United States
Environmental Protection
Agency

Safe and Sustainable Water Resources

STRATEGIC RESEARCH ACTION PLAN
FISCAL YEARS 2023-2026

Office of Research and Development
Safe and Sustainable Water Resources Research Program

Safe and Sustainable
Water Resources (SSWR)

STRATEGIC RESEARCH ACTION PLAN
Fiscal Years 2023–2026

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List of Acronyms

ACE	Air, Climate, and Energy
ACP	Agricultural Conservation Practices
AMB	Antimicrobial Bacteria
AMG	Antimicrobial Genes
AMR	Antimicrobial Resistance
AWQC	Ambient Water Quality Criteria
BCG	Biological Condition Gradient
CCL	Contaminant Candidate List
CECs	Contaminants of Emerging Concern
CEH	Children's Environmental Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CIECs	Contaminants of Immediate Emerging Concern
CSS	Chemical Safety for Sustainability
CWA	Clean Water Act
DBP	Disinfection Byproduct
EJ	Environmental Justice
EPA	U.S. Environmental Protection Agency
FY	Fiscal Year
GI	Green Infrastructure
HABHRCA	Harmful Algal Bloom and Hypoxia Research and Control Act
HAB	Harmful Algal Bloom
HERA	Health and Environmental Risk Assessment
HS	Homeland Security
HTF	Hypoxia Task Force
NARS	National Aquatic Resource Surveys
LSL	Lead Service Line

NGO	Non-Government Organization
NOAA	National Oceanic and Atmospheric Administration
NRP	National Research Program
NTA	Non-Targeted Analysis
NTWC	National Tribal Water Council
ORD	Office of Research and Development
OW	Office of Water
PFAS	Per-and Polyfluoroalkyl Substances
PRST	Program, Regional, State, and Tribal
RA	Research Area
RACT	Research Area Coordination Team
RCRA	Resource Conservation and Recovery Act
RWQC	Recreational Water Quality Criteria
SDR	Solutions Driven Research
SDWA	Safe Drinking Water Act
SHC	Sustainable and Healthy Communities
SOST	Subcommittee on Ocean Science and Technology
SSWR	Safe and Sustainable Water Resources
StRAP	Strategic Research Action Plan
SUD	Smart Urban Design
TMDL	Total Maximum Daily Load
TOF	Total Organic Fluorine
TOP	Total Oxidizable Precursor
USGS	U.S. Geological Survey
WET	Whole Effluent Toxicity
WOTUS	Waters of the United States
WTP	Water Treatment Plant
WW	Wastewater

Definitions

Office of Research and Development (ORD): Scientific research arm of EPA that conducts leading-edge research to inform Agency decisions and support partner needs, including state, tribal, and community partners.

National Research Program (NRP): ORD's overall research effort is organized around six integrated and transdisciplinary national programs and closely aligned with the Agency's strategic goals and cross-Agency strategies. ORD is a matrixed organization with research direction coming from its six NRPs, each being guided by a Strategic Research Action Plan that identifies the most pressing environmental and public health research needs with input from many internal and external partners and stakeholders.

Strategic Research Action Plan (StRAP): A description of the overarching direction of ORD's research in a specified timeframe and under a specific research program. Each of ORD's NRPs is guided by a StRAP to structure and coordinate research activities. A StRAP includes a description of identified environmental and public health challenges, research priorities, and ORD's approach to meeting the challenges.

Topic: Overarching research focus under a NRP that encompasses Research Areas, Outputs, and Products.

Research Area: Science area or body of research and expertise assembled to address partner needs in the protection of human health and the environment. It encompasses problem statements, which are delineated through Outputs. Research Areas are nested under Topics and are composed of Outputs, which are composed of Products.

Output: A statement of the results to be achieved in pursuing a Research Area problem statement. It is not a tangible deliverable but encompasses Products that are deliverables. They are designed and developed to address specific partner needs that draw on the scientific knowledge and expertise represented in research areas. An Output can be expressed in many ways, such as an intended intermediate outcome, a purpose, aim, goal, or target. Outputs are composed of Products and nested within Research Areas, which are nested within Topics.

Product: A tangible scientific or technical deliverable. It addresses the research needs of ORD and ORD's partners. Products are nested within Outputs, which are nested within Research Areas, which are nested within Topics.

Partner: An EPA program office, EPA region, representative of a state, or a representative of a Tribe—often referred to as PRST.

Program, Regional, State, and Tribal (PRST) needs: A description of research needs related to human health and the environment as identified by EPA program offices, EPA regional offices, states, and/or Tribes.

Executive Summary

EPA's Safe and Sustainable Water Resources (SSWR) National Research Program provides robust research and scientific analyses to innovatively and economically support safe and adequate supplies of water—protecting people's health and livelihood while restoring and maintaining watersheds and aquatic ecosystems.

The SSWR national research program developed this Strategic Research Action Plan (StRAP) for fiscal years 2023–2026 (StRAP FY23-26) to support the Agency's overall mission to protect human health and the environment. The SSWR research portfolio is organized into three interrelated topics: watersheds, nutrients and harmful algal blooms, and water treatment and infrastructure. Within each topic are specific research areas and Outputs designed to deliver the science and engineering solutions the Agency needs and provide resources to help states, Tribes, local communities, and other partners.

The SSWR StRAP FY23-26 builds upon the previous StRAP FY19-22 by guiding innovative, cost-effective solutions to meet current, emerging, and long-term water resource challenges for complex chemical and biological contaminants. Development of the SSWR FY23-26 StRAP has been informed by ongoing and extensive engagement with EPA program and regional offices and external partners and stakeholders. ORD's partner engagement during strategic research planning ensures a collaborative, transparent, and highly coordinated research portfolio.

New research or areas of increased focus include evaluating the impacts of changing climate patterns, including drought and flooding on communities and ecosystems. Water reuse research is expanded to include alternative water sources, such as stormwater and wastewater from oil and gas production, to augment water supplies. Research will focus on potable and non-potable fit-for-purpose water reuse for small, decentralized systems.

The harmful algal blooms (HABs) and toxins research is expanded to include additional planktonic species and benthic species that can form toxic algal mats. Other new research includes developing the science required for forecasting HABs. Research on nutrients—one of the primary drivers of HABs—will better define the linkage between aquatic health endpoints and the nutrient concentrations that trigger those endpoints. Additionally, the nutrient inventory will be expanded to include longer time frames and downscaling for application at finer scales.

In addition to lead, copper, and per and polyfluoroalkyl substances (PFAS) issues in drinking water, research focuses on disinfectants, disinfection byproducts, opportunistic pathogens, and the interrelationships among them. PFAS research emphasizes non-targeted analytical methods for assessing unknown PFAS in the environment, quantifying 'total' PFAS in aqueous samples, and characterization, fate, and transport of PFAS in biosolids and remediation approaches.

Wastewater research builds on recent efforts for monitoring wastewater for SARS-CoV2 to evaluate other pathogens and the prevalence of antibiotic resistant pathogens and genes. Research on stormwater focuses on managing stormwater flows through natural and engineered infrastructure, potential impacts on groundwater resources, and the fate and transport of contaminants.

ORD is applying principles of solutions-driven research (SDR) that emphasize stakeholder engagement across its six national research programs. The SSWR research program supports three SDR projects that assist communities in 1) achieving their nitrogen reduction targets and associated water quality goals; 2)

identifying lead service lines; and 3) utilizing wetlands, sea grass, and tidal marshes for long-term carbon sequestration and coastal resilience.

The targeted research mapped out in the SSWR StRAP FY23-26 will yield the innovative tools and information needed to protect and restore the Nation's watersheds, aquatic ecosystems, and water infrastructure to provide clean, adequate, and equitable supplies of water for optimum human health and ecosystem functions.

Introduction

Reliable, safe supplies of water are essential to human and ecosystem health and a robust economy. Chemical and biological contaminants, harmful algal blooms, and the Nation's aging water infrastructure systems can impair the quality and useability of groundwater, surface water, and drinking water. Changing climate patterns compound threats to the availability and quality of water by altering the timing and magnitude of precipitation, snowmelt, floods, extreme temperatures, evapotranspiration, drought, and wildland fires. These dynamic conditions and other stressors can cumulatively impact ecosystems and communities, and in some cases disproportionately impact underserved communities and susceptible life stages. Water is also central to economic sectors including agriculture, energy, industry, fisheries, and recreation. As sources of water decrease while demand rises and water infrastructure systems age, communities, ecosystems, and the economy will increasingly rely on advances in science and technology for 21st century resilience.

To assist the Agency in meeting its goals and objectives, the Safe and Sustainable Water Resources (SSWR) National Research Program (NRP) developed this Strategic Research Action Plan (StRAP) for fiscal years 2023–2026 (FY23-26). The SSWR StRAP is one of six of the following research plans developed for each of the NRPs in EPA's Office of Research and Development (ORD):

- Air, Climate, and Energy (ACE)
- Chemical Safety for Sustainability (CSS)
- Health and Environmental Risk Assessment (HERA)
- Homeland Security (HS)
- Safe and Sustainable Water Resources (SSWR)
- Sustainable and Healthy Communities (SHC)

The StRAPs outline four-year research strategies to deliver the research necessary to support EPA's overall mission to protect human health and the environment. 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. They also inform our partners and the public of the program's strategic direction over the next four years. The SSWR StRAP FY23-26 builds upon the previous StRAP FY19-22, and where appropriate, continues research efforts to address longer-term strategic research objectives that can bridge between the four-year research planning cycles.

The strategic directions and Research Areas (RAs) identified in each StRAP serve as planning guides for ORD's research Centers to design specific research products to address the needs of EPA program and regional offices, states, Tribes, and external partners. Partner engagement is an essential part of the StRAP development process to identify research needs to be addressed.

Solutions-Driven Research

ORD is committed to producing research results that address real-world problems, inform implementation of environmental regulations, and help EPA partners make timely decisions based on sound science. This commitment includes exploring ways to improve research processes through the application of a solutions-driven research (SDR) framework. SDR is a specific research approach that

emphasizes partner engagement and integration of tasks to develop research that is directly along the path to a solution or decision. Solutions-driven research emphasizes the following:

- Planned partner engagement throughout the research process, starting with problem formulation and informing all elements of research planning, implementation, dissemination, and evaluation.
- A focus on solutions-oriented research Outputs identified in collaboration with partners.
- Coordination, communication, and collaboration both among ORD researchers and between researchers and partners to develop integrated research that multiplies value to partners.
- Cooperation with partners to apply research results to develop solutions that are feasible, appropriate, meaningful, and effective.

ORD is applying principles of solutions-driven research broadly across its six NRPs. ORD will also monitor how we engage with our partners and how we design and conduct our research to ensure that it informs solutions for our partners' most pressing environmental problems. By doing this, we are engaging in translational science, which will continually improve and increase the value of our research for our partners. Our emphasis on translating science is exemplified by the Outputs listed in this StRAP—they provide solutions to problems identified by our partners.

SSWR Solutions Driven (SDR) Research

Nutrients: Community-based SDR in Cape Cod, MA is evaluating the cost and effectiveness of nature-based technologies for removing nitrogen at the source, in groundwater, and in receiving waters. The results of this research will inform the community's plans on how to achieve their nitrogen reduction targets and associated water quality goals.

Lead Service Lines (LSL): In collaboration with stakeholders and disadvantaged communities, the LSL SDR aims to demonstrate and evaluate the use of accurate, non-invasive, cost-effective, and minimally disturbing LSL identification technologies in laboratory and field conditions.

