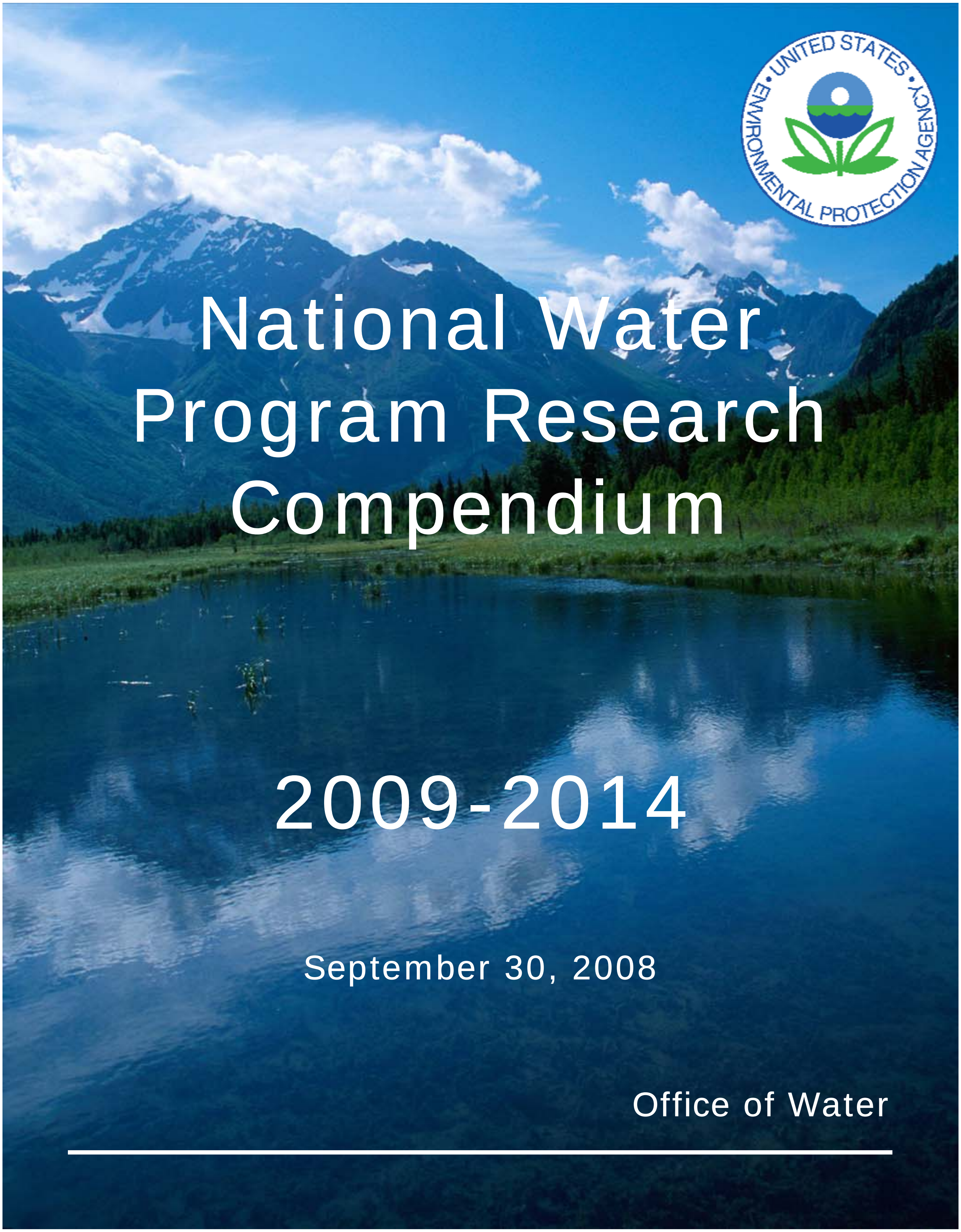

National Water Program Research Compendium

2009-2014

September 30, 2008

Office of Water

Office of Water (4304T)
EPA 822-R-08-015
September 2008
http://www.epa.gov/water

Disclaimer

This *National Water Program Research Compendium* document is a compilation of the research needed by EPA's National Water Program to successfully achieve its statutory and regulatory obligations, and its strategic targets and goals outlined in *EPA's Strategic Plan* and the *Water Program's National Program Guidance*. As such, we hope this document provides useful information and guidance to the public regarding those matters. To the extent the document mentions or discusses statutory or regulatory authority, it does so for information purposes only. The document does not substitute for those statutes or regulations, and readers should consult the statutes or regulations themselves to learn what they require. Neither this document, nor any part of it, is itself a rule or a regulation. Thus, it cannot change or impose legally binding requirements on EPA, States, the public, or the regulated community. The use of words such as "should," "could," "would," "will," "intend," "may," "might," "encourage," "expect," and "can," in this document means solely that something is intended, suggested or recommended, and not that it is legally required. Any expressed intention, suggestion or recommendation does not impose legally binding requirements on EPA, States, the public, or the regulated community. Agency decision makers remain free to exercise their discretion in choosing to implement the actions described in this *Compendium*.

Foreword

Results and Accountability – Innovation and Collaboration – Best Available Science

This *National Water Program Research Compendium* is a compilation of the research needed by EPA's National Water Program to successfully achieve its statutory and regulatory obligations as well as the strategic targets and goals outlined in EPA's Strategic Plan and the Water Program's National Program Guidance. The *National Water Program Research Strategy*, which is currently under development, will provide a clearer articulation of the research priorities for the National Water Program.

The goals of the *National Water Program Research Strategy* (*i.e., Water Research Strategy*) are: (1) to ensure that the Office of Water's (OW's, inclusive of the Regional Water Management Divisions) water research, science, and technology needs are identified and documented in a comprehensive plan; (2) expand partnerships and collaborations across EPA, the federal research family, and the broader research community to meet water research needs; and (3) support our commitment to collaborative corporate planning, prioritization and research management to meet the environmental goals of the National Water Program.

The *Water Research Strategy (future)* and this *Compendium* will bring a broader diversity of relevant and appropriately vetted science to OW's and the Regions' regulatory and non-regulatory tools and water management decisions, thereby increasing program credibility. Expanding the science base will help expedite the production of these tools and water quality environmental outcomes will be achieved faster and quantified better. I invite those researchers that are conducting, or considering conducting investigations in these areas to let us know about their work so we can improve our communications.

Michael H. Shapiro
Deputy Assistant Administrator
Office of Water

Acknowledgements

The development of the *National Water Program Research Compendium* was made possible through the collaboration and commitment of the Office of Water Research Coordination Team. The team provided content, review, and obtained expertise and consensus across the Water Program that ensured the document is both comprehensive and integrated. Their names and affiliations are captured below, as are those of other major contributors.

The project described here was managed by the Office of Science and Technology, Office of Water, USEPA under GS 10F 0105J to the Cadmus Group, Inc. The Office of Water wishes to thank Dr. George Hallberg, Cadmus Project Manager, and key staff including: Maureen Stone, Vanessa M. Leiby, Anne Jaffe Murray, Kristy Burt, and Mary Ellen Tuccillo for the expertise and tirelessness they brought to this project.

Office of Water Research Coordination Team Members (and contributing former members):

Kevin Barnes: OGWDW
Robert Bastian: OWM
Heidi Bethel: OST
Valerie Blank: OGWDW – former member
Robert Cantilli: OST
Octavia Conerly: OST
Tiffany Crawford: OST
Jill Dean: OGWDW
Diana Eignor: OST
Hiba Ernst: OGWDW/ORD - former member
Chris Faulkner: OWOW
Kesha Forrest: OGWDW
Stephanie Fulton: Region 4
Laura Gabanski: OWOW – former member
Hend Galal-Gorchev: OST
Latisha Mapp: OGWDW
Rene Morris: OGWDW – former member
Sandhya Parshionikar: OGWDW
Arleen Plunkett: OST
Santhini Ramasamy: OST
Mary Reiley: OST**
Crystal Rodgers-Jenkins: OGWDW
Roy Simon: OGWDW
Rick Stevens: OST
Lesley Vazquez-Coriano: OST

Major Contributors:

Jan Baxter: Region 9
Ron Landy: Region 3

*** The primary contact regarding questions or comments to this document is:*

Mary C. Reiley
Biologist
USEPA Headquarters
Office of Science and Technology, Office of Water
1200 Pennsylvania Avenue, NW
Mail Code: 4304T
Washington, DC 20460
Phone: 202-566-1123
Email: reiley.mary@epa.gov

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List of Acronyms and Abbreviations

Action Plan	Water Security Research and Technical Support Action Plan
AIEO	American Indian Environmental Office
ASR	Aquifer Storage and Recovery
AWWA	American Water Works Association
AwwaRF	American Water Works Association research foundation
BAFs	Bioaccumulation Factors
BCG	Biological Condition Gradient
BEACH Act	Beaches Environmental Assessment and Coastal Health
Bioterrorism Act	Public Health Security and Bioterrorism Preparedness and Response Act
BMPs	Best Management Practices
BOSC	Board of Scientific Counselors
CADDIS	Causal Analysis/Diagnosis Decision Information System
CAFOs	Concentrated Animal Feeding Operations
CBR	Chemical, Biological, and Radiological
CCL	Contaminant Candidate List
CCL3	EPA's Third Contaminant Candidate List
CHABs	Cyanobacteria
CLAE	Council of Large Aquatic Ecosystems
CNMI	Commonwealth of the Northern Mariana Islands
CO_2	Carbon Dioxide
CPSP	Critical Path Science Plan for Development of New or Revised Recreational Water Quality Criteria
CSOs	Combined Sewer Overflows
CWA	Clean Water Act
DBPs	Disinfection by-product
EcoHAB	Ecology and Oceanography of Harmful Algal Blooms
EDCs	Endocrine Disruptors
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERA	Ecological Risk Assessment
ESA	Ethanesulfonic acid
FR	Federal Register
GAO	Government Accountability Office
GI	Green Infrastructure
GOM	Gulf of Mexico
Guidelines	Aquatic Life Guidelines
HABs	Harmful Algal Blooms
HS-IW	Headwater Stream, Adjacent Wetland, or Isolated Wetland

HSPD	Homeland Security Presidential Directive
ICRI	International Coral Reef Initiative
LCR	Lead and Copper Rule
LCREP	Lower Columbia River Estuary Partnership
LISS	Long Island Sound Study
MARB	Mississippi/Atchafalaya River Basin
MCLGs	Maximum Contaminant Level Goals
MOA	Mechanism of Action
MPRSA	Marine Protection, Research, and Sanctuaries Act
MRB	Mississippi River Basin
MYPs	Multi-Year Plans
NEP	National Estuary Program
NESCS	Non-market Ecosystem Services Classification System
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
NMPs	Nutrient Management Plans
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPDWRs	National Primary Drinking Water Regulations
NRC	National Research Council
OA	Oxanilic acid
OGWDW	Office of Ground Water and Drinking Water
O&M	Operation and Maintenance
OMB	Office of Budget and Management
ORD	Office of Research and Development
OST	Office of Science and Technology
OW	Office of Water
OWM	Office of Wastewater Management
OWOW	Office of Wetlands Oceans and Watersheds
OW-RCT	Office of Water-Research Coordination Team
PAMs	Program Activity Measures
PART	Program Assessment Rating Tool
POTW	Publicly Owned Treatment Works
PPCPs	Pharmaceutical and Personal Care Products
PWS	Public Water System
qPCR	Quantitative Polymerase Chain Reaction
Reg Det	Regulatory Determination
RMST	Research Management and Status Tool
SAB	Science Advisory Board
SABS	Suspended and Bedded Sediments
SBIR	Small Business Innovative Research
SDWA	Safe Drinking Water Act
SO_4	Sulfate

SSOs	Sanitary Sewer Overflows
STAC	Scientific and Technical Advisory Committee
Stage 2 DBPR	Stage 2 Disinfection By-Products Rule
STAR	Science to Achieve Results
SWP	Source Water Protection
TALU	Tiered Aquatic Life Use
TCR	Total Coliform Rule
TCRDSAC	Total Coliform Rule Distribution System Advisory Committee
TEVA	Threat Ensemble Vulnerability Assessment
TMDL	Total Maximum Daily Load
UCMR	Unregulated Contaminant Monitoring Regulation
UIC	Underground Injection Control
USDWs	Underground Sources of Drinking Water
USEPA	United State Environmental Protection Agency
UVR	Ultraviolet Radiation
Water Research Strategy	National Water Program Research Strategy
WERF	Water Environment Research Foundation
WIPD	Water Infrastructure Protection Division
WSD	Water Security Division
WSI	Water Security Initiative
WSP	Water Security Program
WQC	Water Quality Criteria

Executive Summary

EPA's Office of Water (OW) and Regional Water Divisions are responsible for the Agency's water quality and water resource protection activities including development of national programs, technical policies, and regulations relating to drinking water, water quality, ground water, pollution source standards, and the protection of wetlands, marine, and estuarine areas. Within OW are four main program offices: Office of Ground Water and Drinking Water (OGWDW); Office of Wastewater Management (OWM); Office of Wetlands, Oceans, and Watersheds (OWOW); and Office of Science and Technology (OST). OW partners with the EPA Regions to integrate and implement the Agency's water programs.

National Water Program Goals

The National Water Program has three goals:

1. Ensure clean and safe water and drinking water to protect human health.
2. Protect and restore aquatic ecosystems and human health through watershed and place-based programs.
3. Protect and restore water quality to ensure the health of aquatic life and aquatic dependent wildlife.

Four principal programs within OW and the Regions are charged with achieving the National Water Program Goals:

- Drinking water, ground water, source water, and water security protection programs
- Wastewater management for water quality protection programs
- Watershed and place-based protection and restoration programs
- Aquatic life and human health protection programs

Drinking water, ground water, source water and water security protection programs provide comprehensive protection of drinking water sources, health-based drinking water treatment standards, and prepare drinking water systems for large-scale contamination events, natural disasters, terrorist attacks, and other intentional acts.

Wastewater management for water quality protection programs characterize and manage sources of water quality degradation and provide information on the latest wastewater and residuals treatment and reuse technologies and management practices. They also manage potential sources of pollution, such as decentralized wastewater systems and stormwater runoff.

Watershed and place-based protection and restoration programs provide decision-makers with the data and tools to select the most appropriate water bodies, restoration methods, and monitoring schemes to protect and restore the ecological, economic, and cultural services provided by aquatic ecosystems.

Aquatic life and human health protection programs ensure that: 1) State-adopted criteria for pathogens and indicator organisms are current and sound; 2) the science underpinning core water programs is current and appropriately vetted for use in State and Tribal water quality standards, total maximum daily loads (TMDLs), permits, assessments, and drinking water regulations; 3) health effects and human health risk assessment science is available and used to support human health protection programs; and 4) the National Water Program is able to address emerging water quality concerns.

The four principal Program offices and the Regions collaborate on special efforts to protect and restore large aquatic ecosystems.

Strategy Purpose

Results and Accountability - Innovation and Collaboration - Best Available Science

The goals of the *Water Research Strategy* are: (1) to ensure that the Office of Water's (OW's, inclusive of the Regional Water Management Divisions) water research, science, and technology needs are identified and documented in a comprehensive plan; (2) to expand partnerships and collaborations across EPA, the federal research family, and the broader research community to meet water research needs; and (3) support our commitment to collaborative corporate planning, prioritization and research management to meet the environmental goals of the National Water Program.

The *Water Research Strategy* will bring a broader diversity of relevant and appropriately vetted science to OW's and the Regions' regulatory and non-regulatory tools and water management decisions, thereby increasing program credibility. Expanding the science base will help expedite the production of these tools and water quality environmental outcomes will be achieved faster and quantified better.

The *Water Research Strategy* will emphasize:

Results and Accountability: We will design the *Water Research Strategy* to address the long-term goal set out in the *EPA Strategic Plan* of providing "Clean and Safe Water." We will report annually on our progress on the research portfolio and adjust it appropriately to meet changes in objectives and priorities.

Innovation and Collaboration: Our progress toward water and public health protection goals depends both on our ability and continued commitment to identify and use innovative tools, approaches, and solutions to address environmental problems and engage extensively with our partners, stakeholders, and the public.

Best Available Science: EPA needs the best scientific information available to anticipate potential environmental threats, evaluate risks, identify solutions, and develop protective standards. Sound science helps us ask the right questions, assess information, and characterize problems clearly to inform Agency decision makers.

Summary of Research Needs

Science to Support Drinking Water and Ground Water Protection Programs

The drinking water and ground water protection program research needs are captured in three categories.

- ❖ Regulatory development and implementation of drinking water standards
- ❖ Source water protection and underground injection control (UIC)
- ❖ Water security

To determine what contaminants may require regulations, information on health effects, occurrence, and potential exposure to the contaminants is needed, as well as information on analytical methods and treatment technologies. Science-based tools are needed to control nonpoint source pollution and otherwise unregulated point sources of pollution at the water resource scale, for source water protection. Minimum requirements for State UIC Programs must be established to ensure underground injection does not endanger drinking water sources. EPA's Water Program must provide science and tools so that water utilities can identify site-specific vulnerabilities, invest in better system protection, and develop emergency response protocols and methods to detect and respond to threats to drinking water and wastewater systems.

- Health Effects
  - What are the actual or potential human health effects of known and emerging pathogens, chemicals, and suites of contaminants and how can the risk assessment process be improved to best assess these effects?
  - What is the cumulative risk associated with combinations of contaminants that are likely to co-occur and affect similar target organs or modes of action?

- Method Development
  - Do analytical methods exist with enough sensitivity, specificity, accuracy and precision to: (i) detect and quantify the contaminant, and (ii) verify remediation or removal? For pathogens, can the methods address viability?
  - Are the methods robust enough to support national occurrence data collection and/or can they be widely applied to support monitoring for regulatory compliance?
  - How do we assess drinking water resources and their vulnerability to contamination?

- How do we account for and address climate change impacts on water resources? (tools to support integrated water resource planning and management at multiple water resource scales, assessment and multi-decadal projection of water quantity and quality, and the optimization of choices among water supply management and water demand management alternatives)?
- What is the state of the science around injected carbon dioxide (CO_2)?
- What are the physical and chemical processes governing fate and transport of injected CO_2?
- What methods are available for monitoring CO_2 in the subsurface and for evaluating those monitoring techniques?
- What methods should be used to develop well construction, well plugging, and well abandonment procedures appropriate for long term CO_2 injection?
- What technical tools and decision models should be used or built to support aquifer storage and recovery for non-potable reuse?
- What methods and tools are needed to protect water and wastewater utilities from physical and cyber threats?
- How do we evaluate potential utility and system threats and their impacts?
- Are there methods and tools to evaluate and address system vulnerabilities?
- What are the optimal methods for detection of contaminants and means to determine and reduce the impact of such events?

- Occurrence and Exposure
  - What is the national occurrence of contaminants and the resultant exposures to the public?
  - How is the public exposed to these contaminants (*i.e.,* inhalation, ingestion, dermal), how often, and for what duration?
  - What data collection practices best capture the risk for both acute (where applicable) and chronic exposure?
  - How do we determine aggregate exposures to the same chemical from multiple media (*e.g.,* water, air, food)?

- Treatment Technologies – Management Approaches
  - What treatment technologies or techniques exist to remediate the contaminant or are new technologies needed?
  - Control of pollution at the water resource scale (*i.e.,* watershed and aquifer).
  - Are methods available to respond to system contamination events?
  - Are approaches available to decontaminate systems in the event of intentional or accidental contamination?

Science to Support Wastewater Management for Water Quality Protection Programs

Research needs to support wastewater management for water quality protection programs are summarized under five topic areas:

- ❖ Publicly owned treatment works (POTW) treatment effectiveness and management including fate of emerging contaminants
- ❖ Decentralized wastewater system performance
- ❖ Residuals management and treatment for wastewater treatment processes and animal feeding operations
- ❖ Wet weather flow control technologies and effectiveness
- ❖ Aging infrastructure

Current issues of concern for wastewater management programs include: peak flow management (including blending); nutrient control; water reuse; unit process assessment (*i.e.,* a review of the functions and capabilities of a facility), evaluation, and modification. The fate/transport and potential interference/pass through of emerging contaminants, especially pharmaceuticals and personal care products (PPCPs) are also a priority. Information is needed to improve the ability of wastewater utilities to cost-effectively assess, maintain, operate, rehabilitate, and replace their collection and treatment systems. Research needs are outlined below.

- Health Effects
  - Field studies to determine if contaminants in biosolids pose a public health risk where biosolids are applied to land.

- Method Development
  - Determine decentralized wastewater system and residuals treatment effectiveness and management, including fate of emerging contaminants.
  - Assess system failures and their impacts (including cause and effect studies); leach field/soil treatment and water acceptance capacity; comprehensive system management; and fate/transport of pathogens and emerging pollutants.
  - Accurately account for decentralized systems in TMDL models: evaluate the risk associated with decentralized systems on a watershed scale; compare and prioritize at-risk watersheds; the impact of both properly and poorly designed, operated, and maintained systems; new or refined source tracking and remote sensing methods to accomplish reliable watershed-scale assessments.
  - Methods for the detection and identification of pathogens in wastewater, biosolids, and animal wastes to ensure proper disinfection and stabilization.
  - Refine methods for microbial source identification and tracking.

  - Examine economic costs and benefits of green infrastructure (GI) and develop methods and protocols for economic parameters.
  - Develop standard protocols for assessing multiple benefits from GI (*e.g.,* energy savings, carbon sequestration, urban heat island reduction, biodiversity, water conservation).
  - Methods to compare the benefits of GI with those of grey infrastructure approaches.
  - New and innovative condition assessment and rehabilitation methods and technologies for sewerage systems.
  - Comprehensive, integrated management approaches for sewerage systems.

- Treatment Technologies – Management Approaches

  - Approaches to reduce and control nutrients and difficult to treat chemicals and pathogens.
  - Control emerging contaminants, through additional treatment, source reduction, and product substitution.
  - Improve energy efficiency and decentralized power production.
  - Management and treatment of municipal, industrial and construction wet weather flows "outside the fence line" of the POTW.
  - Reduce the volume of wastewater treatment residuals.
  - Ability of various soil types to provide treatment; treatment system efficiencies for currently regulated pollutants (pathogens and nutrients), as well as emerging pollutants of concern (endocrine disruptors, PPCPs, and difficult to treat pathogens); performance capabilities and reliability of many currently available decentralized treatment technologies.
  - Documentation of the effectiveness of current residuals disinfection and stabilization methods.
  - Studies to determine the effectiveness of Nutrient Management Plans for animal livestock operations and other land applications of residuals.
  - Characterize GI practices and their effectiveness at the watershed scale, taking into consideration upstream and downstream conditions, some of which can be done through case studies.
  - New sewer and treatment system design concepts.

Science to Support Watershed and Place-Based Protection and Restoration Programs

Research needs for watershed protection and restoration programs are organized under the following areas:

- ❖ National aquatic resource assessments
- ❖ Watershed assessment, management, and incentives
- ❖ Wetlands in water quality trading

- ❖ Headwaters, adjacent wetlands, and isolated wetlands
- ❖ Gulf of Mexico hypoxia
- ❖ Invasive species
- ❖ Ecological restoration
- ❖ Coral reef protection

Across watershed and place-based management and restoration programs the research needs focus on being able to select candidate water bodies for restoration, select an optimal suite of restoration methods, and monitor results of restoration efforts.

- Health Effects
  - Assess the contribution of isolated wetlands to the integrity of navigable downstream water bodies.
  - Examine how the degradation, loss, or restoration of headwater streams and isolated wetlands affects the quality and integrity of navigable waters.
  - Identify appropriate indicators of aquatic health and determine suitability of new analytical methods.
  - Provide projections of the consequences of future development and other anthropogenic changes (such as climate change) and develop strategies to minimize negative impacts on important ecosystems.
  - Estimate the environmental and economic impacts of invasive species affecting the aquatic environment.
  - Characterize the effects of global change and anthropogenic stressors on conditions of coral and coral reefs.
  - Characterize the interactive roles of ultraviolet radiation (UVR), temperature, and water quality on coral bleaching.
  - Characterize the responses of coral symbionts (*Symbiodinium* spp.) to elevated UVR, elevated temperature and changes in water quality.

- Method Development
  - Provide tools for effective ecosystem monitoring.
  - Develop and improve integrative watershed modeling frameworks.
  - Methods to evaluate and describe condition, thresholds of impairment, and attribute value to watershed goods and services.
  - Methods, tools, and models to determine which (and how) stressors are causing degradation, or likely to cause degradation to enable targeted action for protection and restoration.
  - Tools and knowledge to target watersheds for management and offer the greatest opportunity for achieving positive and intended environmental results.

    - Monitoring strategies to measure the effectiveness of watershed management programs.
    - Methods to determine factors that motivate change in public behavior toward the protection or restoration of water quality.
    - Develop technology transfer mechanisms that provide watershed managers with resources needed to make technically-sound watershed management decisions.
    - Determine how to avoid unintended negative consequences associated with wetlands managed for nutrient removal.
    - Identify an acceptable approach for estimating risk and uncertainty in wetland used in water quality trading.
    - Determine how to manage wetlands used in water quality trading.
    - Classification methods, simple models, mapping techniques, and rapid assessment field methods for headwaters, adjacent wetlands, and isolated wetlands that incorporate and complement best professional judgment.
    - Better model the hypoxic zone to understand its dynamics and predict the impacts of restoration scenarios.
    - Determine how the assessment of ecological conditions, the modeling of ecological and human development futures, and the development of restoration and protection strategies can be done effectively at differing geographic and temporal scales.
    - Develop an improved scientific basis for the establishment and maintenance of rapid response and monitoring programs for non-indigenous species.
    - Create education and outreach opportunities to assist groups and individuals affected by invasive species.

- Occurrence and Exposure

    - Provide national frameworks for statistical assessments.
    - Identify trends in water quality and aquatic systems.
    - Develop scientific knowledge of potential pathways of introduction of non-indigenous and invasive species and tools to ensure their prevention.

- Treatment Technologies – Management Approaches

    - Identify and characterize the watershed structures, features, and processes that influence the likelihood for successful management interventions.
    - Determine the performance and costs of individual management measurements to support the development of watershed management strategies.
    - Optimize the selection and location/placement of management measures in a watershed.
    - Determine the effectiveness of best management practices (BMPs).
    - Identify existing data regarding wetland nutrient removal rates to be used for modeling and assigning trading credits.
    - Feasibility of offsetting stream segment degradation with improvements.

- Effective management strategies to reduce nutrient and sediment ecosystem impacts in the Mississippi Basin and in the Gulf of Mexico.
- Develop tools and scientific knowledge to control invasive species that affect aquatic ecosystems.

Science to Support Aquatic Life and Human Health Protection Programs

The diverse range of research needed to support the Aquatic Life and Human Health Protection Programs is outlined in two broad categories: (1) Human Health Effects and Risk Assessments and (2) Aquatic Life and Aquatic Dependent Wildlife Effects and Risk Assessments.

Human Health Effects and Risk Assessments

- ❖ Regulatory implementation
- ❖ Biosolids
- ❖ Emerging contaminants
- ❖ Recreational waters - assessment of human health risk

- Health Effects
  - Use of mechanistic data in risk assessment. Understanding key events associated with exposure and the ultimate manifestation of an adverse health effect (*i.e.,* the toxicity pathway or mode or mechanism of action) would help reduce the uncertainty associated with data extrapolation from animals to humans and from high to low doses.
  - Cumulative risk. Both exposure assessment information and risk assessment methods to evaluate human health risks from exposure to chemical mixtures.
  - Sensitive subpopulations. Is there differential life-stage responsiveness or exposure to environmental agents (chemical and pathogen)? Which methods and models are appropriate for longitudinal research with children? How should genetic differences among populations that influence their susceptibility to illness or disease from a hazardous substance be considered in risk assessments?
  - Contaminant-specific health studies. Sufficient occurrence, health effects, reproductive effects, etc. data on specific chemicals to determine if regulation is warranted under the Safe Drinking Water Act and/or criteria recommendations under the Clean Water Act (CWA).
  - Determine whether contaminants in biosolids pose a public health risk when applied in compliance with current regulations.
  - For those emerging contaminants (or classes) that are candidates for regulation, conduct the necessary supporting research.

- Methods (including predictive models) that provide more rapid and timely detections of pathogens or indicators of the presence of pathogens that are harmful to human health in recreational waters and drinking waters.
- Understand which human illnesses are caused by swimming in waters contaminated with human fecal matter from different sources, with non-human fecal matter, the levels of fecal matter (human and non-human) that cause human illness, the relationship between different levels of fecal matter (human and non-human) in waters and human illness rates, and differences in risk to children versus adults swimming in these waters.

- Method Development
    - Develop improved analytical techniques for pathogens and priority toxic contaminants in or released from biosolids.
    - Develop approaches to identify/categorize which emerging contaminants (or classes) are risks to the environment or human health.
    - Methods (including predictive models) that provide more rapid and timely detections of pathogens or indicators of the presence of pathogens that are harmful to human health in recreational waters and drinking waters.
    - Establish a framework for prioritizing high-risk emerging contaminants for exposure and hazard assessment and criteria development.
    - Indicators and methods of how well culture and molecular methods for various indicators (singly or in combination) correlate with swimming-related illnesses.

- Occurrence and Exposure
    - Select appropriate pathogens and indicators to properly assess sewage sludge quality.
    - Extrapolation of research results for developing new or revised criteria. Are indicators, methods, and models suitable for use in different types of waters and for different CWA programs?

- Treatment Technologies – Management Approaches
    - Determine effective measures for reducing pathogens and emerging contaminants from sludge in environmental media.

Aquatic Life and Aquatic Dependent Wildlife Protection

- ❖ Bioassessment/Biocriteria
- ❖ Aquatic life guidelines
- ❖ Aquatic habitat
- ❖ Nutrients
- ❖ Suspended and bedded sediments (SABS)

- Integration of multiple stressors
- Socio-economic valuation

- Health Effects
  - Quantify the effects of exposures at, below, and above the criteria; tissue-based criteria to assess the risks posed by compounds that bioaccumulate through diet.
  - Toxicity data, particularly two-generation tests with multiple relevant endpoints. A derivation method for use when available data set does not meet minimum Guidelines requirements.
  - Provide the scientific basis and load-response relationships needed to develop and implement numeric nutrient criteria, with an emphasis on the health of estuaries and coastal wetlands.
  - Evaluate the relationship between nutrient criteria and flow conditions.
  - Understand the relationship between harmful algal blooms and nutrient dynamics (also useful for human health related to cyanotoxins and drinking water).

- Method Development
  - Methods to establish Biological Condition Gradient (BCG) and Generalized Stressor Gradient models.
  - Sampling and analytical methods or models to predict the recovery potential of different water body types.
  - Methods for measuring biocriteria in arid systems, large and great rivers, wetlands, estuarine areas, and marine systems (including coral reefs).
  - Community and population-level assessment models to replace current organism-based criteria. Ecosystem models to integrate risk across an assemblage of species. Dose-based toxicity models to account for multiple routes of exposure, including diet. Bioaccumulation, tissue concentrations, and fate and transport models. Computational toxicology to help set priorities for data requirements and chemical risk assessments.
  - BAFs for methylmercury in fish tissue relative to methylmercury in the water column across different water body types or ecological conditions to develop water column translations of the January 2001 fish tissue-based criterion.
  - Tools to measure and predict the contributions of aquatic habitat protection and restoration to the maintenance and improvement of biological integrity.
  - Integrative methods and approaches to incorporate habitat into BCGs for application to tiered aquatic life use (TALU) frameworks.
  - Tools for measuring and predicting the economic and societal benefits of aquatic habitat protection and restoration at local, regional, and national scales.
  - Incorporate nutrient stressor-response relationships into BCG and TALU approaches.

- Tools (monitoring methods, models, guidance) to implement environmentally sound nutrient trading approaches.
- Improve technical methods used in EPA's Framework for Developing SABS Water Quality Criteria.
- Verify methods and support implementation of the SABS Framework.
- New concepts for defining and classifying ecosystem services and bundles of those services.
- Improved approaches and information for describing the production of services.
- Methods to quantify the values of ecosystem services and innovative ways of using this knowledge in proactive environmental management decisions.
- Methods for valuation of services provided by wetlands and by coral reefs.
- Methods to project the relative and combined risks from multiple stressors to aquatic and aquatic-dependent wildlife populations.
- Conceptual and empirical approaches to predict, diagnose, prevent, and manage the combined effects of multiple stressors in aquatic systems.
- Methods to assess change in aquatic ecosystems that reflect responses to multiple and variable stressors.

- Occurrence and Exposure
  - Classify ecosystems, landscapes, and watersheds for efficient and scientifically sound development and application of biocriteria.
  - Assess emerging water quality concerns; both biological (pathogens, invasive species) and chemical (*e.g.,* pharmaceuticals) and which constituents to regulate.

Science to Support Place-Based Water Protection and Restoration – Large Aquatic Ecosystems Programs

Place-Based Programs are special, geographically-focused subsets of the National Water Program. OW has established directed efforts to protect and restore large aquatic ecosystem because of their sheer size, varied and widespread contributing sources, and often the crosscutting of spatial jurisdictions that need to take action. Each of these ecosystems may need a specific application of a national research topic in order to address their unique hydrologic and land use conditions. The place-based programs currently included in the Large Aquatic Ecosystems initiatives are:

- ❖ Integration of Multiple Stressors
- ❖ Chesapeake Bay
- ❖ Great Lakes
- ❖ Gulf of Mexico
- ❖ South Florida
- ❖ Long Island Sound

- ❖ Lake Champlain
- ❖ Columbia River
- ❖ Puget Sound
- ❖ The Pacific Islands
- ❖ The US – Mexico Border

The Large Aquatic Ecosystem Council will be preparing a portfolio of mutual research needs in 2009. A list of anticipated needs is provided below.

- Health Effects
  - Why is the *Diporeia* population in the Great Lakes declining?
  - What is the impact of contaminants on ecosystem function?
  - What is the relative importance (risk) of emerging contaminants in Puget Sound?
  - How does sedimentation affect coral reefs?
  - How will/are aquatic ecosystems affected by climate changes?

- Method Development
  - What is the relationship between sediment deposition and anthropogenic (land use) and natural (climate change) impacts on a system?
  - What is the origin, transport, and residence time of sediments in estuaries?
  - How do we manage ecosystems for climate change?

- Occurrence and Exposure
  - How have native species become established?
  - What is the distribution of pollutants in runoff, including metals and polycyclic aromatic hydrocarbons in Puget Sound?
  - How often, where, and at what concentrations do emerging contaminants occur?

- Treatment Technologies – Management Approaches
  - Management measures to control hypoxia.
  - What is the effectiveness of BMPs for sediment reduction?
  - Methods to control the introduction of invasive species in ballast water to native waters.
  - How do we best manage sources of toxics as a part of remediation?

Science to Support Cross-Program Needs

As the Water Program has matured, the improved knowledge and understanding of the interrelationship of environmental issues has led to the identification of programmatic and research needs that are common to multiple offices and has fostered development of many cross-program research initiatives and approaches. These efforts are designed to enhance the collaborative process and to find solutions to environmental issues that cut across programmatic areas. Through recognition of the need for integration of these research efforts, the Water Program can more efficiently use resources to address multiple environmental issues and to support and enhance efforts across the various Offices. Many of these topics are noted and discussed throughout this *Compendium*. Five areas, in particular, cut across programs areas and are highlighted in this chapter. They are:

- The sustainable infrastructure initiative
- Watershed approach
- Analytical methods
- Emerging contaminants
- Climate change

The Sustainable Infrastructure Initiative

- Method Development
  - Information on new and innovative condition assessment and rehabilitation and replacement methods and technologies.
  - Comprehensive, integrated management approaches to improve the ability of water and wastewater utilities to cost-effectively assess, maintain, operate, rehabilitate, and replace their collection and treatment systems.
  - Additional data are needed to help utilities evaluate and estimate the costs of treatment and delivery of drinking water and wastewater.
  - Social marketing approaches need to be explored to determine how to best educate the public regarding the benefits and costs of providing high-quality public services.
  - Better define the effectiveness, costs, and benefits of water conservation and water efficiency practices and programs.
  - Social marketing approaches to provide effective education and outreach campaigns on water conservation.

- Treatment Technologies – Management Approaches
  - New sewer and treatment system design concepts.
  - Better understand and integrate Green Infrastructure approaches into a comprehensive approach, as well as water reuse and reclamation approaches.

Watershed Approach

- Health Effects
    - Effectively account for the combined and cumulative effects of point and nonpoint sources of pollution, habitat alteration, and other sources of impairment.
    - Determine how to avoid unintended negative consequences from wetland trading.

- Method Development
    - Providing tools for effective ecosystem monitoring, identifying appropriate indicators of aquatic health and determining suitability of new analytical methods.
    - Develop and improve integrative watershed modeling frameworks for describing the impacts of changing surface water quantity on water quality.
    - Assess the costs associated with various management measures to allow for the development of effective watershed strategies.
    - Develop strategies to optimize the selection and location/placement of management measures in a watershed.
    - Monitoring strategies to measure the effectiveness of watershed management programs.
    - Determine the factors that most motivate changes in public behavior with respect to the protection or restoration of water quality.
    - Effective technology transfer mechanisms are needed to provide watershed managers with resources needed to make technically-sound watershed management decisions.
    - Identify an approach for estimating the risks, costs, and benefits associated with wetland trading.
    - Determine how to manage and monitor wetlands used in water quality trading.
    - Accurately account for decentralized wastewater systems (both properly and poorly designed, operated, and maintained systems) in watershed models and TMDL calculations.
    - Up-to-date technology transfer methods regarding innovations and costs of treatment technologies.

- Occurrence and Exposure
    - Chemical, physical, and biological information that will allow them to understand the status and functioning of aquatic ecosystems and to evaluate the success of watershed protection and restoration measures over time.
    - Determine the geographic scale on which trading might occur.

- Treatment Technologies – Management Approaches
    - Identify existing data regarding wetland nutrient removal rates for modeling and assigning trading credits.

- Evaluate treatments that will improve system performance such as the abilities of the various soil types to provide treatment.
- Evaluate treatment system efficiencies for currently regulated pollutants (pathogens and nutrients) and emerging pollutants of concern (see Emerging Contaminants discussion later in this chapter).
- Evaluate performance capabilities and reliability of many currently available on-site/decentralized treatment technologies.
- Develop science-based tools that better enable the assessment of drinking water resources and their vulnerability to contamination.
- Develop science-based tools that better control nonpoint source and otherwise unregulated point source pollution at the water resource scale (*i.e.,* watershed and aquifer).

Analytical Methods – To Detect Biological and Chemical Contaminants

The National Water Program requires sensitive, specific, accurate, and precise analytical methods that can detect and quantify the occurrence of contaminants in water and other media. Methods are needed to measure water quality to assess the status and health of waters and to develop standards, measure compliance, and/or the verification of their remediation or removal. Of growing concern across the National Water Program is the ability to identify emerging contaminants, both biological (pathogens, invasive species) and chemical (pharmaceuticals, pesticides) not only in water but in land-applied biosolids, septage, and manure. Continued research is needed to develop techniques that are accurate, precise, and suitable for these different environmental matrices. In particular, the development of more reliable and faster methods for identifying pathogens and pathogen indicators is a research priority because of the acute health effects of pathogens.

- Health Effects Methods
  - Select appropriate pathogens and indicators to properly assess sewage sludge quality.
  - Assess how well culture and molecular methods for pathogens (singly or in combination) may perform (new molecular methods must consider the specificity and sensitivity of the methods and how they can address viability and infectivity of the pathogens.
  - Whether or not qPCR for *Enterococci* is applicable to other settings or appropriate for use across the range of CWA programs.
  - Develop improved analytical techniques for pathogens and priority contaminants in residuals/biosolids.
  - Methods to assess emerging pathogens (from viruses to prions, for example).

- Occurrence and Exposure Methods
  - Analytical methods to gather occurrence data for unregulated and emerging contaminants for future UCMR data collection efforts and the CCL Regulatory Determination process.
  - New methods or refine existing analytical methods for the detection and quantification of regulated contaminants to improve existing drinking water standards.
  - More robust methods for measuring pathogens and emerging DBPs and DBP mixtures in drinking water and distribution systems.
  - Developing detectors, analytical methods, sample preparation techniques, and models and tools to detect, in real-time when possible, contaminants introduced into the water and wastewater systems.
  - Improve the accuracy of CANARY, a tool that analyzes water quality data streams and identifies anomalous conditions in distribution systems that require further investigation.
  - Methods (including predictive models) that provide more rapid and timely detections of pathogens or indicators of the presence of pathogens that are harmful to human health in recreational waters and drinking waters.
  - Understand how well the various indicators and methods perform in other settings (*e.g.,* marine versus fresh water; human versus non-human sources of fecal contamination), and how they relate to one another.

Emerging Contaminants

Emerging contaminants refer broadly to those synthetic or naturally occurring chemicals, or to any microbiological organisms, that are new to the environment or that have not previously been monitored for or recognized in the environment, but are of concern because of their known or suspected adverse ecological or human health effects. These contaminants, by definition, are insufficiently understood to determine their need for control and regulation.

Two key groups of emerging contaminants of concern, discussed in this *Compendium*, are the Endocrine Disrupting Chemicals (EDCs) and the Pharmaceutical and Personal Care Products (PPCPs). Others emerging contaminants include nanomaterials, fluorinated compounds, and pathogens – various protozoa, bacteria, viruses, and prions.

- Health Effects
  - Evaluate whether or not the existing toxicological methods can adequately account for and address emerging contaminants.
  - Define appropriate toxicological data and health endpoints to evaluate emerging contaminants, such as pharmaceuticals.

- Method Development
  - Testing procedures or models for evaluating emerging contaminants fate and effects.
  - Assess the quality and utility of data, tools, and methods used for risk assessments for new and unique contaminants, such as prions and nanomaterials.

- Occurrence and Exposure
  - New or improved analytical methods are needed to gather occurrence data on emerging contaminants.
  - Appearance of nanochemicals/particles in products produced from land-applied biosolids.
  - Information about the pollutants in various types of wet weather flows, including pathogens and emerging contaminants.

- Treatment Technologies – Management Approaches
  - Effectiveness of both conventional and innovative treatment technologies for minimizing the risk from emerging contaminants.
  - How antimicrobial resistance in wastewater streams may impact the treatment process.
  - Determine performance capabilities and reliability of many currently available decentralized/on-site treatment technologies for emerging pollutants of concern.
  - Identify appropriate new or existing treatment techniques and BMPs for removing or inactivating emerging contaminants in runoff from various sources, activities and materials.
  - Effects of nanomaterials on POTWs, the abilities of nanomaterials to survive the treatment process.

Climate Change

Climate change will challenge EPA to coordinate across water programs and with cross-media programs to find programmatic solutions to reduce greenhouse gas emissions, increase energy and water efficiency, protect in-stream water quantity and quality, and continue to provide the public with safe and efficient water and wastewater services. Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and manmade structures.

- Health Effects
  - The full effects and consequences of alternative energy production (*e.g.,* biofuels) and carbon sequestration for water quality.
  - Interaction of climate change with land use/land cover change and other global change stressors to exacerbate or ameliorate impacts on water quality and aquatic ecosystems; and the types and levels of human pathogens that can enter, be sustained, and thrive in waters of the U.S.

