contaminants. Validated analytical methods and strategies are needed to treat chemical and microbial contaminants in wastewater and fit-for-purpose water reuse. Additionally, OW and utilities need to know how effective various treatment steps and disinfection processes are in treating AMR bacteria and associated genes.

Output 27: Analytical methods, exposure and effects assessment processes, and tools for wastewater and fit-for-purpose water reuse. This research will focus on the development and application of analytical methods for emerging biological, chemical, and other contaminants in wastewater and water reuse

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matrices. Researchers will also develop and evaluate new and existing methods and tools to more accurately determine the risk posed by groups and individual chemicals, pathogens, and other contaminants in water matrices, including wastewater for discharge and reuse. This research will enhance WET methods using new, more sensitive species, additional chronic methods (e.g., *Daphnia magna* and trout chronic methods), and inclusion of additional endpoints (e.g., modes of action) and bioassays.

Output Type: Website/clearinghouse for new WET and analytical methods; framework for the application of bioassays for screening water safety.

Output 28: Assessment of treatment strategies and technologies for wastewater and fit-for-purpose water reuse. Research will involve the characterization of source waters and treatment technologies (existing and new) to aid in the management of emerging and regulated contaminants, including pretreatment, wastewater unit operations, wastewater practices, biosolids management, and fit-for-purpose reuse scenarios. Water reuse research will address industrial, agricultural, and municipal needs.

Output Type: Reports and technical guidance for optimizing wastewater management and reuse.

Research Area 4: Integrated Stormwater Management

Integrated stormwater management research will continue to focus on reducing combined sewer overflows (CSOs), managing stormwater quality and quantity, and using stormwater for augmenting water resources. Topics in this research area include water quantity, water quality, capturing storm and wastewater for reuse, and topics related to cost, cost effectiveness, and related incentives to ratepayers—all in the context of adaptation and adaptive management. SSWR research will focus on integrated stormwater management, including aspects of green/gray infrastructure and stormwater flow control to help states, municipalities, and utilities reduce the number of CSO incidents.

Program, regional, state, and/or tribal needs. Cost-benefit analysis is an important input to prioritize actions in times of decreasing financial resources and strained staffing resources, and it can help to identify cost-effective ways to decrease stormwater-related pollutants, thereby reducing energy and costs needed to treat and manage water resources. The need for these analyses spans EPA-OW regulatory requirements, to local government actions, to individual citizens' decisions. ORD will investigate the applicability of current tools and processes to help communities manage stormwater. Regulatory drivers include NPDES, Municipal Separate Storm Sewer System, and TMDL requirements.

Output 29: Integrated guidance for planning, implementing, and monitoring stormwater management practices. This research involves synthesizing existing models, methods, assessment data, and approaches (e.g., flow control) to aid communities in stormwater management planning, including evaluation of costs and benefits, operation, and maintenance issues. This research will integrate and account for system hydraulics and interactions with other hydrologic processes in the stormwater/wastewater collection, conveyance, and combined/septic sewer overflow-outfall system. This research will help communities build stormwater management capacity by using both existing gray infrastructure and appropriate forms of green infrastructure. These results will be applied to site selection and implementation, and results will reveal the types and extent of ecosystem services and other ancillary benefits over baseline (i.e., gray only) conditions. The output will demonstrate implementation of monitoring strategies for effectively managing stormwater at multiple scales.

Output Type: Improved guidance for integrated stormwater management.

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Output 30: Integrated stormwater management as a resource for enhanced recharge and reuse. This output involves research on the use of stormwater for augmenting safe water sources (e.g., through fit-for-purpose reuse). Rainfall, irrigation, and snowmelt all redistribute water and may mobilize potential pollutants (e.g., chemicals, nutrients, etc.) through infiltration or runoff. The physical, chemical, and biological aspects of stormwater will be assessed for potential increased integration with water supplies. This integration can result in identifying fit-for-purpose uses, re-establishing recharge, and optimizing other productive entry points into the larger sewershed/watershed hydrologic cycles. The result will be a better understanding of the interrelationships between existing water resources and stormwater influents, and the beneficial uses of stormwater. Research will focus on evaluating water quality in varying stormwater capture scenarios (e.g. direct capture through cisterns, runoff, infiltration through green infrastructure) and conducting risk assessments for reuse recommendations. Contaminant mobilization (or sequestration) from stormwater will also be assessed.

