EPA/600/F-08/010 | November 2009 | www.epa.gov/ord

United States
Environmental Protection
Agency

Water Quality Research Multi-Year Plan 2009 - 2014

November 2009

U.S. Environmental Protection Agency
Office of Research and Development

ACKNOWLEDGEMENTS

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Foreword

This Multi-Year Water Quality Research Plan (WQRP MYP) should be viewed as a living document. By this we mean that it presents the results of a stakeholder driven process that included input from Regional and Program Offices during the 2007-2008 time period in which this document was developed. However, water quality research program and planning activities have not remained static. For example, a 2008 workshop to further advance watershed management information and tools had begun to map out future research directions, but they are not complete within this document and continue to be developed. Likewise, the Office of Water published its report titled "National Water Program Strategy: Response to Climate Change" in late 2008. The release of this document was followed by a 2009 "Stakeholder Workshop on Water Infrastructure Sustainability and Adaptation to Climate Change**"** that is being used to expand and provide more in depth direction for WQRP infrastructure research.

It is our intention to use this document as a general communications tools for the planned direction of the WQRP. Much of the detailed and MYP supporting information will be made available through our Web sites. For example, this document contains listings of Annual Performance Goals (APGs). These are major milestones that are met in general by contributions from multiple laboratories. Annual Performance Measures (APMs) are also designated under each Long-Term Goal (LTG). The APMs broadly define contributions by each Laboratory or Center. APMs represent a compilation and synthesis of multiple products. Detail for APMs is updated annually to include those completed and those locked in for the upcoming year. Product detail and contact information are also being provided electronically and are not included in this document as its purpose is to provide a higher level roadmap for planned research.

Executive Summary

The Clean Water Act (CWA) provides the legislative mandate to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Therefore, a common management goal for all aquatic systems is to maintain their integrity by protecting them against degradation of habitat, loss of system function, and reduced biodiversity. To this end, environmental managers must be able to: 1) assess the condition of an aquatic resource and determine the degree of impairment; 2) diagnose the causes and sources of impairment; 3) forecast the effects of changes in stressor levels on water quality conditions; and 4) develop and implement remediation and maintenance strategies.

This aforementioned process begins with assigning a designated water body use, and then applying the water quality criteria necessary to protect the use. Thus, the Water Quality Multi-Year Plan's first long-term goal is to protect the integrity of the nation's waters through the development of water quality criteria. The second long-term goal is to manage our watersheds, including addressing issues that impact load allocations and water quantity (i.e., to manage pollutant loadings and water quality on a watershed basis). The third long-term goal deals with the control of environmental contaminants though our built infrastructure to manage and treat wastewaters, storm water flows, and residuals.

The Water Quality Research Program is multi-faceted, meeting many needs at national, regional, and local levels. Every stakeholder identified research need cannot be addressed within this plan, as research resources are finite. The program does address research targeted to meet high priority Office of Water needs, and seeks to enhance the value of a stakeholder supported portfolio with research that is recognized as cutting-edge and leading in its field. Additionally, certain research is conducted to help direct the next generation of specific technologies in water quality protection, while other work utilizes Office of Research and Development's (ORD) unique capacity to obtain diverse information and synthesize conclusions of national impact. In some cases, these are highly visible scientific findings; in others, they form the basis for regulations with far ranging impacts.

List of Acronyms

AGWA	Automated Geospatial Watershed Assessment Tool
APG	Annual Performance Goal
APM	Annual Performance Measure
AtiLA	Analytical Tools Interface for Landscape Assessments
BCG	Biological Condition Gradient
BEACH Act	Beaches Environmental Assessment and Coastal Health Act
BMP	Best Management Practices
CADDIS	Causal Analysis/Diagnosis Decision Information System
CAFO	Concentrated Animal Feeding Operation
CSO	Combined Sewer Overflows
CWA	Clean Water Act
DNA	Deoxyribonucleic acid
EDC	Endocrine Disrupting Chemical
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ESRP	Ecological Services Research Program
ETV	Environmental Technology Innovation
FY	Fiscal Year
GI	Green Infrastructure
GOM	Gulf of Mexico
HAB	Harmful Algal Blooms
HUC8	Hydrological Unit Code
KINEROS2	Kinematic Runoff and Erosion Model
LiDAR	Light Detection and Ranging
LID	Low Impact Development
LTG	Long-Term Goal
MOS	Margin of Safety
MRGOM	Mississippi River-Gulf of Mexico
MYP	Multi-Year Plan
NARS	National Aquatic Resource Assessments
NCEA	National Center for Environmental Assessment
NCER	National Center for Environmental Research
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NRML	National Risk Management Research Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
OEI	Office of Environmental Information
OMB	Office of Management and Budget
ORD	Office of Research and Development
OST	Office of Science and Technology
OSV	Ocean Survey Vessel
OW	Office of Water

PEC	Pathogen Equivalency Committee
POTW	Publically-Owned Treatment Works
QMRA	Quantitative Microbial Risk Analysis
qPCR	quantitative Polymerase Chain Reaction
R^3	Repair, Renewal and Replacement
RCT	Research Coordination Team
REMAP	Regional Environmental Monitoring and Assessment Program
SCM	Source Control and Management
SI	Stressor Identification
SSO	Sanitary Sewer Overflow
STAR	Science to Achieve Results
SWAT	Soil & Water Assessment Tool
SWMM	Storm water Management Model
TALU	Tiered Aquatic Life Use
TMDL	Total Maximum Daily Load
US	United States
WM	Watershed Management
WQ	Water Quality
WQI	Water Quality Integrity
WQRP	Water Quality Research Program

Introduction

The Office of Research and Development's (ORD) research multi-year plans (MYPs) present the long-term strategic vision of the EPA's research programs. The MYPs serve as a planning and communication tool to describe the scope of research addressing the Agency's priority science questions. The MYPs are also used to help (1) demonstrate how ORD's research programs contribute to Agency outcomes and strategic goals; (2) provide information to aid in, and support, decisions during budget formulation; and (3) assist in managing performance and accountability reporting

MYPs provide a link between the Agency and ORD's strategic plans and our annual plans that serve as the basis for ORD's budget request. MYPs describe what research ORD wants to accomplish to reach the long term goals and objectives we set to assist our clients in achieving environmental outcomes. The MYPs provide the narrative background for research program evaluations, both internally as well as through external peer review of our program plans and direction.

Background

The Water Quality Multi-year Plan (WQ MYP) addresses the research needs to support the future strategic directions of the Environmental Protection Agency (EPA). Additionally, the MYP is reassessed annually to help reaffirm that our current and future activities appropriately address targeted priorities. The MYP also serves to communicate the Agency's intentions, thereby promoting communications; and it helps ensure the relevance, quality, and performance of ORD's research program.

Program Purpose

The major client for water quality research is EPA's Office of Water. The program also serves the States, Tribes, and Regional Offices. It serves these clients by addressing research needs relating to a number of legislative mandates, most significantly the Federal Water Pollution Control Act of 1972, as amended in 1977, and referred to as the Clean Water Act (CWA) as amended in 1990. In addition to its legislative mandates, the WQ MYP is designed to support Agency needs to meet Clean and Safe Water goals as described in the EPA Strategic Plan (http://www.epa.gov/ocfo/plan/plan.htm). The Water Quality Research Program conducts targeted research to provide the foundation for scientifically defensible environmental policies, programs, and regulations.

The Federal Water Pollution Control Act as amended through P.L. 107-202, 2002 TITLE I, Sec. 101.(a) states that:

> *The goal of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. (b)It is the further policy of the Congress to support and aid research relating to the prevention, reduction and elimination of pollution, and to provide federal technical services and financial aid to State and interstate agencies and municipalities in connection with the prevention, reduction and elimination of pollution. Sec. 102.(a) The Administrator shall, after careful investigation, and in cooperation with other Federal agencies,*

> *State water pollution control agencies, interstate agencies, and the municipalities and industries involved, prepare or develop comprehensive programs for preventing, reducing, or eliminating the pollution of the navigable waters and ground waters and improving the condition of the surface and underground waters. In the development of such comprehensive programs due regard shall be given to the improvements that are necessary to conserve such waters for the protection and propagation of fish and aquatic life and wildlife, recreational purposes, and the withdrawal of such waters for public water supply, agricultural, industrial, and other purposes.*

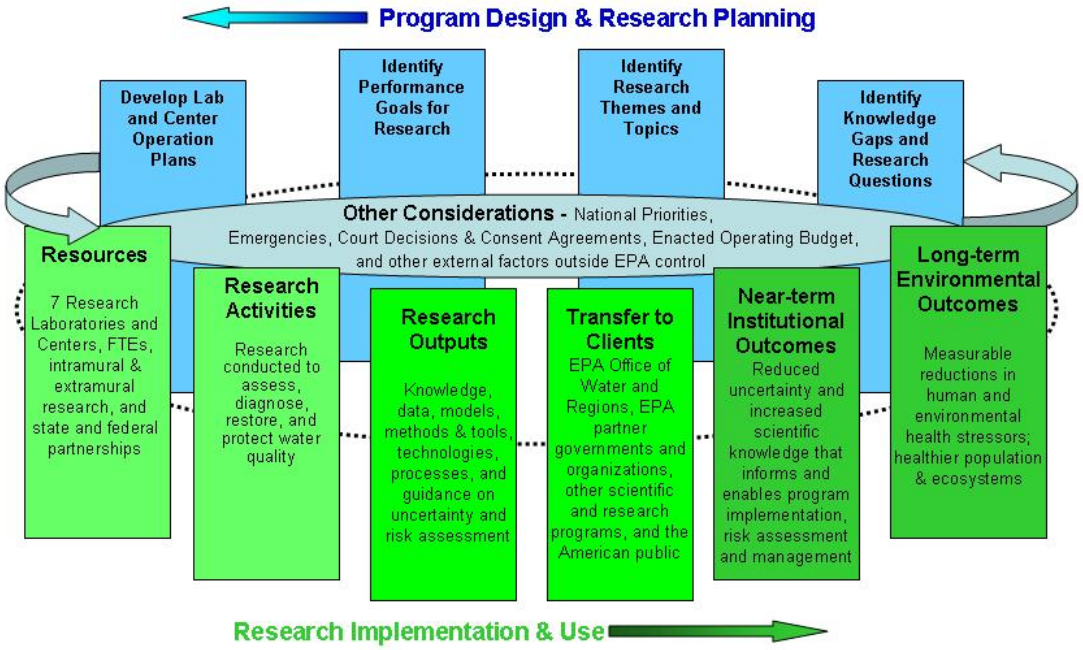
It is this language that defines the water quality program purpose, and forms the basis of the EPA watershed approach for restoring and maintaining the integrity of the nation's waters.

Program Design

The Water Quality Research Program is designed to complement other research programs that support the EPA Strategic Plan. The Strategic Plan sets out an ambitious road map for environmental protection and stresses achievement of measurable environmental results. The Strategic Plan has five strategic goals: Clean Air and Global Climate Change; Clean and Safe Water; Land Preservation and Restoration; Healthy Communities and Ecosystems; and Compliance and Environmental Stewardship. The WQ MYP supports the Agency's Strategic Goal 2: Clean and Safe Water, with its purpose to ensure safe drinking water; restore and maintain oceans, watersheds, and their aquatic ecosystems to protect human health; support economic and recreational activities; and provide healthy habitat for fish, plants, and wildlife. To this end, the Water Quality Research Program conducts research to develop the means and strategies to protect water quality on a watershed basis. This MYP also targets Regional and watershed applications for demonstrating tools to promote the implementation of the Clean Water Act.

Figure 1 represents the Water Quality Research Program logic diagram. The diagram describes the logic linking environmental outcomes to the research ORD plans to conduct. The model is a planning and accountability tool that helps demonstrate how the recommended targeted research aligns with information and tools needed by the Agency to achieve its environmental outcomes.

Figure 1: Water Quality Research Program Logic Diagram



ORD's research provides the scientific basis to support actions taken by EPA's Program and Regional Offices to meet long-term or intermediate environmental outcomes, as identified in EPA's Goals and Objectives. One of the first steps in developing the research plan was to collect information on client science needs, and then construct a corresponding list of key science questions. The science questions represent the critical line of investigation, without assuming constraints in resources or scientific capabilities that define the most important areas of uncertainty to address in order to support the achievement of an environmental outcome.

Key science questions were used to develop the ORD long-term goals (LTGs) that define the endpoints to be achieved. Once the LTGs were defined, they provide the focus for developing annual performance goals (APGs) which are the major steps that are needed to achieve the LTGs. The APGs are major research outputs and/or technical support activities that describe the intermediate and environmental outcome to which they contribute. They represent significant and often multi-laboratory/center, milestones along a critical path toward the accomplishment of the LTGs. The APGs then form the basis for the laboratory/center management and staff-developed annual performance measures (APMs) that define the scientific and technical products that enable ORD to meet its commitments.

By design, the long-term research goals, APGs and APMs proposed herein are intended to specifically enhance the science and engineering content of EPA, Regional, State, and local

programs and actions. Consistent with this approach, many of the annual goals and planned products are phrased as "developing tools and data for..." or as "demonstrating the application to achieve...." where the specific goals or products correspond to one or more of the major logical steps required to meet the nation's water quality goals as defined by the CWA.

Plan Development Activities

The development of the WQ MYP began with the Office of Water (OW) program office and Regional client offices providing ORD with information on their specific research needs. Four OW offices (OGWDW, OST, OWOW, and OWM) provided input, as did the Regions. Following a series of client interviews to elicit additional information on the research drivers and timelines, ORD, OW, and Regional representatives met to reach consensus on the MYP structure, its development, and how decisions on prioritization would be made.

The client priorities identified during the meeting were initially grouped into three theme areas: ***Water Integrity, Watershed Management, and Source Control and Management***. A workgroup was established for each theme area and co-leads from ORD and OW were identified. The three workgroups mirror the structure envisioned for the MYP, and are comprised of ORD, OW, and Regional scientists and managers. The team leads for each workgroup were responsible for identifying and obtaining the necessary expertise and representation from the laboratories, centers, programmatic offices, and Regions. The workgroups were tasked with drafting APGs and outcomes for the planning period. In doing this, the workgroups married top-down priorities from OW, Regional, and ORD management with a bottom-up approach where scientists provided detailed water quality science planning at the bench and field level within and among the laboratories and centers. The workgroups weighed the water quality goals set by the Agency and the levels of uncertainty faced in achieving those goals.

