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United States
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Agency

Safe and Sustainable Water Resources

STRATEGIC RESEARCH ACTION PLAN 2012-2016

SCIENCE

Office of Research and Development
Safe and Sustainable Water Resources

EPA 601/R-12/004

Safe and Sustainable Water Resources

Strategic Research Action Plan 2012 - 2016

U.S. Environmental Protection Agency
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Executive Summary

This document represents a strategic guide to EPA's research actions, alone and in partnership with the broader federal, industry and scientific research community, to provide the science and engineering necessary for safe and sustainable water resources.

Increasing demands are being placed on finite water resources to supply drinking water, water for other societal needs (including energy, agriculture and industry), and the water necessary to support healthy aquatic ecosystems. Having adequate water of sufficient quality underpins the Nation's health, economy, security and ecology. It is the responsibility of the U.S. Environmental Protection Agency (EPA) to conduct research and analyses that will ensure that the Nation's water resources are safe for use and can be sustained for future generations. To ensure that EPA decisions protecting water resources are based on sound science, EPA's Office of Research and Development (ORD) has integrated its Drinking Water and Water Quality research programs to create the Safe and Sustainable Water Resources (SSWR) Research Program. The SSWR Research Program is undertaking development of sustainable solutions to 21st century water resource problems by integrating research on social, environmental and economic outcomes to provide lasting solutions.

SSWR will target two major challenges:

- Provide the best science in a timely manner to allow faster and/or smarter management decisions for the Nation's existing water resource problems; and

- Get scientific knowledge out in front of tomorrow's problems by developing and applying new approaches that better inform and guide environmentally sustainable water resource management.

Increasing demands for sources of clean water, combined with changing land use practices, population growth, aging infrastructure, and climate change and variability, pose significant threats to the Nation's water resources. Failure to manage the Nation's waters in an integrated, sustainable manner can jeopardize human and aquatic ecosystem health and impact our society and economy. The SSWR Research Program seeks to develop sustainable solutions to these complex water issues and proactively develop solutions to emerging and future problems, ensuring that clean, adequate and equitable supplies of water are available to support human well-being and resilient aquatic ecosystems, now and in the future.

The SSWR Strategic Research Action Plan was developed by EPA scientists and managers from ORD, the Office of Water (OW), other programs offices and the regions, with input from stakeholders from water associations, water research foundations, utilities, environmental groups, tribes, industry, and state agencies. The input from these groups was invaluable in identifying the problem statement and vision for SSWR, as well as the key research that will result in timely, relevant and sustainable solutions.

The program uses two broad, interrelated research themes as its framework: (1) Sustainable Water Resources and (2) Sustainable Water Infrastructure Systems.

The goals of these thematic research areas are:

Research Theme 1—Sustainable Water Resources:

Ensure safe and sustainable water quality and availability to protect human and ecosystem health by integrating social, economic and environmental research for use in protecting and restoring water resources and their designated uses (e.g., drinking water, aquatic life, recreation, industrial processes, other designated uses) on a watershed scale.

Research Theme 2—Sustainable Water Infrastructure Systems:

Ensure the sustainability of critical water resources using systems-integrated water resource management in which the natural, green and built water infrastructure is capable of producing, storing and delivering safe and high-quality drinking water, and providing transport and use-specific treatment of wastewater and stormwater.

Introduction

Adequate and safe water underpins the Nation's health, economy, security, and ecology (NRC, 2004). It is the responsibility of EPA to conduct research and analyses that will ensure that the Nation's water resources are safe for use and can be sustained for future generations. In EPA's 40-year history, significant advances have been made in protecting the country's waters through the effective control of potable water treatment and point-source contamination. This has resulted in better protected and improved human and ecosystem health through reductions in waterborne disease organisms and chemicals.

Despite the advances made during the past 40 years, there are 21st century challenges that continue to threaten the Nation's water supplies. The Nation's wastewater and drinking water systems are stretched to serve an increasing population, and they suffer from inadequate, outdated and/or neglected infrastructure, resulting in more than 240,000 water-main breaks per year (Kirmeyer et al. 1994), losing trillions of gallons of water each year at a cost more than $2.5 billion. In addition, there are as many as 75,000 sanitary sewer overflows per year, which discharge billions of gallons of untreated wastewater into the Nation's water resources and contribute to more than 5,000 annual illnesses from contaminated recreational waters (U.S. EPA 2004). Waterborne disease continues to threaten drinking water supplies as well, with Legionella and viruses the more common pathogens attributed to disease incidences (Yoder et al. 2008).

The controls on point sources of pollution will no longer suffice to sustain the Nation's water quality, as nonpoint sources in watersheds, when viewed collectively, are often the main pollutant contributors. An example is nutrient pollution (nitrogen and phosphorous), described as EPA Office of Water's (OW) "water issue of the decade." The events that cascade from nutrient pollution are not simply a pervasive problem for aquatic ecosystems, they also create public health problems. Both of these will likely be exacerbated by climate variability/change and changes in water quantity. Nutrients enter the hydrologic cycle either directly or from other media (air, land) where they adversely impact fresh surface water, groundwater, estuaries and marine systems. Based on Clean Water Act (CWA) Section 303d listings of impaired waters, excessive nutrient loads are responsible for poor biological condition in more than 30 percent of the Nation's stream miles (U.S. EPA 2006) and about 20 percent of the Nation's lakes and reservoirs (U.S. EPA 2009b). In addition, these loads raise public health concerns associated with toxic cyanobacterial blooms, nitrate pollution and the formation of disinfection by-products in drinking water supplies. Solving the nutrient pollution problem and ensuring sustainable, safe water resources will require expertise from the industrial (e.g., energy, agriculture), social (e.g., public health, cultural) and environmental (e.g., wastewater treatment, natural green infrastructure, recreation) sectors.

Another challenge in meeting EPA's responsibilities for managing water quality to meet designated uses is water quantity. The U.S. Geological Survey (USGS) evaluates the withdrawal of water for different uses, including water used for consumptive purposes. The USGS (2005) estimated that more than 85 percent of the withdrawals in the United States were from freshwater, with 80 percent of that being drawn from surface waters. The 340 billion gallon-per-day freshwater withdrawals support primarily irrigation and livestock

(85%), industrial and mining processes (4%), and thermal electric power (3%).

Thus, the increasing demand for sources of clean water, combined with changing land use practices, growth, aging infrastructure, increasing energy and food demands, increasing chemicals in commerce, and climate variability and change, pose significant threats to the Nation's water resources. Specific effects from these pressures on drinking-water quality or aquatic ecosystem condition are more difficult to define, and current assessments are not sufficient to meet the information needs of most water resource managers. These demands and uses are creating diffuse and widespread stressors on finite water resources, and these stressors cannot be accommodated by conventional 20th century approaches. As a result, the rate at which waters are listed as being impaired exceeds the rate at which they are being restored (U.S. EPA 2011a). Without new and better approaches to inform and manage the Nation's changing water condition, the country will continue to slip backward from its earlier progress toward clean water, and this will limit economic prosperity and jeopardize human and aquatic ecosystem health.

To address these challenges, EPA has integrated its Drinking Water and Water Quality research programs and established the SSWR Research Program. The goal of this program is to seek sustainable solutions to the 21st century problems facing the Nation's water resources. This document represents a strategic guide to EPA's research actions, alone and in partnership with the broader federal, industry and scientific research community. The following are the problem statement and vision for the program as developed by scientists and managers from EPA's ORD, OW, other programs offices, regional offices, and external stakeholders from water associations, water research foundations, utilities, environmental groups, tribes, industry, and state agencies.

Problem Statement: Increasing demands for sources of clean water, combined with changing land use practices, growth, aging infrastructure, and climate change and variability, pose significant threats to the Nation's water resources. Failure to manage the Nation's waters in an integrated, sustainable manner will limit economic prosperity and jeopardize human and aquatic ecosystem health.

Vision: SSWR uses an integrated, systems approach to research for the identification and development of the scientific, technological and behavioral innovations needed to ensure clean, adequate, and equitable supplies of water that support human well-being and resilient aquatic ecosystems.

Research Supports EPA Priorities

- *Taking action on climate change*
- *Improving air quality*
- *Assuring the safety of chemicals*
- *Cleaning up our communities*
- ***Protecting America's waters***
- *Expanding the conversation on environmentalism and working for environmental justice*
- *Building strong state and tribal partnerships*

Statutory and Policy Context

EPA is responsible for protecting the Nation's water resources under the Clean Water Act (CWA) and for ensuring that the Nation's drinking water is safe under the Safe Drinking Water Act (SDWA). Further, it is the responsibility of EPA to conduct research and analyses to inform decisions ensuring that the Nation's water resources are safe for use and can be sustained for future generations.

EPA Priorities

Building on EPA's statutory responsibilities, EPA's FY 2011–2015 Strategic Plan, Achieving Our Vision (U.S. EPA 2011b) highlights "Protecting America's Waters" as one of seven key goals for the Agency. Under this goal, EPA will strive to *"protect and restore our waters to ensure that drinking water is safe, and that aquatic ecosystems sustain fish, plants, and wildlife, and economic, recreational, and subsistence activities."*

SSWR is well positioned to support this goal and the two specific objectives of protecting human health and protecting and restoring watersheds and aquatic ecosystems. By focusing on sustainable solutions and integrating the historical drinking water and water quality research into one holistic program, EPA will be able to leverage expertise and capabilities to address not only manifestations of water problems (such as poor water quality) but also the root causes of problems related to increased urbanization, population demographics and nonpoint source pollution as a means toward achieving sustainable solutions (Figure 1). In addition, research under this program will benefit other strategic goals (e.g., *Taking Action on Climate Change and Improving Air Quality, Cleaning Up Communities and Advancing Sustainable Development, and Ensuring the Safety of Chemicals* and *Preventing Pollution*) through the intersection of SSWR with each of the other ORD research programs.

