July 2, 2014

United States
Environmental Protection
Agency

Safe and Sustainable Water Resources

Strategic Research Action Plan, 2016-2019
(Preliminary Draft)

U.S. EPA
Office of Research and Development
Washington, DC 20460

PRELIMINARY DRAFT NOTICE: This Strategic Research Action Plan, 2016–2019 is a preliminary draft. It has not been formally released by the U.S. Environmental Protection Agency (EPA) and should not at this stage be construed to represent Agency policy, nor the final research program.

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TO BE COMPLETED IN FINAL STRATEGIC RESEARCH ACTION PLAN

II. Introduction

Essential for all life, water is the only substance found on Earth naturally in three forms: solid, liquid and gas. Human life, and many plants and animals, depend on freshwater; however, available sources are surprisingly miniscule – 0.007 percent – compared with Earth's total amount of water. Water is not only essential for human health and well-being and all types of ecosystems (freshwater, brackish, saline), but is vital for a robust economy. Water is needed for the production of many goods and services, for example, agriculture, energy, manufacturing, transportation, commercial and recreational fishing, tourism, and others. As the interchange of water through the hydrologic cycle is continually dynamic, so are the changing spatial and temporal demands on water quantity and quality for various uses.

The U.S. Environmental Protection Agency (EPA) Office of Research and Development's (ORD) Safe and Sustainable Water Resources (SSWR) research program provides scientific results and innovative technologies that are needed to protect the chemical, physical and biological integrity of the Nation's waters and to ensure safe drinking water and water systems.

Agency scientists and engineers and their partners are addressing 21st century water resources challenges by integrating research on environmental, economic and social factors to provide lasting, sustainable solutions for the Agency to accomplish its missions, operations, and programs.

The *SSWR Strategic Research Action Plan, 2016-2019* (StRAP FY16-19) outlines a four-year research plan in support of EPA's mission to protect human health and the environment. The research planned in the StRAP FY16-19 focuses on efforts to meet EPA's legislative mandates, as well as the goals and cross-Agency strategies outlined in the Agency's *Fiscal Year 2014-2018 EPA Strategic Plan* (EPA Strategic Plan). Specifically, SSWR supports the Strategic Plan's goal, Protecting America's Waters, and several of its cross-cutting strategies for future sustainability and community, state and tribal partnerships. It is also designed to guide an ambitious research portfolio that delivers science and engineering solutions that EPA needs to meet its goals to protect the Nation's waters.

The SSWR StRAP FY16-19 is one of six research plans, one for each of ORD's national research programs. Collectively, the ORD StRAPs are designed to integrate efforts to provide a seamless and efficient research portfolio to support the Agency's Strategic Plan.

III. Program Purpose

III.A. Problem Statement

Impairment of water quality and diminished water availability are of concern for human and ecosystem health, economic prosperity and social well-being. Across the Nation's watersheds, excess levels of nutrients and sediment remain the largest water quality impediment. The rate at which water bodies are newly listed for water quality impairment exceeds the pace at which restored waters are removed from the list. EPA and the states do not have the capacity or tools to assess each water body individually for chemicals and pathogens. The Nation's wetlands provide numerous ecosystem benefits, for example, water quality improvement, groundwater recharge, erosion and flooding protection, and habitat for commercially and recreationally valuable or imperiled species, Wetlands are continuing to decline, and the rate may accelerate as acreage, even in conservation, is being converted for evolving trends in energy and food production. Groundwater is becoming an increasingly important water source. Sustainability of groundwater, with regard to drawdown and recharge and increasing potential of contamination potential, is a growing concern.

The Nation's water treatment and delivery systems are also of concern. Aging infrastructure and inadequate planning for population expansion pose increasingly greater challenges for human health, social equity, and the economy. Compromised infrastructure not only contaminates clean drinking water or underground sources of drinking water, but causes up to 40 percent loss from leaking pipes and water main breaks. To restore and expand the Nation's deteriorating, buried drinking water pipe system to accommodate a growing population will cost more than $1.7 trillion by 2050 (AWWA 2012). This estimate does not include other critical infrastructure investment needs, including water treatment plants and storage tanks, nor investments in wastewater and stormwater management. Of the Nation's 156,000 public water systems, approximately 95 percent serve fewer than 3,300 persons. These small systems face even greater technical, financial and operational challenges to develop and maintain the capacity to comply with new and existing standards.

Inadequate knowledge of the value of water underlies the daunting challenge to fund the repair and replacement of existing infrastructure with new and innovative technologies that are more resilient and energy-efficient, while also ensuring protection of underground sources of drinking water. Although estimates exist for the cost to deliver safe drinking water to taps – less than $3.75 for every 1,000 gallons (AWWA 2012) – there is not a more comprehensive evaluation of the benefits of water quality that includes environmental and human health and ecosystem services.

Imposed on the challenges described above are other water-resource stressors, for example, climate change and variability. Climate models project there will be distinctive regional differences in climate impacts affecting the hydrologic cycle in several ways, including: warmer water temperatures, changes in precipitation patterns and intensity, more frequent and intense flooding and droughts, increased evaporation, changes in soil moisture, and earlier snowpack melt with lower flows in late summer (GCCIUS 2009). These changes may affect human health, especially vulnerable and sensitive sub-populations, for example, by increased incidence of waterborne disease related to heavy rain events, and ecosystems, for example, by lower stream flows, warmer temperatures, and lower dissolved oxygen. Harmful algal blooms that pose health risks to humans and ecosystems are largely driven by excess nutrients, and are likely to increase with warmer water temperatures.

Water quantity and quality challenges will also be amplified by other stressors, such as extreme events (hurricanes, tornadoes, heat waves, drought, wildfire), some of which are driven by climate change; land use change; energy and food production; contamination by accidents or homeland security events; and population growth. Many of these stressors will be more pronounced in areas that are least resilient to climate impacts. For example, population growth is projected to continue increasing in U.S. shoreline counties that are vulnerable to sea level rise and increased and more extreme storms, and where 39 percent of the population is already concentrated (52 percent live in counties that drain to coastal watersheds) (NOAA State of Coast Report, 2013). However, the highest rate of population growth by 2025 is projected to be in the arid Southwest, where climate models project more frequent and longer duration of drought, and water availability is already in short supply (IPCC Working Group I, 2007).

These water resources challenges also offer opportunities for innovation, economic development, and improvements in watershed sustainability and human health and well-being. For example, wastewater treatment innovations can transform the concept of ‘waste’ to ‘resource’ by recapturing and reusing commercially valuable waste stream constituents (e.g., nutrients, energy, metals). Additional benefits of these newer technologies include improved energy efficiency from both treatment operations and reduced de novo production of resources from their original sources in the environment, which would also lessen ecosystem impacts. Green infrastructure can help mitigate stormwater runoff, while offering co-benefits, such as, potentially reducing gray infrastructure investments, improving property values and social well-being, reducing energy use and the urban heat island effect, and creating wildlife habitat.

III.B. Program Vision

EPA’s Safe and Sustainable Water Resources research program uses an integrated, systems approach to purpose-driven, state-of-the-art research to support innovative scientific, technological and behavioral solutions that ensure clean, adequate, and equitable supplies of water to support human health and well-being and resilient aquatic ecosystems. The focus of our research is on the highest priority, current and long-term water resource challenges to inform EPA’s regulatory and non-regulatory decisions, and its implementation needs, and translating research findings to support communities, states, and tribal partners. The overarching watershed approach to our drinking water, wastewater, stormwater and ecosystems research recognizes the dynamic ‘one water’ hydrologic cycle. Integrated throughout the program are the goals of a sustainable environment, economy and society and the overarching drivers of changing climate, extreme events, land use, energy, agriculture and demographic scenarios.

IV. Research Supports EPA Priorities and Mandates

IV.A. Statutory and Policy Context [this section will be expanded in next draft]

EPA is responsible for protecting the Nation's water resources under the Clean Water Act, which establishes the basic structure for 1) restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters by preventing point and nonpoint pollution sources, 2) providing assistance to publicly owned treatment works for the improvement of wastewater treatment, and 3) maintaining the integrity of wetlands. Groundwater protection provisions are included in the Safe Drinking Water Act, Resource Conservation and Recovery Act, and Comprehensive Environmental Response, Compensation and Liability Act ("Superfund").

The Safe Drinking Water Act (SDWA) directs EPA to set national safety standards for drinking water delivered to consumers by public water systems (PWSs). The SDWA also authorizes other regulatory programs (e.g., Underground Injection Control, Wellhead Protection), as well as funding, training, public information and source water assessment programs to foster the protection of many sources of drinking water. The Clean Water Act (CWA) provides for the protection of above ground sources of drinking water as determined by each State; see CWA section 303(c).