The final workgroup product was a list of the APGs which follow recommended critical paths to achieve measurable institutional actions and environmental outcomes. Each workgroup was charged with developing APGs related to their area of expertise that defined the critical research path for the identified needs. The workgroups were also charged with providing a brief statement of context for the critical research path. This consisted of a statement on what ORD has already contributed in this area, and what the planned work is expected to achieve.

Criteria for Prioritizing Research

Over the course of several stakeholder workshops, ORD scientists and program office and Regional clients discussed how research priorities should be determined. Much discussion focused on the following Office of Management and Budget (OMB) criteria and the workgroups interpretation of how it was applicable:

- Relevance
  - The APG provides fundamental understanding to support the basis of regulation.
  - The APG is crucial to achieving program goals.
  - The APG addresses research requested by client offices.
- Timeliness
  - The APG supports work that is crucial to future regulations or goals.
  - The timeline complements program goals.
  - The timeline supports regulatory mandates.

- Outcome Oriented
  - The output supports several programs or offices.
  - The output is targeted for use by specific offices or Regions.
  - The output supports a measurable outcome.

Stakeholder discussions resulted in defining factors that contributed to making an issue a high priority. These were principal factors in setting priorities during the development of the MYP. They include:

- Information needed to meet short-term needs such as for criteria development (e.g., aquatic life criteria revisions, recreational water quality criteria)
- Research to address high visibility issues (e.g., function of headwaters and isolated wetlands, use of wetlands in trading, improving, and maintaining infrastructure, managing wet weather flows)
- Science to meet future needs (e.g., integrated monitoring, addressing combined water quality and quantity issues, emerging pollutants, managing multiple stressors)

Process for Updating the MYP

In the course of updating the MYP, input was solicited from a number of organizations with the Agency, beginning with the Research Coordination Team (RCT). The RCT sought to achieve uniformity on priorities among the clients of the Water Quality Research Program. The RCT also took on responsibilities that extended beyond the development of this MYP, including providing input on likely impacts of various resource contingencies considered during the annual budgeting process. The RCT role in the MYP development process was to maintain good lines of communication among the three long-term goal workgroups (charged with developing recommendations for APGs) and the clients who initially identified the research needs.

The RCT recommendations were shared with ORD Laboratory and Center management for the purpose of aligning and/or negotiating resources requirements for the recommended APGs. APGs were not final until resources were aligned as part of ORD accountability procedures.

During the process of developing this MYP it became obvious that more high-level participation from the Program Office and Laboratory and Center level was desirable. As a result, leadership meetings are planned as part of an annual review and updating of the MYP. This will allow the RCT and others to annually revise the MYP based on corporate level decision-making relative to water quality issues.

Research Tracking

During the development of this MYP, no ORD-wide system existed for tracking the identification of research needs, through funding decision processes, to the completion of final outputs. This shortcoming is being rectified through the current development of the *EPA Environmental Science Connector*, and through the development of program specific Web sites. Once this MYP has been reviewed and approved, it will be posted on the Water Quality Web site (http://epa.gov/ord/npd/waterqualityresearch-intro.htm). Annual listings of completed APMs and APGs will also be made available, as will APMs and products to be produced in the upcoming year.

Evolution of the Water Quality Research Program

The Clean Water Act provides the legislative mandate to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Therefore, a common management goal is to maintain water quality integrity and to protect aquatic systems from pollution and degradation of habitat. To this end Water Quality LTGs are structured to: 1) inform the development and application of water quality criteria for protecting and restoring the biological, physical, and chemical integrity of U.S. waters; 2) provide tools and expertise to diagnose and predict the causes and sources of water quality impairment on a watershed management level; develop Total Maximum Daily Loads (TMDL); and select, apply, and evaluate the effectiveness of management measures; and 3) provide expertise, research, and tools to characterize, control, and manage sources of water quality impairment in U.S. waters.

The MYP LTGs differs from the previous plan in that the 2003 MYP presented research activities in a risk assessment to risk management fashion. The 2003 WQ MYP was structured around four LTGs that respectively addressed: 1) approaches and methods to develop and apply criteria for stressors and habitat alteration; 2) tools to assess and diagnose impairment causes; 3) tools to restore and protect designated uses; and 4) ways to assess and reduce exposure to biosolids contaminants. In this MYP, the risk assessment to management concept is applied in a more integrated approach, with regard to how research problems are solved by integrating the scientists' efforts to work together and build agency and inter-agency collaborative teams to address priority issues.

Research Needs

The Agency 2006-2011 Strategic Plan, under Goal 2, Clean and Safe Water, provides several sub-objectives that directly establish long-term goals. The sub-objectives that have been identified as pertinent to, but not necessarily exclusive to, the WQ MYP include:

- Sub-objective 2.1.1 – Water Safe to Drink
- Sub-objective 2.1.2 – Fish and Shellfish Safe to Eat
- Sub-objective 2.1.3 – Water Safe for Swimming
- Sub-objective 2.2.1 – Improve Water Quality on a Watershed Basis
- Sub-objective 2.2.2 – Improve Coastal and Ocean Water

These sub-objectives and the programmatic goals were discussed during the stakeholder research planning meetings. These discussions provided the background for identifying the LTGs, the major science questions, the APGs, and lastly, the APMs that lead to the research products that ORD provides.

Identifying Client Priorities

The research needed to support CWA programs is extensive. Table 1 lists some of the water protection programs where water quality research support was requested.

Table 1: Clean Water Act and Water Protection Programs

Criteria – Standards – TMDLs – Permits	Biosolids
Beaches/Recreational Waters/Pathogens	Wetlands Protection & Trading
Water Quality Trading	National Estuary Program/Estuary Restoration Act
Gulf of Mexico Hypoxia Task Force	Ocean Pollution Regulation/Coastal Zone Act
Coral Reef Protection	Invasive Species
Isolated Waters	Watershed Implementation
Infrastructure	Wet Weather

The above information is provided as an example, and is not meant to be definitive. It illustrates the breadth of the Agency's need for water quality tools and data. Research is needed to support the implementation of the Office of Water's core programs, and to provide updates as necessary when new information is available. OW has also identified needs for better methods and indicators for recreational waters; wetlands programs aimed at function, protection, remote sensing, trading, and forecasting; biosolids management and risk reduction; function of headwaters and isolated waters; and infrastructure and other watershed-based wet weather management approaches. Therefore, in developing this plan, it was agreed that the MYP be theme-based and cross-linked. This is intended to help communicate the research and results to the end user; demonstrate research to outputs to outcomes; account for work that is needed under more than one theme and/or MYP; and promote more coordinated and comprehensive planning and an understanding of how the goals will be reached.

Delineating Boundaries for the Water Quality Program

We often refer to water as a universal solvent, and Earth as the water planet. So a water quality research program could be viewed very broadly unless we set program boundaries. Within EPA's research programs, there are several that appear to have overlap with the WQRP. The drinking water and the ecological services research programs are the most obvious examples of this. One way of providing clarity on the boundaries of these programs is to cross reference the research needs addressed within the WQRP with the topical headings identified in the National Water Program Research Needs document that was prepared by the Office of Water. The table provided in Appendix A shows that one area of overlap with the Drinking Water Research Program is the topic of source water protection, which is generally covered within the WQRP. However, the delineation between the WQRP and the Ecosystem Services Research Program (ESRP) is much less clear. This is partially due to the fact that one of the desired outcomes of the ESRP is to develop measures that can be used to quantify ecosystem services provided, lost, or their potential for recovery. Within the long-term view of the WQRP, we seek to relate measures of water quality and quantity with ESRP data trends in benefits provided. Such an ability to measure and to quantify the potential for service gains or losses is essential to future watershed management practice. However, much of the current programmatic overlap occurs because both programs begin with evaluations of the same or similar management measures, but it is done to develop different products. For the WQRP, this is necessary since watershed managers need data, tools and models to help them plan and implement programs to address known impairments, or protect high quality water resources. The research undertaken within the WQRP therefore focuses more on themes such as on design information and effectiveness of management practices, how to measure restoration progress, and where to place interventions to achieve optimal results.

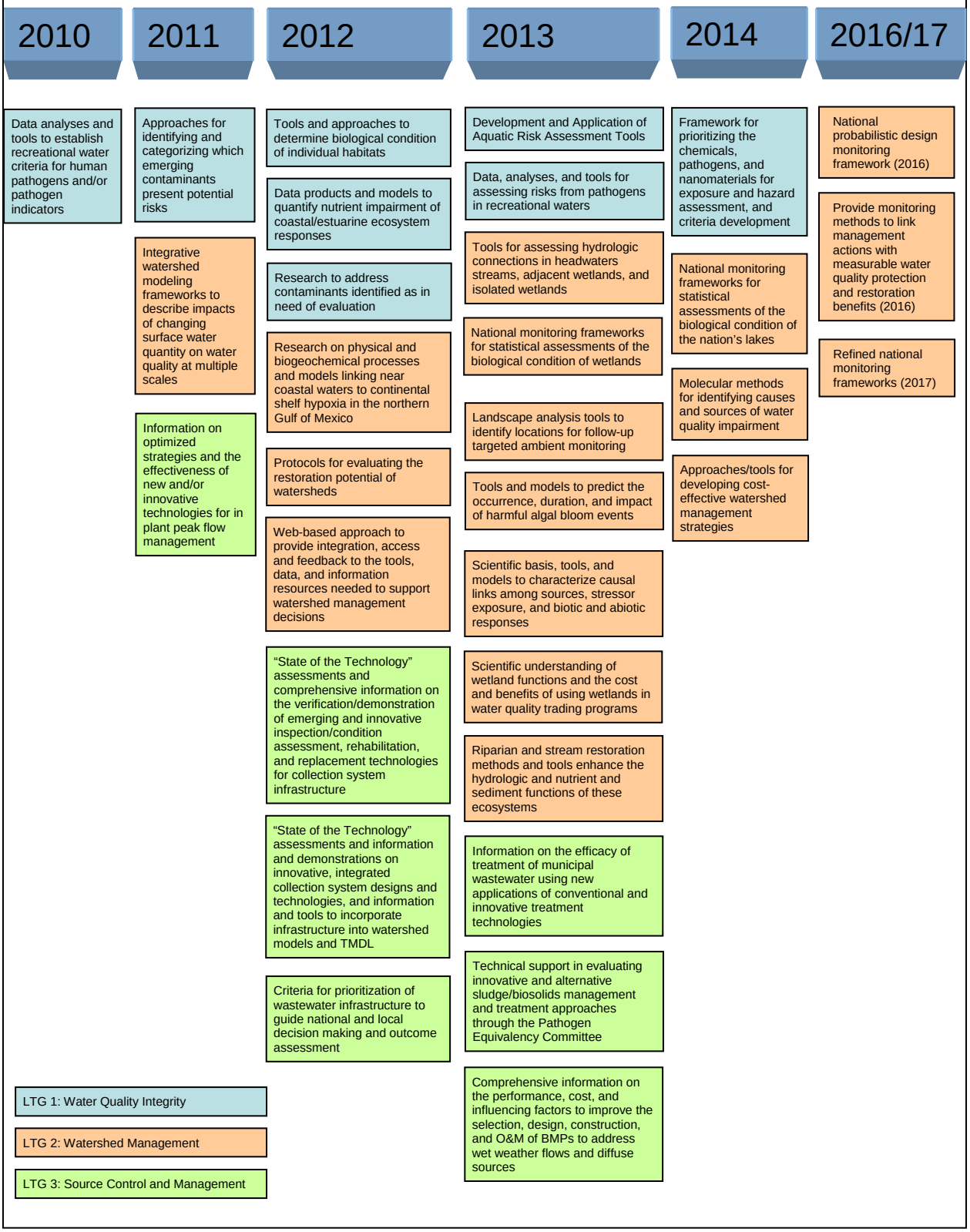
Presenting the LTGs and Planned Research

The presentation of each LTG begins with introductory remarks, followed by comments intended to help place proposed research into perspective. After presenting information on what has been recently accomplished within the program and the future desired state for that LTG, a discussion of planned research follows, including a listing of APGs.

In a future desired state for the overall Water Quality Research Program, all designated uses are met and maintained. It is a simple statement, but it spans many complex environmental problems that must be solved in order to achieve a sustainable society. Continuing in this very long-term and macro view, LTG 1 will have created the knowledge to support the development of criteria that underpin efforts to protect and maintain the quality and quantity of our water resources. LTG 2 follows with the assertion that tools have similarly been developed to help make management decisions on a watershed basis that achieve environmental outcomes over temporal and spatial scales by addressing local to interstate watersheds that comprise river basins from the headwater streams to estuaries. LTG 3 research seeks an understanding of the performance of individual source controls and of general options for managing sources so that their hydraulic and pollutant loading to surface waters are minimized. For example, in LTG 3 we seek to affirm that sustainable practices and green infrastructure are capable of achieving restoration goals in our growing communities. Like LTG 1, LTG 3 contributes research results that support the development and implementation of water quality strategies either for an individual pollutant source impacting a portion of a water body, or for multiple sources impacting an entire watershed.

Each LTG is discussed in more detail in the following pages. As part of this discussion, annual performance goals for each LTG are identified. Figure 2 gives an overview of all of the APGs.

Figure 2: Annual Performance Goals



Water Quality Integrity

Long-term Goal 1: *The Office of Water, EPA Regions, States, and Tribes use ORD research and expertise to inform the development and application of water quality criteria for protecting and restoring the biological, physical, and chemical integrity of U.S. waters.*

The Clean Water Act seeks to protect and restore the integrity of our nation's waters. To achieve this goal, criteria must be established upon which States' standards for water quality are set. LTG 1, therefore, addresses this critical need to provide the information and tools that underpin the Agency's water quality regulatory programs.

Introduction

Developing and applying water quality criteria for protecting and restoring waters may begin with a identified needs for effects data specific to particular contaminants. However, the need for criteria may also be initiated by an assessment of the condition of aquatic resources. Tools for assessing the condition of aquatic resources can demonstrate where resources need to be protected, and where impairments already exist. It follows then that criteria must be developed and utilized to restore those waters found to be impaired, and to protect those that meet use designations.