The overarching and actionable goals for SSWR research stem from EPA's mandate and the needs for EPA's National Water Program to:

• Protect public health and the environment;

• Protect and restore water sustainably to ensure that drinking water is safe and that aquatic ecosystems sustain fish, plants and wildlife and to meet societal, economic and environmental needs; and

• Manage water resources in a sustainable manner that integrates wastewater, stormwater, drinking water and reclaimed water; maximizes the recovery of energy, nutrients, materials and water; and incorporates comprehensive water planning (such as low-impact development and smart growth) and optimum combinations of built, green and natural infrastructure.

Considering the types of challenges facing the Nation's water resources, the program developed the following comparison of current and desired state (Table 1) to illustrate SSWR's research goals for achieving safe and sustainable water resources.

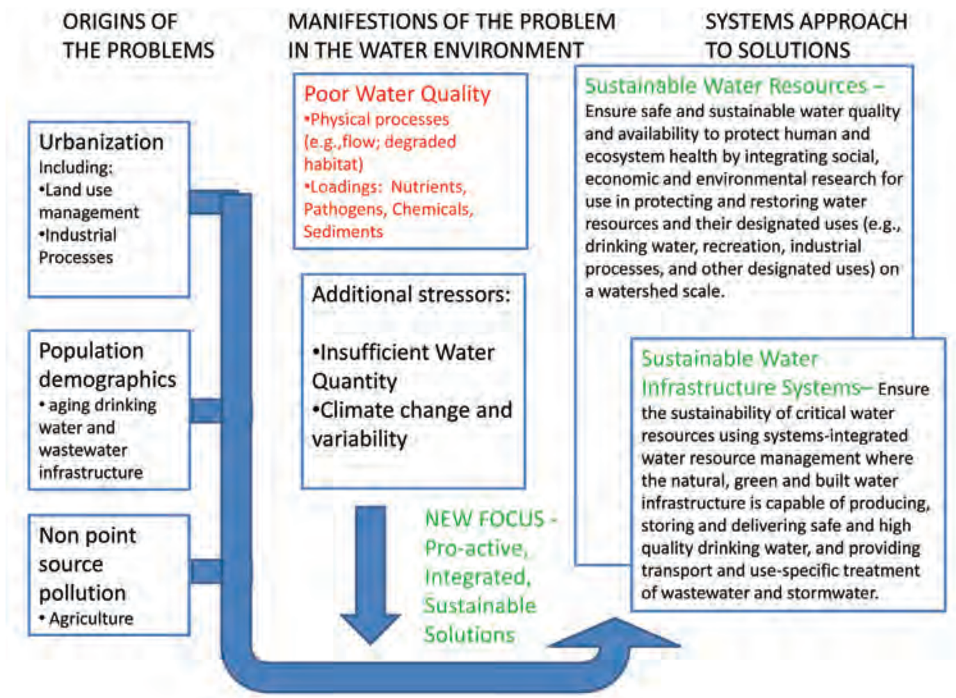

Figure 1. SSWR Research Program to address both the origins and manifestations of problems in the water environment.

Current State	Desired State
Not all communities receive high quality drinking water	All US communities receive high quality drinking water
Human health and aquatic life are challenged by known and emerging contaminants in our water resources	Human health and aquatic ecosystems are proactively protected
Lack of resilience to climate change or other destructive forces	Resilient, climate ready, flexible, efficient, and adaptive systems
Failure of aging water infrastructure outstrips resources to repair, replace, and restore function and uncharacterized public and ecosystem health impacts	Synergistic use of natural ecosystem services and built infrastructure to achieve well characterized and safe public and ecosystem health
Many water bodies are impaired by excessive nutrients	Nutrient levels are in balance with natural water systems and associated safe public and ecosystem health
Watershed integrity is compromised by unsustainable land use practices	Watershed/ basin hydrology has been restored to maintain integrity
Increased urbanization and land development threaten healthy watersheds	Environmental stewardship is incorporated into our societal fabric and land use planning, resulting in an increase in healthy watersheds
Unsustainable practices threaten water resources and water treatment capacity is often insufficient for existing loads	Water availability and quality is consistently maintained in an affordable manner to support human and ecological needs
Potable water demand is increasing in populated areas	Potable water demand is safely met by local sources while maintaining ecological needs

Table 1. Aspirational desired state to achieve safe and sustainable water resources.

To achieve the desired states, SSWR research will seek to:

- Develop next generation water system concepts that decrease energy demands, recover resources and restore the environment through affordable and public health promoting means; and
- Utilize effective tools for various scales and tiers of application to undertake systems analysis of water resources by addressing health/societal needs, economic and ecosystem concerns.

Program Design

Producing an Integrated Program

Historically, EPA's Drinking Water and Water Quality Research Programs conducted research in support of EPA's OW and regional offices. The Drinking Water Research Program provided methodologies, data, tools, models and technologies that inform regulatory decisions, health risk assessments and other needs pertaining to the Safe Drinking Water Act's statutory requirements. Drinking water research has been targeted at the reliable delivery of safe drinking water and developing approaches to improve water infrastructure, promoting high-quality water sources and implementing regulatory decisions while addressing simultaneous compliance issues.

The Water Quality Research Program, alternatively, was designed to support the CWA. It does so by providing scientific information and tools to help protect and restore the designated uses of water bodies that sustain human health and aquatic life. Water quality research has focused on the development and application of water quality criteria, the implementation of effective watershed management approaches, and the application of effective treatment and management alternatives to restore and protect water bodies.

The rationale for realigning the Drinking Water and Water Quality Research Programs into one program is simple: water is one resource. The SSWR Research Program will begin addressing key issues, such as comprehensive water resource management, water sustainability metrics, infrastructure life-cycle assessments, and economical and effective management of multiple stressors (e.g., nutrients, sediments, pathogens and other contaminants). This realignment is designed to draw on ORD's proven internal capabilities and expertise to better plan and conduct the transdisciplinary research needed by EPA to fulfill its mission to protect human health and the environment.

EPA's Six Integrated Research Programs:

Safe and Sustainable Water Resources (SSWR)

Air, Climate, and Energy (ACE)

Chemical Safety for Sustainability (CSS)

Homeland Security Research (HS)

Human Health Risk Assessment (HHRA)

Sustainable and Healthy Communities (SHC)

SSWR's integrated research approach adds this transformative component to EPA's existing water research portfolio by seeking sustainable solutions through integrating research on social, environmental and economic outcomes in solving water resource problems. This research will leverage the diverse capabilities of the Agency, as well as EPA's partners' scientists, engineers, economists, social scientists and policy-makers. This integrated approach to developing scientific, technological and behavioral innovations will help ensure that water bodies within the context of their watersheds meet their designated uses, and that clean, adequate, and equitable supplies of surface, ground and drinking water are available to support human needs and resilient aquatic ecosystems.

Collaborating Across Research Programs

Many of the water issues addressed by this research program are not unique to SSWR and required close coordination and collaboration with the other ORD research programs. For example, energy-related issues such as the impacts of hydraulic fracturing and surface and subsurface mineral extraction on drinking water resources are closely coordinated with the Air, Climate and Energy (ACE) Research Program. Similarly, the impacts of climate change and variability on water resources are addressed in SSWR and coordinated with the ACE Research Program. In addition to climate, nitrogen pollution, a central issue for SSWR, is a cross-cutting issue for other Agency research programs and is being closely integrated with the ACE and Sustainable and Healthy Communities (SHC) Research Programs. The Chemical Safety for Sustainability and SSWR Research Programs collaborate to address the drinking water program's research needs concerning the Contaminant Candidate List (CCL) and new developments in risk assessment. Risk assessment of specific chemical and microbial contaminants is coordinated with the Human Health Risk Assessment Research Program. The SSWR and SHC Research Programs work together on research focusing on green infrastructure, development of indicators and interoperability of models.

Developing Partnerships from the Start

Establishing and building partnerships has been essential to the development of the SSWR Research Program. This was achieved through a series of meetings with program and regional managers within EPA and scientist-to-scientist meetings between ORD, OW and other program office and regional scientists. These meeting discussions resulted in the articulation of a problem statement and vision for the program along with the identification of specific challenges facing the Agency during the next decade for which ORD science could inform future decisions. OW staff have been engaged with ORD in identifying and developing research projects and tasks, focusing particularly on the products to be produced and the timeframes, ensuring that program and regional needs were being met. Web-based tools (e.g., IdeaScale), face-to-face meetings and webinars allowed for the critical interaction and communication needed with a geographically distributed work force.

In addition to coordination within ORD, research addressed by the SSWR program was coordinated with other federal research organizations concerned with water resources, such as the USGS, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, U.S. Department of Agriculture and U.S. Department of Energy. It was also coordinated with external stakeholder groups such as the Water Environment Research Foundation, Water Research Foundation, National Groundwater Research Foundation, Water Reuse Research Foundation, state agencies, tribes, various public health, environmental groups, and consulting groups, and water utility associations.