IV.B. EPA Priorities

In support of EPA's mission to protect human health and the environment, the EPA Strategic Plan identifies five strategic goals and four cross-agency strategies (Box 1).

Box 1. FY 2014-2018 EPA Strategic Plan, Goals and Cross-Agency Strategies

Strategic Goals
Goal 1: Addressing Climate Change and Improving Air Quality
Goal 2: Protecting America's Waters
Goal 3: Cleaning Up Communities and Advancing Sustainable Development
Goal 4: Ensuring the Safety of Chemicals and Preventing Pollution
Goal 5: Protecting Human Health and the Environment by Enforcing Laws and Assuring Compliance

Cross-Agency Strategies
- Working Toward a Sustainable Future
- Working to Make a Visible Difference in Communities
- Launching a New Era of State, Tribal, Local, and International Partnerships
- Embracing EPA as a High-Performing Organization

The SSWR research program supports the Strategic Plan's second goal, Protecting America's Waters, and its aims to protect and restore waters to ensure that drinking water is safe and sustainably managed, and that aquatic ecosystems sustain fish, plants, wildlife and other biota, as well as economic, recreational, and subsistence activities. SSWR research objectives are aligned with the goal's objectives, which are twofold.

1. **Protect Human Health.** Achieve and maintain standards and guidelines protective of human health in drinking water supplies, fish, shellfish, and recreational waters, and protect and sustainably manage drinking water resources.

2. **Protect and Restore Watersheds and Aquatic Ecosystems**. Protect, restore, and sustain the quality of rivers, lakes, streams, and wetlands on a watershed basis, and sustainably manage and protect coastal and ocean resources and ecosystems.

The SSWR research program also supports the cross-agency strategies by efficiently integrating research on social, environmental and economic factors, and translating our research findings into visible and sustainable solutions for local, state, and tribal communities. The program continues to be efficient, innovative, and responsive in providing research for human and environmental health.

Innovative solutions will be key to meeting the Agency's strategic goal of protecting water. EPA has committed to innovation for solving sustainability challenges in two recent documents: *Technology Innovation For Environmental and Economic Progress: An EPA Roadmap* (2012) http://www2.epa.gov/envirofinance/innovation and *Promoting Technology Innovation for Clean and Safe Water, Water Technology Innovation Blueprint– Version 2* (2014) http://water.epa.gov/blueprint.cfm.

The foundation of this research plan was also greatly informed by the articulation of specific, prioritized challenges facing EPA's Office of Water and Regional Offices, and the OW Water Technology Innovation Blueprint. This document also reflects input from partnerships with other federal agencies, state agencies, nonprofit organizations, private industry, and colleagues across the scientific community. *[NOTE: external discussions are ongoing and will continue throughout development of the StRAP*]

V. Program Design

The StRAP FY16-19 builds upon the successful research outlined in the previous research plan, *SSWR Strategic Research Action Plan, 2012-2016*, and will continue advancing science and technology solutions for the Nation's highest priority, current and emerging water resource and human health challenges. This new version consolidates research into four interrelated research topics (listed below and described in detail in Section VI). The various ORD programs and grants, for example, the Water Technology Innovation Center, Science to Achieve Results (STAR), Small Business Innovation Research (SBIR), Regional Applied Research Effort (RARE) and Regional Methods, Pathfinder Innovation Projects (PIP), and others are integrated into the program by the topic each supports. There is a greater emphasis on community support tools, the energy and water nexus, and resilience to climate and extreme events.

The SSWR StRAP FY16-19 is organized by four interrelated research topics.

1. **Watershed Sustainability**: Gathering, synthesizing, and mapping the necessary

environmental, economic, and social (human health and well-being) information of watersheds, from local to national scales, to determine the condition, future prospects, and restoration potential of the nation's watersheds;

2. **Nutrients**: Conducting EPA nitrogen and co-pollutant research efforts for multiple types of water bodies and coordinating across media (water, land and air) and various temporal and spatial scales, including support for developing numeric nutrient criteria, decision-support tools, and cost-effective approaches to nutrient reduction;
3. **Green Infrastructure**: Developing innovative tools, technologies, and strategies for managing water resources (including stormwater) today and over the long term as the climate and other conditions change; and
4. **Water Systems**: Developing tools and technologies for the sustainable treatment of water and wastewater and promoting the economic recovery of water, energy, and nutrient resources through innovative municipal water services and whole system assessment tools. This area focuses on small water systems and can be scaled up to larger systems.

SSWR will be integrating with the other national research programs through critical research areas identified in the ORD crosscutting Roadmaps (Figure 1). SSWR is the lead national program for the Nitrogen and Co-Pollutant Roadmap, which serves as the foundation for research on nutrients (Topic 2). Overarching research on impacts of climate variability and change will be integrated through the Climate Roadmap. Over the course of the next year, additional opportunities to integrate with the Children's Environmental Health and Environmental Justice Research Roadmaps will be explored.

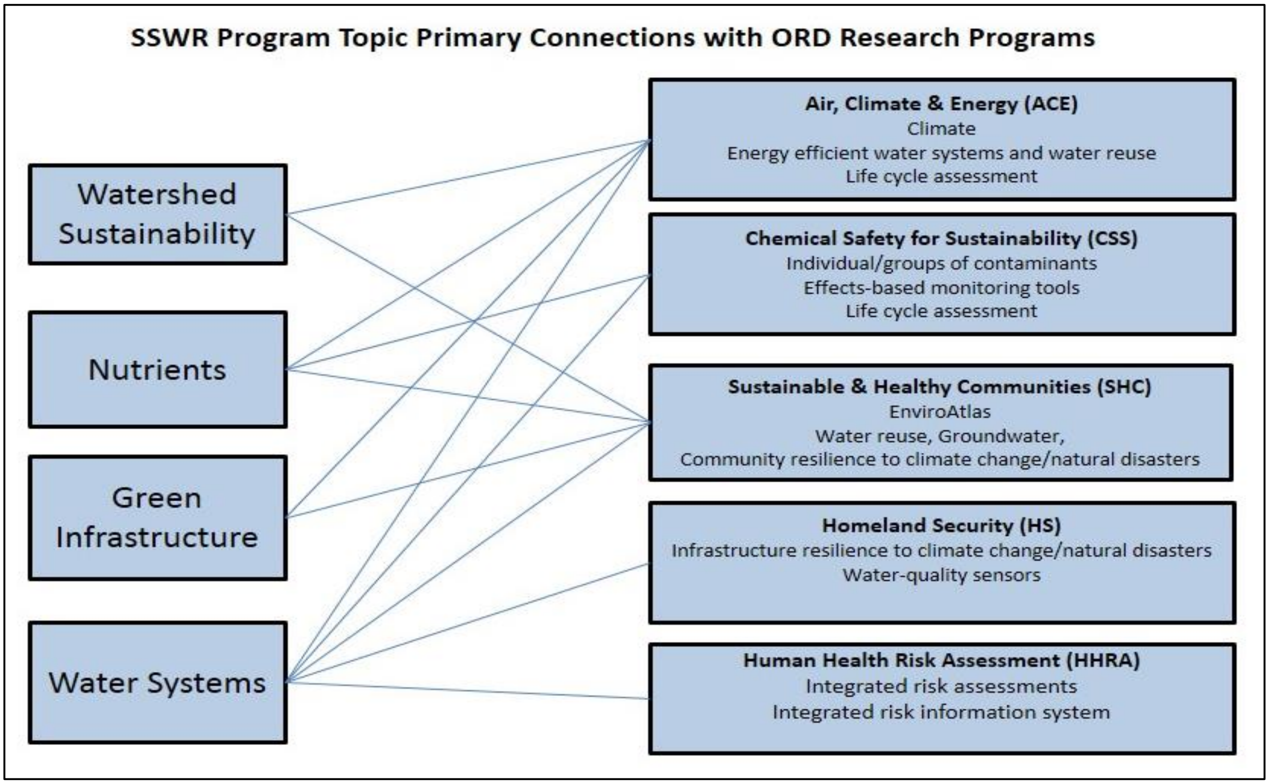

***Figure 1**:* SSWR integration across ORD's six national research programs.

Additional opportunities for integration and leveraging across the national programs will be identified over the coming months as the work plan to implement the FY16-19 StRAP is developed. Examples of linkages between the SSWR research topics and the other national research programs are as follow:

- Watershed Sustainability has clear linkages to SHC through the *EnviroAtlas* and *Report on the Environment*, and to ACE, particularly in the realms of climate change and prediction and management of materials and waste. Integrated watershed management for sustainable outcomes is envisioned as a full partnership with SHC in furthering watershed management and community sustainability, and with other federal and state agencies that conduct water research. Linkages with CSS may include effects-based monitoring tools.