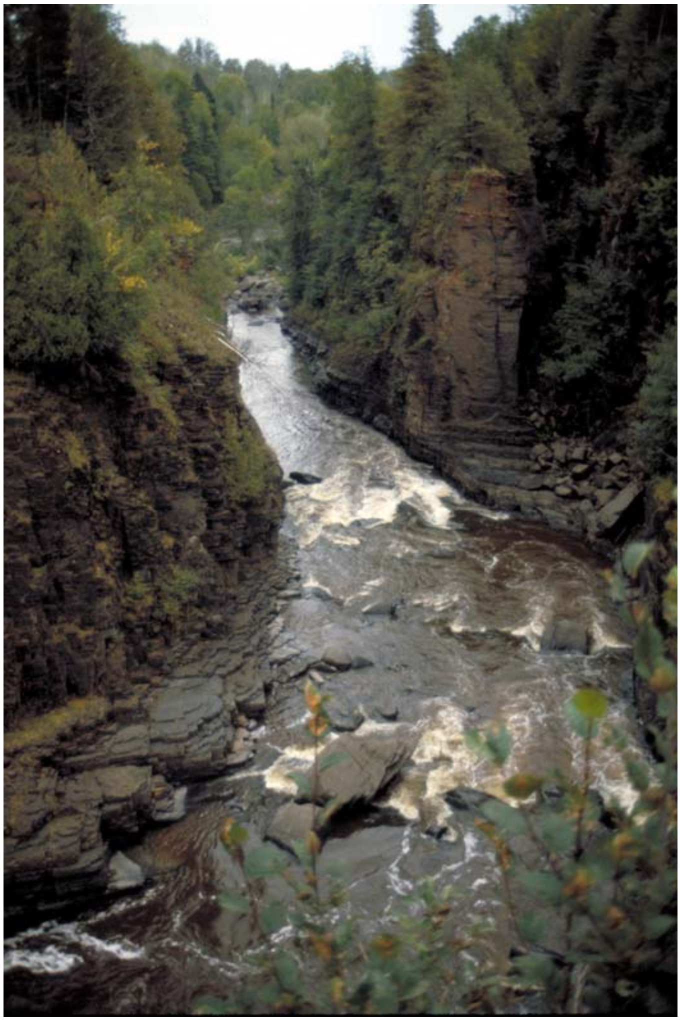
- Impact of climate and other global change stressors on the watershed and ocean processes that influence the structure, functioning, and services of freshwater and coastal ecosystems.

- Method Development
  - The influence of climate change on EPA water quality and ecosystem protection and restoration programs.
  - The influence of the interacting effects of changes in climate, land use, and economic development on human demand for water.

- Occurrence
  - Information, capabilities, and tools to increase their capacity for assessing and responding to global change given uncertainty about the type and magnitude of future change.
  - Identify impaired surface waters and establish causal linkages between climate and other stressors and endpoints of concern.
  - The regional differences in vulnerability of water quantity, water quality, ecosystems, water infrastructure, and human health to global change.
  - Impact of climate and other global change stressors on the design, operation, and performance of water infrastructure (*e.g.,* drinking water treatment, wastewater treatment, urban drainage) and the built environment.

- Treatment Technologies
  - How to increase the resilience of watersheds, water infrastructure, and aquatic ecosystems to global change stressors.

1 • A National Water Program Research Strategy



Background

The Environmental Protection Agency's (EPA) Office of Water (OW) and Regional Water Divisions are responsible for the Agency's water quality, water resource, and public health protection activities. These include development of national programs, technical policies, and regulations relating to drinking water, water quality, ground water, pollution source standards, and the protection and restoration of wetlands, marine, and estuarine areas. OW is organized into four main program offices:

- Office of Ground Water and Drinking Water (OGWDW)
- Office of Wetlands, Oceans, and Watersheds (OWOW)
- Office of Wastewater Management (OWM)
- Office of Science and Technology (OST)

OW and the four program offices partner with the EPA Regional Offices to develop and implement the Agency's National Water Program. The Regions implement water programs with State and local partners to provide public and ecosystem health protection. With respect to the title of this document, the Regions are specifically included as part and parcel to the National Water Program (the Water Program).

The Clean Water Act (CWA)[1] and the Safe Drinking Water Act (SDWA) provide the foundation for the statutory authority for the National Water Program. Coupled with other statutes, court actions, and initiatives of EPA and other agencies, these form the drivers for the Water Program's goals and in turn, the drivers to define the Water Program's Research

[1] The Federal Water Pollution Control Act Amendments of 1972 is commonly referred to as the Clean Water Act.

Needs. These drivers and the Program Offices are further described in the Addendum at the end of this Chapter. The Water Program's goals are described in EPA's strategic plan and OW's program guidance, as summarized below.

The *EPA Strategic Plan* for 2006 – 2011 defines goals for the Agency to meet to protect human health and the environment (the 2009-2014 Agency Draft Strategic Plan proposed complimentary goals and objectives). The Water Program's overarching goal is to provide "Clean and Safe Water", which includes improving compliance with drinking water standards, maintaining safe water quality at public beaches, restoring more than 2,000 polluted water bodies, and improving the health of coastal waters. The Water Program develops the *National Water Program Guidance* which outlines the work that must be accomplished to reach these goals. These public health and environmental goals are organized into ten "sub-objectives" as follows:

1) Provide Water that is Safe to Drink
2) Provide Fish and Shellfish that are Safe to Eat
3) Attain Water that is Safe for Swimming
4) Restore and Improve Water Quality on a Watershed Basis
5) Protect Coastal Waters and Estuaries
6) Protect Wetlands
7) Protect Mexico Border Water Quality
8) Protect the Great Lakes
9) Protect the Chesapeake Bay
10) Protect the Gulf of Mexico

The *National Water Program Research Strategy* (hereafter referred to as the *Water Research Strategy*) is an effort to work towards more completely defining the Water Program's research needs and organizing them around these "sub-objectives." The development, goals, and organization of this document are described in more detail below.

Water Research Strategy Development

> "A course of action marked by the creation and maintenance of a coordinated, comprehensive, and balanced national water resources research agenda, combined with a regular assessment of the water resources research activities … … represents the nation's best chance for dealing effectively with the many water crises sure to mark the 21st century."
>
> Confronting the Nation's Water Problems – The Role of Research
> The National Academies - National Research Council, 2004

EPA received recommendations from the National Academy of Sciences, EPA Science Advisory Board (SAB), and the Board of Scientific Counselors (BOSC) regarding the need for a documented and transparent water research portfolio linked to environmental outcomes. In 2001 and 2005, the SAB suggested that the Office of Research and Development (ORD) and the Water Program should strengthen their collaborations and those with external parties and work together to define the strategic links among long-term goals, desired outcomes, and research. These efforts would help both the Water Program and its stakeholders to meet regulatory obligations and to link ORD's multi-year plans (MYPs) to Water Program needs (*e.g.,* linkage between ambient water quality research and drinking water quality).

The BOSC (2005 and 2006) added to these recommendations and emphasized the need for transparency in prioritizing research, a system to evaluate and report progress jointly with ORD, and "anticipatory" research to address future/emerging needs.

ORD is responsible for a significant portion of the research and development needs of EPA's operating programs and the conduct of an integrated research and development program for the Agency. ORD's research efforts are defined in 15 MYPs, which provide a framework for defining and integrating research across ORD's laboratories and centers. Fourteen of these MYPs contain research that informs Water Program decisions. The principal MYPs pertaining to the Water Program are: Drinking Water, Water Quality, Ecosystems, Human Health, Endocrine Disruptors and Emerging Contaminants, and Climate Change. The *Water Research Strategy* will provide ORD with the necessary information to prepare highly program-relevant MYPs.

The Water Program has research needs beyond what ORD can provide, and some research is more appropriately done by other agencies or institutions. Individual Water Program project leads have been very successful in leveraging the expertise and investigations of researchers outside of EPA. In the past, the Water Program has relied on the entrepreneurial spirit of individuals on its staff to drive the inclusion of non-EPA investigators in programmatic research. But often this is not a comprehensive approach and can result in serious gaps in the research portfolio. Through the development of the *Water Research Strategy,* the Water Program intends to address its research needs in a more complete and comprehensive manner.

Water Research Strategy Goals

Through the *Water Research Strategy*, the National Water Program strives to achieve the following goals:

- Identify and document research needed to achieve Water Program strategic goals, program targets and measures, and statutory, court-ordered, or other obligations;
- Provide a more coordinated description of research needed across the entire Water Program, including the Regions, and a more comprehensive description that may go beyond the MYPs (with ORD);
- Provide a marketing tool to promote research partnerships across EPA, with other federal agencies, and with the broader research community to meet Water Program research needs;
- Coupled with the Water Research Management and Status Tool (RMST), provide for improved management of the Water Program's research portfolio; and
- Provide a baseline for ongoing research planning and assessment of research needs.

The *Water Research Strategy* (future), this *Compendium,* and RMST (future) will also help to stimulate the evaluation and communication of research results to decision makers and users in a form that leads to environmental outcomes.

Consistent with the *EPA Strategic Plan* and the *National Water Program Guidance*, this *Compendium*, and the *Water Research Strategy* (under development) emphasize:

- **Results and Accountability**: We have designed this approach to address the long-term goals set out in the *EPA Strategic Plan* and the *National Water Program Guidance*. We will annually evaluate the number and percentage of research needs being addressed on a timely basis to meet Water Program objectives and use the evaluation to adjust directions and priorities.
- **Innovation and Collaboration**: Our progress toward water and public health protection goals depends both on our ability and continued commitment to identify and use innovative tools, approaches, and solutions to address environmental problems and engage extensively with our partners, stakeholders, and the public.
- **Best Available Science**: EPA needs the best scientific information available to anticipate potential environmental threats, evaluate risks, identify solutions, and develop protective standards. Sound science helps us ask the right questions, assess information, and characterize problems clearly to inform Agency decision makers.

Research is best conceived and most appropriately vetted when it has been identified through purposeful evaluation of the current, near-future, and potential far-future environmental protection and restoration needs. In addition, specific research needs and products for the Water Program will be captured in the RMST. The management and status reports that will be available from the RMST will enable Water Program senior managers to evaluate the relevance and timeliness of research intended to help them achieve strategic goals and specific deadlines. It will also make it possible to assess which specific needs are not being met, evaluate proposed and ongoing research against programmatic needs, and find opportunities for collaboration.

The Water Program will target research efforts to provide data needed to: reach decisions regarding drinking water contaminants that should be regulated, new and revised drinking water regulations, new drinking water treatment strategies, compliance monitoring methods, and tools for source water protection. Research efforts will also help in assessing human and aquatic life exposure to contaminants; identifying contaminant mode-of-action and dose-response; determining treatment, performance, and cost parameters; and evaluating the effects of distribution systems on drinking water quality.

The Water Program will also target research efforts in the following areas to facilitate regulatory and voluntary program decisions for the protection of surface waters: diagnostic and forecasting tools and additional protective criteria for designated uses of aquatic systems; conservation, restoration, and protection of aquatic ecosystems; sustainable watershed technologies; and sustainable management of wastewater infrastructure. Water quality research will help the Agency promulgate protective standards, identify pollutants and how they contribute to impaired waters, and use tools for restoring and protecting the nation's waters. Such tools will consider point and nonpoint sources of pollution and the treatment and beneficial use of biosolids.

Managing the Research Portfolio

OW and the Regional Water Divisions have developed a cross-office research planning infrastructure designed to achieve the goals of the *Water Research Strategy*. The structure includes two principal organizational units: an OW Executive Research Committee and, an OW-Research Coordination Team (OW-RCT).

The Executive Committee (the Deputy Assistant Administrator, the four Office Directors, the Water Division Director from the lead Region for Water, and select staff) is responsible for promoting coordinated and collaborative research activities and planning within the Water Program and between the Program and its research partners. The Executive Committee is also responsible for evaluating:

- The progress of research activities against Program research needs;
- Emerging issues for research;
- The relevance of proposed research to Program objectives;
- Adjustments to research portfolios due to changes in budget or priorities; and,
- The need for new research management tools or the effectiveness of existing ones.

The OW-RCT (a group with leads and members from each Water Office and the lead Region) presents needs and priorities for each of OW's program offices and the Regional Water Division to ORD and other research partners. Engaged participation by all ensures a thorough, robust, and balanced discussion of needs and opportunities. Each will continue to maintain and pursue these activities and relationships and to actively participate in OW-RCT.

The OW-RCT Team Leader is charged with:

- Leading and coordinating the activities of the OW-RCT;
- Responding to research management needs and inquiries of the Executive Committee and OW-RCT; and,
- Representing the Executive Committee to potential research partners and stakeholders.

The OW-RCT is charged with:

- Determining the relevance of Small Business Innovative Research (SBIR) and Science to Achieve Results (STAR) Grants, as well as ORD Fellowship proposals to needed OW research;
- Responding to research management needs and inquiries from the Executive Committee;
- Maintaining the Research Management and Status Tool;
- Coordinating participation in the SAB, BOSC, and Office of Management and Budget (OMB) program review of ORD research programs;
- Organizing OW-ORD management and other meetings;
- Leading OW participation in ORD MYP development and implementation; and,
- Promoting OW research needs to external partners.

Document Organization

The remainder of this *Compendium* is organized into the following chapters

- *Chapter 2 – Science to Support Ground Water and Drinking Water Protection Programs*: Describes the key program goals responsible for the safety and security of drinking water; and the research needs and goals pertaining to the development and revisions of drinking water standards, implementation of these standards, human health protection, source water protection, water security, and emerging areas.
- *Chapter 3 – Science to Support Wastewater Management for Water Quality Protection Programs*: Discusses the program goals and drivers that help define research needs; and those research needs and goals related to publicly-owned treatment works management and treatment effectiveness, decentralized wastewater systems, residuals management and treatment, wet weather flow control technologies and effectiveness, and aging infrastructure.
- *Chapter 4 – Science to Support Watershed Protection and Restoration Programs*: Provides background on key research drivers and research and goals pertaining to watershed assessment, management measures, incentive programs, and coastal and ocean programs.
- *Chapter 5 – Science to Support Aquatic Life and Human Health Protection Programs*: Discusses key research drivers and the research needs and goals related to human health effects, risk assessments, water quality integrity (biological, chemical, and physical), and valuing ecosystem resources.
- *Chapter 6 – Science to Support Place-Based Water Protection and Restoration – Large Aquatic Ecosystems Programs:* Discusses the geographically focused Large Aquatic Ecosystems programs, the major designated water bodies, such as Chesapeake Bay and South Florida. While all of the Water Programs and research needs discussed in the other chapters are pertinent to these place-based implementation programs, their unique drivers and key research needs are also discussed.
- *Chapter 7 – Science to Support Cross-Program Needs*: Describes those initiatives that cut across the Water Program and covers key research drivers. Presents research needs and goals that pertain to the various cross-cutting initiatives (sustainable infrastructure initiative, watershed approach, emerging contaminants, climate change, and analytical methods).

Addendum

Water Program Drivers and Program Office Goals

The Clean Water Act

The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industry. The primary goal of the CWA is to "restore and protect the chemical, physical, and biological integrity of the Nation's waters." Key sections and activities under the CWA implemented by EPA to achieve this goal include the following:

- *Section 106*: "States are required to establish appropriate monitoring methods and procedures (including biological monitoring) necessary to compile and analyze data on the quality of waters of the United States and, to the extent practicable, ground-waters." EPA provides guidance and oversight to States in implementing monitoring programs.

- *Section 303(d)*: Each State is required to adopt water quality standards (WQS) for all waters. WQS serve the dual purposes of establishing the water quality goals for a specific waterbody and serving as the regulatory basis for the establishment of water quality-based treatment controls and strategies. States, Territories, and authorized Tribes also must develop a list of impaired water bodies and develop Total Maximum Daily Loads (TMDL) to improve water quality. States also use WQS to keep waters safe for swimming in their beach monitoring and notification programs.

- *Section 304(a)*: Water quality criteria must be developed, published, and periodically revised by EPA so that they accurately reflect the latest scientific knowledge. 304(a) criteria are guidance to States for use in State Water Quality Standards under section 303(d), above.

- *Section 305(b)*: Every two years, States report on the condition of surface waters based on State monitoring programs. States are also required to include available information on ground water. EPA compiles a national report to Congress that characterizes the states of water quality, identifies water quality problems, and reviews programs to restore and protect the nation's waters.

- *Section 319*: This program provides grant money to States, Territories, and Indian Tribes to support technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific nonpoint source implementation projects.

- *Section 401*: This section requires interstate activities that may result in any discharge into navigable waters to be licensed or permitted to protect against pollution including invasive species.

- *Section 402*: Section 402 regulates the direct discharge of pollutants into navigable waterways. National Pollution Discharge Elimination System (NPDES) permits to point source dischargers (*i.e.,* single identifiable sources of pollution, such as factories or treatment plants) contain technology-based and/or water quality-based effluent limits as well as monitoring and reporting requirements.

- *Section 404*: This section establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands.

- *Section 405(d) and Part 503*: These statutory and regulatory obligations require the protection of human health through standards for the use or disposal of sewage sludge. EPA determines which contaminants in sewage sludge require standards, establish those standards, and resolve Part 503 implementation challenges.

One of the Water Program's missions is to help meet the nation's clean water goals by ensuring that appropriate regulatory standards, voluntary management approaches, information, financial resources, and technical assistance are provided to States, communities, and regulated entities. Compliance with the requirements of the CWA through effective and responsible water use, wastewater treatment, disposal and management, and encouragement of the protection and restoration of watersheds are facilitated by the OGWDW, OST, OWM and OWOW.

The Safe Drinking Water Act

The SDWA and amendments authorizes EPA to set and review national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminations that may be found in drinking water. SDWA is the national law that protects public health by safeguarding America's tap water. SDWA requires EPA to develop and maintain a comprehensive process to assess contaminants in drinking water and to develop standards for contaminants posing the greatest risk. The 1996 SDWA Amendments require EPA to evaluate human exposure and risks of adverse health effects in the general population and sensitive subpopulations when setting drinking water standards. The SDWA also created the Source Water Protection Program and the UIC Program to protect both surface and underground sources of drinking water. The EPA OGWDW along with the OST, Regional drinking water programs, States, Tribes, water utilities, and its many partners, implement the SDWA.

Public Health Security and Bioterrorism Preparedness and Response Act

The Public Health Security and Bioterrorism Preparedness and Response Act (Bioterrorism Act) of 2002, which amended the SDWA, created the Water Security Program (WSP). The WSP ensures that drinking water treatment plants are prepared for natural disasters, terrorist attacks, and other intentional acts.

The 2002 Bioterrorism Act amendments require drinking water systems serving greater than 3,300 persons to conduct a vulnerability assessment and prepare emergency response plans based on the results. The Bioterrorism Act also required EPA to conduct research in prevention, detection, and response to intentional introduction of contaminants into water systems and their source waters. In addition, it required research on methods and means by which terrorists could disrupt the supply of safe drinking water or act against drinking water infrastructure and alternative supplies of drinking water. EPA's research work in water security is also governed by a series of Homeland Security Presidential Directives (HSPDs). In particular, HSPD-7 established EPA as the sector-specific lead for drinking water and wastewater infrastructure protection, and HSPD-9 directed EPA to develop a robust surveillance program to provide early warning in the event of a terrorist attack.

National Environmental Policy Act

National Environmental Policy Act's (NEPA) basic policy is to assure that all branches of government give proper consideration to the environment prior to undertaking any major federal action that significantly affects the environment. The Council on Environmental Quality implementing regulations for NEPA provides authority for explicit valuation and consideration of ecosystem services when Federal agencies prepare environmental impact statements.

Endangered Species Act

The Endangered Species Act (ESA) provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The law requires federal agencies, in consultation with the US Fish and Wildlife Service and/or the US National Oceanic and Atmospheric Administration Fisheries Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. This Act requires EPA to evaluate the current methods and revise them to ensure water quality criteria provide protection of threatened and endangered species. EPA must also ensure that regulatory actions do not jeopardize listed species.

The Beaches Environmental Assessment and Coastal Health

The Beaches Environmental Assessment and Coastal Health (BEACH Act) amends the CWA and protects recreational waters by directing EPA to conduct studies associated with pathogens and human health research by October 2003 and to issue new or revised 304(a) criteria based on those studies by October 2005. The National Resources Defense Council sued EPA in 2007 [Correct?], charging that the Agency did not meet the BEACH Act Amendment to the CWA and that new or revised criteria must be established. EPA's goal is to complete these studies and to develop new or revised CWA §304(a) recreational water quality criteria based on these studies by 2012.

Executive Order 12866: Regulatory Planning and Review

OW continues to be driven by Executive Orders and legislation put in place by Congress. One significant Executive Order is 12866: Regulatory Planning and Review which requires the examination of the environmental cost and benefits of EPA's regulatory actions. This Executive Order continues to challenge EPA because of the inability to account for the value of ecosystem service and costs associated with service losses.

The Strategic Plan and Program Performance

The Water Program's objectives, related to EPA's *Strategic Plan* and the *National Water Program Guidance*, were described in the introduction to this Chapter. As noted, the development of the *Water Research Strategy* is part of the OW effort to more completely define the Water Program's research needs to meet these objectives.

In addition, while EPA sets goals for its programs, the OMB measures the effectiveness of the Water programs through the Program Assessment Rating Tool (PART). EPA Strategic Planning and the PART review process focus on assessing the performance and progress of water resource protection. The PART identifies a program's strengths and weaknesses to inform management decisions to make programs more effective and that may point to areas of needed research.

<u>Other Drivers</u>

Other key drivers for the OW include Climate Change, the environmental indicator initiative, managing wet weather with green infrastructure, and sustainable water infrastructure.

Climate Change

OW has set out actions in five key areas for Climate change in the Office of Water Climate Change Strategy. The five key areas are reducing emissions of green house gases, adapting water programs to the impacts of climate change, working with stakeholders to educate the public and industry on impacts of climate change, research, and national program management to achieve goals. These activities require coordination between all of the Water Programs because advances in one program will benefit another.

Environmental Indicator Initiative

EPA created the Environmental Indicator Initiative to address the need for technical approaches to help States and Tribes manage their programs to achieve specific results by measuring environmental outcomes.

Managing wet weather with green infrastructure

As wet weather events continue to raise concerns about water quality the Managing Wet Weather with Green Infrastructure Action Strategy endeavors to promote the use of green infrastructure by cities and utilities as a means of reducing stormwater pollution and sewer overflows.

Sustainable water infrastructure

As the strain on resources continues to plague drinking and wastewater systems EPA continues to define the Agency's role as an advocate for sustainable water infrastructure and specifies the four pillars to achieve this goal: better management, water efficiency, full cost pricing, and the watershed approach.

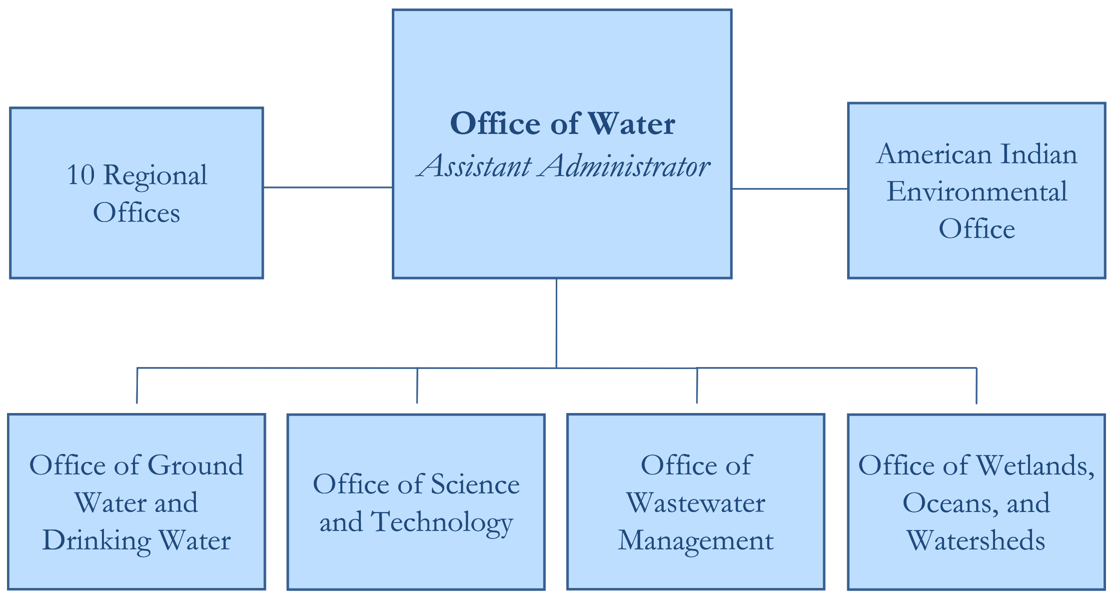
The National Water Programs

EPA's OW and Regional Water Divisions are responsible for the Agency's water quality, water resource, and public health protection activities. These include development of national programs, technical policies, and regulations relating to drinking water, water quality, ground water, pollution source standards, and the protection and restoration of wetlands, marine, and estuarine areas.

The Water Program offices are also responsible for overseeing and developing their national research programs. The Regions work with the program offices to define research needs and to develop their Region-specific research agendas. Because of their unique role and geographic focus, the Regions have a unique and often critical perspective on research needs to address their specific concerns. Meeting nationally defined research needs often requires the integration of Region-specific projects to address the diversity of unique hydrogeologic conditions across the nation. Also, many critical needs are often defined recognized at the local level before their importance can be recognized at the national level.

The OW has several programs established by the CWA and the SDWA. To accomplish each program's goals the OW is divided into several offices. While one office may lead an effort, accomplishing the program goals requires collective implementation of the programs. (See Exhibit 1.1.)

Exhibit 1.1: Office of Water Organizational Chart



Source: http://www.epa.gov/water/org_chart/

The **Office of Ground Water and Drinking Water (OGWDW)**, together with States, Tribes, and its many partners, protects public health by ensuring safe drinking water and protecting ground water. OGWDW, along with EPA's ten Regional drinking water programs, oversees implementation of the Safe Drinking Water Act, which is the national law safeguarding tap water in America.

OGWDW provides comprehensive protection of our drinking water by protecting drinking water sources, providing health-based drinking water and treatment standards, and preparing drinking water systems to protect against and respond to possible contamination events.

OGWDW and States support the efforts of individual water systems by providing a national framework comprised of core programs that are critical to ensuring safe drinking water.

Collectively, these core programs constitute a multiple-barrier approach to protecting public health. They include:

- Identification of priority contaminants for information collection and regulatory decision-making;
- Unregulated contaminant monitoring;
- Methods development;
- Development or revision of drinking water standards;
- Technical assistance and partnerships to enhance optimization of drinking water treatment;
- Implementation of drinking water standards and technical assistance to water systems to strengthen their technical, managerial, and financial capacity;
- Community water system financing;
- Water security;
- Source water protection;
- Underground injection control; and
- Integration of programs to protect surface water that is a source of drinking water.

Further discussion of OGWDW's research needs can be found in Chapter 2 – *Science to Support Ground Water and Drinking Water Protection Programs.*

The **Office of Wastewater Management (OWM)** regulates discharges into surface waters such as wetlands, lakes, rivers, estuaries, bays and oceans. Specifically, OWM focuses on control of water that is collected in discrete conveyances (also called point sources), including pipes, ditches, and sanitary or storm sewers. OWM is also home to the Clean Water State Revolving Fund, the largest water quality funding source, focused on funding wastewater treatment systems, nonpoint source projects and estuary protection.
The OWM Program promotes effective and responsible water use, treatment, disposal and management by encouraging the protection and restoration of watersheds. The program focuses on control of water that is collected in discrete conveyances (also called point sources), including pipes, ditches, and sanitary or storm sewers. The program provides national program direction to the NPDES permit, pretreatment, and sewage sludge management programs under sections 401, 402, and 405 of the Clean Water Act. OWM and OST develop national standards for point source controls, indirect dischargers, and sludge use and disposal which are implemented through the NPDES, pretreatment and sludge management programs. Technical support and training to Regions and States for all aspects of the NPDES permit, pretreatment, and sludge management programs is also provided.

Additional detail on OWM and its research needs are included in Chapter 3 – *Science to Support Wastewater Management for Water Quality Protection Programs.*

The **Office of Science and Technology (OST)** is responsible for developing sound, scientifically defensible standards, criteria, advisories, guidelines and limitations under the Clean Water Act and the Safe Drinking Water Act. OST works with partners and stakeholders to develop the scientific and technological foundations to achieve clean water.

OST identifies and defines water research that assists other EPA Water Programs to implement their statutory and other obligations. OST research also helps the States, Tribes, and Territories to protect their drinking water supplies and minimize the effects of contaminants on fish, wildlife, and the aquatic environment. Federal, State, tribal, and local governments use this information to set limits on pollutants that may occur in drinking water or that may be discharged into all types of waters – rivers, lakes, and streams. Every year under the authorities of the CWA, the SDWA, other acts, and executive orders, OST helps produce regulations, guidelines, methods, models, standards, science-based criteria, and studies that are critical components of national programs that protect human health and the aquatic environment. OST sponsors the development of laboratory and field analytical methods to support Water Programs. These methods are the basis of national regulations. OST also manages Agency programs to limit human exposure to toxics and pathogens from swimming and consumption of non-commercial fish.

OST conducts risk assessments and develops criteria for surface and drinking water to ensure they are safe for human use and consumption and aquatic life. It also uses risk assessments to determine appropriate uses and disposal of biosolids and to develop appropriate regulations that protect human health and the environment.

In support of the CWA, OST endeavors to improve water quality to protect and restore waters to their designated uses, thereby protecting the health of humans, aquatic life, and wildlife. Actions taken to improve water quality will also increase the number of water bodies that can be enjoyed for recreational purposes and from which fish and shellfish can be safely consumed. OST will do this by ensuring that: 1) State-adopted criteria for pathogens and indicator organisms in waters designated for recreational use are current and scientifically sound; 2) the science underpinning the core water programs is current and appropriately vetted for implementation in State and tribal water quality standards, TMDLs, permits, assessments, etc.; and 3) OST is able to address emerging water quality concerns.

Other measures to protect aquatic life include the development and publication of: nutrient criteria that protect waters from nutrient over-enrichment; biological criteria designed to describe and maintain the biological condition of aquatic communities; criteria to define the chemical concentrations below which aquatic life is protected; and clean sediment criteria that protect aquatic life from excessive non-contaminated sediment.

More detail on OST and OST research needs is included in Chapter 5 – *Science to Support Aquatic Life and Human Health Protection Programs*.

The **Office of Wetlands, Oceans, and Watersheds (OWOW)** promotes wetlands protection, oceans and coastal protection, and watershed assessment and protection through a diverse range of programs to manage, protect, and restore the water resources and aquatic ecosystems of US marine and fresh waters. This strategy is based on the premise that water quality and ecosystem problems are best solved at the watershed level and that local citizens play an integral role in achieving clean water goals. OWOW and the Regional Water Divisions implement the programs by providing technical and financial assistance and developing regulations and guidance for various regulatory and cooperative programs.

Within the broad goal of protecting and restoring water resources, OWOW applies the Watershed Approach to organize its efforts. This approach provides a comprehensive and efficient framework through which it can pursue the goal of addressing water quality problems and restoring the ecological, economic, and cultural services provided by aquatic ecosystems. Some of the more prominent objectives are to: 1) understand and mitigate serious environmental problems being faced by a number of significant and sensitive ecosystems, 2) promote the integrated monitoring and assessment efforts needed for ecosystem protection, 3) promote management and restoration of water bodies and ecosystems, 4) provide the information needed to execute TMDL programs; 5) assess 100 percent of rivers, lakes, and streams in the lower 48 States using statistically valid surveys by 2010; and 6) improve the effectiveness of ecological restoration efforts by providing decision-makers with data and tools that will allow them to select the most appropriate water bodies, restoration methods for restoration, and monitoring schemes.

Under Section 404 of the CWA, the OWOW and the US Army Corps of Engineers implement the permit program to regulate discharges of dredged or fill material into US waters, including wetlands. The Program also works with States, Tribes, and local governments to conserve and restore wetlands. The assessment and watershed protection programs include water quality monitoring, nonpoint source control, and TMDL programs. National guidance is developed by the OWOW on water quality assessment and reporting, biological monitoring, water quality criteria, volunteer monitoring methods, and quality assurance. States, Territories, and Tribes receive grants from the OWOW to administer their nonpoint source programs, as well as guidance for improving best management practices to control runoff. In addition, the OWOW oversees the National Estuary Program (NEP), which was established to identify, restore, and protect nationally significant U.S. estuaries.

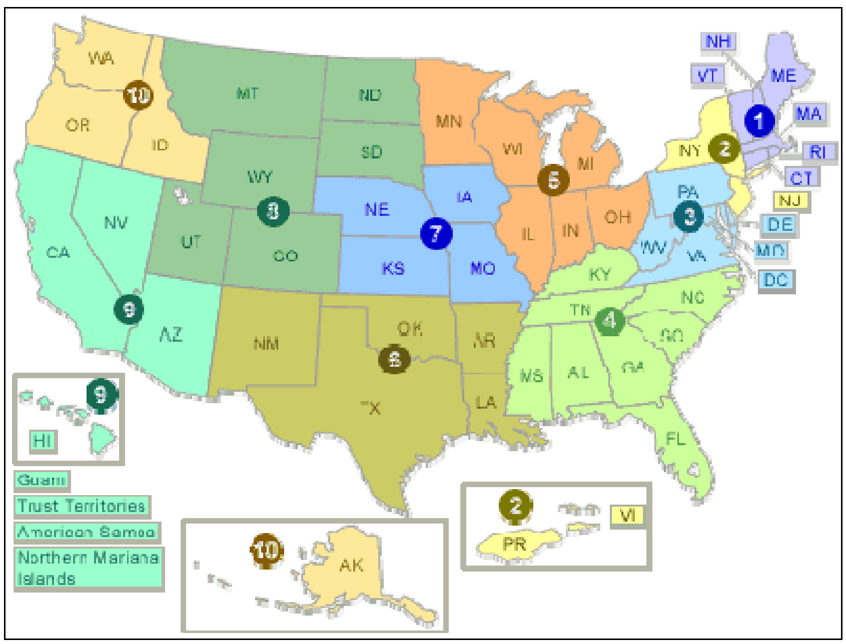
Chapter 4 – *Science to Support Watershed Protection and Restoration Programs* contains additional information about the OWOW and its research needs.

The **American Indian Environmental Office (AIEO)** coordinates the Agency-wide effort to strengthen public health and environmental protection in Indian country, with a special emphasis on helping Tribes administer their own environmental programs. While AIEO does not lead the implement of any one Water program they do ensure that the unique needs of the Tribes are addressed by the other program Offices. The research needs to support the goals of this office are included throughout this document.

EPA Regions

EPA's ten Regional Offices are responsible for the execution of EPA's Water programs. The Regions are the interface with the States, Territories, and Tribes that bring the EPA's environmental programs to the implementation level. The Regions work with and oversee State, Territory, or Tribe implementation, or, for those without primary enforcement authority, the Regions implement programs directly. The Regions also provide technical and compliance assistance, manage grants provided for the States to implement programs, and if needed, take enforcement actions.

Exhibit 1.2: EPA Regions



Region 1 – Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
Region 2 - New Jersey, New York, Puerto Rico and the U.S. Virgin Islands
Region 3 – Delaware, Maryland, Pennsylvania, Virginia, West, and the District of Columbia
Region 4 – Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee
Region 5 – Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin
Region 6 – Arkansas, Louisiana, New Mexico, Oklahoma, and Texas
Region 7 – Iowa, Kansas, Missouri, and Nebraska
Region 8 – Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming
Region 9 – Arizona, California, Hawaii, Nevada, and the territories of Guam and American Samoa
Region 10 – Alaska, Idaho, Oregon, and Washington

Each EPA Region is responsible for working with specific States, Territories, and Tribes. Variations across States, Territories, and Tribes in geology, hydrology, types and number of water bodies, climate, and the types of commerce that support their economy each influence the environmental challenges that Regions face in effectively implementing the various water programs. The research needs for the Regions cover the full spectrum of programs described in this *Compendium*. Specific or unique Regional research needs are noted in the various chapters. A map illustrating the States in each Region is provided above in Exhibit 1.2.

Place-Based Water Protection and Restoration Programs

The core programs of the CWA and SDWA are essential for the protection of the Nation's drinking water and fresh waters, coastal waters, and wetlands. At the same time, additional, intergovernmental efforts are sometimes needed to protect and restore large aquatic ecosystems around the country. For many years, EPA has worked with others to implement supplemental programs, such as the NEP and place-based geographic programs, to restore and protect the Great Lakes, the Chesapeake Bay, the Gulf of Mexico, and waters along the Mexico Border. More recently, OW has formed the *Council of Large Aquatic Ecosystems* to support and promote EPA's implementation of Large Aquatic Ecosystem programs and encourage collaboration within EPA programs and with EPA's external partners. This effort is now incorporating other initiatives addressing: the Long Island Sound; Lake Champlain; the Columbia River; the Puget Sound; and waters in Southern Florida and the Pacific Islands. Chapter 6 describes these large aquatic ecosystems and some of their particular research needs.

2 ● Science to Support Ground Water and Drinking Water Protection Programs

Guided by the Safe Drinking Water Act (SDWA), the Ground Water and Drinking Water Protection Program strives to provide safe drinking water and to protect sources of drinking water. The Office of Ground Water and Drinking Water (OGWDW), together with States, Tribes, and its many partners, protect public health by ensuring safe drinking water and protecting ground water. See the Addendum to Chapter 1 for more information on OGWDW responsibilities. More specific objectives are set out in EPA's 2006-2011 Strategic Plan, in which the Water Program has set a goal to improve the percentage of the population served by community water systems that receives drinking water meeting all applicable health-based standards. This will be accomplished through approaches that include effective treatment and source water protection.

The Ground Water and Drinking Water Protection Program receives input from a variety of outside organizations and formal committees including the National Academy of Sciences, the EPA Science Advisory Board, the National Drinking Water Advisory Council, and the Source Water Collaborative, among others. Many of the Program's objectives will require additional research on the part of EPA and its partners.

Ground Water and Drinking Water Protection Research Needs

The goal of the drinking water research program is to develop leading edge research products that can be used to implement the SDWA and its amendments. The research program directly supports:

- Evaluating unregulated contaminants;
- Assessing public health risk from contaminants;
- Developing or revising standards for contaminants;
- Identifying and developing methods to detect and monitor contaminants;
- Effectively implementing standards;
- Protecting both surface and underground water sources from unintentional and intentional introduction of contaminants to drinking water supplies.

In sum, the research provides methods, data, tools, models, and technologies to characterize and manage health and security risks associated with treatment and distribution of drinking water, and supports the promotion of sustainable water resources and water infrastructure.

These drinking water research needs focus on the science necessary to implement the SDWA's requirements for the Contaminant Candidate List (CCL), to assess and manage the safety of drinking water quality in distribution systems, including developing tools to manage the nation's aging drinking water infrastructure. Research needs also relate to other program areas including the protection of surface and underground sources of drinking water and the Six-Year Review of National Primary Drinking Water Regulations (NPDWRs).

For the purposes of this *Compendium*, Ground Water and Drinking Water Protection Program research needs are organized under three program areas:

- Regulatory Development and Implementation of Drinking Water Standards;
- Source Water Protection (SWP)/Underground Injection Control (UIC), and
- Water Security.

Background information and research needs are presented below for each of these areas. In addition, a detailed listing of specific research projects for each research area will be found in the Water Research Management and Status Tool when it is available. Research needs that pertain to drinking water cut across and intertwine with research needs sponsored by other Office of Water (OW) programs that are identified in other chapters, particularly related, for example, to health effects, watershed management, sustainable infrastructure, or treatment residuals. Also, while EPA's Office of Research and Development (ORD) is responsible for a significant portion of research to support the Water Program, there are a number of governmental and non-governmental partner organizations and research foundations that conduct research and studies to support EPA's efforts. They include the Association of State Drinking Water Administrators American Water Works Association (AWWA) and the AWWA research foundation (AwwaRF), the National Rural Water Association and Water Environment Research Foundation (WERF), among others. The Department of Agriculture and the United States Geological Survey also work in partnership with EPA to improve the quality of America's drinking water and to conduct supporting research.

Regulatory Development of Drinking Water Standards

Under the SDWA, EPA is charged with evaluating unregulated contaminants and developing and revising drinking water standards. The Ground Water and Drinking Water Protection Program sets national standards for drinking water that either limit a particular contaminant in drinking water, require treatment to remove (*e.g.,* filtration) or inactivate (*e.g.,* chemical disinfection, UV, etc.) a contaminant. When setting and reviewing these standards, sound data and peer-reviewed science are used to focus on the contaminants that present the greatest public health risk and are likely found in drinking water. To determine which contaminants may require regulations, EPA needs information on the health effects, occurrence, and potential exposure to the contaminants as well as information on analytical methods and treatment technologies.

The SDWA mandated several programs that help EPA identify contaminants that need new or revised standards. These programs include the CCL, Unregulated Contaminant Monitoring Regulation (UCMR), and the Six-Year Review of existing regulations. EPA is also engaging in research to develop program measures of public health protection resulting from implementation of drinking water programs.

Regulatory Development and Implementation of Drinking Water Standards Research Needs

In developing and revising drinking water standards, EPA evaluates threats to public health from microbial and chemical contaminants. To support these efforts EPA addresses research questions in key categories – Health Effects, Method Development, Occurrence, and Treatment. The outline below notes typical research questions to be addressed for particular contaminants identified in the regulatory development process (see the CCL and Regulatory Determination discussion, for example) and also summarizes some identified research needs. (Further details are provided in the sections of the report that follow.)

- Health Effects
  - What are the actual or potential human health effects of pathogens, chemicals, and suites of contaminants and how can the risk assessment process be improved to best assess these effects?
  - What is the cumulative risk associated with mixtures of contaminants that are likely to co-occur (*e.g.,* disinfection by-products (DBPs), pesticides and their degradates) and exhibit similar target organs or modes of action?
  - What are the relationships among chemical and microbial contaminants and adverse health effects on sensitive subpopulations?
  - What are the health effects of short-term exposure to lead?
  - What is the mode of action and health risk related to low level arsenic exposure?

- Method Development
  - Do analytical methods exist with enough sensitivity, specificity, accuracy, and precision to: (i) detect and quantify the contaminant, and (ii) verify remediation or removal?
  - Are the methods robust enough to support national occurrence data collection and/or can they be widely applied to support monitoring for regulatory compliance? (See the Unregulated Contaminant Monitoring Rule (UCMR) discussion, for example.)

- Occurrence
  - What are the national occurrence of contaminants and the resultant exposures to the public?
  - How is the public exposed to these contaminants (*i.e.,* inhalation, ingestion, dermal), how often, and for what duration?
  - What data collection practices best capture the risk for both acute (where applicable) and chronic exposure?
  - How do we determine aggregate exposures to the same chemical from multiple media (*e.g.,* water, air, food)?
  - What is the pathogen occurrence, and proportion of total waterborne pathogen risk, related to ground water versus surface water sources, distribution systems, storage facilities, and such features as cross connections, backflow, and other intrusion event (pressure fluctuations, main construction and repairs)?
  - What are the best indicators of pathogen or chemical occurrence and contamination?