ORD has developed a scientifically defensible statistical framework for OW national surveys to determine the biological condition of aquatic resources. This approach is now being implemented by the Office of Water in the conduct of national surveys and assessment of the condition of aquatic resources (Regional and National 305(b) reports) [See LTG 2]. These data are critical for determining the "health" of our nation's waters in a scientifically defensible manner, and can be used to link monitoring data for biological condition with condition gradients and criteria development.

Through these activities, biological, physical, and chemical stressors are identified. Research under the Water Quality Integrity (WQI) then focuses on benchmark methodologies and implementation under the CWA. The program is designed to develop approaches for criteria that address stressors associated with both point and nonpoint sources which feed into the development of criteria by OW. Importantly, research under this area is designed to provide data and approaches that apply specifically to the designated use of waterbodies, and that link to integrated watershed management and assessment approaches necessary for effective protection of pristine aquatic resources and for restoration of impaired waters.

Through consultations with ORD's research clients, LTG 1 research addresses topics that fall into five thematic areas. They include:

- Aquatic life guidelines
- Biological assessment approaches to biocriteria and Tiered Aquatic Life Uses
- Nutrient criteria
- Recreational water criteria for pathogens and pathogen indicators
- Emerging contaminants

As the science under this long-term goal progresses, research efforts will transition toward utilizing approaches to integrate the scientific information used in setting criteria for multiple stressors with monitoring, assessment, data interpretation, and restoration.

Recent Advances

Coincident with the initiation of the MYP planning process, the Water Quality program underwent peer review in 2006. Therefore, the starting point for MYP development was to look at research products developed in the previous 6 years. Between 2000 and 2005, research in support of criteria development produced 24 EPA reports, 95 book chapters, and 432 journal publications relating to criteria development research. The EPA reports can be generally categorized as topics addressing research on metals, toxics, sediments, nutrients, classification systems, bioaccumulation, and methodologies for assessing water body conditions or for deriving criteria. Metals research provided guidance for characterizing and ranking metals to support metals risk assessments, and technical support was provided to aid in the development of criteria and/or guidance documents. Sediment work focused on assessing sediment-associated contaminants for the protection of benthic communities, and aquatic life impacts from suspended and bedded sediments. Toxicity research addressed an array of subjects from single species effects-studies to tissue based criteria for bioaccumulative compounds. Nutrient research developed technical guidance manuals for estuarine and coastal marine waters supported by regional studies in the Pacific Northwest and in the Gulf Coast. Landscape classification research developed frameworks for both coastal systems and supported Regional Environmental Monitoring and Assessment Program (REMAP) projects. These efforts addressed methods for assessing wetland conditions, profiling, and approaches to cumulative impact analyses. The research pathways for the majority of this water quality research were laid out in a report titled *Aquatic Stressors: Framework and Implementation Plan for Effects Research.*

Of the over 400 journal publications produced, over 100 dealt with marine and Great Lakes coastal systems, to better understand how to assess the health and productivity of these systems, and when they are adversely impacted by pollution. Research results described linkages between land uses, habitat condition, and measures of water quality. Supporting publications (>60) dealt with assessing the health of invertebrates, nutrient impacts, and sediment quality. One of the most productive efforts (>180 papers) was the development of a framework for developing sediment criteria. Publications dealt with development of new analytical methods, quantification of emerging contaminants, evaluation of metals toxicity, or assessment of the toxicity of single or multiple organic compounds for important aquatic species. Most of this work directly supported criteria development efforts. About 15 papers were published in support of microbiological or pathogen criteria development.

The research conducted over the past six years forms the foundation for the criteria development research identified in this MYP. Past work on bioassessments and biological condition gradients will support future efforts to develop biocriteria using a tiered approach, to improve nutrient criteria and guidance for management, and to advance the concepts of managing multiple stressors. The rapid methods for microbial analysis developed under the last MYP will be applied in human health risk studies to support OW in the development of recreational water quality criteria. The knowledge and understanding developed in studies of toxics and metals will underpin the work identified as priorities for the area of emerging contaminants.

Desired State
The LTG 1 desired state is to have developed the knowledge to set criteria for the protection of human health and aquatic life by maintaining the water quality that supports the associated designated uses. For the clients of ORD research, this means that information is being made available to revise existing regulations as well as to develop the next generation of regulatory and management tools. In the following section each of the aforementioned research themes will be addressed relative to desired future states. Obviously, these desired future states do not yet exist, but they help guide the direction and identify products that are presented as planned research later in this MYP.

Biological assessment approaches to biocriteria and Tiered Aquatic Life Uses: This research takes form for both single and mixtures of stressors, and for multiple endpoints that we wish to protect. In supporting criteria development, it translates to concerns for health and aquatic life risks associated with stressors identified above either occurring separately or in combinations. Stressors will be attended to separately in earlier years, but efforts will transition toward approaches that address multiple stressors in context with impacts on populations, habitat, and biodiversity. The desired state for each system or resource type is that Habitat-informed Biological Condition Gradient (BCG) and Tiered Aquatic Life Use (TALU) that could serve as a framework for integration of stressors in developing a next generation of water quality criteria.

Aquatic life guidelines and multiple stressors: In the short-term, protection of aquatic life is achieved by updating past guidance, and by applying new risk assessment tools that include information on stressor-response relationships for various streams and coastal systems. Biocriteria research quantifies and relates exposures from stressors to impacts on organisms and habitats that can be tiered for various land and water classifications as stated previously. Over the longer term, these concepts are further developed to incorporate information on multiple stressors that allows one to predict population-level responses to mixtures of chemical, physical, and biological stressors occurring at various levels over time. The complexity of this task increases as one considers the types of aquatic habitats and life that could be affected in a diversity of existing eco-regions.

The information sought includes test methods, indicators, approaches, and conceptual, empirical, and mechanistic models to evaluate, diagnose, prevent, manage, and predict the combined effects of multiple stressors to aquatic and aquatic-dependent wildlife. Genomic methods ("DNA bar-coding") can be used for measuring aquatic community composition. However, simpler, less costly and more rapid bioassessment methods can be used for a wide range of water body types and eco-regions; states may readily use these methods to develop biocriteria-based standards.

Nutrient criteria: In continuing to describe a future desired state, knowledge must be developed that includes the impacts of nitrogen and phosphorus pollutants to set protective limits for sensitive aquatic life stages and/or ecosystems. This understanding includes how to prevent local effects as well as cumulative impacts occurring downstream at receiving waters such as estuaries. Also, the impacts of one stressor must be differentiated from other co-occurring stressors, such as sediments. Guidance must exist for upstream ambient water concentrations and loads that will prevent downstream eutrophication, algal blooms, and hypoxia. Such data and

information are necessary for all water body types and eco-region types from headwater streams, wetlands, ponds, and lakes – to large rivers, estuaries, and coastal waters.

Recreational water criteria for pathogens and pathogen indicators: Pathogen research is conducted to support the revision of criteria for the protection of public health for all recreational waters to meet the requirements of the Beaches Environmental Assessment and Coastal Health Act (BEACH Act) of 2000. Fecal indicator methods are developed that are faster, simpler, and more associated with specific health risks and fecal sources. Epidemiologic studies describe associations between fecal indicators and swimming related illnesses. Beach managers have predictive models supported by improved water quality measures that can be used to make decisions that protect public health. Microbial source tracking tools have been developed and applied in approaches to quantify and manage the various sources of fecal pollution using watershed survey methods and tools. Quantitative microbial risk analysis (QMRA) methods are developed to identify critical scientific uncertainties to fill data gaps not met through epidemiologic studies. Criteria are updated to address risk levels associated with various sources of fecal contamination and for different water body types and geographic locations. It should be noted that even though this is described as a future state, it is based upon the continued use of fecal indicators. As ORD continues to conduct research on new methods for enumerating waterborne pathogens, and on the occurrence of recreational illness associated with those pathogens, an entirely different approach to coastal and/or inland water quality management can be envisioned based upon controlling the sources of those pathogens.

Emerging contaminants: Efforts on the point source control of toxic compounds through pollution prevention and permitted treatment programs have been quite successful over the past few decades. While a number of priority toxic pollutants have been addressed, a number of new concerns have been identified resulting from the effects of long-term low concentrations of chemical contaminants, such as endocrine disrupting chemicals and pharmaceuticals, personal care products, and nanomaterials. These are collectively referred to in this plan as emerging contaminants. These emerging contaminants must be prioritized for assessment of their occurrence and effects in the environment. In our desired state, we have the knowledge and tools to predict the magnitude of occurrence and the likely severity of impacts for human health and environmental endpoints for such compounds. This takes form through the provision of tools to set priorities and focus resources on those compounds that are expected to require regulation in the future.

Planned Research

The focus of LTG 1 is to provide the approaches and methods needed to develop and apply protective criteria related to stressors (e.g. nutrients, pathogens, emerging contaminants) and stressor-induced habitat alterations in order to maintain designated uses for aquatic systems. The research will increase understanding of specific responses to each stressor, will address methods for assessing biological responses to multiple stressors and will include bioassessment research as a field-oriented approach to setting biocriteria. Specific approaches are addressed for several thematic areas to provide the scientific basis for assessing the role of habitat in order to predict biological effects of habitat alteration; provide load response information to develop nutrient criteria; demonstrate an approach for suspended and bedded sediment criteria for aquatic systems; support the development of microbial recreational water quality criteria; and develop

scientifically-defensible methods for better describing the risks of toxic chemicals to aquatic and aquatic-dependent populations and communities.

1.1: Aquatic Life Guidelines
APG 1.1.1: By 2013, Development and Application of Aquatic Risk Assessment Tools.

The assessment approach embodied in the existing methodology for deriving water quality criteria for the protection of aquatic life is widely used in Agency regulatory programs. This approach has evolved very little in the past three decades. The application of these methodologies has also not kept pace with either advancing scientific understanding or expanding regulatory needs. New tools and applications are needed to incorporate current understanding of ecotoxicology, including the recognition of multiple exposure routes and the factors that control their significance, expansion of coverage to include aquatic dependent wildlife, and provisions of risk expressions that are more useful in guiding management decisions. Therefore, the major output for this research is the development and application of new aquatic ecotoxicological risk assessment tools.

ORD research in this area will provide risk assessment tools for use in updating criteria. Reports summarizing the evaluation of dosimetry methods for incorporating concentration and time variability into water quality criteria will be used in the media-based toxicity model section to further describe time-variable exposures for determining what is described in the current criteria methodology as the "averaging period. The development of a mercury toxicokinetic model documenting dose-residue-response information on reproductive effects to improve estimation of mercury effects on avian reproduction will be used to illustrate the utility of residue-based assessments and population relevant endpoints on predicting risks to aquatic dependent wildlife. Finally, an evaluation of the use of population models on effects assessment and risk characterization can provide an example of how to utilize exposure and effects assessment tools in deriving water quality criteria.

With these tools in hand, ORD will collaborate as members of the various committees and working groups to provide technical support for a subset of chemicals during the derivation of the next generation of criteria. In doing so, key technical issues and approaches for resolution will likely be identified and future research needs determined to address those issues.

In addition ORD will continue to support OW in developing updated Aquatic Life Guidelines for toxic chemicals through research including: the integration of life-histories of aquatic organisms with toxic effects in population assessments; the continued development of predictive models of population-level effects of toxic chemicals; and an assessment of spatially heterogeneous chemical exposures on wildlife populations at various landscape scales. ORD will continue its long-standing history of technical support and data interpretation for OW criteria development.

1.2 Biological assessment approaches to biocriteria and Tiered Aquatic Life Uses
APG 1.2.1: By 2012, OW will use ORD's research to develop guidance for States and Tribes to conduct bioassessments, develop refined designated uses (i.e., Tiered Aquatic Life Uses), and establish biocriteria for various land and water classifications (e.g., eco-regions, water body types.

The overall intent of this research is to provide OW with tools and approaches to determine the biological condition (from natural or minimally impacted to severely impacted resources) of individual habitats (e.g., wetlands, salt marshes, coral reefs, seagrass beds) and of habitat mosaics at the landscape scale (e.g., whole estuaries or coastlines).

One component of the proposed work will be to develop Biological Condition Gradients (BCGs) in coasts and estuaries at scales ranging from individual habitats to entire estuaries. Research at the individual habitat level will develop BCG relationships for biotic responses to a variety of known or suspected stressors (e.g., nutrients, pollutants, climate change, landfill, non-indigenous species, etc.). Responses to stressors may be characterized though faunal communities and/or the quality/quantity of the biotic habitat. Research at the landscape scale will develop BCG relationships to determine (a) current biological condition compared to historical biological condition using historical data, and (b) future biological condition compared to current biological condition using models (stressor-response models, climate change models, land use change models, etc.) to predict changes. These larger-scale BCG approaches may also consider biological condition as the type, quality, distribution, and/or areal coverage of habitats, including living habitats or biotopes.

Another component of this work will focus on developing a framework to refine designated uses in estuaries by applying the concept of potential habitat-use zones (e.g., Chesapeake Bay's designated uses) with associated populations of valued organisms and their specific tolerances. This work will initially seek to demonstrate a scientific basis for refining habitat-use zones for associated aquatic populations based on dissolved oxygen and transparency requirements.

For marine waters, technical reports have been provided on rapid assessment protocols supporting implementation of coral reef biocriteria. Specifically, we will develop a report on the technical development of rapid assessment protocols supporting implementation of coral reef biocriteria by U.S. jurisdictions. This report will evaluate the Stony Coral Rapid Bioassessment Protocol (EPA 2007) and additional assessment tools for indicators that inform priority management decisions and support regulatory activity under authority of the Clean Water Act.

In parallel efforts, approaches applicable to the Great Lakes coastal wetlands will be evaluated in the development of habitat and nutrient criteria based upon biological responses to an anthropogenic disturbance gradient. To increase the precision and accuracy of estimates of aquatic system condition, bioassessment protocols will be demonstrated in a mid-Atlantic State monitoring program using DNA barcodes. These studies will culminate in the development of a Biological Condition Gradient framework related to multiple landscape stressors for coastal habitats of the Great Lakes. These efforts, individually and together, will provide specific assistance to OW on Biological Condition Gradients for application to coastal and estuarine settings under the Tiered Aquatic Life Use framework.