- The Nitrogen and Co-pollutants Roadmap has promoted greater collaboration and coordination in nutrient research across EPA, identification of gaps and the development of integrated research projects. Significant, sustainable reductions in nutrients must be economically efficient, socially acceptable, environmentally sound, adaptable to climate change, land-use and demographic changes, and permanent. These requirements can be met only through integrated research that informs the systematic collective, adaptive management of air, land, and water. Many opportunities for cross-ORD StRAP coordination and integration of nutrient research exist, particularly with ACE and SHC. Research in SHC on decision support tools for communities should transfer to SSWR nutrient needs.

- Green Infrastructure (GI) and Stormwater efforts support ACE research on climate. The recently released Storm Water Calculator (SWC) and upcoming updates to the Stormwater

Management Model (SWMM), both include downscaled climate change scenarios from the "Fourth Assessment Report of the IPCC" (2014). This allows assessment of GI runoff reductions with historical weather patterns, as well as future scenarios. Both average and episodic (e.g., 30 year storms) future scenarios can be considered. Community pilot studies of Environmental Justice and community planning tools further the incorporation of GI into Environmental Justice communities to offer revitalization co-benefits, while reducing runoff and stormwater issues in the area. Linkage with SHC ongoing efforts to develop and demonstrate community-planning tools is critical for the tool development. Other opportunities to link with other ORD programs include consideration of urban heat island and related air quality impacts that may be associated with GI. Additionally, there is interest in benefits of GI for community resilience especially for coastal areas. This could be an opportunity to work with NHSRC.

- Water Systems research on the energy footprint reduction and mitigating greenhouse gas work has connections ACE. The resiliency to climate and extreme events work, and elements of the monitoring, modeling, contaminants, and technology development and testing has connections to NHSRP. The monitoring protocols and models work has connections to CSS. Finally, the demonstrations and acceptance at the community level, and testbed research has linkages with SHC.

VI. Research Topics and Objectives

The applied research objectives of the SSWR StRAP FY16-19 align with EPA's Strategic Plan to help ensure that natural and engineered water systems have the capacity and resiliency to meet current and future water needs for the range of water use and ecological requirements (Table 1). Each of the four main research topics are addressed by short- and long-term research objective(s), identified by ORD scientists through extensive consultation with Agency partners and stakeholders. Research objectives, in turn, are advanced by research projects, which will be designed to meet articulated science challenges. Examples of research projects are provided for each research objective. Research outputs synthesize and translate scientific and technological accomplishments and will be communicated to a broad audience. Examples of possible outputs are provided in Appendix A.

SSWR Research Objective: The SSWR Research Program provides the tools to help ensure that natural and engineered water systems have the capacity and resiliency to meet current and future water needs to sustain watershed integrity and human health and well being, including for vulnerable and sensitive sub-populations.

Table 1. SSWR Topic Areas Short- and Long-term Research Objectives

SSWR Research	What We Do	Near Term Objective	Long-Term Objective
Watershed Sustainability	Gathering, synthesizing, and mapping the necessary environmental, economic, and social information of watersheds, from local to national scales, to determine the condition, future prospects, and restoration potential of the Nation's watersheds.	Develop the methods to assess watershed integrity nationally, and the tools necessary to manage the integrity of watersheds for sustainability and resilience; develop understanding and tools to address the water-energy-minerals-materials nexus; identify causes of watershed impairment and attributes that promote integrity and resilience; develop approaches to watershed sustainability that integrate ecological condition, human well-being, and economic benefits.	National and scalable assessments of watershed sustainability using indicators of human well-being, ecological condition, and economic benefits. Develop and demonstrate the tools for achieving sustainable and resilient watersheds and water resources.
Nutrients	Conducting EPA nutrient research for multiple water body types with coordination across media (water, land and air) and various temporal and spatial scales, including support for developing numeric nutrient criteria, decision-support tools, and cost-effective approaches to nutrient reduction.	Improve the science needed to define appropriate nutrient levels and develop technologies and management practices to monitor and attain appropriate nutrient loadings. Research will include the occurrence and effects of harmful algal blooms.	Assess ecosystem, human health, and societal benefits resulting from application of management actions to achieve appropriate and sustainable nutrient levels in the Nation's waters.

SSWR Research	What We Do	Near Term Objective	Long-Term Objective
Green Infrastructure	Developing innovative tools, information, and guidance for communities to manage water resources (including stormwater) with green infrastructure and move toward more natural hydrology and increased resilience to future changes such as climate and extreme events.	Assist decision makers, planners, and developers understand how to incorporate effective GI opportunities into their stormwater management plans at the property-level and community scales.	Develop and demonstrate tools, information, and guidance for communities to assess effectiveness and benefits of green infrastructure as part of their approach for managing water volume and improving water quality.
Water Systems	Develop, test and evaluate innovative tools, technologies and strategies for managing water resources and protecting human health and the environment as climate and other conditions change. Support the economic recovery of resources through innovative water services and whole system assessment tools. Particular attention will be made to small drinking water and wastewater systems because of their limited resources.	Support drinking water and wastewater regulations, guidance, and implementation of programs at all levels. Develop, test and promote the adoption of drinking water, stormwater, and wastewater technologies that will protect human health and environment while maximizing resource conservation and recovery. Closely align contaminant research with Topic 1 (Watershed Sustainability) and CSS program to ensure that common tools and models are effectively employed across the water cycle.	Conduct integrated sustainability assessments, develop novel approaches, and prioritize risks to provide a framework for decision making, related to alternative approaches to existing water systems to meet the goals of public health protection and resource recovery.

Natural and engineered water systems are inextricably linked through the hydrologic cycle; therefore, the four research topics are also interrelated (Figure 2). Overarching, all four topics are the goals of environmental, social and economic sustainability and multiple stressors affecting water quality and quantity, including: climate change and extreme events (e.g., flooding, hurricanes, tornadoes, earthquakes, heat waves, drought, wildfire), many of which are amplified by climate change; land use change; energy and agriculture; contamination by accidents or homeland security events; aging infrastructure; and; population growth.

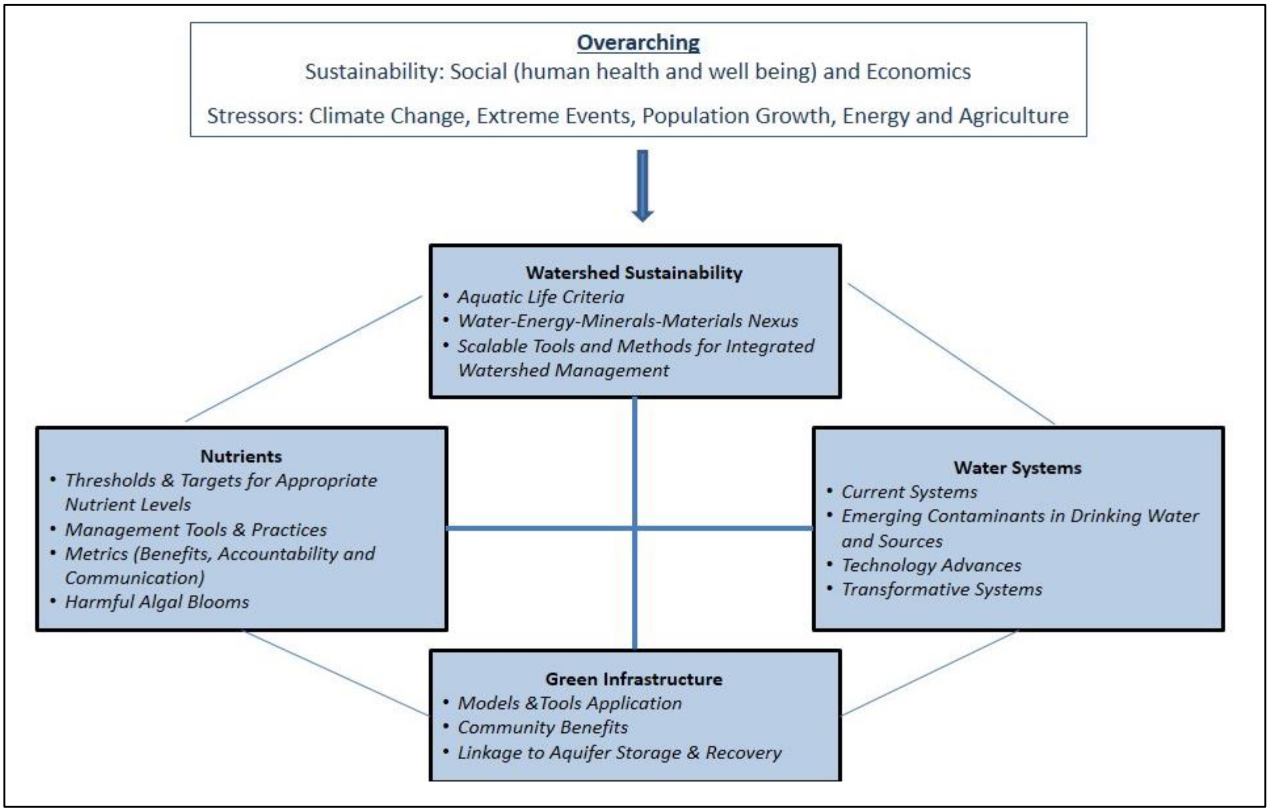

Figure 2: SSWR Research Topics and Overarching Issues.