- Treatment Technologies
  - What treatment technologies or techniques exist to remediate the contaminant or are new technologies needed?
  - What is efficacy of different disinfection and residual levels with various water matrices to achieve efficient pathogen inactivation and to control health risks?
  - What are the implications of simultaneous compliance for drinking water treatment plant operations?
  - What are the impacts of treatment changes, optimal corrosion control, and disinfection practices on lead at the tap?
  - What are appropriate performance measures for membranes?

The CCL, Unregulated Contaminant Monitoring Regulation (UCMR), and Regulatory Determination, are inter-related and with the Six-Year Review form a continuum of programs that identify research needs as part of their process. They are discussed in brief below. Also discussed below is the current effort to review the Total Coliform Rule (TCR), Distribution System concerns, the Lead and Copper Rule (LCR), and the development of performance measures for the drinking water program.

In addition, several of the research questions stated above cut across the other processes and programs described in this document. For example, research questions related to disinfection

by-products (DBPs) may involve new DBPs – a CCL issue – or regulated DBPs – considered under the Six-Year Review. Further information might be needed to assess how to approach a Distribution System rule or improve a performance measure. Similarly, there are many research topics related to microbiological contaminants that cut across programs and relate to implementation. Some of these interwoven research and implementation issues that pertain to human health, analytical methods and occurrence, and treatment technologies are also discussed below under Cross-Cutting Research Needs and apply to topics in the SWP/UIC (*e.g.,* carbon sequestration) and Water Security discussions that follow.

Contaminant Candidate List and Regulatory Determinations

EPA conducts extensive data gathering and analysis to establish a CCL. The CCL is the first step to focus the regulatory determination process and to set priorities for research. The CCL is comprised of unregulated contaminants that are known or anticipated to occur in Public Water Systems (PWSs). These contaminants may have adverse human health effects and may require regulation under the SDWA. EPA also develops drinking water guidance and health advisories for CCL contaminants when appropriate. The first CCL was published in March 1998 (USEPA, March 1998: 63 FR 10273), and the second CCL was published in February 2005 (USEPA, February 2005:70 FR 9071). The draft third CCL was published in February 2008 (USEPA, February 2008:73 FR 9628). When EPA's third Contaminant List (CCL 3) is final OW will identify various chemical and microbial contaminants that will require research and assessment.

Once contaminants are listed on the CCL (see Exhibit 2-1 below for the draft CCL 3 Contaminant List), EPA must determine if a regulation is needed or not for five or more of these contaminants. EPA must decide whether enough information exists to make a regulatory determination (Reg Det) for any of the contaminants or if more research is needed. The CCL and CCL Reg Det is an ongoing process through which EPA will define research needs for these drinking water contaminants. These contaminants may require additional health effects data (*e.g.,* reproductive studies) to conduct a risk assessment, occurrence studies to estimate exposure to a contaminant, the development of analytical methods for monitoring the contaminants, and evaluations of treatment technologies to remove them from drinking water or in some instances to control their formation (*e.g.,* DBPs). As the research needs for various contaminants are established EPA will add this assessment to the OW research plans and enter these findings into the Water RMST. (Refer to *Human Health Effects and Risk Assessments* in Chapter 5 for more information regarding the health effects and risk assessment research needs.)

Exhibit 2.1: Draft CCL 3 Contaminants (February 2008; 73 FR 9628)

alpha-Hexachlorocyclohexane	Dicrotophos	N-nitroso-di-n-propylamine
1,1,1,2-Tetrachloroethane	Dimethipin	N-Nitrosodiphenylamine
1,1-Dichloroethane	Dimethoate	N-nitrosopyrrolidine
1,2,3-Trichloropropane	Disulfoton	n-Propylbenzene
1,3-Butadiene	Diuron	o-Toluidine
1,3-Dinitrobenzene	Ethion	Oxirane, methyl-
1,4-Dioxane	Ethoprop	Oxydemeton-methyl
1-Butanol	Ethylene glycol	Oxyfluorfen
2-Methoxyethanol	Ethylene oxide	Perchlorate
2-Propen-1-ol	Ethylene thiourea	Permethrin
3-Hydroxycarbofuran	Fenamiphos	perfluorooctanoic acid
4,4'-Methylenedianiline	Formaldehyde	Profenofos
Acephate	Germanium	Quinoline
Acetaldehyde	HCFC-22	Hexahydro-1,3,5-trinitro-1,3,5-triazine
Acetamide	Hexane	sec-Butylbenzene
Acetochlor	Hydrazine	Strontium
Acetochlor ethanesulfonic acid (ESA)	Methamidophos	Tebuconazole
Acetochlor oxanilic acid (OA)	Methanol	Tebufenozide
Acrolein	Methyl bromide (Bromomethane)	Tellurium
Alachlor ESA	Methyl tert-butyl ether	Terbufos

Exhibit 2.1: Draft CCL 3 Contaminants (February 2008; 73 FR 9628)		
Alachlor OA	Metolachlor	Terbufos sulfone
Aniline	Metolachlor ESA	Thiodicarb
Bensulide	Metolachlor OA	Thiophanate-methyl
Benzyl chloride	Molinate	Toluene diisocyanate
Butylated hydroxyanisole	Molybdenum	Tribufos
Captan	Nitrobenzene	Triethylamine
Chloromethane (Methyl chloride)	Nitrofen	Triphenyltin hydroxide
Clethodim	Nitroglycerin	Urethane
Cobalt	N-Methyl-2-pyrrolidone	Vanadium
Cumene hydroperoxide	N-nitrosodiethylamine	Vinclozolin
Cyanotoxins (3)	N-nitrosodimethylamine	Ziram
Microbial Contaminants		
Caliciviruses	*Helicobacter pylori*	*Salmonella enterica*
Campylobacter jejuni	Hepatitis A virus	*Shigella sonnei*
Entamoeba histolytica	*Legionella pneumophila*	*Vibrio cholerae*
Escherichia coli (0157)	*Naegleria fowleri*	

Unregulated Contaminant Monitoring Regulation

The SDWA, as amended in 1996, required EPA to establish criteria for a program to monitor unregulated contaminants and in 1999, EPA promulgated the UCMR for Public Water Systems (USEPA, September 1999: 64 FR 50555). The occurrence data collected through the UCMR support analyses related to contaminant occurrence, and EPA's determination of whether or not to regulate a contaminant in the interest of protecting public health. Because of the timing of the CCL and UCMR cycles, monitoring under the UCMR may provide needed occurrence data for contaminants listed in the CCL process and data for emerging contaminants to support a future CCL selection process. The second cycle of the UCMR program was promulgated in January 2007 (USEPA, 2007; 72 FR 368). To support future UCMR data collection efforts, research is needed on analytical methods to gather occurrence data for unregulated contaminants and on approaches and methods to effectively sample for unique contaminants, and potentially on health effects for new and emerging contaminants.

Six-Year Review

Under the Six-Year Review process, EPA reviews existing NPDWRs at least every six years to determine whether revisions are needed. As discussed above, as part of the Six-Year Review process, new data on health effects, analytical methods, occurrence, and treatment efficacy are reviewed to determine if any revisions to the existing regulation are needed. The Six-Year process may also identify needed research in these areas.

Total Coliform Rule and Distribution System Rule

EPA is conducting research to support possible revisions of the existing TCR and the possible development of a separate distribution system rule. As previously discussed, the Total Coliform Rule Distribution System Advisory Committee (TCRDSAC) has a dual function. In addition to providing EPA with advice and recommendations regarding TCR revisions, the Committee is also considering what information about distribution systems is needed to better understand the public health impact from the degradation of drinking water quality in distribution systems. EPA and members of the TCRDSAC need information on the occurrence of non-coliform indicators and the co-occurrence of coliform indicators in distribution systems. This information will help determine what indicators provide evidence of pathogen or chemical occurrence and contamination. Improved methods to detect chemical and microbial contamination are needed as well as information on intrusion events, pressure fluctuations, and the fate, transport, and occurrence of microbial contaminants in distribution systems. Research on treatment efficacy should involve disinfectant studies to determine effective residual levels, and the effectiveness of various management approaches to control and prevent health risks. Studies are needed to better characterize the current profile of disinfection system infrastructure and characteristics in the US.

Lead and Copper Rule

EPA promulgated Maximum Contaminant Level Goals (MCLGs) and NPDWRs for lead and copper. The goal of the LCR is to provide maximum human health protection by reducing lead and copper levels at consumers' taps to as close to the MCLGs as possible. To accomplish this goal, the LCR establishes requirements for community water systems and non-transient non-community water systems to optimize corrosion control in their distribution systems and conduct periodic monitoring. In 2004, EPA undertook a national review of the implementation of the LCR, and workshops were held on specific topics (simultaneous compliance, monitoring protocols, public education, lead service line replacement, and plumbing fittings and fixtures). As a result of this national review, EPA identified seven targeted rule changes, which were finalized on October 10, 2007, to strengthen the implementation of the LCR in the areas of monitoring, treatment processes, public education, customer awareness, and lead service line replacement. The national review also helped EPA to identify longer-term research topics such as optimal corrosion control treatment, improved monitoring frameworks, and lead service line replacement. The Regions have noted that research on the efficacy of remote, in-situ lead sensors for assessment of lead levels in drinking water distribution system and at point-of-use locations is needed in several affected Regions.

Arsenic

The Regions have noted that additional research related to arsenic treatment and regulation is needed in several affected Regions. Region 1 specifically identified the need for additional data and demonstration projects in New England and more information exchange on arsenic strategies, such as an arsenic workshop.

Health Outcome Performance Measures – Program Effectiveness

The Ground Water and Drinking Water Protection Program is working to develop a health outcome-based performance measure(s) in response to the Office of Budget and Management's (OMB) recommendations provided during the FY2006 Program Assessment Rating Tool process. The Ground Water and Drinking Water Protection Program submitted a Waterborne Disease Measure Development and Implementation Plan to OMB in September 2004. Since that time, the Agency has been working on several efforts to develop better estimates of national waterborne illness. In 2006, the Agency released an article that outlined an approach for developing a national estimate of waterborne disease and an estimate using the model and available data. (Messner et al., 2006).

The Agency is also working with the Centers for Disease Control and Prevention (and EPA's ORD to develop a number of projects that range from epidemiological studies to making changes to the forms used for outbreak reporting. As a result of the work done by the National Drinking Water Advisory Council, the Ground Water and Drinking Water Protection Program has expanded its measure to consider both regulated pathogens and chemical contaminants. The measure's goal is to relate the drinking water program's activities to waterborne disease incidence. The measure will look at how the drinking water program reduces the frequency of waterborne disease incidences. EPA is working to develop the measure to be included in future Agency Strategic Plans.

The Regions have identified research needs to help protect the public from water-borne illness. In order to meet the Ground Water Rule, water systems in many Regions need information and guidance to help prevent unintended consequences resulting from disinfection (*e.g.,* simultaneous compliance issues). In addition, data on less expensive and less sophisticated technologies are needed for small water systems to help them meet the requirements of this rule.

The Regions have also noted research needs related to the Enhanced Surface Water Treatment Rule, the Interim Enhanced Surface Water Treatment Rule, the Long Term 1 Enhanced Surface Water treatment Rule, and the Long Term 2 Enhanced Surface Water Treatment Rule. To support the implementation of these regulations, research is needed to identify the appropriate ambient water quality criteria for *Cryptosporidium* and *E. coli* to help to avoid additional treatment at existing surface water treatment plants.

Research is needed to help the Regions meet the new Stage 2 Disinfection By-Products Rule (Stage 2 DBPR). These needs are focused on decentralized treatment approaches. The Stage 2 DBPR may require utilities to address "hot spots" in their distribution, thus driving the need for research to better understand how to treat water on a local basis within a distribution system. A research need specific to Region 2 is the identification of appropriate ambient water quality criteria for organic material and turbidity in source waters. This will help water systems reduce DBP development, avoid possible violations, and avoid increased treatment costs.

Regulatory Development – Cross-Cutting Research Needs – Health Effects

As discussed above, through the CCL, Reg Det, and Six-Year Review processes, EPA may determine that additional health effects data are needed (*e.g.,* reproductive studies) for specific drinking water contaminants to determine if a new or revised drinking water regulation is warranted. Health effects and risk assessment process and research needs are further discussed in Chapter 5. Beyond toxicological and health effects assessments of particular contaminants, there are particular needs, to identify the relationships among chemical and microbial contaminants and populations that are especially susceptible to adverse health effects from exposure. These groups, or sensitive subpopulations, may include children, the elderly, pregnant women, and people that are immune compromised. Tools must be developed to better incorporate these populations into EPA risk assessment models.

Identifying and regulating microbial pathogens is particularly challenging. In recent years, much research has been done, but more remains to be accomplished to fully understand the endemic health effects of pathogens. The additional data will support more comprehensive risk assessments for pathogens. For example, research is needed to determine:

- What portion of pathogen risk is attributable to drinking water;
- What portion of the total waterborne risk is attributable to source, treatment, or distribution systems; and
- What portion of the total waterborne risk is attributable to surface water versus ground water sources.

Another major needed research area is to determine the health effects from chemical mixtures. For example, ongoing research is needed to compare toxicity and health risk information from DBP mixtures in drinking water to determine if controlling the two classes of regulated DBPs (the sum of four trihalomethanes and the sum of five haloacetic acids) is sufficiently protective of public health.

Additional health effects research should focus on both regulated DBPs and emerging/unregulated DBPs, parent pesticides and their degradates, and manufactured chemicals that are chemically transformed to other compounds when released into the environment. Reproductive and developmental effects are one area of particular importance. Of related interest is the development of risk communication approaches, particularly for reproductive and developmental effects of DBPs. The reader may also refer to the discussion of cumulative risk under Human Health Effects and Risk Assessment Research Needs in Chapter 5.

Regulatory Development – Cross-Cutting Research Needs – Analytical Method Development and Occurrence Studies

Central to EPA's determination of whether to regulate a contaminant or revise an existing regulation is the ability to detect and quantify the contaminant and to determine its occurrence in drinking water. Continued improvement of new technologies and analytical methods for the detection and quantification of pathogens is a research priority. These are needed to provide more effective monitoring and occurrence assessment for microbes. For example, EPA needs to better understand the fate and transport of microbial pathogens in distribution systems, including the role of biofilms in pathogen fate and transport. Such studies can affect considerations of pathogens in CCL or regulated programs (see the TCR discussion) and can influence sampling and monitoring designs for the UCMR. Research is also needed to explore the relationship among water quality parameters, pathogen occurrence, exposure, and infection to illness. In addition, EPA needs to understand the factors that contribute to nitrification of biofilms in the distribution system and resulting public health implications.

Studies are also needed to characterize and determine contamination occurrence associated with cross connections, backflow, storage facilities, and main construction and repairs. Needed research includes a national characterization of common waterborne pathogens that have been found at finished storage facilities, water main repair, or new construction, as well as a risk modeling feasibility study to determine the potential occurrence of contaminants at these locations.

DBP rules are reviewed simultaneously with the microbial rules to continue to ensure that controlling DBPs does not jeopardize microbial protection. Research is needed to verify the suite of microbial and chemical contaminants found in ground water and surface water. Additional occurrence studies should assess the environmental prevalence of *E. coli* in source water and distribution systems as an indicator of potential contamination. In addition, research should include developing more robust methods to measure emerging DBPs in drinking water distribution systems and gathering occurrence data. Occurrence data are needed on DBP precursors (*e.g.,* iodine) as well as DBP mixtures and concentrations in drinking water in water systems across a broad geographical range.

Regulatory Development – Other Cross-Cutting Research Needs

Effective treatment technologies are essential to the provision of safe drinking water and protection of drinking water sources. In particular, research is needed to improve EPA's understanding of simultaneous compliance issues, drinking water treatment residuals, and the control of microbes and DBPs. Each of these areas is described in more detail.

As more contaminants are regulated, the ability to obtain and maintain compliance becomes more complex because of the various treatment and monitoring requirements. Simultaneous compliance with drinking water regulations can be difficult because treatment options for one contaminant may result in complications when complying with standards for other contaminants. Conflicts can occur when rules designed to ensure chemical stability compete with rules designed to protect against DBP risk. For example, certain actions that may be necessary for water system compliance with the DBP rules (*e.g.,* enhanced coagulation) can upset the established operating chemistry in a system by lowering the pH. This may cause lead and/or copper to leach into the water from distribution system pipes or the plumbing in the customer's service lines or in-home pipes and faucets. Research is needed to optimize and better understand the implications of simultaneous compliance for drinking water treatment plants. Also related to compliance research is needed on strategies for consecutive water systems to maintain compliance since they are not in control of primary treatment.

Drinking water treatment results in concentrated residuals (the material removed) that can be hazardous. Research is needed on production and disposal, and the fate and transport of residuals, particularly radionuclides (radium and uranium). Drinking water treatment residuals is also discussed below under the UIC Program. This research is also relevant to wastewater programs, and dovetails with research on biosolids for wastewater treatment plants that may receive drinking water residuals (refer to Chapter 3, Science to Support Wastewater Management for Water Quality Protection Programs.)

Research on microbial treatment should focus on performance measures for membranes as well as disinfection studies to evaluate pathogen inactivation achieved in different water matrices. Studies are also needed to evaluate the impact of treatment and disinfection changes on DBP formation, removal, and control.

Research is also needed on water conservation and water efficiency practices and programs to define their effectiveness, costs, and benefits (*e.g.,* conservation programs, water efficient appliance rebates, leak detection). Social marketing approaches need to be explored. Decision makers need to know how to provide effective education and outreach campaigns – not just on water conservation, but on the real benefits and costs of high-quality public water supplies. Additional data are also needed to estimate the full cost of drinking water systems; data are needed to help characterize the true cost of water and cost pricing issues. Issues related to sustainable infrastructure are also discussed in Chapter 3.

Source Water Protection

The SDWA requires the conduct of source water assessments for the protection and benefit of PWSs. States were also required to adopt a program to protect wellhead areas within their jurisdiction from contaminants that may have any adverse effect on public health. The delineation of source water and wellhead protection areas is determined by the State.

The core value of source water protection is as the first barrier of a multi-barrier approach to protect against water borne diseases and illnesses from microbial and chemical contaminants. This preventive barrier also limits human exposure to a myriad of emerging potential contaminants for which the human health risk and drinking water occurrence have not been fully assessed.

Source water protection entails complementary approaches – (a) leveraging other federal and State regulatory programs (*e.g.,* Clean Water Act (CWA), to focus on source water protection) and (b) using State and local authority to prevent source water contamination (*e.g.,* through land use siting restrictions and business licensing prerequisites) where the federal and State regulatory programs lack jurisdiction. States typically have the authority to enact such regulatory controls, or to delegate them to local jurisdictions, to protect public sources of drinking water. The challenges lie in efficiently designing and maintaining comprehensive vulnerability assessments and in designing and implementing measures to prevent source water contamination based on the water resource scale circumstances.

Climate change will add to these challenges. Warmer water will foster the growth of microbial pathogens. Reduced stream flows and ground water levels will concentrate contamination. Increasingly severe storms will increase soil erosion, which increases turbidity, which can fowl micro-filtration treatment facilities more quickly causing higher maintenance costs. Related, water availability is becoming a prominent issue through out the country and this will also be affected by climate change. In fact, research is needed to understand how the amount of water available for drinking can be maintained and increased through protection activities. Additional discussion of climate change can be found in Chapter 7 (Science to Support Cross-Program Needs).

Source Water Protection Research Needs

In general, there is a need to develop science-based tools that are easy for technicians and water managers to learn and efficient for them to use. Such tools should enable the control of non-point source pollution and otherwise unregulated point sources of pollution at the water resource scale. These tools must produce usable outputs for local and State decision-makers that can withstand court challenges.

It is critical that tools be developed that better enable: (1) the assessment of drinking water resources and their vulnerability to contamination; and (2) the control of pollution at the water resource scale (*i.e.,* watershed and aquifer). There is a need to account for climate change impacts on water resources by developing tools to support integrated water resource planning and management at multiple water resource scales including the assessment and multi-decadal projection of water availability (quantity and quality) and the optimization of choices among water supply management and water demand management alternatives (*e.g.,* Best Management Practices (BMPs)).

Research efforts need to better match science-based tools with the needs of source water management practitioners. The effective use of these tools requires that they: (1) reliably reproduce and characterize the uncertainty of the same results under the same circumstances; (2) be adapted to a variety of circumstances; and (3) incorporate current scientific knowledge of relevant issues.

From the perspective of the Regions, additional assessment is needed to determine how to best integrate designated use and source water protection. For example, States need more information on how to set appropriate water quality criteria for a stream or portion of a stream that has a "drinking water designated use." There are also continuing needs related to contaminant source tracking, including molecular microbial source tracking.

Within EPA, the OGWDW leads the source water protection efforts, and other program offices conduct work that supports the Ground Water and Drinking Water Protection Program, including the Office of Wastewater Management; Office of Science and Technology; and Office of Wetlands, Oceans, and Watersheds. These are reported on throughout this *Compendium*. These efforts support the integration of the Clean Water Act (CWA) and the SDWA.

Needed SWP Tools: Tools are needed to: (a) delineate the hydrogeologic boundaries of (and prioritize) the land and water areas to be protected including the preferential flow paths[2] and the 'age' range(s) of water in the underlying aquifers;[3] (b) estimate the recharge of and discharge from aquifers, particularly to assess the relative contribution of ground water to surface water base flows, under varying hydrologic conditions; (c) catalogue and map the potential sources of contamination and link contaminants found to specific sources or species (*e.g.,* genotyping sources of sanitary waste); (d) compare the accuracy, precision, and unit cost of available lab methods to detect, measure, or genotype emerging contaminants in ambient water; (e) rank the likelihood and potential severity of contamination and monitor the health of ground water dependent ecosystems which can serve to pre-treat source water for domestic use; (f) allow the use of drinking water

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[2] Homogeneous and isotropic conditions in aquifers are rare or non-existent and ground water flow is mainly controlled by the presence, magnitude, and orientation of preferential flow paths – all of which means that getting preferential flow paths right is a prerequisite to getting the source water protection area delineations right, which itself is a prerequisite to getting the source water protection plans and investments right.

[3] The presence of 20 million year old water in an aquifer does not mean there is not also 20 day old water there.

monitoring data (of either finished or raw water) in CWA §305(b) assessments; (g) assess the relative effectiveness and cost profiles of alternative point source and non-point source mitigation measures (*e.g.,* from decentralized wastewater disposal); and (h) implement actions with a high probability of preventing or mitigating contamination of surface water and ground water resources from industrial, commercial, and agricultural operations (*e.g.,* BMPs).

Climate Change – Water Availability, Variability and Sustainability: It is critical to account for climate change impacts on water resources by: (1) compiling water availability and water use data, and water planning and management methods, for domestic, industrial, agricultural, and other significant needs at multiple jurisdictional and water resource scales (*e.g.,* by community and State, and by hydrologic unit); and (2) developing tools that meet the criteria described under *Source Water Protection Program Research Needs* (discussed above) to support integrated water resource planning and management. Tools are needed for State and utility water managers to: (a) assess the availability of the water resources currently in use, particularly ground water, as well as the availability of water resources to which they may have future access; (b) project water availability over many decades based on alternative precipitation and demand scenarios; (c) assess the geo-chemical and geo-physical parameters of storing water underground (*e.g.,* aquifer storage and recovery); (d) optimize the choices among water supply alternatives and demand management alternatives based on the water resource scale and local demographic conditions; and (e) prepare for and respond to the water impacts of drought, severe storms, earlier snow melt, and other water related facets of climate change. (A more detailed discussion of EPA's climate change program and research needs is provided in Chapter 7, Science to Support Cross-Program Needs.)

Underground Injection Control

The SDWA, Section 1421, provides that underground injection shall "not endanger drinking water sources." EPA must promulgate regulations that set minimum requirements for State underground injection programs to "prevent underground injection which endangers drinking water sources." Under §1421(d)(2), "Underground injection endangers drinking water sources if such injection may result in the presence in underground water which supplies or can reasonably be expected to supply any public water system of any contaminant, and if the presence of such contaminant may result in such system's not complying with any national primary drinking water regulation or may otherwise adversely affect the health of persons."

Atmospheric scientists have identified carbon dioxide (CO_2) from anthropogenic sources (*i.e.,* those derived from human activity) as the primary contributor to global warming. Major stationary sources of CO_2 emissions to the atmosphere include electric generating facilities, petrochemical processing complexes, and other industrial facilities. These industries are considering the underground injection of CO_2 that is captured from their industrial processes as a means of preventing its emission to the atmosphere (*or* geologic carbon sequestration). Geologic sequestration activities may help control climate change but the injection of CO_2 must also not impair underground sources of drinking water (USDWs). Research is needed to determine how to safely inject CO_2 and if the CO_2 will stay underground once injected. EPA is responsible under the SDWA to regulate such injection and will propose a rule by the end of 2008.

In addition, the risk of climate change-induced droughts is driving increasing numbers of water management authorities to consider or employ aquifer storage and recovery (ASR) as one of their water storage options. ASR has the benefits of protecting stored water from evaporation and requiring relatively low capital investments compared to surface storage but ASR has the drawback of risking the mobilization of geologic contaminants (*e.g.,* arsenic, radionuclides), or the injection of contaminants into an USDW. In the many cases where ASR would be for non-potable reuse (*e.g.,* irrigation or industrial cooling), determining where and how ASR can be accomplished without endangering USDWs is also a challenge the Agency needs to address.

Within EPA, the Wastewater Management Program works with the Ground Water and Drinking Water protection Program to develop policy and research projects dealing with stormwater management and septic systems related to UIC. EPA is working with the Department of Energy to coordinate efforts of geologic sequestration because of potential benefits of storing CO_2 underground. The UIC Program also works with the Ground Water Protection Council, the Ground Water Protection Research Foundation, the Lawrence Berkley National Laboratory, and the US Army Corp of Engineers to conduct research and support State implementation of the UIC Program.

Underground Injection Control and Related Research Needs

EPA's research needs include: (a) critical reviews of existing knowledge and research; (b) understanding the physical and chemical processes governing injected CO_2 fate and transport underground; (c) identifying methods for monitoring CO_2 in the subsurface and evaluating monitoring techniques; (d) developing well construction, well plugging, and well abandonment procedures appropriate for long term CO_2 injection; and (e) developing technical tools and decision models to support ASR for non-potable reuse.

Carbon Sequestration

There are a many research needs related to the sequestration of carbon. They include:

- Syntheses - Synthesize reports of experience from international geologic sequestration projects in Europe, North Africa, and Australia, as well as pilot projects in the United States as data becomes available.
- Models and Risk Assessment - Develop, evaluate, and verify subsurface CO_2 transport models. Models can also be used to predict the impact of injection activities on the quality and water availability of USDWs.
- Human Health Risk Assessment - Review the potential health impacts of CO_2 co-contaminants, such as Sulfate (SO_4), and the implications of those health impacts for managing geologic sequestration.
- Monitoring - Identify and evaluate effective direct and indirect monitoring technologies for CO_2, injected co-contaminants such as SO_4, and displaced brines.
- Construction - Predict the durability of well construction materials and the reliability of construction methods considering the corrosive nature of CO_2 and the duration of its storage.
- Well Plugging - Evaluate current well plugging material and procedures, and well abandonment procedures, considering the corrosive nature of CO_2.

Aquifer Storage and Recovery/Aquifer Recharge

Aquifer modeling tools are needed to assess the geochemical and hydrogeological parameters of storing water underground particularly for future reuse and, more specifically, to predict with a specified degree of certainty the potential for an ASR or aquifer recharge (AR) candidate well to endanger USDWs arising from:

- The release of trace metals caused by interactions between the injectate and the surrounding geologic matrix (*e.g.,* low pH injectate leaching arsenic);
- In situ DBP formation in injectate (*e.g.,* from organic material in chlorinated injectates);
- Untreated injectate (*e.g.,* when storing stormwater or sanitary wastewater for non-potable re-use); and
- The attenuation, if any, of the forms of contamination described above from either long term storage or from repetitive recycling of stored water.

Water Security

As the water sector-specific federal lead for protecting the nation's drinking water and wastewater infrastructure, EPA plays a critical role in homeland security. The OGWDW's Water Security Division (WSD) takes the lead in working with EPA's National Homeland Security Research Center (NHSRC), part of EPA's ORD in Cincinnati, OH to identify and conduct research focused on ways to better secure the nation's drinking water and wastewater systems against threats and attacks. These initiatives focus on the Nation's drinking water and wastewater supply, infrastructure, treatment, and distribution systems.

The Water Security Program has supported drinking water and wastewater utilities by preparing vulnerability assessment and emergency response tools and training, providing technical and financial assistance, and developing information exchange mechanisms. Water Security Program is also charged with supporting best security practices, providing security enhancement guidance, and incorporating security into the day-to-day operations of drinking water and wastewater utilities.

The NHSRC's Water Infrastructure Protection Division (WIPD) conducts research and develops tools to increase the understanding of public health and environmental impacts from various kinds of water infrastructure attacks. This understanding, when integrated into water security practices, leads to improved awareness, preparedness, prevention, response, and recovery from intentional acts against water and wastewater systems. WIPD is producing analytical tools and procedures, technology evaluations, models and methodologies, decontamination techniques, technical resource guides and protocols, and risk assessment methods (http://www.epa.gov/nhsrc/pubs.htm). All of these products are for use by EPA's key water infrastructure customers — water utility operators, public health officials, and emergency and follow-up responders.

Water Security Research Needs

In 2002, EPA and the NHSRC collaborated to identify research needs to better protect the Nation's water and wastewater systems. The Water Security Research and Technical Support Action Plan (Action Plan) (USEPA, September 2005) was developed with the help of stakeholders and other federal and State agencies to ensure that research conducted by NHSRC is responsive to the needs of the water industry. The National Academy of Sciences reviewed the Action Plan prior to publication and conducted a separate follow-up study published in 2007 to advise WIPD regarding future research opportunities. NHSRC, WSD, and the Water Environment Federation jointly conducted a series of stakeholder meetings during 2005 to further inform strategic planning and supplement the Action Plan. The completion of this Action Plan marked a major step towards developing a comprehensive research strategy to protect the Nation's water infrastructure.

In the NHSRC's first four years, research conducted by WIPD was intended to address as many of these gaps as quickly as possible. The research program was very fast paced and primarily designed to support EPA's Water Program and water utilities as they identified site-specific vulnerabilities, invested in better system protection, and developed emergency response protocols and methods to detect and respond to contaminants that may be introduced into the system.

Current security research needs focus on investigating ways and methods to:

- Protect water and wastewater utilities from physical and cyber threats;
- Evaluate potential threats and their impacts;
- Evaluate and address system vulnerabilities;
- Optimize detection of contaminants and develop means to determine and reduce the impact of such events;
- Develop methods to respond to contamination events; and
- Develop approaches to decontaminate systems in the event of an intentional or accidental contamination.

These needs are divided into four critical areas of research:

- Prevention;
- Detection;
- Containment/mitigation; and
- Decontamination/treatment and Disposal.

These needs are described in general terms below under each of these four research areas. More specific project details can be found in the Water RMST.

Prevention

EPA is responsible for developing tools and methods to protect drinking water and wastewater systems from physical and cyber attacks (Bioterrorism Act 2002, Homeland Security Presidential Directive (HSPD) 7 and 9). The priority research in this area is to identify and prioritize physical and cyber security threats; understand the consequences of this type of attack; and design counter-measures for preventing and mitigating the effects of physical and cyber attacks. The principal focus of research in this area is the work being done under EPA's Water Security Initiative (WSI), a program to address the risk of intentional contamination of drinking water distribution systems. The WSI's contaminant warning system involves the deployment of multiple monitoring and surveillance components including on-line water quality monitoring, public health surveillance, sampling and analysis, enhanced security monitoring, and consumer complaint surveillance. A critical aspect of WSI is the development of a consequence management plan to help utilities respond, communicate with stakeholders and the public, and recover from contamination events. The WSI has been developed and is being implemented in one pilot city. Future research efforts will be needed to address the "lessons learned" and to expand this program to additional cities, and to develop guidance and outreach materials to promote voluntary national adoption of effective and sustainable drinking water contamination warning systems.

While physical threats to water and wastewater systems are a significant concern, more research is needed in the area of chemical and microbial contamination threats. Methods must be developed to quantitatively estimate the public health and economic impacts of contamination incidents (*e.g.,* what is the extent of contamination in distribution systems and the likely concentration/doses that might be received through consuming contaminated water). Exposure, dose-response, disease transmission, and economic models are also needed.

Contingency planning is a critical element following an accidental or intentional disruption to normal utility operations. Research and guidance is needed on the deployment of alternative water supplies following delivery interruption as well as conducting an assessment of the deployment of portable treatment facilities to provide safe drinking water.

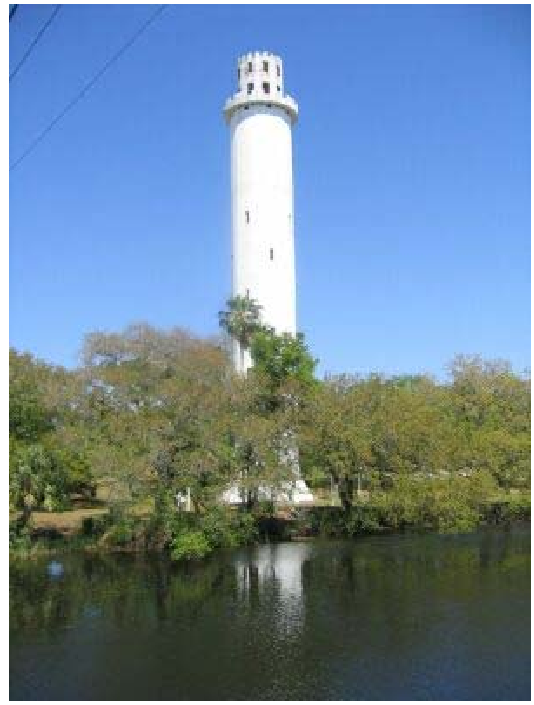
Effective risk communication is essential for mitigating the impacts of a crisis. Risk communication research is needed to determine how to best support utilities' efforts to communicate with the media and public following a crisis incident, which includes identifying the types of information of most use to the public.

EPA also needs to develop outcome-based measures of success for implementation of risk reduction activities.

Detection

Methods to detect and identify chemical, biological, and radiological (CBR) contaminants in drinking water are critical to safeguarding drinking water supplies, the treatment processes, and distribution systems. EPA's detection research program focuses on developing detectors, analytical methods, sample preparation techniques, and models and tools to detect, in real-time when possible, contaminants introduced into the water and the wastewater. The research is being done to meet the goals of Homeland Security Presidential Directive's (HSPD) 7 and 9 and will provide information to help plan for water systems' monitoring strategies, analytical techniques, and treatment information for contamination events.

A critical research area for OW is the development of the Water Laboratory Alliance, which is intended to provide the drinking water sector with an integrated nationwide network of laboratories with the analytical capabilities and capacity to support monitoring and surveillance, response, and remediation to events involving CBR contaminants. EPA is currently developing and testing regional laboratory response preparedness plans, refining various analytical methods, and developing partnerships to enhance environmental laboratory capabilities. As part of this effort, research is being conducted to expand the list of contaminants maintained in the Water Contaminant Information Tool and to assess ways to assist utilities in preparedness planning, incident response, response training, and decontamination.



Detection research will include testing and evaluation of newer, innovative sensor technologies to address the need to detect, in real-time, any contamination introduced to a water system. The development of a cost-effective total organic carbon on-line detector is in progress. Future studies are planned on the development or refinement of economical on-line detectors for total organic nitrogen, sulfur, and/or phosphorous. Additionally, research is underway to develop an alpha-beta radiation detector that can provide on-line affordable, accurate, and automatic detection of these radiological parameters in water.

In threatened and actual attacks with microbial pathogens, detection of an unknown pathogen is of paramount importance. One of the challenges of detecting these pathogens in water is the dilution effect upon the introduction of the contaminant into the water. An ultrafiltration technique was developed to concentrate bacterial spores and protozoan oocycts from large volumes of water. The technique was tested under different protocols and at different concentrations for a number of pathogens. Future research is needed to refine and test this approach for use in the field. Work will also be initiated to allow for automatic water sampling when triggered by a monitoring system.

Many of the automated detection methods currently available will not identify which contaminant is present in the water. Under Water Security Program's Threat Ensemble Vulnerability Assessment (TEVA) Program, event detection systems consisting of data analysis tools have been developed to analyze water quality data streams to rapidly and accurately identify anomalous conditions in distribution systems that require further investigation. As part of this effort, the Water Security Program collaborated with Sandia National Laboratory to develop a tool called CANARY, which reads data in real time, and returns a normal or alarm signal to a utility computer system. Research continues on how to improve the accuracy of this approach while reducing the false alarm rate. Methods are needed to generate simulated contamination incident data to provide better performance data for CANARY and other algorithms. This research is critical to the contamination warning systems under the WSI and is a high priority for the Water Program to respond to HSPD 9 requirements. In response to water utility needs to optimize the placement of sensors in distribution systems, the Water Security Program developed the TEVA Sensor Placement Optimization Tool. Continuing research is needed to make these methods faster and allow utilities to develop sensor designs that meet both security and operational goals.

Containment/Mitigation

To provide accurate and specific information to water utilities in near real-time, the Water Security Program is performing research to develop a real-time version of the EPANET modeling software. EPANET is publicly-available software tool that models dynamic flow in water distribution system pipes. A real-time extension to EPANET would incorporate sensor data on water quality, tank levels, pressures, and flows to update the model characteristics. The model is needed to estimate conditions in the distribution system at locations that lack real-time data. EPA also needs software tools to be developed that would utilize the real-time extension and enable a utility to manage a contamination incident in real-time. Such tools include a back-tracking tool to identify the source of a contamination incident given a positive sensor reading downstream, a sampling tool to identify points where samples could be taken to confirm the presence of a contaminant, and a population at risk tool to identify the people who may need to receive medical treatment following exposure to a contaminant.

Additional software tools are needed to optimize flushing and isolation programs that would be used following contamination incidents. Following detection of a contamination incident, utilities may decide to flush the contaminant from the system and/or isolate the contaminant in place until a later decision is made to treat or remove the water. Optimization models in conjunction with EPANET flow models can be used to identify the best locations for flushing or isolation, and the optimal duration of the flushing program.

Decontamination/Treatment and Disposal

With assistance from a NHSRC-wide Water Sector Decontamination Team, the Water Security Program is currently developing a decontamination white paper recommending a five-year research and development agenda. The Team will recommend new research projects under five major areas including: (1) comparative efficacies of various decontamination and treatment protocols and technologies, (2) target agent fate and transport research and modeling, (3) persistence of contaminants in pipes and infrastructure including transformation by-products, (4) appropriate cleanup levels and verification methodologies, and (5) decontamination procedures for contaminated water and infrastructures. The recommendations in the strategy will recognize and build upon identified existing or planned work performed by NHSRC, other government agencies, AwwaRF, the WERF, and others. Needs and priorities identified by the Water Security Program through the Department of Homeland Security Critical Infrastructure Partnership Advisory Council will also be incorporated into this *Compendium*.

Understanding the persistence of microbial contaminants in distribution systems is important in planning for decontamination approaches. Bench and pilot scale studies examining spore adhesion to pipe materials are needed to provide information for decontamination of these pipes. Similarly sloughing of biofilms and corroded material from the pipes change the disinfection efficacy and impacts the fate and transport of these organisms through the distribution system and to the consumer's tap. The Water Security Program is planning to continue its research that is being done in partnership with the National Institute of Standards and Technology to examine more contaminants and real-world pipes, plumbing material, and actual biofilms. Additionally, as persistence and decontamination of microbial contaminants is better understood, work will begin on studying the association of radiological contaminants with various pipe surfaces and methods of removing adhered agents. As with microbial contaminants, work will begin with a bench scale study to determine whether radiological agents persist in pipe materials, and proceed to the pilot study. Understanding persistence and decontamination of radiological agents is necessary due to the general dearth of information on this topic in the technical literature that could inform water utilities or first responders following a contamination incident.

The Water Security Program is also working on research to develop technology to appropriately handle the large volumes of water that may be generated when responding to an incident (*e.g.,* from activities such as firehosing). The developed technologies or systems may focus on application during early incident response, to enhance decon/treatment/disposal options, and reduce the amount of waste residuals (*e.g.* of radiologically controlled material following a nuclear detention or other radiological incident). The ultimate product from this research will be the development of a water/wastewater disposal tool similar to the Response Protocol Tool.

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3 ● Science to Support Wastewater Management for Water Quality Protection Programs

Wastewater management plays a key role in protecting water resources by promoting conservation and efficient water use, supporting effective decentralized wastewater treatment programs, evaluating point source abatement and control programs, and other functions. The Office of Wastewater Management (OWM) takes the lead in carrying out these activities as an important part of promoting compliance with the requirements of the Clean Water Act (CWA). See the Addendum to Chapter 1 for more information on OWM responsibilities. OWM works in partnership with Environmental Protection Agency (EPA) Regions, States and Tribes to regulate discharges into surface waters such as wetlands, lakes, rivers, estuaries, bays and oceans.

The primary goals of the Water Program research agenda in this area are to characterize and develop methods to manage point sources of water quality degradation, to provide information on the latest wastewater and residuals treatment technologies and management practices, and to validate innovative practices for protecting water quality on a watershed basis. Professionals responsible for the management of wastewater and industrial process water need appropriate resources and information to make decisions regarding treatment and reuse or disposal of wastewater and residuals. They also need to manage potential sources of pollution, such as decentralized wastewater systems and stormwater runoff. Wastewater management decisions should be based on sound science and engineering. The Water Program research goals aim to facilitate such management decisions by serving as a technical resource and informing policy and regulatory actions. Much of the pollutant-specific research needed to support wastewater management programs is described in other chapters (*e.g.,* Chapters 5 for water quality criteria and standards; Chapter 4 for watershed management). Particular research needs for programs led by the wastewater program is described in this section.

Wastewater Management Program Research Needs

Emerging contaminants found in publicly owned treatment works (POTW) and decentralized system waste streams are an increasingly important part of wastewater and residuals characterization and management. Compounds such as endocrine disruptors (EDCs), pharmaceutical and personal care products (PPCPs), and pathogens need to be detected and managed. In addition, as new industries emerge and grow, EPA must stay abreast of new threats to water quality and identify ways to prevent their introduction to waters, and where necessary, to treat them.

Research is needed to support the Water Program goal of providing information on treatment and management of wastewater and residuals from municipal wastewater, industrial wastewater, stormwater, combined sewer overflows (CSOs), concentrated animal feeding operations (CAFOs), and decentralized systems, including beneficial use of residuals and re-use of treated wastewater. In particular, as wastewater technology changes, research is needed to assess both conventional and emerging technologies for their efficacy and cost-effectiveness.

Much of the water quality degradation seen today is from nutrients, pathogens and sediment. Much is still to be learned about how to prevent contamination of waters by these pollutants, as well as how to treat them once they are part of the wastewater stream.

Specific types of wet weather impacts need to be characterized and managed. These include Sanitary Sewer Overflows (SSOs) and CSOs, industrial, municipal and construction stormwater runoff, as well as discharges from concentrated animal feeding operations. Information is needed for selecting optimal means of preventing discharges, as well as treatment for the various discharge types. In particular, research is needed to support implementation of Green Infrastructure methods for controlling stormwater and improving ecosystem health.