Output Type: Guidance on stormwater capture and reuse, including characterization and treatment recommendations.

Research Area 5: Technical Support

The Technical Support research area will provide a means for rapid response to specific, unplanned program office, state, tribe, and community research needs concerning high-priority issues. This may include site-specific analytical and technical support for addressing and resolving sudden issues such as lead, per- and poly-fluorinated alkyl substance, or cyanotoxin contamination in drinking water. This research area will also provide base funding for the annual maintenance and training for widely used EPA models, including the Stormwater Management Model (SWMM), the National Storm Water Calculator (SWC), and EPANET. This research area will also provide base funding for EPA's Annual Drinking Water Workshop for Small Systems held in collaboration with ASDWA and SSWR webinars.

Program, regional, state, and/or tribal needs.

States and EPA's regions and program offices need site-specific, applied research to rapidly respond to emerging issues in the water sector. This technical support research area is not oriented toward immediate response to emergencies, which is under the purview of EPA's National Homeland Security Research Center, but may be positioned to support follow-up actions (e.g., post-emergency monitoring/analytical support).

Output 31: Technical support for water treatment, analytical methods, and risk assessments. Provide timely technical support to states for meeting challenges in drinking water, wastewater, stormwater, and water reuse areas.

Output type: Publicly accessible database listing technical support efforts and case studies that might have wider application across the United States. Central website for current versions of SWMM, SWC, and EPANET.

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Program Design

SSWR Program Components

Through its StRAP 2019-22, SSWR will continue developing innovative, cost-effective solutions to current, emerging, and long-term water resource challenges for complex chemical and biological contaminants. The research areas and outputs were developed based on the research needs prioritized by EPA's Office of Water and regions, as well as other EPA program offices, and states, and tribes. While most of the research in the StRAP 2019-22 is targeted at foreseen immediate needs, capacity is built in for emergency response science, technical support, and research that is exploratory and anticipatory in nature and will lead to capabilities in the future.

In the StRAP 2019-22, there is a greater emphasis on integrated nutrient management programs, including aquatic ecosystem response trajectories, non-regulatory market-based incentive approaches, and socio-economic aspects of nutrient management practices that influence their adoption and maintenance. Other areas of focus include PFAS, lead in drinking water, water reuse, rapid detection of pathogens in recreational waters, antimicrobial resistance, biosolids, and micro/nanoplastics. The stormwater management research will have a more integrated approach—continuing support to communities to prevent combined sewer overflows (CSOs) and exploring beneficial uses of stormwater (e.g., capture and reuse) and other adaptive management approaches.

In addition to the research outlined in this StRAP, SSWR engages EPA regions in collaborative research with ORD experts through the Agency's Regional Applied Research Effort (RARE). Each region proposes priority issues that are typically nearer-term challenges and may be unique to the originating region.

Extramural research, funded through EPA's Science to Achieve Results (STAR) and the National Priorities grant programs, complements and expands the intramural SSWR research program by providing invaluable engagement between the Agency and the Nation's leading scientists and engineers. The SSWR research program also utilizes the Small Business Innovation Research (SBIR) program, Cooperative Research and Development Agreements (CRADA), open-source innovation challenges and prizes, and public-private partnerships to support solutions to pressing water quality problems.

Solutions-Driven Research

ORD is adopting a three-pronged strategy for advancing holistic, solutions-driven research to provide the science needed to inform policy decisions:

1) Apply principles of solutions-driven research broadly across ORD's six national research programs
2) Conduct pilot translational science projects that apply and evaluate methods of solutions-driven research to planning, conducting, applying, and evaluating integrated research that addresses a well-defined and unmet need of partners and stakeholders (Box 1)
3) Conduct case studies of previous and current research activities that embody the principles of solutions-driven research, which will help inform a list of best practices

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Risk communication is a central factor in solutions-driven research, allowing people to understand their risks and adopt protective behaviors, as well as informing risk management decisions. ORD will apply advances in the science of risk communication and will apply best practices for communicating risk to different audiences across the six national research programs.