Current water services are mostly achieved through separate engineering systems to provide distinct functions, including safe drinking water, sewage treatment, stormwater control, and watershed management. Multiple stressors and more stringent water quality goals threaten the future effectiveness and affordability of this "siloed" approach to water resource management. A systems-level view of integrated water services is necessary to develop optimal solutions. Focusing on one part of the system, even when using system analysis tools, such as life-cycle assessment, may shift problems to other sectors. While this document defines four separate topic areas for clarity of presentation, the program emphasizes this systems level view. Broad linkages between topic areas (e.g., the interaction of contaminants between built infrastructure and watersheds) are identified, and more specific relationships across topic areas will be an important element of the detailed project management planning process.

Topic 1: Watershed Sustainability

The goal of sustainability, as contained in the National Environmental Policy Act (NEPA) of 1970, and a 2009 Executive Order is *". . . to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations."* To achieve the NEPA goal of sustainability, conditions of adequate and accessible supplies of clean water for health (human and ecological), social, and economic requirements need to be created and maintained from headwater catchments to great river basins to coastal systems.

There are strong linkages between Topic 1 Watershed Sustainability and the other three topics. For example, nutrients (Topic 2) are perhaps the most widespread and prevalent threats to watershed sustainability; green infrastructure (Topic 3) plays a large and growing role in protecting and restoring watershed sustainability; and water systems (Topic 4) are integral elements of many watersheds, which are the sources of water to water systems and the receptors for wastewater from water systems. Thus, watershed concepts and research do not stand alone, but pervade the SSWR program, and in this sense, Topic 1 is an integrator of the SSWR program.

Research objective 1. Assess, map and predict the integrity, resilience, and restoration potential of the Nation's water resources.

Improve understanding of the condition of water resources, including the underlying causes of impairment and factors that exacerbate adverse water resource conditions, factors that help to maintain integrity and resiliency, and restoration potential. Assess and map current watershed integrity and predict future prospects under scenarios of change (e.g., demographics, climate, extreme events, land use, energy and agriculture), and include ecological, human health, and economic indicators across various spatial and time scales.

There are few tools with which to evaluate the costs and benefits of water quality improvements. Without an investment in data acquisition, causal analyses, and modeling capabilities for water resources at multiple scales, decision makers will not have the information required to make sound decisions on water pollution control policies.

Challenges:

Evaluate and predict 1) the physical, chemical and biological integrity, including degradation pathways, of watersheds at local, state, regional, and national scales, 2) restoration potential, and 3) the relationships between watershed integrity, ecological condition, human health, and economic values. Support economic valuation research to enhance the ability of public and private stakeholders at different spatial scales to evaluate policies and actions to protect, restore, or improve water resources.

Examples of specific research needs

- Current and predictive models that build on data from diagnostic tools, probabilistic National Aquatic Resource Surveys, and targeted watershed studies, coupled with physiographic, hydrologic, land cover-land use data, and data on infrastructure that can affect watershed integrity.

- Modeling and mapping of watershed integrity: Utilize large volumes of environmental data, GIS, and modern computing power to assess, map, and predict watershed integrity, including the roles of groundwater and its uses; includes linkage to SHC through *EnviroAtlas* and *Report on the Environment*, and continue efforts to improve interoperability of models and data from diverse sources.

- Watershed degradation, resilience and recovery: Build on modeling and mapping efforts to determine factors that contribute to degraded conditions and watershed resilience, recovery trajectories under remedial management, and thresholds of impairment that lead to long-term losses of integrity and ecosystem services ("tipping points").

- Scientific methods for determining watershed connectivity: Develop quantitative scientific methods to determine the functions wetlands that benefit the physical, biological and geochemical integrity of down-gradient waters and articulate the specific knowledge gaps that must be resolved (e.g., degree of connectivity, analyses of temporal or spatial variability, cumulative effects) to determine where "geographically isolated" or temporary waters have a "significant nexus" to larger navigable waters, and the contribution of groundwater to connectivity of waters.

- Aquatic life criteria support and ambient water quality criteria: Continue research support to the Office of Water in 1) deriving aquatic life criteria through assessment of exposures and effects, with special attention to groups of pollutants and emerging pollutants; and 2) implementing existing and new EPA water quality regulations (e.g., ammonia ambient water quality criteria). Research will consider how pollutant toxicity and use and species susceptibility may evolve under changing climate scenarios.

- Invasive aquatic species: Develop tools for surveillance, prediction, risk assessment, and remediation of the effects of invasive species on watershed integrity. Address data and research gaps in correlating species movement in ballast water tanks with actual invasions, characterizing the composition of organisms in ballast water tanks and improving monitoring technologies; develop alternate direct ballast water self-monitoring approaches, and refine shipboard testing protocols, standards, and control method testing (e.g., for UV systems).

- Assess the impact of extreme events and climate change on watershed integrity: To support analysis of future adaptive management scenarios that reduce aquatic ecosystem and human health impacts from the prevalence and transport of contaminants, sediment and pathogens under various climate conditions (e.g., drought, low flows, flooding).

- Understand how watershed degradation related to land use, and exacerbated by extreme events and climate change, affects the presence of waterborne pathogens and other emerging contaminants: Emphasize decreasing human exposures to toxic contaminants and etiologic agents of chronic vs. acute disease in both drinking water and recreational waters.

- Technical support to the Office of Water for National Aquatic Resource Surveys: ORD will continue to provide sampling designs, indicators, and other support for the rotating national surveys of lakes, streams, rivers, wetlands, and estuaries. Innovations: (a) integrating ecological condition assessments with human health and economic dimensions; (b) deployment of more rapid and cost-effective methods of assessment, including such innovations as meta-genomic analysis of biotic communities.

- Economic analysis of the benefits of water: A collaborative effort among the Office of Research and Development, Office of Water, and Office of Policy to account for the value of water benefits and to provide tools for determining changes in value associated with changes in water quality, ecosystem services of water bodies, and watershed integrity.

Research objective 2. Assess life-cycle impacts of water, energy, mineral and materials nexus.

There are existing, emerging, and unknown potential impacts of the life cycles (i.e., extraction, production, transportation, use, storage, disposal and residuals) of conventional energy (e.g., coal, petroleum, natural gas) and unconventional energy (e.g., hydraulic fracturing of oil and gas shales, coalbed methane, tight oil and gas resources); metals and minerals; and other materials on the integrity and safety of water resources.

Challenges:

Understand how watersheds and water resources (surface and groundwater) are affected by the life cycles of conventional and unconventional energy, minerals, and other materials for sustainable practices.

Examples of specific research needs

- Proactive approaches to assessing the potential risks to watershed and aquifer integrity and sustainability associated with current, transitioning or emerging technologies and practices, including water use, for the life cycle of conventional and unconventional energy, mineral or other materials.

- Assess the risks and benefits of using aquifers to store water for future uses (aquifer storage and recovery), and to sequester polluted waters (e.g., hydraulic fracturing fluids).

Research objective 3. **Integrate watershed management for sustainable outcomes**

Jurisdictions with responsibility for watershed management often lack the necessary information, indicators, tools, technologies, frameworks, and guidance for managing water resources sustainably, especially in the face of challenges such as climate change, extreme events, population growth and urbanization, aging infrastructure, and land use for energy and agriculture. The threat of invasive species on waterbodies and water resources continues to be a pressing issue requiring a focus on management approaches and addressing data and research gaps.

Challenges:

Increase knowledge and develop methods, tools and technologies that are scalable and transferable, to advance integrated watershed management and achieve sustainable outcomes. For invasive species, address gaps in data and research on species movement, composition, and ballast water organism monitoring approaches, and technology testing methods and protocols.

Examples of specific research needs

- Methods to foster watershed sustainability: Provide accessible information, sustainability indicators, models, and other tools encompassing the three dimensions of sustainability; including multi-sector systems analysis of major environmental changes (e.g., extreme events and climate change).
- Integrated research to link community sustainability in the SHC research program to management and sustainability at watershed scales in the SSWR research program.