Aging infrastructure and associated system failures have the potential to create public health risks. Infrastructure issues are part of the larger EPA Sustainable Water Infrastructure Initiative involving both water and wastewater infrastructure, and incorporating Green Infrastructure (GI) as a management practice. Research is needed on improved condition assessment and rehabilitation methods and technologies; new conveyance and treatment system design concepts; and integrated management approaches to improve utilities' ability to cost-effectively maintain, operate, rehabilitate and replace aging systems.

A new challenge has emerged in the water and wastewater arena – climate change. The need to consider climate change cuts across the entire National Water Program, including its impacts on point source management, For example, by altering the hydrologic cycle, climate change will affect the volumes of CSOs, SSOs, and other forms of wet weather flow in some parts of the country, with the potential for accompanying changes in water quality. Climate change effects should be integrated into all research that is conducted, including on POTW and industrial treatment options, implications for National Pollutant Discharge Elimination System (NPDES) permitting, water quality and watershed protection, protecting the sustainability and integrity of infrastructure, emergency response, and other related topics.

As mentioned, many of these research needs are described in other Chapters. Water Program research needs for management of wastewater, not included elsewhere, are described in the following categories:

- **POTW** treatment effectiveness and management, including fate of emerging contaminants, treatment of nutrients and pathogens, control of peak wet weather flows, and improving energy efficiency;
- **Decentralized wastewater system** treatment effectiveness and management, including fate of emerging contaminants; improving the reliability of decentralized systems; and characterizing the impacts of improperly managed decentralized systems on watersheds;
- **Residuals treatment and management**, including reducing volumes; beneficial reuse and disposal; and improved Best Management Practices (BMPs) for managing residuals from CAFOs;
- **Wet weather flow** control technologies and effectiveness, including characterizing and treating pollutants, effects from climate change, and demonstrating costs and benefits of GI;
- **Aging infrastructure,** including support for the Sustainable Infrastructure Initiative, on condition assessment and rehabilitation methods as well as integrated management approaches; and
- **Climate change** impacts on wastewater infrastructure and water quality; methods for infrastructure adaptation; improving energy efficiency of treatment plants and co-generating energy; and implications for CWA programs.

Background and research needs are presented below for each of these areas. In addition, a detailed listing of specific research projects for each research area will be found in the Water Research Management and Status Tool when it is available.

POTW Treatment and Management

POTW Treatment and Management address the treatment of municipal wastewater and residuals within the physical boundaries ("inside the fence line") of the treatment plant. Current issues of concern include: peak flow management; nutrient control; water reuse; unit process assessment (*i.e.,* a review of the functions and capabilities of a facility), evaluation and modification; and the fate/transport and potential interference/pass through of emerging contaminants, especially PPCPs.

There are a number of POTW Treatment and Management initiatives underway. EPA has been addressing operational and compliance problems at POTWs during peak wet weather flow conditions, including difficulties such as wet weather bypasses of various unit operations, decreased treatment efficiency during and after peak flow conditions, and operational practices, such as blending of wastewaters from different treatment trains during wet weather conditions. These concerns are exacerbated by the nationwide need for infrastructure rehabilitation and replacement over the next several decades. POTW treatment and management is an integral part of EPA's Sustainable Water Infrastructure Initiative, which aims to identify best practices to help many of the nation's utilities address various management challenges. Total maximum daily load (TMDL) requirements and NPDES permits to meet and State water quality objectives also provide incentives for achieving greater nutrient removal.

POTW Research Needs

EPA seeks to assess exposures and reduce the risks to ecosystems and human health from POTW discharges and reclaimed waters. Research related to "within-plant" treatment and management practices is needed to improve understanding of human health and ecological risks from discharging effluents while ensuring sustainable management of wastewater treatment infrastructure. In addition, communities are recognizing that "wastewater" is a valuable commodity. Research is needed to support communities as they turn to integrated water management strategies that include reuse of treated water.

Effective technologies and management practices. Information is needed on the effectiveness of both conventional and innovative technologies for minimizing risk. As emerging contaminants come under increased scrutiny, information will be needed on the abilities of conventional treatment methods to remove them. Conventional wastewater treatment processes have provided a relatively solid barrier between humans, the environment, and the many contaminants in domestic and industrial wastewaters. However, new innovative technologies still need to be identified and evaluated. Desired capabilities of new treatment technologies and management practices include:

- The prevention of excess wet weather flows, identification of best practices to enable handling of larger flows, and technologies to maximize treatment potential to reduce human health and ecological risks from discharging peak flow effluents; including the extent to which different types of pathogens are inactivated during the disinfection of wet weather flows;
- The reduction of nutrients and difficult to treat chemicals and pathogens;
- The ability to control emerging contaminants, including through additional treatment and product substitution;
- Improved energy efficiency and decentralized power production; and
- Reduction of the volume of wastewater treatment residuals.

Many recently developed technologies designed to meet such demands are already in use by communities, often without sufficient data to support their application. Specific new technologies, such as membrane bioreactors, should be evaluated and compared to conventional technologies (*e.g.,* activated sludge, rotating biological contactors, and sequencing batch reactors) for their abilities to treat effluents and sewage sludge. They need to be assessed for their removal of contaminants of greatest concern, flexibility in handling hydrologic changes associated with changing land use and climate, energy use, and operation and maintenance (O&M) costs. Strategies should be developed for combining unit processes to maximize treatment effectiveness, minimize greenhouse gas emissions, and reduce overall treatment costs.

Water reuse. As water shortages in the US increase in severity, communities must increasingly rely on reclaimed/reused water to meet consumer demands. The use of reclaimed water, including the nature and extent of exposure to possible contaminants, will determine the level of risk to human health. Evaluations are needed of the abilities of conventional and new wastewater treatment technologies to produce high quality effluents and to minimize the risk of exposure to specific contaminants due to reuse.

The identification of new applications for the reuse of treated wastewater effluents will require new information regarding which engineering practices and disposal technologies are available and best suited for disposal of the large quantity of brines and rejects produced at a water reuse treatment plant. The minimum water quality (nutrients, chemical and biological contaminants, temperature, etc.) required in POTW design and operation for specific water reuse applications needs to be defined.

Needs of the Regions. Research results must be readily available to those who need to manage POTWs. Regions have expressed a need for a handbook that lists innovative commercially-available technological solutions for reducing nutrient loading and managing stormwater overflow (see also Wet Weather Flow Control, below). To support the Regions during permit appeals, additional research is needed to identify efficient and cost-effective phosphorus treatment technologies. Similar data are also needed on nitrogen removal technologies. Tight limits are included in permits, but questions remain regarding the strategies by which limits may be met. Beyond a handbook, a database is needed to track the latest technologies, validation of success, O&M costs, and other related information.

Region 5 has specified the need for more research on CSOs treatment, particularly measurement of the impacts of High Rate Treatment and disinfection for a full range of pollutants. The measurement should address both influent and effluent characteristics during various wet-weather events. This research would assist the Regions in developing and implementing long-term control plans for CSOs and bypassing.

Decentralized Wastewater Systems

Proper management of decentralized wastewater systems is a critical aspect of source control management. Sometimes referred to as decentralized wastewater treatment, these systems are used by approximately 25 percent of all US homes and about 33 percent of new housing and commercial development. An estimated 10 percent to 20 percent of these systems malfunction each year, causing pollution problems and public health threats. Decentralized wastewater system issues include: performance of new technologies; assessment of system failures and their impacts (including cause and effect studies); leach field/soil treatment and water acceptance capacity; comprehensive system management; and fate/transport of pathogens and emerging pollutants.

EPA concluded that decentralized systems can protect public health and the environment. Decentralized systems typically offer lower capital and maintenance costs for rural communities. They are appropriate for varying site conditions and are suitable for ecologically sensitive areas when adequately managed. However, several major barriers to the improved performance of these systems were identified, including:

- Lack of awareness about system maintenance requirements;
- Public misconception regarding system performance and capability;
- Regulatory and legal constraints;
- Lack of management;
- Fear of liability; and
- Financial constraints and disincentives for engineering consultants.

Barring significant progress in eliminating these barriers, it is likely that decentralized systems will continue to cause health and environmental problems and will not be recognized as a key component of the nation's long-term wastewater infrastructure. Over the past decade, numerous efforts have been made to address these barriers, including developing partnerships, State program commitments, updated technical materials, and program guidance documents (USEPA, 1997; USEPA, February 2002; USEPA, 2003; USEPA, January 19, 2005; USEPA, December 2005; USEPA, January 2005).

Decentralized Wastewater System Research Needs

Current knowledge gaps for decentralized wastewater systems can be grouped into two general categories: system performance to improve the capabilities and reliability of decentralized treatment technologies, and characterizing the extent of watershed-scale effects of improperly managed systems.

Up-to-date technology transfer methods must be an important component of the research strategy for decentralized systems, because many practitioners of decentralized systems do not normally interact with EPA. These practitioners (*e.g.,* designers, installers, management entities, community leaders, and regulators) must be well informed about innovations and costs to make sound decisions. Addressing system performance and watershed-scale effects along with an emphasis on effectively transferring knowledge to practitioners will help to address the barriers of local regulation, lack of management, liability, and financing.

System performance. The first two research goals focus on performance of decentralized systems, that is, infrastructure (*e.g.,* septic tanks, aeration units, filters) and the role of soils in the treatment process. Initial efforts have been made to obtain data and develop an asset management approach for decentralized systems, but additional work remains, particularly related to the abilities of the various soil types to provide treatment. Research is also needed on treatment system efficiencies for currently regulated pollutants (pathogens and nutrients), as well as emerging pollutants of concern (EDCs, PPCPs, and difficult to treat pathogens). Although dependable treatment data exist for some technologies, more work is needed to address the performance capabilities and reliability of many currently available decentralized treatment technologies. In addition, research is needed to characterize the extent of greenhouse gases emitted from decentralized systems, and to identify opportunities for biological carbon sequestration at these sites.

Watershed-scale efforts. The topic of watershed-scale effects has several research gaps. Most watershed models and TMDL calculations do not accurately account for decentralized systems and either ignore them or assume some standard value. Limited work has been done on how to evaluate the risk associated with decentralized systems on a watershed scale, or how to compare and prioritize at-risk watersheds. More research is needed regarding the impact of both properly and poorly designed, operated, and maintained systems. New or refined source tracking and remote sensing methods will be required to accomplish reliable watershed-scale assessments.

Residuals Management and Treatment

Wastewater treatment processes are designed to reduce/remove contaminants and generate residuals (*e.g.,* sewage sludge, liquid side streams, septage, etc.). Animal feeding operations also generate large quantities of residual manure and contaminated stormwater runoff. These waste streams may be either beneficially used or disposed of. All require some form of characterization, treatment, and management. Pressing issues associated with the use or disposal of residuals include identification and control of pathogens, emerging contaminants, and nutrients.

Currently about 55 percent of the sewage sludge produced in the US is beneficially used (*e.g.,* land application) after treatment, and the remaining 45 percent is disposed of in Municipal Solid Waster landfills, monofills, surface disposal units, or incinerated. Pathogens are of special concern in the land application of biosolids. In 2002, the National Research Council (NRC) published a report titled "Biosolids Applied to Land: Advancing Standards and Practices". The NRC noted that there is "persistent uncertainty on possible adverse health effects" from sewage sludge.

Emerging contaminants (*e.g.,* endocrine disrupting compounds, PPCP, nanoparticles, and prions) are another area of concern. They have come under increasing scrutiny over the last decade, and there are growing concerns over the fate of these emerging contaminants in land-applied biosolids, septage, and manure. Pathogens and nutrients in residuals also require management. Excessive discharges of nutrients to water bodies result in eutrophication, with associated degradation of water quality.

Management options for residuals include various treatment and disinfection processes as well as BMPs; these management techniques require continued evaluation and improvement. Decision makers need up-to-date information on how to evaluate residuals and decide if they should be beneficially used or disposed of.

Residuals Management and Treatment Research Needs

Information from research is needed to assist managers who deal with residuals. Decision makers need to know the types and amounts of residuals produced by different treatment processes and how to characterize them. They need to know the best options for beneficially using or properly disposing of residuals. With selection of a beneficial use or disposal option, they need to know what is required to properly prepare the residuals. The research should ultimately be synthesized to provide guidance to those actively involved in such decisions.

Biosolids from POTWs. Almost 11,000 POTWs apply biosolids to the land. The effectiveness of current disinfection and stabilization methods used by these operations needs better documentation. Changes in process should be developed and studied where current processes are found to be inadequate.

Field studies should be conducted where biosolids are applied to land to determine if contaminants in biosolids pose a public health risk. For example, studies are needed to better understand the sudden spike of fecal coliforms that occurs following high-speed centrifugation of anaerobic biosolids at some facilities.

Manure from animal feedlots. Studies are needed to determine the effectiveness of Nutrient Management Plans (NMPs) for animal livestock operations and land application of residuals. NMPs include BMPs and procedures designed to ensure appropriate agricultural utilization of nutrients from animal manure while minimizing nitrogen and phosphorous transport to water bodies. Nutrient-related water quality problems continue even in areas that have implemented NMPs. Flaws in NMPs performance need to be identified, and new, emerging techniques and BMPs need to be investigated.

With recent advances in understanding and awareness of emerging contaminants, research is needed to identify appropriate new or existing treatment techniques and BMPs. Methods are needed for the detection and identification of pathogens in animal wastes to ensure proper manure disinfection and stabilization. Methods for microbial source identification and tracking need to be refined. A related issue – reduction of microbial loads delivered to the environment – needs to be addressed at multiple scales, from farm to watershed. Please see Chapters 2 and 5 for discussion of microbial contaminants.

Wet Weather Flow Control

Wet weather flow control includes the management and treatment of municipal, industrial and construction wet weather flows "outside the fence line" of the POTW. These include discharges from municipal separate stormwater sewers, municipal wastewater overflows (CSOs/SSOs), industrial facilities, and construction sites during and after rainfall and snow melt. A number of management methods currently exist. These include BMPs, both structural (*e.g.,* wet ponds) and non-structural (*e.g.,* street sweeping), and collection system management (*e.g.,* real time control) to manipulate system flows. Models are also available to help manage wet weather flows. Part of the research strategy will involve continued efforts to understand and improve these management options.

In addition to the traditional "gray infrastructure" for controlling stormwater, EPA is giving increasing attention to a new green infrastructure (GI) approach. GI refers to an array of stormwater management practices that utilize soils and vegetation to capture, cleanse, and reuse stormwater runoff. At the largest scale, the preservation and restoration of natural landscape features (such as forests, floodplains and wetlands) are critical components of green stormwater infrastructure. By protecting these ecologically sensitive areas, communities can improve water quality while providing wildlife habitat and opportunities for outdoor recreation. On a smaller scale, GI also includes site-specific stormwater management practices (such as rain gardens, porous pavements, and green roofs) that are designed to maintain natural hydrologic functions by capturing and infiltrating precipitation where it falls.

New challenges to the wet weather program are expected as a result of climate change, which is projected to cause increased intensity of wet weather events in some areas, while increasing intensity of drought in other areas. In many cases both "wetter wet and drier dry" periods are expected in the same Region. The Regions have expressed a need for new tools to assess and predict risks related to a changing hydrologic framework. Such shifts in hydrology may have significant effects on design criteria and planning.

Wet Weather Flow Control Research Needs

Research is needed to characterize and treat pollutants from wet weather flows. Development of BMPs for managing and reducing volumes of wet weather flow is needed, including preventing the occurrence of SSOs and CSOs. GI practices are increasingly being recognized as effective means of controlling both flow and pollutants, and improved practices and documenting results will expand their adoption. Research in all these areas will be used to populate BMP databases accessible to practitioners for selecting appropriate stormwater management practices and restoration technologies.

Climate change is very likely to affect wet weather flows in different Regions of the country. Research is needed to assess the impact of climate change on the frequency of overflows, the performance of BMPs, and design considerations for CSOs and stormwater BMPs. Research should also assess the effectiveness of GI in helping communities adapt to climate change.

Characterizing and treating pollutants in wet weather flows. Information is needed about the pollutants in various types of wet weather flows, including pathogens, toxics and emerging pollutants.

With improved understanding of pollutants in wet weather flows, methods are then needed to control pollutants in runoff from various sources, activities and materials. Major contributing sources of toxics, for example, include construction and transportation (*e.g.,* roads, bridges, and vehicles). Examples of reduction methods include non-toxic product substitution and innovative stormwater treatment at hot spots. Similar studies are needed for the reduction of pathogens in wet weather flows, and attention is needed to evaluate emerging pollutants.

Managing wet weather flows. Methods are also needed to reduce the rate and volume of stormwater runoff in developed (*i.e.,* urban and suburban) areas to pre-development hydrologic conditions. Research is needed on the beneficial use of stormwater for non-potable (*e.g.,* gray water irrigation, fire protection, cooling water, aesthetics) and possibly potable purposes.

The design and operation of stormwater BMPs is an area of ongoing development. Improved information is needed on their costs and effectiveness. To make choices about which BMPs to implement and how to design them, stormwater managers need information on their comparative effectiveness. The Regions have in fact expressed a need to quantify the abilities of BMPs to reduce pollutants and to identify the most effective BMPs for reducing impacts related to TMDLs. However, researchers are not using standardized parameters to conduct studies, making comparison of BMPs difficult. A standardized list of pollutants and other parameters (*e.g.,* volume, temperature, etc.) that are measured in any given research project is needed.

Innovative approaches to reduce collection system infiltration and inflow and other causes of SSOs, CSOs, and treatment system bypass are needed For CSOs, work is needed to compare the effectiveness of different approaches used in long-term control plans. This includes maximized use of collection systems, and maximized performance of treatment systems (*e.g.,* real-time control and alternative in-plant processes for treating storm flow).

Green Infrastructure. Additional information on GI management practices is needed to add to our knowledge of its effectiveness in controlling and managing wet weather flow. The GI Action Strategy's research focus seeks to ensure that potential adopters of GI practices have the information they need. In January 2008, the GI Partnership identified several priority areas for research:

- Characterize GI practices and their effectiveness at the watershed scale, taking into consideration upstream and downstream conditions, some of which can be done through case studies;
- Examine economic costs and benefits of GI and develop methods and protocols for economic parameters;
- Develop standard protocols for assessing multiple benefits from GI (*e.g.,* energy savings, carbon sequestration, urban heat island reduction, biodiversity, water conservation);
- Compare the benefits of GI with those of grey infrastructure approaches; and
- Develop methods for improved GI site operations, including performance assessment and O&M. Models should consider sensitive parameters for optimal design of GI approaches and tie in with multimedia linkages and should incorporate factors for climate change.

The Regions are particularly interested in research on GI and have cited additional research, data collection, and analysis needs to verify and quantify the performance of various GI practices. Some unanswered questions include:

- How does gray infrastructure improve the overall GI?
- How should improvements be selected to provide the most benefit?
- What are the long-term costs of not protecting high integrity components of the GI network from degradation, or restoring degraded areas within or adjacent to the network?
- What are the optimal scales at which GI should be assessed and managed for the various resources/services (*i.e.,* is there an optimum scale for assessing ecosystem services that will vary by the particular service)?
- How can the ecosystem services provided by a GI network be quickly and simply identified and described?

This information is needed to help communities revise their zoning and regulations to incorporate environmentally sound practices.

Making information accessible. EPA, in partnership with Water Environment Research Foundation and the American Society of Civil Engineers, developed the International Stormwater BMP Database to provide information on the effectiveness of different stormwater controls (USEPA, April 2002). Currently, the database is largely populated with conventional technologies. The BMP Database would benefit from a concerted effort to populate it with information on GI and other innovative stormwater controls.

Water and Wastewater Infrastructure

Aging water and wastewater infrastructure is a national challenge that has been identified as a major Agency priority. Central to the challenge are issues related to: a) improving the ability of utilities to conduct cost effective condition assessment and system rehabilitation of collection and treatment systems; b) implementing new and innovative technologies; c) applying new conveyance and treatment system design concepts; and d) using comprehensive, integrated management approaches to move the nation's infrastructure closer to sustainability.

One of the Agency's major programs for addressing this national challenge is the Sustainable Water Infrastructure Initiative. This initiative aims to change how the Nation views, values, manages, and invests in its water infrastructure. It promotes the use of effective and innovative approaches and technologies, encourages a commitment to long-term stewardship of water infrastructure, and forms collaborations with key stakeholders. Led by the Office of Water and supported by many other Program Offices, including the Office of Research and Development, the Office of Enforcement and Compliance Assistance, the Office of Policy, Economics, and Innovation, the Office of Air and Radiation, and the Regions, the Agency is actively promoting sustainable infrastructure, including the provision of research, tools, techniques, and incentives, where appropriate. EPA's four pillars of sustainable water infrastructure are:

- Better Management – Better management contributes to infrastructure sustainability by institutionalizing management systems and adopting innovative technologies and methods which lead to reduced infrastructure costs and improved performance across a full range of utility operations.
- Water Efficiency – Improved water efficiency can reduce the strain on aging water and wastewater utilities and can sometimes delay or even eliminate the need for costly new construction to expand system capacity.
- Full Cost Pricing – Drinking water and wastewater utilities need to recognize the full cost of providing their services over the long-term and implement a pricing

structure that recovers cost and promotes economically efficient and environmentally sound water use decisions by customers.

- Watershed Approach – Utilities and other decision makers need to evaluate a broad array of watershed based approaches as they make infrastructure decisions, to target those investments that have the greatest benefit for the watershed as a whole. Approaches such as source water protection, water quality trading, and embracing GI alternatives, can all contribute to sustainable solutions while achieving water quality and human health protection goals in the watershed.

Water and Wastewater Infrastructure Research Needs

EPA's research initiatives related to aging infrastructure will provide information on new and innovative condition assessment and rehabilitation methods and technologies; new conveyance and treatment system design concepts; and comprehensive, integrated management approaches to improve the ability of water utilities to cost-effectively assess, maintain, operate, rehabilitate, and replace their collection and treatment systems. For aging (wastewater) infrastructure, major research needs and activities include:

- Improved inspection, condition assessment, and cost estimation tools for existing conveyance systems to enable optimal rehabilitation;
- Effective methods to determine performance and cost of innovative rehabilitation for drinking water and wastewater conveyance systems to enhance the ability of utilities to select efficient rehabilitation approaches for deteriorating infrastructure;
- Advanced design concepts such as real-time control options, integrated drainage concepts (*e.g.,* upland flow attenuation before sewer system entry), and steeper sewer slopes for wastewater collection systems to fully utilize the conveyance and storage capacity of existing systems, reduce construction costs, and improve wet-weather flow pollution control;
- Advanced design concepts for existing treatment systems to better utilize capacity and capability. Improved design, utilizing advanced technologies for energy-saving and capacity enhancement and higher capacity treatment for wet-weather flow are needed to reduce construction costs, improve treatment efficiency, and reduce overflows;
- Techniques to improve performance and extend service life of existing systems to effectively address conveyance system capacity, backup, and overflow problems caused by sediments and debris; fats, oils, and grease; pH; corrosion, etc.; and

- Methods and support tools for evaluating how climate change will impact infrastructure sustainability to use when locating, designing and upgrading systems to adapt to likely impacts.

To aid in the replacement of aging infrastructure, the Regions need an easy, inexpensive way to locate buried pipes and other infrastructure prior to conducting a condition assessment or inventorying assets for an asset management plan. By utilizing information technology such as GIS to maintain data, O&M schedules, replacement dates, and other data, communities can retain critical infrastructure information. In addition, this information can be useful for identifying the institutional structures that have resulted in successful asset management programs.

Regions also need a more quantitative understanding of the relationship between energy use and water treatment and distribution technology. This will help guide drinking water and wastewater operations toward better environmental and energy efficiency, both in general and when working to optimize and/or upgrade infrastructure.

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4 • Science to Support Watershed Protection and Restoration Programs

In pursuing the goals of the Clean Water Act (CWA), programs and research geared towards watershed health play a unique and holistic role. EPA's Water Program promotes wetlands protection, oceans and coastal protection, and watershed assessment and protection through a diverse range of programs to manage, protect, and restore the water resources and aquatic ecosystems of US marine and fresh waters. These efforts are headed by the Office of Wetlands Oceans and Watersheds (OWOW), working in collaboration with the Office of Science and Technology (OST), the Office of Ground Water and Drinking Water, and the Regional Water Divisions to implement the Program. Together, the Office of Water (OW) and the EPA Regions provide technical and financial assistance, and develop regulations and guidance for myriad regulatory and cooperative programs. See the Addendum to Chapter 1 for more information on OWOW responsibilities.

The Watershed Protection and Restoration Program has a broad mission to protect and restore the health of a diversity of water resources and aquatic ecosystems. These efforts are organized using the Watershed Approach, integrating multiple facets of an ecosystem's health and functioning.

Greater focus is provided in the EPA 2006-2011 Strategic Plan, which lays out the Agency's goals for achieving measurable environmental results in five areas, including "Clean and Safe Water" and "Healthy Communities and Ecosystems". Salient sub-objectives include: 1) facilitate the ecosystem-scale restoration of Estuaries of National Significance (with strategic targets to protect or restore habitat under the National Estuary Program), 2) improve water quality on a watershed basis, 3) improve coastal and ocean water, 4) restore and protect the South Florida Ecosystem (including the Everglades and coral reefs); and 5) decrease the size of the hypoxic zone in the Gulf of Mexico by reducing nutrient inputs from the Mississippi River Basin. The Water Program's research efforts provide scientific and technical knowledge for the attainment of these goals and objectives.

Watershed Protection and Restoration Program Research Needs

To support the program goals, technical information is needed in a number of areas. Ongoing work is needed to optimize monitoring and assessment programs. The need for reliable and well-conceived monitoring and assessment cuts across several research areas and supports multiple goals. Information on the status of a waterbody or watershed enables a determination of its condition and whether the services it provides (ecological, economic, and cultural) have been diminished. This information can also be used to establish total maximum daily loads (TMDLs). Watershed managers then need to be able to translate such assessments into plans for management or restoration. Further monitoring can indicate recovery and whether a system is able to once again provide the desired services.

Although any waterbody can be subject to degradation, certain water bodies are especially vulnerable and have experienced serious environmental assaults. Research is needed to evaluate the roles of various stressors in causing the severe decline that coral reefs are experiencing. Hypoxia in the Gulf of Mexico (GOM) has emerged as a major concern in a region that provides the nation with tremendous economic, ecological, and cultural benefits. Research is urgently needed to refine our understanding of this phenomenon and to combat it. Headwater streams and isolated wetlands fall into an ambiguous area jurisdictionally. In order to protect them, their relationship to navigable waters needs to be investigated.

Another critical research need involves monitoring for and managing invasive species. Non-indigenous plants and aquatic organisms pose a threat to native species and are undermining the stability of various ecosystems. Research is needed to understand their modes of introduction and how to monitor and respond to them.

Research needs are organized under a number of areas as follows:

- National Aquatic Resource Surveys
- Watershed Management
- Wetlands in Water Quality Trading
- Headwaters, Adjacent Wetlands, and Isolated Wetlands
- GOM Hypoxia
- Invasive Species
- Ecological Restoration
- Coral Reef Protection

Background and research needs are presented below for each of these areas. In addition, a detailed listing of specific research projects for each research area will be found in the Water Research Management and Status Tool when it is available.

National Aquatic Resource Surveys

Land use in the United States is changing rapidly, with great potential for water quality deterioration. Designing and conducting surveys to assess the condition of the Nation's waters and evaluate trends over time is a high priority for EPA. Policy makers and watershed managers need reliable chemical, physical, and biological information that is collected in a scientifically-defensible manner. In addition to understanding the status and functioning of aquatic ecosystems, monitoring also permits evaluation of the success of watershed protection and restoration measures.

Much of the monitoring and assessment activities are performed by States and Tribes, and EPA provides funding, training, design advice, and oversight. The Water Program in particular provides guidance to States on conducting monitoring programs. EPA's National Environmental Monitoring Initiative provides funds to States and Tribes to conduct aquatic surveys.

At a national level, EPA's National Environmental Monitoring Initiative involves collaboration between organizations performing assessments and monitoring. It includes contributions from such diverse government entities as the US Geological Survey and the National Oceanic and Atmospheric Administration. This program links survey results with ecological process research. Assessment activities can also be used in the broader context of developing inventories of the services provided by various ecosystems. ORD's Ecological Research Program multi-year plan addresses ecological monitoring, mapping, and modeling as means to assess conditions and changes in ecological services (USEPA, February 2008). In addition, maintenance of ocean, coastal, and lake sampling capabilities (*e.g.,* research vessels like *BOLD* and *The Lake Guardian*) is essential to obtaining the data needed to support these programs.

National Aquatic Assessment Research Needs

EPA has identified the following National Aquatic Survey research needs to further its understanding of the condition of the nation's waters:

- Provide tools for effective ecosystem monitoring;
- Identify trends in water quality and aquatic systems;
- Provide national frameworks for statistical assessments;

- Identify appropriate indicators of aquatic health and determine suitability of new analytical methods; and
- Develop and improve integrative watershed modeling frameworks.

Each of these research areas is described in greater detail below.

Provide tools for effective ecosystem monitoring

The Office of Research and Development's (ORD) Environmental Monitoring and Assessment Program (EMAP) was a major research initiative that provided the tools needed for effective ecosystem monitoring. It investigated designs that addressed the acquisition, aggregation, and analysis of multiscale and multi-tier data. EMAP focused on transferring science and technology through partnerships with States and Tribes to enable them to complete their assessments. Continued support of EMAP, or similar effort outside of EPA, is a Water Program research priority, particularly in the areas of indicator development and interpretation of complex ecosystem stressor-response relationships at multiple scales.

Identify trends in water quality and aquatic systems

The National Estuary Program also provides assessment data, which are incorporated into the National Coastal Condition Report. A ten-year research plan has been proposed by the National Exposure Research Laboratory's Landscape Science Program. This program will examine the consequences of landscape changes for aquatic resources, including streams and estuaries. Collectively, these initiatives provide much-needed data for tracking and understanding trends in water quality and aquatic ecosystems.

Provide national monitoring frameworks for statistical assessments of the nation's lakes, rivers, streams, estuaries, and wetlands

Aquatic monitoring research can maximize the resources allocated for assessment and monitoring by devising scientifically rigorous sampling protocols that are also time and cost effective. Those responsible for implementing monitoring programs need information to help select optimal spatial and temporal sampling resolutions. Another ongoing goal of monitoring research is consistency in protocols across the country. Continued research by programs such as EMAP will ultimately result in a more reliable picture of the nation's water quality by refining sampling protocols and encouraging uniformity.

Identify appropriate indicators of aquatic health and determine suitability of new analytical methods

Ongoing research is also needed on choices of appropriate indicators of aquatic health. As new analytical methods become available, some suited to field use, their potential incorporation into sampling schemes must be researched. From the Regions' perspective, indicators used for monitoring are often not directly related to pollutants and cannot distinguish among multiple causes of impairment. Resources are too limited to elucidate causes and sources in many cases. Research is needed to better identify inexpensive and standard techniques for identifying causal pollutants.

Develop and improve integrative watershed modeling frameworks for describing the impacts of changing surface water quantity on water quality at multiple scales

Research is also needed to provide an integrative modeling framework/approach for assessing how future urbanization and water resources development and management activities can alter water availability and demand. Such changes can ultimately affect the services provided by an ecosystem. An assessment is needed of available models and their strengths and limitations, and decisions need to be made regarding which endpoints should be modeled and at what spatial and temporal resolutions.

Watershed Management

Watershed Management encompasses assessment of water quality impairments, development of TMDLs, targeting of priority watersheds, watershed management implementation and tracking, and implementation of incentive programs. The following summary of Watershed Management research needs is organized under three areas:

- Watershed Assessment;
- Management Measures; and
- Incentives.

Watershed Assessment

Successful watershed management requires a fundamental understanding of hydrological and ecological processes within watersheds and how those processes are influenced by human actions. Management without adequate scientific knowledge is likely to achieve inadequate or unintended results, or even result in environmental harm. Thus, watershed assessments and monitoring activities are fundamental to the watershed approach. Watershed assessments can focus on a single watershed or may assess a group of watersheds comparatively. CWA-related watershed assessments may involve characterizing basic traits of waters, their watersheds, and their human community context. Assessments may also evaluate condition and functionality, giving an indication of the ecological, economic, and cultural services the watershed is able to provide. They may assess threats, identify causes of problems, and set priorities for specific remedial actions. Other assessments that are important for understanding watersheds include: establishing appropriate reference conditions and refined uses; developing chemical, physical, and biological criteria for identifying impairments and high quality waters; and, tracking interim (small scale) improvements or declines.

Watershed Assessment Research Needs

Watershed managers need watershed assessments that will encompass the combined and cumulative effects of point and nonpoint sources of pollution, habitat alteration, and other sources of impairment. To accomplish this, EPA needs research to address the following areas:

- Provide better characterization of watershed structures, features, and processes that underlie all watershed assessments and influence the likelihood for successful management interventions.
- Provide sound designs and methods to evaluate and describe condition, thresholds of impairment (including establishment of appropriate reference conditions), and attribute value to watershed goods and services.
- Develop an improved scientific basis and/or tools and models to determine which (and how) stressors are causing degradation, or likely to cause degradation to enable targeted action for protection and restoration.
- Provide improved scientific knowledge and tools that will help target watersheds for management that offer the greatest opportunity for achieving positive and intended environmental results.

Each of these research needs is described in more detail below.

Provide better characterization of the watershed structures, features, and processes that underlie all watershed assessments and influence the likelihood for successful management interventions.

Work is needed to provide broad access to baseline characterization of watersheds. Baseline characterization involves understanding the ecological functionality, stressors, and socio-economic elements of a watershed. It underlies all aspects of watershed management. Such a fundamental level of information is needed to produce integrated 305(b)/303(d) assessments, and the information must be widely accessible. In making such data available, attention must be paid to database design, national consistency, and quality of base data sets, and classification that can be challenging enough to prompt research investigations. In recent years, it would be particularly valuable to reevaluate whether EPA has access to the full array of base data commonly needed to support watershed management. Such data include analyses of waters and watersheds, stressors, ecosystem goods and services, and primary natural processes.

Provide sound methods to evaluate and describe condition, thresholds of impairment, and attribute value to watershed goods and services.

Research is needed to develop an improved scientific basis and/or tools to evaluate watershed and waterbody condition. This builds upon information acquired in baseline characterization by applying value judgments (*e.g.,* whether the waterbody is impaired or fully functional; what to consider "reference" conditions; how water bodies provide goods and services dependent upon their condition). To assess condition, researchers need to develop condition gradients, thresholds of impairment, methods to characterize functionality, and reference conditions. Continued effort is needed to improve our ability to compare conditions across eco-regions and water body types, such as the Biological Condition Gradient, and associated use of Tiered Aquatic Life Uses. Information is also needed regarding changes in ecological goods and services, waterbody support of designated uses, or other concepts reflecting worth. Such information is essential for reporting on the conditions of watersheds, for planning and tracking TMDLs and other actions, and for developing and implementing watershed restoration measures.

The Regions have noted that knowing critical values for landscape measures, such as the extent of riparian forest or the degree of forest fragmentation, would be useful in measuring the effectiveness of ecosystem protection in maintaining and improving water quality. For example, it would be useful to know the critical values for impervious surface and other critical ecosystem values beyond which ecosystems are impaired or imperiled. Another research need identified by Regions is for a better understanding of the mitigating factors that lead to differences in studies (and ultimately to field application) of critical values.

Develop an improved scientific basis and/or tools and models to determine which (and how) stressors are causing degradation, or likely to cause degradation to enable targeted action for protection and restoration.

Ongoing research is also needed in causal assessment, which establishes a link between the presence of a threat, the mode of action, and response to exposure. Stressor Identification is a generic approach to causal assessment co-developed by ORD and OW for use by the States; ongoing work is needed on this approach. TMDL modeling also clarifies and quantifies the causal links between sources, stressors, and effects. Continued research in these areas will refine our understanding of the relationship between pollutants and deleterious effects on biota. Progress is also needed in identifying unknown causes of water quality impairment. Over 38,000 waters in the US have been listed by the States as impaired or threatened. The responsible pollutant is unknown for over 11,000 of these waters, seriously hampering the processes of TMDL development and restoration. Also, issues of scale are important for many environmental problems. Our understanding of the effects of stressors on watersheds will be aided by an improved ability to scale processes regulating water quantity and quality at the sub-basin scale to larger basin scales.

Some Regions have concerns about degradation from specific stressors. For example, Region 1 is concerned about runoff from back roads and needs field performance data on practices to control sediment and phosphorus. Region 6 is experiencing deterioration in water quality and aquatic ecosystem integrity from stream bank erosion, exacerbated by rapid urbanization. In particular, they are interested in guidance on development of reference hydrographs for streams to allow them to link hydrograph maintenance to land use and best management practices (BMPs). The information could be used to reduce impairments as urbanization and development progress.

Provide improved scientific knowledge and tools that will help target watersheds for management that offer the greatest opportunity for achieving positive and intended environmental results.

Nationwide, thousands of water bodies have been identified as impaired and needing restoration. Many more are currently in good condition and in need of efforts to ensure that impairment does not occur. However, limited resources prevent immediate action on all water bodies simultaneously. Some sort of logical prioritization procedure is needed. Water programs urgently need information on the ecological, stressor-related, and socio-economic factors that influence recovery, both for individual watersheds and for comparison across large numbers of waters. Watersheds can then be targeted and prioritized with greater chance for restoration success and better return on monetary investment. Correct prioritizing will also help to demonstrate improvement and meet the stated numeric restoration goals in upcoming strategic plan targets. The Regions have echoed this need to be able to predict, target and prioritize impairment.

In addition, information on restoration priorities needs to be coupled with understanding of the threats to healthy waters and the socio-economic costs associated with allowing those waters to degrade (*e.g.,* loss of societal values, cost to restore, etc). Some of the same factors that are important for targeting watersheds for restoration (*e.g.,* community interest) are important for selecting which watersheds to protect. In addition, there is a need to identify "at risk" watersheds where significant development may occur.

Management Measures

A watershed approach is being promoted as an efficient and often more cost-effective way of implementing restoration and protection activities including integration of TMDLs, permit requirements, and other water quality protection and improvement practices. To meet the water quality targets in a given watershed, there are often several management "strategies" from which to choose, each consisting of one or more management measures. To decide what practices and approaches to implement, managers need to be able to compare costs and benefits of various strategies through models that predict the watershed-wide impacts of one or multiple management measures. After a strategy has been selected and implemented, progress towards meeting the targets must be tracked, requiring effective monitoring approaches.

Management Measures Research Needs

A key hypothesis regarding management measures is that their strategic placement in a watershed will reduce the number and cost of measures required to attain water quality standards compared to separately selecting management measures for incremental parts of the watershed. After putting measures in place to test this hypothesis, progress towards meeting the targets must be tracked. This will require improved monitoring strategies, and prioritization of watersheds. Research is needed to:

- Determine the performance and costs of individual management measurements to support the development of watershed management strategies;
- Develop strategies to optimize the selection and location/placement of management measures in a watershed; and
- Develop monitoring strategies to measure the effectiveness of watershed management programs.

Each of these research areas is discussed below.

Determine the performance and the costs of individual management measures to support the development of watershed management strategies.

Information is needed on the performance, construction, maintenance, and monitoring costs of individual management measures. Often, the placement and implementation of management measure(s) are done with limited guidance as to design, cost, or maintenance steps that could optimize performance. This lack of information hinders effective use of resources. In many cases, the costs to be incurred are for construction and maintenance, but there may be other issues to consider. There may be costs from unintended consequences of a management measure, such as a wetland serving as a breeding ground for invasive species. Measuring performance may also generate unavoidable costs if required, for example, as part of a water quality trading program.

The Regions need improvements in analytical capabilities, indicators, and monitoring approaches to better survey a watershed for contaminants. Research is particularly needed on measures to treat and manage phosphorus, especially methods for phosphorous removal. Cost effective technology is also needed to turn manure into fuel. The use of manure as a more complete resource (*e.g.,* nutrients and biofuel) may help to reduce the amount of phosphorous pollution from agricultural runoff.

Develop strategies to optimize the selection and location/placement of management measures in a watershed.

In a watershed approach, management measures will most likely be used in combination, and there may be several potential options for a given watershed. Work is needed to help watershed managers select appropriate combinations of water pollution controls and management measures to meet water quality objectives. The basic approach to optimizing measures within a watershed would consist of using integrated modeling systems that can account for watershed processes and stressor transport and fate. This would be coupled to: a) the performance and cost of individual measures; b) phenomena that naturally attenuate water quality stressors; and, c) information that relates stressor reduction to achieving designated uses, such as aquatic ecosystem stressor-response information. Such systems would also allow the user to compare different management measure scenarios to determine which is most cost effective. Such modeling systems must allow for point and nonpoint sources and management measures. They should also be applicable to varying scales, ecological settings, and stressor combinations.

Develop monitoring strategies to measure the effectiveness of watershed management programs.

Watershed managers need information to help them develop monitoring strategies to measure the results of management actions. Federal and State governments have similar questions about the performance of their programs, be they regulatory, incentive-based, or of another type. Measuring results can also document whether CWA-related goals are being achieved. Information is needed on which metrics should be used in monitoring strategies. The possibilities are many and include: environmental and stressor parameters, ecological services, monetary and non-monetary valuations, management plans developed, and incentives adopted.

The Regions have noted that community planners need methods to demonstrate progress from management actions across a HUC 12 watershed. The methods should examine both aquatic ecosystem response indicators and the performance of management measures. These methods should include simulation tools and predictive models, remote sensing, and ambient monitoring.

To help synthesize information, make management choices, and monitor them, the Regions need a state-of-the-science report describing: 1) integrated watershed modeling system availability, 2) model capabilities to simulate management measures and strategies for optimal selection and placement at the HUC 12 watershed level, and 3) model ability to simulate short- and long-term effects of management measures and ecosystem response to implemented measures

Incentives

Much water quality impairment results from nonpoint sources. Because nonpoint sources are not regulated, economic and other incentives need to be developed to control them as part of watershed-based water quality improvement programs. For example, nonpoint source pollution can be mitigated through the implementation of BMPs. To encourage such implementation, various incentive programs have been developed in scattered watersheds throughout the country. Also, where point source pollution reduction would result in water quality improvements, point/nonpoint source trading may achieve the desired reductions in an economically efficient manner by reducing nonpoint pollution. (Because of its importance and promise as a pollution reduction incentive, wetlands in water quality trading has been discussed above in a separate section.) Socio-cultural factors such as behavioral changes associated with watershed protection and restoration also need to be investigated. Furthermore, because watershed planning and implementation is a complex process, technical support to watershed managers on the overall process will reduce the barriers to what in many cases is a voluntary activity.

Incentives Research Needs

Research is needed to provide environmental managers with the tools they need to improve watershed management programs. In particular, research is needed to:

- Determine factors that motivate change in public behavior toward the protection or restoration of water quality;
- Refine our understanding of the effectiveness of BMPs in order to support BMP implementation programs; and
- Develop technology transfer mechanisms that provide watershed managers with resources needed to make technically-sound watershed management decisions.

Each of these research areas is discussed in more detail below.