Box 1 Nutrients Translational Science Pilot

Translational Science Pilot: Reducing Non-Point Sources of Nutrients via Non-Traditional Approaches
In many parts of the country, septic systems and land management practices have contributed to elevated nutrient levels in surface water and groundwater, resulting in environmental and public health concerns and impacts. Although traditional public sewer systems are effective at reducing nutrient pollution from households, their installation often is neither practical nor economically feasible, so communities are seeking innovative and cost-effective approaches for tackling this problem in ways that improve environmental and societal conditions.

The SSWR research program is addressing this need through a translational science pilot in Cape Cod, MA. This pilot will provide partners in Cape Cod, MA with watershed-based solutions for nonpoint source nutrient loading that can support states and communities with similar challenges.

This solution-driven research pilot will explore watershed-based solutions to expeditiously and cost-effectively reduce nitrogen loadings to the Three Bays system on Cape Cod to help achieve the Total Maximum Daily Load (TMDL) goals. Objectives include 1) solving the nutrient problem in Three Bays in a public-health and environmentally protective and affordable manner; 2) becoming a recognized national model for addressing nonpoint source nutrient management; and 3) serving as a center for education and outreach to support other communities as they address similar issues of nonpoint source nutrient management.

Integration Among Research Programs

EPA's six research programs work together to identify and address science challenges. Coordination efforts can range from formal integration across the programs, to collaboration among EPA scientists working on related issues. There are many opportunities for integration among the programs, and the research programs will continue working together to identify additional opportunities. The SSWR research program is coordinating with other research programs in several areas (Appendix 3). These include the following:

Nutrients: The cross-ORD nutrient research effort is focused on reducing excess nutrient loadings that can cause adverse environmental and human health effects. Using an integrated approach that spans across media (water, land, and air), across types of surface water bodies and groundwater resources, and across temporal and spatial scales, this effort develops and applies scientific information and tools to enable states, tribes, and their EPA program office and regional partners to develop cost-effective regulatory and non-regulatory approaches to nutrient reduction.

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PFAS: The cross-ORD PFAS research effort addresses the four goals of ORD's PFAS action plan: 1) understanding human health and ecological effects of PFAS; 2) understanding PFAS occurrence, fate and transport, and exposure; 3) reducing, removing, and remediating PFAS in the environment; and 4) supporting stakeholders in protecting public health and the environment. The results from this work is designed to support the cross-EPA and cross–Federal Agency efforts to address PFAS. SSWR research will address validating analytical methods for PFAS in environmental samples, treatment technologies and processes for removing PFAS from water, and characterizing PFAS sources and remediation options for protecting drinking and agricultural water resources, wastewater, biosolids, and landfill leachates. Other ORD research includes: PFAS air sampling and emissions (A-E), analytical standards, AOP, rapid toxicity testing (CSS), risk characterization (HHRA), and fate and transport at contaminated sites and estimating human exposure (SHC).

Lead: The cross-ORD lead (Pb) research effort is focused on answering the question: "How can EPA mitigation efforts/techniques and coordinated multimedia assessments most effectively reduce exposures and blood lead levels for children in the United States?" ORD's highest priorities with respect to lead include: 1) identifying the most highly exposed communities for targeting intervention actions; 2) generating critical data on the geographic distributions of media-specific lead exposure sources, key exposure factors, bioavailability, and bioaccessibility; 3) updating and evaluating multimedia exposure-dose models for regulatory determinations; and 4) developing corrosion control strategies, drinking water sampling protocols, and methods to diagnose water distribution system issues. The ORD effort is designed to provide research to support the updated Federal Lead Strategy and EPA's Public Health Approach Addressing Lead.

Wildland Fires: Wildland fires are a persistent and pervasive multimedia issue. Wildland fires and resulting increased runoff can adversely affect ambient waters through increased sedimentation and mobilization of nutrients, heavy metals and other pollutants. These effects may warrant shifts in drinking water treatment processes and associated effects (e.g., higher concentrations of nitrate and disinfection by-products post-treatment). For SSWR, this crosscutting project will provide information needed by OW to work with utilities, especially small drinking water systems, to anticipate and respond to wildfire impacts. Research in this area involves multiple national research programs, specifically A-E, SSWR, SHC, and HSRP.

