Design of Cycle 3 of the National Water Quality Assessment Program, 2013-2022:

Part 2: Science Plan for Improved Water-Quality Information and Management

NAWQA Cycle 3 Planning Team:

Gary L. Rowe Jr. (Chair)
Kenneth Belitz
Charlie R. Demas
Hedeff I.Essaid
Robert J. Gilliom
Pixie Hamilton
Anne B. Hoos
Casey J. Lee
Mark D. Munn
David W. Wolock

Open-File Report 2011-xxxx

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figures

Tables

Acronyms

Acronym	Long version
ACT	Agricultural Chemicals Team
AGNPS	Agricultural Nonpoint Source Pollution Model
ASDWA	Administration of State Drinking Water Administrators
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
BFI	Baseflow Index
BOR	Bureau of Reclamation
CADDIS	Causal Analysis / Diagnosis Decision Information System
CCL	Contaminant Candidate List
CCRI	Climate Change Research Initiative
CDC	Centers for Disease Control
CEAP	Conservation Effects Assessment Project
CFC	Chloroflurocarbon

CMAQ	Community Multiscale Air Quality Modeling System
CWA	Clean Water Act
DBP	Disinfection By-Product
DDT	Dichlorodiphenyltrichlorethane
DSS	Decision Support System
EMAP	Environmental Monitoring and Assessment Program
USEPA	Environmental Protection Agency
ETN	Enhanced Trends Network
EUSE	Effects of Urbanization on Stream Ecosystems
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FY	Fiscal Year
FPS	Flow Path Study
GCM	Global Climate Model or General Circulation Model
GSFLOW	Coupled Groundwater and Surface Water Flow Model
GWRP	Groundwater Resources Program
HBSL	Health-Based Screening Level
HPV	High Production Volume chemicals
HSPF	Hydrologic Simulation Program – Fortran
IMS/ATP	Immunomagnetic Separation / Adenosine Triphosphate
IOOS	Integrated Ocean Observing System
IS	Intensive Study
IWS	Integrated Watershed Study
LGS	Local Groundwater Study
LOADEST	Load Estimator
LUS	Land Use Study
MAS	Major Aquifer Survey
MCL	Maximum Contaminant Limit
MOC3D	Method of Characteristics Solute Transport Model
MODFLOW	Modular Groundwater Flow Model
MODPATH	MODFLOW Particle Tracking Model
MOWS	Modeling of Watershed Systems Project
MRB	Major River Basin
MRBI	Mississippi River Basin Initiative
MT3D	Modular 3-D Groundwater Solute Transport Model
MT3DMS	Modular 3-D Groundwater Solute Transport Model
N0x	Nitric oxide and nitrogen dioxide
NARS	National Aquatic Resource Surveys
NASA	National Aeronautics and Space Administration
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water-Quality Assessment
NCOD	National Contaminant Occurrence Database
NEET	Nutrient Enrichment Effects Team

NEON	National Ecological Observatory Network
NFSN	National Fixed Site Network
NHD	National Hydrography Dataset
NIEHS	National Institute of Environmental Health Sciences
NMN	National Monitoring Network
NOAA	National Oceanic and Atmospheric Administration
NRP	National Research Program
NTAS	NAWQA Target Analyte Strategy
O/E	Observed / Expected indicator of alteration and impairment
PA	Principal Aquifer
PAA	Principal Aquifer Assessment
PAH	Polycyclic Aromatic Hydrocarbons
PAA	Principal Aquifer Assessment
PAS	Principal Aquifer Survey
PCB	Polychlorinated Biphenyl
P-GWAVA	Process-based Groundwater Vulnerability Assessment
PRMS	Precipitation Runoff Modeling System
QPCR	Quantitative Polymerase Chain Reaction
RFF	Resources for the Future
RGS	Regional Groundwater Study
RSS	Regional Synoptic Studies
SDWA	Safe Drinking Water Act
SFIREG	State FIFRA Issues Research and Evaluation Group
SPARROW	Spatially Referenced Regressions on Watershed Attributes
STREON	Stream Experimental and Observatory Network
SWAP	Source Water Assessment Program
SWAT	Soil and Water Assessment Tool
SWQA	Source Water Quality Assessment
SWST	Surface Water Status and Trends
TANC	Transport of Natural and Anthropogenic Contaminants to Supply Wells
TIE	Toxicity Identification Evaluation
TMDL	Total Maximum Daily Load
TOPMODEL	Topography-based Model
UCMR	Unregulated Contaminant Monitoring Rule
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGCRP	United States Global Change Research Program
VOC	Volatile Organic Compound
WARP	Watershed Regressions for Pesticides
WaterSMART	Water (Sustain and Manage America's Resources for Tomorrow)
WBDO	Water-Borne Disease Outbreak
WSA	Wadeable Streams Assessment

About this Report

This document presents a science strategy for the third decade—Cycle 3—of the National Water-Quality Assessment (NAWQA) Program, which since 1991, has provided long-term, nationally consistent information on the quality of the Nation's streams and groundwater. These plans for monitoring and assessment of the Nation's freshwater quality and aquatic ecosystems during 2013-2023 are based on an extensive evaluation of assessment progress by NAWQA and its partners during Cycles 1 and 2 (1991-2012) and an updated analysis of stakeholder priorities.

The purpose and scope of this report is to describe the science plan for Cycle3 of the NAWQA Program. This plan describes four major goals for Cycle 3, the approaches for monitoring, modeling, and scientific studies, key partnerships required to achieve these goals, and products and outcomes that result from planned assessment activities. The science plan, as presented here, provides the framework for detailed design, but will still require much more detailed planning as decisions are made about the scope and implementation timeline for Cycle 3. A brief roadmap to the contents of this report is provided below.

Chapter 1. Introduction and Overview (pages 1-20)

Chapter 1 explains the motivation and vision for Cycle 3 of NAWQA, why it is particularly needed now, how partnerships are vital to success, an overview of major goals and approaches, and, finally, what the Nation will gain from the products of Cycle 3 monitoring and studies that will improve protection and restoration of water quality. The guiding vision for the Cycle 3 design is that

> ***"Science-based strategies can protect and improve water quality for people and ecosystems even as population and threats to water quality continue to grow, demand for water increases, and climate changes."***

Chapter 2. Cycle 3 Design Components (pages 21-36)

Chapter 2 outlines the specific objectives associated with each of the four Cycle 3 goals and describes each of the major design components for implementing Cycle 3. These individual design components for surface water and groundwater are then applied to specific designs for each objective in Chapters 3 to 6. NAWQA's strategy for water-quality assessment in Cycle 3 builds on proven approaches used in the previous two decades of the Program, including multi-scale, interdisciplinary assessments of critical hydrologic systems, systematic regional and national monitoring, detailed local-scale studies of governing processes and ecological effects, and modeling and statistical tools to integrate findings across multiple spatial and temporal scales.

The surface-water design combines an enhanced national monitoring network that features perennial monitoring, enhanced contaminant coverage, and application of continuous real-time water-quality monitoring, regional synoptic studies of specific topics, integrated hydrologic and water-quality studies of representative large watersheds, and local-scale intensive studies to answer specific questions. The groundwater design focuses on assessment of large principal aquifers, with a new emphasis on assessing ground-water quality in three dimensions, increased emphasis on groundwater quality from public supply wells, enhanced contaminant coverage, real-time continuous water-quality monitoring of shallow groundwater in selected aquifers, and flow and contaminant transport modeling for sub-regions and selected local areas.

Chapters 3 to 6: Objectives and Approaches for Addressing Cycle 3 Goals

Chapters 3 to 6 describe in detail the objectives, products, policy and management relevance, progress during Cycles 1 and 2, study approaches, planned studies, and partnership opportunities for each of the four Cycle 3 goals. The objectives and approaches are presented somewhat differently for each of the goals, depending on the specific types studies involved, their degree of integration, and the level of development for specific study designs.

Chapter 3. Goal 1—Assess the current quality of the Nation's freshwater resources and how water quality is changing over time (pages 37-69).

The Cycle 3 design for monitoring surface water and groundwater fills gaps in the Nation's water-quality status assessment that were prioritized based on stakeholder input. A critical first step is to restore the NAWQA fixed-site network for monitoring water quality in streams and rivers which has suffered significant declines in the number of sites and the frequency at which they are sampled over Cycles 1 and 2 (from approximately 500 sites monitored in Cycle 1 to 113 sites currently). Significant increases in the number of stream sites (113 to 331 sites), annual sampling (at all sites), and the use of real-time water-quality monitoring (at most sites) are key features of the enhanced Cycle 3 design.

In addition, there are a number of critical improvements that address key data gaps that are addressed in the Cycle 3 design. These include (1) updated contaminant coverage, (2) enhanced characterization of contaminants in sources of public drinking-water supplies—with new emphasis on lakes and reservoirs, and deeper parts of principal aquifers used for public supply, (3) expanded reference-site monitoring for tracking climate change and evaluating ecological background conditions, (4) a new effort to assess microbial contaminants in streams and rivers used for recreation, (5) enhance monitoring of mercury trends in fish tissue, (6) a renewed emphasis on assessing trends in shallow groundwater quality, and (7) expanded assessment of contaminant, nutrient, and sediment loading to inland and coastal waters.

The assessment activities described in Chapter 3 are essential for identifying and explaining trends in water-quality and ecosystem condition (Goal 2), understanding the effects of climate change and human activities on water quality and aquatic biota (Goals 2 and 3), and are also essential for development and validation of water-quality models (Goals 2, 3, and 4).

Chapter 4. Goal 2—Evaluate how human activities and natural factors, such as land use, water use and climate change, are affecting the quality of surface water and groundwater (pages 70-95).

Studies to address Goal 2 are focused on developing explanations for, and understanding of, the observed patterns and trends in water quality. This understanding is critical for evaluation of the effectiveness of implemented management practices and the susceptibility of water quality to degradation. Stressor studies examining sources and transport of contaminants, nutrients, and sediment, as well as streamflow alteration, will range in scale from individual stream reaches and groundwater flow paths to major river basins and principal aquifers. Modeling tools developed as part of this effort will be used to address Goals 1 and 3 by extrapolating findings to unmonitored areas, and for Goal 4 to explore new management strategies and the influence of potential future land use and climate change of water quality and ecosystem condition.

Chapter 5. Goal 3—Determine the relative effects, mechanisms of activity, and management implications of multiple stressors in aquatic ecosystems (pages 96-119).

Goal 3, which is receiving increased emphasis in Cycle 3, builds upon Goals 1 and 2 by incorporating ecosystem processes and condition into water-quality assessment, understanding, and management. While Goals 1 and 2 provide the foundation for understanding the complex interactions of land use, climate, management practices, and major stressors (contaminants, nutrients, sediment, and streamflow alteration), Goal 3 focuses on understanding ecosystem response and on the development of regionally-based predictive models that relate stressors and management practices to effects on ecosystem condition. These models will be applied for Goal 4 to estimate the effects of future land use, climate change, and management strategies on stream ecosystems.

Chapter 6. Goal 4—Predict the effects of human activities, climate change, and management strategies on future water quality and ecosystem condition (pages 120-134).

A major new direction for NAWQA in Cycle 3 is the development of tools for water-resource managers and policy makers to forecast the effects of future changes in land use, water use, and climate on stressors and the suitability of water for human and aquatic ecosystem needs. These tools will be based on models that have been developed to meet other objectives of NAWQA assessments. Models assessing surface-water quality will be developed at regional (major river basin) to national scales, although time-varying models developed to assess the effects of changes in climate or land use will initially be developed at smaller scales. Groundwater models that couple flow and chemistry to assess groundwater availability will be developed at scales ranging from individual well fields to principal aquifers. Models to predict ecologic response will be done at the regional (level II or III ecoregion). NAWQA will evaluate which of the existing models are most suitable for estimating, within a quantified estimate of error, changes over time in water quality and ecosystem condition due to changes in climate, land and water use, and management practices.

Chapter 1. Introduction and Overview

In 1991, the U.S. Congress established the National Water-Quality Assessment (NAWQA) Program within the U.S. Geological Survey (USGS) to develop long-term, nationally consistent information on the quality of the Nation's streams and groundwater. During the last two decades, NAWQA has served as a primary source for nationwide information on the quality of streams and groundwater; how water quality changes over time; and how natural features and human activities affect the quality of streams and groundwater. Objective and reliable data, water-quality models, and systematic scientific studies characterize where, when, and why the Nation's water quality is degraded—and what can be done to improve and protect it for human and ecosystem needs. This information is used by national, regional, State, and local stakeholders to develop effective, science-based policies for water-quality protection and management (*see sidebar: "NAWQA Results Improve Water-Quality Management").*

This document presents the science plan for NAWQA's third decade—Cycle 3—describing a 10-year strategy for national monitoring and assessment of the Nation's freshwater quality and aquatic ecosystems during 2013-2023. The science strategy for Cycle 3 is based on evaluation of progress by NAWQA and its partners during Cycles 1 and 2 (1991-2012) and an analysis of stakeholder priorities. Specifically, input on key water issues and science needs has been solicited, reviewed, and supported by the National Research Council and more than 50 internal and external stakeholders who provided input during the past two years (2008-2010) of the Cycle 3 planning process.

NAWQA Results Improve Water-Quality Management

Local, State, Tribal, regional, and national stakeholders use NAWQA information to develop strategies for managing, protecting, and monitoring freshwater resources in different hydrologic and land-use settings across the Nation, such as to:

- Support development of regulations and guidelines that address the complex nature of contaminant occurrence, including contaminant mixtures, seasonal patterns, and variability among different environmental settings;
- Identify key sources and characteristics of nonpoint-source contamination in agricultural and urban areas;
- Prioritize geographic areas, aquifers, and watersheds in which water resources and aquatic ecosystems are most vulnerable to contamination;
- Improve strategies and protocols for monitoring, sampling, and analysis of all hydrologic components, including the atmosphere, surface water, and groundwater;
- Contribute to State assessments of the beneficial uses of streams and impaired water (Total Maximum Daily Loads, or TMDLs), and development of strategies for source-water protection and management, pesticide and nutrient management plans, and fish-consumption advisories; and
- Sustain the health of aquatic ecosystems through improved stream protection and restoration management.

Access http://water.usgs.gov/nawqa/xrel.pdf to see how local, State, regional, and national stakeholders use NAWQA information.

Vision

As the Program moves to its third decade, NAWQA's guiding vision is that

"Science-based strategies can protect and improve water quality for people and ecosystems even as population and threats to water quality continue to grow, demand for water increases, and climate changes."

NAWQA contributes to this vision by serving as one of the largest and most comprehensive programs that provide scientific information on the Nation's freshwater resources. The Cycle 3 strategy was developed with the goal of meeting the Nation's water-quality information needs, with a specific focus on meeting those particular needs that NAWQA is uniquely suited to fill (*see sidebar: "NAWQA's Unique Approach to National Assessment"*).

NAWQA's Unique Approach to National Assessment

- ***Interdisciplinary and dynamic* studies** that link chemical and physical conditions of streams (such as flow and habitat) with ecosystem health and the biological condition of algae, macroinvertebrate, and fish communities. Conditions are evaluated in a hydrologic context, which is important because contaminants and their potential effects on drinking-water supplies and aquatic ecosystems vary over time and depend largely on the amount of water flowing in streams and discharging from aquifers. By incorporating interconnections among water quality, hydrology, and biological systems, NAWQA assessments address the susceptibility of aquatic organisms to chemical and physical degradation and determine how ecosystem health and biological responses vary among the diverse environmental settings across the Nation.
- ***Targeted design,*** in which study areas and monitoring locations are chosen because they represent important environmental settings across the country. The NAWQA design targets sites that represent certain land uses, such as agricultural and urban areas, and monitors them over a range of hydrologic conditions to assess seasonal or climatic effects. Understanding sources of water and how that water is transported is critical to ultimately understanding and predicting water-quality conditions and effects on human and ecosystem health. The knowledge gained by this approach helps decision makers to identify streams and aquifers that are most vulnerable to contamination; target actions based on causes and sources of contamination; and monitor and measure the effectiveness of those actions over time.
- ***National design that stresses consistent sampling and analytical methods,*** which allows water issues to be addressed at multiple scales, ranging from local to national. The design ensures that water-resource conditions—including chemical, biological, and physical characteristics—in a specific locality or watershed can be compared to those in other geographic regions and can be aggregated for national assessment. NAWQA thereby builds local knowledge about the condition of water resources, emerging issues, and controlling processes in specific basins and aquifers. At the same time, it builds an understanding of how and why water conditions vary regionally and nationally.
- ***Long-term monitoring*** so that trends in water quality can be analyzed to determine whether conditions are getting better or worse. Consistent and systematic information collected over many years helps to distinguish long-term trends from short-term fluctuations. Analysis of long-term trends is essential for assessing how environmental controls and best management practices are working and for choosing cost-effective strategies for the future.
- ***Integration of modeling and monitoring*** so that water-quality understanding can be extrapolated to unmonitored areas, trends can be predicted, and future water-quality conditions can be better anticipated as a result of various resource, climatic, and land-management scenarios. Statistical and process-based models are used to address specific questions—now and into the future—with a focus on the linkages among sources, transport, and fate of contaminants.

NAWQA's approach combines nationally comprehensive and systematic monitoring with "targeted," but nationally consistent, studies at multiple scales. The goal is to provide a better understanding of conditions, trends, and cause-and-effect relations that are needed to improve the management of our Nation's freshwater resources. Addressing questions such as "What is causing degradation of aquatic ecosystems?", and "What can be done about it?" require a "targeted" design, such as NAWQA's, which focuses on understanding the relations between water-quality conditions and natural and human factors that cause those conditions, including sources, transport, seasonal differences, varying streamflow and groundwater contributions, and processes that control the movement of water. Information provided by NAWQA, as discussed further below, complements information gathered by other national-scale water-quality programs, such as the U.S. Environmental Protection Agency (USEPA) National Aquatic Resources Surveys (NARS), which are national statistical surveys designed to address other important questions, such as "Is there a problem?" and "How prevalent is the problem?" NAWQA also complements State monitoring programs, which generally include multiple designs to address specific needs for the Clean Water Act or State regulatory programs, and many other government and academic programs that have varying and usually more specialized or research-oriented objectives.

The NAWQA 10-year strategy for 2013-2023 is a comprehensive approach to fulfilling NAWQA's unique and vital role in providing information needed to achieve the vision of science-based strategies that protect and improve water quality. The Cycle 3 plan continues strategies that have been central to the Program's long-term success, but also adjusts approaches, monitoring intensity, and study design to address the needs of the next decade. Restoration of degraded monitoring networks and new directions in modeling and interpretative studies also are needed to meet the growing and evolving public and stakeholder needs for water-quality information and improved management, particularly in the face of increasing challenges related to population growth, increasing demands for water, and changing land use and climate.