Topic 2: Nutrients

Nutrient pollution remains one of the most significant environmental and human health issues in the United States and has a considerable impact on local and regional economies. Solutions to nitrogen and co-pollutants (e.g., phosphorus, sulfur, sediments) are complexly intertwined with water and wastewater treatment capabilities and economic and social practicalities, expectations, and behaviors. Since nutrients both sustain and negatively impact humans and ecosystems, a critical question is how to achieve the appropriate beneficial level of nutrients for widely varying water bodies that will protect and sustain ecosystems, while providing the multiple services required by society (SAB 2011). The significant adverse impacts of excessive nutrients on human health and well-being and aquatic and terrestrial ecosystems are likely to be exacerbated in coming years by the pressures of climate change, extreme events, land use change, and the resource needs of an expanding human population.

For SSWR, there is a particular need to develop analyses of system responses to better understand how climate change will affect exposure and response thresholds for nutrients under a range of future climate scenarios. For example, how may rising temperatures interact with nutrients to affect expression of harmful algal blooms and associated algal toxins, potentially impacting ecosystems, human health, and the economic demands for increased water supply treatment?

EPA and its State and Tribal Partners must protect existing aquatic resources from excessive nutrients, and should return affected waters to the proper nutrient balance for healthy ecosystems, aquatic life, and human health. To advance nutrient reduction and recovery efforts, it is necessary to develop 1) the scientific basis to support determination of the appropriate nutrient level for U.S. water bodies, 2) the social, economic and health benefits of achieving such levels and recovering ecosystem services, 3) sustainable nutrient removal technologies capable of meeting low effluent concentrations; and 4) translating and transferring this information to decision makers.

The *Nitrogen and Co-pollutant Research Roadmap* (Roadmap) is a collaborative effort by EPA's research and program offices – Office of Research and Development (ORD), Office of Water (OW), Office of Air and Radiation (OAR) – and the EPA Regions. The Roadmap is a cross-media, integrated, multi-disciplinary approach to sustainably manage reactive nitrogen (Nr) and co-pollutant (e.g., phosphorus, sulfur, sediments) loadings to air, land and water to reduce adverse impacts on the environment and human health. The goal of the Roadmap is to develop a common understanding of EPA's research program portfolios developed by the ORD National Program Directors (NPDs) and to compare them with the OW and OAR program offices' priority research needs to identify major focus areas, opportunities for integration and technological innovation, research gaps and future research directions. The research program outlined below for SSWR draws heavily on content and structure developed as part of the Roadmap process for identification of gaps and future needs, and while it has been focused on water (ecological and human health needs), research objectives should interact and support related research in the other three National Research Programs (SHC, ACE, HHRA) participating in the Roadmap process. The Roadmap proposes that a next step towards nutrients research coordination would be to convene a research integration summit. Representatives of the key research projects, current or planned, under the StRAPs or Offices would convene along with representatives of the Offices, Regions and NPD staffs. Additional details on research needs for nutrients are available in the Roadmap Appendix E.

The Nitrogen and Co-Pollutant Roadmap identified six Science Challenges which map directly to the three Research Objectives identified below. Research Objective 1 includes Roadmap Science Challenges 1 + 2, Research Objective 2 includes Roadmap Science Challenges 3 + 4, and Research Objective 3 includes Roadmap Science Challenges 5 + 6. Together, the three Research Objectives organize the six Science Challenges into an ordered framework to provide the science needed to support reductions in nitrogen and co-pollutants to the nation's waters. Objective 1 is focused on improving our ability to determine appropriate thresholds and identify priority locations for reduction in nutrient inputs. Objective 2 is focused on improving existing management tools and developing new and innovative approaches to managing nutrients. Objective 3 is focused on research translation, i.e. improving the methods used to evaluate the effectiveness of management actions, and on the effectiveness of communication to stakeholders of the need for reductions and the methods that can be used to achieve nutrient reductions.

Research Objective 1: Improve Thresholds and Targeting Actions

Improve the science needed to define appropriate nutrient levels for the nation's waters in order to sustain ecosystem and human health, and the ecosystem services that promote human health and well-being. Provide the methods needed to identify and prioritize locations and sources for nutrient reductions, and the methods to optimize implementation approaches for optimized nutrient management. This research will assist the National Water Program (NWP), communities, and stakeholders by (1) providing the scientific basis to support the NWP in establishing nutrient targets that will achieve sustained integrity of the nation's waters, and (2) developing improved data, tools, and technologies to allow decision makers to determine priority systems for management actions.

Challenges:

Nutrient loadings from atmospheric, aquatic and terrestrial sources are variable on multiple scales, and the vulnerabilities vary across receptors, water bodies, human subpopulations, and water supplies. Prioritization for remedial action requires knowledge of the magnitude and sources of the loads, and the risks associated with expected ecological and human exposures, both locally and for downstream waters. Societal and economic costs/benefits must be incorporated into optimized nutrient reduction strategies. Effective approaches are needed to evaluate (a) nutrient occurrence and sources, (b) exposure by receptor, (c) nutrient pathways through ecosystems, and (d) ecological and human endpoints and thresholds.

Examples of specific research needs

- Develop empirical data and models that better tie nitrogen and co-pollutant related water quality impairments to quantitative loads, and better predict how impairments vary with changes in load, concentration and biogeochemical conditions.
- Determine how the magnitude, frequency, and duration of nitrogen and co-pollutant loading affect expression of impairment for different aquatic endpoints.
- Incorporate climate change (temperature, precipitation, runoff) into models predicting environmental impacts of future nitrogen and co-pollutant loads. Better integrate pollution-response models across air, land and all water body types.
- Develop and integrate ecosystem service metrics and accountability measures for social and economic endpoints of concern that are integrated into exposure-response models for nitrogen and co-pollutants.
- Support the Office of Water in deriving aquatic life criteria and downstream protection values for nitrogen and phosphorus.
- Harmful algal blooms: Understand relationship of water temperature increases to change in development of HABs (volume/unit time) and their duration and change in efficiency / proclivity of HABS to produce cyanotoxins.

Research Objective 2: Improve Nutrient Management Practices

Develop improved technologies and management practices to monitor and reduce nutrient loadings to levels that sustain ecosystem and human health, and the ecosystem services derived from the Nation's waters. In particular, provide technical support to design sustainable approaches, beyond current regulatory approaches, to manage nutrients by considering multimedia pathways of nitrogen and co-pollutants. This research will improve the effectiveness of existing nitrogen and co-pollutant tools to manage the reduction of nitrogen and co-pollutant loadings to achieve nutrient standards. Create cost effective, innovative, sustainable solutions for large scale, single and multimedia, nutrient management approaches for Program Offices, Regions, States, Tribes, and communities. Address sustainable nitrogen and co-pollutant management of important unregulated sources of nitrogen and co-pollutants in high priority areas.

Challenge:

While a suite of tools based on regulatory controls is available for setting standards and then monitoring, managing and reducing nutrients, such measures may not be sufficient to achieve the nutrient reduction goals established for a priority area when non-point sources are dominant. Innovative approaches, such as decision support tools for meeting targets that incorporate sustainable social and economic considerations into nutrient management and that go beyond individual sources may be necessary to be more effective, efficient, socially acceptable and sustainable. Technologies for nutrient removal are available, but can be improved in terms of integrated management, sustainable treatment for small systems, and innovative and sustainable nutrient treatment technologies. Improvements are needed for tools, such as 'best management practices' (BMPs) and 'inspection and maintenance' practices (I/M) for monitoring and managing nutrients at any point in the life cycle, in inputs such as fuels and industrial feedstocks, in improved industrial and agricultural treatment processes, and in waste streams through sequestration and removal in wetlands, ponds and vegetated buffers.

Examples of specific research needs

- Improved tools to assess the effectiveness of management actions on sources of nitrogen and co-pollutants across multiple media.
- Better tools to determine nitrogen and co-pollutant source apportionment in watersheds and aquifers at a range of scales.
- Continue efforts to introduce new technological applications to nitrogen and co-pollutant management problems, such as genomic indictors of sources and effects, satellite monitoring of conditions, and improved sensor technologies.
- Support and enhance monitoring programs that provide the information needed to assess system-level, long-term responses to policies and management.
- Support and enhance the science needed to predict, prevent and remediate contamination of drinking water sources (surface water and groundwater) by nitrogen and co-pollutants.

Research Objective 3: Improve Metrics of Benefits, Accountability and Communication

Develop the metrics, monitoring designs, and methods to assess changes in endpoints indicating the status of the ecosystem, human health, and societal benefits resulting from application of management actions and technologies to achieve appropriate and sustainable nutrient levels in the Nation's waters. Improve the science enabling effective communication and implementation of nutrient load reduction at national, community, and individual scales. This research will help to effectively communicate the need, and how to reduce loadings, to the variety of contributing stakeholders for improved results. Determine the overall accountability for the reductions and verify the expected amelioration of impacts and determine where novel approaches to monitoring and assessment will be needed.