Resilience: The cross-ORD resilience effort is focused on integrating ORD's work preparing for and recovering from disasters, including extreme weather events. This research will deliver metrics, methods, and tools that EPA programs, states, tribes, and communities can use to assess their own vulnerability to, preparedness for, and response and recovery from environmental releases and other conditions due to extreme weather and other disasters. Research in ORD's programs will advance the assessment of trends in, and the development of, future scenario products for disasters for EPA clients (A-E), and Research will address resilience and preparedness with respect to immediate emergency response (HSRP), watersheds and water infrastructure (SSWR), contaminated air and site remedies (A-E, SHC), and long-term planning for resilient communities (SHC).

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Conclusion

The SSWR research program takes an integrated approach that examines the entire water cycle. It produces robust research and scientific analysis for decision-making and innovative, practical solutions for its partners and stakeholders. This Strategic Research Action Plan maps out the targeted steps that will be taken during the next four years. It was developed in collaboration with other ORD national research programs, EPA program offices and regions, federal agencies, states and tribes, and colleagues in the scientific community. This work will yield the innovative tools and information needed to protect and restore America's watersheds, aquatic ecosystems, and water infrastructure so that they, in turn, can provide clean and adequate supplies of water for optimum human and ecosystem health and a strong economy.

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Appendices

Appendix 1: States and tribal needs reflected in ORD research planning

The table below lists the state needs identified in the 2016 Environmental Council of the States (ECOS) survey and in ECOS and National Tribal Water Council (NTWC) discussions with ORD in spring of 2018. These needs are aligned to the Research Areas planned in the ORD StRAPs.

Source	*State Need*	*Research Area*
Water		
ECOS 2016 Survey	Water Quality/Surface Water Quality/Groundwater Quality	Assessment, Monitoring, and Management of Aquatic Resources; Human Health and Aquatic Life Criteria; Assessment and Management of Harmful Algal Blooms; Science to Support Nutrient-Related Water Quality Goals; Assessment and Management of Nutrients; Wastewater/Water Reuse; Integrated Stormwater Management
	Nutrients and Nonpoint sources/agriculture vs. groundwater/HABs	Assessment and Management of Harmful Algal Blooms; Assessment and Management of Nutrients
	MS4 Compliance and Stormwater	Integrated Stormwater Management
	Water Quantity and Reuse	Wastewater/Water Reuse
	Water and Wastewater Infrastructure	Drinking Water/Distribution Systems; Wastewater/Water Reuse; Integrated Stormwater Management; Water Infrastructure Technical Support
	Small System Drinking Water and Wastewater Treatment	Drinking Water/Distribution Systems and Wastewater/Water Reuse; Water Infrastructure Technical Support
	Ensuring Safe Drinking Water and Wastewater Disinfection Byproducts	Drinking Water/Distribution Systems; Wastewater/Water Reuse; Integrated Stormwater Management; Water Infrastructure Technical Support

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	Issues with Altered Hydrology	Assessment, Monitoring, and Management of Aquatic Resources [Please note that the focus will be on water quality/aquatic resources and potential interactions with altered flow/hydrology]
ECOS Media meeting	Groundwater remediation: would be beneficial to see data from past *in situ* efforts and designs related to hydro technologies (AZ)	This need will not be addressed
ECOS Media meeting	Research at the groundwater-surface water interface (OK)	Assessment, Monitoring and Management of Aquatic Resources SHC Groundwater
	HABs (MO): Ecological endpoints, Gulf Hypoxia research, WQS criteria validation, using satellite images for algae bloom prediction, HAB method development and validation, and HAB risk assessment based on lake attributes (WI)	Assessment and Management of Harmful Algal Blooms
	Water reuse (CO, AZ)	Wastewater/Water Reuse
	Nutrient impact on wastewater reservoirs from water reuse (OK)	This need will not be addressed
	More work on wastewater treatment plants and landfills (MI)	Wastewater/Water Reuse
	Removing (emerging) contaminants from direct potable reuse (TN, OK)	Wastewater/Water Reuse, focus on biological contaminants

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	Need more bioassessment tools for estuarine/marine waters (especially since EPA has an emphasis on downstream water quality) (FL)	Assessment, Monitoring, and Management of Aquatic Resources; Science to Support Nutrient-Related Water Quality Goals
	Need tools to discriminate nutrient sources—need to bring down costs and make more accurate (NE)	Assessment and Management of Nutrients
	Need for some waste management or reuse options for the residuals from water treatment, whether it be from produced water or other, where there is the possibility to generate voluminous solids, highly concentrated water, that possibly contain norm and tenorm (OK)	Wastewater/Water Reuse, emphasis on PFAS in biosolids
Emerging Contaminants		
ECOS 2016 Survey	Manage new chemicals of emerging concern and existing chemicals	Drinking Water/Distribution Systems and Wastewater/Water Reuse & Human Health and Aquatic Life Criteria
	Adapt and respond to emergencies	Technical Support
	More info for PFAS, surface water standards, fish consumption and biosolids advisory levels	Drinking Water/Distribution Systems and Wastewater/Water Reuse