1.3 Nutrient Criteria

Under Section 304(a) of the CWA, EPA must develop and publish ambient water quality criteria. Ambient water quality criteria are levels of individual pollutants, water quality characteristics, or descriptions of conditions of a water body that, if met, should protect the designated use(s) of the

water. The most significant cause of surface water impairment in the United States, according to the CWA 303(d) lists, is nutrient over-enrichment. EPA has developed methodologies for deriving nutrient criteria, default criteria for the variety of waters and eco-regions found in the Unites States, and a strategy for implementing the criteria (EPA 2000b, 2001, 2002b) including guidance on the use and development of biocriteria (EPA 1996, 1998, 2000a). Whereas preliminary research has been completed (EPA 2002a), significant research remains to be done that will make it possible for States and Tribes to implement nutrient criteria and address their nutrient stressed waters.

The following areas have been identified as requiring additional understanding to improve the ability of EPA, States, and Tribes to manage aquatic resources.

- Biological response indicators for nutrient criteria development for coastal habitats.
  - Develop comparative assessments to understand resource (estuary and wetland) vulnerabilities and sensitivities to nutrients, including increased understanding of between and within system variability, between habitat sensitivities, and of ecosystem responses along nutrient gradients.
  - Determine loading levels and seasonal delivery regimes under which nutrient inputs to coastal systems shift from being ecologically beneficial to detrimental, and develop threshold criteria for these transitions that account for multiple stressor interactions such as nutrients combined with sediments.
  - Determine loading levels and seasonal delivery regimes for and among different/multiple sources of nutrients (i.e., point sources [industrial, municipal] and nonpoint sources [urban, suburban, agricultural, silviculture, aquaculture, and atmospheric]).
  - Develop implementation guidance for recommended criteria and proposed standards.
- Numeric nutrient standards as a baseline for TMDL development, NPDES permitting, and water quality trading.
  - Identify improved scientifically defensible approaches (including approaches based on classification of systems that respond similarly, weight of evidence from multiple sources, modeling, and associated uncertainty analyses) for developing numeric nutrient criteria, including the use of translator models that relate nutrient inputs to ecosystem response.
  - Identify the best methods for implementing standards in a cost effective manner, including the incorporation of spatial and temporal aspects for implementing criteria protective of designated uses.
  - Provide scientific support for TMDL development, nutrient trading, NPDES permitting, and integration with other water quality programs, including tiered aquatic life use and biological criteria.

APG 1.3.1: By 2012, develop technically sound data products and models that effectively quantify nutrient impairment of coastal/estuarine ecosystem responses and relate impairments to causes in order to support continual improvement of nutrient criteria and guide nutrient management in coupled watershed-estuarine-coastal ocean ecosystems.

Research will initially focus on extension of the most promising products and approaches developed under the National Health and Environmental Effects Research Laboratory (NHEERL) Aquatic Stressors Research Program for coastal systems. Conceptually, the goal is to

expand products developed as a regional proof of concept into nationally applicable methods and models to support nutrient criteria development for multiple coastal resource components. The principal resource focus will be on estuarine and Great Lakes coastal systems of all sizes. In the Great Lakes, the focus may extend to research or approaches to develop open water nutrient criteria. Model development in support of research on Gulf of Mexico hypoxia may also be useful to criteria guidance for near coastal waters, and may guide development of more effective monitoring strategies for both estuarine and coastal waters. East Coast efforts will focus on working to improve existing load response models and using them to aid State/Tribal efforts to manage nutrients for southern New England embayment-type estuaries, and to expand the models to more estuarine classes. By working with the Office of Science and Technology (OST), the National Oceanic and Atmospheric Administration (NOAA) and other partners, models will be developed that are applicable to different classes of estuaries.

In 2011 and beyond, research will continue to refine methods for determining load-response relationships for developing nutrient criteria for estuaries. Information will be provided on physical and biogeochemical process models linking watershed land use and nutrient export to estuarine response endpoints under various nutrient management scenarios. These data will support the development and application of regional-scale integrated monitoring and modeling systems to support review of nutrient criteria for coupled watershed-estuarine-coastal ocean ecosystems.

1.4 Recreational Water Criteria/Pathogens

As a result of the BEACH Act of 2000, EPA initiated a series of studies to develop rapid methods for measuring fecal indicator organisms and to determine swimming related health risks associated with those fecal indicators. Fresh water epidemiologic health risk studies were finished in 2005 and marine studies were subsequently initiated. The following section addresses both the research required to meet the needs for the development of criteria by 2012 and future revisions to those recreational water quality criteria.

APG 1.4.1: By 2010, provide OW with data analyses and tools to use to establish recreational water criteria for human pathogens and/or pathogen indicators.

Waters of varying quality, as viewed by fecal indicator organism content, may vary in level of risk. Research will first establish the levels of risk associated with swimming in waters impacted by Publically-Owned Treatment Works (POTW) effluents. Beaches receiving either agricultural or anthropogenic nonpoint sources of runoff will be studied as other likely sources of recreational water related human health risk.

APG 1.4.2: By 2013, OW has sound data, analyses, and tools to establish policy and guidance for assessing risks associated with human exposure to pathogens and pathogen indicators in recreational waters.

Recreational water quality criteria are based upon associations among swimming related illnesses and fecal indicators. This research will initially focus on developing and evaluating human-specific fecal indicators. These can potentially be used for differential criteria, based on Quantitative Microbial Risk Analysis (QMRA) results and policy decisions. Research to develop

and evaluate animal-specific (e.g., bovine) fecal indicators will also be conducted. Future efforts will seek to protect recreational uses from exposure to waterborne pathogens. "Nowcasting" models will be developed from field observations of the associations between environmental factors (e.g., meteorology) and pathogen fate and transport. To evaluate the relevance of indicators, particularly molecular indicators, pathogen data will be compared to fecal indicators in freshwater and coastal marine recreational waters. These data will support the use of indicators to assess and provide early warnings about levels of indicators that pose health risks (e.g., criteria exceedences). Second generation "Forecasting" models will utilize data that characterize the most critical sources, and fate and transport processes, that affect the concentrations of pathogenic microorganisms (e.g., bacteria, viruses, protozoa) and fecal indicators. This effort is coordinated with that conducted under LTG 2 that seeks to distinguish the risk from human versus non-human sources of pathogens and pathogen indicators.

1.5 Emerging Contaminants

The beginning of most decision processes begin with questions regarding what contaminants are there; are they present at a concentrations of concern; and whether methods are accurate. Once environmental occurrence has been established, then priority for assessing health or environmental risk is necessary. Finally, for those contaminants presenting either a public or aquatic health risk, research to support regulation is needed. Three APGs are described that support the concepts of occurrence, setting priorities, and developing data for regulatory purposes.

APG 1.5.1: By 2011, develop approaches for identifying and categorizing which emerging contaminants (or classes) present potential risks to the environment or human health.

Measurement methods will be developed for specific chemical classes (such as human and veterinary-use pharmaceuticals and personal care products) where analytical gaps are identified for biosolids and other environmental samples (e.g., water, sediment, fish, aquatic life).

APG 1.5.2: By 2014, develop a framework for prioritizing the chemicals, pathogens, and nanomaterials (or other classes of contaminants) for exposure and hazard assessment, and criteria development.

While determining the occurrence of a chemical or pathogen is important, it is essential that we also know whether the contaminant is biologically active (e.g., bioavailable, infective etc). Initial efforts in this area will seek to elucidate analytic methods for quantifying nanomaterials in surface water (from Land MYP). For compounds such as antibiotics, methods will be evaluated for developing blue-green algae based assays to quantify net exposure and activity from antimicrobials found in POTW and Concentrated Animal Feeding Operation (CAFO) effluents.

Other approaches will include the exploration and development of genomic and traditional measures of exposure and effects to marine organisms as part of a framework for identifying and prioritizing emerging contaminants. A bioinformatics approach is currently being used to develop lists of human prescription pharmaceutical active ingredients, prioritized by potential ecological hazard to identify future occurrence studies. Field validation of this approach ensures ecological validity. Future efforts will also investigate the feasibility of developing prioritized lists of veterinary medicines and human 'over-the-counter' active ingredients to guide studies. A

systematic methodology will be developed for measuring leftover medications as a source of active pharmaceutical ingredients occurring as ambient environmental pollutants.

APG 1.5.3: Conduct the research necessary to address those contaminants/classes of contaminants identified as in need of evaluation or potential regulation (i.e., invasive species, criteria, biological impact, diagnosis, regulatable cause, watershed approach).

Research to support regulations for most of the emerging contaminants must first be identified in the efforts in support of the two previous APGs. However, there are recently identified research needs that should be conducted to support regulatory efforts. This research will address the development of a searchable, publicly accessible reference database containing molecular signatures of invasive species likely to be transported in ship ballast. Later research products will provide information on the development and evaluation of diagnostic assays for rapid testing of ballast samples for the presence of high priority invasive species.

Watershed Management

Long-term Goal 2: *The Office of Water, EPA, Regions, States, Tribes, and watershed managers use ORD research, tools, and expertise to diagnose and predict the causes of water quality impairment; develop TMDLs; and select, apply and evaluate the effectiveness of watershed management measures.*

Land use, water quantity and quality, ecosystem services and health status are all inexorably linked to watershed management decisions that seek to protect or restore the aquatic resources. LTG 2 addresses the needs of decision-makers relative to information on assessing conditions, identifying stressors and optimizing interventions. This research sequentially follows the demonstration of effects and the provision of data to support criteria development.

Introduction: The Watershed Approach

The primary goal of the Clean Water Act (CWA) is to "restore and protect the chemical, physical, and biological integrity of the nation's waters." Using a watershed approach to achieving this goal has been an EPA priority since 1991 (*Watershed Protection Approach Framework,* 1991). Both small and larger scale watershed programs have emerged (e.g., Chesapeake Bay, Great Lakes, Clean Lakes, and National Estuaries Programs) under the belief that addressing a suite of water quality concerns within a watershed would be more effective and efficient in meeting Clean Water Act goals than regulating individual sources, pollutants, or problems.

The approach may be implemented within a variety of contexts (e.g., State, basin, and small watersheds within a larger watershed basin) with the level chosen based upon the problems being addressed. The success of the approach is linked to effective watershed plans that are implemented to meet water quality standards that protect or restore water resources. In either case, there are multiple steps to watershed management, as exemplified in Figure 3.

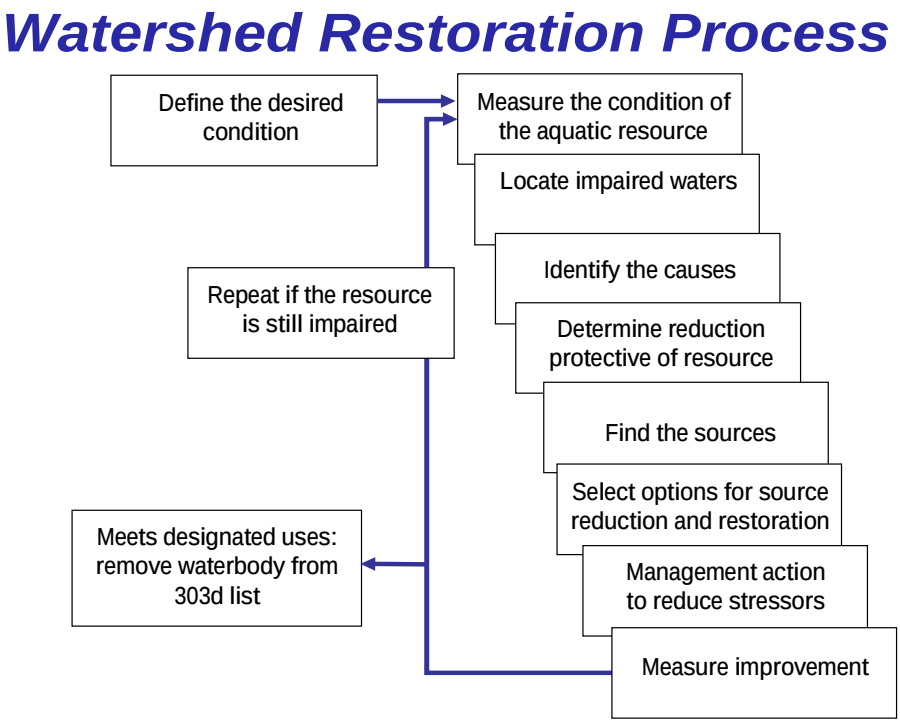
The watershed approach is applied within the geographic boundaries of a specific watershed and is characterized by four major features:

- Targeting of priority problems for efficient and cost effective action
- Integrated solutions that make use of expertise and authority across multiple agencies
- Measures of successful interventions that protect and improve water resources,
- A high level of stakeholder involvement

Using this framework, the Office of Water, EPA Regions, States, and other stakeholders work to protect existing water assets and restore impaired waters. While the steps illustrated in Figure 3 were developed for addressing impaired waters, there is substantial interest in protecting unimpaired waters by applying the watershed approach. With some modification the same steps can be applied.

Key research elements are needed to allow managers to better identify watershed assets and impaired waters, and to determine where, when and how to protect and restore these resources. The ORD research goal is intended to help fill these research needs and to provide a strong technical foundation for implementing the watershed approach.

Figure 3: Multiple Steps are Involved in the Watershed Restoration Process

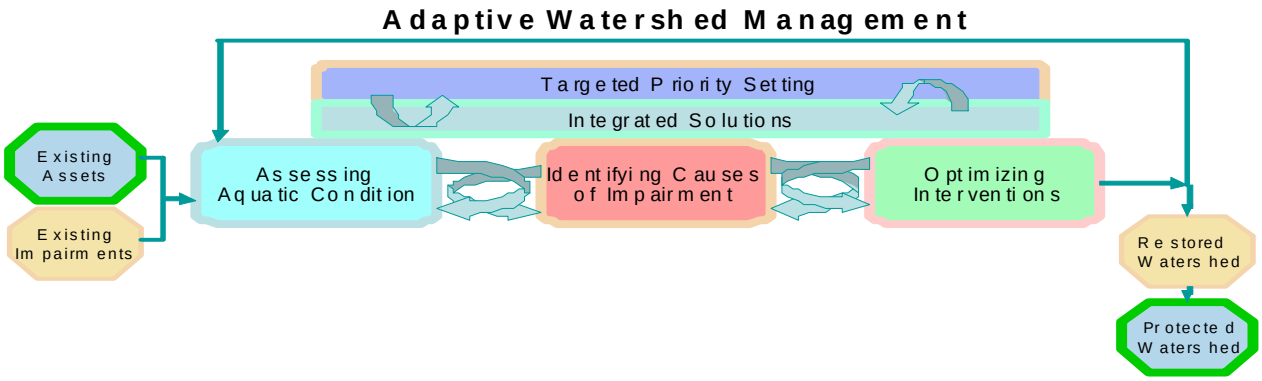


ORD Research Goal: Supporting the Watershed Approach

Land-based contributions to aquatic impairments are based on the assumption that anthropogenic land uses provide socioeconomic services which have impacts on ecologic services. The question of what land-use activities over-stress downstream eco-services falls within the auspices of the Ecological Services Research Program (ESRP). However, under the WQRP, research is undertaken to better understand and model the mechanisms of land-based processes that stress aquatic systems that result in measured impairment and/or recovery. The work undertaken in the WQRP, along with that information generated by the ESRP, help in the providing effective management options for decision-makers.