Why Now?

Growing and constantly changing demands for clean water for humans and aquatic ecosystems are fueling an increasing urgency to protect our Nation's water quality. Because water quality continues to decline, even as the demand for clean water is increasing, and Federal and State water quality monitoring and assessment activities are decreasing, changes in historic approaches to water quality management are needed now. An updated assessment of water quality monitoring needs is being conducted by the NAWQA Program and is driving the Cycle 3 approach to rebuilding the Nation's monitoring and assessment networks in conjunction with expanded Federal and State partnerships.

Water-quality problems and complexity are increasing as demand for clean water grows.

Forty years ago, when "water quality" became a national issue and the Clean Water Act became law, national efforts were focused on the control of point-source contamination from "end-of-pipe" discharges, such as those associated with sewage treatment plants or factories. Significant progress towards cleaner water resulted from engineering improvements in manufacturing processes and wastewater treatment.

Unfortunately, continued advances in wastewater treatment technology are no longer sufficient to address our Nation's water-quality issues. The most important threats to the quality of our surface-water and groundwater resources are now spread over areas much larger than those affected by "end of pipe" point source discharges, and include diffuse and widespread sources of contaminants that can affect entire watersheds. The sources of such "nonpoint" pollution, such as contaminants in runoff and groundwater recharge from urban or agricultural areas, are more difficult to pinpoint, evaluate, and control. In addition, specific effects on drinking-water quality or aquatic ecosystem condition usually are more difficult to define. Overall, we still haven't answered the question "*How do human activities in agricultural, urban, and natural settings affect water quality, cause changes in hydrologic systems, and degrade aquatic habitats*" at a level sufficient to meet the information needs of most water resource managers. Also what the cumulative long-term effects of the introduction of hundreds of synthetic organic compounds on humans or aquatic biota will be is still largely unknown; how to manage and reduce nutrient delivery to inland and coastal waters; or how to balance flow requirements in our streams and rivers to minimize habitat degradation and meet the needs of both humans and aquatic ecosystems.

What we do know, however, is that we face a litany of water-quality issues that continues to grow. Key examples include recognition that almost two thirds of our major estuaries are impacted by nutrients and dead zones that no longer support fish and other life; 40 percent of our streams are impaired and not meeting beneficial uses, such as for drinking, recreation, and ecosystem health because of habitat degradation, nutrients, and (or) sediment; 80 percent of our streams in urban areas were found to have at least one pesticide that exceeded criteria set to protect aquatic life; and more than 20 percent of our public and domestic wells—which serve more than 150 million people—contain at least one contaminant at levels of potential health concern (*see sidebar: "Ever-Increasing Water-Quality Issues Face the Nation").*

Ever Increasing Water-Quality Issues Facing Our Nation

- Forty-two percent of wadeable stream miles in the United States are in poor or degraded condition compared to reference conditions (U.S Environmental Protection Agency, 2006). Widespread causes include nutrients and habitat disturbance—which are greatly affected by streamflow alteration and sediment. NAWQA findings indicate that one or more pesticides exceed concentrations of potential concern to aquatic life in 57 percent of streams in agricultural areas and in 83 percent of streams in urban areas (Gilliom and others, 2006).
- Sixty-four of 99 major U.S. estuaries studied in 2004 have been adversely affected by excessive nutrient loading. The spread of coastal dead zones (areas of low dissolved oxygen) are projected to worsen through 2020 in 48 of these estuaries, as population growth, agricultural production, and other development results in an increase in nutrient inputs to coastal waters (Diaz and Rosenberg, 2008; Rockstrom and others, 2009).
- Artificially modified landscapes—including straightened stream channels in agricultural areas and increases in the number and extent of impervious areas in urban areas—alter streamflow and degrade habitat. A NAWQA assessment found that 86 percent of 2,888 sites across the Nation with streamflow alteration had modified minimum and maximum flows (Carlisle and others, 2010). Habitat changes and losses, often caused by streamflow alteration, are leading causes for the listing of more than 90 percent of threatened or endangered aquatic species under the Endangered Species Act (Wilcove and others, 1998).
- Population growth increases demand for drinking water at the same time it increases potential sources of contaminants. A USEPA national analysis of more than 15 million analytical records from public water systems during 1998 to 2005 showed that exposure to concentrations of one or more regulated contaminants above a Maximum Contaminant Level was relatively common, including about 14 percent of the population for nitrate, 7 percent for tetrachloroethylene, and 12 percent for uranium (USEPA, 2009).
- NAWQA findings for public-supply wells, which provide water to about 105 million people, showed that 22 percent of source-water samples contained at least one contaminant at levels of potential health concern (Toccalino and Hopple, 2010). Similarly, 23 percent of samples from domestic (or privately owned) wells, which supply an additional 43 million people and are usually untreated, also had contaminant levels of potential concern (Desimone and others, 2009).

These and other water-quality issues will not go away without improved, science-based strategies and, moreover, such issues will tend to worsen as our population grows. The U.S. Census Bureau projects that the Nation's population will increase by 100 million people by 2050, to a total of almost 400 million. With population growth comes expanded development of land for agricultural and urban use, increased use of fertilizers and pesticides for food production and urban landscaping, increased use of synthetic organic compounds, hydrologic modification of rural and urban landscapes, and increased demand for water to supply human and ecosystem needs.

In addition to increased stress on water quality related to human activities, we are also entering an era of increased climate variability and change, with associated changes in the amount and timing of precipitation and temperature, and other related climatic factors. The two pervasive drivers of water-quality trends—changes in land and water use with population growth, and climate change—are acting simultaneously, but to varying degrees in different areas and at different times, sometimes affecting physical characteristics, such as streamflow, temperature, and sediment; sometimes affecting chemical characteristics; sometimes both—but all ultimately affecting the sustainability of water for current and future human and ecosystem needs.

The complexities of hydrologic systems and human activities on the landscape mean that we no longer can approach water issues through single-discipline science. Instead, meeting this challenge demands reliable and objective interdisciplinary data on the physical, chemical, and biological conditions of our water resources, as well as an understanding of the changes to natural and human activities that contribute to those conditions. Only by investing in improved monitoring and assessment will we be able to separate natural from human influences, identify the physical, chemical, and biological processes controlling the quality of our waters, and develop predictive tools that provide realistic and reliable projections of future conditions—these are the requirements for effective, science-based water-quality management strategies.

Declining monitoring infrastructure and investment in water-quality science threaten our ability to assess and solve water-quality problems.

Over the past 10-15 years, Federal, State, and academic partners in the water community have faced substantial budget cuts that have reduced national monitoring networks and the collection of water-quality information. The NAWQA Program, for example, currently operates a “national” surface-water trend network comprised of 113 stream and river sites, only about 40 of which are monitored during any given year. This represents a significant decline from the 1990, when almost 500 sites were monitored by NAWQA and parallels similar declines in the amount of surface- and groundwater-quality data collected by other Federal and State agencies (fig. 1.1).

Some reductions in water-quality data collection and studies can be compensated for with models and other statistical tools, but models are only as good as the data that are available for their development and validation. For example, the USGS national model of nutrient sources and transport—the Spatially Referenced Regression on Watersheds (SPARROW) model—was initially calibrated using data collected by both Federal and State agencies from 435 sites (Smith and others, 1997). Currently, only 35 of those sites are still being monitored for model calibration and the sparseness of ongoing data collection by USGS and other Federal and State agencies risks limiting model applications and increasing future predictive uncertainty.

Of equal importance to the decline in water quality data, national investments in spatial and temporal information on the distribution and characteristics of factors that affect water quality, such as landscape features, human activities and environmental settings, remain seriously inadequate and out-of-date. This includes, for example, spatial data on factors such as use of pesticides, fertilizers, and other chemicals, land-use changes over time, water use, land-management practices, hydrologic settings, and point sources of contamination. Overall, understanding of causes and solutions of water-quality issues will only advance if current data on water-quality conditions and the related causative factors on the landscape are available. Our ability to design effective solutions will be remain greatly limited unless we invest in these essential geospatial and time-series environmental data sets as part of our investments in water-quality monitoring and science.

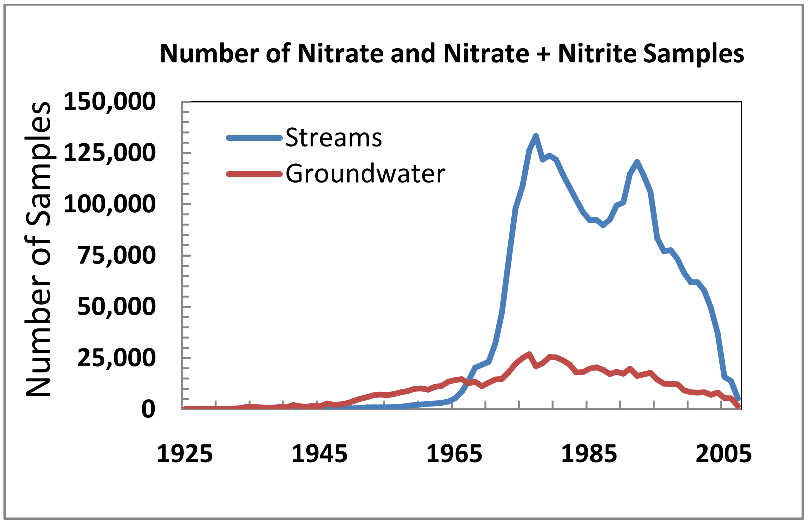


Figure 1.1. Records of nitrate monitoring by State and Federal agencies for streams and groundwater illustrate the decline in monitoring that has occurred over the past 20-25 years, even for one of the most commonly monitored contaminants. Numbers are estimated from U.S. Environmental Protection Agency and U.S. Geological Survey databases and includes nitrate and nitrite+nitrate analyses. An exception to the overall trend is an increase in samples for streams and rivers in the early to mid 1990s; this short-term increase is attributed to NAWQA sampling during Cycle 1, but the peak was soon followed by an even sharper decline over the past 10 to 15 years (Jerad Bales, U.S. Geological Survey, written communication, December 2010).

Scientific foundation and partnerships are well-positioned for making rapid progress.

Fortunately, 20 years of monitoring, modeling, and research have provided a solid foundation of data and scientific understanding to allow the water community to be able to address today's increasingly complex water-quality issues (*see, for example, sidebar: "Looking back on NAWQA since 1991"*). Results of NAWQA studies have been used by stakeholders to inform water-resource policy and management decisions at scales ranging from local to national (http://water.usgs.gov/nawqa/xrel.pdf).

Moreover, the scientific foundation has greatly benefitted from periodic statistical surveys of the Nation's waters by the USEPA in collaboration with its partners in the States, Tribes, and other Federal agencies. These "National Aquatic Resources Surveys" (NARS) help to answer key questions, such as "*What are the most significant water-quality problems?* ", *"Where are problems occurring?",* and "*Is water quality improving*?" States use the data to develop and evaluate water-quality standards, identify impaired waters, and prioritize monitoring and management needs. Nationwide, coastal, lake, and wadeable stream assessments have been completed and a survey of wetland resources is scheduled for 2011 (http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm).

The surveys provide snapshots of water quality and ecosystem condition that is not duplicated by NAWQA and that is highly complementary to NAWQA. Integration of NAWQA and USEPA studies and data is an ongoing activity of both agencies, and has already resulted in an enhanced assessment of the factors affecting invertebrate communities and the condition of stream ecosystems across the country (Carlisle and others, 2009).

Looking back on NAWQA since 1991 – An evolution of approaches and outcomes from Cycle 1 and Cycle 2

The approaches and outcomes of NAWQA assessments during Cycles 1 and 2 provide a useful perspective for developing the Cycle 3 strategy. An overview is provided, with more detail available in noted online sources.

Cycle 1

During 1991–2000, the NAWQA Program focused on interdisciplinary baseline assessments of the quality of streams, ground water, and aquatic ecosystems in 51 of the Nation's river basins and aquifers (referred to as “study units”), supporting sampling of 495 stream sites and more than 5,000 wells. Each Study-Unit assessment resulted in a USGS summary publication written for a broad audience interested in resource management, regulations, and policy at the local level (http://water.usgs.gov/nawqa/nawqa_sumr_complete.html). In each publication, the occurrence and distribution of pesticides, nutrients, volatile organic compounds (VOCs), trace elements, dissolved solids, and radon are described, as well as the condition of aquatic habitat and algae, macroinvertebrate, and fish communities. The assessments relate contaminant sources, land and chemical use, hydrology, and other human and natural factors to water quality and the status of aquatic communities. Results are placed in the context of human-health and aquatic-life water-quality benchmarks, which indicate what these conditions imply for the protection and safety of drinking water, for the health of aquatic ecosystems, and for resource management. The consistent, multi-scale approach of Cycle 1 provides the information needed to synthesize a broad understanding of how and why water quality varies regionally and nationally and enables comparisons of how human activities and natural processes affect water quality and biological conditions among the Nation’s diverse geographic and environmental settings. Major outcomes include comprehensive national assessments of pesticides, nutrients, VOCs, and aquatic ecology at the national scale through data synthesis and comparative analysis of the Study-Unit findings (http://water.usgs.gov/nawqa/nawqa_sumr.html).

Cycle 2

During 2001-2012, NAWQA built upon the Study Unit baseline assessments established in Cycle 1 by increasing emphasis on assessment of long-term trends, by adding topical studies of priority water-quality issues that evaluated hydrologic processes and human activities that affect the quality of streams and groundwater, and by selective additional assessments of water-quality status, including an initial study of contaminants in currently used sources of drinking water.

For trend assessment, long-term monitoring was established at 113 streams representing eight major river basins and at groundwater sites representing 20 principal aquifers with more than 10 to 15 years of consistent monitoring data available. The topical studies evaluated links among sources of contaminants, their transport through the hydrologic system, and the potential effects of contaminants and other water-quality disturbances on humans and aquatic ecosystems. The topical studies focused on: (1) the fate and transport of agricultural chemicals; (2) effects of urbanization on stream ecosystems; (3) effects of nutrient enrichment on stream ecosystems; (4) transport of contaminants to public-supply wells; and (5) bioaccumulation of mercury in stream ecosystems http://water.usgs.gov/nawqa/studies/studies/topical_studies.html. Each topical study includes several nationally distributed study areas that ranged from a few square miles to a few hundred square miles and were nested within selected study units.

The topical studies were integrated with continued regional and national synthesis assessments during Cycle 2. For example, the topical study of effects of nutrient enrichment on stream ecosystems is an integral part of the national synthesis summary report on nutrients in streams and ground water. The topical study on mercury helps to explain occurrence and processes controlling mercury in fish, sediment, and water in streams across the Nation. Regional assessments consider water-quality conditions and trends in eight major river basins (http://water.usgs.gov/nawqa/studies/mrb) that discharge into some of the Nation’s key estuaries, including Gulf of Mexico, Chesapeake Bay, Puget Sound, and the Great Lakes, as well as 19 of the Nation’s 62 principal aquifers http://water.usgs.gov/nawqa/studies/praq/).

Integral to each of the NAWQA assessments in Cycle 2 has been the development and application of water-quality models. The integration of modeling with monitoring helps to extend water-quality understanding to unmonitored areas under a range of possible circumstances. The models are essential tools for cost-effective management of water resources because managing contaminants requires far more information than we can afford to directly measure for all the places, times, and contaminants that are important. In addition, many management decisions—including how much to spend on implementing a management strategy, monitoring priorities, and registering pesticides—inherently depend on predicting the potential effects on water quality for locations that have never been monitored. The NAWQA models integrate information on water quality, chemical use, land use, and environmental factors that help to explain how water-quality conditions vary regionally and nationally. A wide range of models have been employed in Cycle 2, including statistical models, detailed simulation models, and hybrid models.

Examples of important water-quality advances by NAWQA and its partners since 1991 include:

- established interdisciplinary baseline assessments of streams, groundwater, and aquatic ecosystems in 51 of the Nation's major river basins and aquifers;
- synthesized findings and reported on national water-quality conditions for streams and groundwater;
- assessed trends in stream and groundwater quality based on almost two decades of monitoring in diverse environmental settings across the Nation;
- developed national and regional scale water-quality models;
- made major progress toward understanding the interactions among sources of contaminants, and physical, chemical, and biological processes that control the transport and transformation of contaminants through the hydrologic system; and
- made major progress toward understanding the potential effects of nutrients, contaminants, and other stressors on aquatic ecosystems.

Results of NAWQA studies have been used by stakeholders to inform water-resource policy and management decisions at scales ranging from local to national (http://water.usgs.gov/nawqa/xrel.pdf).

In addition to these and other advances in our scientific understanding, partnerships are now well developed for collaboration on water-quality assessment. Since its inception, NAWQA has strived for collaboration with Federal, State, and local governmental organizations, public interest groups, professional and trade associations, academia, and private industry so as to remain relevant to the needs and interests of these organizations, along with the water-resource issues facing our Nation, to fill the most critical information niches, and to get the most possible benefit from all available data and studies. The Program remains committed to integrating information and data from other Federal and State agencies and other organizations into national assessments, where appropriate, so that findings more comprehensively span geographic and temporal scales and the different parts of our water resources. Fortunately, such integration is increasingly achievable as technology and expertise advance in data collection and exchange, assessment, modeling, compatible web services, and reporting.

Collaboration and partnerships not only increase geographic and temporal coverage through integration of multiple data sources, but also are critical to success because no single program can address all national water issues, and NAWQA's approach cannot answer all of our water-quality questions. Some questions require a different approach and a specific set of data collected in certain places and times. For example, the scope of NAWQA is limited to freshwater streams, rivers, and aquifers. The Program is not designed to assess water-quality conditions in estuaries, the near-shore marine environment, the oceans, or the Great Lakes. In these cases, partnerships are essential, and NAWQA information plays a key role in providing coordinated and consistent monitoring and modeling to other agencies that helps to track contaminant sources in watersheds and the amount and timing of sediment, nutrients, and contaminants delivered to receiving waters—information that is critical to support healthy coastal waters and ecosystems.

Selected external NAWQA partnerships are highlighted below, but more detailed information on specific partnerships is provided in Chapters 3-6, in relation to specific goals, objectives, and approaches.

- National Water-Quality Monitoring Council and its Federal, State, Tribal, and non-governmental members to develop a national long-term collaborative network of reference sites;
- National Ecological Observatory Network (NEON) to coordinate interdisciplinary monitoring for better understanding nutrient processing in streams;

- National Oceanic and Atmospheric Administration (NOAA) and National Federation of Regional Associations to relate nutrient and sediment loadings from the land to ecosystem conditions in coastal estuaries;
- U.S. Department of Agriculture (USDA) on evaluating the effectiveness of conservation and management practices on water quality; and
- USEPA, NOAA, and USDA to improve models and decision-support tools for predicting the effects of changing human activities and climate on water quality and aquatic ecosystems.