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All Areas		
Source	**Tribal Need**	**Research Area**
NTWC meeting Spring 2018	Predictive modeling capability for Harmful Algal Blooms	Assessment and Management of Harmful Algal Blooms; Assessment and Management of Harmful Algal Blooms
	Develop guidance for addressing drinking water and wastewater home-based technologies for rural/tribal communities[1]	Drinking Water/Distribution Systems; Wastewater/Water Reuse; Water Infrastructure Technical Support
	Develop guidance for water system operators on corrosion control[1]	Drinking Water/Distribution Systems; Water Infrastructure Technical Support
	Dependable, affordable continuous water quality monitoring equipment.	Assessment, Monitoring, and Management of Aquatic Resources; Assessment and Management of Harmful Algal Blooms; Assessment and Management of Nutrients; Assessment and Management of Nutrients; Drinking Water/ Distribution Systems; Wastewater/Water Reuse; Integrated Stormwater Management; Water Infrastructure Technical Support
	Develop ecologically-based criteria for sulfate and identify treatment technologies[1]	Human Health and Aquatic Life Criteria
	Hydraulic fracturing water reuse study for evaluating ecological impacts	This need will not be addressed
	Human health & ecological effect studies for large vessel ships - dumping sewage and gray water in international waters.	This need will not be addressed

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Appendix 2: National Research Program environmental regulations and policies mandated by legislation

The following table lists the legislation supported by SSWR research.

Legislation	Acronym	Website
Safe Drinking Water Act	SDWA	https://www.epa.gov/sdwa
SDWA 42 U.S. Code, Chapter 6A, SUBCHAPTER XII—Safety of Public Water Systems		http://uscode.house.gov/view.xhtml?path=/prelim@title42/chapter6A/subchapter12&edition=prelim
SDWA 42 U.S. Code § 300g-1: National drinking water regulations		http://uscode.house.gov/view.xhtml?path=/prelim@title42/chapter6A/subchapter12&edition=prelim
SDWA 42 U.S. Code § 300j–1. Research, technical assistance, information, training of personnel		http://uscode.house.gov/view.xhtml?path=/prelim@title42/chapter6A/subchapter12&edition=prelim
Clean Water Act	CWA	https://www.epa.gov/laws-regulations/summary-clean-water-act
CWA 33 USC CHAPTER 53, Section 4001— Harmful Algal Bloom and Hypoxia Research and Control Amendments Act		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter53&edition=prelim
CWA 33 U.S. Code Chapter 26, Sections 1251-1387		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1251. Congressional declaration of goals and policy		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1252. Comprehensive programs for water pollution control		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1254. Research, investigations, training, and information		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1257. Mine water pollution control demonstrations		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1266. Hudson River reclamation demonstration		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim

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CWA 33 U.S. Code § 1267. Chesapeake Bay		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1273. Lake Pontchartrain Basin		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1274. Watershed pilot projects		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1311. Effluent limitations		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1314. Water quality criteria development		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1315. State reports on water quality		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
CWA 33 U.S. Code § 1321. Oil and hazardous substance liability		http://uscode.house.gov/view.xhtml?path=/prelim@title33/chapter26&edition=prelim
Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014	HABHRCA	https://www.govinfo.gov/content/pkg/BILLS-113s1254enr/pdf/BILLS-113s1254enr.pdf
Clean Air Act	CAA	https://www.epa.gov/clean-air-act-overview
National Environmental Policy Act	NEPA	http://www2.epa.gov/nepa
Water Infrastructure Improvements for the Nation Act	WIIN Act	https://www.congress.gov/bill/114th-congress/senate-bill/612/text
Coastal Zone Act Reauthorization Amendments of 1990	CZARA	https://www.congress.gov/bill/101st-congress/house-bill/4030

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Appendix 3: Cross-cutting research areas

The following table lists the research areas coordinated across the ORD national research programs.