The SSWR Research Program builds on OW's National Water Program Research Strategy (U.S. EPA 2009b). It ensures that the necessary research, science and technology are in place to meet the needs of the National Water Program, and it engages its federal partners and the broader water community in the identification and investigation of the most pressing current and future water research needs. SSWR will help ensure that EPA's National Water Program successfully achieves its statutory and regulatory obligations while also conducting research needed for addressing emerging 21st century problems. OW's Research Strategy and SSWR's research both are designed to address EPA's Strategic Goals and Subobjectives.

SSWR will continue to be responsive to Agency program and regional offices and leverage partnerships with many of the program's outside stakeholders (e.g., federal, tribal, state and local governments; nongovernmental organizations; industry; and communities affected by environmental problems) to better identify the most important environmental problems facing the Nation. These interactions have occurred at the earliest planning stages for the program and its implementation and will continue through ultimate product delivery and subsequent technical support.

Central to the development of the SSWR Research Program was an understanding of the problems and issues facing EPA's OW and regions, states and other stakeholders during the next decade. Six programmatic challenges were identified by EPA's Office of Water and the EPA regions:

1. The National Water Program and the states need to fully implement cost-effective nutrient pollutant reduction strategies that protect aquatic ecosystems from nutrient pollution and enable recovery/restoration of impacted waters.

o High-priority ecological focal areas include the Mississippi River Basin, Gulf of Mexico, Chesapeake Bay and Florida.

o Associated human health issues stem from cyanobacterial blooms in fresh, estuarine and marine waters related to nutrient pollution.

2. The National Water Program needs to be more efficient and effective in managing and/or regulating both known and emerging chemicals of concern (e.g., pharmaceutical and personal care products).

o Critical needs include cumulative risk impacts, water quality criteria and methods, nonpoint source introductions, and impacts on susceptible populations.

3. The National Water Program and the states need to fully implement regulatory strategies to protect human health from new and emerging pathogens.

o Critical needs include microbial source tracking, quantitative cumulative microbial risk, criteria and methods, and pathogen level reduction.

4. The National Water Program needs to provide states, local governments and municipalities with the tools, technology and approaches for sustainable water infrastructure that ensures public health protection.

o High priority areas include drinking water and wastewater infrastructure sustainability, new treatment technology, stormwater management, cost-effective and energy-efficient solutions, and pollutant source reduction.

5. The National Water Program and the states need to fully embrace systems approaches to protect watersheds to better maintain, protect and restore water resources, including groundwater, to ensure that they are sustainable now and in the future.

o High-priority areas include climate change impacts and adaptation, green infrastructure and water reuse, wetlands, alternative fuels impacts minimization, watershed best management practices, futures/alternatives analysis, monitoring, modeling, and analysis for water quality/quantity trends and decision-making for freshwater and estuarine ecosystems.

6. The National Water Program needs to understand and address the impacts of climate change on water management programs. It is necessary to understand how to modify tools and approaches to set water quality criteria and standards in the face of a changing climate.

EPA's regional offices expressed further needs in addressing issues such as the development of water quality criteria, cost effective tools and technologies, and cumulative risk.

The *Strategic Research Action Plan for EPA's Safe and Sustainable Water Resources Research* maps out a research program for the next approximately 5 to 10 years. It has been designed with the flexibility needed to leverage scientific breakthroughs, address emerging priorities, and the changing needs of decision makers. As such, it is a "living document" that will be updated as needed over that time.

Research Themes and Priority Science Questions

Background

From the programmatic challenges (see "Developing Partnerships From the Start,") identified by EPA and the program's other stakeholders, seven issue areas that impact water resources were selected to build the foundation for developing an integrated transdisciplinary research approach across ORD's SSWR Research Program.

Nitrogen (N) and Phosphorous (P) Pollution

Excess loading of various forms of N and P, plus pathogen contamination, are among the most prevalent causes of water quality impairment in the United States; water quality impairments totaled 6,950 surface waters for nutrients, 6,511 surface waters for organic enrichment/oxygen depletion and 10,956 surface waters for pathogens per the 2010 CWA Section 303(d) List of Impaired Waters. Excess N and P in water bodies originates from many point and nonpoint sources, which can be grouped into six general categories: (1) urban and suburban stormwater runoff associated with residential and commercial land development, (2) municipal and industrial wastewater discharges, (3) row crop agriculture and fertilizer use, (4) livestock production and manure management practices, (5) atmospheric deposition resulting from nitrogen oxide emissions from fossil fuel combustion and ammonia emissions from row crop agriculture and livestock production, and (6) legacy nutrient pollution, often a result of nitrogen contamination of groundwater and/or phosphorus contamination of sediments. Furthermore, land use and land cover in watersheds across much of the Nation has been altered such that a higher fraction of the N and P applied to the landscape will reach surface and groundwater resources and impact aquatic life uses, human health and economic prosperity.

N and P pollution creates significant and ever-growing water quality concerns across the Nation. Often, the most immediate effects are economic because contaminated water sources can no longer be used and must be replaced with new water sources that are safe to use. This can be especially challenging where limited water resources already are tightly managed and heavily utilized. More latent effects, but no less important, are nutrient impacts on human health and aquatic life, which can occur as both a direct (e.g., methemoglobinemia) and indirect (e.g., toxins from hazardous algal blooms) consequence of nutrient pollution.

Existing regulatory and nonregulatory efforts to control N and P pollution have not, in most cases, kept pace with the growth of N and P impairments. Absent a change in approach, N and P pollution likely will continue to increase in the future. SSWR intends to conduct the research that provides innovative and integrated scientific, management and regulatory approaches for sustainable solutions to reduce N and P pollution while providing the greatest opportunity to enjoy long-term economic prosperity, ecosystem health and human well-being.

Agricultural Uses of Water

Improvements to agricultural production will be required to meet the increasing societal demand for food and renewable energy. Currently, agriculture and energy combined account for nearly 80 percent of the freshwater withdrawals in the United States, and agricultural irrigation accounts for the largest consumptive use. Agricultural production of crops and livestock also significantly alter soils, surface and groundwater quality, hydrology, biodiversity, and landscapes. Crop production can expose soil to erosion, requires addition of nutrients (e.g., chemical fertilizers, manure, biosolids) and pesticides, and can physically alter hydrology (e.g., drainage of croplands, draining or filling of wetlands, removal of riparian areas, channelization of headwater and stream environments, soil compaction, construction of levees), resulting in the direct physical and chemical alteration of surface and groundwater. Irrigation, where used, alters water availability, flow and chemistry in streams, rivers, soils and groundwater. Livestock production and application of livestock waste to crops or pastures at greater than agronomic rates can cause constituent contaminants in the manure to runoff to water. Hormones, antibiotics and heavy metals added to feed often end up in both the manure and in receiving waters. These livestock feed contaminants and others from agricultural production, such as pesticides, nitrates, fine sediments and pathogens, often end up in surface and groundwater. Either singularly or in combination, these contaminants can pose a health threat to aquatic life, humans drinking this water and aquatic-dependent wildlife. SSWR scientists will conduct research that provides sustainable water quality and quantity for meeting society's agricultural production needs and minimizes adverse public health and ecosystem impacts from water associated with agriculture use.

Energy/Mineral Extraction and Injection Processes

Increasing demands for energy and mineral resources, the desire to supply a greater fraction of energy and mineral demands from domestic sources, and the need to mitigate the production and release of greenhouse gases all point to the need to increase diversification of energy and mineral production. The nation's energy portfolio likely will span such diverse activities as enhanced recovery of unconventional fossil fuel sources and geothermal, wind and wave, solar, and possibly nuclear energy, all of which exert differing pressures on water resources. Energy and minerals production in the United States already has an important impact on surface and subsurface water resources; future impacts can be expected to be even greater and more diverse. SSWR research is being conducted to produce scientifically rigorous information and assessment techniques to assist society in making sound choices for a more sustainable water-energy-minerals future. These assessment and mitigation tools of the future will address the diversity of impacts. They also will account for cumulative impacts of mixtures of such activities, in differing proportions and in differing geographic and climactic regions. Evaluating the true life-cycle impacts and costs of current and future resource extraction/injection technologies is critical. Public education about the advantages and limitations of resource extraction/injection activities and options to minimize resource use and consumption will help reduce potentially harmful impacts to the Nation's health and environment.

Protecting Aquatic Ecosystems and Their Supporting Watersheds

Aquatic ecosystems and their supporting watersheds provide critical economic and social benefits to society. Protecting the integrity and beneficial uses of aquatic systems is the primary goal of the CWA. Achieving this goal requires a detailed understanding of which human uses of watersheds create critical pressures and stressors, how those stressors interact, and how they cumulatively affect the structure and function of aquatic ecosystems. These beneficial uses of many watershed aquatic ecosystems currently are threatened by a complex array of pressures and stressors, including nutrient and sediment loading, climate change, habitat alteration, introduction of invasive species, toxic pollutants and hydrologic alteration. In the face of increasing anthropogenic pressures, sustaining and restoring aquatic ecosystem integrity will require that watersheds be understood and managed as complex ecological systems. The interactions of watershed-scale controls, climate and human drivers control the key watershed processes that are observed as fluxes of water, sediment and organic matter, heat and light, invasive species, and nutrients and chemicals.