In addition to partnerships with other agencies, partnerships with programs within USGS also are critical to success and for leveraging data collection, technical expertise, and complementary research topics. For example, this science plan is designed to deliver critical water-quality data and information that directly supports other major USGS water programs, including evaluation of water availability and use as constrained by water quality and development of ecological flow requirements with the Water Census (WaterSMART) Program; and coordinated assessments of groundwater availability in specific aquifers with the Groundwater Resources Program. The strategy also contributes to the development of reference site monitoring, which will support the Global Change, Toxic Substances Hydrology, and Contaminant Biology Programs to conduct joint research on contaminant effects on aquatic ecosystems.

NAWQA partnerships with other USGS programs are aligned along common goals outlined in the USGS science strategy for the decade 2007-2017 (U.S. Geological Survey, 2007). The Cycle 3 design provides a national framework of monitoring and assessment for NAWQA and other programs to support recently reorganized mission areas of the USGS, particularly programs related to water, environmental health, ecosystems, and climate and land-use change. Selected contributions to specific mission areas include:

- *Ecosystems Mission Area* through continued monitoring and assessment of trends in the biological conditions of streams; improving our understanding of how environmental change affects ecosystem services; describing effects of chemical, physical, and hydrologic stressors on aquatic ecosystems; and developing models for predicting aquatic ecosystem response to land use and climate change.
- *Climate and Land Use Change Mission Area* through continued long-term monitoring of flow, water quality, and biological condition in streams and rivers; increased monitoring of climate-sensitive reference streams; and, expanded collection of real-time data for temperature and other parameters to differentiate short-term variability from long-term change; and development of models and decision support tools that produce forecasts of how water-quality and aquatic ecosystems will respond under different climate and land-use change scenarios.
- *Environmental Health Mission Area* through expanded monitoring of source waters used for drinking-water supply including streams, rivers, lakes, reservoirs, and aquifers; assessments of sediment and fish-tissue quality for contaminants of concern for humans and aquatic biota; monitoring of microbial contaminants and algal toxins in surface water used for recreation; and enhanced tracking of contaminant movement at the watershed and aquifer scale.
- *Water Mission Area* through assessments of the Nation's water quality with respect to its suitability for human use and for maintaining healthy aquatic ecosystems, the extent and severity of streamflow alteration (changes in the hydrologic regime) and its effects on stream ecosystems; development of three-dimensional models of flow and chemistry in selected principal aquifers to assess groundwater availability; and development and testing of improved water-quality models for simulating concentrations and loads of nutrients, sediment, and other contaminants in streams and rivers from headwaters to receiving waters.

- *Core Science Systems* by providing data and information on water quality and ecosystem condition available in a format that is understandable and accessible. Although this has been a long-term goal of NAWQA in Cycle 3 there will be a new emphasis on rapid delivery of data and findings and on the delivery of tools and models that facilitate management of critical water resources.

Priorities and Goals for NAWQA Cycle 3

Periodic evaluations of assessment goals, approaches, and products have played a key role in enabling NAWQA to stay abreast of stakeholder priorities. In 2009, stakeholders identified 11 priority issues that are important for NAWQA to address (Rowe and others, 2009). Six of the issues reflected specific water-quality “stressors”, such as contaminants and sediment that directly affect water quality and its suitability for use by humans and aquatic ecosystems. The other five issues reflected “environmental drivers”, such as land use and climate change, which directly affect the water-quality stressors. Two “environmental drivers” of change—climate and shifts in land and water use related to population trends—and four water-quality stressors—contaminants, nutrients, sediment, and streamflow alteration—were identified as the most critical threats to the sustainability of our water resources for the health of humans and aquatic ecosystems (fig. 1.2).

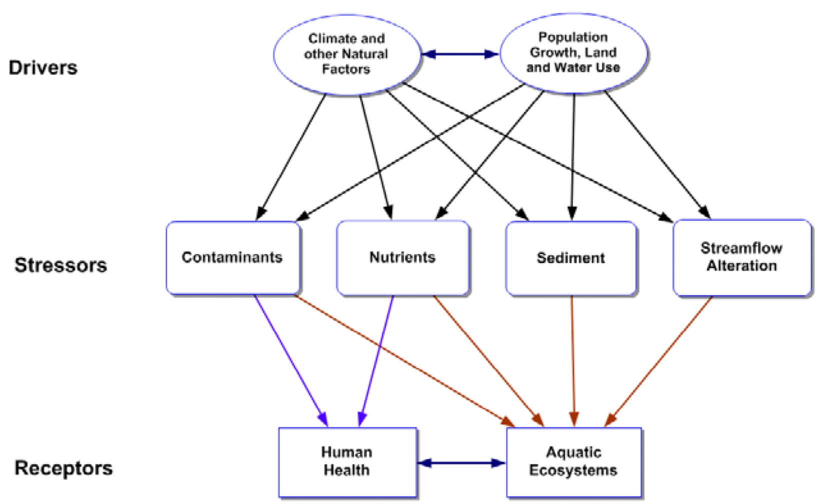


Figure 1.2. The Cycle 3 design is based on an interdisciplinary approach to determine where, when, and how the physical, chemical, and biological quality of water resources is affected by four major stressors—contaminants, nutrients, sediment, and streamflow alteration–all of which are simultaneously affected by large-scale environmental drivers related to climate and other natural factors, or to population growth, land and water use, and associated human activities. Additional feedback loops exist between human activities and climate, and aquatic ecosystems and individual stressors; for example, the effect of biological activity on nutrient levels in streams, rivers, and coastal estuaries. These are the factors that ultimately govern the sustainability of water for human health and healthy aquatic ecosystems.

Cycle 3 centers on four major goals that will guide development of the interdisciplinary studies that are needed to address the four priority stressors and their impacts on water quality. Goal 1 focuses on the physical, chemical, and biological characteristics of our waters and how they are changing over time. Goal 2 focuses on analyzing the roles of human and natural factors that affect water-quality stressors. Goal 3 assesses the impact of these stressors on ecosystem condition. Goal 4 is about forecasting the effects of the environmental change and stressors on water quality in the future. These interrelated goals maintain and expand upon original NAWQA goals and collectively, are critical to achieving the vision set forth for NAWQA in Cycle 3 (*see sidebar: “Vital Connections among Cycle 3 Goals”).*

Goals 1 and 2 continue NAWQA goals initiated in 1991, which are to assess status and trends in water-quality conditions and to evaluate the human and natural factors that affect those conditions. While these broad goals have remained unchanged, since 2001 greater emphasis has been placed on evaluation of trends and controlling factors. Additional shifts are recommended in Cycle 3, based on stakeholder input and findings to date—notably including the addition of sediment and streamflow alteration, increased emphasis on the quality of deep groundwater used for public supply, and increased assessment of contaminant loads to estuaries. Goals 3 and 4, however, encompass the greatest changes in scope for Cycle 3 and extend NAWQA assessments much further into two critical areas: determining the effects of multiple stressors on stream ecosystems and forecasting future water-quality conditions.

Vital Connections among Cycle 3 Goals

To achieve the vision expressed for Cycle 3, this science plan establishes four goals that represent an integrated approach to water-quality assessment. The goals are not intended to be pursued in exclusion to the other goals. Instead they represent high priority issues identified by internal and external stakeholders where NAWQA resources should be directed over the next decade. Approaches recommended to achieve the four science goals will either depend on or influence products and outcomes from the other goals, as described below:

Goal 1 continues NAWQA's ongoing, long-term commitment to monitor surface-water and groundwater quality at multiple scales. Data collected will be used to assess geographic patterns and temporal trends in water quality across the Nation and also are essential for development and validation of water-quality models as part of addressing Goals 2, 3, and 4.

Goal 2 continues NAWQA's long-term goal to link the nature and distribution of water-quality conditions, as well as changes and trends in water-quality and aquatic ecosystems, to the human and natural factors that influence water quality and aquatic ecosystems. Goal 2 studies focus on developing explanations for the observed patterns and trends in water quality identified by Goal 1 monitoring activities. This understanding is critical for evaluating the effectiveness of management practices and impacts on ecosystem services. Modeling tools developed as part of Goal 2 studies will be used in Goal 1 assessments to extrapolate findings to unmonitored areas and in Goal 4 to explore the effect of different management strategies, changing land or water use, and climate-driven changes in hydrology on water quality and aquatic ecosystems.

Goal 3 studies evaluate relations between important water-quality and hydrologic stressors that cause degradation of stream ecosystems; findings will be incorporated into regional ecological models that examine the interdependent effects of multiple stressors. These models, which predict the effects of stressors on ecosystem condition for specific land use and environmental settings, will be applied to meet the Goal 4 objective to evaluate the effects of management practices and future land use on stream ecosystems. Evaluating the effectiveness of strategies to control adverse effects on steam ecosystems will rely heavily on the understanding gained from Goal 2 studies and models.

Goal 4 predictions of the effects of future scenarios of land use, management strategies, and climate on water quality and ecosystem conditions depend on the data and models developed from monitoring and studies undertaken to address Goals 1, 2, and 3. Achieving Goal 4 also depends on scenarios of future management, land use, water use, and climate made by other USGS programs, agencies, and stakeholders.

The Cycle 3 goals are listed below along with examples of some of the primary related questions asked by water resource managers. Details on the science objectives, management relevance, outcomes, and partnerships associated with each goal are provided in Chapters 3-6.

Goal 1: Monitor and assess the current quality of the Nation's freshwater resources and how water quality is changing over time.

Examples of Management Questions:

- Are water quality goals, standards, and criteria being met for safe drinking and sustainable ecosystems at regional and national scales?
- Where are water-quality problems most severe?
- Where and how are conditions changing over time?
- What are the freshwater inflows and loads of nutrients, contaminants, and sediment to estuarine ecosystems, the Great Lakes, and other receiving waters?

Goal 2: Evaluate how human activities and natural factors, such as land use, water use, and climate, are affecting streamflow alteration and the sources, transport, and transformation of contaminants, nutrients, and sediment.

Examples of Management Questions:

- Are the most important point and nonpoint sources of contaminants being addressed by current management strategies?
- Are protection, conservation, and remediation programs working effectively to control sources and transport of contaminants?
- What strategies are needed to protect sources of drinking-water?
- What areas should be targeted for more intensive monitoring, protection, or remediation?
- What are the sources and transport processes controlling nutrients, contaminants, and sediment delivery to estuarine ecosystems, the Great Lakes, and other receiving waters?

Goal 3: Determine the effects of contaminants, nutrients, sediment, and streamflow alteration on aquatic ecosystems.

Examples of Management Questions:

- What is the importance of various physical and chemical stressors on ecosystem condition, and which are most important to control?
- Which management strategies will most effectively improve and protect ecosystem condition?
- What ecological measures are most appropriate as early warning indicators for assessing ecosystem degradation due to physical or chemical stressors and for monitoring recovery after changes in management practices?
- What levels of stressors can be tolerated by aquatic ecosystems and how can this information best be used to develop regional thresholds for use in management issues such as nutrient criteria?

Goal 4: Predict the effects of human activities, climate change, and management strategies on water quality and aquatic ecosystems.

Examples of Management Questions:

- How will projected changes in climate, population, land use, water use, management actions, and other human activities affect water quality for future beneficial uses?
- Which strategies will most effectively improve and protect biological communities and ecosystem conditions?

- Which management strategies are most cost effective?
- What are the expected lag times between implementation of management practices and beneficial outcomes?
- Is water quality more sensitive to changes in land-use practices or climate?

Introduction to the Cycle 3 Approach

NAWQA partners and stakeholders offered two recommendations to guide the updated strategy for Cycle 3. First, NAWQA should stay on course with its overall approach to national assessment through Cycles 1 and 2 —maintaining priorities on national-scale policy relevance, continuity of long-term goals and design, national consistency, and building partnerships (*see sidebar: "Guiding Principles for Cycle 3 Design"*). Second, NAWQA needs to rebuild and enhance surface-water and groundwater quality monitoring networks, as well as expand its scope, in order to adequately meet new and continuing information needs for water management in the coming decade. The expansion in scope refers to addressing critical gaps in water-quality information, such as a need for expanded contaminant coverage, improved monitoring of water-quality trends, and developing a capability to forecast future water-quality conditions, as identified by stakeholders as high priorities for the Cycle 3 design.

Guiding Principles for Cycle 3 Design

- Maintain a Priority on National-Scale Relevance: NAWQA achieves national-scale assessment by combining several inter-related approaches, including (1) cumulative interdisciplinary assessments of the most important hydrologic systems, (2) nationally consistent monitoring and data analysis that yields synthesis of findings at the national scale, (3) detailed topical studies of specific issues in relatively few locations, but with high transfer value to other parts of the Nation, and (4) development of statistical and water-quality models that enable extrapolation to unmonitored areas and resources.
- Maintain Continuity of Long-Term Goals: The long-term goals of NAWQA are to (1) provide a nationally consistent description of current water-quality for a large part of the Nation's water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, characterize, and explain major factors that affect observed water-quality conditions and trends. These goals remain the foundation for Cycle 3 design, although specific goals for each 10-year cycle are adjusted to reflect progress in earlier cycles, stakeholder priorities, and changing issues.
- Maintain Policy Relevance: Priority in Cycle 3 is given to nationally relevant issues that align with the goals and strengths of NAWQA and that are considered a high priority by our stakeholders. Outcomes of Cycle 3 activities will produce data, scientific studies, and modeling and decision-support tools that can be used by water-resource managers and policy makers to evaluate the effectiveness of past, current, and proposed water-quality regulations and management practices.
- Align with USGS Science Strategy: Cycle 3 of NAWQA will be a vital and closely coordinated component of the USGS science strategy described in the *USGS Science Strategy for the decade 2007-2017* (U.S. Geological Survey, 2007).
- Leverage Resources through Collaboration and Partnerships: The ambitious vision for Cycle 3 cannot be fully achieved without increased integration of NAWQA assessment activities by partnering with other USGS programs, other governmental agencies (Federal, State, regional, and local), nongovernmental organizations, industry, and academia. These partnerships expand NAWQA and the Nation's ability to assess status and trends in water quality and biological condition spatially and temporally. Equally important is avoiding duplication of assessment and monitoring activities conducted by other USGS programs or external agencies.

The NAWQA approach to achieving Cycle 3 goals relies on the Program's scientific foundation, existing networks, and proven approaches used over the past 20 years. This includes systematic regional and national monitoring, multi-scale, interdisciplinary assessments in representative hydrologic systems and environmental settings, detailed local-scale studies of governing processes and ecological effects, and modeling and statistical analysis to integrate findings across multiple spatial and temporal scales. The details of the design elements and approaches for Cycle 3 are described in Chapters 2 to 6, but are introduced here with a focus on some key aspects that do not change, and some that do.

Continuing approaches that remain essential to national-scale water-quality assessment include:

- → Adequate spatial representation of the hydrologic and environmental settings of the Nation, as well as specific areas of concentrated water use and ecosystem needs;
- → Characterization of changes in the chemical, physical, and biological conditions at time scales (daily, seasonal, annual, decadal, and multi-decadal) most relevant to each type of problem in different environmental settings;
- → Assessment of processes controlling the transport and fate of contaminants and other constituents by approaches that address their importance across multiple scales and that build transfer value of information to other settings;
- → Development of models and statistical approaches for extrapolation and forecasting of water-quality and biological conditions at varying spatial and temporal scales;
- → National and regional synthesis of information for important water-quality issues; and
- → Development and cultivation of partnerships and data integration with other programs and agencies.

Even with the continued integration and collaboration with others, selective rebuilding of NAWQA surface-water and groundwater networks and assessments that have been significantly reduced over the past decade due to fiscal constraints will be required. For example, the current NAWQA water-quality trend network for surface water conducts monitoring at most sites only one year out of every four. Such infrequent sampling is not sensitive enough to track changes in water chemistry over time and therefore cannot meet information needs for evaluating the effectiveness of management practices implemented to sustain clean water and healthy ecosystems. Some of the major changes in scope and emphasis that are part of the Cycle 3 strategy include:

- → Expansion of the national surface-water monitoring network, from 143 to 331 sites, including the addition of 30 reference sites, 70 drinking-water sites, 55 small watershed sites in specific land-use settings, and 33 large river coastal sites. Sampling will change to every year instead of a 2- or 4-year rotation, and real-time water-quality monitoring, including measurements of turbidity, will be added at most sites.
- → Intensive studies nested within integrated watershed study areas will focus on the highest priority issues and concerns, such as effects of urbanization and agriculture on stream ecosystems.
- → Initiation of integrated watershed studies in selected major river basins to assess how water moves and transports contaminants, nutrients, and sediment over the land, from small headwater watersheds, to downstream rivers, coastal ecosystems, and to groundwater. Multi-scale monitoring and modeling will be used to assess sources and transport.

→ Increased monitoring and modeling of deep aquifers including sampling of approximately 2,000 public supply wells, sampling of which, was not emphasized in previous assessments. Overall, the number of groundwater samples will double compared to Cycle 2.

→ Synoptic monitoring of regional biological conditions in streams across diverse environmental settings and across varying gradients of key stressors (contaminants, nutrients, sediment, and streamflow alteration), which will be used to test and extrapolate knowledge of processes demonstrated in intensive studies.

→ Development and application of predictive models and forecasts, accompanied by decision-support tools that can be used to assess the effectiveness of implemented or proposed regulatory policies and strategies, and potential effects of land-use and climate change.

Although these assessment and study activities span a wide range of spatial scales, their implementation is highly interdependent. The locations chosen for monitoring, modeling, and research will based on their contribution towards supporting national-scale interpretations. Surface-water assessments will be systematically organized within the eight Major River Basins (MRB) that cover the conterminous United States, plus Alaska and Hawaii (http://water.usgs.gov/nawqa/studies/mrb). NAWQA uses the MRBs for regional-scale analysis and modeling of surface-water quality. In addition to the geographic organization by Major River Basins and environmental setting, the location of surface-water studies and regional or smaller-scale modeling efforts will be closely tied to the national network of stream monitoring sites, which serves to provide broad geographic coverage within the Basins and to provide anchors of consistent long-term data collection upon which other studies are built (fig. 1.3).