Determine the factors that most motivate changes in public behavior with respect to the protection or restoration of water quality to incorporate into watershed management program strategies.

People have ingrained cultural values and attitudes associated with environmental protection. Incentives are sometimes needed to change behavior to implement management plans. These incentives may include education on the benefits and costs of management measures (*e.g.,* stakeholder participation in a watershed rain garden program). Examples of successful programs include placement of cisterns and rain barrels on private property in Seattle and Portland. Other incentives include creation of conservation easement programs to pass along green spaces or protected areas to future generations. Increased information on how successful initiatives are executed would help to facilitate their adoption in other potentially receptive communities.

Refine our understanding of the effectiveness of BMPs in order to support BMP implementation programs.

It is believed that BMPs limit nonpoint source pollution, although data on the extent to which this occurs indicate a wide range of performance. More information on their effectiveness is needed to establish the pollution reductions achievable by the various types of BMPs. Clear documentation of the benefits provided by BMPs will support the economic programs aimed at their installation and implementation and help them to become widely accepted by watershed managers, decision makers, and stakeholders.

Develop technology transfer mechanisms that provide watershed managers with resources needed to make technically-sound watershed management decisions.

Data and tools for watershed management may be highly specific. Furthermore, these materials are widely distributed across government, Web sites, and academic institutions. Work is needed to simplify access to watershed management science and information. To this end, EPA is proposing to organize this information for watershed managers in a central location in a framework that permits easy access. EPA's OW, ORD, and the Office of Environmental Information are developing new concepts for integrating information and decision support tools to make water quality management more effective at the State and local level. The concept is called "Watershed Central." It would provide a central access point for watershed information on the EPA Web site. In the future, it may link key tools and resources from various parts of EPA to particular steps in the watershed management process. EPA is now discussing the format of such a web site with potential users. To design and implement this web site, scientists need to determine which processes should be included. It is important to research which watershed model data analysis tools are appropriate and which computer applications are best for management measure optimization. Also, uncertainties in watershed decision and support tool development need to be addressed. Given a well-conceived source of relevant information, incentive programs can be more easily put into place.

Wetlands in Water Quality Trading

Wetlands are unique ecosystems that provide critical habitat for thousands of species of aquatic and terrestrial plants and animals. As transitional zones between land and water, wetlands naturally help to absorb and slow floodwaters, and help to absorb excess nutrients, sediment, and other pollutants before they reach rivers, lakes, and other water bodies. Human activities are causing wetland degradation and loss by changing water quality, quantity, and flow rates; increasing pollutant inputs beyond the capacity of wetlands to absorb; and changing species composition as a result of disturbance and the introduction of non-native species.

The Water Program is evaluating the feasibility of using wetlands in a water quality trading as one approach for facilitating the restoration, creation, and enhancement of healthy wetlands that contribute to water quality within a watershed, as well as further downstream. Water quality trading is a voluntary exchange of pollutant reduction credits through which, in a given watershed, a facility with higher pollutant control costs can buy pollutant reduction credits from a facility with lower control costs, thus reducing their cost of compliance. Such trading programs can allow a given watershed to meet water quality targets (*e.g.,* TMDLs) at lower overall costs, and can provide ancillary benefits such as flood retention, riparian improvement, and habitat (USEPA, July 2007).

The concept of "wetland credits" for restoration, creation, or enhancement is not new. In 1995, for example EPA issued guidance allowing States and others to use "wetland mitigation banks" to offset unavoidable wetland losses permitted under CWA Section 404. Mitigation banks allow a Section 404 permittee to purchase wetland credits to compensate for wetland losses that will occur at another location. Though mitigation banks can provide ancillary water quality improvements, they have not yet been incorporated into water quality trading programs. More widespread implementation of watershed-scale trading could create opportunities to restore and/or construct wetlands as a means to generate pollutant reduction credits. Strategically located and designed wetlands serve multiple functions and can improve water quality, generating credits that could be used by permitted dischargers to comply with national pollutant discharge elimination system (NPDES) permit limits. This strategy could attain the Agency goal to restore, improve, and protect millions of acres of wetlands in a cost-efficient manner.

Wetlands in Water Quality Trading Research Needs

Before wetlands can be reliably incorporated into water quality trading programs, research is needed to:

- Identify existing data regarding wetland nutrient removal rates to be used for modeling and assigning trading credits;
- Determine how to avoid unintended negative consequences associated with wetlands managed for nutrient removal;
- Determine the feasibility of offsetting stream segment degradation with improvements;
- Identify an acceptable approach for estimating risk and uncertainty; and
- Determine how to manage wetlands used in water quality trading.

Each of these research areas are explained in more detail below.

Identify existing data regarding wetland nutrient removal rates to be used for modeling and assigning trading credits

One need is to identify existing data regarding wetland nutrient removal rates. This information can be used for modeling and assigning trading credits with respect to wetland type (*e.g.,* native, engineered, restored, riverine, floodplain, etc.); geomorphology; hydraulic loading rate; age, state, and ecological trajectory; and relative landscape position. Studies are needed to clarify the relationship among abundance, distribution, and condition of wetlands and the delivery of ecosystem services.

Determine how to avoid unintended negative consequences associated with wetlands managed for nutrient removal

For wetlands managed for nutrient removal, research is needed to determine how to avoid unintended negative consequences, such as invasion of non-native species; excess nutrients entering waterways; increased risks from greenhouse gases; or contaminated wetlands becoming an "attractive nuisance" for wildlife.

Determine the feasibility of offsetting stream segment degradation with improvements

Research is also needed to determine the feasibility of offsetting stream segment degradation with improvements elsewhere in a watershed and the geographic scale on which trading might occur.

Identify an acceptable approach for estimating risk and uncertainty

Methods are needed to evaluate the risks, costs, and benefits of generating water quality credits for wetlands restoration, re-establishment, or enhancement. Planned ecological research will provide assessments of the economic, ecological, and cultural services provided by wetlands. This input will assist in placing value on the protection and restoration of wetlands. Methods are also needed to monitor, assess, and verify performance. The trading approach can then be weighed against other management strategies. Research may also indicate whether water quality credits for wetlands restoration, enhancement, or re-establishment could be incorporated into NPDES permits as one way to comply with water quality-based effluent limits.

Determine how to manage wetlands used in water quality trading

Wetlands trading may prove to be a viable option for meeting TMDL requirements, but clarification is needed in several areas. An approach is needed for estimating risk and uncertainty, and an acceptable level of risk must be determined if there is a chance that trading will not meet performance expectations. Research is needed to evaluate what trading ratios (or other mechanisms) would help to overcome or reduce risks. Research is also needed to determine how to manage wetlands used in water quality trading and how to monitor for and prevent damage or diminishing quality. Ecological research is planned to develop interactive mapping tools that will provide decision-makers with information on wetland ecosystem services and value and the effects of local and landscape manipulations (*e.g.,* protection, restoration, and degradation) on wetland ecosystem services. Such tools should be considered for integration into a wetlands trading approach.

Headwater Streams, Adjacent Wetlands, and Isolated Wetlands

The CWA applies only to the surface waters of the United States. However, not all surface waters are legally "waters of the United States." The exact dividing line between waters meeting this definition and those that do not can be hard to determine, and has changed with new court rulings, new regulations, or amendments to the Act itself.

In the January 9, 2001 case of Solid Waste Agency of Northern Cook County v. US Army Corps of Engineers, the Court determined that isolated wetlands must have some "significant nexus" to navigable waters if they are to be regulated under the CWA. On June 19, 2006, the Court issued decisions on two additional cases (Rapanos v. United States and Carabell v. US Army Corps of Engineers) that dealt with the jurisdictional status of wetlands that border, are contiguous to, or neighbor a navigable water, a tributary to a navigable water, and certain other waters (*i.e.,* adjacent wetlands), as well as non-navigable tributaries. The opinions resulted in two separate jurisdictional criteria for adjacent wetlands and tributaries. The plurality opinion, argued that adjacent wetlands and tributaries must have continuous surface connection or relatively permanent flow. The second opinion stated that a wetland meets the significant nexus criteria if it "either alone or in combination with similarly situated lands in the region, significantly affect the chemical, physical, and biological integrity of other covered waters more readily understood as 'navigable.' "

Headwater Streams, Adjacent Wetlands, and Isolated Wetlands Research Needs

Given the scientific uncertainty highlighted by these recent Court cases, EPA regulatory and enforcement staff need a standardized way to determine if a headwater stream, adjacent wetland, or isolated wetland (HS-IW) significantly affects the integrity of a navigable water (hereafter referred to as the nexus question) or has relatively permanent flow/connections. This issue is especially relevant in the southwestern US, where intermittent or ephemeral streams constitute over 80 percent of the total stream length. Regions 4 and 6 need to establish a defensible basis for CWA jurisdiction in arid environments. However, standardized tools for making these determinations do not exist, and fundamental information that would be required to develop such tools is also lacking. Before these tools can be developed, basic research is needed that can establish and quantify the contributions of HS-IWs to the chemical, physical, and biological integrity of navigable waters.

Also, a great deal of ecological restoration is underway and planned to address the environmental damage from the destruction of HS-IW (*e.g.,* from mining). But the benefits of many of these restoration approaches are not clear, nor do they seem to be based on adequate science. Mitigation techniques to restore flow and function of streams warrant scientific inquiry.

Provide research and develop tools for assessing significant nexus and permanence of hydrologic connections in headwaters streams, adjacent wetlands, and isolated wetlands

Research is needed to assess the contribution of isolated wetlands to the integrity of navigable downstream water bodies. Studies should focus on which factors (*e.g.,* physiography, land use, spatial location, hydrology, configuration, and ecological processes) control the permanence of hydrologic connections. Influences on the chemical, physical, and biological integrity of downstream navigable waters also need to be understood. It may then be possible to determine which categories of HS-IWs have continuous hydrologic connections and/or significant influences on the downstream navigable waters. In addition to focusing on how HS-IWs contribute to navigable waters, the research needs to examine how the degradation, loss, or restoration of HS-IWs affects navigable waters. To that end, there is a need for further efforts to identify and measure the anthropogenic and natural stressors to headwater stream systems. Work is also needed to validate wetlands as a management practice in decreasing pollutant loadings. The appropriate types of wetlands, optimal number of acres, and approaches to determine how the wetlands are functioning all need research before the full potential of wetlands in mitigating pollutant loadings can be realized.

Using this more sophisticated understanding of HS-IWs, tools can be formulated to allow regulatory and enforcement staff to apply jurisdictional tests in the field, especially during critical times when staff cannot make repeated visits to observe permanence of flow/connections. These tools could include classification methods, simple models, mapping techniques, and rapid assessment field methods that incorporate and complement best professional judgment.

Gulf of Mexico Hypoxia

A large area of low oxygen or hypoxia continues to form in the GOM during periods in the summer off the coasts of Louisiana and Texas. GOM hypoxia is an increasing threat to the ecological integrity of the Gulf, where approximately 40 percent of the United States fisheries are located. In 2002, the hypoxic zone was estimated at 22,000 square kilometers, the largest measured extent since measurement of the zone began in 1985 (MRGOM Watershed Nutrient Task Force, 2004).

The increase in the size of the hypoxic zone is coincident with an increase in Mississippi River Basin nutrient loading. This is consistent with our scientific understanding of eutrophication and the effects of excess nutrients on coastal ecosystems; excessive nutrients cause increased production of micro-algae that subsequently die, sink to the bottom, and decompose. Microbial decomposition depletes the bottom water of dissolved oxygen. Low dissolved oxygen causes severe physiological stress on marine organisms, often resulting in death and avoidance in bottom-dwelling fish and other organisms. The continental shelf of the northern GOM along Louisiana and Texas is particularly susceptible to hypoxia owing to the large volume of freshwater discharged by the Mississippi-Atchafalaya River system.

Freshwater discharge causes stratification of the water column, which isolates the bottom water from the surface, preventing oxygen exchange with the atmosphere.

The Mississippi River Basin (MRB) is the largest river basin in North America, draining about 41 percent of the continental United States. Thirty-one States and two Canadian provinces are located within the basin. Over the last century, the MRB has experienced widespread changes in landscape, agriculture practices, demographic patterns, and river draining/channelization patterns that contribute to water quality problems within in the Basin and in the Gulf. Reducing nutrients and sediments is complicated due to the diversity of climates, geologies, and human activities in such a large basin. In addition, each State has its own set of water quality standards, which increases the difficulty of setting Basin-wide goals for decreased loadings. The Mississippi River/GOM Watershed Nutrient Task Force works towards a unified effort to improve GOM hypoxia. Comprising representatives from both State and federal agencies, the Task Force developed the 2008 Action Plan, which outlines steps to reach three goals: 1) By 2015, reduce the 5-year running average areal extent of the GOM hypoxic zone to less than 5,000 square kilometers; 2) Restore and protect the waters of the 31 States and Tribal lands within the Mississippi/Atchafalaya River Basin (MARB) through implementation of nutrient and sediment reduction actions; and 3) Improve the communities and economic conditions across the MARB. The Task Force's work is authorized by the Harmful Algal Bloom and Hypoxia Amendments Act of 2004, reauthorizing the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998.

Gulf of Mexico Hypoxia Research Needs

States, Tribes, and federal agencies are working together to take action to reduce the size of the hypoxic zone while protecting and restoring the human and natural resources of the Mississippi Basin. Improved monitoring and modeling approaches are needed to identify and quantify key processes regulating the development and size of hypoxic bottom waters. Such knowledge will help in reducing uncertainty in the nutrient load reduction estimates required to achieve the goals of the multi-agency Hypoxia Action Plan (USEPA, June 2008). Better understanding of physical processes and biogeochemical cycles in coastal waters will result in tools that assist federal, Regional, and State-based efforts to reduce watershed nutrient loadings, reduce the areal extent of hypoxic waters, and restore/protect aquatic habitats and species.

Research will be designed to address the following areas:

Identify effective management strategies to reduce nutrient and sediment ecosystem impacts in the Basin and in the GOM

State-wide nutrient reduction strategies must be developed, and the planners need an understanding of effective management strategies and agricultural BMPs that will protect and improve water quality in the Basin. Identifying the relationship between nutrient and sediment loading in Basins and formation of the GOM hypoxic zone will assist in directing the timing and distribution of fertilizer application and other agricultural practices.

Better Understand the Processes Regulating the Hypoxic Zone in Order to Improve Predictive Models of the Zone and the Impacts of Restoration Scenarios

Continued monitoring is needed in the northern GOM on a seasonal basis to track the extent and duration of hypoxia. Research is also needed to 1) better understand how biogeochemical processing of riverine nutrients leads to formation of hypoxic bottom waters; 2) quantify the magnitude and uncertainty in nutrient load reductions required to reduce the extent and duration of hypoxic waters; and 3) develop models to forecast the effects of nutrient management on the extent and severity of hypoxia in the northern GOM. The development of empirical and integrated numerical modeling capabilities will provide improved tools for evaluating nutrient management options and for federal, Regional, and State-based efforts to reduce watershed nutrient loads, improve Mississippi River Basin water quality, and reduce the areal extent of hypoxic waters.

Provide projections of the consequences of future development and other anthropogenic changes (such as climate change) and develop strategies to minimize negative impacts on important ecosystems

Urban nonpoint sources represent permanent changes in the landscape and are large nitrogen and phosphorous sources. Hypoxia and other eutrophication-related impacts on water quality are centered on major population concentrations or closely associated with developed watersheds that export large quantities of nutrients and organic matter. Agricultural practices, such as those associated with biofuels and energy independence, as well as climate-induced alternations in weather and precipitation patterns, will also likely alter the sources, transport, and fate of nutrients. Research is needed to better understand the impacts of these future conditions in the GOM to develop predictive models and to plan management strategies.

Determine how the assessment of ecological conditions, the modeling of ecological and human development futures, and the development of restoration and protection strategies can be done effectively at differing geographic and temporal scales within the Basin

Protecting and restoring water quality throughout the Mississippi River Basin is a multi-step process. While the big picture strategies are developed and implemented, local work at the small watershed scale will improve local water quality. The streams assessments and surveys provide a rich dataset to allow these models to be better refined, and the data must continue to be collected and analyzed throughout the Basin to continue understanding the local water quality impacts and issues.

Invasive Species

Invasive (and nonindigenous) species are one of the largest threats to our terrestrial, coastal, and freshwater ecosystems, representing the second leading cause of species extinction and loss of biodiversity in aquatic environments worldwide. These species can affect aquatic ecosystems not only by entering the water directly but also by affecting the land in ways that can harm aquatic ecosystems. Deleterious effects from invasive species include decreased native populations, modified water tables, changes in run-off dynamics, and an increase in fire frequency. These impacts cost the public and private sectors billions of dollars in prevention, management, control, and research costs.

The public and Congressional legislators are increasingly aware of threats posed by aquatic invasive species and have introduced legislation. The 1996 National Invasive Species Act addresses aquatic nuisance species that are unintentionally introduced into water bodies. This Act authorized funding for research on aquatic nuisance species prevention and control in areas such as the Chesapeake Bay, the GOM, the Pacific Coast, the Atlantic Coast, and the San Francisco Bay-Delta Estuary. This Act also requires a ballast water management program to demonstrate technologies and practices to prevent non-indigenous species from being introduced. Ballast water released from ships is a tremendous source of foreign organisms introduced into the nation's aquatic ecosystems.

Executive Order 13112 on invasive species was signed on Feb 3, 1999, mandating the creation of a Council of Departments dealing with invasive species. The National Invasive Species Council was formed and comprises 13 Departments and Agencies including EPA. This Council helps to coordinate and ensure complementary, cost-efficient, and effective Federal activities regarding invasive species.

Invasive Species Research Needs

To protect aquatic ecosystems (along with the recreational and commercial activities that depend on these environments), it is essential for those who use the ecosystems to understand how to prevent and control the spread of invasive species. Questions also arise on how do invasive and/or nonindigenous species affect the ability of some water bodies to attain designated uses. If NPDES permit controls are considered (Chapter 3), research must address compliance monitoring needs, as well. Research is needed to:

- Develop tools and scientific knowledge of potential pathways of introduction that will ensure the prevention of invasions of non-indigenous species;
- Develop an improved scientific basis for the establishment and maintenance of rapid response and monitoring programs;
- Develop tools and scientific knowledge to control invasive species that affect aquatic ecosystems;
- Create education and outreach opportunities to assist groups and individuals affected by invasive species; and
- Estimate the economic impacts of invasive species affecting the aquatic environment.

Each of these research areas is discussed in more detail below.

Develop tools and scientific knowledge of potential pathways of introduction that will ensure the prevention of invasions of non-indigenous species

Research is needed to understand the pathways by which invasive species become introduced to a new environment. Examples of such pathways include ballast water, aquaculture escapes, intentional introduction, and vehicular transportation. Globalization has greatly increased long-distance travel and commerce, altering waterways in extreme ways. These changes have increased the frequency with which non-native plants, animals, and pathogens are introduced into new areas, often with costly results. Once invasive species are introduced, they may be difficult to control. Therefore, preventing their introduction could be an essential part of lessening the negative effects that non-indigenous species can have on aquatic ecosystems.

Develop an improved scientific basis for the establishment and maintenance of rapid response and monitoring programs

Work is also needed to increase our ability to monitor for invasive species in all coastal regions and to identify new invasions over time. In particular, information is needed on diagnostic assays for rapid testing of ballast samples for high priority invasive species. If NPDES compliance approaches are considered, sampling and testing methods may need to address viability and quantification as well as specificity. Additionally, understanding the statutory, regulatory, and policy barriers to rapid response can help to determine why controlling invasive species may be difficult. The negative effects of invasive species can be better dealt with both before and after introduction if aquatic ecosystems are continuously monitored and if watershed managers have tools for responding quickly when invasions are discovered.

Develop tools and scientific knowledge to control invasive species that affect aquatic ecosystems

Greater understanding is needed of the biological, chemical, and mechanical methods for control of invasive species. Potential control methods include physical removal of aquatic plants and animals, the use of herbicides and algaecides, and the introduction of other species, such as fungi, to control invasive species. Because invasive species lack natural controls in their new habitat, they can grow rapidly. They can often cause disease in, prey upon, or compete with native species. Understanding the various options for controlling invasive species can benefit all that depend on affected aquatic ecosystems.

Create education and outreach opportunities to assist groups and individuals affected by invasive species

Invasive species are often introduced unintentionally through recreational activities (boat hulls, fishing boots, diving gear, etc.), the release of unwanted pets from aquaria, the disposal of solid waste or wastewater, the release of fishing bait, and a number of other pathways. Education and outreach work is needed to increase public awareness of the potential threats of invasive species.

Estimate the economic impacts of invasive species affecting the aquatic environment

Estimates are needed of the economic impacts of aquatic invasive species on industries, recreational activities, and public health. This can help groups and individuals who interact with aquatic ecosystems understand the importance of invasive species control. Identifying the ecological services provided by aquatic ecosystems and the loss of services due to invasive species can provide further incentives for developing prevention, monitoring, rapid response, and control programs. The establishment of conceptual frameworks and bioeconomic tools are needed as practical ways to assess the market and non-market economic impacts of aquatic invasive species.

Ecological Restoration

Ecological restoration is integral to the recovery of impaired aquatic ecosystems. The issue of restoration cuts across numerous areas of the Water Program (*e.g.,* TMDLs, watersheds, source water protection, wetlands, and estuaries) and is an important component of watershed management. Ecological restoration can be defined as the return of a waterbody to its pre-disturbance level of functioning. The ability of a given system to recover will depend on the severity of damage and on the degree to which environmental stressors are controllable. Selection of appropriate and effective restoration techniques for a given setting is also important. Although not all water bodies will be able to be fully restored, correct application of active onsite restoration techniques can bring about substantial improvement, and meeting research needs will improve the potential for successful restoration efforts.

EPA's Ecosystem Restoration Research Program has conducted basic and applied field research to evaluate the abilities of restoration and management activities to achieve environmental conditions that support and maintain water flows and water quality. Research has focused on the watershed response to stressors and the effectiveness of restoration techniques for reinstating important ecosystem functions (*e.g.*, flood damage, erosion control, water quality improvement). The program is implemented through in-house research linked to collaborative efforts with other government agencies, non-profit agencies, and the academic community. Such teamwork permits a holistic approach to restoration of rivers, streams, wetlands and associated ecosystem services through the evaluation and assessment of restoration and management practices and strategies.

Ecological Restoration Research Needs

This research will focus on the development of decision support tools to provide clients with the ability to make better management decisions for protecting our land and aquatic resources. In particular, ecological research is needed to provide data and tools to:

- Select candidate water bodies for restoration;
- Select an optimal suite of restoration methods; and
- Monitor results of restoration efforts.

Each of these research needs is discussed below.

Provide data and tools needed to select candidate water bodies for restoration to help target limited resources

The results of any restoration effort will hinge on the capacity of the ecosystem to regain healthy function. A science-based evaluation of the natural processes involved in recovery is needed. Some issues to be explored include the quantity, quality, and spatial distribution of waterbody types that are needed to support aquatic life in a watershed. Linked to this is the need to document the biological change that occurs as human-induced stressors increase for these water body types and within appropriate eco-regions. Enhanced understanding, combined with an assessment of the setting, ongoing stressors, and economic factors will help in evaluating the degree to which a given waterbody can be restored. The size of the restoration effort and temporal framework should also be considered. A multifaceted approach to assessing the recovery potential of a given waterbody will allow watershed managers to prioritize and target water bodies that will reap the greatest benefit from restoration measures.

Provide data and tools needed to select an optimal suite of restoration methods

Restoration is an emerging discipline, and our understanding of the effectiveness of interventions is still limited. Guidance is needed on how to select the optimal techniques for specific sites because active onsite restoration techniques are not universally applicable. To begin to make such choices, it is critical to know the degree of success of as many restoration-related practices as possible. Numerous BMP and restoration techniques are available, but there are insufficient data on their effectiveness in reducing pollutant loads, and current data show highly variable efficiencies. Research is needed to provide information on the ranges of effectiveness, uncertainties, time frames, costs, life expectancies, and geographic and water body type applicability.

Many restoration techniques involve physical alterations to a system. A study of the linkage between physical restoration techniques (*e.g.,* stream bank restoration, buffer strips) and resulting water quality improvements is needed. Data are also needed to link low impact development practices to water quality improvements and to reductions in runoff.

Ensuring proper nutrient and sediment management is especially important in managing a system for desired ecosystem services. Excess anthropogenic nitrogen, phosphorus, and sediments have been implicated for decades as the major cause of unbalance in aquatic ecosystems. An understanding of how these nutrients and sediments are processed, sequestered and apportioned at the micro- and process-level scale will help design and select efficient management and restoration techniques.

Provide data and tools needed to monitor results of restoration efforts

Once restoration has been initiated, recovery must be monitored and evaluated. Improved post-implementation and TMDL effectiveness monitoring tools are needed. Such evaluation protocols should quantify individual pollutant loads, biological measures, and pollutant sources. Monitoring approaches should also include evaluation of the appropriate spatial and temporal scales for evaluating effectiveness since little is currently known about how to predict the time frame for recovery. EPA also needs to determine how many waters that have undergone restoration were 303(d) listed, unlisted, or are only recently developing impairments. Developing this inventory and comparing it to project outcomes will provide additional information on how best to meet clean water objectives.

Coral Reef Protection

Coral reefs are among the world's richest ecosystems, second only to tropical rain forests in plant and animal diversity. They play a major role in the environment and economies of Florida, Hawaii, and most US Territories in the Caribbean and Pacific. They provide fishing, tourism, biodiversity, and aesthetics. However, coral reefs are extremely sensitive and have special temperature, salinity, light, oxygen, and nutrient requirements. If environmental conditions fall outside acceptable ranges, the health and dynamics of a coral reef community can be severely disrupted and the services they provide will be diminished. Corals respond to alterations within the entire coastal watershed, such as changes in freshwater flows and nutrient inputs, as well as pollution. Exposure to such stressors over long periods of time can result in growth retardation, bleaching (loss of photosynthetic dinoflagellates), lowered capacity to shed sediments and resist disease, invasion by non-reef building species, habitat loss, and reef death.

Coral communities in South Florida and other areas have changed dramatically over the past few decades. For example, up to 28 percent of the coral in the Florida Keys have died since 1996, altering communities and resulting in the loss of several key coral species; the corals do not appear to be recovering. In addition, relatively synchronous disease and bleaching events have occurred world-wide, even in the relative absence of human populations and influence, indicating involvement of large-scale processes.

There have been government efforts to address the plight of the coral reefs. The International Coral Reef Initiative (ICRI) was formed in 1994 by EPA, the State Department, the National Oceanic and Atmospheric Administration, and the Department of the Interior to coordinate information and bring higher visibility to the need for coral reef ecosystem preservation. ICRI has more than 90 member countries. On June 11, 1998, President Clinton signed Executive Order 13089 on Coral Reef Protection, which directs all federal agencies to protect coral reef ecosystems to the extent feasible. It also instructs particular agencies to develop coordinated, science-based plans to restore damaged reefs and mitigate current and future impacts on reefs, both in the United States and worldwide. This Executive Order also established the US Coral Reef Task Force of which EPA is an active participant. The Task Force is charged to work with the scientific community to develop and implement a research program to identify the major causes and consequences of degradation of coral reef ecosystems. The President's Ocean Action Plan, signed in 2004, provides that EPA will develop coral reef bioassessment procedures and biological criteria to use in evaluating the health of coral reefs and associated water quality. Also, the Marine Protection, Research, and Sanctuaries Act (MPRSA), provides some protection for coral reefs by authorizing the establishment of sanctuaries and allowing for the promulgation of regulations for the conservation of these special ecosystems.

Coral Reef Protection Research Needs

In order to protect coral reefs, research is needed to better understand how climatic and anthropogenic stressors impact coral reefs (*e.g.,* disease, bleaching) and how anthropogenic sources can be distinguished from climate change effects and natural variation. Research is needed to understand how quantitative thresholds can be established for reference conditions, biological criteria and sustainable reef ecosystems, and how monitoring programs should be implemented to provide consistent, low-cost, scientifically-defensible data on coral reef condition. More specific research needs are discussed below.

Characterize the effects of global change stressors on conditions of coral and coral reefs

Global change is characterized by increasing tropospheric temperatures, increasing penetration of solar radiation (particularly ultraviolet wavelengths, UVR), increasing acidification of the ocean from high atmospheric carbon dioxide, and altered land use patterns that increase the types and amounts of sediment, nutrient, contaminants, and microorganisms exported to coastal waters. As a result of these multiple, interactive stressors, corals and coral reefs are in a critical decline. Research is specifically needed on the potential effects of interacting stressors on the health of coral reefs. Results of such research can help to direct appropriate mitigative and adaptive actions toward protection of coral reefs.

Characterize changes in the condition of coral reefs in South Florida and define potential effects of anthropogenic and climatic stressors

Anthropogenic and climatic stressors appear to be substantial contributors to disease and bleaching. These stressors include physical (elevated temperatures, sedimentation, and UVR), chemical (pesticides, herbicides, nutrients, oil spills, industrial pollutants), and biological (disease, bleaching, and algal competition) factors. Research is needed to document the cause(s) of coral decline in South Florida, an area that has been particularly hard hit. Surveys of coral condition are needed to determine changes and to establish patterns and associations with potential stressors. In particular, understanding the effects of dumping on reef health will help to fulfill statutory responsibilities under the MPRSA. Development and validation of measures to characterize coral reef condition can ultimately lead to an integrated biological indicator for coral habitats. Ideally, research will be able to quantitatively relate human stressors to declines in reef health and loss of services, pointing the way to management alternatives that can improve delivery of services.

Characterize the interactive roles of UVR, temperature, and water quality on coral bleaching

Coral "bleaching" is defined as the loss of symbiotic zooxanthellae. Bleaching in Scleractinian (hard) corals has increased over the last several decades worldwide, threatening the condition of corals and entire reef ecosystems. Potential causes include natural and anthropogenic factors in the reef environment, such as high and low temperatures, elevated UVR, abrupt salinity changes, eutrophication, and disease. Cause(s) of coral bleaching and decline must be documented before effective control and protective measures can be defined and implemented. Research efforts are needed that examine corals in both field and laboratory experiments. It is important to determine, for example, if temperature and UVR are significant coral bleaching causal agents and, if so, establish validated exposure-response scenarios.

Characterize the responses of coral symbionts (Symbiodinium spp.) to elevated UVR, elevated temperature and changes in water quality

Corals are dependent upon symbiotic algae, usually *Symbiodinium* spp., for energy transferred in the form of carbon compounds. Anticipated effects of temperature, UV, and water quality on corals usually stem from effects on the physiology of these algal symbionts. Therefore, research on the impact of these stressors on *Symbiodinium* spp. is necessary to understand their effects on coral and for the development of control/management strategies to protect coral ecosystems and the services they provide. A useful secondary benefit of this research is the potential for using *Symbiodinium* as a screening agent for determining exposure-response relationships for various stressors and coral health.

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5 ● Science to Support Aquatic Life and Human Health Protection Programs

The Office of Science and Technology (OST) is the lead office for the Human Health Protection Program. See the Addendum to Chapter 1 for more information on OWM responsibilities. The Human Health Protection Program identifies and defines water research that assists the Water Programs to implement their statutory and other obligations. The research also helps the States, Tribes, and Territories to protect their drinking water supplies and minimize the effects of contaminants on fish, wildlife, and the aquatic environment. Federal, State, Tribal, and local governments use this information to set limits on pollutants that may occur in drinking water or that may be discharged into all types of waters – rivers, lakes, and streams. Every year under the authorities of the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), and other acts and executive orders, the Human Health Protection Program helps produce regulations, guidelines, methods, models, standards, science-based criteria, and studies that are critical components of national programs that protect human health and the aquatic environment.

Aquatic Life and Human Health Protection Program Goals

The Water Program conducts risk assessments and develops criteria for surface and drinking water to ensure they are safe for human use and consumption and aquatic life. It also uses risk assessments to determine appropriate uses and disposal of biosolids and to develop appropriate regulations that protect human health and the environment. (More information can be found in Chapter 1.)

In support of the CWA, the Water Program endeavors to improve water quality to protect and restore waters to their designated uses, thereby protecting the health of humans, aquatic life, and wildlife. Actions taken to improve water quality will also increase the number of water bodies that can be enjoyed for recreational purposes and from which fish and shellfish can be safely consumed.

Aquatic Life and Human Health Protection Program Drivers

There are several internal and external drivers that help direct the research that will be conducted to support Water Programs. Some of the major drivers are mentioned below and discussed in further detail in Chapter 1.

Important drivers include the CWA Section 303 (d), 304 (a), 305 (b), 404, 405, and Part 503. The CWA is the nation's most significant piece of legislation regarding surface water protection and the primary driver for water quality research. The BEACH Act amends the CWA and protects recreational waters by directing EPA to conduct studies associated with pathogens and human health research also driving the water quality research. The SDWA Amendments require EPA to evaluate human exposure and risks of adverse health effects in the general population and sensitive subpopulations when setting drinking water standards. (Refer to Chapter 2 for information on the regulatory development and review of drinking water standards). Other important legislation includes the Endangered Species Act and the National Environmental Policy Act. The Water Programs research needs are also shaped by Executive Order 12866 which is also discussed in Chapter 1.

As part of implementing EPA's Strategic Plan, the Office of Water establishes Program Activity Measures (PAMs) to achieve specific programmatic and water quality goals in its National Water Program Guidance. (Refer also to Chapter 2 for discussion of PAMs related to drinking water program goals.) These PAMs reveal information gaps that in turn identify needed research efforts. Some of the PAMs relevant to Aquatic Life and Human Health Protection research are:

- Issue new or revised criteria documents that assist States and Tribes to better control water pollution.
- Develop TMDLs for impaired waters.
- Increase attainment of water quality standards.
- Reduce the loadings of nitrogen, phosphorus, and sediment to water bodies.
- Improve ratings on National Coastal Condition Report for Benthic Quality.
- Protect and restore additional acres of habitat within National Estuary Program (NEP).

Environmental Indicator Initiative: In 2001, EPA created the Environmental Indicator Initiative to address the need for technical approaches to help States and Tribes manage their programs to achieve specific results by measuring environmental outcomes. As an outcome of this initiative, EPA published the *EPA's 2007 Report on the Environment: Science Report* (ROE SR) (USEPA, August 2007.) which identifies indicators and trends in environmental health, including water.

EPA – Association of National Estuary Programs Workshop: In the fall of 2005, EPA held a joint workshop with the Association of National Estuary Programs. The findings from the workshop noted: 1) States need tools for ecosystem-based management to protect and restore their estuaries; 2) the National Estuary Programs needs tools to communicate condition and inform management; and 3) the tiered aquatic life use (TALU) framework was identified as a promising approach and is currently being piloted.

Strategy for Water Quality Standards and Criteria (USEPA, August 2003): In 2003, EPA developed a strategy to assist State and Tribes in developing tools for water quality standards and criteria. The research needs that were outlined in this document included developing tools for: 1) determining highest attainable water body uses; 2) tiering uses; 3) use attainability analyses; 4) describing reference conditions; 5) developing biological criteria for different water body types (*e.g.,* rivers, coral reefs, Great Lakes estuaries, wetlands); and 6) integrating tiered aquatic life uses and the different types of water quality criteria including nutrients and suspended/embedded sediments.

Government Accountability Office Review of EPA's Water Quality Standards Program: In 2003, the Government Accountability Office (GAO) reviewed EPA's Water Quality Standards (WQS) Program (GAO, January 2003). One of the GAO's suggestions was that the EPA Administrator take actions to improve States' abilities to adopt, implement, and modify water quality criteria. To help ensure that States' criteria are a valid basis for impairment decisions, GAO recommended that the Administrator direct OST to develop guidance and a training strategy to help EPA Regional staff determine the scientific defensibility of State-proposed criteria modifications.

National Academy of Sciences - National Research Council **Report on TMDL Program**: In 2001, the National Academy of Sciences – National Research Council (NRC) published a report on EPA's TMDL program that identified a number of research needs including: 1) better, more specific and refined, designated uses to protect watersheds; 2) designated uses for aquatic life that are as specific as possible; 3) tiered aquatic life uses; and 4) biological criteria that can be used in conjunction with physical and chemical criteria to determine if a water body is meeting its designated use.

Millennium Ecosystem Assessment ecosystem service categories. The Millennium Ecosystem Assessment, produced for the United Nations in 2005 by more than 1,300 scientists from around the world, is one of the most comprehensive reports to date on ecosystem services. Many of the document's suggestions and concepts have been incorporated into EPA's Ecological Research Program's new research strategy, including its depiction of the complex relationship that exists between ecosystem services and human well-being.

National Academies report: Biosolids Applied to Land: Advancing Standards and Practices (National Research Council, July 2002**).** The recommendations and findings in this report helped identify research needs of the Biosolids Program. These recommendations included: 1) Use improved risk-assessment methods to better establish standards for chemicals and pathogens; 2) Conduct a new national survey of chemicals and pathogens in sewage sludge; and 3) Establish a framework for an approach to implement human health investigations.

Aquatic Life and Human Health Protection Research Needs

The SDWA requires EPA to set national drinking water standards to ensure the safety of water consumed by the millions of people in the US who receive their water from public water systems. Under the 1996 Amendments to SDWA, EPA is directed to use a risk-based standard-setting process and sound science in fulfilling the requirements of the Act. The Amendments contain specific requirements for research on waterborne pathogens (*e.g., Cryptosporidium* and Norwalk virus), disinfection byproducts (DBPs), arsenic, and other harmful substances in drinking water. EPA is also directed to conduct studies to identify and characterize groups that may be at greater risk than the general population following exposure to contaminants in drinking water (*i.e.,* sensitive subpopulations). Health effects and risk assessment research is needed that will allow risk assessors and risk managers to reduce their reliance on default assumptions in human health risk assessment.

Section 304(a)(1) of the CWA requires EPA to develop criteria for water quality that accurately reflect the latest scientific knowledge. These criteria are developed for the protection of aquatic life and human health and are based on data and scientific judgments regarding pollutant concentrations and environmental or human health effects. Water quality criteria are used by States, Territories, and Tribes to develop their WQS. These WQS serve the dual purposes of establishing the water quality goals for a specific water body and serving as the regulatory basis for the establishment of water quality-based treatment controls and strategies.

Water quality criteria are crucial for monitoring the condition of water bodies and for planning, implementing, and tracking restoration measures. Ongoing research is needed to develop and revise water quality criteria. As the collective understanding of aquatic systems advances, new knowledge must be incorporated into water quality criteria and standards. Ongoing research is needed to develop and utilize new approaches to managing aquatic systems, such as the TALU framework currently being piloted by States and Tribes. These new paradigms are needed to address simplifications and limitations in older approaches. As research progresses, assessments will become more refined and will take into account the combined effects of multiple stressors in an ecosystem (chemical, physical, biological).

Research efforts must support the goal of addressing emerging water quality concerns. Emerging contaminants, both biological (*i.e.,* pathogens, invasive species) and chemical (pharmaceuticals, pesticides), are a topic of growing national interest. Sound science is needed to support decisions on which constituents may require regulation. Continued research is needed to develop techniques that are accurate, precise, and suitable for environmental matrices (*e.g.,* water, soil), especially with respect to emerging contaminants. Research evaluating pathogens and pathogen indicators cuts across several priority areas for the Water Program. Pathogens are of concern as emerging pollutants, as multiple stressors, and in the land application of biosolids. Ongoing research is needed to protect human health when using recreational waters, consuming fish, or drinking water. All assessment activities need reliable and up-to-date analytical methods.

As part of its obligations and mandates, EPA must understand the cumulative impacts of multiple stressors on human health and healthy aquatic ecosystems and must determine how to best convert that knowledge into criteria and effective management tools. In addition, EPA needs to provide information and tools (such as those for ecosystem valuation) that decision makers can use in making proactive policy and management decisions that ensure ecological and human well-being.

Aquatic Life and Human Health Protection research needs are organized under a number of areas as follows:

- Human Health Effects and Risk Assessments.
- Bioassessment/Biocriteria.
- Aquatic Life Guidelines.
- Aquatic Habitat.
- Biosolids.
- Nutrients.
- Emerging Contaminants.
- Suspended and Bedded Sediments (SABS).

- Multiple Stressors.
- Socio-economic Valuation.
- Recreational Waters.

Background and research needs are presented below for each of these areas. In addition, a detailed listing of specific research projects for each research area will be found in the Water Research Management and Status Tool when it is available.

Human Health Effects and Risk Assessments

The SDWA requires EPA to evaluate human exposure and risks of adverse health effects in the general population and sensitive subpopulations, such as infants and young children, the elderly, and those with weakened immune systems, when setting drinking water standards. Risk assessments are the process by which the Agency determines whether exposure to an environmental stressor may have adverse consequences for humans. Risk assessment is essential in determining whether regulatory action is warranted, what actions should be implemented, and whether such actions are effective. Risk assessment integrates scientific data on exposure and associated adverse human health outcomes and provides scientific guidance to Water Program decision makers, who must set water quality standards.

The risk assessment process is divided into four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization. There are many uncertainties associated with the risk assessment process, including unknown levels of environmental concentrations of contaminants; human exposures to these contaminants; and relationships among human exposure, affected tissue, dose, and response. This uncertainty is further compounded by the need to extrapolate observed health effects from one set of circumstances (*e.g.,* cancer incidence in rats subjected to high, chronic exposures in controlled laboratory experiments) to an entirely different set of circumstances (*e.g.,* individual excess cancer risks in humans experiencing intermittent, low-level exposures).

Human Health Effects and Risk Assessment Research Needs

EPA's risk assessment research will reduce uncertainties in the extrapolations necessary for the risk assessment process by providing a greater understanding of the fundamental determinants of exposure and dose and the basic biological changes that follow exposure to environmental toxicants. In particular, research is needed in the following areas:

- Use of mechanistic data in risk assessment;
- Cumulative risk;
- Nationally representative data on chemical and microbial exposure;

- Sensitive subpopulations; and
- Contaminant-specific health studies.

Each of these needs is discussed in more detail. Additional research needs in this chapter that pertain to human health are also included under the following three sections: Biosolids, Emerging Contaminants, and Recreational Waters.

Use of Mechanistic Data in Risk Assessment

The pathway between exposure to an environmental agent and the resulting health effect cannot be fully characterized for every possible exposure scenario. In addition, much data on response to environmental agents must be gathered from laboratory animals under entirely different sets of exposure conditions than humans may experience. Extrapolation from laboratory animal data to estimate human risks from high to low doses involves a variety of assumptions and the application of default assumptions and uncertainty factors in the risk assessment process.

A more thorough understanding of key events associated with exposure and the ultimate manifestation of an adverse health effect (*i.e.,* the toxicity pathway or mode or mechanism of action (MOA)) would help reduce the uncertainty associated with data extrapolation. Knowledge of the MOA allows for the overall process of extrapolation to be broken up into its biological elements.

Research on the use of mechanistic data in risk assessment will focus on addressing the following questions:

- What methods and models are needed to identify modes or mechanisms of action that can be used for risk assessment?
- How can knowledge of toxicity pathways inform the development of pharmacokinetic and pharmacodynamic models for risk assessment?
- How can knowledge of toxicity pathways (or mode of action) be used to reduce uncertainty in extrapolation in risk assessment, including: extrapolation from high to low dose; extrapolation from laboratory animals to humans; extrapolation from in vitro data to in vivo exposures; and harmonization of cancer and non-cancer risk assessments?
- What methods are most appropriate for determining uncertainty factors based on intraspecies and interspecies experimental data and on duration of exposure.