These processes then act to regulate ecosystem structure, its function and, ultimately, aquatic biological integrity.

SSWR will conduct research to assess the condition of aquatic ecosystems and by obtaining a systems understanding of the watershed processes, help to sustain high quality ecosystems. By quantifying the social, economic and environmental costs of water quality degradation, the program can begin to examine the triple bottom line for sustainable water quality in watersheds. With the large number of watersheds that currently are degraded, it is necessary to understand the factors associated with protecting, maintaining and restoring the integrity and resilience of the nation's aquatic resources, so that successful restoration actions can be prioritized.

Contaminants and Industrial Processes

Protection of aquatic systems, both as ecological entities and as sources of water for drinking and other human uses, is compromised by shortcomings in our abilities to adequately assess and mitigate the full range of risks posed by waterborne contaminants (chemicals and microbial pathogens). The rate at which waterborne chemical hazards are assessed with traditional approaches cannot keep pace with the rate at which new chemicals are being introduced. Better understanding of the risks posed by chemicals also is challenged by increasingly complicated mixtures of chemicals, uncertainties about chemical transfer and transformations within the environment, and inadequacies in monitoring in situ exposures and effects. This inability to adequately assess chemical risks hinders the evaluation and advancement of remediation strategies. Similar issues compromise the assessment of microbial pathogens, including insufficient virulence data, uncertain fate and transport in the environment, and incomplete understanding of the effectiveness of treatments. Mitigation of risks typically emphasizes treatment rather than prevention, and available treatments often are costly and can result in the creation of hazardous byproducts or residual wastes that require further management. Institutional compartmentalization of the evaluation and management of wastewater, natural water bodies and drinking water makes addressing the total problems less effective, and all of this is occurring in a period when increasing population and expanding energy demands are requiring more efficient use (and re-use) of finite water resources.

A more sustainable path for the Nation's water resources requires a better integration of the understanding, assessment and management of chemical and microbial threats across the entire water cycle. It also requires doing so in a manner that recognizes the connections of water resources to the social, environmental and industrial functions they serve. SSWR will conduct research that develops the tools and technologies to ensure that the quality and quantity of water used by society is returned to a watershed in a state similar to when it was withdrawn. In addition, it must avoid significant adverse effects on humans and aquatic ecosystems. To accomplish this, research will focus on: reducing the number, amounts and hazards of contaminants entering waste streams; improved monitoring for the occurrence and effects of chemical and microbiological contaminants in the environment and drinking water supplies; improved ecological and human health risk estimates for chemical and microbial contaminants that do enter water resources; and development of sustainable means to treat or otherwise manage contaminants that cannot be otherwise controlled.

Sustainable Infrastructure

Improving the sustainability of the Nation's water infrastructure (including components used in the agricultural and energy sectors) is the country's top water priority. Much of the difficulty is a result of the nature of the current system design and changing human demographics and population growth, which are combined with ongoing deficiencies in infrastructure replacement; many of the Nation's wastewater, stormwater and drinking water systems have exceeded their designed lifetime (some systems are greater than 100 years old). These problems are exacerbated by competing regulations and a lack of a systems-economics approach within the water sector and risks arising from new sources and types of pollution, concerns regarding emerging contaminants, climate variability and other hazards (such as earthquakes or hurricanes). These challenges require a fundamental shift to more resilient water infrastructure solutions and technologies to sustain the quality and quantity of water available for human and ecological uses and needs. Also, metrics are lacking for evaluating the public health and ecosystem implications from existing and declining infrastructure and assisting in selecting and maintaining innovative solutions.

In 2002, the Agency estimated that if spending for capital investment and operations and maintenance remained at current levels, the potential funding gap between what likely will be invested in U.S. municipal water infrastructure and what is truly needed for the next 20 years would be $270 billion for wastewater infrastructure and $263 billion for drinking water infrastructure. Given the current economic realities, this funding gap is highly unlikely to be filled. Furthermore, the municipal water services consume more than 7 percent of the Nation's electricity production. SSWR research will focus on developing economical new innovative technologies to provide sustainable solutions in rehabilitating and modernizing the country's water infrastructure systems. This research will include the minimization of energy use, effective recycling and re-use of water and waste, with the ultimate goal of providing communities with management options for sustainable water quality and availability at the watershed scale.

Climate

Projected impacts of climate change include local to regional shifts in the hydrologic cycle (e.g., increased droughts, more extreme rainfall events, more frequent precipitation events, earlier spring melt, increased surface water temperatures) with the expectation that patterns will shift outside of historical trends. The current U.S. water supply and water quality models and decisions, however, were built on these historical experiences. Every region of the country is experiencing impacts from hydrologic shifts. More than two-thirds of the states are anticipating local to statewide water shortages within the next 2 years. Also, better strategies for treating and delivering safe water and for delivery and treating wastewater are needed to reduce the water-related energy demand while protecting human and ecosystem health. SSWR views climate variability and change as an additional overarching stressor impacting all aspects of the research program. Therefore, climate stressors are incorporated throughout each section of the current SSWR research program.

Developing a Safe and Sustainale Water Resources Research program

To place the above seven areas into context, EPA's research historically focused on manifestations of problems in the water environment. These include issues such as physical processes (including temperature, flow and degraded habitat) and concentrations for nutrients, pathogens, chemicals and sediments. Additional stressors related to increasing demands on the Nation's water supply and climate change/variability exacerbate water quality problems. To solve these problems, EPA's research must also address the origins of the problems associated with increased urbanization, which includes land use management and industrial processes; changing population demographics and the pressures placed on aging drinking water and wastewater infrastructure; and nonpoint sources of pollution that include agricultural practices (Figure 1). **Only by considering the root causes and the manifestations of the problems can sustainable solutions be sought.**

To investigate the sustainability of water resources, it is necessary to consider three basic attributes of human well being: the environment, the economy and society (including public health). According to the National

Environmental Policy Act of 1969, sustainability is defined as being able "to create and maintain conditions under which humans and nature can exist in productive harmony, [and] that permit fulfilling the social, economic, and other requirements of present and future generations." Sustainability challenges cannot be addressed in isolation because many problems are highly interdependent, and many solutions have hidden adverse consequences. For example, the research community has recognized the close linkage between water and energy resources: water is needed to generate energy, and energy is needed to convey water. A systems approach is necessary to understand these complex, interdependent relationships and develop sound environmental and economic policies that lead to a sustainable society.

When addressing sustainability challenges, the development of "solutions" requires a balancing of the three aspects of sustainability. A preferred solution or management intervention will improve the environmental dimension of the system in question without degrading the economic and social dimensions and ideally will improve all three. In some cases, however, trade-offs will be necessary. For example, initial financial investments may be required to reverse environmental degradation. In practice, there will be a need for finer resolution of the three dimensions (e.g., short-term vs. long-term, workers vs. consumers) and careful definition of the system scale and boundaries (e.g., supply chain, urban community, ecosystem). To explore sustainable solutions, the SSWR research framework utilizes an overarching conceptual model (Figure 2) that depicts the linkages and flows of value among economic, social and environmental systems (Fiksel et al. 2012). Environmental systems