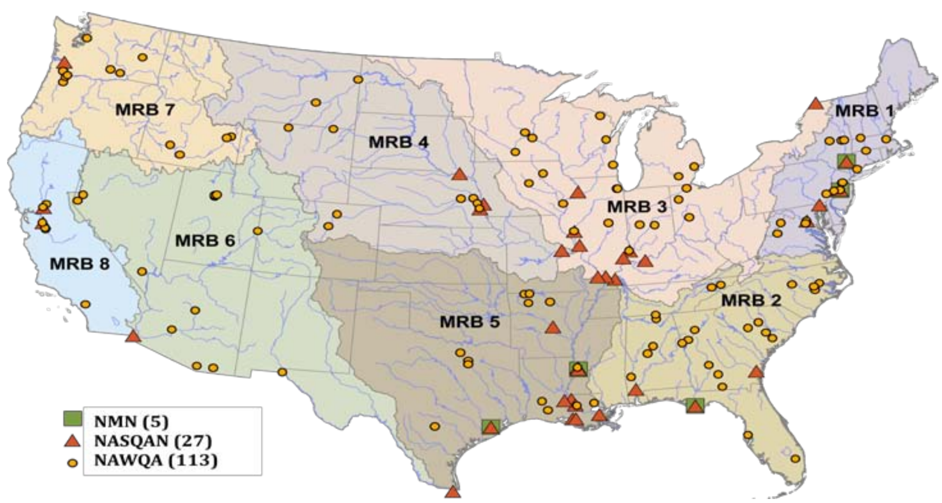


Figure 1.3. The Cycle 3 fixed-site network for monitoring surface-water quality will approximately double the number of sites in the Cycle 2 network, shown in this figure, which is a combination NAWQA, NASQAN (National Stream Quality Accounting Network), and NMN (National Monitoring Network) sites. The distribution of existing sites is shown in relation to the eight Major River Basins (MRBs) that NAWQA uses for regional-scale synthesis and modeling of surface-water quality.

Additional criteria for selection of individual surface water and ecologic monitoring and study locations include: (1) availability of long-term water-quality, ecologic, or ancillary data (NAWQA or other sources) that supports or augments planned Cycle 3 assessment activities; (2) ability to partner with ongoing monitoring or research conducted by other USGS Programs or external partners; and (3) an emphasis on geographic locations that exemplify nationally relevant water-quality issues and important ecosystem concerns. For example, NAWQA will continue to assess nutrient, sediment, and contaminant transport in key agricultural and urban settings in the Mississippi River Basin and watersheds flowing into other important estuaries, such as Chesapeake Bay or Puget Sound. Water-quality assessments will also focus on important watersheds where water-quality is a factor in limiting water availability, such as in the arid Southwest, the upper Midwest, and the southeastern United States.

Groundwater assessments in Cycle 3 will be designed to evaluate status and trends at the Principal Aquifer (http://water.usgs.gov/nawqa/studies/praq/studies/praq) and national scales. Principal Aquifers (PA) represent large areas (10,000 to >100,000 km^2) with common lithostratigraphic and hydrogeologic characteristics (fig. 1.4). In Cycle 3, assessments are planned in 24 PAs; those selected will account for the majority of current and future national groundwater use for drinking water. In each PA assessed, multi-scale geographic and temporal monitoring will be combined with groundwater flow modeling (done in collaboration with the USGS Groundwater Resources Program) to provide a three-dimensional assessment of groundwater quality and availability and the factors that influence groundwater quality in different settings.

Figure 1.4. Groundwater monitoring and assessments are organized by Principal Aquifers, which are large areas (10,000 to >100,000 square kilometers) with common lithostratigraphic and hydrogeologic characteristics. Those serving the majority of public drinking water supplies are shown on this map. Green and yellow squares show the distribution of public-supply wells sampled during Cycle 1 and 2 studies.

What does the Nation Gain by this Plan?

Cycle 3 collaboration, monitoring, and assessment will produce the data and scientific information needed to develop effective solutions to protect and sustain clean water and healthy ecosystems. The strategy emphasizes the integration of interdisciplinary assessments of the processes and cause-and-effect factors that govern water quality across the Nation and uses this information to develop conceptual and mathematical models that can be used to forecast and assess impacts of land-use activities and climate change. Moreover, the Cycle 3 strategy promotes the development and application of these models in the form of decision support tools that can be used by managers to estimate conditions that cannot be directly measured and to predict how changes in our actions within a watershed, such as implementing best-management practices, are likely to affect water quality and aquatic ecosystems.

The Cycle 3 strategy also increases the priority on timely reporting of data, findings, and model results, because management decision-making increasingly needs rapid feedback on conditions and changes. In addition to continuing national synthesis of multi-scale data and findings on key topics at regular (5 or

10-year) intervals, the Program will regularly report key findings through a combination of systematic annual reporting, and accelerated online access to data, models, and decision support tools.

Cycle 3 will produce four general types of products that align with Cycle 3 goals. These products will advance water-quality science and improve the effectiveness of policies and strategies for water-quality management by increasing the availability and reliability of science and tools that support decision making. Each represents much needed advances over our current knowledge and capabilities. Each general type of product outlined below will include scores of specific products that focus on specific water-quality issues within different geographic areas and with varying cause-and-effect factors. Although the details of these products are described in Chapters 3-6 of this document, a specific example is shown below for each type to provide a visual sense of the outcomes.

Reliable and Timely Status and Trend Assessments

NAWQA Cycle 3 will systematically fill information gaps in resource assessments and emphasize rapid feedback on changing water-quality conditions, so that managers can identify emerging problems, develop effective responses, and evaluate the performance of management strategies.

Example: Tracking Trends and Change in Streams and Rivers

Policy- and management-relevant trend and change assessment must be sensitive enough to detect trends at the time scales in which important changes in contaminant sources or management occur (fig 1.5). Timely feedback enables policy-makers and managers to rapidly respond to changes in water-quality conditions and improves evaluation of progress toward water-quality goals and whether management strategies are working to improve water-quality conditions. The Cycle 3 design for monitoring trends in surface-water quality calls for sampling at all sites every year, as well as collection of water-quality surrogate data in real time so that short-term trends typical of those caused by source changes or management strategies can be discerned and tracked.

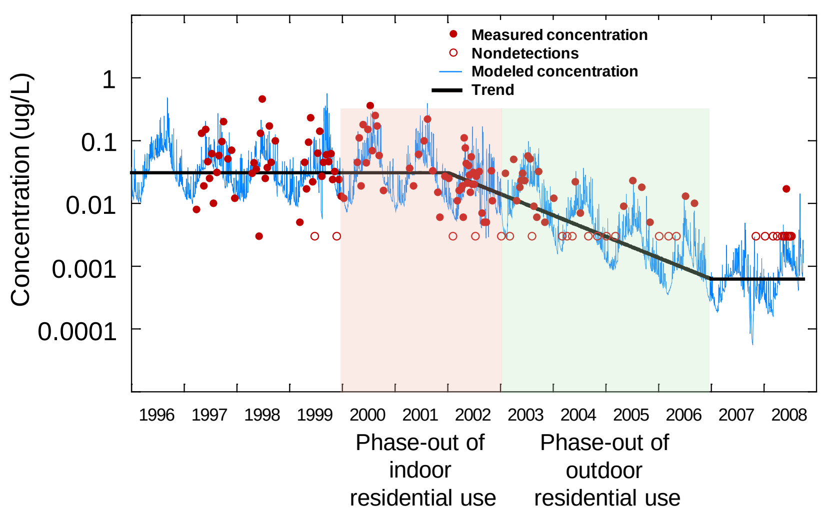


Figure 1.5. This example, a trend analysis for the insecticide diazinon in Accotink Creek, an urban stream in Virginia, shows the type of trend-analysis product that would result from implementation of the Cycle 3 design.

Every-yearmonitoring of diazinon concentrations (except 2007) and continuous monitoring of flows throughout every year provided the data necessary to develop a time-series and trend model of concentrations in Accotink Creek for 1997 to 2008. Every-year monitoring, as proposed in the Cycle 3 design, showed the clear downtrend in concentrations during 2002-2006, resulting in more than a 90 percent concentration decline. The decline corresponds to reduced residential uses resulting from a regulatory phase-out required by USEPA. Understanding the effectiveness of the regulations in improving water quality is vital to USEPA and other stakeholders for tracking regulatory performance and determining implications for future strategies.

Models and Decision-Making Tools

NAWQA models will quantitatively link sources and management practices to water-quality benefits and impacts at multiple hydrologic scales, from headwater streams to rivers flowing into estuaries, and from shallow groundwater to deep regional aquifers.

Example: Prediction of Groundwater Quality

A key product of Cycle 3 will be models and decision-support tools that quantitatively link sources and management practices to water-quality conditions at the full range of management-relevant scales—from local to regional to national). In NAWQA Cycles 1 and 2, important progress was made on the application of process-based models to limited case-study areas and on the application of statistical and hybrid models that link causal factors and individual contaminants, such as the effect of intensive agriculture on atrazine and nitrate (fig. 1.6). The model developed for predicting nitrate concentrations in shallow groundwater (Nolan and Hitt, 2006) provides an example of one type of model and its application to predicting conditions at the National scale.

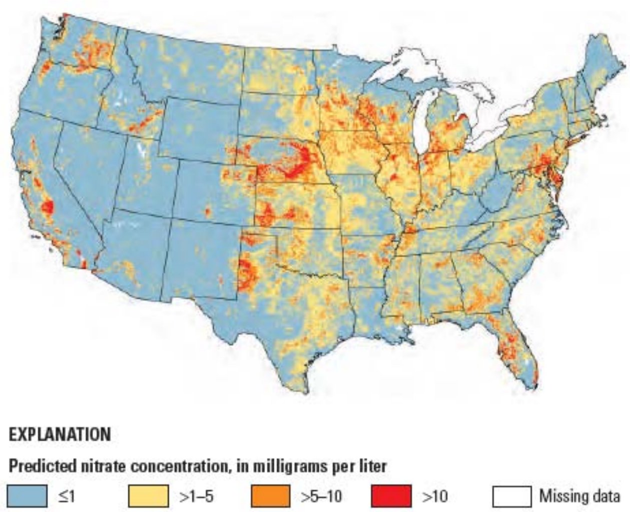


Figure 1.6. A model of nitrate concentrations in shallow groundwater predicts the highest concentrations in the High Plains, northern Midwest, Central Valley, and other areas of intensive agriculture. These are areas with a combination of large nitrogen sources, natural factors that promote rapid transport of nitrogen in groundwater, and a lack of attenuation processes.

Factors used to represent nitrogen sources include farm fertilizer, manure from confined livestock, and population density. Factors in the model that represent the rate at which nitrate is transported to groundwater include water input, rock type, the presence of drainage ditches, and percentage of clay. The nitrate model for shallow groundwater illustrates one type of model that can be further developed as data and understanding improve. Such models can be developed for other contaminants and specific regions, providing an important starting point for evaluating deeper parts of aquifers used for domestic and public supply, and for developing three-dimensional models that couple ground-water quality with groundwater flow to evaluate the distribution and transport of contaminants in aquifers.

Understanding of Cause-and-Effect Relations

NAWQA Cycle 3 stresses analysis of relations between specific water-quality stressors—contaminants, nutrients, sediment, and streamflow alteration—and their individual and combined impacts on aquatic ecosystems so that management strategies can target the most critical causes of ecological degradation.

Example: Evaluating Causes of Ecological Impacts

Improved protection and restoration of aquatic ecosystems requires an understanding of what factors have the potential to adversely affect aquatic organisms, and where such factors may present the greatest risk. Data collected as part of NAWQA Cycles 1 and 2, and from assessments by USEPA and the States, have been used to develop statistical correlations between several different stressors and the biological condition of streams. Cycle 3 studies are designed to build on these correlation analyses by refining cause-and-effect relations and by combining the findings with ecological and water quality models so that estimates can be made of the potential extent and conditions of potential concern. For example, a recent USGS study of fathead minnows (Tillitt and others, 2010) showed that the herbicide atrazine affects egg production at relatively low concentrations (fig. 1.7).

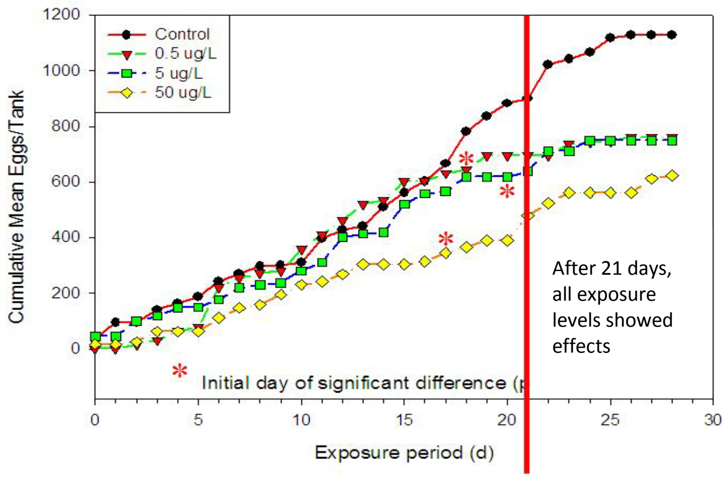


Figure 1.7. Results of laboratory tests showing reduced egg production in fathead minnows at at atrazine concentrations as low as 0.5 micrograms per liter with an exposure duration in the range of 21 days. These findings raised the question as to where such atrazine levels are found in streams and may, therefore, be a concern requiring further investigation.

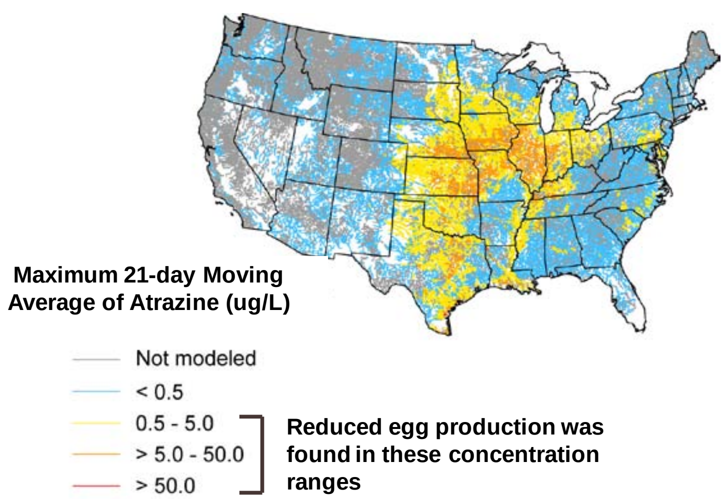


Figure 1.8. Predicted maximum 21-day average atrazine concentration in streams for concentration levels shown to affect egg production in laboratory studies.

The atrazine WARP model (Watershed Regressions for Pesticides; Stone and Gilliom, 2008)), which was developed from NAWQA Cycle 1 and 2 monitoring data—plus extensive data on atrazine use patterns, soils, precipitation, and agricultural practices—allows rapid estimation of what areas of the country have streams that exceed the concentration levels identified as potential concerns by the laboratory results. The model was used to estimate the distribution of atrazine concentrations in streams where potential effects on actual fish populations may occur and can be used to guide follow-up investigations (fig. 1.8). This example illustrates one way in which new cause-and-effect studies can be combined with statistical or simulation models developed from NAWQA's sustained commitment to monitoring data to rapidly assess the characteristics and geographic extent of a potential management problem.

Forecasting and Scenario-Testing Tools

Forecasting tools developed from Cycle 3 models will enable timely evaluation of current water-quality issues and future scenarios of changing land use, management practices, and climate.

Example: Forecasting Reductions in Nitrogen Loading to Estuaries

Cycle 3 assessments will apply hydrologic and statistical models to forecast how potential changes in climate, population, land-use, and other factors will affect ground- and surface water quality. These forecasts are needed by managers and policy-makers tasked with ensuring stable, clean water-supplies for humans and ecosystem needs. The SPARROW model, for example, relates nutrient concentrations from a large network of monitoring stations to (1) upstream sources, such as fertilizer, manure, wastewater discharges, and the atmosphere; and (2) watershed characteristics affecting transport, including soil permeability, stream size, and streamflow (Smith and others, 1997). These sources and watershed characteristics are spatially referenced to a detailed network of stream reaches that represents pathways of water movement through the modeled region. The SPARROW model can be used to address a variety of management issues.

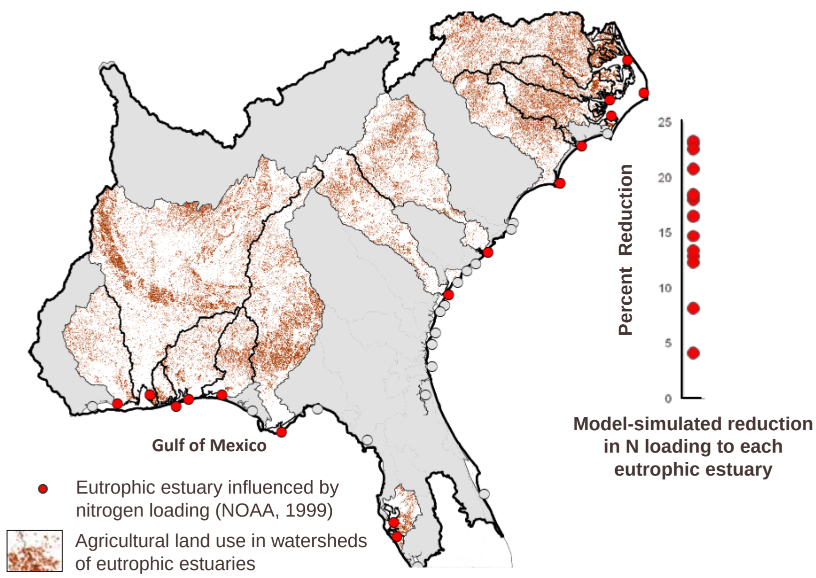


Figure 1.9. SPARROW model prediction of how nitrogen loads delivered to eastern Gulf of Mexico and South Atlantic estuaries would respond to a 50 percent reduction in agricultural nitrogen inputs. The SPARROW model predicts that the response to a reduction of agricultural nitrogen inputs of this magnitude would be a decrease in estuarine loading from as little as 5 percent, to a maximum of 24 percent, depending on the estuary.

This example shows that—in terms of total annual nitrogen load—reduction of agricultural sources alone may not markedly improve eutrophication in some of these estuaries (fig. 1.9). Cycle 3 will expand the capabilities of SPARROW and other models to include additional contaminants and to include simulation of changes over time. In addition, NAWQA will develop web-accessible models and tools for managers to evaluate how water quality and aquatic ecosystem conditions may change in response to different management scenarios.

Chapter 2. Cycle 3 Design Elements

NAWQA's strategy for water-quality assessment in Cycle 3 builds on proven approaches used in the previous two decades of the Program, including multi-scale, interdisciplinary assessments of critical hydrologic systems, systematic regional and national monitoring, detailed local-scale studies of governing processes and ecological effects, and modeling and statistical tools to integrate findings across multiple spatial and temporal scales. Although the basic approaches will remain the same, the increasing and changing demands for water-quality information, the improved technology for water-quality monitoring, and the need to rebuild from reductions in monitoring and assessment that resulted as Program resources declined over the past decade, require that the Cycle 3 approach incorporate a substantial evolution in emphasis and expanded scope to meet the Nation's current and future requirements for water-quality information. This overview lists specific objectives for each of the four major Cycle 3 goals and then summarizes the approaches and design components for surface water and groundwater studies.