Blue Carbon and Coastal Resilience: This SDR is a collaborative effort across EPA's ORD, Office of Water, Region 3, and Chesapeake Bay Program Office, as well as coastal communities in the Chesapeake Bay region. It aims to restore, conserve, and monitor wetlands, tidal marshes, and sea grasses to help mitigate climate change by promoting long-term carbon sequestration and empowering communities with knowledge and tools to build resilience to future flooding, storm surge, coastline erosion, and habitat degradation.

Program Vision

The SSWR program provides robust research and scientific analyses to innovatively and economically support safe and adequate supplies of water to protect people's health and livelihood while restoring and maintaining watersheds and aquatic ecosystems.

In addition to ORD's overarching research mandates (Environmental Research, Development and Demonstration Act, PL-95-155. 95th Congress, 1977), SSWR research activities are authorized, required, or otherwise encouraged by several statutes. The objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 USC12519a) for the protection and improvement of surface water resources. The Safe Drinking Water Act (SDWA) directs EPA to set national health-based standards for drinking water to protect against naturally occurring and anthropogenic contaminants; it also authorizes other regulatory programs (e.g., Underground Injection Control). Provisions in the SDWA and other statutes, including, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), address groundwater protection and improvement.

Strategic Direction

Relationship to EPA and ORD Strategic Plans

The FY 2023-2026 EPA Strategic Plan is designed to implement the Administrator's priorities for the next four years. This Strategic Plan identifies four cross-cutting strategies and seven strategic goals with related objectives, describing how the Agency will work toward its mission to protect human health and the environment.

ORD will develop its own strategic plan to respond to and build upon the FY 2023-2026 EPA Strategic Plan. ORD's Strategic Plan will align with the StRAPs for ORD's six research programs, which outline specific research activities that address objectives of the Agency's Strategic Plan.

The SSWR program supports Strategic Goal 5, *Ensure Clean and Safe Water for All Communities*, by addressing issues associated with Objective 5.1: *Ensure Safe Drinking Water and Reliable Water Infrastructure*; and Objective 5.2: *Protect and Restore Waterbodies and Watersheds*. Research also supports Goal 1, *Tackle the Climate Crisis*, by strengthening community and ecosystem resilience and adaptation to wildland fires, droughts, floods, and other climate impacts as outlined in Objective 1.2: *Accelerate Resilience and Adaptation to Climate Change Impacts*. Research efforts integrated across SSWR will help advance measurable water-related improvements in human and environmental health in support of Goal 2, *Take Decisive Action to Advance Environmental Justice and Civil Rights*.

Changes from FY 19-22 StRAP

The FY 23-26 StRAP will continue guiding innovative, cost-effective solutions to meet current, emerging, and long-term water resource challenges for complex chemical and biological contaminants. Technical support for communities and exploratory research that may lead to future capabilities are also included in the strategic plan.

New research or areas of increased focus include evaluating the impacts of changing climate patterns and other stressors on communities and ecosystems, nutrient dynamics, coastal acidification and hypoxia, and harmful algal blooms. Water infrastructure research will have greater emphasis on how to improve resilience to natural disasters and climate change. Water reuse research is expanded to include alternative water sources, such as stormwater and wastewater from oil and gas production. Research will focus on potable and non-potable fit-for-purpose water reuse for small, decentralized systems.

The harmful algal toxin research will expand toxicity evaluations of additional planktonic cyanobacteria cells and cyanotoxins. New research will address benthic species that can form algal mats and produce toxins. Other new research includes developing the science required for forecasting harmful algal blooms.

Nutrient research will expand the nutrient inventory to include longer time frames and downscaling for application at finer scales. New research will evaluate on-the-ground conservation practices in a watershed context by application of models such as the Agricultural Conservation Planning Framework (acpf4watersheds.org/). Research will be expanded to better define the linkage between endpoints SSWR is developing and the nutrient concentrations that trigger changes in those endpoints.

In addition to lead, copper, and per and polyfluoroalkyl substances (PFAS) issues in drinking water, research will focus on disinfectants, disinfection byproducts (DBPs), opportunistic pathogens, and the interrelationships among them in support of OW's Six-Year Review of microbial and DBP regulations. SSWR research on PFAS will emphasize the development and implementation of non-targeted analytical methods for assessing unknown PFAS in the environment and quantifying "total" PFAS in aqueous samples, including drinking water. Research will also focus on the characterization, fate, transport, and treatment of PFAS in wastewater and biosolids.

Wastewater research will build on recent efforts for monitoring wastewater for SARS-CoV2 to evaluate other pathogens and the prevalence of antibiotic resistant pathogens and genes. Wastewater related research will also place more emphasis on characterizing contaminants in biosolids and improving management and disposal strategies.

Research on stormwater focuses on managing stormwater flows through natural and engineered infrastructure, potential impacts on groundwater resources, and the fate and transport of contaminants.

Partner Engagement

Development of ORD's StRAPs has been informed by ongoing and extensive engagement with EPA program and regional offices and external (non-EPA) partners. ORD's partner engagement during strategic research planning ensures a collaborative, transparent, and highly coordinated research portfolio that delivers the data and information that Agency program and regional offices need, and provides resources that help states, Tribes, local communities, and other partners. ORD relies on partner engagement as an essential component throughout the research cycle and especially during problem formulation to identify partner research needs and develop the research Outputs outlined in the StRAPs.

The SSWR Research Program engages partners at different levels and stages throughout the research cycle to identify and discuss their research needs. Building from engagement during StRAP FY19-22 planning and implementation, engagement methods for the SSWR StRAP FY23-26 included the following:

- Recurring dialogues and meetings with EPA program and regional offices.
- Listening sessions with external partners, including state, tribal, and local partners.
- Engagement meetings with NGOs (e.g., Ground Water Protection Council, National Municipal Stormwater Alliance, Ohio River Sanitation Commission, Water Research Foundation, Association of State Drinking Water Administrators, American Water Works Association, National Groundwater Association, and Association of Clean Water Administrators).
- Workshops with ORD staff and EPA program and regional offices.
- Participation in organizational meetings with EPA regions and states (e.g., Environmental Council of the States and ERIS) and Tribes (e.g., Tribal Science Council, National Tribal Water Council).
- Collaboration with other federal agencies including the Department of Defense, Department of Agriculture, U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Fish and Wildlife Service, Centers for Disease Control and Prevention, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and U.S. Forest Service.

The SSWR Research Program will continue to engage with our EPA partners and state, tribal, and local organizations as we implement the research program outlined in the StRAP, support our research products after they are delivered, and evaluate the usefulness and effectiveness of our research in helping solve environmental and public health problems.

Research Topics and Research Areas

The SSWR research portfolio is organized into three interrelated topics: watersheds, nutrients and harmful algal blooms, and water treatment and infrastructure. Within each topic are specific research areas and Outputs. The Outputs serve as planning guides for ORD to design specific research products to address partner needs. More detail on the Outputs can be found in Appendix 1.

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 the science and tools to assess the condition of the Nation's aquatic resources and trends over time, identify scientifically sound indicators for establishing attainable water quality goals, improve capabilities to estimate water quality benefits, and build capacity to support water policy development and decision-making. Watersheds research will provide the information needed to manage existing and future water resource challenges related to climate change, environmental justice, and equity, and develop solutions to help build resilient communities and ecosystems facing interacting and complex challenges from multiple stressors. Research on priority water issues, such as pathogens in recreational waters and chemical and non-chemical contaminants in surface and groundwater, will advance existing approaches and develop new tools for managing ambient water quality to protect human health and aquatic life. This research will develop toxicity data and predictive toxicological methods for priority chemicals and chemical mixtures to support aquatic life criteria and address current limitations in the characterization of mixtures and the resulting toxicity through predictive models, non-targeted analytical methods, and effects-based measures in support of the ambient water quality criteria.

Research Area 1: Watershed Assessment

The physical, chemical, and biological integrity of aquatic resources across the Nation are threatened by multiple, interacting stressors, including climate change. The Watershed Assessment research area focuses on advancing research to support aquatic resource monitoring and assessment, characterize aquatic resource responses to cumulative impacts of multiple stressors, and estimate economic benefits of water quality improvements to protect and restore aquatic resources. Watershed Assessment research will develop tools, data, and applications that advance biological assessments, indicators, and monitoring approaches to assess ecological conditions and changes over time, causal analysis, and stressor-response analyses across aquatic resource types. By improving EPA's capabilities for economic valuation and the linkages to water quality improvements, the research will provide water resource managers with essential science and tools to advance water quality goals.

Watershed Assessment research addresses many high priorities of SSWR partners. EPA's National Aquatic Resource Surveys (NARS), a partnership between EPA (OW, EPA Regions, and ORD), states, and Tribes, are designed 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. SSWR research and technical support help implement and improve NARS, including designing NARS surveys, improving and expanding indicators and assessment benchmarks, and harmonizing datasets (Output SSWR.1.1). Research is needed to advance biological indicator development and applications of biological condition gradient tools, further develop stressor-response datasets, and elucidate cumulative impacts of multiple stressors, including climate change on aquatic resources, to support water quality criteria development (Output SSWR.1.2). SSWR research seeks to improve capabilities, address data gaps, and advance water quality benefits estimation and economic valuation models in support of federal, regional, state, and tribal programs (Output SSWR.1.3). The research addresses gaps in our understanding of benefits associated with different waterbody types, as well as tools for human health valuation, and our ability to evaluate climate change, environmental justice, and equity issues within a water quality benefits framework.

Research Area 2: Ecosystem and Community Resilience

The Ecosystem and Community Resilience research area focuses on improving capabilities to manage existing and future water resource challenges related to climate change, advancing environmental justice and equity, and developing tools to help build resilient ecosystems and communities. Surface waters, including streams, inland and coastal wetlands, and associated groundwater interactions, provide essential functions to support healthy, resilient watersheds that benefit human uses and ecosystems. Ecosystem and Community Resilience research will improve mapping, modeling, and validation of datasets depicting the Nation's dynamic surface and subsurface waters, including waters of the United States to advance water management, climate change resiliency, and environmental justice. This Area also includes research to develop tools, applications, and solutions for coastal ecosystems and communities to mitigate, adapt, and build resilience to climate change impacts utilizing blue carbon resources.

SSWR research addresses high-priority partner needs, including the growing need to clarify the impacts on coastal communities from the complex and interacting challenges of climate change, including rising sea levels, storm surges, and a loss of coastal resources and habitats (Output SSWR.2.1). By using a solutions-driven research approach and working with community leaders and citizen scientists, the

research will seek to develop solutions that can help build and maintain coastal community resilience. SSWR will continue to address the need to advance aquatic resource mapping capabilities and stream duration assessment methods in support of federal, regional, state, and tribal programs (Output SSWR.2.2). Current mapping of aquatic resources on a national level is incomplete and inadequately represents important components of aquatic resources. SSWR research addresses the need to further define changes in the characteristics of streams, stream networks, and wetlands, including changes in flow volumes, shifts in temperature, and shifts of wetlands from perennial to ephemeral under current and future climate scenarios.

Research Area 3: Advanced Ambient Water Quality Research

Human health and aquatic life are impacted by exposure to a wide array of chemical and non-chemical contaminants in water, including chemical mixtures, microbial pathogens, microplastics, and other contaminants of emerging concern. The Advanced Ambient Water Quality Research Area develops the science information utilized by SSWR partners to develop new or revised ambient water quality criteria recommendations and methods to protect human health and aquatic life from chemical and non-chemical contaminants in ambient waters. The data, models, tools, and applications developed will advance recreational water quality criteria and aquatic life criteria recommendations. Anticipatory research aims to explore and develop innovative methods, approaches, and technologies that provide improved understanding of effects of chemical and non-chemical contaminants on environmental health and support potential future Ambient Water Quality Criteria.