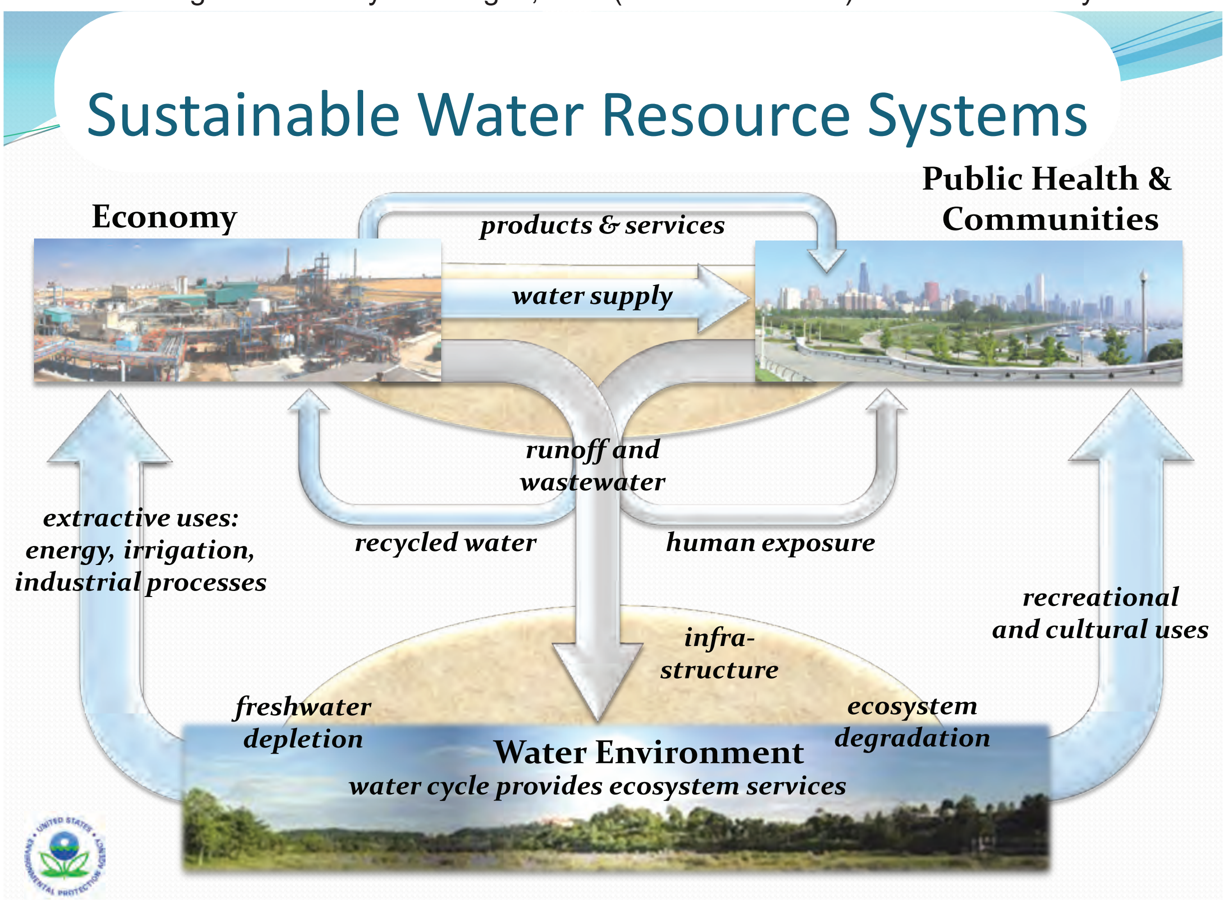

Figure 2. Conceptual model of the SSWR research framework shows the linkages and flows between the economic, social and environmental systems (from Fiksel et al. 2011)

provide critical ecosystem services, including water resources, which provide value to both industrial and societal systems. Human communities consume products and services supplied by the industrial economy, and they generate waste that may be recycled into industrial systems or deposited into the environment. In addition, communities benefit from the recreational and cultural amenities provided by water resources. Economic growth may be adversely impacted when markets fail to account for economic externalities such as gradual degradation of water quality; the result is a loss of opportunity for future generations, sometimes called an "inter-temporal market failure" (Binswanger and Chakraboty 2000). Research in the fields of natural resource economics and ecological economics seeks to prevent such market failures through explicit valuation of natural resources.

Using the program's conceptual model of sustainable water resource systems (Figure 2), the programmatic challenges (see "Developing Partnerships From the Start,") identified by EPA and the program's other stakeholders, and the SSWR goal of ensuring that clean and adequate supplies of water are available to support human well-being and resilient aquatic ecosystems, two interrelated research themes emerge: **Sustainable Water Resources** and **Sustainable Water Infrastructure Systems.** These interrelated research themes and their intended outcomes form the basis of the integrated SSWR Research Program to inform decisions and policies regarding water resource management.

Research Themes and Priority Science Questions

Theme 1: Sustainable Water Resources

Ensure safe and sustainable water quality and availability to protect human and ecosystem health by integrating social, economic and environmental research for use in protecting and restoring water resources and their designated uses (e.g., drinking water, aquatic life, recreation, industrial processes) on a watershed scale.

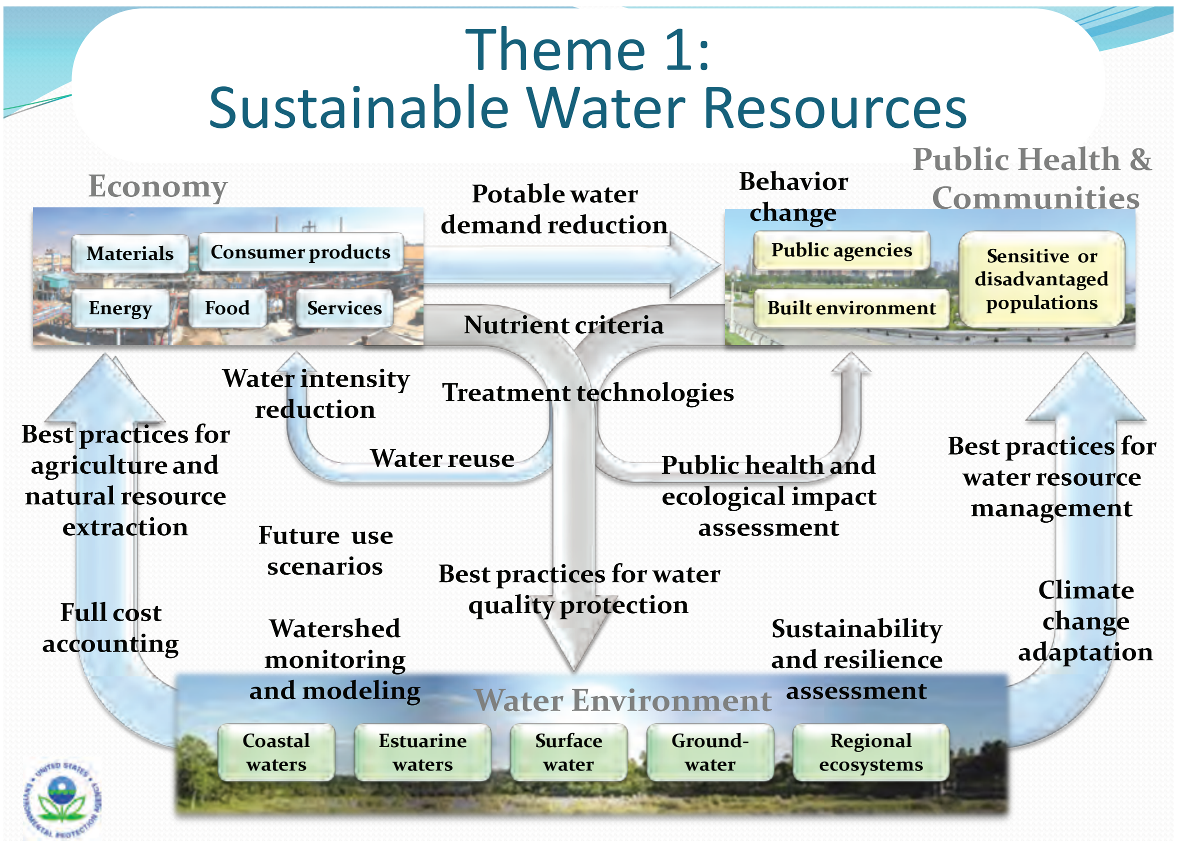

Figure 3. Theme 1 Conceptual Model.

Theme 1 focuses on the flow and uses of water in the system (Figure 3). Research in Theme 1 informs the protection and restoration of the quality of water to sustainably provide safe drinking and recreational waters for humans, maintain healthy aquatic life and aquatic-dependent wildlife and ecosystems and provide adequate water for any other state-designated uses. Integral to this theme is the need to have sufficient availability of quality water to achieve sustainable societies, ecosystems and economies. Research into the protection and maintenance of the chemical, physical and biological integrity of the Nation's waters cannot be successful without some consideration of the need for a sufficient quantity and quality of water, particularly in the face of increasing and competing uses associated with increased housing, food and energy production, and economic development, which are compounded by climate variability and change. Developing a more complete understanding of the complex interplay of water resources and their desired uses is a key, necessary aspect of sustaining healthy people, ecosystems and economies into the future.

Water quality is affected by naturally occurring contaminants and anthropogenic activities. Currently, the rate at which waterborne contaminants are assessed cannot keep pace with the rate at which new contaminants are introduced into the environment, potentially impacting human and ecological health. The lack of environmental and public health assessment data, analytical sensitivity, and an understanding of the properties, fate and transport of new contaminants challenges scientists' ability to evaluate and prioritize contaminant risk. Consequently, this affects the Agency's ability to effectively regulate and manage these new contaminants. Theme 1 research focuses on: developing better approaches to identify, assess and prioritize contaminant risks; developing new approaches to minimize the impacts of these contaminants on water resources; and considering the impacts of climate change and variability—as well as increased population and changing human demographics— on water resources.

Science Questions

What factors are most significant and effective in ensuring the sustainability and integrity of water resources?

This research will focus on keystone factors that promote sustainable water resources, as well as the anthropogenic activities and natural contamination that threaten the sustainable quality and quantity of water resources.

What approaches are most effective in minimizing the environmental impacts of naturally-occurring and anthropogenic contaminants and different land use practices (e.g., energy production, mineral extraction and injection activities, agriculture, urbanization) leading to the sustainability of surface and subsurface water resources?

This research will describe current and future best and cost-effective management practices that minimize impacts to water resources. Research also will include the evaluation of contaminant risk.

What are the impacts of climate variability and changing human demographics as stressors on water quality and availability in freshwater, estuarine and coastal aquatic ecosystems?

The research on this question, because of the overarching impact of these stressors on water systems, has been considered within all of the SSWR research questions.

Research under Theme 1 also will provide the data, models and tools to develop a systems approach to protect and restore the ecological integrity of water resources within watersheds. Integrated assessments are an important component that can establish the health of watersheds and capture the dynamic spatio-temporal context of aquatic ecosystems and the role of water interconnectivity in the landscape. Assessments will require water-use data and models of stream flows and lake levels for hydrologic classes across the country. Water quality gains during the last several decades are not sustainable without a better understanding of aquatic systems and pollutant fate and effects along with improved technology and decision-analysis tools.