Goals and Objectives

The Cycle 3 approach was developed by defining specific science objectives for each of the broad goals introduced in Chapter 1. The objectives are defined in relation to the four priority water-quality stressors—contaminants, nutrients, sediment, and streamflow alteration—and their potential effects on humans and aquatic ecosystems. These objectives, which are listed below, will be addressed to varying degrees of comprehensiveness and detail—determined by scientific and stakeholder priorities—to meet each goal and provide information that is of greatest use in addressing water-quality management questions.

Goal 1: Assess the current quality of the Nation's freshwater resources and how water quality is changing over time.

Objectives:

1a. Determine the distributions and trends of contaminants in current and future sources of drinking water from streams, rivers, lakes, and reservoirs.

1b. Determine mercury trends in fish tissue.

1c. Determine the distributions and trends in microbial contaminants in streams and rivers used for recreation.

1d. Determine the distributions and trends of contaminants of concern in aquifers needed for domestic and public supplies of drinking water.

1e. Determine the distributions and trends for contaminants, nutrients, sediment and streamflow alteration that may degrade stream ecosystems.

1f. Determine contaminant, nutrient, and sediment loads to coastal estuaries and other receiving waters.

1g. Determine trends in biological condition in relation to trends and changes in contaminants, nutrients, sediment, and streamflow alteration.

Goal 2: Evaluate how human activities and natural factors, such as land use and climate change, are affecting the quality of surface water and groundwater.

Objectives:

2a. Determine how hydrologic systems—including water budgets, flow paths, travel times and streamflow alterations—are affected by land use, water use, climate, and natural factors.

2b. Determine how sources, transport, and fluxes of contaminants, nutrients and sediment are affected by land use, hydrologic system characteristics, climate and natural factors.

2c. Determine how nutrient transport through streams and rivers is affected by stream ecosystem processes.

2d. Apply understanding of how land use, climate, and natural factors affect water quality to determine the susceptibility of surface-water and groundwater resources to degradation.

2e. Evaluate how the effectiveness of current and historic management practices and policy is related to hydrologic systems, sources, transport and transformation processes.

Goal 3: Determine the relative effects, mechanisms of activity, and management implications of multiple stressors in aquatic ecosystems.

Objectives:

3a. Determine the effects of contaminants on degradation of stream ecosystems, which contaminants have the greatest effects in different environmental settings and seasons, and evaluate which measures of contaminant exposure are the most useful for assessing potential effects.

3b. Determine the levels of nutrient enrichment that initiate ecological impairment, what ecological properties are affected, and which environmental indicators best identify the effects of nutrient enrichment on aquatic ecosystems.

3c. Determine how changes to suspended and depositional sediment impair stream ecosystems, which ecological properties are affected, and what measures are most appropriate to identify impairment.

3d. Determine the effects of streamflow alteration on stream ecosystems and the physical and chemical mechanisms by which streamflow alteration causes degradation.

3e. Evaluate the relative influences of multiple stressors on stream ecosystems in different regions that are under varying land uses and management practices.

Goal 4: Predict the effects of human activities, climate change, and management strategies on future water quality and ecosystem condition.

Objectives:

4a. Evaluate the suitability of existing water-quality models and enhance as necessary for predicting the effects of changes in climate and land use on water quality and ecosystem conditions.

4b. Develop decision-support tools for managers, policy makers, and scientists to evaluate the effects of changes in climate and human activities on water quality and ecosystems at watershed, state, regional, and national scales.

4c. Predict the physical and chemical water-quality and ecosystem conditions expected to result from future changes in climate and land use for selected watersheds.

Design Elements

Surface-water and groundwater assessments for NAWQA Cycle 3 will each be based on several primary study components that have evolved from experience gained from Cycles 1 and 2. The study components are described below for surface water and groundwater. Each objective is highly dependent upon information derived from other objectives and, thus, all objectives for surface and groundwater will depend upon having flexible, but closely coordinated, study components. The study components provide a consistent structure for organizing multi-purpose, interrelated studies across multiple scales of investigation for surface water and groundwater. A common component for all types of studies will be review and analysis of existing data and information, which will be referred to as Retrospective Analysis. Following an overview of the design components Chapters 3-6 will describe how these components are applied to the design of studies that will meet each goal and its related objectives.

Surface Water

The surface-water design must address a complex array of objectives regarding the chemical and physical aspects of water quality and the effects of water-quality stressors on human health and aquatic ecosystems. Priority water-quality stressors for Cycle 3 are contaminants, nutrients, sediment, and streamflow alteration. Depending on the specific objective, spatial scales of interest extend from stream sites and reaches, to small watersheds, up to the entire Mississippi River Basin and the Nation; time scales of significance range from hours to decades; and environmental settings are diverse.

In general terms, the array of Cycle 3 goals and objectives related to surface water has many similarities to those of Cycles 1 and 2, but the emphasis has evolved to reflect improved information and newly identified needs. The proposed Cycle 3 design, as described below, involves several broad enhancements and changes to the Cycle 2 design that are needed to adequately address Cycle 3 goals and objectives. The Cycle 3 design components are briefly introduced below and then explained in more detail, all as the foundation for explaining the specific approach to each goal and objective in subsequent chapters:

- <u>The National Fixed Site Network (NFSN)</u> is a national network of monitoring sites that serves as the foundation for systematic tracking of the status and trends of stream and river water quality and for supporting and linking shorter-term studies at smaller scales. The Cycle 3 NFSN is expanded and upgraded to improve trend analysis, support for model development and validation, analysis of drinking water sources, analysis of reference conditions and climate change, nutrient and contaminant loads to coastal ecosystems, and other specific analysis requirements.
- <u>Regional Synoptic Studies (RSS)</u> are short-term, targeted water-quality or biological assessments of specific regions or environmental settings. RSS are a flexible design component that help fill spatial gaps between national fixed-site monitoring and the geographically limited Integrated Watershed Studies and Intensive Studies (described below). The RSS are well suited for assessing water-quality or biological conditions where spatial variability is more important than temporal variability. These types of studies are particularly important for the development and testing of regional ecological models. RSS were employed to a limited degree in Cycle 1 and Cycle 2, but will take on a larger role in Cycle 3.

- Integrated Watershed Studies (IWS) are a limited number of large-scale surface-water quality assessments introduced in Cycle 3 to address the increasing need for integrated understanding of contaminant, nutrient, and sediment sources and transport in large watersheds and for developing reliable predictive models at these scales. The IWS will fill gaps in surface-water assessment that were created by the phase-out of Study-Unit Investigations during Cycle 2.
- Intensive Studies (IS) are focused studies at a limited number of sites, reaches, or small watersheds, selected to investigate specific topics in comparative designs. IS are vital to meeting Cycle 3 objectives to improve understanding of specific sources, processes, and cause-and-effect relationships for aquatic ecosystems. IS were an important part of the approach of NAWQA Topical Studies done in Cycle 2. In Cycle 3, IS will be nested in IWS study areas to facilitate upscaling of findings, and to leverage monitoring, modeling, and ancillary data in the IWS.

With these components as the building blocks for design, Cycle 3 can accommodate multiple scales of monitoring and assessment with sufficient structure to enable systematic integration of findings to address objectives at regional and national scales. The components also enable timely and targeted studies of specific topics with unique design requirements. Although policies often target regional and national scales, land and water management strategies usually are implemented locally. Thus, to be successful in providing scientific information that improves management, NAWQA places a high priority on making the linkages of cause and effect across the scales.

In the following, more detailed description of each design component, the NFSN is described most completely, although not with detailed specifics on factors such as site selection and sampling and analytical strategy, whereas the IWS, IS, and RSS are illustrated with examples and will be highly dependent on design details developed by focused study teams.

National Fixed-Site Network (NFSN)

The Cycle 3 National Fixed-Site Network (NFSN) is a national network of monitoring sites with a long-term commitment to (1) perennial and systematic water-quality sampling, with timing, frequencies and laboratory analyses designed for Cycle 3 objectives, including assessment of long-term trends, and (2) continuous monitoring of streamflow (all sites) and selected water-quality parameters (selected sites). The Cycle 3 design relies upon, and is comprised of, monitoring sites and activities supported to varying degrees by several national programs, including NAWQA, National Stream-Quality Accounting Network (NASQAN), Hydrologic Benchmark Program, Global Change Program, and the interagency National Monitoring Network (NMN).

The NFSN produces the consistent and common core of information that other Cycle 3 components rely on. Fixed-site monitoring has been a vital component of the NAWQA design since the beginning of Cycle 1. During Cycle 1, more than 500 sites were operated for varying periods of time during study unit investigations. During Cycle 2, these sites were reduced to a national network of about 113 sites, about two-thirds of which are sampled intensively only one of every four years. When combined with 27 NASQAN sites, and 5 NMN sites, the current fixed-site monitoring network consists of 145 sites (fig 2.1).

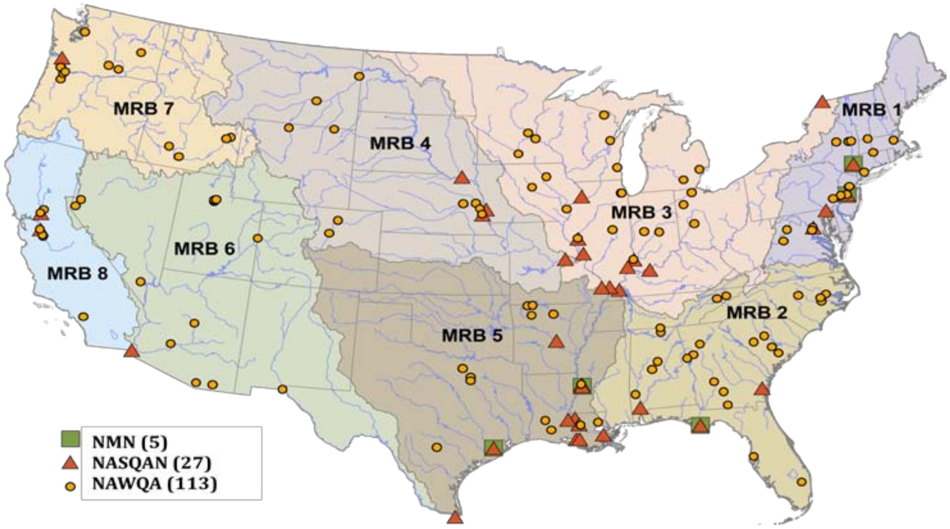


Figure 2.1. The Cycle 2 fixed-site network for monitoring surface-water quality is a combination NAWQA, NASQAN (National Stream Quality Accounting Network), and NMN (National Monitoring Network) sites. Of the 145 sites included in the combined network, only 44 are monitored every year; 15 sites are sampled one in every two years, and the remaining 86 sites are monitored only one out of every four years. MRB refers to the eight Major River Basins NAWQA used for regional-scale synthesis and modeling of surface-water quality.

To meet Cycle 3 objectives, the NFSN needs to be substantially expanded and enhanced, including:

- Monitoring every year rather than using rotational schedules. Trend analysis of water-quality data from 1992-2008 has shown that important trends, such as for many pesticides, are happening within a few years and are not adequately characterized with rotational sampling (see fig. 1.5).
- Real-time continuous monitoring of selected water-quality parameters at most sites. Continuous monitoring of selected parameters, such as specific conductance and turbidity—now more economically and technically feasible than in the past—will enable detailed and accurate estimates of concentrations and loads for dissolved solids and suspended sediment and will contribute to improving estimates of other parameters through correlation analysis. Continuous data also yield improved understanding of the effects of short-term hydrologic events (e.g. storms, floods, dam releases) on water quality and provide time-dense data for developing dynamic simulation models.
- Additional sites to support improved assessment of sources of drinking water, loadings of nutrients, contaminants, and sediment to coastal ecosystems, and background conditions. These sites fill information gaps that are essential to meet Cycle 3 goals.

<u>Specific roles of the NFSN in the NAWQA Cycle 3 design are:</u>

- Primary data source for basic assessments of the distributions and trends in contaminants, nutrients, and sediment, including associated models
- Perennial "anchor" sites for IWS and other studies that have limited study periods
- Primary data source for assessing contaminant, nutrient, and sediment loading to coastal ecosystems.
- Primary data source for assessing surface-water sources of drinking water.
- Primary source of reference watershed data for evaluating effects of changing climate and human activities on water quality and aquatic ecosystems.

Design Features

The design of the NFSN for Cycle 3 is described in comparison to the Cycle 2 design in Table 2.1; figures 2.2-2.4 show the general distribution of large river, wadeable stream, and drinking-water intakes sites by land use. NFSN site selection and site-specific sampling and analysis plans will be completed after Cycle 3 plans develop further and more is known about the budget, analytical methods, external partnerships, and coordination with other NAWQA study components and USGS programs.

Table 2.1 Changes from Cycle 2 to Cycle 3 in the National Fixed Site Network.

Characteristic	Cycle 2	Cycle 3
Total sites	145 total sites (113 NAWQA sites, 27 NASQAN sites, 5 NMN sites)	331 total sites
Sampling Schedule	Most sites every 2 or 4 yrs	All sites sampled all years
Sampling Frequency	12-26 samples per yr	12-26 samples per yr
Real-time monitors	None	Most sites
Ecological monitoring sites	58	88 (includes 30 new reference sites)
Reference sites	11	41 (includes 30 new reference sites listed above)
Drinking water intake sites on streams and rivers	Temporary at selected intakes	20 perennial
Drinking water intake sites on lakes and reservoirs	None	50 perennial
Coastal sites	13	46 (added 33 NASQAN sites)
Contaminant analyses	Limited	Expanded
Suspended sediment	Limited	Suspended sediment and continuous turbidity monitoring

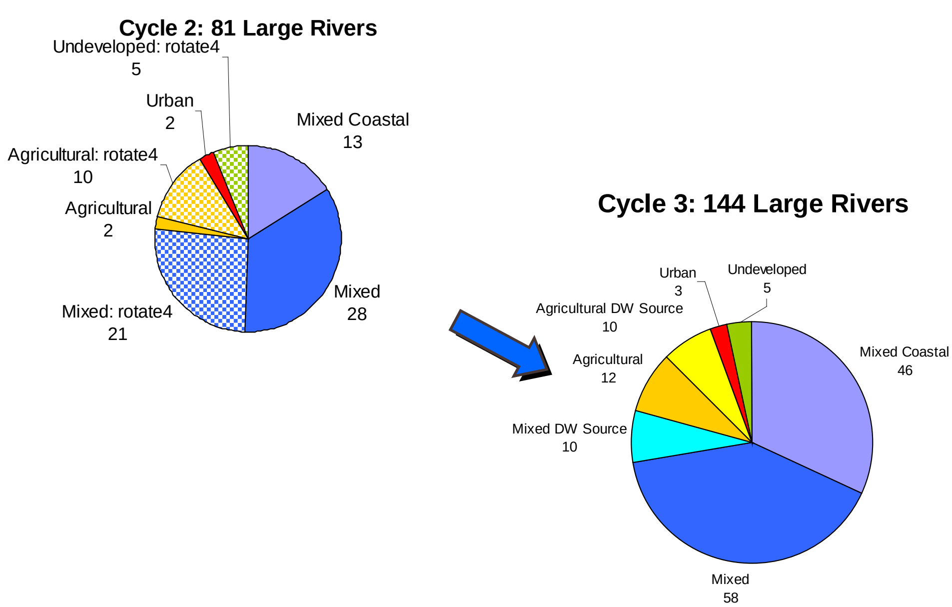


Figure 2.2. The Cycle 3 allocation of National Fixed Site Network sites on large rivers (nonwadeable) increases the number of sites from 81 to 144. Major changes include more coastal sites, sites at drinking-water intakes, and increased monitoring to

every-year sampling. [DW=drinking water source; rotate4=sampled one in every four years; Undeveloped, agricultural, urban and mixed refer to dominant watershed land use]

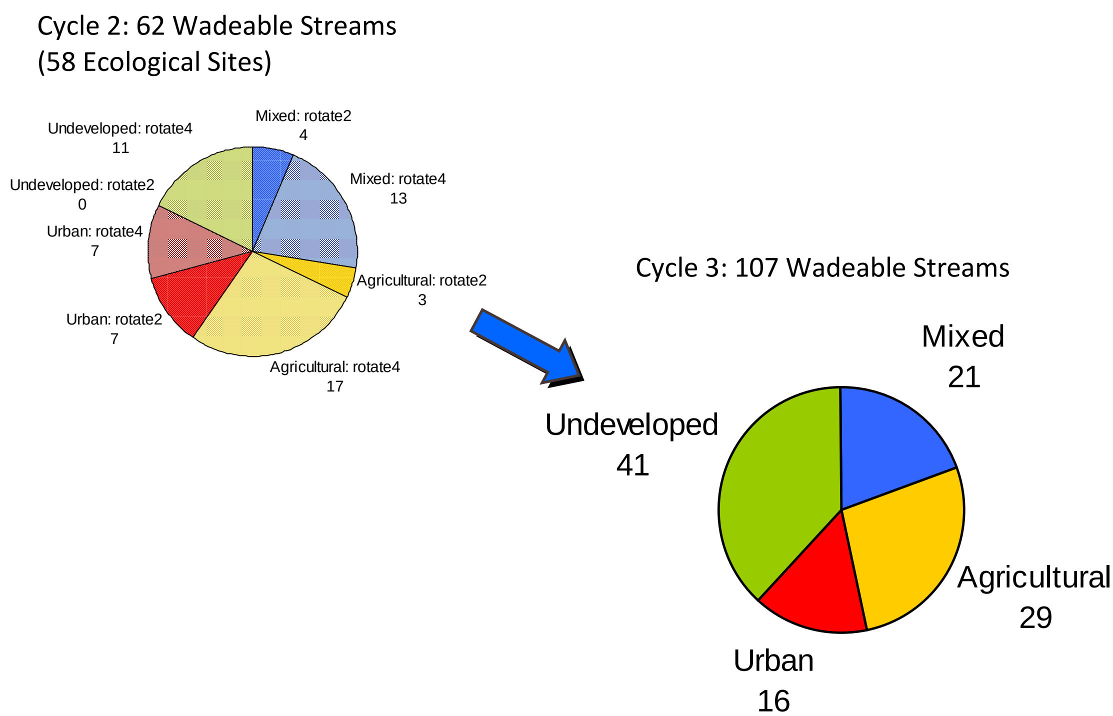


Figure 2.3 The Cycle 3 allocation of National Fixed Site Network sites on wadeable streams increases the number of sites from 62 to 107. Major changes include and increase in undeveloped reference sites from 11 to 41 and increased monitoring to every-year sampling. [rotate4=sampled one in every four years; rotate2=sampled one in every two years; Undeveloped, agricultural, urban and mixed refer to dominant watershed land use]

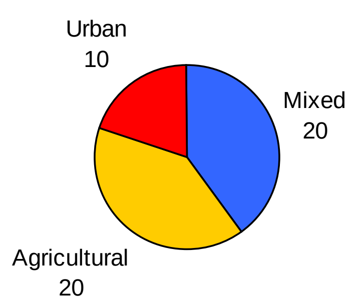


Figure 2.4 The Cycle 3 allocation of National Fixed Site Network sites at 50 lake or reservoir drinking-water intakes is a new assessment component that was not part of Cycle 2. [Undeveloped, agricultural, urban and mixed refer to dominant watershed land use]

Relation to Other Components

- Integrated Watershed Studies (IWS): On average, each IWS watershed will contain 2 to 4 NFSN sites that provide a core of long-term, consistent data at key locations.
- Intensive Studies (IS): Most IS will be anchored by a NFSN site that provides a longer term temporal reference for the shorter term intensive study.