The primary focus of this long-term goal is to support the restoration and protection of water quality based on the watershed approach in Figure 4 by: 1) supporting the assessment of the condition of aquatic resources; 2) enhancing guidance for determining what is causing impairments in surface waters; and 3) creating opportunities and tools to optimize management interventions. ORD's research priorities to support the watershed approach are represented by the three horizontal rectangles with feedback loops. Research will support adaptive management, an inherently iterative process where information at each step informs other steps in the process, and reflects ongoing prioritization of how and where integrated solutions will promote interventions within financial and other constraints.

Figure 4: Modified Schematic of the Watershed Management Process



Watershed Management Research Plan

This Watershed Management (WM) research plan targets technical uncertainties associated with planning and implementing components of watershed management (e.g., assessment of aquatic resources and water quality impairments, development of TMDLs, targeting priority watersheds, watershed management measures, implementation of best management practices (BMP), tracking effectiveness, and developing incentive programs). Planned research includes developing and applying watershed targeting tools; linking watershed impairments to potential causes; developing and applying diagnostics, forecasting, monitoring and tracking tools; understanding land to water interfaces; understanding the effectiveness of watershed scale implementation of source controls and management measures, including low impact development (LID) BMPs; ecosystem restoration practices; water quality trading, especially for wetlands; and measuring the benefits of watershed management programs.

Recent Advances

The 2003, MYP restoration/protection research activities provided the foundation for watershed management research now identified in this MYP. Earlier research initiated efforts to understand the extent to which BMPs could benefit watersheds. Data were also collected to better understand the transport and fate of selected stressors, and for use in the development of models to support nutrient and sediment TMDL allocations, selection and placement of multiple BMPs, and to predict watershed scale impacts. Many of these watershed studies involved major stressors, including nutrients, sediments, or pathogens. Urban inputs and nonpoint agricultural and CAFO sources of contaminants to the watersheds were evaluated. Models were developed to describe sediment-water interactions. Initial work was conducted on development of DNA indicators to differentiate amongst human and various animal species contributing to down stream fecal pollution.

The Storm water Management Model (SWMM) was upgraded. EPA' SWMM has been in the public domain for approximately 30 years and is the most widely used urban runoff model in the United States. It is used as the engine for many commercial models. Improvements to SWMM include a modern graphical user interface, Windows platform, a more intuitive modeling

approach, and improved computational speed. This newest version – SWMM5 – was released in 2005.

Watershed protection and restoration research included a considerable amount of methods development (e.g., boating and wading techniques for water quality assessments of the chemistry and habitats in large rivers). Conceptual approaches were also developed for integrating ecological risk assessment with economics analyses and evaluated in a series of case studies.

Research under the 2003 MYP included the assessment and diagnosis of the causes and pollutant sources of impairment which supported development of classification frameworks for geographic regions at the watershed, water body, and habitat scale to support the 303(d) listing process.

Diagnostic methods were developed, including stressor identification (SI) for major classes of individual stressors and related biological indicators in freshwater and marine systems. EPA's SI process served as the basis for the Causal Analysis/Diagnosis Decision Information System (CADDIS), a Web-based decision support system to help Regional, State, and Tribal scientists find, access, organize, and share information useful for causal evaluations of impairment in aquatic systems. EPA released the first version of CADDIS in 2006. Current features of CADDIS include a step-by-step guide to conducting causal analysis, downloadable worksheets and examples, a library of conceptual models, and links to useful information sources. For the CADDIS 2007 release, a set of key stressor modules (for metals, sediments, nutrients, dissolved oxygen, thermal alteration, ionic strength, flow and toxic chemicals), new analytical tools, and significant expansion of the conceptual model library were added, intended to aid users in determining what to list as potential causes and how to approach SI analysis.

Desired State

Our research agenda is designed to develop a state of science and technology that will result in cost effective watershed management for the purposes of restoring impaired and protecting vulnerable waters. Our intended purpose is to enable State and local water quality managers to implement effective interventions that enhance watershed protection while minimizing cost, uncertainty, and unintended consequences. To conduct research that meets this vision we need to strengthen the technical basis for assessing condition, identify the causes of impairment, and target restoration and protection to optimize effective intervention. Proposed research includes:

- Developing and using protocols and modeling tools, assessing impaired and vulnerable waters, predicting where impairments are likely to occur, evaluating restoration potential, and providing the necessary framework to set restoration or protection priorities.
- Developing methods, models, and tools to link water quality impairments to specific stressors, suites of stressors, and land use practices.
- Developing cost-effective watershed management strategies, including the use of incentive programs to reduce costs and accelerate restoration and protection activities.
- Forecasting or predicting outcomes to allow decision-makers to choose the most appropriate tools to reduce contaminant(s) or other stressor(s) when linked to causes of water quality degradation. Understanding how changes in surface water quantity affect water quality.

- Developing monitoring protocols to assess the benefits of watershed management over time, to determine whether water quality standards are being met and what additional improvements to watershed management could be made (e.g., adaptive management).

Watershed Management Research Priorities

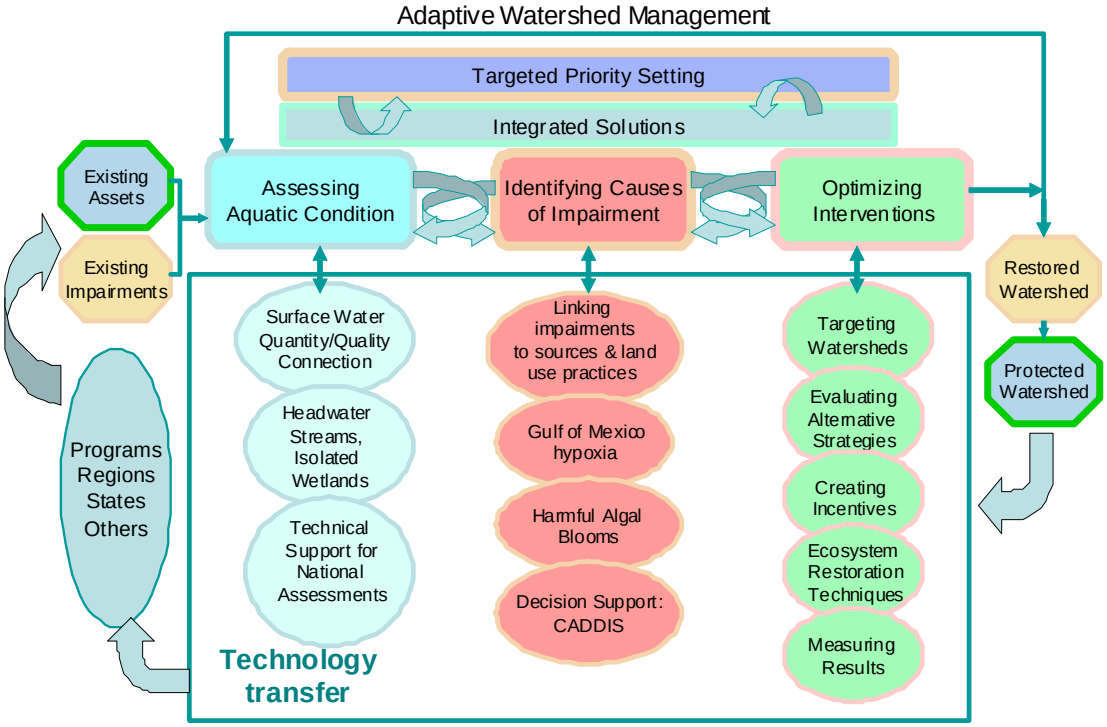
Watershed management is a challenging and complex activity without simple solutions. As we continue developing the tools and knowledge required to increase the success of the watershed approach, past work provides a solid foundation for future. This new research plan targets the highest priority areas, research gaps, and regulatory program needs. We plan to develop tools and processes to identify or measure:

- Impaired and vulnerable resources
- Threats and causes of impairment for effective decision-making
- Ways to reduce impairment and vulnerability
- The effectiveness of implemented management measures

As these advances are made, technology transfer will be a priority effort to ensure users have access to information for successful implementation.

The rest of this section is a discussion of the ORD research activities in LTG 2, describing why they are important and what critical scientific/technical uncertainties they will address, along with more detailed information on the research and the types of products for each activity. Figure 5 is a conceptual diagram of ORD Watershed Management research, showing what research activities support each of the three components of the watershed management process. As indicated above, technology transfer of research results crosses all research activities.

Figure 5: Major ORD Watershed Management Research Themes for the WQ MYP and the Steps in Watershed Management Process They Support – Processes and Research Represented are Inherently Iterative



Modifications to Watershed Management Research

Because Watershed Management is a growing research area for ORD, we continue to enhance our understanding of the research priorities in the LTG. In April 2008, representatives of the Office of Water, Regions, and ORD identified science and research needs in the following areas: protecting watersheds from future changes in land use and from climate change; targeting watersheds for restoration or protection; selecting management strategies to restore or protect watersheds; and measuring the effectiveness of management strategies. As a result of the workshop and follow-up activities, five research topics were identified and proposals are being developed either under the Water Quality and/or the Ecological Services research programs. These proposals are:

- Targeting research deals with issues regarding the consideration of restoration potential in making watershed management decisions on setting priorities for work with the watershed. The work is likely to be addressed under both the WQRP and ESRP. WQ APG 2.3.1 may be modified or new APGs may need to be developed.
- Ecosystem impacts may be considered as an addition to APG 2.3.5 as it focuses on the demonstration of benefits of management strategies.
- Prediction can be incorporated partially under APG 2.3.2 as the main need from OW and Regions appears to be having ways to incorporate management options into future projections of watershed impacts. If improved modeling work is needed, collaboration with the ESRP utilizing place-based research will be sought.
- Strategy selection will result in a modification to APG 2.3.2.
- Monitoring effectiveness will be included under APG 2.3.5.

An expanding focus for ORD Watershed Management research is the application of green infrastructure (GI)[1] to wet weather flow problems. There is a knowledge gap that is prohibiting the widespread adoption and deployment of GI to meet water quality and ecological protection goals. The application of GI also has advantages of returning the watershed hydrology to a more natural condition. The goal of the ORD research program is to address this lack of knowledge and provide State and local managers/utilities/engineering firms and other stakeholders with the tools and information needed to more confidently select and apply green infrastructure options. Prior to FY10 ORD has been principally addressing the use of GI in urban areas. Starting in FY10, ORD will be looking additionally at applications in suburban and "urban fringe" areas, including their use in protecting aquatic ecosystems in these watersheds.[2]

Planned Research

Additional information on the planned or ongoing ORD research activities that support each of the three watershed management steps is presented in Figures 4 and 5. Given the numerous

[1] In the Water Quality Research Program "green infrastructure (GI)" includes the engineered natural systems (e.g., rain gardens) and other techniques that are utilized to return wet weather flow to more natural runoff conditions, as well as strategically managed networks of natural lands (e.g., riparian corridors, headwaters) that directly impact water quality, hydrology or aquatic ecosystem health during wet weather flow conditions.

[2] Note that GI research is also being conducted under LTG 3 to determine how to best design, monitor and maintain individual green BMPs that are part of green infrastructure.

needs represented previously in Figure 3, ORD's research activities are focused on high priority activities in areas where research can have the most significant outcomes. These activities are presented in sections 2.1-2.4.

2.1 Assessing Aquatic Condition

Three topics of the highest OW priorities are addressed. They include:

- Surface Water Quantity/Quality Connections
- Headwater Streams and Isolated Wetlands
- Technical Support to EPA National Aquatic Resource Assessments

Surface Water Quantity/Quality Connections: Water quality is strongly influenced by changes in water quantity. In many watersheds, the quantity of water in a stream changes over time due to changes in land use for urban, agriculture, mining, and forest-development activities, or due to changes in climate and water-resources development and management for water supply, navigation, recreation, hydropower, and irrigation. Research is needed to improve modeling of the fate and transport of contaminants, and that capacity is directly linked to improved hydrologic information. This research will enhance our ability to link stressors to specific impairments by minimizing the confounding effects of water quantity changes on water quality and ecosystem health.

APG 2.1.1: By 2011, develop and improve integrative watershed modeling frameworks for describing the impacts of changing surface water quantity on water quality at multiple scales.

To accommodate modeling needs for a wide range of model users and resource managers, two watershed-based modeling approaches will be pursued: a process or semi-process-based approach and a statistically-based approach. The semi-process based approach is expected to where water supply and re-use decisions are made at the HUC8 or coarser scale by water management districts, while in other regions, decisions are made at the municipal or township scale by water utility managers and statistically-based approaches may be preferable. Each approach may consist of a number of modules or sub-models and by itself can be considered as a framework. Research will provide an integrative modeling framework/approach for assessing how future urban and water resources development and management activities can alter water availability and demand, and then projecting how these alterations affect downstream water quality. Case studies will be conducted on the performance of the framework in test watersheds. Guidance documents will provide information on how to use the process-based methodology to address complex watershed hydrology management issues.