Cumulative Risk

Cumulative risk assessment is broadly defined as "the combined risks from aggregate exposures to multiple agents or stressors." Agency risk assessors need both exposure assessment information and risk assessment methods to evaluate human health risks from exposure to mixtures of chemicals. In response to the 1996 SDWA Amendments, EPA needs to conduct research to understand new approaches for assessing the adverse effects of contaminant mixtures in drinking water. For example, the Water Program is concerned with contaminant mixtures such as DBPs and other contaminants that co-occur in drinking water. Frequently, it is not possible to directly measure all of the forms of chemicals in the environment that may contribute to cumulative risk. In such cases, it is important to identify potential surrogates (*i.e.,* biomarkers) that could be used to estimate exposure and dose. Depending on the level of biological information that is known, such biomarkers could also be characterized as biomarkers of effect or even susceptibility. Information concerning MOA or the basis for biological susceptibility will be crucial. Sensitive biomarkers can provide the basis for assessing the cumulative exposure from specific classes of environmental pollutants or from complex mixtures to estimate risk and to determine the efficacy of various remediation efforts.

Key questions to be addressed include:

- How can biomarkers be used in cumulative risk assessment?
  - What tools are needed to identify biomarkers for cumulative risk assessment?
  - How can those biomarkers be applied for cumulative risk assessment?
- What source-to-dose models are needed for cumulative risk?
  - What methods and models are available for assessing cumulative risk?
- How can tools be used to conduct cumulative risk assessments on stable chemical mixtures and those that undergo chemical changes during their contact with the environment?
- How can cumulative risk at the community level be evaluated?
  - What tools are necessary for community-based risk assessments?
  - How can those tools be applied for community-based risk assessments?

Nationally representative data on chemical exposure

There is a void in nationally representative biological data on chemical exposure. Monitoring for some pesticides and nutrients is conducted, but many other agents of concern are lacking data. Further refinement of the exposure assessment process requires more environmental monitoring data and biomonitoring data. Access to additional information will make more probabilistic and detailed assessments possible.

Key research items include:

- Research to aide in monitoring human exposure to chemicals of concern, such as those proposed on the Contaminant Candidate List.
- Approaches to quantifying chronic human exposure to chemicals with limited water data.

- Further research and monitoring on exposure based on nationally representative dietary information on water consumption (including, but not limited to, tap water, water in food recipes, and bottled water).

Susceptible Subpopulations

Human variability in exposure and response to environmental agents is a key uncertainty in health risk assessment (NRC, 1993, 1994). The SDWA Amendments of 1996 mandate that the Agency consider risks to groups within the general population that are identified as being at greater risk of adverse health effects, including children and the elderly. Key research questions related to susceptible subpopulations are:

- Is there differential life-stage responsiveness or exposure to environmental agents?
  - What are the long-term effects of developmental exposure to chemicals including their role in increased infection and/or disease susceptibility to microbial pathogens?
  - How does aging affect responsiveness to environmental chemicals and microbial pathogens?
  - How can we model exposure and effects to protect susceptible subpopulations?
- Which methods and models are appropriate for understanding and projecting health effects that accrue with age and development in infants and children?
- How should genetic differences among populations that influence their susceptibility to a hazardous substance be considered in risk assessments?

In addition, Region 10 points to the need for research focusing on children's health in Alaska. This research will help the Region meet its tribal trust responsibilities, address research gaps, and add further information to results of the National Children's Study. The Region would like to work with researchers to jointly develop communications, outreach, and other activities that convey research results to those in Alaska who need this information.

Contaminant-Specific Health Studies

As detailed in Chapter 2, Science to Support Ground Water and Drinking Water Protection Programs, EPA is required under the SDWA 1996 Amendments to establish a chemical candidate list (CCL) every five years. This list includes unregulated contaminants that are known or anticipated to occur in public water systems, which may adversely affect human health and may require future regulation under SDWA. EPA also must evaluate whether sufficient information exists to make a determination whether or not a contaminant warrants regulation for any of the CCL contaminants or if more research is needed. EPA may also develop drinking water guidance and health advisories for contaminants on the CCL when appropriate.

EPA published the draft third CCL (*i.e.,* CCL 3) in February 2008. As noted in Chapter 2, the CCL and Regulatory Determination is an ongoing process that will determine research needs over time. These needs will be defined and cataloged in the Water RMST. As an example, Exhibit 5.1 includes select draft CCL 3 contaminants with potentially sufficient occurrence data to make a determination, but that may need refined health effects data. These contaminants may be appropriate for a risk assessment in the Regulatory Determination (RegDet) process, but require additional health effects research data. For example, research studies are needed to determine the impact of 1,2,3-trichloropropane on developmental and reproductive processes.

Exhibit 5.1: Draft CCL 3 contaminants that may require additional health effects research to make a regulatory determination

Common Name - Registry Name	
1,1-Dichloroethane	Methyl tert-butyl ether
1,2,3-Trichloropropane	Metolachlor
Acetochlor	Metolachlor ethanesulfonic acid
Acetochlor ethanesulfonic acid	Metolachlor oxanilic acid)
Acetochlor oxanilic acid	Molybdenum
Chloromethane (Methyl chloride)	N-nitrosodimethylamine
Diuron	Vanadium
Methyl bromide (Bromomethane)	

Also, as discussed in Chapter 2, the CCL, RegDet, and unregulated contaminant monitoring regulation, are inter-related and with the Six-Year Review form a continuum of programs that define research needs as part of their process. The Six-Year Review evaluates available information for contaminants already regulated by a National Primary Drinking Water Regulation. As part of this process, new health effects data are reviewed to assess if changes may be warranted in the regulations or whether new health effects research and risk assessments may be warranted to improve the protection of public health. EPA Regions also point to the need for research to determine if there is an association between methylmercury exposure and coronary heart disease.

Studies of both regulated and emerging microbial pathogens are needed to determine the impacts of climate change on human pathogens. In particular, these studies examine how climate change will affect the types and levels of human pathogens that can enter, be sustained, and thrive in waters of the US (refer to Chapter 7 for more research on Climate Change). Another needed area of research is the development of animal models to replace human feeding trials to establish dose response relationships for enteric human pathogens.

Bioassessment – Biocriteria Research

The CWA requires States and Tribes to adopt in their water quality standards, where attainable, designated uses that include the protection and propagation of fish, shellfish, and wildlife. In 2001, the NRC published its report on *Assessing the TMDL Approach to Water Quality Management* (NRC 2001). In the report, the NRC recommended tiering designated uses as an essential step in setting water quality standards and improving decision-making. The NRC, finding that the CWA's goals (*i.e.,* "fishable," "swimmable") are too broad to serve as operational statements of designated use, recommended greater specificity in defining such uses. For example, rather than stating that a water body needs to be "fishable," the designated use would ideally describe the expected fish assemblage or population (*e.g.,* cold water fishery, warm water fishery, or salmon, trout, bass, etc.) as well as the other biological assemblages necessary to support that fish population. In particular, NRC recommended the use of biological information to help determine more appropriate aquatic life uses and to couple the narrative use statements with quantitative methods.

Biologically-based tiered aquatic life uses paired with numeric biological criteria provide a direct measure of the aquatic resource that is being protected. The condition of the biota reflects the cumulative response of the aquatic community to individual or multiple sources of stress. Biological criteria (biocriteria) are regulatory standards that can be used to measure attainment of water quality goals. They are qualitative or numeric indices that describe the biological/ecological conditions associated with a desired level of water quality. By comparing bioassessments with biocriteria, impaired waters can be identified, and regulatory efforts can be appropriately directed. Improvements due to pollution controls may also be documented. A primary strength of biocriteria is the detection of water quality problems that other standards may miss or underestimate. Using these measures, impairment can be detected and evaluated without knowing the exact cause(s) of the impairment (*i.e.,* impairment from one chemical or an integration of many effects), and without trying to sample and measure all possible contaminants and stressors. In addition, biological measures often provide evidence about the source of the impairment.

Biological assessments (bioassessments) study such factors as the presence, condition and numbers of types of fish, insects, algae, plants, and other organisms as a way of evaluating the health of a body of water. They can identify impairments from contamination of the water column and sediments from unknown or unregulated chemicals, non-chemical impacts, and altered physical habitat. This information can be used to set water quality goals.

Bioassessment – Biocriteria Research Needs

The Water Program's Bioassessment/Biocriteria research initiatives will help Regions, States, Tribes, and Territories refine aquatic life uses and biocriteria in their WQSs. They include:

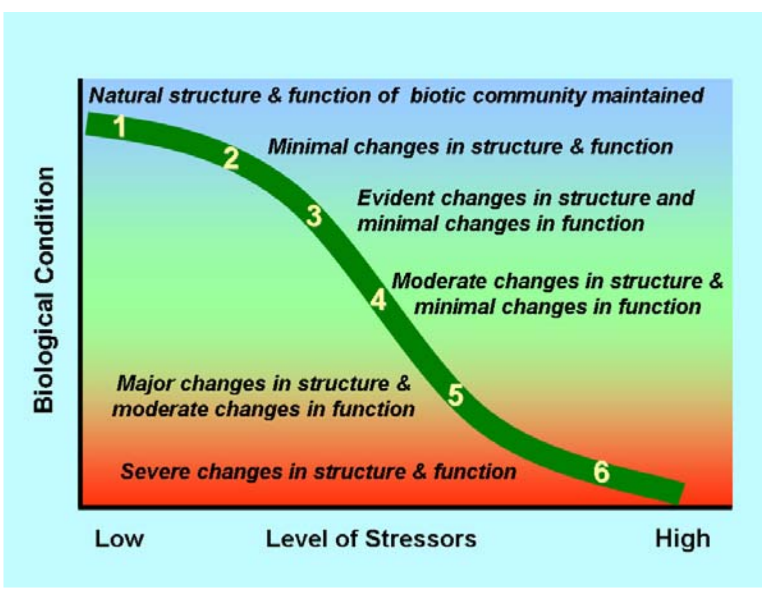
- Biological condition gradient and generalized stressor gradient model development;
- TALU development; and
- Biocriteria measurement in varying environments.

These research needs overlap with those for Aquatic Life Guidelines Revisions (discussed in this chapter); Watershed Protection and Restoration Programs (refer to Chapter 4); and with the Water Program's Climate Change research (refer to Chapter 7).

Develop technically sound methods for establishing Biological Condition Gradient and Generalized Stressor Gradient models

The biological condition gradient (BCG) in particular is a highly useful concept. It describes biological response to increasing levels of stressors (*i.e.,* physical, chemical or biological factors that induce an adverse response from aquatic biota). BCG does not represent the laboratory response of a single species to a specified dose of a known chemical, but rather the *in situ* response of the biota to the sum of stresses to which it is exposed. The BCG is divided into six tiers of biological condition along the stressor-response curve (see Exhibit 5.2), ranging from observable biological conditions found at no or low levels of stress to those found at high levels of stressors. The model provides a common framework for interpreting biological information regardless of methodology or geography. When calibrated to a Regional or State scale, States and Tribes can use this model to more precisely evaluate the current and potential biological condition of their waters and use that information to make decisions on aquatic life designations, as well as more clearly and consistently communicate these decisions to the public.

Exhibit 5.2: The Biological Condition Gradient illustrates the relationship between implied anthropogenic stressors and biological condition.



Develop technically sound methods for establishing tolerance values and evaluating minimum monitoring data needs for TALU development

TALU is a scientific model for predicting biological response to anthropogenic stress (*i.e.,* those caused by human activity) that is based on the concept of the BGC. It offers an effective way to incorporate science into the management of water bodies. It determines how human factors impact water resource features such as habitat structure, flow regime, water quality and toxicity, energy source, and biotic interaction that ultimately results in a biological response. For example, human activity could allow invasive species to thrive, resulting in a loss of native species. Research to support TALU development must include identifying sampling and analytical methods or models that are useful for predicting the recovery potential of different water body types.

Develop methods for measuring biocriteria in varying environments

Methods need to be developed for measuring biocriteria in arid systems, large and great rivers, wetlands, estuarine areas, and marine systems (including coral reefs). Research is also needed to clarify the optimal ways to classify ecosystems, landscapes, and watersheds to enable efficient and scientifically sound development and application of biocriteria.

Aquatic Life Guidelines Research

Under Section 304(a) of the CWA, EPA must develop and publish ambient water quality criteria (WQC). Such criteria are levels of individual pollutants, water quality characteristics, or descriptions of water body conditions that, if met, should protect the environment and human health. Ambient water quality criteria are recommended guidance that States and Tribes may use as part of their water quality standards. The existing Aquatic Life Guidelines (Guidelines) were published in 1985 (USEPA, 1985), and the majority of EPA's current aquatic life criteria are based on the relationships between pollutant concentrations and effects on aquatic life. Procedures for deriving aquatic life WQC are useful for managing toxic chemical inputs to water. However, these procedures are based on assumptions and a narrow, outdated framework that may limit their use in fully assessing impacts from certain types of toxic chemicals.

Since 1985, considerable advancements have been made in aquatic sciences, aquatic and wildlife toxicology, population modeling, and ecological risk assessment (ERA) that are relevant to deriving aquatic life criteria. Also, EPA is facing the possibility of having to regulate new classes or types of pollutants (*e.g.,* endocrine disruptors, pharmaceuticals, nanoparticles, etc.) that the Guidelines currently address only on a case-by-case basis. The Guidelines must be revised to more explicitly and consistently incorporate new and emerging science.

Aquatic Life Guidelines Research Needs

Revised ERA tools are needed to revise the Aquatic Life Guidelines. The work will enable EPA to update the WQC methodologies to better reflect current scientific knowledge about aquatic life and aquatic-dependent wildlife. Research in the following areas will also allow the Water Program to address limitations in the current criteria methodology:

- Revised methods for water-based and tissue-based criteria,
- Community and population-level assessment models,
- Laboratory and computational toxicology research,
- Chemical toxicology studies, and
- Refined mercury bioaccumulation factors.

Develop revised methods for water-based and tissue-based criteria

The current approach for formulating water-based criteria does not adequately quantify the expected effects of exposures at, below, and above the criteria. Revised tissue-based criteria are needed to assess the risks posed by compounds that bioaccumulate through diet. Development of revised criteria methods will aim to address these weaknesses.

Region 2 also points to the need for these efforts to re-visit some of the older traditional criteria for conventional pollutants, such a freshwater dissolved oxygen, temperature and pH, to determine if there is a need to revise these criteria to better reflect the latest scientific information.

Develop community and population-level assessment models

Current methods for criteria development have a number of limitations that need to be addressed. Community and population-level assessment models should be developed to replace the current organism-based criteria. Multiple pathways of exposure should be accounted for, providing a more comprehensive prospective risk characterization for aquatic and aquatic-dependent life. Persistent bioaccumulative toxicants should also be incorporated. Other issues to be considered include extrapolation of toxicological data from the laboratory to the field, combined effects of multiple chemicals, spatial sampling issues, seasonal effects, how to assess risk with limited exposure and effects data, and uncertainty analysis. Addressing these issues will result in more scientifically rigorous guidelines that more effectively protect ecosystems.

Criteria development is a prospective ERA approach in which an acceptable level of risk to aquatic communities is defined. Media concentrations are then back-calculated, depending on the chemical and its exposure routes. In traditional criteria development, effects are predicted for water exposure. Alternative methods address chemical/exposure route/receptor combinations where tissue burdens or dietary exposure are used to estimate risks. A more comprehensive approach is needed that includes all of these approaches.

Conduct laboratory and computational toxicology research

These efforts should be focused toward developing a number of models. Ecosystem models are needed to integrate risk across an assemblage of species. Dose-based toxicity models will be able to account for multiple routes of exposure, including diet. Other models should address issues such as bioaccumulation, tissue concentrations, and fate and transport. Computational toxicology integrates modern computing and information technologies with molecular biology and chemistry to help set priorities for data requirements and chemical risk assessments.

Such models could help to address the need for improved understanding in areas affected by mining. Regions 3 and 4 have specified the need for research into the mechanisms of impairment from alkaline mine drainage associated with coal mining. Specific parameters that cause the impairment or the mechanism of impairment remain unknown. Parameters of interest include total dissolved solids and conductivity, with related questions including: Does elevated conductivity have an acute or chronic toxic effect on the resident aquatic life, and what is the mechanism; and, does the elevated conductivity interfere with osmo-regulation in aquatic insects, or is there some other physiological endpoint.

Conduct chemical toxicity studies

The derivation of chemical criteria for the protection of aquatic life, whether they be for existing, known, or emerging contaminants, is dependent on the availability of toxicity test data. Data for most chemicals for which criteria should be derived are sparse to non-existent. A significant research need is the derivation of toxicity data, particularly 2-generation tests with multiple relevant endpoints. Research is also needed to design a derivation methodology for use when the available data set does not meet the minimum requirements of the Guidelines.

Develop refined mercury bioaccumulation factors

Research is needed to develop bioaccumulation factors (BAFs) that are more refined than those included in EPA's January 2001 Methylmercury Water Quality Criterion (USEPA, January 2001). BAFs for methylmercury in fish tissue relative to methylmercury in the water column across different water body types or ecological conditions would be a useful and cost-effective way for States to develop water column translations of the January 2001 fish tissue-based criterion. Developing such BAFs is not yet a routine implementation function. Many important research issues would need to be addressed, including accounting for different rates of methylation in different aquatic ecosystems.

Aquatic Habitat Research

The biological integrity of our nation's coastal and estuarine environments has been and continues to be substantially impacted by a suite of biological, chemical, and physical stressors. Specific stressors include habitat alteration, nutrients, SABS, pathogens, and toxic chemicals. Overharvesting of fish and shellfish populations and habitat alterations, in particular, have drastically altered the biological communities in these systems (Jackson et al., 2001). Some of these impacts occurred generations ago, while others have occurred more recently (Lotze et al., 2006, Jackson et al., 2001, Kirby 2004). Identifying the historical biological integrity of these systems is important because it represents the baseline against which to measure the success of any management efforts.

Aquatic habitat research is interwoven with several other research areas. Research and implementation of ecological restoration measures will certainly benefit from advances in our understanding of habitats (refer to Chapter 4 for a more detailed discussion of EPA's Ecological Restoration Research Program). As efforts to develop aquatic life guidelines proceed (see previous section), understanding what constitutes a healthy aquatic habitat and what effects pollutants have on them will be crucial. Aquatic habitat research is also linked to bioassessment/biocriteria research through use of the BCG/TALU approach.

In the BCG/ TALU approach, EPA has created a universal framework to characterize a variety of aquatic systems and associated landscapes. As previously discussed, the BCG/TALU model assumes that different types of biological attributes respond to increasing ecosystem degradation in a predictable manner, and that these responses offer a scientifically robust, quantifiable method for assessing condition, evaluating restoration potential, setting attainable restoration goals, and tracking and communicating progress. Originally developed for and applied to hard-bottom streams, its application in estuaries has proven to be difficult because these systems are highly vulnerable, dynamic, and exposed to a broad range of stressors. Most uniquely, they are comprised of a mosaic of multiple sub-systems.

Aquatic Habitat Research Needs

EPA needs to improve decision-making by enhancing its ability to identify, quantify, and value the ecological benefits of its policies. With aquatic habitats, it generally has not been possible to evaluate the trade-offs between: a) habitat alterations at local scales for the purposes of development, infrastructure, shoreline protection, flood control, etc.; and b) long-term, large-scale, cumulative ecological effects that such alterations may have. A successful application of the BCG in complex estuarine systems would demonstrate its value as a universal management tool by proving its ability to incorporate specialized local characteristics within a conceptually rigorous common framework.

To accomplish this, three primary research needs have been identified:

- Develop reliable tools to measure and predict the contributions of aquatic habitat protection and restoration to the maintenance and improvement of biological integrity.
- Develop integrative methods and approaches incorporating habitat into development of BCGs for application to TALU frameworks.

- Develop reliable tools for measuring and predicting the economic and societal benefits of aquatic habitat protection and restoration at local, Regional, and national scales.

In addition, some EPA Regions have identified geographically specific aquatic habitat research needs.

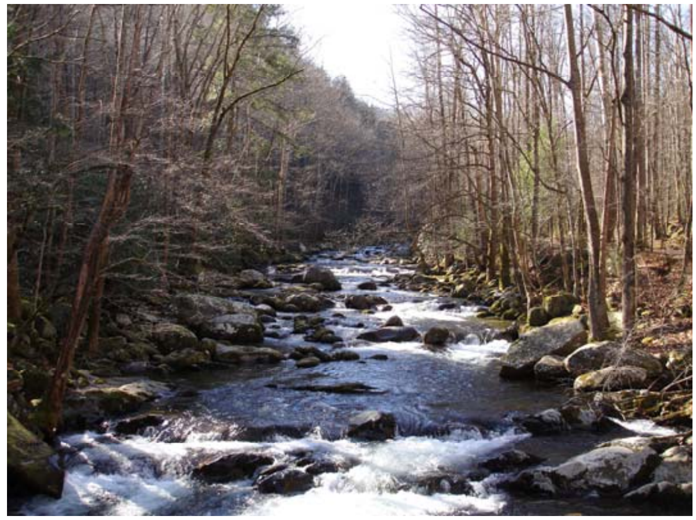
Achieving these research needs will require integration of efforts within the Water Program and across EPA. For example, the Water Program is actively interested in the application of BCGs to coasts and estuaries at appropriate scales under the TALU framework. Application of integrated tools to NEP management plans is area of interest for the Water Program in collaboration with other EPA program offices. Input from aquatic life guidelines research will complement aquatic habitat work; as contaminant criteria (*e.g.,* toxics, nutrients) are refined, they can be incorporated into efforts for habitat protection and restoration (refer to Chapter 4 for more information on ecological restoration).

Develop reliable tools to measure and predict the contributions of aquatic habitat protection and restoration to the maintenance and improvement of biological integrity

Initial research efforts will focus on developing historical baselines for the biological integrity of ecosystems and habitat distribution. In stream environments (Davies and Jackson, 2006) indices of biological integrity have been the primary tool for determining the current state of biological integrity. Various indices of condition (*e.g.,* health of organisms, biodiversity) have been developed for estuarine systems, though few if any have been evaluated for their utility to describe the BCG. Once appropriate indices are developed, it will be important to integrate them into routine water quality monitoring activities. This will require development of indices of biological integrity for application to BCGs in estuarine and coastal systems, with an emphasis on spatial scale and distribution of habitat types.

Restoration of biological integrity will draw upon the practice of ecological restoration and the science of restoration ecology, both relatively new disciplines and potentially highly integrative. Setting restoration goals for a system could serve to integrate water quality and watershed management by focusing both on the same set of goals. Ecological restoration could also provide a focus for integrating multiple scientific disciplines. To date, the success of ecological restoration activities has been mixed (Zedler 2005). The mixed success indicates the need to conduct research to improve our understanding of how systems respond to restoration actions. Ecological restoration actions require a substantial commitment; determining restoration goals in conjunction with partners and stakeholders, and designing adaptive restoration strategy(ies) for one or more systems will be a critical final aspect of this research.

Develop integrative methods and approaches incorporating habitat into development of BCGs for application to TALU frameworks



Research is needed to develop a framework to construct coastal and estuarine BCGs that incorporate the critical importance of habitat in order to allow application at several scales. For example, BCGs might be developed and applied at the scale of a single identified habitat (*e.g.,* soft sediments, salt marshes) or at the scale of an entire estuary (*e.g.,* considering the entire mosaic of habitats that constitute an estuary). These BCGs will provide a basis for bioassessment under the TALU approach, and will link to ecological service analyses (to be developed under the next research need below). This approach is designed to maximize applicability of these BCGs to TALU approaches in environmental assessment, monitoring, protection, restoration, and communication.

Develop reliable tools for measuring and predicting the economic and societal benefits of aquatic habitat protection and restoration at local, Regional, and national scales

Research is needed that will build upon pre-existing models relating habitat extent and health to the sustainability of communities of aquatic organisms. Economic analysis should be applied to resource uses (*e.g.,* fisheries and recreation) to predict the long term values that can be achieved through habitat protection and restoration. Non-use benefits (*e.g.,* biodiversity, aesthetics) must also be quantified. Collaboration among ecologists, economists, and social scientists will permit such interdisciplinary valuations to be achieved.

There is a strong connection between aquatic habitat work and the TALU approach. Research initiatives need to provide the Water Program, Regions, States, Tribes, and Territories with habitat-based tools for bioassessment of coasts and estuaries for application to the TALU framework. The research should also provide information for estimation and prediction of the economic and societal values of protecting and restoring habitats for the benefit of aquatic life. Integrated habitat-based BCG tools can help bring the benefits of TALU to coasts and estuaries. Such tools can also improve protection of essential habitats from the cumulative effects of alteration over a range of geographic scales. Improved criteria and standards will also preserve the benefits of fisheries and aquatic life by protecting their habitats.

Biosolids Research

Sewage sludge is the solid, semi-solid, or liquid product that comes from municipal wastewater treatment. Biosolids are created by the treatment and processing of sewage sludge. Rich in nutrients and organic matter, biosolids are applied to land as fertilizer or for soil amendments. Municipal waste potentially contains a variety of contaminants, both biotic and abiotic, that may remain with the solids during wastewater treatment.

Detecting chemicals and biological pollutants in and released from sewage sludge raises concerns about potential risks to human health and the environment from land application. These concerns highlight the need for continued research. The priority goal for the Biosolids Program is to ensure that Part 503, the *Standards for the Use or Disposal of Sewage Sludge*, is protective of human health and the environment.

The standards for the use and disposal of sewage sludge cover land application, surface disposal, and incineration. The standards for use or disposal of biosolids consist of pollutant limits for metals, operational standards for pathogens, management practices, monitoring, recordkeeping, and reporting requirements.

Biosolids Research Needs

Biosolids research needs are interwoven with other aspects of Water Quality Integrity research, such as nutrients, SABS, and emerging contaminants. Biosolids management issues are also related to Wastewater Management (refer to Chapter 3) and Watershed Protection and Restoration needs (refer to Chapter 4).

To ensure public health and environmental safety of land application of biosolids, EPA needs to proactively fill the information and scientific gaps, keep abreast of the latest issues, and expand its tools. Key gaps in our knowledge include the occurrence of and risk posed by pathogens and other pollutants in biosolids. For example, do we understand all the risks and have all the needed risk assessment tools? There is evidence of pathogen reactivation or sudden increase in indicator organisms following anaerobic digestion and dewatering at some treatment facilities. There is also limited knowledge of what may be in biosolids, due in part to a lack of analytical methods and the large universe of chemicals and pathogens that could be in or released from biosolids. We also need a better understanding regarding a growing concern about antimicrobial resistance and horizontal gene transfer, treatment effectiveness, and whether operation standards (*e.g.,* harvesting and grazing restrictions) work.

In setting the priorities for the Biosolids Program, the Water Program considered such questions as:

- Would the action provide an important link for detecting and quantifying pollutants in biosolids?
- Would the action assess/ensure the protectiveness of Part 503 standards to human and environmental health?
- Would the action address the increasing scientific and policy complexities posed by the land application of biosolids?

The Water Program needs to conduct research and provide other Part 503 support in three general areas as follows:

- Selecting appropriate pathogens and indicators to properly assess sewage sludge quality and determine effective measures for reducing pathogens in environmental media.
- Developing improved analytical techniques for pathogens and priority toxic contaminants in or released from biosolids.
- Determining whether contaminants in biosolids pose a public health risk when applied in compliance with current regulations.

Each of these research needs is discussed in more detail below. Carrying out needed research will require joint efforts among EPA and its partners and will also entail creativity and new approaches. Partners will have key roles in developing products and implementing the work outlined in the *Compendium*.

Selecting appropriate pathogens and indicators to properly assess sewage sludge quality and determine effective measures for reducing pathogens in environmental media

Research is needed to determine if the best indicator organisms are being used and if treatment facilities can inactivate and remove pathogens to protect public health. Research is also needed to compare the agents causing disease outbreaks with those routinely found in treated sewage sludge.

There are concerns about the abilities of existing treatment technologies to remove emerging chemical and microbial contaminants. Research on innovative or alternative sludge disinfection processes that can significantly reduce both existing and emerging pathogens is needed. More information is needed on the best criteria to evaluate unproven treatment technologies. Research is also needed to determine the best standardized and validated analytical methods to quantify fecal coliform, *Salmonella* spp., enteric viruses, and *Ascaris* spp.

Develop improved analytical techniques for pathogens and priority toxic contaminants in or released from biosolids

Continued development of analytical methods is needed for priority contaminants in complex heterogeneous mixtures (*i.e.,* biosolids). Priority contaminants include viruses, bacteria (*e.g., E. coli*, *E. coli* 0157:H7, enterococci), protozoa (*e.g., Giardia* and *Cryptosporidium*), pharmaceutical and personal care products (PPCPs), and endocrine disrupting compounds. To assist in this area, EPA plans to develop standardized methods to measure emerging contaminants in biosolids and bioaerosols.

Determine whether contaminants in biosolids pose a public health risk when applied in compliance with current regulations

Methods are needed for contaminant (biotic and abiotic) risk assessments and to develop models to address pathogen risk from land application. Single and multiple stressor exposure, similar modes of action, chemistry, or other attributes should be investigated. EPA's research will also address the fate of emerging contaminants (chemical and microbiological) during sludge processing. In addition, EPA will look at some of the innovative, more cost-effective techniques available for reducing volumes and pollutant concentrations in land-applied biosolids.

Ongoing work is needed to determine the effectiveness of existing treatment technologies in removing or inactivating current and emerging contaminants. Of particular importance is whether storage or attenuation after publicly owned treatment works (POTWs) treatment results in pathogen die-off. Continued research is also needed to assess the quality and utility of data, tools, and methodologies used for pathogen risk assessments including those needed to evaluate other emerging contaminants (*e.g.,* prions and nanomaterials). Another treatment-related research question involves antimicrobial resistance in wastewater streams and how they impact the treatment process. The effects of nanomaterials on POTWs needs to be assessed, as well as the abilities of nanomaterials to survive the treatment process and appear in products produced from land-applied biosolids.

Field studies are needed to test for natural attenuation to reduce pathogens after land application of biosolids. The factors (*e.g.,* pH, nutrient availability, etc.) controlling natural attenuation should also be investigated. To control odors and nuisance conditions, appropriate measures of biosolids stability, disinfection, and vector attraction are needed. EPA is also investigating whether there is a link to biosolids exposure and health effects. Additional field research will investigate how to characterize releases to the air and soil during application of Class B biosolids (*i.e.,* those biosolids that have undergone treatment that has reduced but not eliminated pathogens). Human exposure measurements are needed to determine contaminant transport. Research is also needed on the fate of contaminants (microbial and chemical) in biosolids after their use or disposal.

Nutrients Criteria Research

According to the CWA 303(d) lists, nutrient over-enrichment (eutrophication) is among the top five causes of surface water impairment in the US In particular, harmful algal blooms (HABs), which are an excessive growth of algae caused by nutrient enrichment, and the resulting hypoxia can have a devastating effect on aquatic ecosystems. This is exemplified by the well-known Gulf of Mexico hypoxia problems. There is a clear need for scientifically up-to-date nutrient criteria to protect vulnerable ecosystems such as estuaries and wetlands from excess nutrients.

A number of efforts have been directed towards nutrient management. EPA has developed methods for deriving nutrient criteria, default criteria for the variety of waters and eco-Regions found in the US, and a strategy for implementing the criteria (USEPA 2000, 2001, 2002). In December 2004, the Harmful Algal Bloom and Hypoxia Amendments Act of 2004 was signed into law (Public Law 108-456), reauthorizing the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998. The new bill requires a one-time assessment of freshwater HABs, for which the Water Program has the lead. Additionally, the Act requires the development of a research plan for incorporating freshwater HAB research into the Ecology and Oceanography of Harmful Algal Blooms (EcoHAB) Interagency Grant Program. Scientific guidance has been provided by a 2002 workshop in Woods Hole, Massachusetts, in which academic and government agency scientists drafted a framework for a report on the "priority research needed to protect against nutrient pollution and to rehabilitate degraded coastal waters of the United States" (Howarth et al., 2003).

Nutrient management is an active research area, and much remains to be done to help States and Tribes implement nutrient criteria and address their nutrient stressed waters. The needed research will rely upon collaborations within EPA and National Estuary Programs or other local partners through existing workgroups and other avenues. Other federal agency partnerships have also been developed. Through the EcoHAB Interagency Grant Program, collaborations have been fostered with other federal agency partners, including the National Oceanic and Atmospheric Administration (NOAA), National Science Foundation, Office of Naval Research, and the National Aeronautics and Space Administration. These joint funding efforts have enhanced interagency communication and allowed for the effective use of federal resources. The monitoring efforts of the US Geological Survey also provide valuable data on nutrients in the Nation's waters.

Nutrients Criteria Research Needs

Ongoing nutrients research will provide information needed to improve management of coastal aquatic resources and resolve impaired waters listings. Research results will provide scientific support for TMDL development, nutrient trading, National Pollution Discharge Elimination System permitting, and integration with other water quality programs, including TALU and biological criteria. There is also a need for improved, scientifically defensible approaches for developing numeric nutrient criteria. Research will also help to identify the best methods for implementing standards in a cost-effective manner. Specific needs are to:

- Provide additional scientific basis and technical guidance for nutrient load-response relationships to develop and implement numeric nutrient criteria, with an emphasis on estuaries and coastal wetlands.
- Evaluate the relationship between nutrient criteria and flow conditions.
- Incorporate nutrient stressor-response relationships into BCG and TALU approaches.
- Understand the relationship between HABs and nutrient dynamics.
- Provide the tools (monitoring methods, models, guidance) needed to implement environmentally sound nutrient trading approaches.

Provide scientific basis and load-response relationships required to develop and implement numeric nutrient criteria

Under the first goal, research will initially focus on extension of work done under EPA's National Health and Environmental Effects Research Laboratory's Aquatic Stressors Research Program for coastal systems. Products that were originally developed for specific Regions need to be expanded to be nationally applicable. By working with NOAA, and other partners, models can be developed that are applicable to different classes of estuaries. This will enable States and Tribes to connect nutrient loads to biological responses and will make it possible to establish numerical nutrient criteria.

A specific example of the use for this research is in Region 2, where there is a need for nitrogen indicator(s) for estuarine systems because nitrogen has eutrophic effects on coastal ecosystems throughout that Region. Nitrogen inputs, including CAFOs, agricultural activities, stormwater, and nonpoint sources affect the ecological health of the estuarine systems, causing reductions in shellfisheries and the degradation of submerged aquatic vegetation. The appearance of invasive species, such as brown tides and sea nettles (stinging jellyfish), adds to the evidence of serious adverse ecological conditions in these estuaries.

Evaluate the relationship between nutrient criteria and flow conditions

The relationship between nutrient criteria and flow conditions needs to be studied. Research is needed on how frequently waters (both fresh and marine) should be monitored for impacts to assess nutrient criteria exceedances. Understanding the connections between criteria, flow, and monitoring will enable the development of models that set appropriate benchmarks for TMDLs and will enable listed waters to regain designated uses.

Region 5 points to the specific need for its States to better understand how daily fluctuations in dissolved oxygen levels can explain the effects of nutrient enrichment in streams, especially in light of confounding factors such as turbulence, light, turbidity, temperature, and/or the amount of algae present.

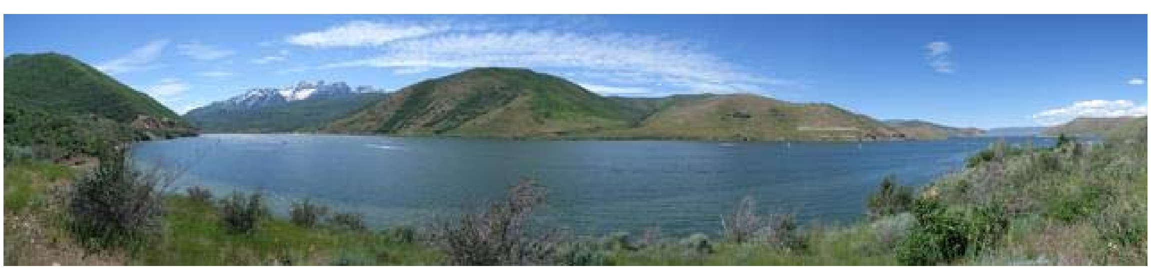
Incorporate nutrient stressor-response relationships into BCG and TALU approaches

Through the use of TALU, stressor-response relationships can be brought to bear on creating management plans, setting restoration goals, assessing water bodies, diagnosing impairments, and evaluating effectiveness of management actions. Because nutrients are a significant anthropogenic stressor, nutrient stressor-response relationships need to be incorporated into BCG and TALU approaches. Research in this area will be directly applicable to nonpoint source and point source management for critical waters.

Understand the relationship between HABs and nutrient dynamics

EPA will continue its participation in the Interagency EcoHAB Program to better understand the relationships among nutrient loading (eutrophication), HABs, and food web dynamics. Coastal Eutrophication Models are needed to understand the impacts of nutrient loadings into coastal ecosystems and the impacts of boundary conditions. HABs have been increasingly observed in both fresh and marine waters in Region 9. Such research will also support the need to better understand the generation of cyanotoxins that affect drinking water sources.

In addition, the Water Program and ORD will sponsor a specific new initiative on freshwater HABs, particularly those caused by cyanobacteria (CHABs), under the EcoHAB Program. Research is needed on how nutrient supply rates interact with a number of other environmental factors (*e.g.,* light, turbulence, pH, etc.). Important questions include: 1) whether a specific water body is susceptible to CHAB formation; 2) the extent to which CHABs may dominate planktonic and or benthic habitats; and 3) whether management will reduce CHABs in a water body. A number of environmental factors (light, temperature, organic matter, etc.) and human activities (toxic discharges, climate change, etc.) may influence CHAB formation and characteristics. It is crucial to develop an understanding of how to predict, prevent, and control these unwanted occurrences.



Provide the tools (monitoring methods, models and guidance) needed to implement environmentally sound trading approaches

Improved modeling tools and monitoring protocols are needed to support the implementation of effective nutrient water quality trading programs. The research must address both point and nonpoint sources and the effectiveness of agricultural best management practices in reducing nutrient loading to streams. EPA's research program in support of nutrient trading will allow stakeholders to determine the feasibility of proposed water quality trading initiatives. Additionally, this research program will provide monitoring protocols to evaluate the effectiveness of nutrient trading initiatives after implementation.

Emerging Contaminants Research

EPA's Water Quality Program has established water quality criteria, numeric standards, or operational standards to address many of the significant pollutants known to cause water quality impairments and adverse environmental or health effects. EPA's Drinking Water Program takes measures to protect the nation's drinking water sources. However, many new or existing constituents are reported to appear in sewage sludge, surface waters, and ground water. Chemical and biological contaminants in the environment that are either new, are existing but represent novel forms, or are just coming into focus are referred to as emerging contaminants.

The universe of emerging contaminants includes many (*i.e.,* hundreds to thousands) biotic and abiotic constituents for which EPA needs to determine pollutant status. Determining whether an emerging contaminant will be classified as a pollutant will depend on having adequate data to conduct an exposure and hazard assessment in appropriate environmental media. The list of emerging contaminants is long. It includes, among others, endocrine disrupting compounds, nanomaterials, fluorinated compounds, pharmaceutical and personal care products (PPCPs), viruses, prions, bacteria (*e.g., E. coli*, *E. coli* 0157:H7, enterococci), and protozoa (*e.g., Giardia* and *Cryptosporidium*).

Emerging pollutants have been documented in surface and receiving waters associated with wastewater treatment plant outfalls in numerous areas (Lazorchak and Smith 2004; Hemming et al., 2004). The literature also documents emerging contaminants in sewage sludge associated with wastewater treatment (Heidler et al., 2006; Kinney et al., 2006; Song et al., 2006; and Xia et al., 2005). The literature documents endocrine-disrupting properties of some emerging contaminants in fish (Flick et al., 2004; Lattier et al., 2002). Many emerging contaminants are known to have effects at the individual, community, and population levels (Gordon et al., 2006), yet many specifics remain unknown. Research is needed to fill data gaps and evaluate pollutants for potential regulation. Collaboration with other organizations (*e.g.,* Water Environment Federation, Water Environment Research Foundation, Water Reuse Foundation, American Water Works Association, and the American Water Works Association Research Foundation) will also be critical. Also, other federal agencies have important programs underway to monitor for new contaminants of concern where coordination will inform specific research needs (*e.g.,* the US Geological Survey).

Emerging Contaminants Research Needs

The Water Program is tasked with assessing levels of emerging contaminants in various environmental media and determining whether the pollutant levels may cause human or environmental harm. Research concerning emerging contaminants is aimed at providing the data and tools for EPA, States, Territories, and Tribes to monitor, evaluate, contain, treat, remediate, or, if need be, regulate these potential pollutants.

The Water Program has three primary research needs that are directly linked to the research needs of human health criteria, aquatic life guidelines, and aquatic life criteria:

- Develop approaches for identifying/categorizing which emerging contaminants (or classes) are risks to the environment or human health.
- Establish a framework for prioritizing high-risk emerging contaminants for exposure and hazard assessment and criteria development.
- For those contaminants (or classes) that are candidates for regulation, conduct the necessary supporting research.

Develop approaches for identifying/categorizing which emerging contaminants are risks to human health or the environment

A number of approaches will be needed to identify emerging contaminants. A bioinformatics approach (*i.e.,* one that integrates computers, software tools, and databases to address biological questions) may be needed to make logical decisions from the data that are accumulating from high-throughput biological and chemical experiments. Available literature should also be utilized, and a list of priority compounds will need to be formulated. Field screening will need to be done for concentrations of the prioritized compounds in sewage sludge, sediment, water, and tissues in areas near wastewater treatment plants. Backwash water at water treatment plants should also be examined for soluble unregulated and non-monitored treatment chemicals (*e.g.,* acrylamide and epichlorohydrin). This research would help inform decisions regarding the reuse of backwash water.

There are many new developments in analytical methods. Traditional toxicological approaches may be replaced with newer assays using standardized gene arrays. Research should determine which biological pathways are affected by previously unrecognized chemicals. Analytical and genomic methods should be developed for assessing the occurrence of prescribed pharmaceuticals in POTWs and receiving waters. Newly developed technologies must then be communicated to Regional laboratories through technology transfer.

Establish a framework for prioritizing high-risk emerging contaminants for exposure and hazard assessment and criteria development

As emerging contaminants are identified, EPA must differentiate between those of "high" and "low" priority. Prioritization may be done on the basis of bioavailability, toxicity, mobility, or frequency of occurrence. Certain contaminants may be chosen for further research based on data availability, similarity of structure, health or environmental effects, or other attributes. Class-specific case studies may be helpful for determining the parameters for prioritizing within class and matrix. Case studies may also be useful for determining effects and endpoints for compounds.