In response to identified partner needs, SSWR will continue to support research needs for EPA's Recreational Water Quality Criteria (RWQC) program, including advancing research on beach water quality and modeling, rapid methods for fecal indicators, microbial source tracking, antimicrobial resistant bacteria, and health and economic valuation studies for applications in freshwater and marine beaches, including tropical environments (Output SSWR.3.1). Research is needed to develop toxicity data and predictive toxicological methods for chemicals and chemical mixtures, with an emphasis on PFAS, to support aquatic life criteria development (Output SSWR.3.2). SSWR research will address current limitations in the characterization of chemical mixtures and resulting toxicity through predictive models, non-targeted analytical methods, and effects-based measures for applications in ambient water quality criteria development (Output SSWR.3.3). Research is needed to address knowledge gaps on the growing concern of microplastic (particles >1nm and <5mm) pollution, including research advancing methodologies, models, and tools to elucidate exposure and impacts of microplastics on human health and aquatic resources (Output SSWR.3.4).

Topic 2: Nutrients and Harmful Algal Blooms

Waterbodies and coastal areas around the world are threatened by increased nutrient loads, which adversely affect drinking water sources, aquatic species, and other ecological functions and services. Excess nutrient loading is the most widespread water quality problem facing the United States, with far-ranging consequences for human and environmental health and economic prosperity. The Nutrients and Harmful Algal Blooms (HABs) topic will comprehensively address nutrient issues and two of the primary impacts associated with excess nutrients in waterbodies—HABs and hypoxia.

Research Area 4: Assessment and Management of HABs

Cyanobacteria, or blue-green algae, can produce dangerous toxins, such as microcystins and cylindrospermopsins, that can cause significant health effects and mortality. Their excess biomass alone can raise treatment costs for drinking water, cause dead zones in waterbodies, reduce recreational opportunities, and have significant economic impacts. HABs result from complex ecological processes that are affected by a variety of factors, including nutrient and light availability, water temperature, weather patterns, limnological effects, and competing microorganisms—they have been observed in all 50 states. Much of what is understood about HABs is based on planktonic forms of algae or cyanobacteria in the water column or on the water surface. Less is known about benthic species that can form algal mats and produce toxins.

This research area directly supports the CWA, Harmful Algal Bloom and Hypoxia Research Recovery and Control Act (HABHRCA), SDWA, and the Drinking Water Protection Act. This research will support EPA and states as they work to adopt water quality standards for algal toxins that protect designated human and aquatic life uses (CWA 40 CFR 131.11).

EPA, states, and Tribes need research on the toxicity of cyanobacterial cells and cyanotoxins (especially nodularin and anatoxin and its derivatives) on humans, pets, livestock, aquatic life, and aquatic-dependent wildlife for criteria development. These needs will be addressed by examining the toxicity using in vivo animal models, in vitro mammalian and aquatic animal toxicology, epidemiological investigations, and by developing dose-response models using biomarkers (Output SSWR.4.1). This research will inform regulatory decisions for developing and/or updating existing Drinking Water Health Advisories, Recreational Criteria for cyanotoxin exposures and Aquatic Life and Environmental Health Criteria that are protective of aquatic organisms. States and public water systems need information on assessing and quantifying drinking water treatment plant vulnerability to HABs, how best to mitigate HABs in surface waters, and how to most effectively remove HAB-related biomass and toxins through drinking water treatment. Research will address these needs by 1) developing a rigorous framework for identifying water sources and drinking water systems vulnerable to HABs; 2) evaluating the efficacy and impacts of chemical and physical HAB interventions applied to source waters; and 3) evaluating the efficacy and impacts of interventions applied to remove cyanobacterial biomass and metabolites from drinking water and agricultural water (Output SSWR.4.2).

The 2014 HABHRCA specifies that EPA "shall include research on the ecology and impacts of freshwater harmful algal blooms; and forecasting and monitoring of and event response to freshwater harmful algal blooms in lakes, rivers, estuaries (including their tributaries), and reservoirs." Building the science required to forecast freshwater HABs is a primary need in supporting states, Tribes, and local organizations. Research will focus on developing the science required for forecasting, including the use of bioindicators, environmental drivers, and aquatic community structure, comparing multiple forecast models, and linking the ecological factors to human populations and communities with environmental justice concerns (Output SSWR.4.3). Model development and validation in this Output will capture a range of critical ecosystem types as well as study sites that represent different community types.

Research Area 5: Nutrients in a Changing Climate

Managing excess nutrient runoff, understanding legacy nutrient sources, and connecting nutrient reduction practices to water quality improvements are key to providing the information needed by communities to solve problems associated with excess nutrients. While EPA, states, and Tribes have

made great progress toward reducing nutrient pollution nationwide, it is still a challenge to determine the appropriate spatial and temporal context for reductions and best practices for tracking interventions to meet nutrient reduction goals in a comprehensive manner. Policy actions related to nutrient management are carried out under the CWA, as well as more specific laws such as HABHRCA. Under the CWA (40 CFR 131.11), states must adopt water quality standards as necessary to protect designated human and aquatic life uses in their state waters. EPA may support these efforts by issuing guidance to states and supporting them in the development of nutrient thresholds and the periodic assessment of the condition of U.S. waters (e.g., under Sections 304(a) and 305(b) of the CWA). These efforts require sound science to inform their development.

Research will provide science to support CWA decisions related to Total Maximum Daily Loads (TMDLs) and nutrient criteria development nationally, and more specifically, to assist the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (Hypoxia Task Force or HTF) in implementing the Gulf Hypoxia Action Plan. This research will address 1) the application of the nitrogen and phosphorus inventories developed under the SSWR FY 19-22 StRAP; 2) identification of high nutrient source and sink areas to help meet water quality goals (using locally based tools); 3) how legacy nutrient storage in groundwater, soils, and freshwater sediments modifies the effectiveness of nutrient management practices; and 4) the use of novel measurement and methods to accomplish these objectives so that the information can be applied at regional and local scales (Output SSWR.5.1).

Effective nutrient management requires knowledge of how diverse aquatic ecosystems—from streams and rivers, to freshwater lakes and reservoirs, to downstream systems, such as estuarine and coastal marine systems—are affected by both excess nutrients and interactions between nutrients, nutrient-related stressors, and climate-related variables.

Research will focus on 1) impacts of nutrients and nutrient-related stressors on aquatic life and priority habitats, including defining the linkage between biotic endpoints and the nutrient concentrations that trigger changes in those endpoints; 2) effects of nutrient-climate interactions on nutrient thresholds, criteria, and aquatic ecosystems; and (3) tools and approaches to support nutrient criteria development and assessment of water quality and biotic condition (Output SSWR.5.2). Partner engagement will be a key component to ensure co-production of knowledge and the development, application, and communication of methods that best address priority needs.

Many coastal and freshwater systems in the U.S. are adversely impacted by high nutrient levels. Authorities at local, state, and national levels are undertaking efforts to reduce nutrient loading to these waters. Research will provide information, approaches, and tools or tool improvements—such as the 319 STEPL tool—to help decision makers reduce nutrient releases from a variety of sources, document nutrient reductions, and monitor improvements in water quality associated with these efforts based on available datasets (Output SSWR.5.3). This Output will synthesize available information on nutrient reduction practices and their effectiveness toward pollution reduction, including relative costs, so that nutrient reduction policies and programs can be more cost-effective and ecologically beneficial.

Given the magnitude of nutrient reduction that is needed in many communities, strategies and partnerships are required to implement sufficient individual practices and/or suites of reduction approaches over larger spatial scales and consistently over time to make noticeable improvements. At the system-scale, socioeconomic characteristics and governance mechanisms need to be considered, as well as the changing dynamics of the integrated natural and built environments under changing climate

patterns. Research will focus on the science supporting implementation of conservation practices and nutrient reduction strategies at appropriate spatial and temporal scales to have a meaningful impact on improving the quality of downstream waters, including source waters. This research will be conducted through interrelated research themes: 1) nutrient reduction program design and implementation, 2) program assessment of existing nutrient reduction programs, 3) studying and documenting innovation in nutrient reductions realized through partnerships, and 4) development or enhancement of tools to assist in prioritizing areas to optimize nutrient reduction outcomes (Output SSWR.5.4).

Topic 3: Water Treatment and Infrastructure

The Nation's water treatment and distribution systems face increasingly greater challenges for delivering adequate supplies of safe drinking water. EPA's 6th Drinking Water Infrastructure Needs Survey and Assessment indicates that $472.6 billion is needed to maintain and improve the Nation's drinking water infrastructure over the next 20 years[1]. The American Society of Civil Engineers estimates the cost to maintain and expand service over the next 25 years is around $1 trillion[2]. Lead in service lines is another legacy issue, requiring advances in identifying lead service lines, evaluating approaches for safe lead service line replacement, improvement in lead sampling techniques, and a further understanding of the complexities 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. Changes in the frequency and intensity of prolonged drought, combined with increased water demand, present a threat to safe water supplies. 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. Evaluations of alternative water sources to provide communities with information on augmenting water supplies is also needed.

Wastewater and stormwater infrastructure also faces numerous challenges. Extreme precipitation events resulting in flooding and sewer overflows threaten community health and safety and ecosystems. Pathogens, chemical contaminants, and anti-biotic resistance need to be further evaluated for safely discharging treated wastewater. Many states are moving forward with restrictions on the land application of biosolids, which could severely limit disposal options and increase management costs. Water Treatment and Infrastructure research will provide states, Tribes, utilities, and EPA regions and programs with results for addressing challenges related to drinking water, stormwater, and wastewater management.

Research Area 6: Alternative Water Sources for Climate Adaptation

Meeting the demand for clean and adequate supplies of water, especially in regions undergoing hotter and drier climate conditions, requires addressing research gaps associated with water reuse and water storage, including enhanced aquifer recharge. Key research needs include determining what exposure risks are associated with water reuse from different water sources and for different applications, identifying how the use of alternative water sources can be facilitated through improved treatment

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[1] epa.gov/drinkingwatersrf/epas-6th-drinking-water-infrastructure-needs-survey-and-assessment
[2] infrastructurereportcard.org/cat-item/drinking-water/

characterization and monitoring, and developing information that will help communities make decisions on alternative water use.

The work performed in this research area will help support the [National Water Reuse Action Plan](), as well as the needs of EPA regions, states, and Tribes for safe and reliable water supplies. High-priority partner needs include identification, risk assessment, and management of chemical and microbial contaminants of emerging concern in alternative water sources (e.g., advanced treatment wastewater, stormwater, produced water) for fit-for-purpose treatment targets and use (Outputs 6.1 and 6.2). Research will also focus on developing tools and resources for communities to support their decision-making regarding alternative water sources (Output SSWR.6.3).

Research Area 7: Drinking Water and Distribution Systems

This Research Area will provide critical information to inform regulatory actions and guidance developed by EPA's Office of Water, implementation actions at the region and state levels, management of water systems by local municipalities, and technical assistance to communities. Research will fill knowledge gaps related to the Lead and Copper Rule; measurement, characterization, treatment, and removal of known pathogens and chemicals (including DBPs, PFAS, and lead) from drinking water; and identification of emerging contaminants likely to occur in drinking water. Research will also address management of distribution systems, including disinfection, monitoring, and operation of storage tanks. Improving the resilience and sustainability of infrastructure to natural disasters and climate change is a priority, including methods to assess pipe conditions, map infrastructure, and make repairs. Emphasis will be placed on providing actionable and affordable solutions for rural and urban low-income communities, supporting initiatives under new Presidential Directives, and the 2021 Infrastructure Investment and Jobs Act.