Headwater Streams and Isolated Wetlands

APG 2.1.2: By 2013, provide research and develop tools for assessing significant nexus and permanence of hydrologic connections in headwaters streams, adjacent wetlands, and isolated wetlands

The research will provide a relatively stepwise approach to evaluating the existence of connectivity or a significant nexus. The research begins with the development of a conceptual framework for quantifying hydrologic connectivity and significant nexus. Following the

framework, a preliminary classification system for evaluating connectivity and nexus will be developed. LiDAR data will be used to support methods for estimating and mapping the extent and permanence of these waters. Once a preliminary classification system is developed, case work will be undertaken to demonstrate data on subjects such as N uptake rates and/or subsurface N loading in headwater streams. The next step will be to develop and test a multi-scale, physically-based ground water modeling approach for evaluating seasonal expression of perennial stream networks, and for mapping the spatial distribution of seasonal baseflow. Data will also be provided on the usefulness of stable isotope tracers to document the nexus between adjacent wetlands and downstream waterbodies.

The frameworks and data developed will then be applied in a series of regional case studies. The results of these case studies will be compiled into synthesis documents providing simplified methods for evaluating connectivity and nexus.

Technical Support to EPA National Aquatic Resource Assessments (NARS):
ORD provides technical support efforts on each Office of Water National Aquatic Resource Assessment. These data are critical for determining condition in a scientifically defensible manner and as a dataset used to link monitoring data for biological condition with condition gradients and criteria development.

The primary focus of NARS is the ecological condition for aquatic resources using effects endpoints. Because ORD researchers developed the designs and helped select the indicators for OW's NARS assessments through the Environmental Monitoring and Assessment Program (EMAP), they are uniquely able to conduct the statistical analysis of the data in the time frames required. ORD provides a unique service to the Agency by ensuring the scientific adequacy of the tools and analysis for NARS assessments of aquatic ecosystem condition and for ranking the stressors which are affecting conditions. The NARS assessments are providing scientifically-defensible national condition baselines for aquatic ecosystems. Each NARS requires collaboration among OW, ORD, EPA Regions, States, Tribal nations, and potentially other EPA program offices or other federal agencies, with OW providing overall leadership. For each assessment, a national steering committee is established as well as technical committees that focus on monitoring design, indicators, and other topics as required. ORD is a member of the national steering and technical committees and provides scientific guidance to ensure that the assessments are scientifically defensible. Each national assessment involves technical support in multiple areas: 1) monitoring probability design; 2) indicators of biological condition and stressors; 3) operational implementation; and 4) preparation of national assessment report. Figure 6 outlines the timing and sequence of activities associated with the assessments on water resources. Data derived from these assessments will also be used in the development of criteria (LTG 1). The four APGs for ORD technical support in condition assessment follow.

Figure 6: Schedule for Providing Technical Support

	2007	2008	2009	2010	2011	2012
Lakes	Field	Lab, data	Report		Design	Field
Flowing Waters	Design	Field		Lab, data	Report	
Coastal	Research	Research	Design	Field	Lab, data	Report
Wetlands	Research	Research	Research	Design	Field	Lab, data

Lakes
APG 2.1.3: By 2014, provide national monitoring frameworks for statistical assessments of the biological condition of the nation's lakes in 2009 and a refined probability frame for Office of Water's second assessment.

Flowing Waters
APG 2.1.4: By 2016, provide national probabilistic design monitoring framework for Office of Water's National Flowing Waters Survey that allows for establishing the biological condition of the nation's rivers and streams and a refined survey design for Office of Water's second assessment of flowing waters.

Estuaries
APG 2.1.5: By 2017, provide refined national monitoring frameworks for Office of Water's continuing assessment of the biological condition of the nation's estuaries and a refined survey design for Office of Water's next assessment.

Wetlands
APG 2.1.6: By 2013, provide national monitoring frameworks that allow for statistical assessments of the biological condition of the nation's wetlands.

2.2 Identifying Causes of Impairment

- Linking Impairments to Sources & Land Use Practices

Landscape *Analysis Tools*

Bacterial indicators of fecal pollution have been useful tools for protecting public health. However, more specific information on the animal source of the fecal contamination is needed to allow for identification of host-specific source of pathogens within a watershed. Information on the likelihood of these possibilities will assist in the development of more effective TMDLs. Research will focus on finding genetic indicators for differentiating types of animal sources (e.g., bovines versus other animal sources). Techniques will be sought that are relatively simple to utilize, but are applicable across the United States. In addition, these techniques will be applied to improved characterization of CAFO releases and of the performance of structural pathogen BMPs.

APG 2.2.1: By 2013, ORD provides landscape analysis tools for the Office of Water, States, and local watershed managers to use to identify locations for follow-up targeted ambient monitoring, to assist in stressor and source identification, and to help evaluate effectiveness of management actions.

States and Regions need efficient and effective tools for determining the causes and sources of water quality impairments. Therefore, less costly and more informative monitoring and diagnostic techniques are needed. Since monitoring is not always an option and is expensive, landscape assessment tools have also been demonstrated as a way to reduce monitoring needs and focus and target more effective monitoring. The research supporting this APG includes novel monitoring and diagnostic techniques, as well as further developments and demonstrations of landscape assessment tools. An approach to evaluating impacts of storm water discharge using LIDAR and remote sensing tools will be investigated. The potential for using DNA barcode approaches to diagnose causes of impairment will also be investigated. ATiLA (Analytical Tools Interface for Landscape Assessments), a user-friendly tool for calculating landscape metrics, will be further developed to allow watershed managers to evaluate the relative contributions of multiple stressors spatially and temporally across a watershed. The Automated Geospatial Watershed Assessment Tool (AGWA), which uses widely available spatial datasets and runoff/erosion models (KINEROS2 and SWAT), will be further developed to help watershed managers identify potential problem areas where additional monitoring can be undertaken or mitigation activities focused.

APG 2.2.2: By 2014, ORD provides to OW and Regional, State, and local watershed managers with molecular methods (i.e., microbial source tracking, DNA barcoding) for identifying causes and sources of water quality impairment.

Genetic source tracking markers will be developed for key animals groups (e.g., ruminants, seagulls). The utility of these markers for confirming the presence of animal fecal sources of pollution in waters will be evaluated across a varied range of conditions. The reliability of new and existing tools will be evaluated and advances in the development of biochip technologies will be reported. The application of host specific markers to calculate/support TMDL determinations and to evaluate the effectiveness of best management practices will be assessed. The results of this research will be applicable in the development of criteria and management strategies for recreational swimming as described in LTG 1 – Recreational Water Quality Criteria. The potential for using DNA barcode approaches to diagnose causes of impairment will also be investigated. DNA-based approaches have the capacity to provide rapid, inexpensive, and technically accessible tools for managers.

For situations where infrequent occurrences of highly severe illness may occur, genetically based methods for the identification of microorganisms (such as Salmonella and *E. coli* O157:H7) will be evaluated for identifying the source of animal waste contamination as well as to identify the effectiveness of specific management practices designed to prevent pathogen release into the watershed. This research mainly addresses CAFO sites.

Gulf of Mexico Hypoxia
APG 2.2.3: By 2012, ORD research on physical and biogeochemical processes and models linking near coastal waters to continental shelf hypoxia in the northern Gulf of Mexico are used by stakeholders in evaluating issues related to the Gulf of Mexico (GOM).

This research will develop a suite of model applications, data products, and other tools to assess and predict the relationships between nutrient loads and Gulf hypoxia, forecast the effects of nutrient management actions on Gulf hypoxia, and reduce the uncertainty in nutrient load reduction targets. Seasonal field surveys using OSV Bold and satellite ocean color remote sensing are underway to characterize the magnitude and variability in physical, biological, and chemical oceanographic conditions and processes along the northern Gulf continental shelf from the Mississippi River delta to Texas. These surveys are designed to quantify key processes influencing the development and persistence of hypoxia, and support the development of predictive models. A suite of models ranging from multiple regression models to fully integrated hydrodynamic/water quality/sediment diagenesis models are being developed that will relate the loadings and concentrations of riverine nutrients to the development and size of hypoxic waters in the northern Gulf. The integration of hydrodynamic and water quality modeling with synoptically estimated biogeochemical parameters will allow for a regional assessment of nutrient and organic matter loads to the coastal ocean, improve our understanding of the causal mechanisms regulating hypoxia, and support the goals of the Hypoxia Action Plan.

Harmful Algal Blooms
APG 2.2.4: By 2013, ORD provides research necessary for the development of tools and models aimed at predicting the occurrence, duration, and impact of harmful algal bloom events.

The Water Quality Research Program has supported extramural research on Harmful Algal Blooms (HABs) for several years, and has made tremendous progress in addressing priority research needs surrounding this area. The products currently being developed will provide information critical for predicting the duration and impact of a HAB event, including information on the function of marine toxins and their persistence in the environment. Other efforts will detail the effects of environmental and physical factors, as well as biotic interactions, on the dominance and succession of mixed Raphidophyte blooms, and provide an understanding of the mechanisms underlying herbivore-nutrient-phytoplankton interactions.

Research on specific toxins will provide risk assessors with a useful tool for the exploration of mechanisms responsible for controlling the selective retention of domoic acid by certain shellfish and will detail the patterns of environmental and biological factors stimulating population growth and domoic acid production by Pseudo-nitzschia. Researchers will assess the potential pathways of introduction and consequences of shellfish transfer (commercial or personal) on HAB distribution and determine the risk of transferring toxic algal cells/cysts during transport of live bivalves between sites. In support of this assessment, methodologies will be developed to investigate the economic effects of HABs. In later work, we will continue to explore the impacts of how trophic interactions, such as zooplankton grazing, potentially alter toxic cyanobacteria blooms, how nutrient loading may affect such alterations, and how HAB events respond to anthropogenic global change. Development and application of novel approaches will be sought for measuring grazing on harmful algae utilizing quantitative polymerase chain reaction (qPCR).

Decision Support: CADDIS

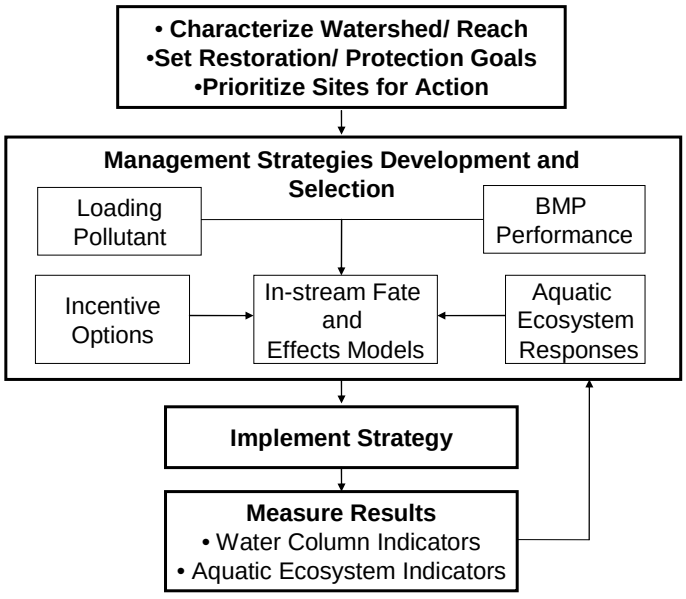
APG 2.2.5: By 2013, provide State and local watershed managers with the improved scientific basis, tools, and models to characterize causal links among sources, stressor exposure, and biotic and abiotic responses, enabling the determination of probable causes of water quality degradation.

Research is continuing on the development of CADDIS III and CADDIS IV. The release of the third Web-based version will address additional stressors (e.g., altered habitat structure), different waters (e.g., western rivers), and new analytical tools (e.g., multivariate methods). These additions, along with an emphasis on outreach (e.g., workshops, training sessions), will enhance CADDIS and allow for increased use by water resource managers. CADDIS IV will incorporate a scientifically rigorous collaborative platform designed to allow registered users to contribute to selected CADDIS elements.

2.3 Optimizing Interventions

- Targeting Watersheds
- Evaluating Alternative Strategies
- Creating Incentives
- Ecosystem Restoration Techniques
- Measuring Results

Figure 7: Watershed Management Options Selection and Benefits Assessment



Restoration Potential: Given limited resources, States and communities often have to prioritize their watershed restoration and protection activities; a number of factors play into decision-making, including the feasibility of restoration and the benefits that will result. These factors usually fall into one of three categories: technical, economic, or social considerations. Research is being conducted to determine which factors typically influence decisions the most, and then to consider what frameworks to develop for gathering and assessing information to compare restoration potentials for those representative watersheds.

APG 2.3.1 By 2012, provide State and local WQ managers with protocols for evaluating the restoration potential of watersheds.

Water resource managers need tools to target watersheds for restoration due to limited available resources and other factors. Research will demonstrate the use of indicators of recovery potential, using landscape assessment and other approaches, to assist selecting amongst watershed for restoration. Information to be provided includes regional maps, databases, and analytical tools.

Management Strategies:
APG 2.3.2 By 2014, provide State and local water quality managers with approaches/tools for developing cost-effective watershed management strategies that optimize the selection and placement of management measures in urban and rural dominated settings.

To improve watershed management, enhanced modeling systems will be developed to simulate implementation of management measures and strategies in a watershed so that optimal selection and placement of measures can be determined. Novel methodologies will be developed for estimating model predictive uncertainty and its implication on decision-making (e.g., TMDL MOS). Small channel stressor attenuative processes will be incorporated into these modeling systems. The research will focus on managing nutrient and sediment stressors. The results will be improved watershed management models and technical reports that describe how they can be applied. These products can be used for more cost-effective selection and placement of management measures within a watershed in different ecological and stressor settings.

Creative Incentives:

APG 2.3.3 By 2013, develop the scientific understanding of wetland functions and the cost and benefits of using wetlands in water quality trading programs to support stakeholders in improving water quality through development and implementation of such incentive programs.

Field evaluations will be conducted of constructed/restored wetlands located in different eco-regions and functioning in different hydrologic regimes. Wetlands will be evaluated for their ability to attenuate stressors as a function of a variety of ecologically relevant variables and will also be studied to evaluate the effect of watershed stressors on the viability and health of the wetlands themselves. Model development and adaptation will seek to describe key wetlands processes, and to predict and optimize performance with respect to the scale and location of a wetland within a watershed. Marginal cost curves as a function of relevant wetlands design and performance parameters will be developed. Subsequently, data will be provided on the cost

effectiveness of wetland-based nutrient reduction programs. These data will be combined in an integrated modeling system capable of optimally selecting and placing wetlands for nutrient pollutant reduction at a minimum cost/benefit ratio.

Ecosystem Restoration Techniques:
APG 2.3.4 By 2013, provide the Office of Water, EPA Regions, States, and local watershed managers the riparian and stream restoration methods and tools developed by ORD to enhance the hydrologic and nutrient and sediment functions of these ecosystems.