	A-E	CSS	HHRA	HSRP	SHC	SSWR
Nutrients	• Atmospheric deposition of nitrogen and phosphorus to ecosystems	• Toxicity testing				• Sensors & Water Infrastructure • N & Co-pollutants
PFAS	• Air sampling and emissions	• Analytical standards • Adverse outcome pathways • Rapid toxicity testing	• Risk characterization	• Treatment of contaminated water from emergency response activities.	• Tech Support • Fate and transport at contaminated sites and landfills • Human exposure	• Analytical methods • Remediation • Wastewater treatment
Lead			• Regulatory models • Risk Assessment	• Sensors and water infrastructure modeling, including contaminant fate and transport	• Locations • Exposure data & evaluated models • Innovative solutions	• Water treatment systems • Drinking water quality sampling • Risk Assessment
Wildfire	• Models and measurement methods			• Wildland fires	• Models and measurement methodologies	• Drinking water treatment and utilities • Source water protection
Resilience	• Sector-based approaches to resilience			• Emergency preparedness and response for all hazards	• Indicators of long-term resilience • Preparation and response to natural disasters	• Coastal Resilience • Stormwater
Ecosystem services	• Secondary NAAQS				• Ecosystem services	• Secondary NAAQS

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Appendix 4: Summary table of proposed outputs for the Safe and Sustainable Water Resources Research Program (FY2019 -2022)

The following table lists the expected SSWR outputs, organized by topic. It should be noted that the outputs might change as new scientific findings emerge. Outputs are also contingent on budget appropriations.

Research Area	Program/Region/State /Tribal Needs	Output Title
Topic: Watersheds		
Research Area 1: Assessment, Monitoring, and Management of Aquatic Resources	Technical support and tools to implement NARS.	Output 1: Science to support NARS survey design, indicator development and assessment benchmarks, methods development, and data tools.
	Analytical approaches and new tools to leverage survey data for condition assessment, trends analysis, stressor identification, and causal analysis.	Output 2: Extended applications of NARS data and approaches to support priority setting and management actions.
	Tools to advance integrated watershed assessments, establish attainable biological targets, and evaluate recovery potential.	Output 3: Tools, indicators, and information to inform water quality goals, assess biological condition, and support effective management of diverse water bodies.
	Analytical methods for micro/nanoplastics in water and tools to assess potential adverse health outcomes from exposure.	Output 4: Methods, models, and tools to evaluate the potential health effects from exposure to micro/nanoplastics.
	Technical support for water quality modeling and applications for linking water quality and economic models.	Output 5: Water quality models and economic analyses to support science-based water quality decisions.
	Technical support and tools for monitoring and modeling sources, fate, and transport of metals and other pollutants in the Animas-San Juan watershed.	Output 6: Research support for the San Juan Watershed Program
Research Area 2: Improved Aquatic Resource Mapping	Tools for aquatic resource mapping of waters of the United States.	Output 7: Transferrable methodologies, tools, and datasets to improve the accuracy and application of geospatially-explicit aquatic resource data.

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Research Area 3: Human Health and Aquatic Life Criteria	Analytical tools for pathogens, fecal indicators and sources, including antimicrobial resistance, and science supporting recreational water quality criteria.	Output 8: Data and innovative tools to advance public health protection from microbial contaminants in surface water.
	Technical support and tools to address data gaps and modeling challenges to developing bioaccumulation factors for metals and other contaminants for human health criteria.	Output 9: Data and innovative tools to advance public health from consumption of chemical contaminants in surface waters and aquatic organisms.
	Scientific and technical support to update the 1985 Aquatic Life Guidelines. Developing next generation toxicological tools for new and emerging contaminants, including mixtures, for aquatic life guidelines.	Output 10: Science to advance the methodology for deriving water quality criteria to protect aquatic life from toxic chemicals.
Topic: Nutrients and Harmful Algal Blooms		
Research Area 1: Assessment and Management of Harmful Algal Blooms	Epidemiological and toxicological data on existing and emerging cyanotoxins.	Output 11: Data and tools to assess human and environmental adverse health outcomes from exposure to HABs and associated toxins.
	Research and evaluation of management actions in watersheds, including economic analyses.	Output 12: Information for preventing, treating and managing HABs and their impacts in water bodies, ambient water, and drinking water.
	Tools for predicting, characterizing and monitoring HABs.	Output 13: Tools for HABs risk characterization and assessment
Research Area 2: Science to Support Nutrient-Related Water Quality Goals	Scientific support for developing numeric nutrient criteria. Methods to determine nutrient-related impacts in watersheds and waterbodies.	Output 14: Research for characterizing nutrient-related impacts across multiple spatial scales.
	Information on water body recovery rates from nutrient pollution.	Output 15: Trajectories of aquatic ecosystem responses to and recovery from nutrient pollution.