Partner needs for lead and copper include research on sampling approaches for lead in drinking water, identification of lead service lines, and mitigation strategies for reducing lead exposure (Output SSWR.7.1). Drinking water contaminant research priorities consist of analytical method development for unregulated DBPs and other emerging chemical and biological contaminants, DBP precursor management, and tools for supporting potential revisions to the microbial and DBP rules (Output SSWR.7.2). This research area will also provide tools and resources for managing opportunistic pathogens in drinking water treatment and distribution systems (Output SSWR.7.3). Research on small system water treatment is also needed to address a wide variety of challenges in underserved communities (Outputs SSWR.7.4 and SSWR.7.5).

Research Area 8: Per- and Polyfluoroalkyl Substances (PFAS)

PFAS are a complex class of chemicals, some of which are very persistent in the environment and human body. PFAS contamination of water is a significant issue in the U. S. and a high priority for the Agency. The SSWR PFAS research area will focus on developing analytical methods, drinking water and wastewater treatment approaches, residual stream treatment and management, and remediation of PFAS sources for protecting water resources.

Research needs focus on tools for evaluating and managing risks from PFAS in water resources. SSWR research on analytical methods (Output SSWR.8.1) will explore approaches for measuring large groups of PFAS and identifying unknown PFAS through non-targeted analysis. Improved fate, transport, exposure, and assessment models are needed for identifying and evaluating PFAS sources in water

(Output SSWR.8.2). Much of the research for drinking water treatment focuses on aspects that will support future regulatory and rulemaking efforts regarding PFAS, such as drinking water treatment technologies (Output SSWR.8.3). Research is also needed on characterization, fate, treatment, and destruction/disposal of PFAS in water treatment processes and residuals (e.g., spent drinking water treatment media and sludge) and in other matrices that are difficult to treat (Output SSWR.8.4).

Research Area 9: Wastewater

Wastewater management is a critical part of the anthropogenic water cycle that helps ensure that water is clean, safe to use, and protective of ecosystems. More information and tools are needed to address known contaminants and to identify emerging risks to human health and the environment. Research will be invested in several areas, including 1) the development and implementation of effects-based methods for detecting chemical contaminants; 2) the assessment of antimicrobial resistance (AMR) in wastewater, including source identification and control; 3) the development of methods to monitor municipal wastewater for SARS-CoV2 and other contaminants; 4) the evaluation of treatment approaches for wastewater and biosolids, with consideration of how climate change may impact existing systems; and 5) the assessment of wastewater and biosolids for contaminants of emerging concern.

Partner research needs focus on the development of new whole effluent toxicity (WET) test methods for use by EPA regions and states. Risk evaluation of treated wastewater discharge is also a priority need and could be addressed through the application of new bioassays (Output SSWR.9.1). Partners also expressed needs for research on wastewater surveillance and evaluation of antibiotic resistant bacteria and genes in wastewater treatment operations (Output SSWR.9.2). Research needs also include risk assessment and management of contaminants in wastewater and biosolids (Output SSWR.9.3).

Research Area 10: Stormwater Management

Wet weather planning and stormwater management research will continue to focus on managing stormwater and leveraging ecosystem services from greenspace and associated green infrastructure. Research targeted at adaptation and adaptive management addresses water quantity, water quality, impacts to groundwater, and topics related to cost, effectiveness, and incentives to ratepayers. SSWR research on green/gray infrastructure and stormwater flow control will help states, municipalities, and utilities improve water quality, manage water quantity, and reduce flood frequency in the face of changing precipitation, especially in underserved communities.

Partner research needs include the development of tools for evaluating consequences and public health risks in communities with combined sewers from flooding events and strategies for minimizing those impacts through improved stormwater management. Evaluations of industrial inputs to stormwater quality are needed, including contaminants that can affect human health and the environment (e.g., 6ppd-quinone) (Outputs SSWR.10.1 and SSWR.10.2). Continued research is needed on effectively monitoring and assessing stormwater control measures, through grey and green infrastructure, for reducing flows and improving water quality (Output SSWR.10.3).

Research Area 11: Technical Support for Communities

SSWR technical support activities apply research results, models, tools, and technical expertise to support program office, regional, state, and tribal needs for site-specific environmental challenges. This support addresses needs across all three SSWR Topics: Watersheds, Nutrients and HABs, and Water Treatment and Infrastructure. This Research Area includes tools and webinars, workshops, and other

outreach and training activities that provide capacity building support for SSWR partners and communities.

States, Tribes, utilities, and EPA program and regional offices need timely technical support for dealing with water issues. Dissemination of research results will be accomplished through outreach, training, and web-based resources (Output SSWR.11.1). Site-specific technical support will also be provided through this research area (Output SSWR.11.2).

Implementing the Strategic Research Action Plan

In collaboration with EPA program, regional, state, and tribal partners, ORD scientists and engineers design specific research products responsive to the Outputs outlined in the StRAPs. During the implementation of the previous FY19-22 StRAPs, ORD piloted a successful process in which Research Area Coordination Teams (RACTs), made up of ORD scientists and engineers, EPA program and regional staff, and state members, collaborated to determine the individual research products responding to each Output. ORD is continuing this process for the FY23-26 StRAPs.

Each Output in the StRAPs is reviewed by a RACT, which develops goals and objectives for the Output and establishes criteria for the work needed to accomplish it. ORD researchers propose research products, which the RACT reviews and refines to ensure products will meet the goals and objectives of the Output and reflect the timing and specific needs of EPA program and regional, state, and tribal partners. RACT members serve as liaisons to their programs or organizations, which ensures that ORD's partners are able to provide input into the proposed research products. Products developed to address the Outputs may take the form of assessments, reports, tools, methods, journal articles, or other deliverables.

Throughout implementation of the StRAPs, ORD's researchers develop and deliver products. Research to deliver StRAP products is implemented by staff scientists and engineers at research laboratories and facilities in twelve locations across the country, which collectively comprise ORD's four Centers and four Offices. EPA staff are joined in this endeavor by a network of collaborators and partners within and external to EPA. In addition to the extensive intramural research program outlined in the StRAPs, ORD's research portfolio includes extramural research programs that complement or add special focus areas to the overarching program.

Cross-Cutting Research Priorities

For priorities that cut across their programs, ORD's six NRPs will work together to integrate efforts, provide a research portfolio aligned around the Agency's goals, and assist all of EPA's program and regional offices, as well as states and Tribes. Where appropriate, the NRPs will combine efforts to conduct research that advances the science and informs public and ecosystem health decisions and community efforts on the following cross-cutting priorities (Appendix 4):

- Environmental Justice
- Climate Change
- Cumulative Impacts
- Community Resiliency

- Children's Environmental Health
- Contaminants of Immediate and Emerging Concern

EPA program and regional offices and external (non-EPA) partners and stakeholders will also be engaged for these integrated efforts. Long-term, innovative, and multi-disciplinary research is needed to make progress on these complex issues to support a sustainable pathway towards equitable distribution of social, economic, health, and environmental benefits.

Appendix 1: Summary of Proposed Outputs Mapped to Program, Regional, State, and Tribal (PRST) Needs

The following table lists the proposed Safe and Sustainable Water Resources Research Program Outputs organized by topic and mapped to PRST needs. It should be noted that Outputs may change as new scientific findings emerge and are contingent on budget appropriations. See Appendix 2 for more detailed descriptions of the PRST needs and Appendix 3 for detailed descriptions of Outputs for cross-cutting priorities.

Research Area	Output	PRST Need(s)
Topic 1: Watersheds		
SSWR.1 Watershed Assessment	SSWR.1.1 NARS and National Assessment	• NARS methods and approaches • Expanding and improving indicators
	SSWR.1.2 Stressor-Response and Cumulative Impacts	• Stressor effects on aquatic ecosystems
	SSWR.1.3 Water Quality Benefits and Modeling	• Economic valuation and benefit analysis • Water modeling and mapping
SSWR.2 Ecosystem and Community Resilience	SSWR.2.1 Coastal Community Resilience	• Impacts of climate change challenges to coastal communities • Environmental justice and resilience
	SSWR.2.2 Water Mapping and Functional Analyses	• Water modeling and mapping • Advanced aquatic resource mapping
SSWR.3 Advanced Ambient Water Quality Research	SSWR.3.1 Recreational Water Quality and Human Health	• Antimicrobial resistant bacteria • Health and economic valuation • Rapid methods for fecal indicators
	SSWR.3.2 Aquatic Life Guidelines for Chemicals	• Develop toxicity data • Toxicological methods for chemicals and chemical mixtures
	SSWR.3.3 New Approaches to Support AWQC for Chemical Mixtures	• Non-targeted analytical methods • Effects-based measures • Chemical mixtures and toxicity characterization
	SSWR.3.4 Environmental Health Effects of Microplastics	• Advancing methodologies, models, and tools • Impacts on human health and aquatic resources
	SSWR.3.5 Environmental Health Effects of Sunscreens (TBD)	• *Tentative pending NASEM report*

Research Area	Output	PRST Need(s)
Topic 2: Nutrients and Harmful Algal Blooms (HABs)		
SSWR.4 Management and Assessment of HABs	SSWR.4.1 Health Effects and Toxicity	• Toxicity evaluation through *In vivo* models, *in vitro* toxicology, and epidemiological studies • Biomarker-based dose-response models
	SSWR.4.2 Managing HABs in the Built and Natural Environments	• Water systems vulnerability to HABs • Efficacy and impact of chemical and physical interventions in source waters and during drinking water treatment
	SSWR.4.3 Science of Harmful Cyanobacteria Bloom Forecasting	• Factors and models required for forecasting
SSWR.5 Nutrients in a Changing Climate	SSWR.5.1 Nutrient Sources and Fate: Terrestrial, Freshwater, and Estuarine	• Nitrogen and phosphorus inventories application • Legacy nutrient storage impact on management practice effectiveness
	SSWR.5.2 Nutrient Impacts and Tools to Support Nutrient Criteria Development	• Stressor impacts on aquatic life and priority habitats • Nutrient-climate interactions
	SSWR.5.3 Nutrient Reduction Approaches	• Approaches and tools evaluation to reduce nutrient source release
	SSWR.5.4 Implementation of Nutrient Reduction Strategies	• Science supporting practices and strategies at spatial/temporal scales • Program design and implementation • Documenting innovation realized through partnerships
Topic 3: Water Treatment and Infrastructure		
SSWR.6 Alternative Water Sources for Climate Adaptation	SSWR.6.1 Risk Characterization to Inform Fit-for-Purpose Water Use	• Identification and assessment of chemical and microbial CECs in alternative water sources
	SSWR.6.2 Facilitating Implementation of alternative Water Use through Improved Treatment Characterization and Monitoring	• Monitoring and management of treatment targets and fit-for-purpose use
	SSWR.6.3 Informing Community Decisions on Alternative Water Use	• Tools and resources for community consideration for use of alternative water sources