The research conducted under Theme 1 will fully implement a systems approach to protect and restore the ecological integrity of freshwater, groundwater, coastal waters, watersheds and wetlands. It also will be focused on methods to provide sustainable drinking water and enhance aquatic ecosystems. Such capability is required to protect aquatic ecosystems and human health while addressing a broad range of 21st-century challenges that include: hydraulic fracturing, geologic sequestration, climate change adaptation, alternative fuels impacts and mountain-top coal mining. Solutions will require integrated approaches involving improvements to green infrastructure and water reuse; watershed best management practices; futures analysis of water use alternatives; monitoring, modeling, and analysis for water quality and drinking water quality; trends in quality; trading for mitigation; and improved decision-making support tools. In addition, this research will support regulatory strategies to protect human health and aquatic ecosystems from pathogens, known and emerging chemical contaminants, and nutrient/sediment pollutants. Furthermore, it will enable recovery and restoration of impacted waters.

Illustrative Outputs/Products/Outcomes

The following provides illustrative examples of research outputs from Theme 1.

Example 1: Cost-effective nutrient pollution reduction strategies. EPA researchers are establishing safe nutrient levels in aquatic resources.

Example output: Science-based interpretation of state narrative nutrient standards for inland waters as numeric nutrient criteria to prevent eutrophication and aquatic ecosystem degradation.

Research product contributing to this output: Technical synthesis and approaches for developing quantitative, measurable standards that would interpret existing state nutrient criteria such as "water shall be free from materials that impair the waters for any designated uses."

Expected outcome of the research: To address the overabundance of nutrients (nitrogen and phosphorus) in water, EPA's Office of Water and the States will develop numeric nutrient criteria for water resource protection and restoration.

Impact

Scientifically defensible regulation of nitrogen for the protection of the Nation's waters, reduction of listings of water quality impairment resulting from nitrogen on the CWA Section 303(d) List and effective development of criteria necessary for successful restoration of impaired waters.

Example 2: Efficient and effective management of both known and emerging chemicals of concern.

EPA researchers and their partners are developing advanced analytical methods and technologies for prioritizing and assessing existing chemicals and emerging substances of concern.

Example 1 output: Dose-response relationships for chemicals of concern.

Product contributing to this output: Methods to evaluate human health risk (including susceptible populations) to groups of chemicals of concern.

Expected outcome of the research: The health risk information on chemical contaminants will be used by EPA's Office of Water to prioritize chemical groups for the Contaminant Candidate List (CCL) for upcoming listing in CCLs 4 and 5.

Example 2 output: Evaluation of the potential impacts of hydraulic fracturing on drinking water resources.

Product contributing to this output: Report to Congress on the potential impacts of hydraulic fracturing on drinking water resources

Expected outcome of this research: Policymakers have sufficient information to ensure that access to vital energy resources is accomplished in a way that the Nation's drinking water continues to be safe and available for human consumption.

Impact

1. Provide greater protection for human health by focusing on the most susceptible populations and life stages and by regulating groups of chemicals based on their toxicity rather than on an individual basis.
2. Ensure that accessing one of the Nation's most vital energy resources is accomplished in

such a manner that the Nation's drinking water continues to be safe and available for human consumption.

Example 3: Fully implement regulatory strategies to protect human health from new and emerging pathogens.

EPA researchers are developing the science needed to support drinking water standards and other policies that protect people from waterborne diseases.

Example output: Methodologies and information to support improved human health risk assessment for pathogens, including cumulative risk with an emphasis on vulnerable/susceptible populations.

Product contributing to this output: New or improved methods to measure human exposure to waterborne pathogens from source waters and drinking waters.

Expected outcome of this research: Information on the health risks of waterborne pathogens will be used by EPA's Office of Water to prioritize pathogen groups for upcoming listing in CCLs 4 and 5.

Impact

Provide greater protection for human health by including a focus on the most susceptible populations and life stages and by identifying and regulating groups of pathogens.

Research Themes and Priority Science Questions

Theme 2: Sustainable Water Infrastructure Systems

Ensure that water of sufficient quality is available to meet human uses and needs and maintain resilient aquatic ecosystems.

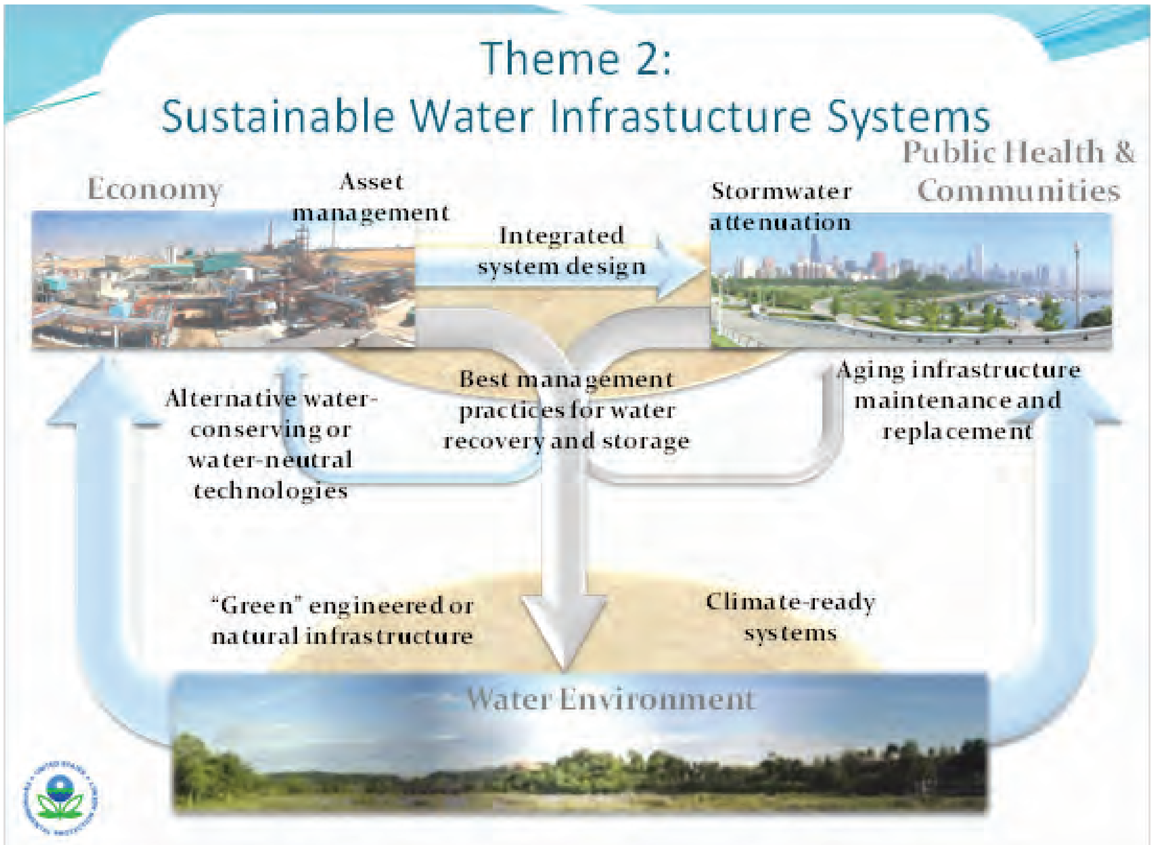

Figure 4. Theme 2 Conceptual Model.

Theme 2 focuses on the use of natural and engineered water infrastructure (Figure 4). More specifically, water infrastructure management approaches are needed that optimize the use of water conservation, wastewater (and grey water) reuse, groundwater recharge by stormwater and reclaimed water, green infrastructure, and energy conservation and resource recovery.

Conceptually, Figure 4 illustrates the extraction of freshwater resources from the environment to support economic activities and provide water to communities, the discharge of wastewater and runoff into the environment for removal and treatment, the infrastructure systems necessary to manage these flows, and efficiency considerations in water utilization. In addition, it identifies relevant services provided by ecosystems in the watershed such as recreational amenities, filtration of stormwater run-off, and flood regulation.

Theme 2 research includes topics concerning the design, treatment , life cycle analysis, and best management practices for sustainable water infrastructure systems; this also includes their integration into watershed management for a holistic, systems approach to integrated water resource management. The results of this research will allow states, local governments and municipalities to protect human health and ecosystem condition while providing them with the tools and technology for sustainable drinking water and wastewater infrastructure management, for water re-use, to address the impacts of wet-weather discharges, and to reduce the sources of pathogens and water pollutants (including invasive species).

Science Questions

The science questions to be addressed under Theme 2 are:

What are the most effective and sustainable approaches for maintaining and improving the natural and engineered water system in a manner that effectively protects the quantity and quality of water?

This research will use systems analysis tools at various scales and for different regions of the United States to take full advantage of the use of natural ecosystem services and the built environment to protect and manage water resources.

How can the Agency effectively manage water infrastructure to produce safe and sustainable water resources from source to drinking water tap to receiving waters?

This research will focus on developing the next generation of water infrastructure to promote sustainable water resources from watersheds to piped systems to receiving waters. This will include developing effective public/private partnerships through mechanisms such as EPA's Water Technology Innovation Cluster.

What effective systems-based approaches can be used to identify and manage causes of degraded water resources to promote protection and recovery?

This research will synthesize research and approaches across the two SSWR themes to develop a systems approach aimed at protecting high quality waters and restoring degraded water resources. This will include developing effective demonstrations of systems approaches to sustainability; we will initially demonstrate a systems approach to watershed protection focusing on nutrient pollution in southern New England.