Challenge:

The science behind communication for results is not well incorporated by the regulatory programs and regions, nor is it a substantial element of ORD expertise. To obtain nutrient load reductions by the multiple types of nutrient contributors, there needs to be a clear understanding of stakeholder perceptions of the problem, effective communication of how they can take action, *what tools may be used, and the benefits of doing so. At a minimum, review and synthesis of research on optimal communications approaches that lead to stakeholder action are needed. To accomplish effective assessments of the impact of management decisions will require collecting appropriate baseline data on nutrients to provide a basis for tracking changes. Information will be needed on other factors that are expected to cause changes in nutrient loadings, such as economic growth and extreme events, or that cause changes in effects of nutrient loadings, such as climate and land use changes. Development of both multimedia models (conceptual or computer-based) of the causal chain from sources to effects, and accountability measures for environmental, economic and social endpoints of concern will be needed. Scalable and transferable monitoring systems to detect changes in both exposure and human and ecosystem responses to changing levels of nutrients are also required.*

Examples of specific research needs

- Review and synthesis, and additional research if needed, into the communication approaches that result in individual, community, and corporate action.
- Review and synthesis, and additional research if needed, into the appropriate scale and complexity of communication tools for the need and user.
- Research to quantify the relation of nitrogen and co-pollutant reductions to ecosystem and human health benefits.
- Socio-economic techniques that provide (1) the ability to model the span of ecosystem responses to changes in exposure at numerous locations and (2) the ability to model the socio-economic metrics of key ecosystem endpoints of concern.
- Modeling systems for terrestrial effects that integrate biogeochemical and vegetation models and link with ecosystem services that can model biodiversity change as part of an accountability assessment.
- Improved modeling capability that includes accountability measures for social and economic endpoints, and improved ability to tie quantitative biological responses in a rigorous fashion to quantitative loads or concentrations of nutrients in natural water bodies.

Topic 3: Green Infrastructure and Stormwater

Over the last century, communities have developed and altered landscapes for residential, business, commercial, and service facilities. Because many of the land surfaces that were once permeable are now covered with impermeable surfaces, such as, buildings, roads, and other paved surfaces, the hydrology of the area changed from net infiltration to net runoff of stormwater. This net runoff carries increased pollutant loads and leads to erosion. In addition, many communities rely on combined sewer systems, which route stormwater and wastewater into the same pipes for conveyance to wastewater treatment plants. This has resulted in systems that cannot handle the large volumes of runoff that occur during storm events. To avoid storm event impacts, such as basement flooding, outfalls were built into the design of these combined sewer systems so that when the system was overloaded from stormwater, untreated wastewater would be released, resulting in combined sewer overflows (CSOs). These CSOs have become one of the most significant sources of water quality impairments in the United States.

Communities are now faced with aging wastewater infrastructure systems that are overstrained beyond their original design by expanding community size and population. This infrastructure, referred to here as gray infrastructure, must inevitably be enhanced and updated to support these larger communities; however, by reducing the amount of stormwater that enters the sewer system, the needed capacity and cost of gray infrastructure can be reduced. A way to achieve this is through the use of green infrastructure (GI) practices. Green infrastructure practices, such as permeable parking lots, infiltration trenches, rain gardens, green roofs, and rain barrels can increase the infiltration, retention or detention, and evapotranspiration of stormwater; thereby, reducing the amount that enters the sewer system. These GI practices are attractive to communities because they can potentially reduce the amount of gray infrastructure investments required, while also offering other co-benefits. For example, vacant properties in many older cities are being repurposed as GI landscape areas, which improve the aesthetics of neighborhood and can improve property values and social well-being. By replacing dark surfaces with vegetation associated with many of the GI practices, urban heat island conditions can be reduced. Because of the direct and indirect economic benefits of incorporating a combination of green and gray infrastructure practices, many communities are including GI investments into their stormwater management plan requirements, CSO control strategies, and infrastructure investment plans. Tools for determination of the optimal combination of green and grey infrastructure and address community-specific hydrology, infrastructure, and land characteristics are needed.

Research objective 1: Support increased adoption of green infrastructure into community stormwater management plans and watershed sustainability goals through advancement of GI models and tools.

Challenge:

Feedback from local governments highlights the need for additional tools and information to help decision makers and planners identify effective GI opportunities and understand how it will meet their stormwater goals. To date, ORD's GI research has provided key tools, such as the Storm Water Management Model (SWMM), the National Stormwater Calculator (SWC), and the Hydrological Simulation Program - FORTRAN (HSPF), to address stormwater management and pollutant loading at different scales. The SWC is an easy to use tool that developers and planners can use for estimating runoff reductions using GI practices at the site scale (e.g., home, commercial facility). The SWMM, on the other hand, can be used for entire urban watersheds with great detail given to land use and sewer system dynamics, and HSPF can be used for even larger watershed-scale management of pollutant loading for Total Maximum Daily Loads (TMDLs). These more comprehensive models require a significant level of technical expertise and data; however, this level of detail is critical for design and planning needed in the implementation of major stormwater and/or TMDL efforts.

Examples of specific research needs

- GI Models and Tools
  Research in this area will be focused on two targeted areas: development/adaptation and assessment.

- Tools will be developed and/or adapted to provide community planners and decision makers the ability to integrate GI practices and stormwater runoff into their planning options across their area. These intermediate tools will complement the more complex tools like SWMM (for more detailed implementation and design of green and gray infrastructure) and HSPF (for watershed pollutant loading reductions). This will involve collaboration with the Sustainable and Healthy Communities (SHC) research program efforts with geospatially-based (GIS) community planning tools.
- The current inventory of available EPA stormwater related tools will be assessed to improve their accessibility and advance their use for managing stormwater and pollutant loading at multiple scales. Each of the tools offer users the capability to manage stormwater and associated pollutant loading; however, their collective use can offer a more comprehensive watershed management strategy with effective GI BMPs. Each is discussed further below.

The current EPA set of GI and stormwater tools include SWMM, SWC, HSPF, VELMA, and the BMP Siting Tool (beta). Some of these tools focus on site and very local scales, and others, like the BMP siting tool, SWMM, and HSPF, can address larger and more complex watersheds. New efforts will be developed to study how these tools can be collectively used to assess the impact of GI on runoff and water quality at different watershed scales for surface water and groundwater. Based on gap analysis and how these tools are being used separately and together in the scientific literature and by users, additional improvements may be identified to further the tools' capabilities. One or more locations will then be selected to apply these tools to demonstrate the impacts of GI on runoff and pollutant loading at varying scales. The modeling demonstration pilots may be located at community partner studies where extensive data are available (Research Objective 2, Topic 3).

- Making existing stormwater modeling tools more accessible to the user community.

  For example, the accessibility of the SWMM model would benefit from adaptations to link with GIS systems. The BMP siting tool~~s~~, which are a plug-in to ArcGIS version 10, can be used to map GI across a community and then be used in SWMM modeling scenarios. Since many of the input data needed by SWMM as well as the GI scenario development are originally developed in a GIS platform, developing links between SWMM inputs and outputs is a logical improvement to this extensively used stormwater tool[1].

  An additional functionality that will make some tools more accessible would be to convert to a web-based approach. In particular, we have received many requests from the public to make the SWC compatible with Mac computer systems and/or iPads and iPhones. The most feasible solution is to convert this widely used tool to a web-based approach that is platform independent.

- Analysis of life cycle costs of green versus gray infrastructure. Existing studies, tools, and information will be explored to develop an approach for this analysis based on the literature and existing data and information available.

[1] ~20,000 downloads per year from EPA's website.

With recent additions of climate scenarios to stormwater modeling tools, many of the suggested activities mentioned above will be able to consider potential climate changes and those impacts on average and episodic (e.g., 20 year storm) changes in precipitation and temperature.

Research objective 2: Support increased adoption of green infrastructure into community stormwater management plans and watershed sustainability goals: Information and Guidance through Community Partnerships.

Challenge:

As communities consider whether they can address some of their stormwater challenges with green infrastructure in addition to needed gray infrastructure upgrades, they need guidance and information about green infrastructure placement, performance, and longevity. For example, soil survey protocols have been developed and demonstrated to assess optimal locations for green infrastructure practices. Additional information about the performance of various green infrastructure practices in different environmental and regional conditions has been requested.

Ongoing community GI pilots in areas such as Philadelphia, Cleveland, and most recently Camden are providing information on the performance, operation and maintenance of GI practices. Notably, Philadelphia is the recipient of five research cooperative agreements through the ORD STAR program. Many of these community pilots are located in areas where environmental justice issues are relevant and benefit from revitalization (a notable link with SHC). The lessons learned and the information gained from the ongoing partnerships can be applied to other communities through guidance and information about the use of GI practices in their CSO plans and stormwater management. The information gained from the pilots includes runoff and water quality impacts of GI, socio-economic and environmental justice (EJ) factors in some cases, the creation of a national atlas of soils, and the regional analyses of stream/river habitat and biota impacts.