Research Area	Output	PRST Need(s)
Topic 3: Water Treatment and Infrastructure		
SSWR.7 Drinking Water and Distribution Systems	SSWR.7.1 Lead and Copper Drinking Water Research to Support Communities	• Identification of lead service lines • Mitigation strategies to reduce lead exposure
	SSWR.7.2 Data, Methods, Models and Tools to Inform Current and Future Health-Based Drinking Water Decisions	• Analytical method development for emerging biological and chemical contaminants • Management and tools for potential revisions to microbial and DBP rules
	SSWR.7.3 Characterization and Management of Opportunistic Pathogens and DBPs in Drinking Water Systems	• Tools and resources for simultaneous management of opportunistic pathogens and DBPs in treatment and distribution systems
	SSWR.7.4 Drinking Water Infrastructure Resilience and Sustainability for Small, Low-Income, and/or Socially Vulnerable Communities	• Small system water treatment challenges for underserved communities
	SSWR.7.5 Advancing Treatment Technologies and Providing Small and Socially Vulnerable Communities Access to Treatment Information	• Small system water treatment challenges for underserved communities
SSWR.8 Per- and Polyfluoroalkyl Substances (PFAS)	SSWR.8.1 Analytical Methods for PFAS in Drinking Water, Wastewater, and Environmental Samples	• Non-targeted analytical methods for unknown and large groups of PFAS
	SSWR.8.2 PFAS Sources and Occurrence in Water	• Improved models for identifying and evaluating PFAS sources in water
	SSWR.8.3 Treatment Technologies and Processes for Removing PFAS from Public Water Systems	• Research on treatment technologies supporting future regulations and rulemaking efforts for PFAS in DW; treatment technologies regarding PFAS
	SSWR.8.4 Disposal and Destruction of PFAS in Difficult to Treat Water Matrices and biosolids	• Treatment and destruction of PFAS in residuals and challenging matrices (e.g., landfill leachate)

Research Area	Output	PRST Need(s)
Topic 3: Water Treatment and Infrastructure		
SSWR.9 Wastewater	SSWR.9.1 Development and Implementation of Effects Based Bioassays for Monitoring Chemical Risks in Wastewater	• New WET test methods for EPA Regions and States • New bioassays for application in risk assessment of wastewater treatment
	SSWR.9.2 Monitoring Wastewater Collection Systems and Treatment Plants to Inform Public Health and Environmental Decision-making	• Research in wastewater surveillance and evaluation of antibiotic resistant bacteria and genes in wastewater
	SSWR.9.3 Wastewater and Biosolids Treatment in Changing Climates: Evaluation and Mitigation of Chemical and Microbial Contaminants of Emerging Concern	• Research support for risk assessment and management of contaminants in wastewater and biosolids
SSWR.10 Stormwater Management	SSWR.10.1 Leveraging Benefits from Greenspace while Managing Stormwater	• Tools to evaluate public health risk from flooding and overflow of combined sewers • Evaluation of effects of industrial inputs to stormwater quality on human health and the environment
	SSWR.10.2 Managing Stormwater in the Face of Climate Uncertainty	• Tools to evaluate public health risk from flooding and overflow of combined sewers • Evaluation of effects of industrial inputs to stormwater quality on human health and the environment
	SSWR.10.3 Recommendations and General Procedures for Monitoring and Managing Stormwater	• Effective monitoring and assessment of stormwater control measures, including green and grey infrastructure effectiveness to reduce flow and improve water quality
Cross-Topics: Technical Support for Communities		
SSWR.11 Technical Support for Communities	SSWR.11.1 Training and Outreach	• Support for communities through outreach, training, and web-based resources
	SSWR.11.2 Site-Specific Technical Support	• Provide site-specific technical support across the SSWR National Research Program

Appendix 2: Descriptions of Program, Regional, State, and Tribal (PRST) Needs

The following describe, in more detail, the PRST needs summarized in the body of the SSWR Research Program StRAP for each Research Area and as referenced in Appendix 1.

- **NARS Methods and Approaches:** Adjusted, improved, and expanded water quality monitoring and assessment methods are needed to increase the effectiveness of management actions. Expanding and improving water quality indicators, providing additional insights into nutrient sources and impacts, and researching and assessing innovative management approaches are key to providing data, tools, and methods that are both accessible and applicable to PRST partners.

- **Effects and Management of Climate Change and Stressors on Aquatic Resources:** Reliable and informed indicators for temperature, flow variability, and additional climate change-related stressors are needed to accurately distinguish the effects of climate change from anthropogenic drivers on aquatic systems. Climate change effects (e.g., rising temperatures, ocean acidification, sea level rise, wildland fires) must be assessed for extent, ecological influence, economic effects, health concerns, and effects on surface and groundwater supply. Effective management methods and tools require expanded and improved data, monitoring networks, geodatasets, maps, and understanding of response patterns to stressors.

- **Water Modeling and Mapping:** Advanced water modeling and mapping methodologies and techniques are needed to more effectively and accurately manage watersheds and aquatic resources and address issues from contamination, climate change, and environmental justice. Needs include future and real-time prediction modeling capabilities, source and transport tracking for bacterial and chemical contaminants, groundwater modeling for better visualization and assessment of resources for use in watershed management planning, and planning tools to mitigate future issues. These improved modeling and mapping methods will allow for a larger-scale understanding of water quality and resource impairments and priorities for PRST partners.

- **Microplastics:** Innovative indicators and methods of impact analysis are needed to respond to increased concern for microplastics in water resources for anthropogenic and ecological uses. Standards for collection and assessment of microplastics across various medias and resources are needed for use across regional and national scales.

- **Environmental Justice and Resilience:** Rural, impoverished, and minority communities are often disproportionately affected by issues related to water quality (e.g., contaminated sites, funding for improved treatment and distribution systems, surface and groundwater resources). Resources and tools need to be developed, advanced, and made readily available to these communities as they address these concerns. Ecological, economic, and water quality resiliency in coastal communities are major concerns as climate change leads to sea level rise, flooding events, and increased ocean acidification. Research is needed on methods for monitoring water quality and coastal conditions, determining economic valuation, and assessing impacts of climate change in climate and inland water resources.

- **Informed decisions, Benefits, and Valuations:** Informed economic management and planning decisions require efficient water quality monitoring and assessments of stressor and climate change impacts on coastal and other recreational waters. Valuation methods for economics and human health must be developed and expanded based on environmental justice principles, risk factors, and extent of impact.

- **HABs Health Impacts:** Health impacts due to HABs need to be studied for toxicity to aquatic life, aquatic-dependent wildlife, and humans. Exposure terms and routes (short term, chronic, dermal, inhalation, oral, etc.) lead to varying health effects and need to be categorized and analyzed to determine best methods for prevention and treatment. Individual algal toxins (e.g., saxitoxin, anatoxin-a) require research into their derivatives and specific toxicities and health risks through epidemiological studies and literature reviews.

- **HAB Monitoring, Forecasting, and Management:** Monitoring HAB formation through specific criteria (e.g., temperature, nutrients, stagnancy, climate change events) allows for determining the vulnerability of water systems to HABs. Predictive models for forecasting HABs and estimating related exposures require both advanced research into those factors leading to HAB formation and analysis of risk factors to consumers. Predictive models are needed to aid in timely recreational use decision making processes and to improve management strategies for reducing exposure risk and ecological impacts. Advanced HAB management tools and methods are required to help prevent and treat blooms as they occur and improve the efficacy and impact of chemical and physical interventions in both source waters and during drinking water treatment.

- **Nutrient Transport, Transformation, Sources, and Fate:** Tools and methods to reduce pollutants loads (with an emphasis on agriculture-related pollutant loads) are dependent on understanding the relationship of nutrient sources, transport, and transformation with their fate in surface and groundwater resources. Legacy nutrients (internal loading), water quality response and lag response, and sample/data collection and analysis are all necessary to research for developing monitoring and management strategies.

- **Nutrient Monitoring and Effects of Climate Change and Stressors:** Monitoring nutrient loading must include hypoxic volume, in addition to area and duration, to improve flow and flux measurements and increase accuracy of simulations and models. The climate change-related expansion of the growing season in forest, agricultural, and other lands may affect their nutrient export trends.

- **Nutrient Reduction Strategies and Implementation:** Reducing nutrient loading, specifically of nitrogen and phosphorus, requires evaluation of the drivers of hypoxia and the water quality stressors to develop better models and other analytical tools needed to guide reduction and restoration activity. Additional management practices and strategies must be developed at spatial and temporal scales to better aid in this reduction and restoration.

- **Water Reuse:** Chemical and microbial CECs need to be identified in the assessment of alternative water sources to prepare for greater implementation of water reuse. Careful monitoring and management of alternative water sources, setting available, high standard treatment targets, and determining fit-for-purpose uses are required to enable communities to consider the use of alternative water sources. Tools and resources should include validation protocols for pathogen removal or inactivation, programs to research and optimize water reuse applications (e.g., fertilizer

applications, sustainable agricultural practices, forestry practices), and funding for projects to advance treatment technologies.

- **Contaminants (Lead and Copper, DBPs, Opportunistic Pathogens, etc**.)**:** Lead service line distributions need to be mapped, samples taken, and proactive health measures taken to protect public health. Public education programs need to be developed to encourage behavioral changes (e.g., flushing the tap prior to drinking, testing water, using a filter, replacing service lines). DBPs and microbial pathogens require the development of models to analyze human health impacts and determine areas of highest exposure and risk. Better characterization and regulation of DBPs should be researched; effective, low-cost, and low-maintenance treatment technologies must be developed for small- and household-scale systems; and the extent of precursor and nutrient removal in the control of multiple types of contaminants needs to be better characterized. Toxicological and analytical measures and methods for chemicals and chemical mixtures need to be further developed to better understand health risks and treatment options.

- **PFAS in Water Resources:** Research needs to be conducted regarding wastewater surveillance, toxicity values, risk assessment, contaminant management, and analytical methods for presence of PFAS groupings in treatment and distribution systems. Further development of PFAS removal, destruction, and disposal methods to meet determined allowable concentrations in discharges are needed to reduce risks to human and ecological health. PFAS risk communication and regulation as a class rather than individually must be addressed to further reduce contamination and risk to public health.

- **Wastewater Systems and Management:** Wastewater systems require new analytical methods for emerging biological and chemical contaminants and improved management tools for microbial pathogens and DBPs. Research is needed to assess contaminants present in wastewater and biosolids and expand the management options for those contaminants and media. Advanced tools to evaluate public health risk from stormwater influence on combined sewer overflow and flooding, and to monitor and assess stormwater control measures, are needed to further develop green and grey infrastructure methods and minimize risks to neighborhoods and communities.

- **Antimicrobial Resistance (AMR):** Wastewater screening methods for current and potential disease surveillance are needed to capture broad-scale general and antibiotic resistant pathogen emergence and improve epidemiological models. Investigation into the extent of AMR in the environment is necessary due to the amount of AMR in raw sewage and the proliferation of AMR in natural development, animal husbandry, and exposure of intestinal flora to antibiotics.

- **Drinking Water Systems and Management:** Drinking water systems require new analytical methods for emerging biological and chemical contaminants, and improved management tools for microbial and, specifically, opportunistic pathogens and DBPs. Small system water treatment challenges need to be addressed for underserved communities and low-cost and effective regionalized systems and management options provided to reduce the health risks to their populations. These systems additionally need to be updated with better protection and resilience against climate change events (e.g., hurricanes, extreme weather, flooding, sea level rise, droughts).

Appendix 3: Output Descriptions

The following describe, in more detail, the SSWR Outputs listed in Appendix 1. Outputs are planned under each Topic and respective Research Area (RA). It should be noted that the Outputs might change as new scientific findings emerge and are also contingent on budget appropriations.

Topic 1: Watersheds

RA SSWR.1: Watershed Assessment

Output SSWR.1.1: NARS and National Assessment

This Output will address the research and support needs to monitor and assess 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 science and support for designing NARS surveys; improving and expanding indicators and assessment benchmarks; harmonizing datasets; developing national reports; evaluating survey design frames, target populations, and analysis approaches for ranking single and multiple stressors; and evaluating and improving assessment thresholds for NARS indicators. Additionally, research will advance the application of DNA technologies and explore remote sensing approaches for use in NARS assessments. NARS faces the challenge of continuing to assess the current and traditional stressors to aquatic resources and developing indicators and/or assessment approaches that will sort out the signal of climate change impacts on these waters. The Output results will make the NARS data more broadly accessible within and outside of EPA, supporting policy and management decisions at spatial scales beyond the traditional national and regional focus of NARS.