What highly targeted programmatic support is needed by SSWR's partners?

This research will encompass highly targeted programmatic support to OW, program offices and regions, Regional Applied Research Efforts, and Pathfinder Innovation Projects.

Illustrative Outputs/Products/Outcomes

The following provides illustrative examples of research outputs and products from Theme 2.

Example 1: Sustainable water infrastructure that ensures public health protection.

EPA researchers are developing and evaluating sustainable technologies for water and wastewater treatment.

Example output: Innovative technologies and approaches for small drinking water and wastewater systems, including those technologies that combine pollution prevention, water reuse and resource recovery, and have potential economic advantages with low capital, operations, and maintenance costs.

Product contributing to this output: Innovative technologies for small water and wastewater treatment facilities.

Expected outcome of this research: EPA's Office of Water provides guidance on new and improved technologies for water and wastewater to small, publicly-owned treatment works helping them to meet current regulatory standards and reduce overall treatment costs while preserving energy and resources.

Impact

More effective, sustainable treatment for small municipalities' water and wastewater, allowing them to meet current regulatory standards and reduce overall treatment costs while preserving energy and resources.

Example 2: Systems approaches to reduce impacts of stormwater on aquatic resources.

EPA scientists are investigating the combined use of green and gray infrastructure in the watershed for improved stormwater management.

Example output: Development of effective, integrated green and gray infrastructure approaches to stormwater management at the sewershed/watershed scale.

Product contributing to this output: Guidance on municipal-level best management practices to facilitate increased adoption of green infrastructure by community stakeholders.

Expected outcome of this research: EPA provides guidance on the use of green infrastructure along with gray infrastructure for stormwater management. The use of green-gray hybrid approaches provides cost-effective solutions to consent decree settlements to redress sewer overflows in violation of the CWA, and in addition, green infrastructure provides further social and economic benefits.

Impact

The use of a green-grey hybrid approach can more cost-effectively provide solutions to consent decree settlements to redress sewer overflows in violation of the CWA, and in addition, the green infrastructure can provide further social and economic benefits.

Example 3: Understand and address the impacts of climate change on the availability and quality of water resources.

EPA scientists are working to develop innovative tools and technologies for water management that will increase system sustainability in the face of droughts, water shortages, more intense storms, and other potential impacts of climate change.

Example output: Watershed modeling to assess climate change impacts on water resources.

Product contributing to this output: Watershed models that assess hydrologic and biogeochemical sensitivity to climate change and land use change.

Expected outcome of this research: This research will provide the science to support implementation of EPA/OW's National Climate Strategy, which identifies specific actions to prepare the Nation's water and wastewater management systems for climate change impacts.

Impact

Water and wastewater treatment systems have reduced the vulnerability of their water resources in the watershed to climate change and have climate-ready infrastructure.

Conclusion

Adequate water supplies of sufficient quality are critical to support human health and aquatic ecosystems, and it underpins the Nation's health, economy, security and ecology. Increasing demands are being placed on the Nation's finite water resources, and the choices being made influence the sustainability of these precious resources. The development of management solutions to sustain water resources requires the balancing of water needs for human health, economic and societal health, and environmental health. To accomplish this requires sustainable solutions and an appreciation that all forms of water are interrelated and connected; it is all one resource. SSWR's research embraces this concept from the overarching conceptual diagram to the interconnection of the program's themes of Sustainable Water Resources and Sustainable Water Infrastructure Systems to the interconnections of SSWR's science questions. This holistic approach to research on water resources will provide the science necessary to inform the societal choices about maintaining clean, adequate and equitable supplies of water to support human well-being and resilient aquatic ecosystems, now and in the future.

Summary Tables of Outputs and Outcomes

The following tables list the expected outputs from the SSWR Research Program along with the associated partner outcomes. Although each output is listed under a single theme and science question, many of them serve to answer multiple questions.

Theme 1. Sustainable Water Resources

Science Question 1.1: What factors are most significant and effective in ensuring the sustainability and integrity of water resources?

Outcomes: Improved condition assessment of the Nation's waters in support of OW's CWA 305b reporting requirements; improved approaches to identify, maintain and restore watersheds, aquatic resource integrity and sustainability as part of OW's Healthy Watersheds Initiative; guidance on definition of Waters of the U.S.; science to support EPA's National Water Program Strategy on Climate Change.

Output	Output Year	Relevance to other
SSWR Science Questions		
Watershed indices of integrity and sustainability, including those related to climate change	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Ecological Condition Indicators	2015	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Diagnostic and stressor indices	2014	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Analytical tools for assessment	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Watershed classification	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Modeled pressures and stressors most responsible for loss of water resource integrity	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Develop improved assessments of multiple interacting causal factors	2014	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships	2015	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Develop models for forecasting and decision making on future water resource and watershed conditions at multiple scales	2014	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Decision support tools to aid development of market based activities that promote watershed integrity	2017	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Interoperability of models	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6

Science Question 1.2: What approaches are most effective at minimizing the environmental impacts of different land use practices (e.g., energy, mineral extraction, and injection practices, agriculture, urbanization) leading to the sustainability of surface and subsurface water resources?		
Outcomes: Supports Drinking Water and Water Quality standards development (CCL, UCMR, Regulatory Determination, six year review; aquatic life criteria). Informs nutrient criteria, biosolids guidance, UIC program, Drinking Water Strategy, energy, mineral, extraction, and injection impacts to drinking water resources. Informs watershed restoration potential and provides the science to support EPA's National Water Program Strategy on Climate Change		
Output	**Output Year**	**Relevance to other SSWR Science Questions**
Conceptual models for sustainable land use (agriculture: crop, animal production, urban, mixed use: urban/suburban, forest, natural green) treatment practices (biosolids, dbps) and climate change as they impact water-resources	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Improved diagnostics, including metrics and baselines, to inform water resource sustainability including contaminant occurrence, land management decisions, public health and ecological condition	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Stressor (including mixed wastes, cumulative impacts and multiple stressors) -response models (including predictive models) of land use practices (including urbanization and climate change) on water quality and quantity for surface and subsurface water resources at a range of watershed scales and settings	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Optimization of land use and treatment practices. Simulations of innovative solutions, including best management practices (BMPs) and their improved placement, that minimize the production of aquatic stressors associated with land uses or climate change and improve water resource sustainability.	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Pathogen indicators and risks associated with land application of biosolids	2016	Theme 1, SQ1, 3 Theme 2, SQ 4, 5, 6
Develop analytical and prioritization tools and optimize the effectiveness of treatment approaches for individual contaminants	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Develop analytical and prioritization tools and optimize the effectiveness of treatment approaches for groups of contaminants	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Develop stressor/dose response models and relationships to support regulatory actions associated with individual contaminants	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Develop stressor/dose response models and relationships to support regulatory actions associated with groups of contaminants	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Develop methodologies and information to support improved assessment, including cumulative health risk of individual contaminants with an emphasis on vulnerable/susceptible populations	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Develop methodologies and information to support improved assessment, including cumulative risk of groups of contaminants with an emphasis on vulnerable/susceptible populations	2017	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6
Development of Numeric Nutrient Criteria and Science-Based Interpretation of Narrative Standards for Inland Waters and Downstream Estuarine and Coastal Waters	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6

Output	Output Year	Relevance to other SSWR Science Questions
Development of Water Quality Simulation Modeling for Managing N and P Pollution	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Decision Support System for Sustainably Managing Nutrients	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Improved Assessment Approaches and Biological Indicators to Assess Responses to N&P and Compliance	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Sustainable nutrient removal technologies	2016	Theme 1, SQ 1, 3 Theme 2, SQ 4, 5, 6
Impacts of Hydraulic Fracturing on drinking water resources (See EPA Study Plan)	2015	Theme 2, SQ 5
Human health implications of mountaintop mining	2012	Theme 1, SQ 1 Theme 2, SQ 5, 6
Recharge of subsurface water resources (aquifer storage and recovery, ASR)	2016	Theme 1, SQ 1, 3 Theme 2, SQ 5, 6

Science Question 1.3: What are the impacts of climate variability and changing human demographics on water quality and availability in freshwater, estuarine, coastal aquatic ecosystems? What approaches are needed to mitigate these impacts?

Outcomes: Science to inform the implementation of EPA/OW's National Water Program Climate Strategy.