Studies need to be done to document environmental concentrations and spatial and temporal occurrences. Persistence or pseudo-persistence (*i.e.,* contaminants that degrade but are continually introduced into the environment) should be accounted for, and bioaccumulation potential should be determined. Special attention should be paid to compounds that are demonstrated or suspected carcinogens or genotoxics. Unusual mechanisms and modes of action should also be noted. Finally, the effects on aquatic and human populations and aquatic communities should be modeled or demonstrated. Similar lines of evidence need to be developed for emerging pathogens. These data could be used to help inform the aquatic life and human health chemical selection processes (*e.g.,* the drinking water CCL) to determine the risks posed by the contaminant. With risks evaluated, emerging contaminants can then be prioritized for criteria development.

For those contaminants (or classes) that are candidates for regulation, conduct the necessary supporting research for the appropriate water regulatory program

Where unavailable, analytical methods must be developed for emerging contaminants in relevant media (*e.g.,* drinking water, wastewater, biosolids). The methods must be validated in several labs, and the detection and quantitation limits must be determined. Methods must be able to analyze emerging contaminants in complex matrices, such as sewage sludge.

Research is also needed to evaluate whether or not the existing aquatic life guidelines and human health methods can adequately account for and address emerging contaminants. Tools are needed to diagnose biological impacts from emerging contaminants and connect the causal agents to sources.

Research is also needed (and planned) to develop testing procedures or models for evaluating the fate and effects of emerging contaminants. Examples of particular interest is exploring the extent antimicrobial compounds may contribute to antimicrobial resistance via wastewater and how to evaluate the estrogenicity potency in rivers and streams that receive wastewater treatment plant discharges.

Suspended and Bedded Sediments Research

SABS occur naturally in all types of water bodies. They are particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies. In appropriate amounts, they are essential to aquatic ecosystems. However, imbalanced sediment supplies have repeatedly ranked high as a major cause of water body impairment throughout the US The quantity and characteristics of SABS (such as nitrogen and phosphorous content) may affect the physical, chemical, and biological integrity of streams, lakes, rivers, estuaries, wetlands, and coastal waters. Excessive SABS (or in some cases, insufficient SABS) can impair water body designated uses for aquatic life, navigation, recreation, and filterable sources of drinking water.

SABS Research Needs

In response to evidence that imbalanced sediment supplies have negatively affected water resources throughout the US, EPA has developed a Framework for Developing Suspended and Bedded Sediments (SABS) Water Quality Criteria (USEPA, May 2006). The intent of the framework is to provide the tools to support the States, Tribes, and Territories in their efforts to establish SABS criteria in water quality standards. Such measures are an important component of efforts to protect the ecological integrity and beneficial uses of water resources.

There are two primary SABS research needs:

- Improve technical methods used in EPA's Framework for Developing SABS Water Quality Criteria.
- Verify methods and support implementation of the Framework.

In addition, EPA Regions have pointed to the need for sediment quality guidelines to address potential food chain effects of bioaccumulative sediment pollutants.

These needs are discussed in more detail below. The anticipated management research products will assist with SABS standards implementation and will facilitate scientifically sound and effective management decisions Expected outcomes include improved water quality and attainment of a variety of programmatic activity measures (*e.g.,* removing waters from 303(d) list, reducing sediment loadings, improving water clarity and benthic quality, and increasing habitat acreage in the NEP).

Improve technical methods used in EPA's Framework for Developing SABS Water Quality Criteria

The process for developing SABS water quality criteria includes gathering information, synthesizing the state of the knowledge, analyzing available data, and selecting criteria values. Several technical methods need to be improved and validated using real world data.

Scientists and watershed managers need to be able to evaluate the effects of SABS on aquatic communities, biotic assemblages, or key aquatic species and guilds (*i.e.,* groups of species using the same kinds of resources). Methods are needed for diagnosing causes of biological impairment (*i.e.,* dose-response information). Hypotheses should be tested regarding sediment-limiting organisms, and natural sediment conditions should be measured. Also, natural or unimpaired water bodies should be compared to altered water bodies.

EPA Regions need additional information and guidance on SABS criteria. Critical questions include:

- Should these criteria be based on empirical relationships with bioassessment endpoints (what levels cause impairment) rather than classical toxicity testing?
- Should they be based on total dissolved solids and SABS levels at reference sites without reference to biological impairment thresholds?
- Would some combination be best?

Verify methods and support implementation of the Framework

Some of the methods in the Framework for developing SABS criteria have been useful for ecological risk assessment and eco-epidemiological studies. However, the Framework needs to be verified as to its effectiveness for selecting SABS criteria. Using data from case studies that have been conducted in a variety of geographic regions, EPA can evaluate the stepwise process for gathering and analyzing available information, synthesizing the state of knowledge, gathering more data if needed, and selecting criteria values outlined in the Framework. These case studies will also provide an opportunity to compare different analytical methods.

Additional research needs identified by EPA Regional staff include projects that address: sensitivity of different taxa and assemblages to SABS exposure; sublethal impacts from SABS; and protection of endangered species (*e.g.,* salmonids). A basic understanding is needed of dynamic systems and sediment loads and what constitutes a natural disturbance. Research should also be conducted on which water body uses need to be protected, what level of protection is needed, and which measures/criteria are needed to enable protection. Technical training/workshops will then be needed to help watershed managers address uncertainties related to SABS management.

Improved sediment quality guidelines

Recent research to develop sediment quality guidelines (including those based on equilibrium partitioning) have been incorporated into guidance on how to use multiple lines of chemical and biological evidence to assess sediment contamination. Though useful, these guidelines have been developed for the protection of benthic organisms from direct toxicity. They generally have not addressed potential food chain effects of bioaccumulative sediment pollutants (*e.g.,* DDT and PCBs). Research needs identified by the Regions include:

- Development of guidance on how to interpret ecological sediment toxicity studies (lab or in situ caged studies) and how to interpret the significance of the results in relation to site populations and communities;
- Development of additional tools to characterize ecological risk. These include practicable guidance for considering community or population level response in setting permissible limits on mortality; reviews of available sublethal bioassay protocols; identification of recommended protocols; development of guidance for evaluating test results (as above); development of guidance for modeling additive effects of contaminants; and development of residue (or dose) based species sensitivity distributions for assessing field and laboratory accumulated residues and interpretation; and
- Development of methods to characterize exposure to individual stressors and in particular, development of guidance on assigning (dis)equilibrium conditions for uptake and trophic transfer modeling and guidance for probabilistic consideration of exposures (*e.g.,* single, pulse exposure).

Integration of Multiple Stressors Research

Steadily increasing population has given rise to increased pressures on the landscape and waters, as well as greater demand for economic benefits. The result is the widespread occurrence of multiple stressors on natural resources. Most urbanized aquatic systems have contaminated sediments, excess nutrients, degraded marine habitats, industrial usage, risk of invasive species, and changing land-use in their watersheds. Legacy practices in forested and agricultural lands have also resulted in multiple stressors in watersheds, water bodies, and associated ecological systems. Research is needed to identify causes of specific impairments when many co-exist. The sensitivity of waters and populations to various stressors must be assessed, and alternative scenarios must be envisioned in order to make sound decisions.

Attempts to refine designated use through the TALU process represent one response to the need to manage multiple stressors. Often, the cumulative effects of degraded habitat (for which criteria are often lacking) and chemical criteria (for which criteria are available) must be considered. In these cases, States need to understand the effect of habitat quality constraints on the expression of other chemical stressors.

Most water quality research has focused on the effects of one stressor alone, and sometimes a combined effect of two stressors, on specific endpoints. Further research is needed to evaluate the combined effects of multiple chemical, biological, and physical stressor impacts on specific endpoints (*e.g.,* wildlife populations) and water quality. Research on multiple stressors will need to be integrated with EPA research in several other areas (*e.g.,* Gulf of Mexico Hypoxia, nutrients, toxic, wetlands, ecological assessment, etc.). Multiple-stressor research and tools can define ecological response under various combinations of stressor presence and intensity, which is needed for both setting criteria and for evaluating ecological benefits.

Integration of Multiple Stressors Research Needs

To meet its obligations and mandates, EPA must understand the cumulative impacts of multiple stressors on healthy aquatic ecosystems and must determine how to best convert that knowledge into criteria and effective management tools. EPA has identified the three research areas:

- Develop and test methods for projecting the relative and combined risks from multiple stressors to aquatic and aquatic-dependent wildlife populations.
- Develop conceptual and empirical approaches (including models) to predict, diagnose, prevent, and manage the combined effects of multiple stressors in aquatic systems.
- Develop methods to assess change in aquatic ecosystems that reflect responses to multiple and variable stressors.

Each of these research needs is discussed in more detail.

Develop and test methods for projecting the relative and combined risks from multiple stressors to aquatic and aquatic-dependent wildlife populations

Research is needed to develop scientifically valid approaches for protecting aquatic and aquatic-dependent wildlife populations from multiple aquatic stressors. Research is needed to combine the effects of stressors in isolation into quantitative projections of cumulative effects. To do so, research on multiple stressors must be integrated with other EPA research related to impacts of toxics on water quality. Specifically, proposed research continuing the development and refinement of methods to assess population-level risk will be coordinated with activities to incorporate population-level effects into the development of regulatory criteria for wildlife (see Bioassessment and Biocriteria, and Aquatic Habitat discussions). In addition, specific data produced through this research will document population-level effects of chemicals of emerging concern and for which data are currently lacking (see Emerging Pollutants discussion).

EPA Regions and many State programs are using the Causal Analysis/Diagnosis Decision Information System (CADDIS) to help identify probable stressors. Most have not fully integrated the use of biological metrics, which will allow more detail in stressor identification and ultimately establish stressor specific tolerance values based on indicator taxa. Some Regions have used CADDIS to identify problems, and the Regions support further development of CADDIS.

Develop and both conceptual and empirical approaches (including models) to predict, diagnose, prevent, and manage the combined effects of multiple stressors in aquatic systems

Research is needed in several areas including indicator development and testing; use of classification (by region, trophic status, habitat type) to partition variability in response related to distribution of modifying factors and processes; development of empirical analyses to allocate causality among multiple stressors that may be operating in an additive fashion; and modeling approaches to evaluate and predict stressor interactions and indirect effects.

Both diagnostic and integrative indicators of multiple stressors are needed. Diagnostic indicator development will focus on defining groups of organisms with unique sensitivity to different stressors or modes of action. Integrative indicators of multiple stressors will be identified either by: 1) identifying a common mode of action and using this to combine stressor units or responses, 2) identifying a common measurement for expressing stressor magnitude (*e.g.,* landscape development index), or 3) evaluating effective concentrations of stressors after modification by other stressors or factors.

Empirical analysis approaches are needed to evaluate various statistical techniques (*e.g.,* quantile regression, graphical analysis, multivariate statistics) to partition effects among stressors. Mechanistic modeling will be needed to evaluate non-additive, interactive, or indirect effects of multiple stressors with disparate modes of action. Classification will be an important component of both empirical analyses (to partition variability in modifying factors) and in mechanistic modeling (to evaluate the potential for extrapolating results).

Develop methods to assess change in services provided by aquatic ecosystems in response to multiple and variable stressors

Research is needed to evaluate the best methods for assessing the cumulative impacts of multiple stressors on the services provided by aquatic ecosystems. Such methods must be demonstrated so that they provide support for improved water quality, better regulation, better management, and an informed public.

Research on multiple stressors, when combined with the research in other offices across EPA, will enhance the ability of watershed managers to attain water quality goals, maintain ecosystem services provided by rivers, lakes, and other aquatic ecosystems, and protect wildlife populations.

Socio-Economics – Valuation

In making decisions involving our ecological resources, the needs and interests of a variety of stakeholders must be addressed. The information provided to decision makers, and to society as a whole, must be in forms most useful for establishing policy and evaluating the tradeoffs among decision alternatives. In many cases, considering the values that society places on the services provided by ecosystems can be an essential part of making decisions that affect ecosystems. Aquatic ecosystems provide a wide range of services, including drinking water, food, and recreation. Ecosystem services are produced by the structures and processes of ecosystems, as influenced by human activity. Therefore, determining the values of these services that healthy aquatic ecosystems provide can help to encourage policymakers and general citizens to protect these ecosystems from critical impairment.

Although a number of regulatory authorities exist that call for the use of these values in decision-making (including Executive Order 12866 and the National Environmental Policy Act), there remain ecological benefits for which value estimates are not currently available, along with a lack of information about ecosystem services and their production. In addition, approaches and methodologies to value ecosystem services are not coordinated across all elements. As a result, the development and refinement of consistent, standardized, and transferable valuation methods for aquatic ecosystems is an important research endeavor for effective decision support.

Socio-Economics – Valuation Research Needs

Knowledge gaps currently exist in accurately defining and classifying the services that can be attributed to aquatic ecosystems and in how these values can be transferred in forms that are useful and understandable to decision makers and the public. Additionally, there are critical voids in valuation expertise due to a lack of strategic alliances within and external to EPA. The refinement of current methods and the development of new approaches for valuation of aquatic ecosystem services will help to address these information gaps. Research is needed in the following areas:

- New concepts for defining and classifying ecosystem services and bundles of those services.
- Improved approaches and information for describing the production of services.
- Enhanced and supplemental methods for quantifying the values of ecosystem services and innovative ways of using this knowledge in proactive environmental management decisions.
- New and refined potential methods for valuation of the services provided by wetlands and by the structural and functional attributes of coral reefs (including shoreline protection, fishing, tourism and non-use aspects (biodiversity, aesthetics)).

Each of these research areas are discussed in more detail.

Provide a system for defining and classifying aquatic ecosystem services

Individual services not currently traded in markets often lack standard definitions and units of measurement. EPA will conduct research needed to develop a Non-market Ecosystem Services Classification System (NESCS). The NESCS will be based on the principles of the US Census Bureau's North American Industrial Classification System. It will aggregate ecosystem services in a hierarchical classification system based on similarities in their production and substitutes or complements in their consumption.

Develop improved approaches and information for describing the production of services

Ecosystem services are produced by the structures and processes of ecosystems, as influenced by human activity. The economic value to society of an ecosystem service refers to its contribution to human welfare. Economic value is measured as society's willingness-to-pay to preserve the ecosystem service, which is influenced by the quality and reliability of the service, its scarcity and degree of substitutability by other services, and the availability of complementary services—the *economic production function*. Once the physical effects of ecosystem services (and changes therein) on human health and well-being have been quantified, economic methods can be used to estimate the value of these changes. Thus, defining and quantifying the various components of the services produced by ecosystems are necessary ingredients to understanding value.

In association with construction of the NESCS, EPA will develop broad guidance for characterizing ecosystem service production functions. The science of ecosystem services, and its role in decision making, will benefit from guidance communicating: 1) general issues to consider when describing ecosystem service production functions, 2) critical ecological, economic, and human health elements to include, and 3) important requirements to consider in support of the decision-support process.

Enhance and supplement methods for quantifying the values of aquatic ecosystem services

EPA is pursuing economic methods as the primary approach to valuation of ecosystem services, in part to support customary (and often mandated) decision processes based on benefit-cost analysis, and in part because money is an easily understood common denominator. EPA aims to build upon the foundation laid by the Science Advisory Board Committee on Valuing the Protection of Ecological Systems and Services on valuation methods for environmental decision-making. Needs are to: 1) determine the efficacy of certain valuation methods in specific situations, 2) develop approaches for economic valuation of bundles of services, 3) improve valuation methods and the understanding of ecosystem services in general, 4) encourage the academic community explore novel economic methods through the STAR Grant Program, and 5) pursue development of donor-based and other methods of valuation to supplement economic approaches. Conversely, Region 3 would like to consider the question: what are the "costs" to society in a broad sense - economically, public health, quality of life, long term sustainability - of not protecting and restoring ecological integrity?

Develop new and refined potential methods for valuation of the services provided by wetlands and by the structural and functional attributes of coral reefs

Wetlands and coral reefs are unique aquatic ecosystems, and each provides a unique and valuable set of services for human well-being. Therefore, providing a scientifically defensible research approach to support policy and management actions that protect, enhance and restore these ecosystems and their goods and services would have far reaching effects on human well-being.

Although much is known, conceptually or qualitatively, about the links among wetland condition, function, and services, research is needed to quantify those links at multiple scales and to demonstrate the impact of alternative futures on the ability of wetlands to provide services. Landscape models of wetlands and interactive mapping tools for decision makers will be developed to further this goal.

Coral reefs provide a variety of services, most notably shoreline protection, tourism, fish production, and non-use aspects (biodiversity, aesthetics). Although methods to valuate coral reef services have matured over the last two decades, the mechanisms through which a number of these ecosystem services are produced are complex, and most reef services have not been quantitatively linked to the reef attributes that provide them.

For both wetlands and coral reefs, EPA will explore how surveys of condition can be used to estimate the delivery of ecosystem services and characterize the relationships between ecological function and delivery of services. EPA research will focus on an 1) inventory and characterization of the services provided by wetlands and coral reefs (ecosystem assessment), 2) the influences of natural and anthropogenic activities on those services (quantifying agents of change, both adverse and beneficial), and 3) the outlook for sustained services under alternative future scenarios (forecasting service sustainability). Refer to Chapter 4 for other coral reef research needs.

Recreational Waters

Swimming in some recreational waters can pose an increased risk of illness as a result of exposure to microbial pathogens. In some cases, these pathogens can be traced to sewage treatment plants, malfunctioning septic systems, and discharges from stormwater systems and animal feeding operations.

To protect recreational waters, the BEACH Act, was signed into law on October 10, 2000, amending the CWA. Two major provisions of the BEACH Act are CWA sections 104(v) and 304(a)(9). Section 104(v) requires EPA to conduct studies in cooperation with federal, State, Tribal, and local governments to provide additional information for use in developing: 1) an assessment of potential human health risks resulting from exposure to pathogens in coastal recreation waters, including non-gastrointestinal effects; 2) indicators for improving detection in a timely manner in coastal recreation waters of the presence of pathogens that are harmful to human health; 3) methods (including predictive models) for detecting in a timely manner in coastal recreation waters the presence of pathogens that are harmful to human health; and 4) guidance to help States develop water quality criteria for pathogens and pathogen indicators.

Since EPA last published recreational water quality criteria in 1986, significant advances have been made, particularly in the areas of molecular biology, microbiology, and analytical chemistry. EPA believes that that these new scientific and technological advances need to be considered and evaluated for feasibility and applicability to the development of new or revised criteria for pathogens and pathogen indicators. To this end, EPA has conducted a significant amount of research including developing new methods for measuring microbiological organisms in water and conducting epidemiologic studies to provide the scientific foundation for new or revised criteria. EPA's review of existing research and science raised a number of questions that must be answered in order for EPA to move forward with criteria development.

To help address these questions, EPA held a scientific workshop in March 2007, which 43 international and US experts attended. The purpose of the workshop was for EPA to obtain input from members of the broad scientific and technical community on the "critical path" research and related science needs for developing scientifically-defensible new or revised recreational water quality criteria. Based on their input, EPA developed The Critical Path Science Plan for Development of New or Revised Recreational Water Quality Criteria (CPSP). The CPSP describes the research and science that EPA will conduct between 2007 and 2010 to establish water quality criteria by 2012.

Recreational Waters Research Needs

The research needed to properly develop water quality criteria for recreational waters mirrors the requirements of section 104(v) and can be divided into three broad categories: 1) assessment of human health risk; 2) development of indicators and methods; 3) extrapolation of research results for developing new or revised criteria. Each is discussed in more detail below.

Assessment of Human Health Risk

Epidemiologic studies and quantitative microbial risk assessment are needed to understand the risk to human health (including non-gastrointestinal effects) from swimming in water contaminated with human fecal matter as compared to swimming in water contaminated with non-human fecal matter. Specific uncertainties to address include:

- Understanding which human illnesses are caused by swimming in waters contaminated with non-human fecal matter, the levels of non-human fecal matter in these waters that cause human illness, and the relationship between different levels of non-human fecal matter in waters and human illness rates.

- Understanding any differences in risk to children swimming in waters contaminated with fecal matter versus adults swimming in these waters.

Development of Indicators and Methods

EPA studies have demonstrated the utility of a new indicator and method (*i.e.,* quantitative polymerase chain reaction (qPCR) for *Enterococci*) as a predictor of swimming-related illness in the Great Lakes. EPA's current CWA 304(a) recommended criteria for bacteria are based on methods that require 18 to 24 hours to culture and enumerate *E. coli* and *Enterococci* as indicators of fecal contamination. Whether qPCR for *Enterococci* is applicable to other settings or appropriate for use across the range of CWA Programs is not fully understood. Data gaps include understanding how well the various indicators and methods perform in other settings (*e.g.,* marine versus fresh water; human versus non-human sources of fecal contamination), and how they relate to one another.

Research is needed to identify appropriate indicators of fecal contamination to allow for a reliable correlation between indicator concentrations and health effects. Studies are also needed to evaluate temporal and spatial variability in indicator concentrations to appropriately characterize water quality and improve recreational water quality management decisions. Appropriate methods for measuring fecal contamination indicators must be developed, evaluated, and validated to allow for a reliable correlation between indicator concentrations and health effects. Through these efforts, EPA hopes to answer the question of how well culture and molecular methods for various indicators (singly or in combination) correlate with swimming-related illnesses.

Extrapolation of Research Results for Developing New or Revised Criteria

Environmental factors, such as meteorology or the physical and chemical characteristics of freshwater and marine environments vary geographically and may influence the presence and viability of indicators and pathogens. Consequently, they may also influence any observed indicator-illness relationship. Therefore, studies are needed to assess the influence of variability in geographic and aquatic conditions on indicator and method performance, and to assess the suitability of indicators and methods for various CWA purposes (*e.g.,* beach monitoring, assessments, TMDLs, and permitting). EPA also needs to develop, evaluate, and validate predictive models and tools to understand the extent to which data from epidemiologic study sites can be extrapolated to other geographic locations and aquatic conditions. Researchers must examine the role of models as a tool in predicting water quality problems to assist in new or revised criteria implementation. Through these research activities, EPA hopes to address whether the indicators, methods, and models are suitable for use in different types of waters and for different CWA programs.

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6 ● Science to Support Place-Based Water Protection and Restoration – Large Aquatic Ecosystems Programs

Place-Based Programs are special, geographically-focused subsets of the national Water Program (States are the more typical jurisdictional, spatial focus). The Office of Water (OW) has established these supplemental implementation efforts to protect and restore large aquatic ecosystems that have been identified as having significant water pollution problems. Because of their sheer size, their varied and widespread contributing sources, and often the crosscutting of spatial jurisdictions that need to take action, these special water bodies require well-coordinated supplemental attention. All OW programs (*e.g.,* watersheds, wastewater, drinking water) described throughout this *Compendium* are pertinent to the protection of water and public health in these specific aquatic ecosystems. Moreover, essentially all the research needs described throughout this *Compendium* have some applicability to these areas. However, each of these ecosystems may need a specific application of a national research topic related to their unique hydrogeologic and land use conditions.

OW's Large Aquatic Ecosystems Program has evolved over the past two decades. After initial implementation of the core OW programs, evidence emerged in the 1980s of serious and complex water quality problems in specific, large aquatic ecosystems. In response to this, new programs were developed focusing on the unique needs of these regions. The first large aquatic ecosystem protection programs were developed to protect the Chesapeake Bay, the Great Lakes, and the Gulf of Mexico (also discussed in earlier chapters). Each of these three major "place-based" clean water programs has different elements, but there are several key features in common:

- EPA plays a leadership role in cooperation with other Federal agencies and States;
- There is a significant financial investment in research and program support; and
- The programs give significant attention to aspects of aquatic ecosystem health not addressed directly in the Clean Water Act (*e.g.,* sediment remediation in the Great Lakes, wetlands restoration in the Chesapeake Bay).

In addition, EPA has worked with State and local governments and non-governmental organizations since 1987 to improve water quality and habitat in 28 coastal estuaries. These watersheds are designated as nationally significant estuaries through the National Estuaries Program (NEP). A number of these NEP programs have grown to include major, intergovernmental efforts to protect large aquatic ecosystems (*i.e.*, Long Island Sound, Puget Sound, Columbia River, and San Francisco Bay).

Several major national organizations have recently released reports endorsing the concept of programs to protect critical large aquatic ecosystems and recommending the expansion of this effort. For example, a report by the National Academy of Public Administration calls for "making large aquatic ecosystem restoration a national priority" and "identifying the specific actors, tools, and funding necessary to achieve pollution reduction targets in each area".

To address ways to improve coordination and programmatic efforts to protect these vital water resources, EPA has formed the *Council of Large Aquatic Ecosystems* (CLAE) (USEPA, April 2008). The CLAE will support and promote EPA's implementation of Large Aquatic Ecosystem programs and encourage collaboration within EPA programs and with EPA's external partners, especially the States. The CLAE will also review needed research to support these efforts.

In the following sections of this chapter, basic information is presented about the individual large aquatic ecosystems considered under the CLAE. This information helps to identify their unique needs. A few general unifying themes in the research needs for these important ecosystems are discussed at the end of the chapter.

Chesapeake Bay

Chesapeake Bay, the largest estuary in the United States, holds great ecological, cultural, and economic significance for the States that border it (Virginia, Maryland, Delaware, and Washington, DC). The Chesapeake Bay watershed is roughly 64,000 square miles and also includes parts of New York, Pennsylvania, and West Virginia. According to the Northeast Midwest Institute, the bay supports more than 3,600 species of plants, fish and animals. Given the substantial population living in the watershed (about 16 million people), however, the bay is vulnerable to the effects of development, including point and nonpoint source pollution and overfishing. Some of the impacts include decreased dissolved oxygen and water clarity, loss of submerged aquatic vegetation, oyster fishery depletion, reduced blue crab harvests, and loss of forest cover. The most serious ongoing environmental stressors include excess nutrients and sediment (see discussions on nutrients and sediments in Chapter 5).

Because of the large size of the watershed and the number of States involved, activities to manage the health of the bay must involve collaborations among a number of entities. EPA's

Chesapeake Bay Program has operated since 1983, with the goals of preventing water pollution and protecting aquatic systems. Members of the Chesapeake Bay Program include Maryland, Pennsylvania, Virginia, the District of Columbia, the Chesapeake Bay Commission, the EPA, and citizen advisory groups.

Throughout the years, there have been a number of restoration initiatives and activities. Currently, restoration activities are guided by the Chesapeake 2000 Agreement, which lays out objectives through 2010. In April, 2003, as part of the agreement, EPA Region 3 issued the "Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries" (USEPA, April 2003). These criteria provide an indication of the effects of excess nutrients and sediment on the bay's ecosystems. In 2003, the "Technical Support Document for the Identification of Chesapeake Bay Designated Uses and Attainability" (USEPA, August 2003) was issued. This document outlines the spatial extent of the designated use and the applicable water quality criteria for the areas. Successes of the Chesapeake Bay Program include the new water quality standards, the adoption of nutrient and sediment allocations throughout the watershed, strategies for pollutant reductions in the tributaries, and improvements in National Pollutant Discharge Elimination System permitting (see also Chapters 4, 5, and 6).

Great Lakes

The Great Lakes - Superior, Michigan, Huron, Erie, and Ontario- constitute the largest system of fresh surface water on Earth, containing roughly 20 percent of the world's fresh water supply. In addition to their natural beauty, the Great Lakes serve as a source of drinking water for more than 30 million people, support the culture and life ways of native communities, form the backbone for billions of dollars in shipping, trade, and fishing, and provide food and recreational opportunities for millions of American and Canadian citizens. (See also the recreational waters discussions in Chapter 5.)

The Great Lakes are highly stressed ecosystems. Invasive species continually change the food web and all processes associated with it, with ballast water from commercial ships being a primary route of entry. Nearshore conditions have worsened within the past decade, with Cladophora (green algae) mats fouling beaches, hazardous algal blooms and waterfowl die-offs associated with botulism type e. Also, nonpoint source runoff and industrial and municipal discharges have introduced contaminants into the lakes' waters and sediments; persistent organic contaminants remain a serious problem. Native fish and wildlife have suffered from the pressures of over-fishing and habitat loss. These are areas of ongoing research and monitoring. (Invasive species research is discussed in Chapter 4 and later in this chapter.)

Individual watersheds contribute to a greater or lesser extent to Great Lakes environmental problems. The tributary input to the nearshore regions of the lakes accounts for most of the nutrient load entering the lakes (*e.g.,* Warren and Kreis, 2005). Recent evidence (Richards,

2008) points to a large increase in the soluble, reactive fraction of the total phosphorus entering the nearshore as a concern and potential cause of nearshore algal problems. The change in type of phosphorus entering the lakes may indicate watershed changes in farming practices, urban surfaces/land management, weather or climate related changes to precipitation, or atmospheric deposition.

As with other large aquatic ecosystems, multiple States have a stake in the health of the Great Lakes. The Great Lakes also have the distinction of straddling the US–Canadian border. Therefore, a number of collaborative initiatives operate to protect and restore the Great Lakes. The Great Lakes Water Quality Agreement of 1987 established international efforts with Canada. EPA work is done through the Great Lakes National Program Office, which brings together federal, State, local, Tribal, and industry partners. The Great Lakes Interagency Task Force was formed in 2004. It fosters regional collaboration with the Council of Great Lakes Governors and the Great Lakes Cities Initiative. The Great Lakes Regional Collaboration includes the Task Force, the Great Lakes States, local communities, Tribes, non-governmental organizations, and other interests. Their strategy was released in 2005 and continues to serve as a guide for restoration of the Great Lakes Ecosystem.

Gulf of Mexico

The Gulf of Mexico is the ninth largest water body in the world. Its coastline in the United States is 1,630 miles long. It is bordered by Florida, Alabama, Mississippi, Louisiana, Texas in the United States, five Mexican States (Tamaulipas, Veracruz, Tabasco, Campeche, Yucatan), and Cuba to the southeast. Its watershed is enormous, draining 31 States in the US (including the entire Mississippi River drainage) and a similar area in Mexico. The Gulf of Mexico is renowned for its fisheries, producing an estimated $689 billion in 2006. The area is especially prolific with respect to shrimp and oysters. Sport fishing is also popular in this region. The Gulf figures prominently in US gas and oil production, providing a quarter of the US domestic natural gas and one eighth of its oil. Ecologically, the gulf region contains coastal wetlands, submerged vegetation, upland areas, and marine/offshore areas. It includes about half of the US wetlands, and provides habitat for migratory birds, sea birds, and wading birds. The Gulf region also has a thriving tourism business, as well as containing vital shipping areas, including the Port of South Louisiana and the Port of Houston.

As of 1995, the population in the US coastal areas surrounding the Gulf of Mexico was 44.2 million, and growth in the region is rapid. With such a large population, environmental pressures in the region are large. Restoration of water quality in the Gulf of Mexico is a major priority in the efforts to improve the health of the Gulf ecosystem. A major concern in the area is a large area of low oxygen (hypoxia) that develops during the summer of the coasts of Louisiana and Texas. The size of the hypoxic zone has been increasing due to excess nutrient inputs into the Gulf and poses a serious threat to the integrity of Gulf ecosystems. Gulf of Mexico hypoxia has been the subject of research in both the government and academic sectors (see additional discussion in Chapter 4). Another, related problem, harmful algal blooms (HABs) can cause human health problems and affect commercial fishing (see Chapter 5 for additional discussion of HABS). Also, wetland losses in the Gulf area have been severe (about fifty percent).

In 1988, the EPA founded the Gulf of Mexico Program to address major environmental issues in the Gulf of Mexico using an ecosystem-based framework. The program is intended to be collaborative in nature and includes participation from State and local governments, the private sector, and universities. Because of the urgency of the hypoxia problem, the EPA has developed the Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico (USEPA, 2008). Further information on the efforts and research needs surrounding Gulf of Mexico Hypoxia are provided later in this document. Efforts initiated by the States and supported by federal agencies (including the EPA) include the Gulf of Mexico Alliance, a partnership of the five Gulf States that works to implement the Gulf of Mexico Governors' Action Plan (March 2006).

South Florida

South Florida is home to a diversity of ecosystems, including the Everglades and the Florida Keys coral reef systems. This area includes the largest wilderness east of the Mississippi River and the United States' only living coral reefs. It is home to large commercial and sports fisheries and includes important habitat for wading birds, crocodiles, manatees, panthers, and other animals. The coral reefs, seagrass beds, and mangroves in particular make the Keys a unique and precious natural resource. The Region contains three national parks (including the Everglades National Park), ten national wildlife refuges, and a national marine sanctuary.

As with other significant aquatic ecosystems, South Florida is under pressure from an expanding population. About eight million people currently live in South Florida, and substantial growth is anticipated in the next 10 to 20 years. As a result of suburban development and agriculture, fifty percent of South Florida's wetlands have been lost. Changes in nutrient dynamics and habitats have also taken place. Furthermore, the region is susceptible to climate change. The coral reefs require optimal environmental conditions and may experience coral bleaching due to increased temperatures, disease, excess shade, increased ultraviolet radiation, sedimentation, pollution, and salinity changes (see Chapter 4). Mangrove communities may also be harmed by climate change and are also vulnerable to invasive plants and agricultural runoff.

The EPA's South Florida Geographic Initiative implements programs to protect and restore South Florida's ecosystem. It operates from Region 4's South Florida Office, located in West Palm Beach. In 1993, EPA's Everglades Ecosystem Assessment Program was initiated to provide long-term research, monitoring, and assessments. This program has been able to document the effectiveness of measures to control mercury and phosphorous. It provides information on how effective restoration measures have been, and it is able to provide an indication of the effects of multiple stressors on the ecosystem. In 2002, the US Coral Reef Task Force passed a resolution that prompted the formation of Local Action Strategies. Goals of this program include reef ecosystem characterization and identification of pollution sources, research on the effects of pollution on coral reefs, and efforts to reduce the impacts from pollution. (Research support for South Florida and coral reefs are further discussed in Chapter 5.)

Long Island Sound

Long Island Sound is bounded by New York and Connecticut and is 110 miles long and 21 miles across at its widest. It is an integral part of the landscape for both States, encompassing the entire coastline of Connecticut. Designated in 1987 as a national estuary, the Long Island Sound ecosystem supports more than 170 species of fish and 1,200 invertebrate species. Its watershed is home to more than eight million people. The Sound provides $5.5 billion per year in economic benefits to the region from boating, commercial and sport fishing, swimming, and beaches.

The Long Island and Connecticut shorelines are heavily developed, and the Sound faces a number of environmental challenges. Excess nutrient loads from sewage treatment plants and polluted runoff have led to hypoxia. In fact, more than one billion gallons per day of treated effluent enter the Sound from 106 treatment plants; reducing nutrient loads is a top management priority for the Sound. Other environmental challenges include floatable debris, toxic pollutants, the impacts of dredged materials, and the impact of water quality degradation on marine resources. In addition to reducing nutrient loads, top priorities for restoration and management of the Sound include habitat restoration, disposal of dredged materials, and public education and involvement.

The Long Island Sound Study (LISS) was formed in 1985 with the goal of restoring the Sound. It is a bi-State partnership of federal and State agencies and other organizations. It is now supported by EPA's Long Island Sound Office, which was established in 1992 by congressional legislation. The Long Island Sound Comprehensive Conservation and Management Plan (CCMP) (LISS, March 1994) was approved in 1994 and represents a partnership between EPA's Regions 1 and 2 and the States of New York and Connecticut. The long term goals for the Sound include meeting Connecticut and New York water quality standards for dissolved oxygen by 2014 and restoring 2000 acres of tidal wetlands and other coastal habitats and 100 river miles of migratory fish habitat by 2008.

Lake Champlain

Lake Champlain is the sixth largest inland water body in the United States and is of great historical and cultural significance to upstate New York, Vermont, and Quebec. It is 435 square miles in size and has more than 50 islands. More than 600,000 people live within its 8,234 square mile drainage basin, and it supplies drinking water to an estimated 200,000 people. The lake provides fishing opportunities for a wide variety of freshwater fish, as well as boating and winter ice fishing. With canals linking it to the St. Lawrence and Hudson rivers, it also serves as a commercial harbor. Industrial activities include paper mills. Water quality in Lake Champlain is threatened by seven industrial and 66 sewage treatment plants. High levels of phosphorous lead to algal blooms in parts of the lake. Toxic substances are found near urban areas such as Burlington, VT, and Plattsburgh and Ticonderoga, NY, and fish advisories have been issued for PCBs and mercury. There are also 34 hazardous waste sites and 95 landfills in the Lake Champlain drainage basin. Additional problems include toxic cyanobacteria in the northern parts of the lake, which have lead to beach closings and pose a risk to drinking water.

The Lake Champlain Special Designation Act (1990) designated Lake Champlain as a resource of national significance. The Act created a coalition of organizations to create a plan for pollution prevention, control, and restoration, titled *Opportunities for Action: An Evolving Plan for the Lake Champlain Basin* (Lake Champlain Steering Committee, April 2003*)*. This plan is in the implementation phase, and it guides the efforts of the Lake Champlain Basin Program, a federal, State, provincial, and local initiative to restore and protect Lake Champlain and its surrounding watershed. USEPA Region 2 is part of this program.

Columbia River

The Columbia River Basin includes parts of seven States (Oregon, Washington, Idaho, Montana, Nevada, Wyoming, and Utah) and British Columbia. It is more than 260,000 square miles in size. The river itself is 1,200 miles long, and its largest tributary is the Snake River. Ecosystems within the basin range from temperate rain forest to semi-arid plateaus. The Columbia and Snake rivers provide valuable economic services to the region by serving as a shipping route to and from the Pacific Ocean. From a cultural standpoint, the Columbia River is the site of historic salmon and steelhead runs. It provides recreational value in sport fishing for salmon and steelhead, sailing, swimming, water skiing, canoeing, and rafting. The river is extensively used for hydroelectricity. Also, approximately one percent of the system's annual flow is used for irrigation.

Fish populations in the Columbia River have suffered heavy impacts. Overharvesting, habitat destruction, and pollution all harm wild salmon. There has been a 90 percent decline in salmon populations and a 55 percent loss of salmon and steelhead habitat. Together with observed accumulations of toxic pollutants in fish tissues, the environmental conditions are severely detrimental to the fish populations. Habitat loss and other environmental stressors have also taken their toll on birds; several species of birds in the Columbia River Basin are listed as threatened or endangered. In the lower Columbia River, the last 100 years have brought habitat loss in the estuary.

The Lower Columbia River Estuary Partnership (LCREP) (part of EPA's National Estuary Program) works on managing toxic substances and restoration of wetlands in the estuary. It was formed in 1996. It developed a management plan in 1999, which has provided guidance for estuary restoration activities. The LCREP provides information on toxics and on habitat and implements the Lower Columbia River's Comprehensive Conservation and Management Plan (Jerrick, June 1999). Goals for 2011 include protection and/or restoration of wetland and upland habitat in the Lower Columbia River Watershed, cleanup of contaminated sediments, and reduction of contaminants of concern in water and fish tissues. Region 10 has identified a variety of research needs related to the Columbia River Basin. The Region expressed a need for research assistance to support monitoring and assessment of toxics in fish, water, and sediment in the mainstream river and tributaries, which could include case study work. Another area of research needs in Region 10 is support for seven indicator species that have been identified in the Columbia River Basin as a part of the State of the River characterization to fill data gaps and better understand short-term and long-term trends.

Puget Sound

The only fjord system in the United States, Puget Sound has a shoreline of more than 2,000 miles. It is part of the National Estuary Program, and its watershed includes more than 16,000 square miles of land and water and has more than 10,000 rivers and streams. It is extremely diverse ecologically; according to the Puget Sound Partnership, it is home to 220 species of fish, 26 types of marine mammals, 100 species of sea birds, and many marine invertebrates and plants. In addition to its biologically diversity, the Puget Sound area provides many cultural, social, and economic services. It provides salmon fisheries, sport fishing, shellfish, and tourism. The area also hosts international ports and defense installations.

The Puget Sound Georgia Basin watershed is home to over six million people, with a high rate of growth expected. This large and increasing population will continue to stress the Puget Sound ecosystem. A number of environmental problems are already prominent. Since 1980, 30,000 acres of shellfish beds have been closed. As with many other aquatic ecosystems, excess nutrients have given rise to hypoxic zones. Each year, about one million pounds of toxic substances are released into the water and five million pounds are released into the air. As a result, marine species have high levels of toxic compounds in their tissues. The Puget Sound Georgia Basin Ecosystem Indicators can be used to monitor the health of the ecosystem. For example, the water quality index includes pH, dissolved oxygen, phosphorous, and suspended sediments. The indicators for 2003 showed that 50 percent of Puget Sound's permanent monitoring stations had fair water quality. These areas were generally close to urban centers.

As part of the National Estuary Program, Puget Sound restoration efforts receive federal support. Other Puget Sound initiatives include the Puget Sound Action Team and the Puget Sound Council. The Action Team includes representatives from State and federal agencies, Tribes, and local governments and handles amendments to the Puget Sound Management Plan. The Council consists of various stakeholders (shellfish growers, business, agriculture, cities, the environmental community, etc.) and works with the Action Team to implement management efforts.

The Pacific Islands

The unincorporated US Pacific Island Territories of Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands (CNMI) are volcanic islands with rainforests and coral reef systems. Such ecosystems have great biological diversity, with large numbers of fish species noted in the marine systems. These islands are remote and their populations are relatively small; Guam has the largest population at 173,000. Tourism is a principal industry for both Guam and CNMI, and American Samoa has important tuna fisheries.

Island ecosystems are especially vulnerable to climate change. Immersion from rising sea levels poses a threat to coral reefs and mangroves. Increased sea temperatures also present a danger to corals. (See Chapter 4 for discussion of coral reefs and Chapter 7 for discussion of climate change.) Although population densities are low compared to the heavily urbanized areas of the United States, delicate ecosystems are sensitive to population growth in these Territories. Pollution (including pesticides), overfishing, and invasive species are other prominent environmental issues. The Territories face additional problems as they struggle with aging infrastructure and the resulting deficiencies. Drinking water and sanitation are top priorities; poor wastewater handling systems can result in contamination of surface and subsurface water drinking water supplies. Beach closings due to pollution are frequent. Efforts in recent years have yielded successes. Guam now has safer water, with fewer sewage spills, and new marine preserves have been established. But much work remains to be done with respect to ensuring safe beaches, drinking water, and treated wastewater. EPA's Region 9 works with the Pacific Island Territories through its Pacific Islands Office, which provides funding and technical assistance to the Territories' environmental protection agencies.

The US-Mexico Border

More than nine million people live along the border of the United States and Mexico. The border is 2,000 miles long and includes parts of California, Arizona, New Mexico, and Texas. The population in the region has grown rapidly, with an accompanying increase in industrialization. Pressures exerted by such expansion have led to problems both with drinking water supply and wastewater treatment. The Rio Grande often receives untreated and industrial sewage. Water supply and waste problems are especially serious in the unincorporated "colonias" on the US side of the border, where there is a lack of safe drinking water and wastewater and waste disposal infrastructure. Region 6 has noted that there are more than 1,220 colonias in Texas and New Mexico. Conditions in these settlements leave the residents vulnerable to health problems from waterborne illnesses. Increased industrial waste also creates toxic pollutants.

Cooperative efforts have been established to address environmental needs in the border region. EPA has provided funds through the Tribal Border Infrastructure program to provide basic sanitation and access to safe drinking water. The Border 2012 program has several goals: 1) improve water quality in the region; 2) improve the availability of low sulfur diesel fuel on the border; 3) stabilize abandoned hazardous waste sites; 4) remove used tire piles along the border; 5) define baseline and alternative scenarios for air emissions reductions along the border region; and, 6) bi-national emergency preparedness drills and exercises at border sister cities. Also, North Atlanta Free Trade Agreement has created the Border Environment Cooperation Commission and the North American Development Bank for infrastructure development. EPA participates in these programs.