- Regional Synoptic Studies (RSS): Most RSS will include 10 to 20 NFSN sites that will serve as longer term temporal references for the short-term synoptic approach of the RSS.
- Local, Regional, and Principal Aquifer-Scale Groundwater Studies (LGS, RGS, and PA): Most LGS, RGS, and PA assessments will include one or more NFSN sites that will be used to perform baseflow separation analyses to determine water-quality and quantity contributions from groundwater to monitored watersheds.

Regional Synoptic Studies (RSS)

The RSS are short-term, targeted water-quality assessments of specific regions and conditions. Generally, the number of sampling sites for a RSS in a particular region is much greater than the number of NSFN sites in the same geographic area, typically in the range of 10 to 20 times more, depending on the scale characteristics and variability of the natural and anthropogenic environmental setting. RSS are a very flexible design component. Some may be unique, one-time studies aimed at specific topic in one region, such as the distribution of a specific contaminant in spring runoff within a particular agricultural region. Others may be part of long-term rotational series of RSS, such as geographic assessments of biological conditions in regions that are assessed by a similar design, rotating regions over time to build a national data set on a particular topic.

These assessments fill a gap between NFSN and geographically limited IS and IWS components by increasing the spatial extent of assessment for issues that are expected to be more dominated by spatial variability than temporal variability. The RSS are particularly important for assessment of biological conditions and contaminants in bed sediments or fish tissue.

Specific roles of the RSS in the NAWQA Cycle 3 design are:

- Expand geographic assessment for water-quality characteristics identified from other studies to be of potential regional interest, particularly biological conditions.
- Geographically extensive reconnaissance assessments of particular water quality characteristics, such as bed sediment contaminants, which are expected to vary more spatially then temporally.

Design Characteristics

Most RSS are studies of a contiguous large region spanning multiple states, such as an MRB or ecoregion, depending on the objective. Some RSS, however, target a specific environmental setting that is not contiguous, such as urban areas. Most RSS are one-time short-term studies, usually one sampling visit or limited multiple samplings during a single season, but some trend assessment objectives may require repeated RSS over appropriate time intervals. Each RSS generally targets a relatively narrow range of water-quality conditions.

Relation to other components and associated analyses

- Point-in-time testing and verification of predictions for selected constituents and biological conditions from national and regional models developed from NFSN and RSS.
- Up-scaling of findings for selected parameters from IWS and IS to regional scale

Integrated Watershed Studies (IWS)

Integrated Watershed Studies (IWS) are long-term, interdisciplinary water-quality assessments of large watersheds. The IWS are nationally distributed examples of regional environmental settings, each of which is characterized by a defined range of natural hydrologic settings and human activities. The IWS will consist of a stable set of 10 - 20 watersheds that are generally in the range of 5,000 to 50,000 square kilometers, depending on the scale characteristics and variability of the natural and anthropogenic environmental setting in a particular region. Example candidate IWS are shown in Figure 2.5 to illustrate potential distribution and scale. The regions and IWS watersheds will be prioritized and selected with the goal of representing the national range of important human influences on water quality. Most, if not all, IWS will be large watersheds selected from the NAWQA Cycle 2 trend network and are either entire NAWQA Cycle 1 study units or one of their major sub-basins. Characterization and prioritization of IWS will follow the same type of process and use similar information as was employed to prioritize study units and topical study areas for Cycle 2. There will likely be 1-2 IWS in each NAWQA Cycle 2 Major River Basin (MRB), but selection and implementation of IWS will be phased in to coordinate with IS priorities, partnerships with other agencies, and available resources.

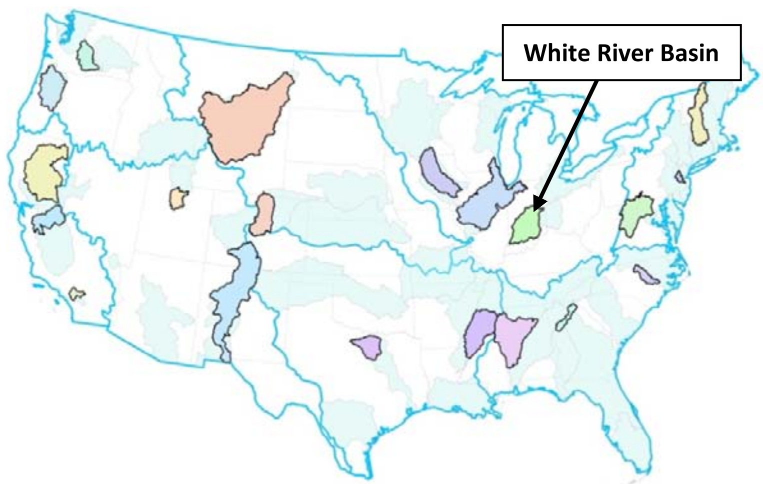


Figure 2.5. Hypothetical map of 20 possible Integrated Watershed Study locations distributed among the 8 NAWQA Major River Basins in the conterminous United States. The actual number of IWS and timing of implementation will be determined based on coordination with IS priorities, partnerships with other agencies, available resources, and other factors to be evaluated as Cycle 3 begins. Also indicated is the location of the White River Basin, which is used as an example to illustrate an Integrated Watershed Study design in Chapter 4.

The overall role of the IWS is to bridge the gap in scale between National Fixed-Site Monitoring and Cycle 3 Intensive Studies to address large-scale and multi-scale source and transport objectives, predominantly for contaminants, nutrients, and sediment. In the context of the NAWQA study-unit investigations that evolved through Cycle 1 (52 study units) and Cycle 2 (started with 42 but most study-unit based activity phased out), IWS can be considered as more selective, more intensive, surface-water focused “study units”. Although primarily focused on surface-water, IWS will also be the primary areas where hydrologic systems studies will address relations between surface water and groundwater in different hydrologic settings.

Specific roles of the IWS in the NAWQA Cycle 3 design are:

- They serve as selected focus areas for developing intensive and high-quality information on water-quality characteristics, hydrologic system characteristics, and the human and natural factors that are affecting water quality.
- They are the real-world laboratories for developing and testing hydrologic and water-quality models that link human activities and natural factors to sources and transport of contaminants, nutrients, and sediment from headwaters to large rivers, and ultimately, for development and testing of

predictive models used to forecast water-quality conditions under various scenarios of climate or land-use change
- They define the geographic areas for locating intensive studies so that the IS are nested in a well-characterized large watershed for analysis of larger-scale significance and downstream implications.
- By linking local-scale studies and land-use activities to effects on downstream systems in larger watersheds, they contribute to evaluating the significance of land and water management practices to large-scale improvements in water quality.
- They are well-suited for developing collaborative partnerships with local, state, and Federal agencies, such as USDA and USEPA, and with academic researchers because of their focus on linking across scales, from site-specific studies to large watershed water-quality conditions, thus spanning a wide range of research and management interests in key settings, supported by NAWQAs monitoring and assessment infrastructure.

Design Characteristics

In general, each IWS will focus on a watershed that has already been included in NAWQA studies. These watersheds generally have a solid baseline of hydrologic, water quality, and ancillary information from Cycles 1 and 2, combined with other data sources. A potential exception to this may occur if high-value partnerships can be formed between multiple agencies in watersheds that have large amounts of water-quality and ancillary data and (or) existing water-quality models that can be leveraged to advance NAWQA and other agency goals. As an initial step for Cycle 3 planning and implementation, on the order of 20 candidate IWS will be characterized using existing information, following a consistent approach. This will facilitate, as Cycle 3 plans evolve, selecting IWS for detailed assessment.

Initial Characterization of Candidate IWS

- The initial characterization will serve as a well-defined starting point for design that identifies critical issues in each watershed as they relate to the Cycle 3 objectives, inventories available information and critical gaps, and begins to explore potential partnerships. Initial characterization will include, but not be limited to:
- Review, update, and synthesize readily available existing information, such as:
    - Geographic characterization of natural and anthropogenic characteristics
    - Land use characteristics and distribution
    - Point-source discharges
    - Drinking water intakes
    - Active streamgages and current monitoring programs
    - Current water-quality issues and stakeholders
    - Characterize other studies and related activities in progress in the IWS, such as other USGS studies, USDA Agricultural Research Service (ARS) research sites, Long-Term Ecological Research (LTER) sites, and others.

Selection and Implementation of IWS

- All IWS will not be implemented at the same time because of funding and personnel constraints and the timing of study priorities. A range of implementation options will be considered, but the favored approach to begin Cycle 3 would be to implement approximately 6-10 IWS, with a 10-year study period. The 10-yr study period for a limited number of studies is preferred over the alternative of studying more IWS on a shorter rotational schedule. The 10-yr study period is needed for developing sustainable study partnerships and efficiently phasing in data collection and modeling. Although there are a number of specific issues to consider regarding the number of IWS that can be implemented at one time (which will not be resolved until later in the design process), examples of some of the primary factors that will determine priorities for implementation are listed below:

- Relevance to highest priority intensive studies
- Relevance to current regional issues, such as nutrient loading to the Mississippi River Basin, Chesapeake Bay, and other large estuaries affected by eutrophication
- Readiness of data and infrastructure for studies
- Suitability of staff
- Geographic distribution
- Likelihood of partnering with other USGS Programs, Federal or State agencies, and academic researchers on shared scientific interests

Core Assessment Activities

- Each implemented IWS will have a standard core of assessment and modeling activities that are generally similar among all selected IWS, but also will be customized to address local conditions, and supplemented as needed for support of synoptic and intensive studies. Although details of assessment activities will be determined separately by a later planning effort, basic core activities would include:

  - Detailed update and enhancement of ancillary information on all human activities in the watershed that affect water quality.
  - Inventory the locations and quantities of water withdrawals for drinking water and other purposes
  - Compilation and verification of historical and ongoing water quality data collection and studies
  - Enhanced fixed-site monitoring. Typically this would involve supplementing the 1-2 NFMN sites typically in an IWS with 10-12 additional sites, monitored using a similar sampling and analytical strategy. The additional sites will be located to measure water quality and fluxes at outlets of major sub-basins in the watershed, to support model development and analysis, and for selected land-use or best management practice settings.
  - Streamflow and mass-balance analysis for fluxes of water, dissolved solids, sediment, and other constituents, through and from the watershed as data allow.
  - Model analyses to simulate water and constituent movement through the watershed and to account for the distribution and characteristics of point and nonpoint sources.

Relation to Other Components

- Testing and verification of predictions from national and regional models developed from NFSN and RSS.
- Up-scaling of findings from IS to larger watershed context
- Nesting within LGS and RGS studies examining groundwater-surface water interactions, including flow and transport modeling.

Intensive Studies (IS)

Intensive studies (IS) are interdisciplinary studies ranging in scale from individual stream reaches to small (50-200 km^2) watersheds. The primary purpose of these studies is to address specific process- or effects-based objectives that cannot be studied at larger scales, but that are critical for understanding processes and effects at the larger scale. Examples include assessment of:

- Effects of stream ecosystem processes on the transport of nutrients by streams and rivers, and how ecosystem processes are influenced by watershed alterations and management practices
- Effects of sediment and sedimentation on the function and structure of aquatic ecosystems.
- The effects of contaminants in water, sediment, or the aquatic food chain, on degradation of stream ecosystems
- Assess effects of reach-scale geochemical and hydrologic processes on contaminant transport from groundwater to streams and streams to groundwater and how these processes are influenced by hydromodification of a watershed in agricultural and urban areas.

Design Characteristics

- The IS could include single sites for addressing the interactions of flow, contaminants, nutrients, or sediment, or multiple sites for studies that address nutrient processing in small watersheds or the role of surface-water/groundwater interactions. The studies will be nested inside the larger IWS, with 1 to 2 IS sites per IWS, depending on the specific questions being addressed. As in the IWS, the IS sites will be anchored by sites in the NSFN.
- IS are an important scale for collaborative work with other USGS long-term programs like the National Research Program, the Toxic Substances Hydrology Program or the Global Change Program’s Climate Effects Network and are well suited for coordinating with the National Ecological Observatory Network (NEON) and other non-USGS programs.
- Each IS will be selected primarily from sites or small watersheds that have been studied during Cycle 1 or 2 in order to capitalize on the amount of baseline data available. Because the intensive site will be used to address different questions there is no single design that would necessarily work for all questions. Due to the variable levels of effort at these sites, IS will rotate among the different IWS, with some IS lasting from two to four years and others lasting longer.

Relation to other components

- Include at least one NSFN site in each IS and locate within an IWS.
- Provide understanding of specific processes or cause-effect relations for interpreting findings from all other components.
- Provide information on rates of key hydrologic, geochemical, and biological processes for use in water-quality and hydrologic models used to extrapolate and forecast water-quality conditions.

Groundwater

In Cycle 3, NAWQA will provide a comprehensive national assessment of groundwater quality in the context of its suitability as a source of drinking water and with respect to its influence on ecosystem conditions. In Cycles 1 and 2, NAWQA implemented a targeted design that provided a basis for assessing groundwater quality across a broad range of conditions representative of the Nation, with a particular focus on evaluating the relationship between land use and shallow groundwater quality. In Cycle 3, NAWQA will implement an integrated design that utilizes data and models at multiple scales, with an emphasis on developing three-dimensional perspectives on groundwater quality. The Cycle 3 groundwater design will complement and build upon the data and models developed by NAWQA during Cycles 1 and 2, by other USGS Programs (Cooperative Geologic Mapping Program, Groundwater Resources Program, Water Cooperative Program), and by other Federal and non-Federal entities.

In Cycle 1, NAWQA groundwater studies were implemented within study units (2000 to 10,000 km^2), with National Synthesis teams focusing on specific contaminant groups (pesticides, volatile organic compounds, nutrients, and trace elements). In Cycle 2, NAWQA evaluated previously collected data in the context of Principal Aquifers (10,000 to 100,000 km^2), implemented topical studies designed to develop a better understanding of groundwater quality at local to regional scales (100 to 1000 km^2), maintained a groundwater sampling network for the purposes of assessing trends, and has been assessing trends at multiple scales. In Cycle 1 NAWQA sampled about 2,700 observation wells, 3000 domestic wells, approximately 500 public supply wells and 500 wells with other uses, mainly irrigation. Observation wells were installed in randomly chosen locations at shallow depths (generally less than 50 feet below land surface) beneath specific land uses such as row-crop agriculture or urban areas as part of Land-Use Studies (LUS networks). Results were used to assess the effects of specific land uses on shallow groundwater quality. Existing domestic and public supply wells randomly located within the target aquifer were sampled as part Major Aquifer Surveys (MAS); data from these wells were intended to provide a snapshot of water-quality conditions in the used resource. In Cycle 1 NAWQA used statistical analysis and statistical models to evaluate groundwater quality at the study unit and National scales. In Cycle 2, NAWQA used statistical summaries and statistical models to assess groundwater quality at the Principal Aquifer and the National scales, and developed groundwater simulation models to understand the distribution, transport, and trends of contaminants at local to regional scales.

The primary organizational unit for Cycle 3 groundwater studies will be the Principal Aquifer (PA), rather than the Study Unit. Principal Aquifers represent large areas (~200,000 to >3,000,000 km^2) with common lithostratigraphic and hydrogeologic characteristics, whereas Study Units correspond to surface water basins (watersheds) or smaller aquifer units. Within the context of Principal Aquifers, NAWQA will collect data and develop models at multiple scales. In Cycle 3, NAWQA will develop models that can be used to extrapolate groundwater quality into unmonitored areas and to forecast changes in groundwater quality that might occur due to changes in broad-scale driving forces.

- Principal Aquifer Assessments (PAA)

  The Principal Aquifer Assessments (PAA) will be the primary organizational unit for groundwater studies in Cycle 3, and PA assessments will be designed for assessment of status and trends at PA to National scales.

- Regional Groundwater Studies (RGS)

  Regional Groundwater Studies will be nested within Principal Aquifers and selected RGS will be co-located with surface-water Integrated Watershed Studies (IWS). Regional Groundwater Studies will be designed for assessment of status and trends at Regional scales with an emphasis on improving understanding of the human activities and natural factors affecting groundwater quality.

- Local Groundwater Studies (LGS)

  Local Groundwater Studies will be co-located with surface-water Intensive Studies and/or nested within Regional Groundwater Studies and are designed to improve, at a more specific level of cause and effect than Regional Studies, understanding of the human activities and natural factors that affect groundwater quality.

With these components as the building blocks for design, Cycle 3 can accommodate multiple scales of monitoring, assessment, and modeling with sufficient structure to enable systematic integration of findings, yet with sufficient flexibility to enable timely and targeted studies of specific topics with unique design requirements. Below are more detailed descriptions of each design components, followed by initial plans for national implementation.