Specific areas of need for additional pilots include green infrastructure for arid environments (e.g., groundwater recharge and quality, water reuse), constructed natural green infrastructure, such as wetlands, for wastewater management and nutrient removal, and longevity of green infrastructure performance over time.

Examples of specific research needs

1. Continued and new community pilot studies to study the effectiveness of GI pilots and potential co-benefits to develop guidance and lessons learned for other communities. Ongoing partners will likely include Philadelphia, Cleveland, Camden, and some larger regional analyses of aquatic ecosystem condition with EPA Regional partners. Future partnerships will be decided OW, OECA and the Regions.
2. Study linking green infrastructure for infiltration, groundwater recharge, and potentially linking with aquifer storage and recovery. Working with a community partner with goals for aquifer storage and recovery, green infrastructure designed could be considered to facilitate groundwater recharge, arid environment conditions, and consider groundwater

quality issues.

3. Study assessing impacts of excess nutrient loading on wetlands as a means for wastewater treatment or nutrient management. Results from these controlled studies could be used to inform future modeling development.

Topic 4: Water Systems

Earlier approaches to water systems have achieved great improvements in public health; however, sustainable solutions are needed for a growing global population facing increased resource constraints. The availability of drinking water, including surface water and groundwater, is a critical issue that is expected to intensify over time necessitating technological innovation for sustainable, cost effective and low carbon footprint reduction of pollutants. Innovation is also needed to foster direct and indirect potable water reuse and expanded use of nontraditional waters — such as treated wastewaters, brackish and saline waters, and produced waters from oil and gas — suitable for various non-potable uses. Several approaches affect many of these areas, such as aquifer storage and recovery. New approaches are needed to continue the high level of public health protection, while maximizing the recovery of other resources embedded in treated waters, such as nutrients, energy, and materials (e.g., metals, chemicals), with resilient and energy efficient technologies. Producing and delivering safe drinking water, and collecting and treating wastewater to safe levels for ambient waters requires infrastructure that has continually improvements in resilience, sustainability, and acceptability.

Public acceptance, awareness, and community outreach are important challenges given the critical role public acceptance plays in the use of new technological approaches for both conservation and reuse. There has been resistance to adoption of some technological innovations due to lack of public acceptance and other societal factors, such as financing and business development gaps that prevent widespread commercialization of promising new technology. These non-technological, societal factors need to be understood and addressed to more effectively develop implementable and sustainable technological solutions to water systems challenges. Better understanding of the opportunities for water reuse at the local and national scale and of obstacles to wider implementation of water reuse projects are needed.

Small water systems are a particular focus of SSWR research because they often lack financial, human, and infrastructure resources to choose, build, operate, and maintain even moderately complex systems. They often have limited options for residual disposal, do not have managerial capability to comply with regulatory requirements, such as meeting Maximum Contaminant Levels (MCL) for microorganisms, disinfectants, disinfection byproducts, inorganic and organic chemicals, radionuclides; lack capacity to manage regulatory paperwork; and their state agencies often have limited resources for providing support to the large number of small systems that they must regulate. Small-scale system research can be translated to larger systems, either through sustainable treatment in centralized small systems or more direct use of clustered decentralized ones. Of particular need is the availability of cost-effective treatment approaches that enable small systems to meet new stringent requirements, such as the recent ammonia ambient water quality criteria given the economic, technical and administrative capacity limitations of many small communities.

Finally, the concept of resilience, here defined as “the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions", is an important consideration in the development of the next-generation of water systems. Resilient approaches will not only protect water quality and availability from impacts of climate variability and change and extreme weather events (e.g., drought, heavy precipitation and flooding), but also protect capital investments and minimize reconstruction costs resulting from short-term disruptions (e.g., earthquakes, flooding) or long duration changes (e.g., water table elevation changes, sea level rise and saltwater intrusion). Research in resilience must address water quality issues, such as expected degradation of water quality due to reliance on more heavily impacted water sources. The role of infrastructure is particularly important in this regard. The development of new infrastructure concepts for the long term is critical in providing for this resiliency. There should be close interface between the SSWR, SHC, HSRP, and ACE programs for resilience-related projects.

Research objective: Develop, evaluate, and facilitate adoption of technologies to support, advance and transform water systems.

This research objective provides for a continuum of research, ranging from application of the newest tools that address current community concerns and inform regulatory actions, to assessment of new monitoring and treatment approaches, and to consider more inventive restructuring of water systems to meet sustainability goals. This research will support the Agency's goals to:

- Assist small systems to reliable deliver safe drinking water in sustainable manner.
- Promote economic recovery of water, energy, and nutrient resources through innovative municipal water services and system-wide assessment tools.
- Provide innovative tools, technologies, and strategies for managing water resources (including stormwater) currently and in the future as climate and other conditions change.
- Enhance the capability of drinking water distribution systems and wastewater collection systems to proactively protect human health and the environment.

Challenges:

- *To develop solutions and technologies that are accessible to all systems, including small systems.*
- *To assess research gaps and collaborate with industry stakeholders to address the gaps and support steps needed for development, testing, and introduction of sustainable technologies.*
- *To safeguard human health and the environment from known and emerging chemical and biological contaminants in water resources (e.g., drinking water, source water, treated wastewater, recreational waters), while maximizing resource conservation and recovery (e.g., water, energy, nutrients, and other beneficial materials).*
- *To gain state agency, community water systems, and public acceptance of alternative approaches.*
- *To enhance the resilience of water systems to continue to reliably provide safe drinking water in light of current and future climate and other challenges.*
- *To develop and introduce new sustainable, cost-effective, and low carbon footprint technologies in collaboration with industry partners to enable communities to meet low*

nutrient limits (below the current limits of technology) in an environmentally acceptable manner.

Research Objective: Safety of the Nation's water

This research objective addresses the continuing needs to assure the safety of water to protect human health and the environment. Research needs to be conducted to assess the health and environmental impacts of known and emerging chemical and biological contaminants in water, including drinking water and its sources. This research will support the Agency's goals to:

- Evaluate individual and groups of contaminants for protection of human health and the environment.
- Enhance the resilience of water systems to continue to reliably provide safe drinking water in light of current and future climate challenges.

Challenges:

- *To determine the safety of water resources for human consumption, recreation, and other uses; understand the attributes of watersheds that contribute to lesser or greater harmful contamination by toxic substances and pathogens.*

- *To assess drinking water exposures and effects of contaminants: with primary focus on emerging contaminants and contaminant groups and mixtures.*

- *To developing effective risk assessment and mitigation approaches for a range of water fit for purpose options (e.g., water reuse for non-potable purposes, such as toilet flushing, irrigation, energy production, etc.).*

Examples of specific research needs

The topic (including both research objectives) is organized into three Projects that reflect the time spectrum from near- to intermediate term and then long-term research needs related to water systems:

1) Current Water Systems
2) Next Steps: Technology Advances
3) Long Term: Transformative Systems

This organization provides temporal continuity to the work, emphasizing all three elements of the overall research objective (i.e., supporting, advancing, and transforming water systems). Crosscutting science challenges can be iteratively addressed. For instance, the regulatory and implementation work in Project 1 would inform the requirements for technological advances in Project 2, which would then inform the direction of research on transformative systems further in the future (Project 3). It is also expected that the results of research on the second and third projects will help provide insight in future regulatory frameworks (Project 1).

The specific objective of Project 1 (Current Water Systems) research is to support a) federal regulations and guidance, and b) regional, state, and community programs and rule implementation. This includes the risk assessment (e.g., determination of MCL standards for drinking water contaminants) and risk management (DW Treatment Technologies to meet MCL requirements, including priority contaminants and groups of contaminants). The needs are particularly acute for small systems as discussed above. Short-term needs of the program office and communities can be rapidly addressed via flexible planning, providing timely input to influence regulatory and guidance issues to the agency. Research support to the communities, states, regions, and program offices (e.g., RARE projects, support to regulatory development, or Six Year Review projects) would be grouped within Project 1. This work would influence Project 2 (Next Steps: Technology Advances) and Project 3 (Long Term: Transformative Systems). Potential efforts anticipated for Project 1 include:

- Develop and validate methods for efficient detection and quantification of emerging chemical and biological contaminants, including pathogens and cyanotoxins.
- Occurrence, exposure and transport of contaminants (chemical and biological) of concern.
- Health effects of contaminants (chemical and biological) or mixtures of concern for both human and environmental health.
- Management of contaminants (chemical and biological) or mixtures of concern in drinking, storm, and wastewater.
- Performance and costing of potential regulations.
- Implementation guidance to the states and regions.
- Guidance support (e.g., current *Legionella* guidance).
- Small system support and training (e.g., The Small System Workshop).
- Future water reuse guidelines.
- Research to support regulatory development.
- Research to support implementation of existing and new EPA water quality regulations.
- Six year review projects.
- Screening hydraulic fracturing wastewater treatment options, including management of residuals.
- Support and enhance current U.S. and international research on sustainable point source nutrient removal and recovery technologies and collaboration with industry stakeholders to expedite the development and market introduction of cost effective and low carbon footprint technologies.