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	Assessment of nutrient-related impacts on aquatic life. Approaches to identify watershed and water bodies that will most effectively respond to restoration and recovery efforts.	Output 16: Scientific approaches for identifying which watersheds and water bodies may most efficiently attain water quality goals.
Research Area 3: Nutrient Reduction Strategies and Assessment	Scientific support to determine which practices, in which combinations, in which locations are best suited to reduce nutrient loadings to ambient water.	Output 17: Tools, technologies, and best practices to predict, monitor, and reduce nutrients in surface water and groundwater. *(Application of state-of-the-science for nutrient reduction strategies)*
	Program designs for monitoring and tracking nutrient management activities, including low-cost sensor technology.	Output 18: Information for assessing the effectiveness of restoration and conservation systems and practices. *(Effectiveness monitoring)*
	Social science applications to address water quality. Information on water body recovery rates from nutrient pollution.	Output 19: Best practices for integrated nutrient reduction programs. *(Whole system integrated nutrient science, engineering, economics, and stakeholder engagement)*
Topic: Water Treatment and Infrastructure		
Research Area 1: Drinking Water/Distribution Systems	Technical support for revisions to the Lead and Copper Rule. Resources for states to minimize lead exposure.	Output 20: Resources and tools for characterizing and mitigating lead in drinking water distribution systems and premise plumbing.
	Technical support for 6-year reviews on DBPs and future decisions on the Unregulated Contaminant Monitoring Rule. Resources for small systems for optimizing disinfection strategies.	Output 21: Best practices, tools and information for assessing and controlling pathogens and biostability, managing disinfectant residuals, and minimizing disinfection by-products in drinking water systems.
	Treatment options and technical support for future regulatory determinations and health advisories.	Output 22: Analytical methods, occurrence, health effects, and treatment assessments for emerging contaminants.
	Technical support for states and small systems for maintaining and improving drinking water infrastructure.	Output 23: Resources and tools towards a systems approach for maintaining drinking water

		infrastructure performance and integrity.
Research Area 2: Per- and Poly-Fluorinated Alkyl Substances (PFAS)	Robust analytical methods for analyzing PFAS in water, solid, and tissue samples.	Output 24: Validated analytical methods for PFAS in environmental samples.
	Centralized website for treatment and pre-treatment recommendations for wastewater and water reuse treatment strategies.	Output 25: Treatment technologies and processes for removing PFAS from water.
	Characterization of PFAS in biosolids, wastewater, and landfill leachates with an emphasis on pre-treatment strategies for minimizing PFAS contamination in water resources.	Output 26: Characterization of PFAS sources and remediation options for wastewater, biosolids, and landfill leachates.
Research Area 3: Wastewater/ Water Reuse	Scientific data to support risk assessments of wastewater for discharge and for reuse. Technical support for developing or optimizing whole effluent toxicity tests. Advancement of new methods (bioassays) for monitoring effluents.	Output 27: Analytical methods, exposure and effects assessment processes, and tools for wastewater and fit-for-purpose water reuse.
	Technical evaluations for states and program offices on water reuse treatment technologies Technologies and treatment targets for fit-for-purpose reuse.	Output 28: Assessment of treatment strategies and technologies for wastewater and fit-for-purpose water reuse.
Research Area 3: Integrated Stormwater Management	Support for states/regions to implement the most effective and economical green and gray infrastructure combinations for managing CSOs.	Output 29: Integrated guidance for planning, implementing, and monitoring stormwater management practices.
	Research results on stormwater capture and water quality for augmenting safe water supplies.	Output 30: Integrated stormwater management as a resource for enhanced recharge, reuse, and ecological functions and benefits.
Research Area 4: Technical Support	Application of research results and technical expertise to support state/region needs for site-specific environmental challenges.	Output 31: Technical support for water treatment, analytical methods, and risk assessments.

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