Principal Aquifer Assessments

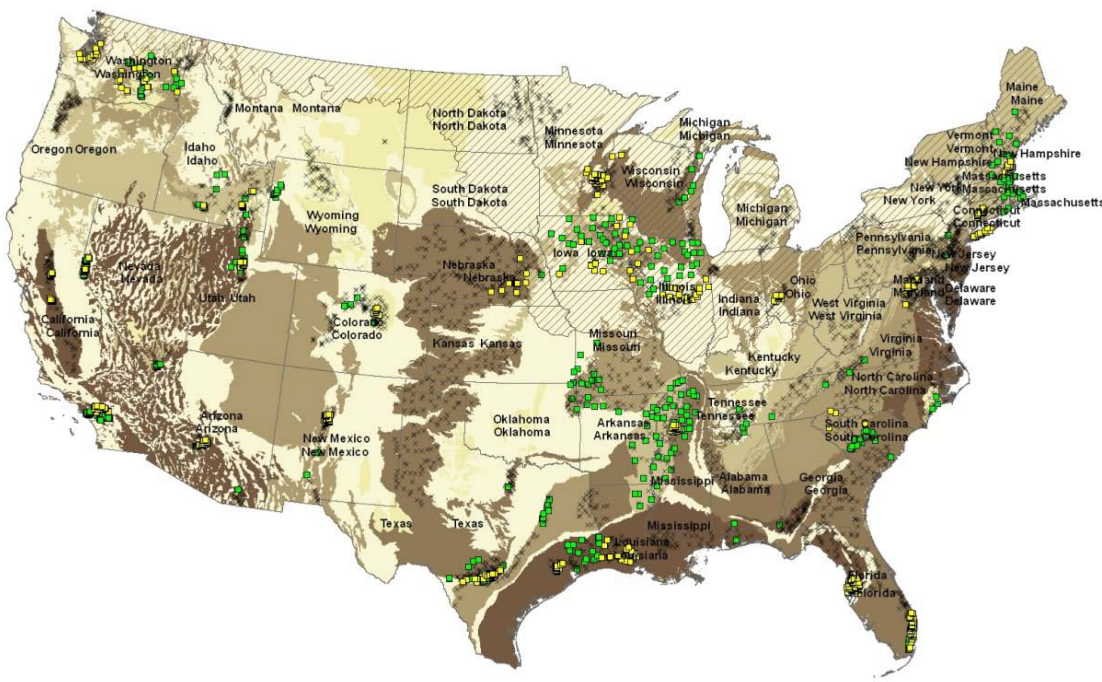
The PAA will be designed for assessment of groundwater status and trends at the PA to National scales. Figure 2.6 shows the distribution of PAAs in relation to use as public supplies of drinking water and to public-well sampling during Cycles 1 and 2. In Cycle 3, NAWQA will evaluate existing regional groundwater networks and develop new regional networks in the context of the Principal Aquifer. NAWQA will also develop two new network types in Cycle 3, the Principal Aquifer Survey (PAS) and the Enhanced Trends Network (ETN). PAS wells will be distributed across PAs using methods previously developed by NAWQA for distributing wells within LUS and MAS networks. NAWQA will use data from PAS wells to assess groundwater quality in aquifers and at depths used for domestic supply, and in aquifers and at depths used for public supply. ETN wells will be selected from existing networks, instrumented with continuous recorders (water level, specific conductance, and temperature), and sampled bimonthly for selected constituents. NAWQA will use data from ETN wells to gain a better understanding of short-term variability and long-term trends in groundwater quality. ETN wells will target shallow groundwater in aquifers and hydrogeologic settings where changes in climate or land use are expected to be quickly reflected in groundwater.

In Cycle 3, NAWQA will use statistical and quantitative groundwater models to assess the status and trends in groundwater quality at the PA scale. Output from statistical modeling could be constituent concentrations or probabilities associated with a constituent concentration exceeding a specified threshold (e.g. health-based screening level [HBSL] or some fraction of an HBSL). Quantitative models will include three-dimensional groundwater flow simulation and, potentially, particle tracking. When available, NAWQA will use or build upon models previously developed by the USGS Groundwater Resources Program. Output from quantitative flow models, such as hydrologic position and residence time, may be used as potential explanatory factors in the development of statistical models.

Regional Groundwater Studies

Cycle 3 RGS will be designed to contribute to assessment of status and trends at regional to national scales, and to improve understanding of the human activities and natural factors affecting groundwater quality. RGS (~1000 to >100,000 of square kilometers) were a major component of NAWQA during Cycles 1 and 2 and included LUS and MAS networks, Large-Scale Transport of Natural and Anthropogenic (LS-TANC) topical studies, and Source Water Quality Assessments (SWQA). In Cycle 3, NAWQA will use existing data when available (retrospective data), continue to sample selected existing networks, implement additional networks where needed, and develop quantitative models. Additional networks will be located to fill gaps in the existing NAWQA networks, with a particular emphasis on evaluating groundwater quality in three dimensions and in areas where groundwater is an important source of drinking supply. With the shift to assessment at the PA-scale new networks may be located outside of Cycle 1 or 2 study-unit boundaries.

Quantitative models can include groundwater simulation with particle tracking and groundwater simulation with solute transport. Quantitative models will account for the three dimensional and temporal aspects of regional groundwater flow systems. Extension of these models may include conceptualization of the aquifer system as a dual-domain system in order to better represent residence time and transport of contaminants. When available, NAWQA will use or build upon previously developed models including those developed for large- and small-scale TANC studies and (or) models produced by the USGS Water Cooperative Program. Refinement of the models may include simulation of the flow system as a dual-domain system to better represent residence time and transport of contaminants. RGS will be nested within PA assessments and may be co-located with IWS. Knowledge gained from RGS assessments will provide a basis for extrapolating groundwater quality into unmonitored areas.



Dark brown: PAs that account for 50% of pumping for public supply
Medium-dark brown: PAs that account for 50% to 75% of pumping for public supply
Medium-light brown: PAs that account for 75% to 90% of pumping for public supply
Light brown: PAs that account for 90% to 95% of pumping for public supply
Yellow: PAs that account for 95% to 100% of pumping for public supply
Beige: PA not identified
Green squares: public supply wells sampled with an MAS network
Yellow squares: public supply wells sampled as part of TANC or SWQA
X: additional wells sampled as part of an MAS network

Figure 2.6. Map of principal aquifers showing the percentage by volume of pumping by public supply wells in each aquifer and the distribution of public supply wells sampled by NAWQA in Cycles 1 and 2.

Local Groundwater Studies

Cycle 3 LGS will be designed to develop a better understanding of the human activities and natural factors that affect groundwater quality. These studies can include two-dimensional flow-path studies (FPS) that examine how groundwater quality changes from recharge to discharge areas at scales ranging from a few hundred meters to several kilometers. Local groundwater studies can also be three-dimensional at scales ranging from 10s to 100s of square kilometers, and can address questions related to the human, hydrologic, and geochemical processes affecting groundwater quality (as done at small-scale TANC studies). LGS will utilize existing (retrospective) data when available, newly acquired data, and quantitative modeling. Quantitative models could range from relatively simple mass balance models to complex simulation models of groundwater flow coupled with reactive chemical transport. LGS will be nested within surface-water Intensive Studies or RGS.

National Implementation and Integration

In Cycle 3, NAWQA will provide a national perspective on the quality of groundwater, particularly focused on groundwater used now or needed in the future for domestic and public supplies of drinking water. NAWQA will develop national or PA-scale exceedance maps for selected constituents that are present at concentrations of concern; concentrations of concern will be defined relative to health-based screening levels (Toccalino and others, 2007), and for emerging constituents of concern, on other criteria. Exceedance maps will be based on statistical models and incorporate data collected by NAWQA and others. The exceedance maps will include explanatory factors identified through RGS and PAA data collection and statistical models.

In Cycle 3, about 24 Principal Aquifers will be identified for assessment. About one-third of the PAs will be evaluated at a high level of intensity, one-third at a moderate intensity, and one-third at low intensity. High-intensity studies would involve sampling of about 200 PAS wells; implementation of two to four new MAS, LUS, or FPS networks; development of 1 to 3 regional-scale groundwater flow and particle-tracking models; development of a PA-scale groundwater flow and particle-tracking model; and development of PA-scale statistical models for selected constituents. Regional-scale models of flow and solute transport may be implemented in two to four high intensity PAAs and local-scale models of coupled flow and reactive chemistry may be implemented in one or two high intensity PAAs.

Moderate-intensity studies would involve sampling of about 100 PAS wells; may or may not include implementation of new MAS, LUS, or FPS networks; development of 1 or 2 regional-scale groundwater flow and particle-tracking models; development of a PA-scale flow model (with or without particle tracking); and development of PA-scale statistical models for selected constituents.

Low-intensity studies would involve sampling of about 50 PAS wells and development of PA-scale statistical models for selected constituents.

Enhanced Trend Network wells could be located within any of the Principal Aquifers, but it is expected that ETN wells would be located primarily in high or moderate intensity PAs. Criteria for selection of a PA as a high, moderate, or low intensity study may include population served by public and domestic supply wells (or volume of pumping), climate, hydrogeologic setting, availability of prior data and models, and national distribution. Details on the number of networks and wells proposed for the Cycle 3 design can be found in the section of Chapter 3 that describes the approach for Objective 1d.

Chapter 3. Assess the current quality of the Nation's freshwater resources and how water quality is changing over time (Goal 1)

Objectives, approaches and partnership opportunities that will be used to address the four Cycle 3 goals are described here and in subsequent chapters. For each of the four science goals and their associated objectives, progress made during Cycles 1 and 2 is briefly reviewed, remaining information needs are listed, and the approaches that will used to address each goal and objectives are described. Key products and outcomes, critical partnerships, and technical support requirements for activities proposed under each goal or objective, are also described. In this chapter, Goal 1 objectives and approaches are described individually; however in subsequent chapters, study objectives group together because of similar information requirements and al description of the overall approach that will be taken to achieve the science goal objectives is given.

Outcome: An updated and enhanced assessment of spatial patterns and temporal trends of the Nation's freshwater resources.

Products

1. Annual web-based reports on contaminant, nutrient, and sediment concentrations and loads at approximately 260 streams and large rivers with expanded analytical coverage per recommendations of NAWQA Target Analyte Strategy (NTAS) work group (*see sidebar on pg 45*).
2. Annual web-based reports on source and finished water-quality at 20 large river and 50 lake or reservoir drinking-water intakes with expanded analytical coverage per NTAS recommendations.
3. Annual web-based reports on contaminant concentrations and trends in groundwater used for domestic and public supply with expanded analytical coverage per NTAS recommendations.
4. Real-time reporting of continuously monitored water-quality parameters (temperature, specific conductance, dissolved oxygen, turbidity, nitrate, etc) and (or) related surrogate water-quality parameters (salinity, nutrients, sediment, or bacteria) at a subset of NFSN monitoring locations and shallow groundwater monitoring sites.
5. Annual web-based reports on trends in mercury in fish tissue at the national scale based on annual sampling at 100 to 200 locations.
6. Annual web-based reports on trends in water-quality and biological condition at approximately 50 streams in watershed undergoing rapid land-use change (urbanizing) and at approximately 40 reference condition watersheds.
7. Exceedance maps for groundwater contaminants of human health concern (nitrate, trace elements, radionuclides, microbial constituents and organic compounds) at depth zones used for domestic and public supply at the principal aquifer scale and for different time periods.
8. Updated (annual or 5-year) versions of steady-state statistical and hybrid water quality models such as WARP and SPARROW that provide estimates of contaminant, nutrient, and sediment concentrations and loads at monitored and unmonitored sites at national and regional scales.
9. Web-based delivery of steady-state model results that allow users to access model predictions for particular aquifers, streams, or watersheds.
10. National-scale synthesis reports that summarize data and findings on water-quality conditions and trends for surface water and groundwater at regular intervals (every 5 or 10 years).

Connections among NAWQA Cycle 3 Goals

Data, analyses, models, and tools associated with the seven Goal 1 objectives described below represent the continuation of the original NAWQA Program objectives of assessing the status and trends of the Nation's water quality and the factors that affect water quality and aquatic ecosystems. The data collected using the NAWQA design will be needed to:

- develop the understanding necessary to build national-scale statistical models that allow extrapolation of water-quality conditions to unmonitored parts of the country (Goal 2),
- understand trends in water-quality at a time-scale relevant to changing regulatory policies and management practices (Goal 2),
- assess the effects of changing land-use and climate on key water-quality and aquatic ecosystem stressors (Goal 2),
- assess the effects of key stressors (contaminants, excess nutrients, sediment, and altered streamflow) on aquatic ecosystems (Goal 3), and
- support the development of transient (time-varying) models that forecast and predict water-quality and ecosystem response to changing climatic and land-use conditions (Goal 4).

Policy and stakeholder concerns driving key management questions

Water-quality legislation enacted in this country at the Federal level has been driven by two primary concerns: protection of human health and restoring and maintaining the chemical, physical, and biological integrity of the Nation's surface and groundwater. Hence, stakeholders and policy makers are focused on mitigating ongoing persistent water-quality problems as well as new or emerging issues that relate to human health and (or) aquatic ecosystem condition. Because most of the concerns and related policies and regulations that drive the need for water-quality assessment apply to assessing the current condition of the Nation's water resources and how those resources are changing over time, a brief overview of those policies and concerns is given below per the two major receptors of interest: humans and aquatic ecosystems.

Policies and Concerns Related to Human Health:

The occurrence of contaminants in source and treated drinking water is the primary water-quality concern related to human health. Also of concern are threats related to consumption of aquatic organisms (primarily fish in freshwater), and microbial contamination of waters used for recreation and drinking. Safe drinking water is essential to public health and the quality of the Nation's drinking-water supply is an issue of growing national importance. Surface water is the largest source of drinking water for the United States, with more than 10,000 water systems accounting for about two-thirds of the water used for public supply in 2005 (Kenny and others, 2009). Of the surface-water supplies, reservoirs supply more than twice as much drinking water as rivers and streams (Hutson and others, 2004). The remainder is supplied by water systems that rely on groundwater sources. In 2005, about 258 million people received their water from public supplies; the remaining 43 million people were self-supplied with the vast majority (about 98 percent) obtaining their water from private wells (Kenny and others, 2009). The critical importance of surface and groundwater sources of drinking water makes it a high priority for NAWQA to provide a National perspective on the quality of both present-day sources of supply *and* resources that are likely to be used in the future.

The Safe Drinking Water Act (SDWA) provides a national framework for the protection of water quality provided by public suppliers, and thus applies to virtually all surface-water sources (very few are private). It also regulates groundwater sources used for public supply and suppliers who rely on groundwater under the direct influence of surface water. The SDWA authorizes and directs USEPA to establish health-based standards for drinking water and requires public suppliers to test for regulated and selected non-regulated contaminants in the water that they provide to their customers. The Source Water Assessment Program (SWAP), established in an amendment to the SDWA, requires delineation of well-head protection areas for public supply wells, identification of potential sources of contamination in those areas, determination of susceptibility of public supply wells to contamination, and communication of findings to the public. However, the quality of water from privately-owned domestic wells is not regulated by SWDA, nor in most cases, is it regulated by the states.

States are responsible for determining the need for and issuing fish-consumption advisories, but USEPA acts as a central repository for national information on the advisories and USEPA has published guidance to States, Territories, Tribes, and local governments to use in establishing fish-consumption advisories. Most advisories involve five primary bioaccumulative contaminants: mercury, PCBs, chlordane, dioxins, and DDT. These chemical contaminants persist for long periods in sediments where bottom-dwelling animals accumulate and pass them up the food chain to fish. Mercury, PCBs, chlordane, dioxins, and DDT were at least partly responsible for 97 percent of all fish consumption advisories in effect in 2008, with 80% of all advisories based at least partly on mercury (http://www.epa.gov/waterscience/fish/advisories/fs2008.html).

Monitoring, treatment and disinfection aimed at eliminating the threat of water-borne disease caused by microbiological contamination of public water supplies is regulated by the SWDA. The Clean Water Act (CWA) also addresses microbial contamination and enables protection of surface water for drinking water, recreation, and aquatic food source uses. Although the recreational water quality of beaches, lakes, and reservoirs is monitored by USEPA, the States, and local health departments, the recreational water quality of streams and rivers used for recreation is only infrequently monitored.

Policies and Concerns Related to Aquatic Ecosystems:

There is growing pressure to demonstrate that present policy and management practices are protecting and/or improving the quality of our streams and rivers. The CWA is the cornerstone for protection of surface-water quality in the United States and for restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support "*the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water*"—in other words, high-quality aquatic ecosystems. The statute employs a variety of regulatory and non-regulatory tools to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. The Act requires a series of biennial national reports, known as 305(b) reports, which summarize water-quality assessments by states, territories, tribes, and jurisdictions of the U.S. This is the primary vehicle used by USEPA for informing Congress and the public about water-quality conditions as they have been monitored and analyzed by states and other jurisdictions. These reports have major weaknesses from a national perspective, however, because of the inconsistency in approaches among states and overall sparse data.

Understanding the factors governing the status and trends in the quality of aquatic ecosystems is a national concern because of the present extent of impairment and the potential that effects may increase in the future. As of 2004, 42 percent of wadeable stream miles in the United States were found to be in poor condition, compared to least-disturbed reference conditions, and 25 percent in fair condition (U.S. Environmental Protection Agency 2009). The most widespread stressors identified in this USEPA national study were nutrients, riparian habitat disturbance, and streambed sediment. However, contaminants and other known stressors were not extensively assessed, resulting in an incomplete understanding of causes. In addition, there are increasing concerns regarding the potential effects of less well understood threats to aquatic ecosystems, including “newly recognized” contaminants, such as endocrine disrupting chemicals, mixtures of low-level contaminants, and changing climate.

Within this backdrop of clear-cut documentation of widespread impairment, but uncertainty regarding dominant causes, contaminants are an important class of ecosystem stressors that need to be characterized and understood in relation to their role in affecting aquatic ecosystems. Without an understanding of the role of contaminants and their relative importance and relation to other stressors, management strategies aimed at improving aquatic ecosystems cannot be reliably and efficiently devised or implemented.

Examples of management questions related to the Goal 1 status and trend assessment activities described throughout this chapter include:

- Are water quality goals, standards, and criteria being met for safe drinking and sustainable ecosystems at regional and national scales?
- Where are water-quality problems most severe?
- Where and how are conditions changing over time?
- What are the freshwater inflows and loads of nutrients, contaminants, and sediment to estuarine ecosystems, the Great Lakes, and other receiving waters?

Objective 1a: Determine distributions and trends for contaminants in current and future sources of drinking waters from streams, rivers, lakes, and reservoirs

NAWQA Progress during Cycles 1 and 2

NAWQA monitoring of contaminants in sources of drinking water in Cycles 1 and 2 was primarily focused on assessing ambient water-quality in streams and rivers across the Nation with a primary focus on pesticides and nitrate. Pesticide and nitrate studies supported basic assessments of conditions by region and land use, as well as the development of predictive models that allow extrapolation of results to current and potential source waters in unmonitored watersheds. In addition to the national assessment of ambient stream conditions, selected stream and river sources of drinking water were monitored for about 280 organic contaminants, including selective analysis of both source and finished water, to assess occurrence patterns in source water and to determine if these patterns also occurred in finished water prior to distribution. With the exception of an USEPA-sponsored study of pesticide occurrence in reservoirs conducted in the latter stages of Cycle 1 (Blomquist and others, 2001), NAWQA has not addressed contaminant occurrence in lakes and reservoirs used for drinking-water supply.

Information needs not addressed during Cycles 1 and 2

Remaining information needs identified below include those resulting from a combination of design decisions, budget deficiencies, and technological constraints during Cycles 1 and 2. The needs have a wide range of importance and are not listed in priority order.