Proper nutrient and sediment management will have a strong effect on the ability to manage a system for desired water quality. Excess anthropogenic nitrogen, phosphorus, and sediments have been implicated for decades as the major cause of unbalance in aquatic ecosystems. Pathogens pose risks to human health during recreation and water consumption. To minimize the impacts of these pollutants, ORD conducts empirical studies to understand how in-stream and riparian ecosystems can control these pollutants.

The ORD ecosystem restoration program will focus on evaluating the effectiveness of restoration techniques for aquatic ecosystems to maximize their functions (e.g. flood damage, erosion control, water quality improvement). This program is designed to conduct work at multiple scales with on-the-ground evaluations of existing restorations. An understanding of how nutrients and sediments are processed, sequestered and apportioned at the micro- and process-level scale is necessary to design efficient means for managing these nutrients and sediments in the environment.

Measuring Results:
APG 2.3.5 By 2016, provide monitoring methods to link management actions with measurable water quality protection (anti-degradation) and restoration benefits, including tools and indicators to measure the effectiveness of management practices for protection/restoration.

Management decisions benefit from access to the best information, including initial research results and follow-up analysis of previous decisions and implementation. ORD's longer-term research efforts will incorporate information on the effectiveness of selected types of BMPs in improving or protecting water quality at local and watershed scales. These tools include data, assessments, and case studies incorporating on-site wastewater management effectiveness into local watershed and TMDL models. This supports the ultimate goal of developing approaches for linking multi-source and multi-stressor loads to stream biotic responses.

Technology Transfer
Watershed Central:

APG 2.4.1: By 2012, provide a Web-based approach implemented to provide integration, access and feedback to the tools, data, and information resources needed to support federal, State, Tribal, and local watershed management decisions.

Because data and tools for watershed management may be highly specific and because these materials are widely distributed across various levels of government, Web sites, and academic

institutions, EPA has proposed to organize this information for watershed managers in a central location in a framework that promotes easy access. As one example, EPA's Office of Water, ORD, and Office of Environmental Information (OEI) 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." In the future the website may link key tools and resources from various parts of EPA to particular steps in the process of managing watersheds. Watershed Central would also link to tools and information from outside the Agency. EPA is now discussing the format of such a Web site with potential users. The site is intended to be fully functional by 2011, with a long-term site management plan implemented by 2012.

One of the ORD decision support tools that will be developed and incorporated into Watershed Central is a Web-based prototype (e-Estuary) for integrating geospatial databases, classification schemes, and diagnostics tools to support management of coastal watershed and associated estuaries at multiple scales. e-Estuary will incorporate the results of research described in other parts of this MYP and will support multiple OW programs at the national scale (e.g., nutrient and sediments WQ criteria, TALU, TMDLs), as well as providing decision support for watershed management at local and regional scales.

Source Control and Management

Long-term Goal 3: *The Office of Water, EPA Regions, States, Tribes, and communities, especially municipal utilities use ORD expertise, research, and tools to characterize, control and manage sources of water quality impairment in U.S. waters.*

Once the effects of environmental stressors have been established (LTG 1) and the sources of those stressors have been identified (LTG 2) it is essential to establish the utility of various control options. LTG 3 seeks to describe such control options for high priority point and nonpoint source contributions to pollutant loads. This includes improving our understanding of how both built (gray and green infrastructure) can work to sustain and enhance and natural environmental processes, for storm water flows and adaptations to climate induced alterations of flow. One of the key elements for this LTG is to research design elements of green infrastructure options that show cost benefits, environmental effectiveness, and how and where such interventions can be placed and managed within watersheds to achieve water quality goals. The research does not extend to characterizing and quantifying the benefits to ecological services.

Introduction

For this MYP, a "source" is defined as any activity, facility, structure, or other anthropogenic influence that creates potential or actual degradation of water quality or aquatic/estuarine/marine habitats. Source control and management (SCM) is the direct or indirect change in the characteristics of a source to prevent, reduce, or eliminate its detrimental effects.

SCM seeks to provide information and technical guidance on the design and implementation of discrete control techniques and technologies and management measures to assist water quality managers to attain State mandated water quality and aquatic habitat criteria developed as a result of the research conducted under the Water Quality Integrity theme. While SCM provides information on the performance of control techniques and management measures, it complements the work conducted under Watershed Management that provides information and tools for applying the most cost effective mix of control techniques and management measures within a watershed to meet its specific overall water quality and aquatic habitat goals. In general, SCM provides information to help wastewater and storm water facility managers to meet water quality goals.

SCM addresses research needs for point sources and: nonpoint source control using best technological control and management practices. Planned SCM research is presented within three themes: 1) Aging Infrastructure; 2) POTW Management and Treatment; and 3) BMP Performance. Aging wastewater infrastructure is a national challenge that has been identified as a major Agency priority issue. In general, infrastructure issues relate to improving the ability of wastewater utilities to conduct cost effective condition assessment and rehabilitation of collection and treatment systems and to adopt new, innovative system designs, and management approaches that will lead towards sustainability. POTW management and treatment research focuses on two POTW issues: management of peak wet weather flow and residuals management. Wet weather flow control includes the management of peak wet weather flows at municipal wastewater treatment plants and the prevention, management, and treatment of storm water and municipal wastewater overflows (e.g., CSOs/SSOs) during and subsequent to rainfall and snow

melt. This theme area also includes residuals management and treatment relative to the management and treatment of municipal wastewater sludge and biosolids, wet weather/storm water treatment residuals, septage, drinking water treatment residuals subject to pretreatment/NPDES regulations, and animal manure. BMP performance research is intended to better determine how to design and implement structural BMPs and measure their performance. BMP performance is a measure of reduction in mass transport out of a BMP compared to that measured at its input; it is distinguished from BMP effectiveness, which is measured by the water quality benefits that result from the application of a BMP (or multiple BMPs) on a reach, or in a watershed or sub-watershed.

Infrastructure

Aging infrastructure has been recognized as a major problem requiring a substantial increase in capital and operations and maintenance (O&M) investments. Estimates of national investment needs have ranged from $300 billion to $2 trillion for water and wastewater infrastructure (i.e., operation, maintenance, and capital investment) over the next 20 years. Therefore, given the magnitude of this issue, even modest improvements in current practices could yield large savings. The research proposed supports the goals of the Agency's Sustainable Water Infrastructure Initiative.

The main goal of the Agency's Sustainable Water Infrastructure Initiative is to change how the nation views, values, manages, and invests in its water infrastructure through the use of effective and innovative approaches and technologies. Considering these principles, the research presented herein, is to generate the science and engineering to evaluate and improve promising innovative technologies and techniques to reduce the cost of operation, maintenance, and replacement of aging and failing wastewater treatment and conveyance systems.

Recent Advances

The 2003 WQ MYP addressed water quality restoration and protection and biosolids issues under LTGs 3 and 4, respectively. As the program has evolved, biosolids issues have been integrated into the current MYP LTGs; the current LTG 3 now addresses contaminant source control and management. While there are some activities that are not in complete alignment, much of the former LTG 3 and 4 research has led to what is now proposed in this MYP.

Almost half of the 47 EPA reports resulting from previous WQ MYPs and published from 2000 to 2005 actually deal with infrastructure issues or wet weather management practices as they affect urban systems. The reports cover a wide range of topics from the use of radar based rainfall data for real-time system control, the integrity of collection systems, in-system storage, disinfection of combined sewer overflows (CSOs), best management practices and design of treatment options for storm water and wet weather affected wastewater flows, technology verification, sediment and solids management, cost information, and decision-making support. Much of this work supported the various infrastructure analyses that were performed and led to the funding initiative that now supports the infrastructure research described in this plan.

An important contributor to bring innovative source controls to commercialization is the ORD Environmental Technology Innovation (ETV) Program's Water Quality Protection Center. The Center has completed over 30 verifications on a variety of treatment and monitoring

technologies, including seven for decentralized treatment, 15 for storm water control, and nine for watershed protection (e.g., animal waste treatment, wastewater disinfection).

Desired State

The desired state is one where water infrastructure reflects innovation and advanced concepts, such as green infrastructure and low impact development, and demonstrates how they are incorporated into planned and rehabilitated urban environments, following a roadmap to sustainable communities. On the broader scale, decisions are made on the use of cutting edge technologies to extend and enhance the performance of existing, in-place facilities (e.g., rehabilitation of pipes and treatment facilities), and balancing repair and replacement against the use of decentralized technologies (e.g., rain gardens or other low impact development technologies). Tools are available to assess the condition of infrastructure; prioritize where resources are most needed to construct, repair, or replace infrastructure; and manage these issues while cost-effectively meeting permit discharge limits and ambient water quality criteria.

For aging water infrastructure, the application of new and innovative technologies, new system design concepts, and comprehensive, integrated management approaches have moved our nation's wastewater infrastructure closer to sustainability. Information and tools have been made available to locate, value, and assess the condition of wastewater conveyance and treatment assets. Decision support tools also exist for prioritizing the timing and utilization of resources that best provide critical services and meet water resource goals. Reliable information is available on technological innovations including designs of components and systems, methods and procedures, and innovative financial, ownership, personnel, and management approaches.

Decision makers utilize information to manage wet weather flows on a watershed basis. The information that supports these efforts includes performance data on specific best management practices, both structural (e.g., wet ponds) and nonstructural (e.g., street sweeping); the application of models for managing runoff and collection systems; and for managing collection systems (e.g., real time control) to minimize and/or control system flows, overflows and peak flows to the treatment facility. Facility managers have the information and tools needed for the control, treatment, and management of municipal wastewater system wet weather flows, and to prevent and control CSOs and SSOs.

The management and treatment of residuals and byproducts are conducted in an environmentally sound and publicly acceptable manner. Programs are considered to be protective of health and optimized to support energy efficiency programs. The information needed to achieve this end addresses health, environmental, and energy concerns related to the treatment, disposal, and use of residuals from human and animal wastes.

Planned Research

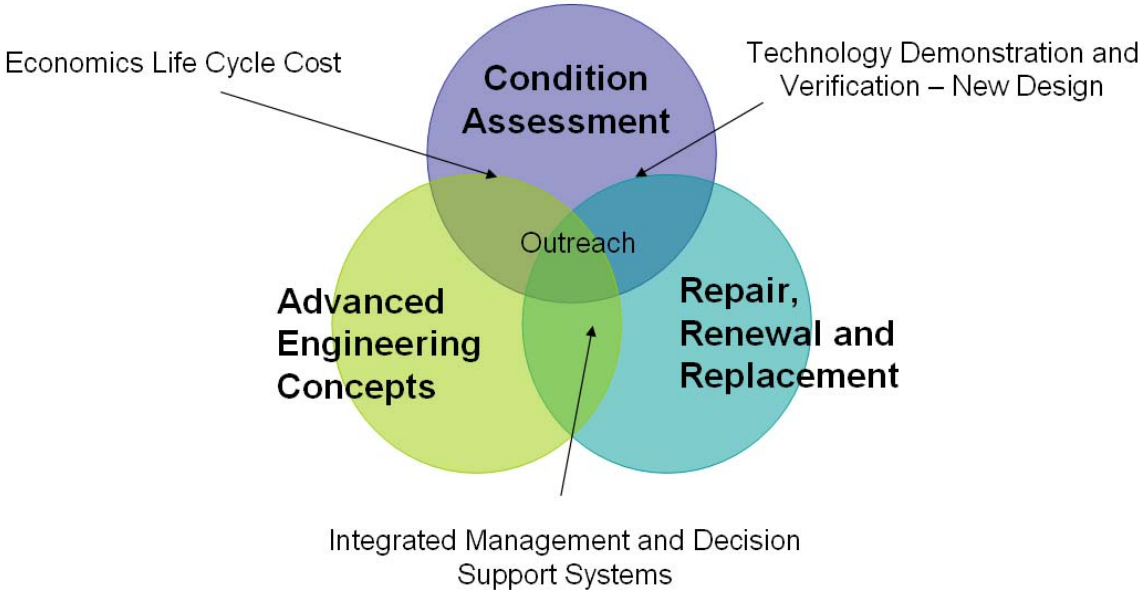
3.1 Aging Infrastructure

U.S. water infrastructure is critical for providing essential services for the protection of public health and the environment, and supporting our economy. The American Society of Civil Engineers' 2005 and 2009 Infrastructure Report Cards rated wastewater infrastructure a "D-," stating that "sanitary sewer overflows, caused by blocked or broken pipes, result in the release of

as much as 10 billion gallons of raw sewage yearly." The magnitude of this issue can be further expressed by recognizing that over 600,000 miles of sewers and 16,000 POTWs serve 190 million people in the United States, and all continue to age. These issues define the need for aging infrastructure research. The outputs from this program will assist utilities to more effectively implement comprehensive asset management, provide reliable service to their customers, and meet their Clean Water Act and Safe Drinking Water Act requirements.

ORD's infrastructure research program consists of three main components, as depicted in Figure 8. Condition assessment encompasses the collection of data and information through direct inspection, observation, and investigation; indirect monitoring and reporting; and the analysis of the data and information to make a determination of the structural, operational, and performance status of capital infrastructure assets. System rehabilitation is the application of infrastructure repair, renewal, and replacement (R^3) technologies in an effort to return functionality to a wastewater system or sub-system. The decision making process for determining the proper balance of repair, renewal, and replacement is a function of the condition assessment, the life cycle cost of the various rehabilitation options, and the related risk reductions. Advanced concepts relate to the application or adoption of new and innovative infrastructure designs, management procedures, and operational approaches. Accomplishing this research will involve economic life cycle cost analysis, technology demonstrations, and verifications, the development of integrated management and decision support systems and outreach to stakeholders.

Figure 8: Components of the Aging Infrastructure Research Program



Four performance goals have been set for the Aging Infrastructure Research Program. They are:

New and Innovative Technologies for Wastewater Collection System Condition Assessment and System Rehabilitation:
APG 3.1.1: By 2012, provide "State of the Technology" assessments and comprehensive information on the verification/demonstration of emerging and innovative inspection/condition assessment, rehabilitation, and replacement technologies for collection system infrastructure.