Output SSWR.1.2: Stressor-Response and Cumulative Impacts

Research is needed to characterize the responses of aquatic resources to the cumulative impacts of multiple, interacting stressors across space and time. Research in this Output will develop indicators, techniques, and methods to assess stressor-response relationships and cumulative impacts, including climate change impacts, across a range of aquatic resources, including streams, wetlands, coral reefs, submerged aquatic vegetation, and estuaries. The Output will support continued development and improvements of biological assessment and monitoring tools, data, and applications including local case studies. This Output will consider ways to effectively communicate the cumulative, biological impacts of the stressors described above. Doing so will empower communities to make informed decisions on restoration and conservation priorities and promote equitable distribution of the resulting benefits.

Output SSWR.1.3: Water Quality Benefits and Modeling

Federal, state, tribal, and local management actions to improve water quality can lead to a broad range of benefits for communities. However, important categories of benefits remain incomplete or missing, decision-makers lack information about the distribution of water quality benefits related to surface water and community groups of concern, and water quality measures that support economic analyses are inconsistent and can be limited spatially and temporally. This Output will focus on addressing missing or incomplete categories of water quality benefits and help to expand the capacity of current economic valuation models. Research in this Output will address the distributional impacts of water quality benefits, including how water quality changes impact underserved communities. Water quality modeling research will support economic analysis, water quality valuation, environmental justice analysis, water quality index or other associated metrics development, and national policy or regulations.

RA SSWR.2: Ecosystem and Community Resilience

Output SSWR.2.1: Coastal Community Resilience

Coastal communities are increasingly facing interacting and complex challenges, including those associated with the impacts of climate change. These communities are looking for solutions that can help build and maintain resilience—i.e., the ability to respond to, withstand, and recover from adverse situations. Key gaps in scientific knowledge include understanding how multiple future stressors including climate change will affect coastal ecosystems, due to complex and indirect interactions; better approaches to monitoring the condition of estuarine systems, as well as monitoring improvements due to restoration; understanding the amount of carbon sequestered through various water quality and water habitat restoration projects; and understanding and assessing best practices for increasing coastal resiliency. General approaches include solutions-driven research for building and maintaining coastal community resilience through blue carbon resources (SOST-related), development and application of models, tools, and technologies for coastal communities, case studies in specific coastal communities and National Estuary Program estuaries, and innovative approaches to enhance coastal resilience.

Output SSWR.2.2: Aquatic Mapping and Functional Analyses

This Output seeks to improve mapping, water quantity and quality modeling of surface waters, and functional assessments of natural and constructed aquatic ecosystems; and assess the utility of emerging EPA, other federal agency and state collaborative datasets depicting the Nation's dynamic surface and subsurface waters. Research in this Output will 1) characterize surface water extent and dynamics locally and regionally through improved modeling, monitoring, and remote sensing; 2) support local determinations of stream dynamics via assessment methodologies like the regionally adjusted Streamflow Duration Assessment Methods; 3) investigate how regional and local surface waters and associated groundwater inputs may shift with changes in climate; 4) better quantify the role of aquatic resources in mitigating the effects of floods and drought under current and future conditions, particularly as they are experienced by disadvantaged communities; 5) better understand and integrate urban and agricultural infrastructure into watershed networks, including the assessment of ecosystem functions of constructed wetlands and ditches; and 6) advance techniques and tools to visualize and communicate these important surface water dynamics for assessments, implementation, and public communication. Monitoring, modeling, and regional analyses research in this Output will augment remotely sensed, field-based, and data mining and modeling work of the collaborating Federal Interagency Aquatic Resources Mapping workgroup. These combined efforts will develop and expand the methodologies, geospatial datasets, validation measures and tools required for models of aquatic resources and address needs related to the Clean Water Act, water management, climate change, and environmental justice as they relate to the adaptive management of resilient surface waters.

RA SSWR.3: Advanced Ambient Water Quality Research

Output SSWR.3.1: Recreational Water Quality and Human Health

This Output will focus research in priority areas identified in the EPA 2017 and upcoming 2023 Five-Year Reviews of the 2012 Recreational Water Quality Criteria (epa.gov/wqc/recreational-water-quality-criteria-and-methods#fiveyear) prepared by OW in collaboration with ORD. Research will support new and revised criteria as well as implementation, including analyses of new and existing health studies, evaluation of rapid analytical methods for fecal indicators, and development and implementation of microbial source tracking approaches. Research will also be conducted to further develop persistence

information and water quality forecasting tools using statistical and process modeling. Additionally, research will advance the development and application of methods to evaluate antimicrobial resistance in bacteria and their gene occurrence in fresh and marine surface waters.

Output SSWR.3.2: Aquatic Life Guidelines for Chemicals

Water quality criteria for the protection of aquatic life from toxic chemicals are typically developed based on toxicity data requirements that are not satisfied for many chemicals of interest, do not address mixture toxicity, and do not consider extrapolation of toxicity information across chemicals and endpoints. ORD will conduct research regarding predictive toxicological methods to support OW in the derivation of regulatory values for individual chemicals and mixtures, addressing extrapolation across chemicals, response endpoints, and exposure conditions. Research will emphasize per- and polyfluoroalkyl substances (PFAS) to support OW goals for PFAS regulation and the Agency's PFAS Action Plan and will include other chemicals as appropriate. Efforts will coordinate with other Outputs in the SSWR and Chemical Safety for Sustainability research programs that are addressing toxicological tools relevant to these issues.

Output SSWR.3.3: New Approaches to Support Ambient Water Quality Criteria (AWQC) for Chemical Mixtures

Traditional exposure and effects assessment methods are generally ineffective at identifying drivers of toxicity from complex mixtures, such as wastewater treatment effluent. This Output will focus on the development and assessment of new methods to better characterize mixture composition and toxicity, as well as computational methods to predict chemical co-occurrence in complex sources. Research will include the development and evaluation of 1) in vivo and in vitro effects-based methods to identify activated response pathways and modes of action, 2) non-targeted analytical methods to identify mixture components, and 3) in silico methods to predict mixture composition based on co-occurrence patterns. This Output aims to support AWQC by addressing current limitations in the characterization of mixtures and the resulting toxicity using predictive models, non-targeted analysis (NTA), and effects-based measures.

Output SSWR.3.4: Environmental Health Effects of Microplastics

This Output seeks to develop or adapt methods to evaluate the human health and aquatic life effects of microplastics, particularly the smaller size range of particles less than 1,000 μm, often referred to as nanoplastics. Research will focus on 1) developing applications of in-vitro and computational toxicology approaches to assess health impacts from exposure to microplastics in experimental models, and 2) developing methods, models, and tools to evaluate cellular uptake and clearance of microplastics using cell cultures. Research on aquatic resources will focus on 1) determining the potential toxicological impacts of bio-based plastics on aquatic life, and 2) evaluating the cumulative effects on coral growth from exposure to environmentally relevant microplastic concentrations and elevated temperatures. This research will fill key data gaps necessary for EPA program offices and regions, states, and Tribes to assess microplastic effects and inform possible regulations.

Topic 2: Nutrients and HABs

RA SSWR.4: Management and Assessment of HABs

Output SSWR.4.1: Health Effects and Toxicity

There is strong need to develop data, methods, and tools to advance the understanding of adverse health impacts among people, other animals and plants that are associated with exposure to harmful algal blooms (HABs) from both planktonic and benthic cyanobacteria. This Output will 1) examine the effects of cyanobacteria and cyanotoxins (anatoxin, derivatives and nodularin) on animals utilizing a complementary set of approaches to define adverse outcomes associated with individual cyanotoxins; 2) utilize a multi-faceted epidemiological approach to characterize human health effects associated with recreational and occupational exposure to cyanobacterial cells and cyanotoxins; and 3) develop methods to measure toxins in various media at more sensitive environmental concentrations and characterize basic properties of planktonic and benthic cyanobacteria and associated toxins related to observed adverse health outcomes. The approaches used will focus on toxicity using in vivo animal models, in vitro mammalian and aquatic animal toxicology, and epidemiological investigations, and by developing dose-response models using biomarkers.

Output SSWR.4.2: Managing HABs in the Built and Natural Environments

The management of HABs is dependent on the ability to systematically identify ambient waters, including source waters, and water treatment systems that are vulnerable to blooms, and to apply interventions at any point from the source water to the final point of use for any purpose. This Output 1) develops a rigorous framework for identifying water sources and drinking water systems vulnerable to HABs, 2) evaluates the efficacy and impacts of chemical and physical HABs interventions applied to source waters, and 3) evaluates the efficacy and impacts of interventions applied to remove cyanobacterial biomass and metabolites from drinking water and water used for agricultural purposes. Efforts will focus on the evaluation of the efficacy of intervention processes to remove the commonly recognized toxins (microcystin, cylindrospermopsin, anatoxin, nodularin, and saxitoxin) and other less common metabolites.

Output SSWR.4.3: Science of Harmful Cyanobacteria Bloom Forecasting

There is a strong demand by states and regions for forecasting freshwater HABs, with recent Office of Inspector General and Government Accountability Office audit recommendations to maintain and enhance a national program to forecast, monitor, and respond to freshwater HABs. This Output will focus on developing the science required for forecasting, while not building an operational forecast tool at this time. The research focus for this Output includes 1) forecasting freshwater HABs across systems—with greater than random chance—the probability the existing system might increase, decrease, or have no change, using bioindicators; 2) quantifying environmental drivers and aquatic community structures to inform the forecast; 3) assessing model convergence to provide more confidence in forecasts; and (4) linking human populations and communities with environmental justice concerns. Model development and validation in this Output will capture a range of critical ecosystem types as well as study sites that represent different community types. It is anticipated that the focus on forecast models may be primarily bioindicators based, such as biomass, not directly forecasting toxins. Early toxin warnings might be a two-step process, with an initial bioindicator forecast followed by gene profiling for early toxin detection.

RA SSWR.5: Nutrients in a Changing Climate

Output SSWR.5.1: Nutrient Sources and Fate: Terrestrial, Freshwater and Estuarine

There is a need to advance the science that informs decisions to prioritize nutrient sources in watersheds—and the fate of these sources—to guide EPA's approach to address nutrient pollution. This Output is designed to understand the magnitude of and processes controlling nutrient source inputs and retention on the landscape and in aquatic systems across a wide variety of spatial and temporal scales, from small watersheds to large river basins. Efforts will involve the collection, synthesis, and dissemination of spatial, sensor, and measured data, and the development and application of models and tools, to identify the types and locations of nutrient sources in watersheds and water bodies as well as where the highest and lowest levels of nutrient sinks, transformations, and transport will most likely occur. The Output will also address how climate change (including changing seasonality and extreme events), changes in nutrient sources, and legacy nutrient storage in soils, sediments, and groundwater affect watershed-scale nutrient fate and transport via future model scenario projections. Collectively, this information will help to characterize how effectively surface waters will respond to restoration and recovery efforts.