Research Needs for Large Aquatic Ecosystems

Despite having their own unique cultural, ecological, and economic features, the large aquatic ecosystems share several common environmental concerns. These arise largely related to continued, intensifying human activities, both along shorelines and in the watersheds. Both urban and agricultural land uses can alter landscapes and provide undesirable inputs into these water bodies and into the streams and rivers that feed them. This section briefly mentions some of these prominent concerns. Greater detail on these various research needs is provided in other chapters of this document.

Excess Nutrients

Input of nutrients results from runoff from agricultural lands, suburban runoff, discharges from sewage treatment plants, and air deposition from various sources. By promoting excessive plant growth and decay, high nutrient inputs can ultimately lead to oxygen depletion, fish kills, and a decline in water quality. The dynamics of nutrient cycling and ways to mitigate nutrient inputs are common threads for the various large aquatic ecosystems. In Long Island Sound, for example, research is needed on the response of the Sound (biologically, geochemically, or physically) to local nitrogen reductions and to ocean climate/variability. Research is needed on the processes that control hypoxia in the sound (*e.g.,* phytoplankton dynamics, mixing, sedimentary geochemistry). In the Great Lakes, collaborative research between EPA and National Oceanic and Atmospheric Administration will focus on monitoring the dead zone in Lake Erie and will update models of Lake Erie's response to nutrients. Also, in all affected water bodies, there is an ongoing need for improved management measures to control hypoxia. (See also the discussion of Gulf of Mexico and Gulf of Mexico Hypoxia earlier in this chapter and in Chapter 4. A more extensive discussion of nutrients research is presented in Chapter 5. Management of nutrients associated with residuals is discussed in Chapter 3).

Excess Sedimentation

Changes in land use permit erosion and promote the transport of excess sediments to water bodies. The excess sediment degrades aquatic habitats and harms coral reefs. The Scientific and Technical Advisory Committee (STAC) for the Chesapeake Bay Program has presented detailed research needs for sediments in the Chesapeake Bay. Among other issues, scientists in the STAC have noted that research is needed on the relationships between sediment deposition and various anthropogenic (land use change) and natural (*e.g.,* climate variability) factors. Research is also needed on the origins, transport, and residence times of sediments in the estuary. Another important topic is how much nutrients and other pollutants are associated with sediments. The effectiveness of best management practices needs ongoing research. The types of research questions framed for the Chesapeake Bay are applicable to many ecosystems, although some have unique needs. For example, research regarding sediments in South Florida must focus on the special needs of the coral reefs and how sediment affects them. Additional discussion regarding sediments is provided in Chapter 5.

Invasive Species

By displacing native terrestrial and aquatic species, invasive species cause great harm to ecosystems. In the Great Lakes, research is needed on the causes of the decline of Diporeia population in the Great Lakes (possibly due to invasive species). In the Great Lakes, zebra mussels clog water intake pipes and encrust boat hulls and engines. Puget sound is beset by various invasive species (*e.g.,* Chinese mitten crabs, European green crabs, knotweed, and nutria). Because prevention is preferable to control, EPA is studying how native species have become established in aquatic ecosystems with the goal of preventing future invasions. In particular, methods to control the introduction of invasive species in ballast water are needed. For additional discussion, see Chapter 4.

Toxic Substances

Contaminated sediments are a common environmental concern in all of the large aquatic ecosystems, especially those with inputs from industrial areas. Aside from their immediate impacts on the water column, inputs of toxic substances can have long term ramifications when associated with sediments. In Puget Sound, for example, studies are needed to understand the distribution of pollutants in runoff, including metals, polycyclic aromatic hydrocarbons. Studies are needed on the occurrence of emerging contaminants in the Sound and their relative importance. In the northeast, the LISS has presented a detailed summary of research needs. Sources and inventories of conventional and emerging toxic contaminants are needed. Research is also needed on the impacts of contaminants on ecosystem function. New technologies are needed for management of sources and for remediation. Similar needs are echoed for the other aquatic ecosystems. (See also the discussion on emerging contaminants in Chapter 5.)

Climate Change

With rising waters and rising temperatures, the large aquatic ecosystems will be vulnerable to the effects of climate change. South Florida, for example, will be exposed to inundation, degradation of the Everglades, coral reef bleaching, and potential contamination of drinking water supplies. American Samoa would also face damage to coral reefs. Northern aquatic ecosystems may see changes in their hydrologic cycles as precipitation patterns change and ice formation is delayed or reduced. Increases in runoff and combined sewer overflows, with their accompanying loads of nutrients and toxic substances may occur. With shifts in environmental conditions, many ecosystems may see the disappearance of some species, or the ranges of some species shift. Understanding how aquatic ecosystems will be affected by these changes is needed, as is research on options for management and mitigation. Chapter 7 provides further climate change discussion.

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7 ● Science to Support Cross-Program Needs

The implementation of the National Water Programs, and development of its related research plans, have historically been developed to address specific statutory (*e.g.,* SDWA, CWA) or regulatory responsibilities. As described in Chapter 1, to meet its statutory obligations, the OW Offices are organized, in part around these programmatic responsibilities. As the Water Program has matured, the improved knowledge and understanding of the interrelationship of environmental issues has led to the identification of programmatic and research needs that are common to multiple offices and has fostered development of many cross-program research initiatives and approaches. These efforts are designed to enhance the collaborative process and to find solutions to environmental issues that cut across programmatic areas. Through recognition of the need for integration of these research efforts, the Water Program can more efficiently use resources to address multiple environmental issues and to support and enhance efforts across the various Offices. Many of these topics are noted and discussed throughout this *Compendium*. Five areas, in particular, cut across programs areas and are highlighted in this chapter. They are:

- The Sustainable Infrastructure Initiative
- Watershed Approach
- Analytical Methods – To Detect Biological and Chemical Contaminants
- Emerging Contaminants
- Climate Change

Each of these areas is discussed in earlier chapters. This chapter will summarize the cross-program needs briefly, for most of these areas, and will direct the reader to the appropriate chapters for more detail. The major discussion of the climate change initiative is presented in this chapter, including the drivers for research. This is presented here because OW is developing a strategy to respond to climate change and climate change issues clearly will impact each of the OW Programs.

Sustainable Infrastructure Initiative

Drinking water and wastewater treatment plants, sewer lines, drinking water distribution lines, and storage facilities ensure protection of public health and the environment. (See Chapters 2 and 3 for an in-depth discussion of the Drinking Water program and Wastewater program, respectively.) As a nation, we have built this extensive network of infrastructure to provide the public with access to safe drinking water and proper sanitation. Much of the drinking water and wastewater infrastructure in the United States was built more than 50 years ago, following World War II, mirroring the increase in the urbanizing population – and some is far older, particularly in the eastern U.S. The useful design life of much of this infrastructure is nearing its end. The arriving wave of needed infrastructure rehabilitation and replacement over the next several decades will be unprecedented. Infrastructure needs are estimated at over $240 billion over the next 20 years – well in excess of the funds estimated to be available to meet the Nation's infrastructure needs.

Through the Sustainable Infrastructure Initiative, EPA is committed to promoting sustainable practices that will help to reduce the potential gap between funding needed and spending at the local and national level. The Sustainable Infrastructure Initiative will guide efforts in changing how the nation views, values, manages, and invests in its water infrastructure. EPA is working with the water industry to identify best practices that have helped many of the nation's utilities address a variety of management challenges and extend the use of these practices to a greater number of utilities. EPA is collaborating with a coalition of water industry leaders to build a roadmap for the future promotion of sustainable infrastructure through a "Four Pillars" approach based on 1) better management of water and wastewater utilities; 2) rates that reflect the full cost pricing of services; 3) efficient water use; and 4) watershed approaches to protection.

Sustainable Infrastructure Research Needs

The Water Program has identified research needs to promote each of the four pillars of sustainable infrastructure. Those that pertain to Improved Management, Full Cost Pricing, and Efficient Water Use are discussed in this section. Because of the breadth of the Watershed Approach, it is also a Cross-Program area and it is discussed in its own section that follows.

Improved Management

Water infrastructure is expensive as are the monetary and social costs incurred when infrastructure fails. If a system is well maintained, it can operate safely over a long time period. A new system that is not properly operated can threaten public health more than an older system that is properly operated. Water and wastewater utilities need to carry out an ongoing process of oversight, evaluation, maintenance, and replacement of their assets as needed to maximize the useful life of infrastructure.

Research is needed to provide utilities with tools that will allow them to better manage the nation's aging drinking water and wastewater infrastructures. EPA's research initiatives related to aging infrastructure will focus on providing information on new and innovative condition assessment and rehabilitation and replacement methods and technologies; new sewer and treatment system design concepts; and comprehensive, integrated management approaches to improve the ability of water and wastewater utilities to cost-effectively assess, maintain, operate, rehabilitate, and replace their collection and treatment systems. Further, research is needed to better understand and integrate Green Infrastructure approaches into a comprehensive approach, as well as water reuse and reclamation approaches. (See Chapters 2 and 3 for further details.)

Full Cost Pricing

When measured as a percentage of household income, the U.S. pays less for water/wastewater bills than other developed countries. Because of this, the public has been led to believe that water is readily available and cheap. Pricing that recovers the costs of building, operating, and maintaining a system is essential to achieving sustainability. Drinking water and wastewater utilities must be able to price water to reflect the full costs of treatment and delivery, and additional data are needed to help utilities evaluate and estimate these costs. In addition, social marketing approaches need to be explored to determine how to best educate the public regarding the benefits and costs of providing high-quality public services.

Efficient Water Use

EPA is focused on developing a water efficiency program that takes a broad approach by setting water efficiency levels for products, in conjunction with manufacturers, utilities and other stakeholders; building partnerships with manufacturers, distributors, utilities and others to promote water efficient products; and promoting an ethic of water efficiency through promotional activities. EPA is developing a market enhancement program for water efficient products and services in the residential and commercial sectors.
Research needs to build on these efforts to allow decision makers to better define the effectiveness, costs, and benefits of water conservation and water efficiency practices and programs. Additional efforts should focus on social marketing approaches to provide effective education and outreach campaigns on water conservation.

Watershed Approach

The Water Program's Watershed Approach is a coordinating framework for environmental management that helps to integrate and focus public and private sector efforts to address the water protection and restoration implementation efforts within hydrologically-defined geographic areas. The approach considers both ground water and surface water flow and the multidisciplinary and multijurisdictional partnerships that must come into play for effective and efficient water management. Such comprehensive approaches promote recognition of the priority needs of local water resources and will result in significant protection, restoration, and maintenance of water resources in the United States.

Watershed Approach Research Needs

The Watershed Approach cuts across all OW program offices and requires the integration of CWA and SWDA authorities. As such, all the programmatic and research needs discussed throughout this *Compendium* are pertinent for implementation to "the watershed." As described in detail in Chapter 4, key objectives of the Watershed program are: to promote integrated monitoring and assessment for water body and ecosystem protection; assess 100 percent of water bodies in the lower 48 States; promote management and restoration off water bodies and ecosystems; provide the information needed to execute TMDL programs; and improve the effectiveness of ecological restoration. Current implementation of the Watershed Approach is focusing on four main areas including 1) watershed management training; 2) Statewide watershed approach facilitation; 3) watershed program scoping; and 4) technical analysis assistance. As noted these help to define the research needed. But in the broader sense of a cross-program topic, the Watershed Approach (Chapter 4) recognizes the need to integrate OW Programs to provide cost-effective and efficient protection of ecological and human health. (See also the Addendum to Chapter 1.)

This integration involves recognizing the linkages among the National Water Program initiatives that include, for example:

- Assessment of water quality and ecosystem impairment (*e.g.,* Chapters 4 and 5);
- Developing water body use designations;
- Developing and setting water quality standard (WQS) (Chapter 5);
- NPDES permitting (Chapter 3);
- TMDL development (Chapter 4);
- Implementing point and non point source control and management, including wet weather management (Chapters 3 and 4);
- Promoting "Smart Growth" and Green Infrastructure practices in communities (Chapter 3);
- Improving decentralized wastewater management (Chapter 3);
- Protecting and restoring wetlands (Chapter 4); and
- Water quality trading (Chapter 4).

Improvements in each of these areas contribute to meeting WQS, which in turn will protect aquatic ecosystems and provide source water protection for drinking water (see Chapter 2).

There are research needs to improve and effectively target each of these efforts discussed throughout this *Compendium*. Some examples of research needs are highlighted for these initiatives, and summarized below for:

- Watershed/Aquatic Resource Assessments (also refer to Chapters 4 and 5)
- Implementation Program Needs (also refer to Chapters 3 and 4)
  - Management Measures
  - Incentives
  - Wetlands and Water Quality Trading
  - Decentralized Water Systems
- Source Water Protection (also refer to Chapter 2)

Watershed/Aquatic Resource Assessments

Watershed assessments can focus on a single watershed or a group of watersheds comparatively. CWA-related watershed assessments may involve characterizing basic traits of waters, their watersheds, and their human community context. Assessments may also evaluate condition and functionality, giving an indication of the ecological, economic, and cultural services the watershed is able to provide. They may assess threats, identify causes of problems, and set priorities for specific remedial actions. Research is needed to allow these assessments to effectively account for the combined and cumulative effects of point and non point sources of pollution, habitat alteration, and other sources of impairment.

Policy makers and watershed managers also need reliable chemical, physical, and biological information that will allow them to understand the status and functioning of aquatic ecosystems and to evaluate the success of watershed protection and restoration measures over time. To accomplish this, research must focus on providing tools for effective ecosystem monitoring, identifying appropriate indicators of aquatic health and determining suitability of new analytical methods; and develop and improving integrative watershed modeling frameworks for describing the impacts of changing surface water quantity on water quality.

Implementation Program Needs

A few components are summarized to illustrate the breadth of Implementation Program issues: Management Measures, Incentives, Wetlands and Water Quality Trading, Decentralized Wastewater Systems.

Management Measures. To meet the water quality targets in a given watershed, managers may have several management "strategies" from which to choose, each consisting of one or more management measures. Strategic placement of specific management measures in a watershed should reduce the number and cost of measures required to attain WQS compared to separately selecting management measures for incremental parts of the watershed.

Research is needed to assess the costs associated with various management measures to allow for the development of effective watershed strategies, to develop strategies to optimize the selection and location/placement of management measures in a watershed, and to develop monitoring strategies to measure the effectiveness of watershed management programs.

Incentives. Non point sources account for much of the water quality impairment to our nation's waters. Because these sources are not regulated, economic and other incentives need to be developed to control them as part of watershed-based water quality improvement programs. In addition, people have ingrained cultural values and attitudes associated with environmental protection. Thus, incentives may be needed to change behavior to implement management plans.

Research is needed to determine the factors that most motivate changes in public behavior with respect to the protection or restoration of water quality. In addition, effective technology transfer mechanisms are needed to provide watershed managers with resources needed to make technically-sound watershed management decisions (*e.g.,* establishing a central access point for watershed information on the EPA Web site). Another important and promising pollution reduction incentive is wetlands in water quality trading, which is discussed in more detail below.

Wetlands in Water Quality Trading. OW is evaluating the use of wetlands in a water quality trading program as one approach for achieving water quality goals more efficiently. The program operates at the watershed level in which a facility with higher pollutant control costs can buy pollutant reduction credits from a facility with lower control costs in the same watershed, thus reducing their cost of compliance. Such trading programs can allow a given watershed to meet water quality targets (*e.g.,* TMDLs at lower overall costs), and can provide ancillary benefits such as flood retention, riparian improvement, and habitat.

Before wetlands can be reliably incorporated into water quality trading programs, research is needed to: identify existing data regarding wetland nutrient removal rates for modeling and assigning trading credits; determine how to avoid unintended negative consequences; determine the geographic scale on which trading might occur; identify an approach for estimating the risks, costs, and benefits associated with wetland trading; and determine how to manage and monitor wetlands used in water quality trading.

Decentralized Wastewater Systems. Decentralized wastewater systems consist of septic systems that treat and disperse relatively small volumes of wastewater from individual or small numbers of homes and commercial buildings. EPA research is needed to evaluate treatments that will improve system performance such as the abilities of the various soil types to provide treatment; treatment system efficiencies for currently regulated pollutants (pathogens and nutrients) and emerging pollutants of concern (see Emerging Contaminants discussion later in this chapter); and performance capabilities and reliability of many currently available decentralized treatment technologies.

Research is also needed to accurately account for decentralized systems (both properly and poorly designed, operated, and maintained systems) in watershed models and TMDL calculations. In addition, up-to-date technology transfer methods regarding innovations and costs must be an important component of this research *Compendium* because many practitioners of decentralized systems do not normally interact with EPA.

Source Water Protection. Source Water Protection – protecting waters that will become public drinking water supplies – can be successful in providing public health protection and reducing the treatment challenge for public water suppliers. The many threats to watersheds, water bodies, and ecosystems discussed, point and nonpoint sources of impairment, are in turn threats to source water quality. The 1996 SDWA Amendments required the conduct of source water assessments for the protection and benefit of public water systems. States were also required to adopt a program to protect wellhead areas within their jurisdiction from contaminants that may have any adverse effect on public health. As noted, effective source water protection requires the integration of CWA and SDWA programs. Implementation of watershed protection and water quality restoration programs, in turn affect source water improvement and protection.

Research is needed to develop science-based tools that better enable the assessment of drinking water resources and their vulnerability to contamination, and the control of non point source and otherwise unregulated point source pollution at the water resource scale (*i.e.,* watershed and aquifer). In addition, EPA must account for climate change impacts on water resources and how this may affect drinking water supplies by developing tools that allow integrated water resource planning and management at multiple water resource scales across multiple decades. (Note: Climate change and related research needs are discussed in greater detail later in this chapter.)

Analytical Methods – To Detect Biological and Chemical Contaminants

The National Water Program requires sensitive, specific, accurate, and precise analytical methods that can detect and quantify the occurrence of contaminants in water and other media. Methods are needed to measure water quality to assess the status and health of waters and to develop standards, measure compliance, and/or the verification of their remediation or removal. For example, from across the programs, the availability of such methods is needed to:

- Develop, implement, or revise drinking water standards for existing or unregulated contaminants (refer to Chapter 2);
- Protect and provide water security for our drinking water sources (also refer to Chapter 2);
- Develop, implement, or revise water quality criteria and water quality standards for ambient waters, to support water quality goals, aquatic life guidelines,

TMDLs, as well as wastewater guidelines and the NPDES process (also refer to Chapters 3, 4, and 5);
- Assess and promote the safety of recreational waters (also refer to Chapter 5);
- Conduct watershed assessments, including source tracking, to help target programs for water quality improvement (also refer to Chapters 4 and 5);
- Manage residuals and biosolids from drinking water and wastewater treatment processes (also refer to Chapters 3 and 5);
- Identify invasive species that threaten our waters (also refer to Chapter 4); and
- Assess the occurrence of new or emerging contaminants (Chapter 7).

Analytical Methods Research Needs

As noted, there are analytical methods needs across the National Water Program. Cross-cutting needs that have been highlighted in the earlier chapters, are summarized below. Of growing concern across the National Water Program is the ability to identify emerging contaminants, both biological (pathogens, invasive species) and chemical (pharmaceuticals, pesticides) not only in water but in land-applied biosolids, septage, and manure. Continued research is needed to develop techniques that are accurate, precise, and suitable for these different environmental matrices. In particular, the development of more reliable and faster methods for identifying pathogens and pathogen indicators is a research priority because of the acute health effects of pathogens. After some specific program needs are reviewed this section provides a brief overview of methods needs related to pathogens and then chemicals. (Emerging Contaminants and associated research are further discussed later in this chapter.)

Develop, Implement, or Revise Drinking Water Standards (See Chapter 2)

Under SDWA, EPA is charged with evaluating unregulated contaminants and developing and revising drinking water standards. EPA sets national standards for drinking water that either limit a particular contaminant in drinking water, or require treatment to remove or inactivate a contaminant. The SDWA mandated several programs that help EPA identify contaminants that require new or revised standards. These programs include the Contaminant Candidate List (CCL), the Unregulated Contaminant Monitoring Regulation (UCMR), and the Six-Year Review of existing regulations (see Chapters 2 and 5). In developing and revising drinking water standards, EPA evaluates threats to public health from microbial and chemical contaminants. These evaluations cannot be made, nor standards set, without adequate analytical methods to support national occurrence data collection and monitoring for regulatory compliance.

In particular research is needed to develop:

- Analytical methods to gather occurrence data for unregulated and emerging contaminants for future UCMR data collection efforts and the CCL Regulatory Determination process.

- New methods or refine existing analytical methods for the detection and quantification of regulated contaminants to improve existing drinking water standards.
- More robust methods for measuring pathogens and emerging DBPs and DBP mixtures in drinking water and distribution systems.

Protect and Provide Water Security (See Chapter 2)

To safeguard our drinking water supplies, the treatment processes, and distribution systems from natural disasters and physical attacks, methods to detect and identify chemical, biological, and radiological (CBR) contaminants in drinking water are critical. EPA's detection research program focuses on developing detectors, analytical methods, sample preparation techniques, and models and tools to detect, in real-time when possible, contaminants introduced into the water and wastewater systems (see Chapter 2). Additional research is required to improve the accuracy of CANARY, a tool that analyzes water quality data streams and identifies anomalous conditions in distribution systems that require further investigation.

Recreational Waters (see Chapter 5)

As noted in Chapter 5, under section 104(v) of the Beach Act, EPA is working toward improving assessments of potential human health risks resulting from exposure to pathogens in recreation waters (including non-gastrointestinal effects). EPA needs methods (including predictive models) that provide more rapid and timely detections of pathogens or indicators of the presence of pathogens that are harmful to human health in recreational waters.

For example, EPA studies have demonstrated the utility of a new indicator and method (*i.e.,* quantitative polymerase chain reaction (qPCR) for *Enterococci*) as a predictor of swimming-related illness in the Great Lakes. However, whether or not qPCR for *Enterococci* is applicable to other settings or appropriate for use across the range of CWA programs is not fully understood. Data gaps include understanding how well the various indicators and methods perform in other settings (*e.g.,* marine versus fresh water; human versus non-human sources of fecal contamination), and how they relate to one another.

Residuals and Biosolids Management (see Chapters 3 and 5)

Wastewater treatment processes are designed to reduce/remove contaminants and generate residuals (*e.g.,* sewage sludge or biosolids, liquid side streams, septage, etc.). Drinking water treatment also results in concentrated residuals that can be hazardous (*e.g.,* radionuclides), and may be included in the influents of wastewater treatment plants. In addition, animal feeding operations generate large quantities of residual manure and stormwater runoff.

To ensure public health and environmental safety associated with the use or disposal of residuals, EPA must be able to identify and control pathogens, emerging contaminants, and nutrients. Research is needed to select appropriate pathogens and indicators to properly assess sewage sludge quality and to develop improved analytical techniques for pathogens and priority contaminants in residuals/biosolids.

Pathogens

There are various needs for improved pathogen indicators and detection methods that cut across programs and environmental media – ambient water, fresh and coastal marine recreational waters, wastewater, drinking water, ground water, and biosolids, for example. While each media may require some special considerations (*e.g.,* pretreatment, filtering, etc.), knowing that methods are needed across these program areas may afford efficiencies in method development research.

For example, to protect public health, there is a need for the development of faster, reliable methods for identifying pathogens and/or pathogen indicators in both drinking water and recreational water because of the acute health effects of pathogens. Such tests could provide for more rapid and timely notification to the public. New tests and new indicators need to be compared and calibrated with standard methods and must provide for a reliable correlation between indicator concentrations and health effects. Studies are also needed to evaluate temporal and spatial variability in fecal indicator concentrations to appropriately characterize water quality and improve management decisions. Related to watershed management, indicators that can be used for tracking sources of fecal contamination are also essential. Such methods may not have the same requirements as those needed for public health management determinations, but the must be effective to guide source reduction approaches.

All OW programs have expressed the need for new and improved methods to be able to more specifically identify pathogens in drinking water, including distribution systems and biofilms, in ambient and recreational waters, wastewaters and biosolids that are land applied and may contribute agents into the environment. Research is needed to assess how well culture and molecular methods (singly or in combination) may perform. Especially with new molecular methods this work must consider the specificity and sensitivity of the methods and how they can address viability (and infectivity) of the pathogens. Similarly, methods must be developed to begin to assess emerging pathogens (from viruses to prions, for example).

Chemicals

Consideration of any new or revised drinking water or water quality standard may identify the need for new or improved methods for particular chemicals. This is a routine part of those programs. For example, to move from the CCL Regulatory Determination process to promulgating a new drinking water standard, it is necessary to have a method that can be used for national compliance monitoring.

A key research area for the National Water Program is the development of analytical methods that can be used to identify and assess the occurrence of emerging contaminants.

Many of the new contaminants of concern for the Water Program, such as pharmaceuticals, and many now termed "personal care products" and endocrine disruptors, need assessment of their entry in to the environment through wastewater and in land-applied biosolids, septage, and manure. The most apparent effects of some of these compounds may be on aquatic life, and methods are needed for ambient waters. Methods may be useful that can address multiple chemicals, with common modes of action, as well, to begin to assess the cumulative effect of low dose chemicals. Methods are also needed to assess their occurrence in drinking water, through the UCMR program, and in support of the CCL process. Emerging Contaminants are a cross-program theme that is further discussed in the next section of this chapter.

Emerging Contaminants

A common need noted throughout this *Compendium* is the ability to better identify, understand, and manage the threat to human health and the aquatic environment from emerging contaminants. Emerging contaminants refer broadly to those synthetic or naturally occurring chemicals, or to any microbiological organisms, that are new to the environment or that have not previously been monitored for or recognized in the environment, but are of concern because of their known or suspected adverse ecological or human health effects. These contaminants, by definition, are insufficiently understood to determine their need for control and regulation.

These contaminants can fall into a wide range of groups, often currently defined by their effects, uses, or by their key chemical or microbiological characteristics. Two key groups of emerging contaminants of concern, discussed in this *Compendium*, are the Endocrine Disrupting Chemicals (EDCs) and the Pharmaceutical and Personal Care Products (PPCPs). Others emerging contaminants include nanomaterials, fluorinated compounds, and pathogens – various protozoa, bacteria, viruses, and prions.

Recent studies show that many of the contaminants of concern, such as PPCPs, are related to human use and waste, entering the environment through the wastewater stream. Various pharmaceuticals and animal care products are discharged into the environment through animal waste from livestock production, as well. Emerging contaminants have been found in wastewater effluents and sewage sludge, runoff from livestock areas, surface waters, ground water, fish tissue, and sediment, and drinking waters. While concentrations are typically very low, below therapeutic doses, many questions and concerns need to be answered. Adverse health impacts in aquatic life have been attributed to PPCPs and EDCs in surface waters, yet many specifics remain unknown. Research is needed to fill data gaps and evaluate these contaminants to protect human and aquatic life.

Emerging Contaminants Research Needs

The Water Program is tasked with identifying emerging contaminants, assessing their occurrence levels in various environmental media and determining whether they may cause human or environmental harm. Research is aimed at providing the data and tools for EPA and its partners to assess, monitor, evaluate, and, if need be, regulate, contain, treat, and remediate these contaminants. Collaboration with other offices within EPA and with other federal agencies, and concerned organizations (*e.g.,* Water Environment Research Foundation, Water Reuse Foundation, and the AWWA Research Foundation) will also be critical, given the scope of these issues. In addition, other federal agencies have important programs underway to monitor for new contaminants of concern where coordination will help inform specific research needs (*e.g.,* the U.S. Geological Survey).

The National Water Program has various research questions that cut across program areas that directly pertain to human health criteria and standards for drinking water, recreational exposure, and shellfish consumption, and aquatic life guidelines, and aquatic life criteria. These research needs are:

- Develop approaches for identifying/categorizing which emerging contaminants (or classes) are risks to the environment or human health.
- Develop analytical methods to detect and quantify emerging contaminants in various media – from ambient water, drinking water, to wastewater and biosolids.
- Establish a framework for prioritizing high-risk emerging contaminants for exposure and hazard assessment and criteria/standard development.
- Determine the routes of discharge and release into the environment, fate and transport, and avenues of exposure to humans and aquatic life.
- Develop approaches to assess the toxicological significance of long-term exposure to mixtures of these chemicals at low doses.
- For those contaminants (or classes) that are candidates for regulation, conduct the necessary supporting research for the appropriate water regulatory program.
- Determine improved methods of risk communication to the public related to these emerging contaminants.

Amidst these broad needs another key question to address is whether pharmaceuticals, antibiotics in particular, discharged into the environment in low doses can contribute to antibiotic resistance in microbes and humans?

This emerging contaminant research will support programs that:

- Assess risk to human and ecological health protection;
- Provide for effective treatment and management of wastewater and residuals; and
- Develop drinking water standards for unregulated contaminants

Human and Ecological Health Protection

The need for assessing risk to human health and aquatic life cuts across OW programs. As discussed in more detail in Chapter 5, both pathogens and chemicals are of concern as emerging contaminants individually and as multiple stressors, through water and the land application of biosolids. Research is needed to evaluate whether or not the existing toxicological methods can adequately account for and address emerging contaminants. Research is needed to develop testing procedures or models for evaluating their fate and effects. Continued research is also needed to assess the quality and utility of data, tools, and methods used for risk assessments for new and unique contaminants, such as prions and nanomaterials. This research must support the development of standards for human health protection (*e.g.,* drinking water) as well as aquatic life guidelines.

Unique to pathogens, studies are also needed to determine the impacts of climate change on human pathogens. In particular, these studies should examine how climate change will affect the types and levels of human pathogens that can enter, be sustained, and thrive in waters of the U.S. (See also Climate Change discussion later in this chapter.)

Management and Treatment of Wastewater and Residuals

Emerging contaminants found in publicly-owned treatment works (POTWs) and decentralized system waste streams are an increasingly important part of wastewater and residuals characterization and management. Compounds such as PPCPs and pathogens need to be detected and managed. In addition, as new industries emerge and grow, EPA must stay abreast of new threats to water quality and identify ways to prevent their introduction to waters, and where necessary, to treat them.

Research is needed to support the Water Program goal of providing information on treatment and management of wastewater and residuals from municipal wastewater, industrial wastewater, stormwater, combined sewer overflows (CSOs), concentrated animal feeding operations (CAFOs), and decentralized systems, including beneficial use of residuals and re-use of treated wastewater. In particular, as wastewater technology changes, research is needed to assess both conventional and emerging technologies for their efficacy and cost-effectiveness.

Refer to Chapter 3, Science to Support Wastewater Management for Water Quality Protection Programs, for a more in-depth discussion of these programs and research needs. The Biosolids Research Program is detailed in Chapter 5.

Additional examples of research needs related to emerging contaminants in the Wastewater Management are discussed below.

POTW Treatment and Management. An area of concern includes the fate/transport and potential interference/pass through of emerging contaminants, especially PPCPs, through the POTW treatment process. Information is needed on the effectiveness of both conventional and innovative treatment technologies for minimizing the risk from emerging contaminants. Another treatment-related research question involves antimicrobial resistance in wastewater streams and how this may impact the treatment process.

Decentralized Wastewater Systems. Research is needed to determine performance capabilities and reliability of many currently available decentralized treatment technologies for emerging pollutants of concern (EDCs, PPCPs, and difficult to treat pathogens).

Biosolids and Other Residuals. Wastewater treatment processes are designed to reduce/remove contaminants and generate residuals (*e.g.,* sewage sludge/biosolids, liquid side streams, septage, etc.). Animal feeding operations also generate large quantities of residual manure and stormwater (wet weather flows) runoff that may be contaminated with PPCPs and pathogens. There are growing concerns over the fate of these emerging contaminants in land-applied biosolids, septage, and manure. Research is needed to identify appropriate new or existing treatment techniques and BMPs for removing or inactivating emerging contaminants. The effects of nanomaterials on POTWs needs to be assessed, as well as the abilities of nanomaterials to survive the treatment process and appear in products produced from land-applied biosolids.

Wet Weather Flow Control Research. Wet weather flow control includes the management and treatment of municipal, industrial and construction wet weather flows "outside the fence line" of the POTW. Information is needed about the pollutants in various types of wet weather flows, including pathogens and emerging contaminants. With improved understanding of pollutants in wet weather flows, methods are then needed to control pollutants in runoff from various sources, activities and materials. Examples of reduction methods include various source reduction and pollution prevention programs, as well as innovative stormwater treatment at hot spots.

Develop Drinking Water Standards

As discussed in Chapter 2, the Ground Water and Drinking Water Protection Program (under the Safe Drinking Water Act) sets national standards for drinking water that either limit a particular contaminant in drinking water or require treatment to remove or inactivate it. Two SDWA-mandated programs, the Contaminant Candidate List (CCL) and Unregulated Contaminant Monitoring Regulation (UCMR), help EPA identify emerging contaminants and which emerging contaminants may require regulations to protect public health. EPA conducts extensive data gathering and analysis of existing data on health effects and occurrence to establish a CCL. Once contaminants are listed on the CCL, EPA must determine if a regulation is needed or not for a select number of these contaminants (see Chapter 2). Through the UCMR program, EPA collects monitoring data from public water systems to assess the occurrence of unregulated, emerging contaminants of interest.

OW has done considerable work to institute a process to develop the third CCL (CCL 3) to identify new and emerging contaminants of concern for drinking water and public health, as well as a framework for prioritizing these contaminants. The process has also helped to identify information and research needs, such as what are the appropriate toxicological data and health endpoints to evaluate emerging contaminants, such as pharmaceuticals? (See the Human Health research needs, discussed above, as well as Chapters 2 and 5.)

To support the future CCL selection and the CCL Regulatory Determination process and UCMR data collection efforts, emerging contaminant research is needed in several other areas. New or improved analytical methods are needed to gather occurrence data (also refer to the "Analytical Methods" section in this chapter). These data are used to assess potential population exposure to a given contaminant.

For a more detailed discussion of the drinking water regulatory process and associated research needs, refer to Chapter 2, Science to Support Ground Water and Drinking Water Protection Programs, and Chapter 5 for further Human Health research discussion.

Climate Change

Climate change will challenge EPA to coordinate across water programs and with cross-media programs to find programmatic solutions to reduce greenhouse gas emissions, increase energy and water efficiency, protect in-stream water quantity and quality, and continue to provide the public with safe and efficient water and wastewater services. Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and manmade structures. Some of these water-related impacts of climate change include:

- Increases in Water Pollution Problems: Warmer air temperatures will result in warmer water. Warmer waters are able to hold less dissolved oxygen, and instances of low oxygen levels and "hypoxia," (*i.e.,* when dissolved oxygen declines to the point where aquatic species can no longer survive) are more likely. Warmer waters also foster harmful algal blooms, and some pollutants (*e.g.,* ammonia) become more toxic at higher temperatures. The number of waters recognized as "impaired" is likely to increase, even if pollution levels are stable.
- Increased Health Risks from Microbiological Contaminants in Water: Warmer waters will support higher levels of microorganisms and pathogens in drinking waters and in recreational waters at beaches and other locations and pose increased risks to human health.
- More Extreme Water Related Events: More intense and frequent coastal and inland storms and more intense downpours will increase the risks of flooding,

expand floodplains, increase the variability of streamflows (*i.e.,* higher high flows and lower low flows), and increase the velocity of water during high flow periods causing increased erosion. These changes have adverse effects on water quality and aquatic system health.

- Reduced Availability of Drinking Water Supplies: In some parts of the country, changing patterns of precipitation and snowmelt and increased water loss due to evaporation as a result of warmer air temperatures will result in reduced availability of water for drinking. In other Regions, sea level rise and salt water intrusion will have similar effects.
- Water Body Boundary Movement and Disappearance: Rising sea levels will move ocean and estuarine shorelines. Changing water flow to lakes and streams, increased evaporation, along with reduction in freshwater recharge from underground supplies, will shrink the size of wetlands and lakes, including the Great Lakes. This will result in the disappearance of some wetlands and ephemeral streams.
- Increasing Demand for Water: Warmer air temperatures will result in increased human demand for water while the water needs for agriculture, industry, and energy production are likely to increase. Underground water supplies, already low in some areas, will recharge more slowly and be less able to replace limited surface water supplies.
- Changing Aquatic Biology: As waters become warmer, the aquatic life they now support will be replaced by other species better adapted to the warmer water. This process, however, will be at an uneven pace, disrupting aquatic system health and allowing non-indigenous and/or invasive species to become established. In the long-term (*i.e.,* 50 years), warmer water and changing flows will result in aquatic ecosystem collapse in some cases.
- Collective Impacts on Coastal Areas: Coastal waters are at risk from multiple impacts of climate change including sea level rise, increases in storms, increased storm intensity and storm surges, loss of drinking water supplies, and increasing temperature and acidification of the oceans.
- Secondary Impacts on Water Resources: Some climate change impacts on terrestrial systems will also impact water resources. Lower levels of soil moisture will increase demand for irrigation. Increased incidence of wildfires will make soils more prone to erosion. This evolution of the terrestrial ecosystem will reduce water retention and limit aquifer recharge, increasing risk of flooding and scouring of aquatic systems.
- Cultural Dislocation that Undermines Community Response Capacity: As familiar water bodies and fisheries change in the future, the communities that value and rely on these resources will be stressed in economic and other ways. Communities in Alaska and the Arctic are most vulnerable to these stresses, but other communities (*e.g.,* subsistence Tribal fishers, Chesapeake Bay crabbers, Gulf coast shrimpers) are also at risk. These threats to economic livelihoods and

ways-of-life will make finding consensus responses to these problems more challenging.

Drivers for Climate Change Research

The climate research and assessment activities planned for 2008 – 2013 were developed with a strong emphasis on the National Water Program and its needs. In particular, most were developed based on information in The Office of Water's National Water Program Strategy for Responding to Climate Change (draft March 2008). Research and assessment activities thus address questions of basic science as well as questions specific to particular Water Program activities.

To continue making progress in meeting safe drinking water and clean water goals, Water Program managers defined the following five major goals for responding to climate change:

- Water Program Mitigation of Greenhouse Gases: use water programs to contribute to greenhouse gas mitigation;
- Water Program Adaptation to Climate Change: adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate;
- Climate Change Research Related to Water: strengthen the link between EPA water programs and climate change research;
- Water Program Education on Climate Change: educate water program professionals and stakeholders on climate change impacts on water resources and programs; and
- Water Program Management of Climate Change: establish the management capability within the National Water Program to engage climate change challenges on a sustained basis.

Other drivers for climate change research are discussed below (see also the Addendum to Chapter 1).

SDWA: SDWA provides for a comprehensive process to assess public drinking waters for contaminants and to develop drinking water standards for contaminants posing the greatest risk. Because climate change could impact weather patterns and result in increased rain events, the runoff from these events will likely increase the occurrence of regulated and unregulated contaminants in public drinking water sources and supplies (also refer to Chapter 2).

The Underground Injection Control (UIC) Program under SDWA regulates injection of fluids, including solids, semi-solids, liquids, and gases – including CO_2 – to protect underground sources of drinking water. Underground injection wells figure prominently in some climate mitigation strategies.

CWA: Under CWA, EPA establishes standards that define when surface water is clean enough to support uses such as drinking, fishing, and recreation. EPA also sets standards that must be met for all dischargers in a common type of industry (*e.g.,* paper mills) called "effluent guidelines." Each of these standards will be affected by climate change.

Intergovernmental Panel on Climate Change (IPCC): IPCC is an interagency panel that was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. IPCC's role is to assess the "technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, and its potential impacts and options for adaptation and mitigation." EPA scientists and grantees make a significant contribution to the IPCC as authors, and through research cited by the IPCC. The IPCC completed its Fourth Climate Change Assessment and is publishing a series of reports summarizing worldwide research on climate change. Much of this research relates to water resource impacts and a significant portion addresses water issues in North America. More information on the IPCC is available at www.ipcc.ch.

U.S. Climate Change Science Program (CCSP): This program provides coordination and integration of scientific research on global change and climate change, including research related to water, sponsored by 13 participating departments and agencies of the U.S. Government. The planning and implementation of EPA's Global Change Research Program is integrated by the CCSP with other participating Federal departments and agencies to reduce overlaps, identify and fill programmatic gaps, and add integrative value to products and deliverables produced under the CCSP's auspices.

A major activity called for in the 2003 CCSP Strategic Plan is the production of 21 Synthesis and Assessment Products (SAPs) that respond to the CCSP highest priority research, observation, and decision support needs.

Climate Change Research Needs

To help define the type of research that will be needed, EPA has identified a number of questions that capture the set of research and assessment issues, both technical and operational, where activities should focus. These include:

- How will climate and other global change stressors affect the watershed and ocean processes that influence the structure, functioning, and services of freshwater and coastal ecosystems?
- How will climate change interact with land use/land cover change and other global change stressors to exacerbate or ameliorate impacts on water quality and aquatic ecosystems?
- How will climate and other global change stressors affect the design, operation, and performance of water infrastructure (*e.g.,* drinking water treatment, wastewater treatment, urban drainage) and the built environment?
- How will the human demand for water be influenced by the interacting effects of changes in climate, land use, and economic development?
- How will climate change influence EPA water quality and ecosystem protection and restoration programs mandated under the CWA, SDWA, and other relevant statutes?
- What are the regional differences in vulnerability of water quantity, water quality, ecosystems, water infrastructure, and human health to global change?
- What influence will climate change have on the ability of States and Tribes to identify impaired surface waters and establish causal linkages between climate and other stressors and endpoints of concern?
- What information, capabilities, and tools can be provided to managers, decision makers, and the scientific community to increase their capacity for assessing and responding to global change given uncertainty about the type and magnitude of future change?
- What opportunities exist for water resources and ecosystem managers to increase the resilience of watersheds, water infrastructure, and aquatic ecosystems to global change stressors?
- What are the full effects and consequences of alternative energy production (*e.g.,* biofuels) and carbon sequestration for water quality?

To address these questions, OW has identified three areas for focused research:

Research and assessments of key aquatic ecosystems and associated watersheds will result in information that managers can use in their decision-making about how to adapt to the effects of global change

The impacts of global change will vary among different ecosystem types and across different geographic regions in the U.S. Managing these impacts will require strategies for increasing resilience and decreasing vulnerability to global change stressors at the watershed scale.

Research and assessments of the potential vulnerabilities of water infrastructure to climate change and analyses of adaptation opportunities will be used by resource managers to increase their capacity to respond to global change

Global change can impact water resources and infrastructure engineering and management in many aspects such as design, operation, maintenance, and performance of water infrastructure and the built environment. Future infrastructure needs can also be affected. Managing these impacts will require strategies for decreasing the vulnerability of existing infrastructure, assessing future needs, and developing and adopting new engineering and management concepts and methods to assure compliance with CWA, SDWA and its amendments, and other related congressional mandates.

Decision support tools and information from EPA's research and assessment program will enhance the ability of decision makers in the States and EPA Regional, program, and Tribal offices to protect water quality and aquatic ecosystems by adapting to global change

A critical aspect of EPA's research program is to build the capacity of State, Regional, and Tribal resource managers to respond effectively to global change. Research and assessments are needed to provide decision-relevant information. Decision support tools that provide stakeholders with the capability to assess system vulnerabilities and opportunities for adaptation are a complementary way to build capacity.

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