The specific objective of Project 2 (Next Steps: Technology Advances) is to develop, test, and promote adoption of drinking water, stormwater, and wastewater technologies that will protect human health and the environment while maximizing resource recovery. This project develops the unit process data that will inform Project 1 (Current Systems) and feed into the transformative Project 3. Specific potential efforts that may be included into Project 2 are:

- Improved disinfection approaches for wastewater and drinking water (e.g., peak flow treatment, and UV disinfection and monitoring for adenovirus inactivation and DBP control).
- Develop novel human and environmental health effect assays and predictive models for individual and groups of contaminants.
- Microbiological treatment for multiple contaminants (understanding microbial assemblages, contributing members, enzymatic pathways, and process control).

- Utilization of real-time sensors to manage collection systems.
- High rate treatment for wet weather flows (e.g., BOD, disinfection).
- Wastewater optimization (e.g., nutrient removal, nitrification optimization and control, and small system retrofits).
- New monitoring tools for mixtures (e.g., bioactivity).
- Net Zero technology development.
- STAR centers (two recently funded Small Drinking Water System centers, four nutrient management research centers, and the upcoming water reuse center).
- Technology innovation cluster activities to support and facilitate commercialization of promising innovative technologies (i.e., funding EPA scientists/engineers, networking with external cluster organizations to access business accelerators, collaboration with industry stakeholders to identify research gaps, venture funding, and small/large companies).

Contaminant (microbiological and chemical) related research in both Projects 1 and 2 will be closely aligned with relevant watershed related contaminant research in Topic 1 to ensure that common tools and models are effectively employed across the water cycle (e.g., informing research on the basis of the interrelationships between contaminants in water system discharges, fate and transport in the environment, and resulting levels in source water).

The specific objective of Project 3 (Long Term: Transformative Systems) is to conduct integrated sustainability assessments, develop novel approaches, prioritize risks, and provide a framework for decision making, related to alternative approaches to existing water systems. The time line of this research will be longer in scale as compared to Projects 1 and 2, focusing on far reaching issues of how to best restructure water systems to meet the future goals of public health protection and resource recovery. This project will develop approaches that may be integrated into Project 1 and 2 efforts to lay the groundwork for future regulations and technological advances. Potential efforts that may be included in Project 3 are:

- Integrated sustainability assessments, including life cycle assessments, life cycle costs, advanced water foot printing approaches, and sustainable use of chemicals.
- Development/evaluation of novel water system configurations, including a more holistic approach to water services based on the linkage of drinking water, wastewater, stormwater, and watersheds (link to Topic 1).
- Assessment/prioritization of risks within alternative systems.
- Rapid, inexpensive approaches to efficacy monitoring including human and ecological health endpoints.
- Scenario-based planning.
- An integrated framework for stakeholder decision making, including climate change.

The three Projects will address the crosscutting science challenges discussed above (small systems; reuse and recovery; public acceptance, awareness, and community outreach; resiliency). Also, the effort to conduct a unified framework across multiple programs will create a more efficient research program, and allow for synergistic research projects.

The overarching goals of the SSWR StRAP include addressing problems resulting from climate change, extreme events, population/social issues and economics. The research in this topic reduces the impacts of climate and extreme events on the availability and quality of water, promotes public acceptance and maximizes economic benefits. These issues will be addressed in each of the Projects but mostly in Project 3 (Long Term: Transformative Systems) where these issues, requiring a longer-term research approach, are more formally addressed. Project 3 is specifically geared toward these issues, although as mentioned earlier, the aspects of Project 3 will translate into the other two and vice versa.

Overall, Topic 4 develops and encourages the acceptance and application of new scientific advances, thereby demonstrating innovation. Ultimately, all three Projects will have an impact, but these impacts will differ with respect to their programmatic implementation and time scales. Project 1 will impact regulations and their implementation. Project 2 will impact the next generation of innovative technologies that communities will employ. Finally, Project 3 will chart a vision for a sustainable future.

VII. Anticipated Research Accomplishments

- **Watershed Sustainability**: Map and predict the physical, biological, and geochemical integrity of our Nation's waters, from headwaters to streams, rivers, lakes, estuaries, coasts and wetlands for the purposes of 1) understanding causality of deterioration and attributes that promote integrity and resilience, 2) identifying areas that most warrant protection or restoration and implement measures to maintain or improve their integrity and resilience, and 3) linking the integrity and resilience of waters to human health and well-being and economic prosperity for sustainable use and stewardship of our Nation's water resources.

- **Nutrients**: Work towards understanding nutrient thresholds to balance the beneficial use of nutrients by ecosystems and society across various temporal and spatial scales and targeting where the greatest improvements can be achieved by reducing point and nonpoint source nutrient loading. Research will support the development of numeric nutrient criteria and improved technologies, best management practices and inspection and maintenance practices to cost effectively monitor and reduce nutrient loading using current regulatory, voluntary and green infrastructure approaches, and will consider multimedia pathways and under-regulated nutrient sources. Integrated with the Watershed Sustainability and Water Systems topics, develop innovative technologies and market opportunities for nutrient recapture and reuse to offset investments in energy efficient treatment technology and to minimize the environmental impacts and energy demand of novel source extraction. Develop the metrics to assess progress in achieving these accomplishments and communicate the ecosystem, human health, and societal benefits to communities and other various stakeholders.

- **Green Infrastructure**: Develop and implement innovative tools, technologies, and strategies for managing stormwater runoff and other flooding events, using natural and built green infrastructure in combination with gray infrastructure, over the long term when existing infrastructure will require repairs or replacement and improved resiliency is needed for climate change, extreme events, and security threats. Verify reliability and explore with partners the ability to quantify the comparative costs and benefits of gray and green infrastructure for managing water volume and improving water quality and other co-benefits (groundwater recharge, rainwater harvesting for irrigation, improving human health by reducing ground level ozone and particulate matter and providing opportunities for recreation, reducing urban heat islands, creating habitat, improving property values, new jobs, etc.). Anticipate any unintended consequences related to increased water permeation in soil and groundwater.

- **Water Systems**: Continue the high level of public health protection with a focus on sustainable treatment technologies to address existing and emerging, chemical and microbial contaminants (individual and groups), while increasing water reuse (and public acceptance) and maximizing the treatment and recovery of other resources embedded in treated waters, such as nutrients, energy, and materials (e.g., metals, chemicals), with resilient and energy efficient technologies. Focus research on cost-effective treatment technologies and operation and maintenance for small water systems, either by novel treatment processes or sustainable approaches including effective decentralized systems. Resilient approaches are needed for all systems for extreme event, climate change, and security preparedness for the protection of water quality and availability, human and environmental health, and capital investments.

VIII. Conclusion

TO BE COMPLETED IN FINAL STRATEGIC RESEARCH ACTION PLAN

Appendix A. Examples of Outputs

Table of Example Outputs, Safe and Sustainable Water Resources FY16-19

Watershed Integrity

- Framework for structured evaluation of model approaches and applications needed to assess the interaction of watershed-based stressors with aquatic ecosystem responses (FY16)
- Analytical techniques and systems modeling to aid development of market based activities that promote watershed integrity (FY17)
- Proactive approaches to assessing risks to watershed integrity and sustainability associated with current, transitioning or emerging technologies and practices, including water use, for the life cycle of conventional and unconventional energy, minerals, and other materials. FY18
- National-scale assessment of the economic benefits of water (FY19)

Nutrients

- Models, technologies and decision support tools that include economic and sustainability approaches to aid with setting nutrient reduction goals and optimize implementation approaches (FY19)
- Provide technical support to design sustainable approaches, beyond current regulatory approaches, to managing nitrogen and co-pollutants that consider multimedia pathways of nitrogen and co-pollutants (FY19)

Green Infrastructure

- Performance information, guidance and planning tools are developed to facilitate increased adoption of GI (FY 16)
- Demonstrate modeling tool approaches to assess green infrastructure effectiveness for managing both runoff volume and water quality at multiple watershed scales (FY19)

Water Systems

- Develop health assays for regulatory and evaluation purposes, and determine effectiveness of innovative and flexible design, construction, and treatment approaches for small and disadvantaged systems to assure safe water quality within distribution and conveyance systems to protect public health (FY16)
- Integrated life-cycle assessment of human health impacts and social acceptance of novel/alternative approaches to water systems that emphasize resource recovery technologies and energy efficiency (FY19)