The research to support this APG consists of state of the technology assessments for emerging and innovative conditions assessment, inspection, rehabilitation, and replacement for collection system infrastructure. This work addresses the needs for the assessment and rehabilitation of buried wastewater assets, especially collection systems. Along with collection system condition assessment and rehabilitation technologies, work will look into the application of emerging tools for the identification and assessment of cause and effect relationships between items such as crown corrosion. Information and data from evaluations of rehabilitation technologies will help provide guidance for infrastructure repair and replacement decision making.

Completion of the condition assessment and rehabilitation technology assessments will lead to technology demonstration efforts. New, innovative technologies for inspection, including the use of smart materials, will have to be successfully demonstrated. Likewise, best practices and other novel and innovative approaches will need to be demonstrated to show how O&M can be enhanced and how the service life can be extended.

Advanced Collection System Designs and Integrated Management Approaches:
APG 3.1.2: By 2012, provide "State of the Technology" assessments and comprehensive information and demonstrations on innovative, integrated collection system designs and technologies, and information and tools to incorporate infrastructure into watershed models and TMDL.

Research to enhance collection systems through the application of innovative and integrated sewerage system designs will be conducted. Information will be developed for incorporating new system designs into new, expanding, and existing urban areas. Retrofitting existing sewer systems and adding to combined sewer systems with new, innovative designs—including green infrastructure and low impact development—will be demonstrated. This will provide municipalities with information specific to their particular sewer design issues. Supporting research will evaluate and demonstrate these advanced concepts. Resulting synthesis products will provide data and information on innovative technologies and systems designs, including integrated management approaches, and will help existing, expanding, and new wastewater collections systems move toward sustainability.

Comprehensive Asset Management and Decision Making:
APG 3.1.3: By 2012, provide criteria for prioritization of wastewater infrastructure to guide national and local decision making and outcome assessment; "State of the Technology" assessments and comprehensive information on innovative data collection and management.

National and regional analyses and assessments of infrastructure needs and impacts will be provided; information on decision support tools to support infrastructure asset management will be developed; and assessments that document positive environmental outcomes will be conducted. Work on defining sustainable infrastructure metrics will also be undertaken. Work is sequenced to define the current conditions of our wastewater infrastructure and then to show how condition assessment data, life cycle cost analyses, service life failure modeling, and rehabilitation and replacement approaches can be incorporated into asset management programs to move systems towards sustainability. The final piece to this work seeks to document environmental improvements and reductions in contaminant exposures due to improved infrastructure performance.

New and Innovative Wastewater and Storm water Reuse Innovations Applications:
APG 3.1.4: By 2013, provide information on the efficacy of treatment of municipal wastewater using new applications of conventional and innovative treatment technologies to address high priority issues, including information on innovative approaches, technologies, designs and system management for potential reuse applications.

The use of reclaimed municipal wastewater and storm water for non-potable purposes is increasing greatly, especially in the arid Southwest. This research will address the application of innovative and conventional treatment technologies for these reclaimed waters. In addition, innovative and emerging wastewater treatment technologies will be evaluated. Initial deliverables will address potential reuse applications and associated minimum water quality requirements. These studies will focus mainly on reuse scenarios and the effectiveness of municipal wastewater treatment to meet those requirements. In conducting these studies, information will be developed for a variety of emerging contaminants in addition to the necessary reductions for nutrients and pathogens. These reports will gather key scientific and technical data and models on environmental and human health safety as they pertain to the specific reuse applications. Additionally, other reports will address energy efficiency information in terms of energy savings and reduced volumes of residuals.

3.2 POTW Management and Treatment

Wet Weather Flow Events

Wet weather flow events result in a variety of runoff and pollution scenarios. Event specific impacts are related to topography, storm intensity, and total precipitation amount. POTWs can experience significant increases of flow during wet weather. This is somewhat dependent upon the integrity of the sewer system. Rainfall derived infiltration and inflow elevates wet weather peak flows to be treated at POTWs. Such events can cause increased operating costs and can be detrimental to treatment efficiency; this can result in bypasses of all or part of the treatment system.

Research is needed to support within plant treatment of excess wet weather flows, including understanding the human health and ecological risks from discharging peak flow effluents and the treatment effectiveness of conventional and innovative technologies.

Research needs include:

- Improved understanding of the performance of management practices, including the development of evaluation standards and conducting post-implementation evaluations
- Managing peak flows at wastewater treatment plants
- Increased understanding of treatment effectiveness of blended wastewater
- Characterization of performance of alternative technologies for addressing peak flows
- Innovative approaches to manage peak flows within a collection and treatment system, including infiltration and inflow reduction, POTW performance enhancement and blending avoidance

Recent Advances
No major investment was coupled with research on POTWs under the 2003 MYP. The dominant research from that MYP focused on storm water collection, CSO issues, and related issues. Continuing research on those interests remain as priority research needs, and are addressed under Aging Infrastructure.

Planned Research

Management and Control of Peak Wet Weather Flows at POTWs:
APG 3.2.1: By 2011, provide to EPA Program Office, EPA Regions, States, and other stakeholders information on optimized strategies and the effectiveness of new and/or innovative technologies for in plant peak flow management.

The general intent for this research is to provide data and tools to support the operations of POTWs under conditions during peak wet weather flows. Public health issues relate to the occurrence of pathogens in blended effluents and how effectively and efficiently those effluents can be disinfected. Studies of disinfection efficacy and efficiency are greatly complicated by the large and fluctuating volumes flow that POTWs experience during storm events. Due to plant influent flow variation during wet weather, research on monitoring strategies is necessary to quantify treatment process effectiveness. Following the development of data and methods on disinfection and monitoring strategies, information will be made available on management practices and treatment process modifications needed to optimize wastewater treatment plants during wet weather flows. This research effort will also include providing information and protocols for stress testing facilities so that operators can determine their peak wet weather flow treatment capacity.

Residuals Management
Most water and wastewater treatment process byproducts and residuals require management. Prior to their beneficial reuse or disposal, it is critical that they be properly handled, prepared, and managed (e.g., thickening, disinfection, stabilization, dewatering, etc.). Decision makers need to understand the types and amounts of byproducts and residuals produced by different processes, how to characterize them, and how to develop and select the best management options for meeting their goals and all regulatory requirements.

Public concerns continue to be reported regarding health effects associated with the beneficial use of wastewater biosolids and the combustion of sewage sludge. Roughly 64% of sewage sludge is beneficially used after appropriate treatment and 25% of sewage sludge is combusted.

Pathogen indicators need to be improved for both raw and treated sewage sludge. The effectiveness of currently applied disinfection and stabilization needs improved documentation. Process enhancements need to be investigated to address situations where current processes are found to be lacking. Future studies on the land application of biosolids should consider the occurrence and frequency of molecular markers (i.e., using the tools now being evaluated as indicators of surface water quality) and their relevance and significance as indicators of human fecal contamination.

Recent Advances
Biosolids research under the former LTG 4 resulted in published analytical methods for both fecal coliforms and Salmonella species in sewage sludge and biosolids. These methods have since undergone additional validation by OW and were published as standard EPA methods in the Federal Register. ORD has conducted or supported workshops on biosolids topics such as exposure measurement methodologies.

Planned Research

Sludge Disinfection Processes: Pathogen Equivalency Committee (PEC):
APG 3.2.2: By 2013, provide technical support to the Office of Water, EPA Regions, States and utilities by evaluating innovative and alternative sludge/biosolids management and treatment approaches to meet pathogen and vector attraction control requirements through the Pathogen Equivalency Committee (PEC).

During the period covered by this MYP, the PEC will assess innovative and alternative sludge/biosolids management and treatment approaches to determine whether they meet pathogen and vector attraction control requirements. The Committee will disseminate information, through the preparation and publication of guidance manuals and workshop proceedings, and through its associated Web sites.

Biosolids research will also continue to be conducted as part of its criteria development research program under LTG 1. ORD is completing methods for measuring virus and helminth ova in biosolids, but is not conducting additional research to support OW's development of pathogen criteria for biosolids. ORD is developing analytical tools for measuring select emerging contaminants in a subset of biosolids collected during OW's 2006-2007 National Biosolids Survey project.

3.3 Best Management Practices Performance

This research deals with understanding the performance of point source controls and nonpoint source BMPs for water quality protection and restoration. Selected BMPs will continue to be evaluated under this LTG to enhance database information and provide technical guidance. An additional challenge is to evaluate the performance of BMPs applied in one setting, and then transfer the knowledge to other settings to permit BMP placement elsewhere. One example is to consider how low impact development (LID) techniques (e.g., rain gardens) function, and how to appropriately design and manage them, as such knowledge is currently limited. Also, the performance of BMPs at CAFOs (including those used to reduce pollution from the field

application of manure) remains uncertain, and will be assessed as these are major sources of pollutants in agricultural regions.

Recent Advances

Initial work focused on structural BMP design, management, and performance, including mesocosm studies to assess which key parameters influence BMP performance. A two volume design guide was published for conventional BMPs (e.g., retention ponds), along with other technical reports on BMPs often found in urban watersheds.

Planned Research

APG 3.3.1: By 2013, provide comprehensive information on the performance, cost, and influencing factors to improve the selection, design, construction, and O&M of BMPs to address wet weather flows and diffuse sources, including CAFO management practices for controlling microorganism and nutrient releases.

Case study work on LID or green infrastructure (GI) techniques will better determine how to design and implement techniques such as rain gardens, bioretention etc. Information will be provided to enhance the use of comprehensive management plans to control nutrients and pathogens from CAFOs and from lands receiving manure applications. Reports and technical guidance will be designed to improve the selection and application of various management practices to control the release of water quality stressors from watersheds during wet weather events. Products from these efforts will focus on guidelines for design, construction, maintenance, and placement of management practices to optimize their effectiveness.

APPENDIX A

Water Quality Multi-Year Plan (MYP) Cross-walk with the 2008 Draft National Water Program Research Needs and Management Strategy Document

Major water research needs categories were identified in each chapter of the 2008 draft document titled *National Water Program Research Needs and Management Strategy 2008-2013*. Detailed information on the research ORD plans to conduct relative to each category is identified by its corresponding APG in the following Table. The APG number represents its associated Long-term Goal (LTG) and major sub-divisions therein. If for example, one wished to only review 'Residuals' research activities, MYP section 3.2.2 would contain the relevant information. If no APG is listed, then there is no current research addressing that category. This does not mean that the category is unimportant, but that either it was of insufficient priority to be included at this time or it may be addressed in another MYP.

Table A is currently being updated to provide information from all other MYPs. The next iteration of this table will link all currently identified APGs in other MYPs to the research needs.

Table A. Linking Water Quality Annual Performance Goals with National Water Program Research Needs

Chap 2. Ground and Drinking Water	**WQ**
Priority contaminants	
Unregulated contaminants	
Method development	
Technical assistance	
Finance	
Security	
Source water protection	2.1, 2.2, 2.3.2, 2.3.5, 2.4.1, 3.3.1
Underground injection	
Chap 3. Wastewater Management	
POTW effectiveness	3.2.1, 3.2.2
Onsite systems	
Residuals	3.2.2
Wet weather flow	3.1.4, 3.2.1
Infrastructure	3.1.1, 3.1.2, 3.1.3
Green infrastructure	2.3.2, 3.1.4, 3.3.1
Chap 4. Watershed Protection/Restoration	
National aquatic resource assessment	2.1.1, 2.1.3, 2.1.4, 2.1.5, 2.1.6

Watershed management	2.3.1, 2.3.2
Watershed assessment	2.2.1, 2.2.2, 2.2.5
Management measures	2.3.5
Incentives	2.3.3
Wetlands - WQ Trading	2.1.6, 2.3.3
Headwaters - Isolated waters	2.1.2
Gulf of Mexico	2.2.3
Invasive species	1.6.1
Ecological restoration	2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.3.5
Coral reef protection	1.2.1
Chap 5. Aquatic Life & Human Health	
Human health effects and risk assessment	1.1.1, 1.2.1
Bioassessment/biocriteria	1.2.1
Aquatic life guidelines	1.1.1
Aquatic habitat	1.2.1, 2.2.4
Biosolids	1.6.1, 3.2.2
Nutrients	1.3.1, 2.2.4, 2.3.2, 2.3.3, 2.3.5, 3.3.1
Emerging contaminants	1.6.1, 1.6.2, 1.6.3
Suspended and bedded sediments	2.3.4, 2.4.1
Multiple stressors	1.4.1
Socio-economic valuation	2.2.3, 2.3.4
Recreational waters	1.5.1, 1.5.2, 2.2.2
Chap 6. Regional Programs	Overlaps with all Chap. listings
Chap. 7 Cross-Program Science	
Sustainable infrastructure	See Chap. 3 listings
Watershed approach	See Chap. 4 listings
Emerging contaminants	See Section 1.6
Climate change	See Global MYP

Climate Change

The subject of climate change merits some discussion as water quantity and quality issues are linked to the frequency and severity of storm events, and with the capture or runoff volume of storm flows. While there are many climate research issues to address, Water Quality research priorities focus mainly on understanding precipitation induced impacts on aquatic systems, the performance of control pollutant and flow control measures, and the development of effective watershed scale management strategies.

LTG 1 research relates primarily to understanding the effect or impacts of stressors and how they interact to affect ecosystems and humans to support the development of criteria using new approaches to provide more comprehensive environmental protection. This research is necessary to link stressors to effects relevant to endpoints that support regulatory and management objectives.

LTG 2 research generates watershed management tools in a stepwise fashion that are targeted for use by the local/county level planners. First, it is necessary to be able to predict how future land use changes, including climate change impacts, would affect aquatic ecosystems in relatively small watersheds. To do this, one must establish relationships between flow and pollution on the response or health status of the ecosystem. This research must establish watershed scale models that include stressor to effect components. Finally, the performance of source control measures must also be linked with various watershed management strategies before watershed benefits can be demonstrated and modeled. While climate change is an important aspect in this research, it is not the primary variable in the work to be conducted. For LTG 3, like LTG 2, the research must account for temporal and spatial considerations of flow variation that may be attributed to climate change. However, the goal of the work is to establish performance data and management measures that can be applied in the protection and/or restoration of watersheds.

The tools developed under these Water Quality LTGs are not designed to predict climate change impacts on watersheds. However, they will advance our understanding of linkages between pollutants, hydrology, and ecosystem impacts, and will provide valuable to the Ecology, Climate Change, and other programs identified previously in the crosswalk of MYPs with national program needs.

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