Output	Output Year	Relevance to other SSWR Science Questions
Watershed modeling to assess climate change impacts on water resources	2016	Theme 1, SQ 1, 2 Theme 2, SQ 4, 5, 6

Theme 2. Sustainable Water Infrastructure Systems

Science Question 2.1: What are the most effective and sustainable approaches that maintain and improve the natural and engineered water system in a manner that effectively protects the quantity and quality of water?		
Outcomes: Improved municipal consent decrees for CSO control policy; support for MS4 stormwater discharge policy; supports Chesapeake Bay Executive Order Implementation and science to inform the implementation of EPA/OW's National Water Program Climate Strategy.		
Output	**Output Year**	**Relevance to other SSWR Science Questions**
Develop effective integrated green and gray approaches at the sewershed/watershed scale	2014	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Measure effectiveness of green/gray infrastructure to improve hydrologic cycles, reduce runoff, and reduce risk for the green/gray approach	2014	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Identify key data gaps regarding BMP Performance (e.g., regional relevance, types of GI BMPs, longevity of performance, etc)	2015	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Improve designs and reliability for GI under regionally-relevant conditions	2015	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Determine GI BMP impacts on aquatic ecosystems and function at the watershed scale	2016	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Establish databases on green BMPs performance for stormwater management under regionally-relevant conditions	2014	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale.	2014	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Develop predictive modeling tools for the design of integrated green/gray infrastructure for use in urban watersheds	2014	Theme 1, SQ 1, 2, 3 Theme 2, SQ 5, 6
Improved water conveyance technologies and innovative approaches to monitor, assess treatment effectiveness and manage current, and replace aging, water infrastructure	2015	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Determine effectiveness of health protection and evaluate innovative and flexible design, construction, and treatment approaches and technologies for problems faced by small and disadvantaged systems	2015	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Improved water conveyance technologies and innovative approaches to assess and replace/rehabilitate aging water infrastructure	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6
Better monitoring methods and models for infrastructure systems	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 6

Science Question 2.2: How do we effectively manage water infrastructure to produce safe and sustainable water resources from source to drinking water tap to receiving waters?	
Outcomes: Next generation of innovative water and wastewater technology and conveyance systems that support OW guidance and permitting programs for POTWs; reduce small system drinking water treatment non-compliance.	
Output	**Output Year**
Development of assessment frameworks with appropriate tools and metrics for integrating sustainability into water service option selection, and asset management practices, at different scales and levels of investigation	2013
Develop novel infrastructure comparisons that address public health, societal/economic and ecological water needs	2013
Develop decision support tools, including economic considerations, that allow comparison between status quo and novel/alternative water service approaches (i.e., for drinking water, wastewater/stormwater, water reuse, and their associated conveyance systems) and that allow scaling from small communities to river basins.	2015
Protocols and metrics for developing and demonstrating sustainability assessment framework as applied to treatment, including climate ready designs	2015
Advanced technologies for energy efficiency and recovery at DW treatment and wastewater facilities	2015
Develop innovative technologies and approaches for small drinking water and wastewater systems including those that combine pollution prevention, water reuse, resource recovery and potential economic advantages with low capital, operations and maintenance costs	2014
Water Technology Innovation Cluster: Develop sustainable processes for contaminant (including nutrient) removal below the limits of current technologies that minimizes costs, energy consumption, environmental burden, chemical consumption, and associated greenhouse gases production	2016
Identify and develop and demonstrate technologies that optimize recovery of energy, nutrients, and water within water systems	2015
Improved water conveyance technologies and innovative approaches to monitor, assess treatment effectiveness and manage current, and replace aging, water infrastructure	2015
Determine effectiveness of health protection and evaluate innovative and flexible design, construction, and treatment approaches and technologies for problems faced by small and disadvantaged systems	2015
Improved water conveyance technologies and innovative approaches to assess and replace/rehabilitate aging water infrastructure	2016
Better monitoring methods and models for infrastructure systems	2016

Science Question 2.3: What effective systems-based approaches can be used to identify and manage causes of degraded water resources?		
Outcomes: Improved governance options based on a systems approach to watershed protection and restoration		
Output	**Output Year**	**Relevance to other SSWR Science Questions**
Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models	2015	Theme 1, SQ 2, 3 Theme 2, SQ 4, 5, 6
Develop decision level support tools leading to resource sustainability at the watershed level	2016	Theme 1, SQ 2, 3 Theme 2, SQ 4, 5, 6
Evaluate effectiveness of a systems approach to watershed protection and restoration	2017	Theme 1, SQ 2, 3 Theme 2, SQ 4, 5, 6
Science Question 2.4: What research and expertise are needed to address highly targeted program and regional issues along with new innovative research problems impacting water resources?		
Outcomes: Highly targeted program and regional science needs are met. New innovative approaches are developed to address water resource issues.		
Highly targeted programmatic support	ongoing	Varies
RARE Projects	2014	Varies
Pathforward Innovation Projects	2012	Pathforward Innovation

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List of Acronyms

ACE	Air Climate and Energy
ACoE	Army Corps of Engineers
CAFO	Concentrated Animal Feedlot Operation
CCL	Contaminant Candidate List
CDCP	Centers for Disease Control and Prevention
CSO	Combined Sewer Overflow
CSS	Chemical Safety for Sustainability
DoE	Department of Energy
DW	Drinking Water
HABs	Harmful Algal Bloom
HH	Human Health
HHRA	Human Health Risk Assessment
ITR	Integrated Transdisciplinary Research
LAE	Large Aquatic Ecosystems
NARS	National Aquatic Resource Survey
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NIH	National Institutes of Health
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
OGWDW	Office of Ground Water and Drinking Water
ORD	Office of Research and Development
ORMA	Office of Resources Management and Administration
OST	Office of Science and Technology
OW	Office of Water
OWM	Office of Wastewater Management
OWOW	Office of Wetlands, Oceans and Watersheds
PH	Public Health
POTW	Public Owned Treatment Works
PPCP	Pharmaceuticals and Personal Care Products
SHC	Sustainable and Healthy Communities
SSO	Sanitary Sewer Overflow
SSWR	Safe and Sustainable Water Resources
UAA	Use Attainability Analysis
UCMR	Unregulated Contaminant Monitoring Rule
UIC	Underground Injection Control
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WQ	Water Quality

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List of Definitions

Aquatic-dependent wildlife – organisms (including plants) that live on or in the water for some portion of their life-cycle, or for which a significant portion of their diet is made up of those that do, or that are dependent on, at least occasionally, water-inundated habitat for survival, growth, and reproduction.

Contaminant – a contaminant is defined by the Safe Drinking Water Act (SDWA) as "any physical, chemical, biological, or radiological substance or matter in water" (U.S. Senate, 2002; 40 CFR 141.2). This broad definition of contaminant includes every substance that may be found dissolved or suspended in water—everything but the water molecule itself. Therefore, the presence of a contaminant in water does not necessarily mean that there is a human health concern.

Ecosystem Services – benefits supplied to human societies by the natural environment. These services are represented by processes by which the environment produces resources such as clean water, timber, habitat for fisheries, and pollination of native and agricultural plants.

Greenhouse Gas Mitigation – practices to reduce net concentration of greenhouse gases in the atmosphere through, for example, reduced energy use, water use, geological or biological or chemical sequestration of carbon dioxide, or by producing alternative low-emission energies and fuels.

Infrastructure:

> ***Built Infrastructure*** – use of grey infrastructure, i.e., pipes and conveyances that do not make use of natural systems
>
> ***Green Infrastructure*** – engineered systems that make use of natural waterways and other natural systems that complement traditional systems to manage land use impacts on hydrology
>
> ***Natural green infrastructure*** – natural ecosystem components that function to capture and retain water, and remove some level of natural and anthropogenic substances from the water
>
> ***Natural Infrastructure*** – natural environment, not engineered or manipulated by human design

Integrated Water Resource Management – a voluntary collaboration of state, interstate, local, and tribal governments across water sectors to manage the quality and quantity of water resources sustainably within watersheds and underlying aquifers.

Life Cycle Analysis (LCA) – a systematic approach to the identification of a product's total impacts on the environment, accounting for all the inputs and outputs throughout the life cycle of that product from its genesis (including design, raw material extraction, material production, production of its parts, and assembly) through its use and final disposal.

Non Point Source Pollution - Source of pollution in which wastes are not released at one specific, identifiable point but from a number of points that are spread out and difficult to identify and control

Output – outputs are synthesized and/or translated Products that are delivered to the Partner/Stakeholder in the format needed by the Partner. Outputs should be defined, to the extent possible, by Partners/Stakeholders during Problem Formulation and are responsive to Program Office/Stakeholder need. The date a Partner/Stakeholder needs to use the output should drive the output delivery date.

Partner/Stakeholder Outcome – the expected results, consequences that a Partner or Stakeholder will be able to accomplish due to ORD research.

Point Source Pollution – any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture.

Pollutant – as defined in Clean Water Act Sec. 502(6), a pollutant means dredged soil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water.

Product – a product is a deliverable that results from a specific Research Project or Research Task. Products may include (not an exhaustive list) journal articles, reports, databases, test results, methods, models, publications, technical support, workshops, best practices, patents, etc. One or more products may require translation or synthesis to be considered an Output.

Resilience – the capacity of a system to survive, adapt, and flourish in the face of turbulent change.

Sustainability – 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 (from the National Environmental Policy Act, 1970).

Sustainable solution – a system intervention that offers measurable improvements in an integrated set of sustainability indicators (economic, social, and environmental) such that the projected outcomes are valued by stakeholders in the affected system or systems.

Water resources – a general term encompassing all water types that may include groundwater, lakes, streams, rivers, wetlands, drinking water, estuaries, coastal waters, and marine waters.

Watershed – a topographically delimited area, scale independent, which drains surface and subsurface water to a common outlet. The hydrological system within a watershed is comprised of precipitation inputs, surface water (e.g., streams, rivers, lakes), soil water, and groundwater; vegetation and land use greatly affect these processes.

Healthy Watershed – a well-functioning watershed that has a high integrity (see definition below) and is resilient to stress (see definition below).

Watershed integrity – refers to the overall biological, physical, and chemical condition of the watershed being unimpaired, interconnected, and stable.

Watershed resiliency – refers to a watershed's ability to maintain its structure and function in the presence of stress.