Output SSWR.5.2: Nutrient Impacts and Tools to Support Nutrient Criteria Development

Because excess nutrients continue to be a leading cause of impairment in U.S. waterbodies, adversely impacting aquatic life and human health, information is needed to develop protective water quality thresholds and new approaches to improve assessments of nutrient status and identify impairments. This Output focuses on 1) impacts of nutrients and nutrient-related stressors on aquatic life and priority habitats, including identification of nutrient and related stressor concentrations that result in biotic endpoint changes; 2) effects of nutrient-climate interactions on nutrient thresholds and criteria and aquatic ecosystems; and 3) tools and approaches to support nutrient criteria development and assessment of water quality and biotic condition. Partner engagement will be a key component throughout this Output to ensure co-production of knowledge and the development, application, and communication of methods that best address priority needs. This effort will develop and apply approaches to characterize ecological impacts of nutrients, nutrient-related stressors, and nutrient-climate interactions on aquatic life and ecosystem function. New methods may incorporate both novel and existing indicators of aquatic ecosystem structure and function; less labor-intensive methods to assess biotic condition (e.g., molecular techniques, in situ sensors, remote sensing); and integrative methods that allow synthesis of multiple sources and types of information.

Output SSWR.5.3: Nutrient Reduction Approaches

There is a need to better understand nutrient pollution from nonpoint sources including agriculture, urban, and forests, and how management practices of nitrogen and phosphorus impact water quality and ecological functions. There has been significant federal investment to implement agricultural conservation practices (ACPs) intended to reduce nutrient and sediment losses from farmland, rangeland, and animal operations, including buffers, bioreactors, floodplain management, and natural and constructed wetlands. This Output will 1) emphasize the review and synthesis of available information about the effectiveness of ACPs and other management practices (urban and forest) in reducing nonpoint source pollution and associated costs; 2) address the optimization of monitoring approaches along with models (e.g., Agricultural Conservation Planning Framework) and existing data for tracking nutrient reduction; and 3) evaluate Water Quality Trading and market-based approaches

that blend social and environmental science to investigate improved adoption and implementation of nutrient reduction approaches.

Output SSWR.5.4: Implementation of Nutrient Reduction Strategies

Since excess nutrient issues are complex and typically have multiple causes and drivers, working in partnership with tribal, federal, state, and local community agencies and stakeholders is critical. Since excess nutrients are largely a nonpoint source issue, no single entity has complete jurisdiction over the problem. Effective strategies for the implementation of nutrient reduction are, therefore, dependent on partnerships with federal, state, and local community agencies, and require good communication with partners and stakeholders. This Output focuses on 1) nutrient reduction program design and implementation, 2) studying and documenting innovation in nutrient reductions realized through partnerships, and 3) development or enhancement of tools to assist in prioritizing areas to optimize nutrient reduction outcomes. Efforts will rely on water quality and economic analysis of nutrient reduction programs, the socio-economic aspects of the implementation of reduction practices that influence community adoption and maintenance, and evaluating the real-world innovations in nutrient reduction realized through ORD's partnerships. Much of the research will have direct ties to source water protection. These innovations could include application of sensors and other novel technologies, new monitoring and modeling approaches, and/or new financing options. Partnership efforts will be centered on achieving quantifiable, system-scale reduction of nutrient mass storage and fluxes at watershed (or larger) scales, as well as design, modeling, monitoring, statistical analysis, and interpretation and application of results. Overall, this Output implements and evaluates solutions-driven research to reduce nonpoint nutrient pollution at scales necessary to achieve water quality goals.

Topic 3: Water Treatment and Infrastructure

RA SSWR.6: Alternative Water Sources for Climate Adaptation

Output SSWR.6.1: Risk Characterization to Inform Fit-for-Purpose Water Use

Defining treatment requirements for safe use of alternative waters for a variety of end uses is a key roadblock to adoption of new strategies for augmenting water resources. This Output will focus on 1) development of chemical risk frameworks utilizing non-targeted and effects-based assays, particularly for potable end uses; 2) reducing uncertainty in microbial and chemical contaminant levels for atmospheric water collections (e.g., stormwater and roof-collected rainwater); and 3) application to non-domestic scenarios such as industrial wastewaters (e.g., produced water), agricultural operations (both food production and processing), and enhanced aquifer recharge of surface runoff and/or treated effluents, including geochemical impacts.

Output SSWR.6.2: Facilitating Implementation of Alternative Water Use through Improved Treatment Characterization and Monitoring

The research in this Output will define surrogates for contaminants of concern by using non-targeted analysis to screen for potentially abundant, naturally occurring chemical or microbial surrogates. Researchers will also conduct quantitative studies comparing the removal rates of candidate surrogates and the specific contaminants of concern.

Output SSWR.6.3: Informing Community Decisions on Alternative Water Use

This research Output will produce information and tools to inform community operations and planning to best adapt water systems to a changing climate. Assessments will range from best management practices to mitigate impacts of the use of alternative source waters with existing drinking water infrastructure, to cost-benefit analysis of changes in infrastructure to provide a range of fit-for-purpose water sources. Systems level assessment will include risks, life cycle costs and impacts (e.g., global warming potential, energy use), and resiliency to inform community decisions on adaptive infrastructure investments.

RA SSWR.7: Drinking Water and Distribution Systems

Output SSWR.7.1: Lead and Copper Drinking Water Research to Support Communities

This Output will focus on lead and copper source identification, relative source contributions, and sampling approaches; and improve models for estimating lead exposure and mobility. Researchers will also address corrosion control issues in distribution systems and the physical and chemical attributes of distribution system water that may lead to the release of lead and copper.

Output SSWR.7.2: Data, Methods, Models and Tools to Inform Current and Future Health-Based Drinking Water Decisions

Research under this Output will apply physiological and biokinetic models to evaluate the potential for and the impact of multiple routes of contaminant exposure (oral, dermal, inhalation) on target-organ dose and toxicity and the potential for increased health risk resulting from population characteristics (e.g., genotype, age) or exposure to mixtures. Results will help OW with future decisions on drinking water regulations and review of existing regulations.

Output SSWR.7.3: Characterization and Management of Pathogens in Drinking Water Systems

Research under this Output will focus on 1) the development, validation, and application of methods for detecting the occurrence and improving the understanding of human/ecological health impacts of opportunistic and zoonotic pathogens, such as *Legionella*, *Mycobacteria*, and *Pseudomonas*, as well as other organisms including viruses and protozoans; 2) development, evaluation, and application of equitable treatment technologies for mitigating microbial contamination throughout drinking water systems, including premise plumbing; and 3) identify and evaluate water management plans, with emphasis on effective removal and mitigation of pathogens in distribution systems (e.g., storage tanks) and premise plumbing to ensure safe drinking water.

Output SSWR.7.4: Drinking Water Infrastructure Resilience and Sustainability for Small, Low-Income, and/or Socially Vulnerable Communities

This Output will address multiple approaches for maintaining water quality and improving the resilience and reliability of distribution systems, including monitoring, modeling, booster disinfection, optimization of tank operations, and replacing/repairing infrastructure, with a focus on developing/testing approaches that are affordable and practical for small and/or socially disadvantaged communities.

Output SSWR.7.5: Advancing Treatment Technologies and Providing Small and Socially Vulnerable Communities Access to Treatment Information

Research in this Output will 1) develop and evaluate effective and low-cost treatment technologies for small, disadvantaged and vulnerable systems; 2) evaluate how precursor (e.g., natural organic matter

and ammonia) concentrations and their removal via different treatment processes affect DBP concentrations and opportunistic pathogens in treated drinking water; 3) update EPA's Drinking Water Treatability Database with additional contaminant information; 4) support OW by developing a web platform for accessing water treatment models, including the multiple versions of the WTP model; and 5) conduct research on advanced, innovative, and sustainable treatment technologies.

RA SSWR.8: Per- and Polyfluoroalkyl Substances (PFAS)

Output SSWR.8.1: Analytical Methods for PFAS in Drinking Water, Wastewater, and Environmental Samples

Research in this Output will focus on developing and optimizing methods for analyzing PFAS in water and water-related samples. The Output will focus on methods for total organic fluorine, total oxidizable precursors, and non-targeted methods.

Output SSWR.8.2: PFAS Sources and Occurrence in Water

Research in this Output will help to develop approaches for identifying and characterizing PFAS sources to facilitate pretreatment and treatment technologies for integration into management approaches.

Output SSWR.8.3: Treatment Technologies and Processes for Removing PFAS from Community Drinking Waters

This Output will collect existing treatment data from the literature and combine it with results from additional laboratory studies on PFAS removal using a wide variety of technologies (e.g., granular activated carbon, ion exchange, membranes). The research will evaluate, model, and where appropriate, optimize treatment technologies at various scales, emphasizing small and disadvantaged systems, including point-of-entry and point-of-use applications.

Output SSWR.8.4: Disposal and Destruction of PFAS in Difficult to Treat Water Matrices

Research in this Output will evaluate multiple unit operations (or treatment trains) across various technologies and scales for performance, cost, and residual stream management issues. The research will focus on wastewater and hard-to-treat wastes, such as biosolids and landfill-leachates.

RA SSWR.9: Wastewater

Output SSWR.9.1: Development and Implementation of Effects Based Bioassays for Monitoring Chemical Risks in Wastewater

Research under this Output will 1) develop whole effluent toxicity tests in collaboration with OW and Regional Offices; and 2) develop innovative approaches for the application of bioassays for screening water quality in engineered systems.

Output SSWR.9.2: Monitoring Wastewater Collection Systems and Treatment Plants to Inform Public Health and Environmental Decision-making

Research under this Output will develop approaches for monitoring wastewater collection systems for pathogens and other contaminants of concern. The focus will be on antibiotic resistant bacteria and viruses (e.g., SARS CoV2) and source area identification.

Output SSWR.9.3: Wastewater and Biosolids Treatment in changing climates: Evaluation and Mitigation of Chemical and Microbial Contaminants of Emerging Concern

The research conducted to support this Output will focus on the effects of climate change on the detection, evaluation, and mitigation of chemical and microbial contaminants in systems that collect and treat wastewater and biosolids. These contaminants include a wide range of pathogenic microbes, including bacteria; viruses and protozoans; and chemicals, such as household chemicals, pharmaceuticals, personal care products, and natural toxins.

RA SSWR.10: Stormwater Management

Output SSWR.10.1: Leveraging Benefits from Greenspace while Managing Stormwater

This research involves synthesizing existing models, methods, assessment data, and approaches (e.g., flow control) to aid communities in stormwater management planning and practice, including evaluation of costs and benefits, operation and maintenance issues, groundwater impacts, and stormwater storage. This Output will demonstrate implementation of monitoring strategies for effectively managing stormwater at multiple scales and assess and explore resilience and adaptation.

Output SSWR.10.2: Managing Stormwater in the Face of Climate Uncertainty

Research in this Output will help us better understand how stormwater infrastructure is equipped to respond to uncertainty related to a changing climate and effects on watersheds and sewersheds. The Output will demonstrate implementation of monitoring strategies for effectively managing stormwater at multiple scales and assess and explore resilience and adaptation.

Output SSWR.10.3: Recommendations and General Procedures for Monitoring and Managing Stormwater

This Output will establish methods and techniques applicable across the U.S. by creating standard procedures and practical methodologies to help communities understand what/how to manage their stormwater and estimate the costs of infrastructure strategies. Research will review and incorporate climate change into major stormwater management tools and methods, green infrastructure planning and guidance, and Smart Urban Design (SUD) tools for stormwater planning, stormwater capture and aquifer recharge.

RA SSWR.11: Technical Support for Communities

Output SSWR.11.1: Training and Outreach

This Output will support water related training materials, webinars, and workshops.

Output SSWR.11.2: Site-Specific Technical Support

This Output will answer requests for and provide technical support to our stakeholders and partners across the SSWR portfolio. The accurate and complete accounting of our interactions with entities, such as water utilities, state regulatory agencies, and other on-the-ground decision makers is critical.

Appendix 4: Cross-Cutting Research Priorities

Working together on Agency priorities that cut across the six National Research Programs (NRPs), ORD will integrate efforts, provide a research portfolio aligned around the Agency's goals, and assist all of EPA's program and regional offices as well as states and Tribes. Where appropriate, the NRPs will combine efforts on the following cross-cutting priorities to conduct research that advances the science and informs public and ecosystem health decisions and community efforts. Although research efforts have been highlighted for each of these cross-cutting priorities, this does not mean that the research efforts only support that priority; the efforts may cut across priorities.

NRPs: Air, Climate, and Energy (ACE); Chemical Safety for Sustainability (CSS); Health and Environmental Risk Assessment (HERA); Homeland Security (HS); Sustainable and Healthy Communities (SHC); and Safe and Sustainable Water Resources (SSWR). The Strategic Research Action Plans for the NRPs are available on ORD's website at epa.gov/research/strategic-research-action-plans-2023-2026.

Environmental Justice

ORD's NRPs will integrate research efforts to identify, characterize, and solve environmental problems where they are most acute, in and with communities that are most at risk and least resilient. Research will strengthen the scientific foundation for actions at the Agency, state, tribal, local, and community levels to address environmental and health inequalities in vulnerable populations and communities with environmental justice and equity concerns. Coordinating research efforts will lead to a better understanding of how health disparities can arise from unequal environmental conditions, including impacts from climate change and exposures to pollution, and inequitable social and economic conditions. By working across NRPs, and through partner engagement, information, tools, and other resources will be developed that help support decision-making and empower overburdened and under-served communities to take action for revitalization.

| Integrated Efforts Across National Research Programs	
ACE	Understand inequities in air pollution exposures and impacts, and impacts of climate change, accounting for social, cultural, and economic determinants that can lead to disproportionate exposures and impacts. Develop science to support effective interventions to reduce air pollution exposures and impacts, and adaptation and resilience measures to address climate impacts, including excessive heat (urban heat islands), flooding, and wildfires.
CSS	Investigate factors relevant to exposures for populations experiencing disproportionate adverse impacts from chemical exposures.
HERA	Expand the identification and consideration of information on susceptibility and differential risk in assessments, advance the evaluation of chemical mixtures and improve cumulative risk assessment practices to better characterize and assess health disparities.
HS	Assess and address community needs and vulnerabilities to ensure equitable incident management during disaster response and recovery by analyzing the community-specific cumulative impacts and the social implications of environmental cleanup; and by identifying potential interventions.
SHC	Identify risks and impacts to vulnerable communities and groups and improve the ability of communities to address cumulative impacts from contamination, climate (e.g., natural disasters and extreme events), and other stressors on health and the environment.
SSWR	Help provide clean and adequate drinking water and tools for stormwater management and urban heat island mitigation.

Climate Change

Understanding and addressing climate change impacts to human health and the environment is a critical component of ORD's research. To be effective, climate change research must be scientifically broad and systems-based. Where appropriate, the NRPs will integrate efforts to avoid duplicative efforts, fill critical gaps, and provide results that reflect the multiplicity of impacts and needs associated with climate change. Each NRP recognizes the critical need for continued communication with ORD partners to ensure that we are taking advantage of opportunities for collaboration, integration, and understanding.

Integrated Efforts Across National Research Programs	
ACE	Better understand and characterize air pollution and climate change and their individual and interrelated impacts on ecosystems and public health and identify and evaluate approaches to reduce the impacts of climate change through mitigation of climate forcing emissions, adaptation strategies, and building resilience in communities and ecosystems. Model energy, emissions, and environmental impacts of transformations in the nation's energy, transportation, and building sectors, and identify approaches to increase equitable benefits of those transformations.
CSS	Explore the use of newer analysis methods for identifying chemical contamination in environmental media after large catastrophic environmental events, such as wildland fires.
HERA	Continue development of assessments of air pollutants to inform climate policy efforts and leverage expertise, approaches, tools, and technologies in support of further climate change impact assessments.
HS	Enhance capabilities and develop new information and tools to maximize relevance and support for response and recovery from natural disasters related to climate change.
SHC	Integrated systems-approach research applicable to challenges that communities, including those with contaminated sites, face in preparing for and recovering from the impacts of natural disasters and climate change, ensuring that approaches are beneficial and equitable for the communities at risk.
SSWR	Improve resiliency of water resources and infrastructure to mitigate impacts related to climate change, including coastal acidification and hypoxia, harmful algal blooms, wildland fires, drought and water availability, stormwater flooding and combined sewer overflows, and urban heat islands.

Cumulative Impacts
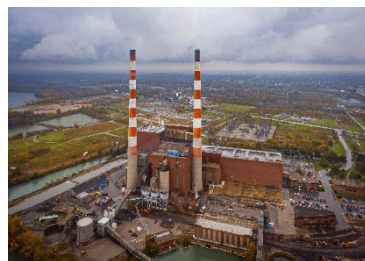
Addressing the cumulative impacts of exposure to multiple chemical and non-chemical stressors is necessary for EPA to fulfill its mission to protect human health and the environment with the best available science. Cumulative Impacts refers to the total burden—positive, neutral, or negative—from chemical and non-chemical stressors and their interactions that affect the health, well-being, and quality of life of an individual, community, or population at a given point in time or over a period of time. It is the combination of these effects and any resulting environmental degradation or health effects that are the focus of ORD's cumulative impacts research. The NRPs will integrate efforts to improve understanding of cumulative impacts and develop and apply the necessary models, methods, and tools to conduct real-world assessments of cumulative impacts that result in both adverse and beneficial health and environmental effects. With this information, internal and external partners can

make informed, scientifically credible decisions to protect and promote individual, community, and environmental health.

Integrated Efforts Across National Research Programs	
ACE	Develop measurement methods and approaches to characterize ambient air quality and deposition, and human and ecosystem exposures to chemical (including criteria pollutants and air toxics) and non-chemical (including built environment, social, and climate-related) stressors, and health impacts from exposure to the combination of chemical and non-chemical stressors
CSS	Development and application of new approach methodologies to rapidly generate exposure and hazard information for chemicals, chemical mixtures, and emerging materials and technologies (including safer alternatives).
HERA	Research to advance the evaluation of chemical mixtures and improve cumulative risk assessment practices to better characterize and assess health disparities in communities with environmental justice and equity concerns.
HS	Through a focus on resilience equity, ensure that information and tools include the multitude of stressors impacting a community when used to support incident response. Research will recognize that resilience to an incident is directly impacted by the cumulative impacts of the incident and other stressors affecting a community.
SHC	Address the risks and impacts to improve the ability of communities to address cumulative impacts from contamination, climate, and other chemical and nonchemical stressors on health and the environment.
SSWR	Support human health ambient water quality criteria for chemical mixtures through research using bioassays and risk management, and assessment for exposure to groups of regulated and unregulated disinfection byproducts (DBPs) and opportunistic pathogens.

Community Resiliency

It is critical that communities have the knowledge and resources needed to prepare for and recover from adverse situations, such as natural disasters, contamination incidents, and failing infrastructure. Through combined research efforts, the NRPs will provide information and resources that support and empower communities to make science-based decisions to withstand, respond to, and recover from adverse situations.

Integrated Efforts Across National Research Programs	
ACE	Improve evaluations of climate change adaptation and mitigation measures and community resiliency to extreme events in a changing climate, such as wildfire, floods, heat waves, and drought—especially for vulnerable and disadvantaged communities experiencing environmental injustice.
CSS	Efforts relevant to chemical safety evaluations will be leveraged with other NRP activities.
HERA	Continue to expand the portfolio of assessment products to improve understanding of potential human health and environmental impacts of contamination incidents.
HS	Generate resources and tools for environmental cleanup, risk communication, outreach, building relationships, and community engagement to improve equitable community resilience for environmental contamination incidents and other disasters.
SHC	Increase resilience by reducing potential risks, promoting health, and revitalizing communities.
SSWR	Support coastal resilience by advancing monitoring, mapping, and remote sensing and by the economic valuation of coastal resources. Improve the performance, integrity, and resilience of water treatment and distribution systems through research on water infrastructure and water quality models.

Children's Environmental Health

From EPA's [2021 Policy on Children's Health](#), "children's environmental health refers to the effect of environmental exposure during early life: from conception, infancy, early childhood and through adolescence until 21 years of age." Environmental exposures that impact health can occur before conception, and during pregnancy, infancy, childhood, and adolescence; and include long-term effects on health, development, and risk of disease across lifestages. Much of ORD's research is relevant to communities, including susceptible and vulnerable populations. Where appropriate, the NRPs will combine efforts to conduct research that will inform public health decisions, advance our scientific understanding of early-life susceptibility to environmental stressors, and inform community efforts that create sustainable and healthy environments protective of all lifestages.

Integrated Efforts Across National Research Programs	
ACE	Explore air pollution and climate health impacts within different lifestages and populations, including overburdened groups. Assess vulnerabilities to air pollution for those with chronic illnesses and sequelae from respiratory viruses. Research social determinants of health, and air pollution impacts resulting from different exposure time-activity patterns.
CSS	Research will build the scientific foundation to predict adverse outcomes resulting from chemical exposures in various biological contexts, including early life-stage susceptibility.
HERA	Continue to evaluate health effects, over the course of a lifetime, from environmental exposure to stressors during early life (i.e., from conception to early adulthood) to inform decision-making and advance research on methods to properly characterize risks to children.
HS	Improve and develop decision-support tools and cleanup capabilities to make children less vulnerable during response to, and recovery from, contamination incidents.
SHC	Address the risks and impacts to vulnerable communities and lifestages, including underserved/overburdened communities, and improve the ability of communities to address cumulative impacts from contamination, such as site clean-ups of per- and polyfluoroalkyl substances (PFAS) and lead; climate, such as natural disasters and extreme events; and other stressors on health and the environment.
SSWR	Evaluate health effects and toxicity related to algal toxins and expanded research that will explore exposure risks for lead, DBPs, and—through quantitative microbial risk assessment models—for high priority opportunistic pathogens in drinking water (e.g., *Mycobacterium*, *Pseudomonas*, *Naegleria fowleri*).

Contaminants of Immediate and Emerging Concern

Contaminants of immediate and emerging concern (CIECs) include chemical substances that may cause ecological or human health impacts and are either new or existing contaminants of increased priority. The NRPs will work with EPA partners in the program and regional offices, along with input from Agency leadership, to identify the highest priority contaminants (broadly defined to include chemical, biological, and other

categories as appropriate), including those of immediate concern, such as PFAS and lead, that warrant further research attention.

Integrated Efforts Across National Research Programs	
ACE	Develop and evaluate measurement methods and approaches to characterize sources of air pollutants and climate forcing pollutants, such as measurement of emissions of criteria pollutant precursors and air toxics, including emerging concerns, such PFAS and EtO.
CSS	Continue to develop new approach methods for CIECs with a focus on applying these, as appropriate, for prioritization, screening, and risk assessment for decision making.
HERA	Continue and expand the portfolio of assessment products, as well as advance risk assessment models and tools, to better characterize potential human health and environmental impacts of new and existing contaminants.
HS	Predict the movement of chemical, biological, and radiological contaminants in the environment resulting from environmental contamination events and develop tools and methods for effective characterization, decontamination, and waste management.
SHC	Advance site clean-ups of PFAS and lead to protect vulnerable groups, especially children.
SSWR	Research on PFAS, including innovative drinking water and wastewater treatments, support for future drinking water regulations, the development of aquatic life criteria, management in water resources, and evaluation of land-applied biosolids; contaminants of emerging concern (CECs), lead, opportunistic pathogens, and DBPs in drinking water; cyanobacterial metabolites other than microcystin (e.g., anatoxin, saxitoxin, and nodularin); microplastics in sediments and surface water; and CECs (non-PFAS) in wastewater treatment systems and biosolids.