- Reservoirs and lakes were not assessed.

- Few source-water intakes were directly monitored—the design was oriented toward characterization of ambient stream waters, with inference or extrapolation to particular intakes.
- Contaminants not extensively assessed in surface water (not at all or only in limited, selective studies) including: (1) many pesticides and their degradates and adjuvants, (2) numerous additional unregulated organic contaminants, including high production volume chemicals (HPVs), and pharmaceuticals, (3) disinfection by-products (DBPs), (4) algal toxins, (5) microbial contaminants (including pathogens), and (6) many types of contaminant mixtures.
- Finished water was assessed for only a small subset of sampled public systems
- Gradual erosion of geographic and temporal coverage of the surface-water status and trends monitoring network has reduced the reliability and completeness of ambient stream quality.

NAWQA's Role in Cycle 3

The Cycle 3 design for assessing the status and trends of contaminants in surface-water sources of drinking water focuses on (1) assessing the quality of present and potential future source waters, including potentially important new or previously unrecognized environmental contaminants, (2) identifying contaminants of potential human-health significance, (3) limited monitoring of lakes and reservoirs used for drinking water supply, (4) evaluating trends with a particular focus on contaminants of greatest concern, and (5) relating observed status and trends to natural and human factors that cause observed conditions.

Planned Outcomes:

- Enhanced and updated occurrence and distribution assessments for present and potential future source waters, which:
  - Build upon previous assessments by updating and expanding target contaminants (based on guidance from NTAS work group).
  - Expand scope of assessment to include 50 lakes and reservoirs that are current or potential supplies of drinking water.
  - Improve geographic coverage of contaminant monitoring for streams and rivers to increase the reliability of assessments for the most important present and future source-water intakes (importance determined by balancing vulnerability to contamination against population served).
  - Improve statistical models that extrapolate contaminant occurrence in streams, rivers, lakes, and reservoirs used for public supply based on watershed characteristics, chemical use, and other relevant ancillary data.
  - Regular (annual and five-year summaries) of water-quality data via the web and online reports.
- Targeted assessments of relations between source and finished water quality.
- Assessment of water-quality trends for selected contaminants in source waters and at intake sites for the duration of Cycle 3 featuring improved tracking of the most critical contaminants in important surface-water supplies.
- Periodic national reports on the status and trends of source water quality.

Approach:

Overview

This objective will primarily be addressed through expanded data collection conducted at National Fixed Site Network sites, and to a lesser extent, data from Regional Synoptic Studies, and data from other agencies. Table 3.1 lists elements of the proposed monitoring strategy, including sampling frequency and parameters to be monitored continuously.

Table 3.1 Sampling strategy for National Fixed Site Network [Temp = temperature; DW = drinking water; P = possibly]

Site Type	Number of Sites	Sampling Frequency (samples/year)	Continuous Water Quality Monitoring Parameters				
			Streamflow	Temp	Specific Conductance	Turbidity	Dissolved Oxygen
Ambient Large River	124	18	Yes	Yes	Yes	Yes	Yes
Ambient Wadeable Stream	107	26	Yes	Yes	Yes	Yes	Yes
Stream or River DW Intake	20	18	Yes	Yes	Yes	Yes	Yes
Lake or Reservoir DW Intake	50	12	P	P	Yes	No	No

In addition to an upgraded network of ambient stream and river monitoring sites, new monitoring components required to assess the suitability of surface-water sources for human use include a sub-network of 20 stream and river sites (lakes and reservoirs dealt with separately below) that are at or near public-supply intakes. These sites would be chosen to represent intakes most vulnerable in particular regions to contaminants, based on watershed characteristics, such as agricultural or urban land development. Blended water systems would be avoided to the degree possible so that the sites are suitable for finished water comparisons (discussed further below). The 20 sites would be distributed geographically across national environmental settings (most within IWS) and weighted towards population served and greatest exposure to contaminants. Site selection will need to balance distribution of sampling sites across a gradient of system size and vulnerability to contamination while also filling critical needs in the NFSN with respect to geography, environmental setting, and stream size.

To more fully assess a key source of the Nation's drinking water, NAWQA will create a new network of 50 lake and reservoir sites at intakes used for public-supply. The focus will be on monitoring intake water quality (1 site per supply reservoir) with a subset of 10-25 percent of sites selected for source-water/finished-water comparisons (see below). These studies will be strictly focused on water-quality monitoring and will not involve detailed studies of reservoir dynamics. Site selection criteria will be similar to those described for stream sites above with the exception that 10 reservoirs in relatively undeveloped watersheds will included in the monitoring design (see fig 2.4).

Regional synoptic studies, in which a selected set of contaminants are targeted for sampling during specific periods of interest (e.g. application periods, specific climatic or hydrologic conditions, etc.), may also be conducted to fill spatial or temporal occurrence and distribution needs.

Note that variable sampling frequencies at different site types reflect different requirements for characterizing contaminant concentrations over the annual hydrologic cycle. For example, weekly sampling of small (wadeable) streams over several months is required to fully characterize the concentrations of pesticides during spring application periods.

Contaminant Coverage

Proposed contaminant coverage for this objective by site type is given in Table 3.2 and is based on data needs for this and other Cycle 3 objectives. The proposed addition of new or emerging contaminants to Cycle 3 monitoring for this objective is based on recommendations from the NAWQA Target Analyte Strategy (NTAS) work group (*see sidebar on next page*) and is subject to having approved analytical methods and adequate funding. A key step will be continued development of (HBSLs; Toccalino, 2007) for any new contaminants added to NAWQA analytical schedules. This is critical for assessing which contaminants are of greatest concern and will be done in collaboration with USEPA.

Table 3.2 Water-quality constituents or contaminant groups to be monitored for characterizing surface-water quality for human health [DW-drinking water]

Site Type	Water Quality Constituents to be Monitored								
	Major Ions	Nutrients (N, P, C)[a]	Suspended Sediment[a]	Pesticides	Volatile Organic Compounds[b]	Human and Veterinary Drugs[c]	Semi-Volatile Organic Chemicals[d]	Algal Toxins	Pathogens[e]
Ambient Large River	✓	✓	✓	✓		✓	✓		✓
Ambient Wadeable Stream	✓	✓	✓	✓		✓	✓		✓
Large River DW Intake		✓		✓	✓	✓	✓	✓	
Lake or Reservoir DW Intake		✓		✓	✓	✓	✓	✓	

[a] Nutrient and sediment monitoring at ambient stream and river sites reflects monitoring requirements for Goal 1 Objectives 1f and 1g.

[b] Covers volatile organics, selected high production volume chemicals and disinfection by products of potential human-health concern per findings of the NTAS work group.

[c] Covers pharmaceuticals, antimicrobials, and hormones of potential human-health concern per findings of the NTAS work group.

[d] Covers wide variety of trace organic chemicals including compounds found in personal-care products, detergents, flame retardants, and other organic contaminants of potential human-health concern per findings of the NTAS work group. Although some compounds may be of natural origin most are associated with household, industrial, and agricultural waste and wastewater.

[e] Pathogen monitoring is proposed for a subset of the NFSN sites under Objective 1c.

Use of continuous monitoring technology that yields real-time water quality information for basic parameters such as temperature, specific conductance, dissolved oxygen, turbidity, and other related constituents is an integral feature of the NFSN monitoring design. Data from such monitoring will provide information regarding short-term (minutes to days) responses of water-quality to hydrologic, climatic, or human influences and will provide an improved understanding of cause-and-effect relations and will provide time-dense data for the development of transient water-quality models.

Expand compilation and analysis of non-USGS data

NAWQA will continue to selectively compile and analyze non-USGS data collected by the States and other organizations to improve spatial coverage of both regulated and unregulated contaminants relevant to human use of water. An important step will be to improve tracking of new data from ongoing monitoring efforts. Such tracking will benefit from improved methods of data sharing being developed by USGS, USEPA, and the States. Such data will be critical for working with the USGS WaterSMART Program to produce assessments of water availability relative to water quantity and quality in selected parts of the country.

NAWQA Target Analyte Strategy

A high priority for many stakeholders is for NAWQA to assess new or previously unrecognized contaminants that are currently unregulated and yet pose a threat to humans or aquatic ecosystems. Emerging contaminants include, but are not limited to pharmaceuticals, antimicrobials, personal care products, algal toxins, newly introduced pesticides and high-use industrial chemicals, various breakdown products, and selected microbial contaminants. Recognizing a need to weigh the addition of new contaminants against the need to continue monitoring of current NAWQA contaminants as well as a need to upgrade NAWQA's existing analytical portfolio the Cycle 3 Planning Team established a NAWQA Target Analyte Strategy (NTAS) work group in Spring 2009. The NTAS work group was instructed to provide recommendations regarding:

- which current NAWQA contaminants should continue to be monitored,
- which contaminants could be dropped from laboratory schedules used by the NAWQA Program, and
- which emerging contaminants should be added, considering the current understanding of the national importance of different contaminant groups to Cycle 3 assessment activities

The NTAS work group was initially tasked with prioritizing current NAWQA analytes and candidate contaminants in water and sediment (an evaluation of priority contaminants in fish tissue is ongoing) with a focus on trace organics and trace elements Microbial contaminants were evaluated separately. Several thousand candidate contaminants in known to partition in either water or sediment were evaluated: prioritization of contaminants was based on:

- Relevance to human or aquatic ecosystem health based on toxicity data, human or aquatic health benchmarks, or other documented or suspected health effects noted in the scientific literature,
- Actual or predicted occurrence in the environment at concentrations approaching or exceeding health benchmarks based on existing data, chemical use information, physiochemical properties, or literature reports,
- Other agency priorities such as a compound's presence on the USEPA Contaminant Candidate List 3 (CCL-3) or the Unregulated Contaminant Monitoring Rule (UCMR) list.

After prioritization was complete, NTAS, in collaboration with the Cycle 3 Planning Team, research chemists at the National Water Quality Laboratory, and scientists from the USGS Toxics Substances Hydrology Program produced a plan for upgrading existing methods and developing new ones for the highest priority contaminants.

Information regarding the contaminants evaluated, their priorities within specific contaminant groups, and the methods used to develop the NTAS recommendations will be made available at:

ftp://ftpext.usgs.gov/pub/cr/co/denver/NAWQA%20Cycle%203%20Science%20Plan/

Continue highly selective and targeted comparisons of source and finished water

At a subset of source-water sites (10- 25 percent of all monitored public supply intakes) conduct source-water/finished-water comparisons. Site selection will focus on the most contaminated source waters in a variety of environmental and land-use settings based on an initial round of source-water sampling. Subject to the above constraints, sites serving the largest number of people will be targeted.

Critical Requirements for Technical Support and Data Support

An initial design requirement for this objective will be a reliable analysis, which is currently underway, done in collaboration with USEPA and water suppliers, of the locations of water supply intakes and the boundaries of their watersheds. Reliable data on surface water-quality conditions in candidate streams, rivers, lakes, and reservoirs considered for drinking-water studies will be needed from states, water utilities, and USEPA. For the lake and reservoir studies data and analysis of the physical characteristics of supply reservoirs, such as volume, flushing rate, and seasonal mixing and turnover characteristics will be needed for site selection. Finally, continued development of appropriate statistical and process-based water-quality models to support source and transport analysis (as covered in Chapter 4) will be needed to extrapolate occurrence and distribution data to unmonitored areas.

Objective 1b: Determine mercury trends in fish tissue

NAWQA Progress during Cycles 1 and 2

Substantial progress was made during Cycle 1 on assessing levels of organic contaminants in whole fish (~1000 sites sampled nationally), resulting in national assessments that include statistical extrapolation models for key individual contaminants. However, trace elements, including mercury, were assessed in fish livers and other organisms such as Asiatic clams, which is difficult to relate to human consumption issues. From 1998 through 2005, NAWQA and the Toxics Substance Hydrology Program collaborated on a national reconnaissance study of mercury in streams, streambed sediment, and fish fillets at approximately 300 locations (Scudder and others, 2009). Explicit monitoring of mercury trends in fish was not design feature of Cycle 2; however, progress was made in assessing the sources and factors that control mercury accumulation in water, streambed sediment, and fish in selected watersheds across the country (Brigham and others, 2009; Marvin-DiPasquale and others, 2009; Chasar and others, 2009). A recent retrospective analysis of fish mercury data collected by State and Federal agencies found, that out of several thousand locations where fish mercury samples had been collected, only about 60 sites had enough consistent, long-term data for trends evaluation (Chalmers and others, 2010).

Information needs not addressed during Cycles 1 and 2

Information needs noted below include those resulting from a combination of design decisions, budget deficiencies, and technological constraints. The needs have a wide range of importance and are not listed in priority order.

- Lack of nationally consistent monitoring program to assess trends in fish-tissue mercury and by implication, trends in atmospheric mercury caused by reductions related to policy changes
- Contaminants not extensively assessed in fish tissue
- Cycle 1 assessments of Hg were based on whole fish or livers, emphasizing the use of fish as sampling media or wildlife food sources, rather than as human food sources.
- Resampling of Cycle 1 tissue sites for trend analysis has not been conducted.

NAWQA's Role in Cycle 3:

NAWQA's appropriate role with respect to addressing potential concerns with human consumption of contaminated fish is to build on existing regulatory monitoring of edible fish tissues, as well as the USEPA National Fish Contaminants Survey, to address information needs that are most critical to long-term protection of human health from contaminants that bioaccumulate in fish. Given that USEPA and the States monitor contaminants responsible for consumption advisories, and that an extensive assessment on a wide range of contaminants in fish of lakes, rivers, and coastal waters is being done by USEPA as part of the National Aquatic Resource Surveys Program, NAWQA will focus on trends in mercury concentrations in fish in Cycle 3. Nationally consistent long-term monitoring of trends in mercury is an important information gap that is not being addressed by others, yet such monitoring will be critical for evaluating the effectiveness of regulatory control strategies for mercury. As Cycle 3 progresses, and if other priorities emerge, other contaminants may be added to assessments. Monitoring of various contaminants in fish tissue may be included in some studies for Goal 3 objectives for evaluating ecological effects of contaminants on fish health.

Planned Outcomes:

- Annual updates reported on the web of trends in mercury in fish tissue in a set of watersheds that represent a range of mercury deposition and methyl-mercury production rates.
- Provide a substantial investment in the proposed national mercury monitoring network (MERCNET; see URL: http://nadp.sws.uiuc.edu/mercnet/).

Approach

Overview:

The basic approach is to monitor Hg concentrations in fish in a network of stream and river sites annually over the duration of Cycle 3. Site selection will be based on the extent and quality of historic data and coverage over a range of watershed characteristics that have been shown to be important in methyl-mercury production and bioaccumulation in fish consumed by humans such as Hg deposition rates, percent wetlands, organic carbon in streambed sediment, dissolved sulfate, and pH. Candidate sites would include NFSN sites, USGS Biomonitoring of Environmental Status and Trends and National Contaminant Biomonitoring Program sites, and NAWQA lake-coring sites. The total number of sites to be monitored would range from 100 to 200 sites, with minimum 25 percent overlap with NFSN sites, especially those selected for ecosystem trends monitoring. Hg trend sites would be sampled annually and would sample one or more targeted fish species that represent the top predator sport fish that fall within a defined age range. At sites lacking predator sport fish, other species may be used as an indicator species.

Expand compilation and analysis of non-USGS data

NAWQA will continue to selectively compile and analyze non-USGS data collected by the States and other organizations on Hg in fish tissue. The primary reason to do so is to improve spatial and temporal coverage Hg concentrations in fish tissue.

Critical Requirements for Technical Support and Data Support

A key ancillary data need is to improve current geographic and factual information on state-level monitoring programs. Finally, there is a need to continue work on improving data sharing and infrastructure to allow for more efficient and collaborative aggregation of state, Federal, and tribal fish Hg monitoring data.

Objective 1c: Determine distributions and trends for microbial contaminants in streams and rivers used for recreation

NAWQA Progress during Cycles 1 and 2

Although indicator bacteria were collected at NAWQA stream and river sites in Cycle 1 the data were never synthesized at the national level and only a few Cycle 1 study units issued reports to describe the indicator organism data sets that were collected. Recommendations given in Francy and others (2000a) were not implemented because of funding constraints although a pilot effort to evaluate the occurrence of several indicator organisms in streams and groundwater for the proposed Cycle 2 monitoring program was conducted in the latter part of Cycle 1 (Francy and others, 2000b).

Information needs not addressed during Cycles 1 and 2:

Limited monitoring was focused on sampling of traditional indicator organisms (fecal coliform, *Escherichia coli* (*E. coli*) or enterococci). Newer, molecular and polymerase-chain-reaction (PCR) techniques that provide more accurate and pathogen-specific data could not be implemented because the methods were either still in development or not approved (Cycle 1) or because NAWQA did not have the funding (Cycle 2).

NAWQA's Role in Cycle 3

Microbial contamination of water is very relevant to a national water-quality assessment program. Unlike most chemical contaminants, microorganisms cause nearly instant illness upon exposure to an infective dose and water-borne diseases from microorganisms are readily understood by most people. Water-borne disease outbreaks are relatively common in the United States as reported by the Centers for Disease Control, but not as widespread or deadly as in undeveloped countries. Beaches, lakes, and reservoirs used for recreation are heavily monitored by USEPA, the states, and local health departments. However, although many people recreate in and on rivers, few states routinely monitor streams and rivers for microbiological quality to determine suitability for water-contact recreation.

NAWQA can address three important deficiencies with respect to the microbiological assessment of streams and rivers: (1) assess the microbiological quality of streams and rivers used for body contact recreation, (2) evaluate relations between rapid and culture methods for key indicator organisms, and (3) determine if physical or hydrologic surrogates, such as turbidity or streamflow, are reliable predictors of microbial contaminants in inland streams or rivers.

Planned Outcomes:

- In streams and rivers, an assessment of the occurrence and distribution of indicator bacteria that are used as current and future measures of recreational water quality and the factors and sources that affect their distribution will be done using state of the art monitoring technology and analytical methods.
- A determination if rapid analytical methods for selected indicator bacteria are reliable substitutes for traditional culture methods. If it is shown that the new methods yield consistent results across different hydrologic and climatic settings, it is likely USEPA would recommend adoption of new rapid methods by State and local health departments tasked with monitoring recreational water quality.
- Creation and refinement of statistical models that rely on continuously measured surrogates to generate real-time predictions of bacterial concentrations and unsafe conditions in streams and rivers used for recreational activities. After development, calibration, and quality assurance, data

and regression-based estimates of microbial contaminant concentrations would be placed on the USGS Water-Quality Watch website (URL: http://water.usgs.gov/waterwatch/wqwatch) on a near real-time basis (fig 3.1)

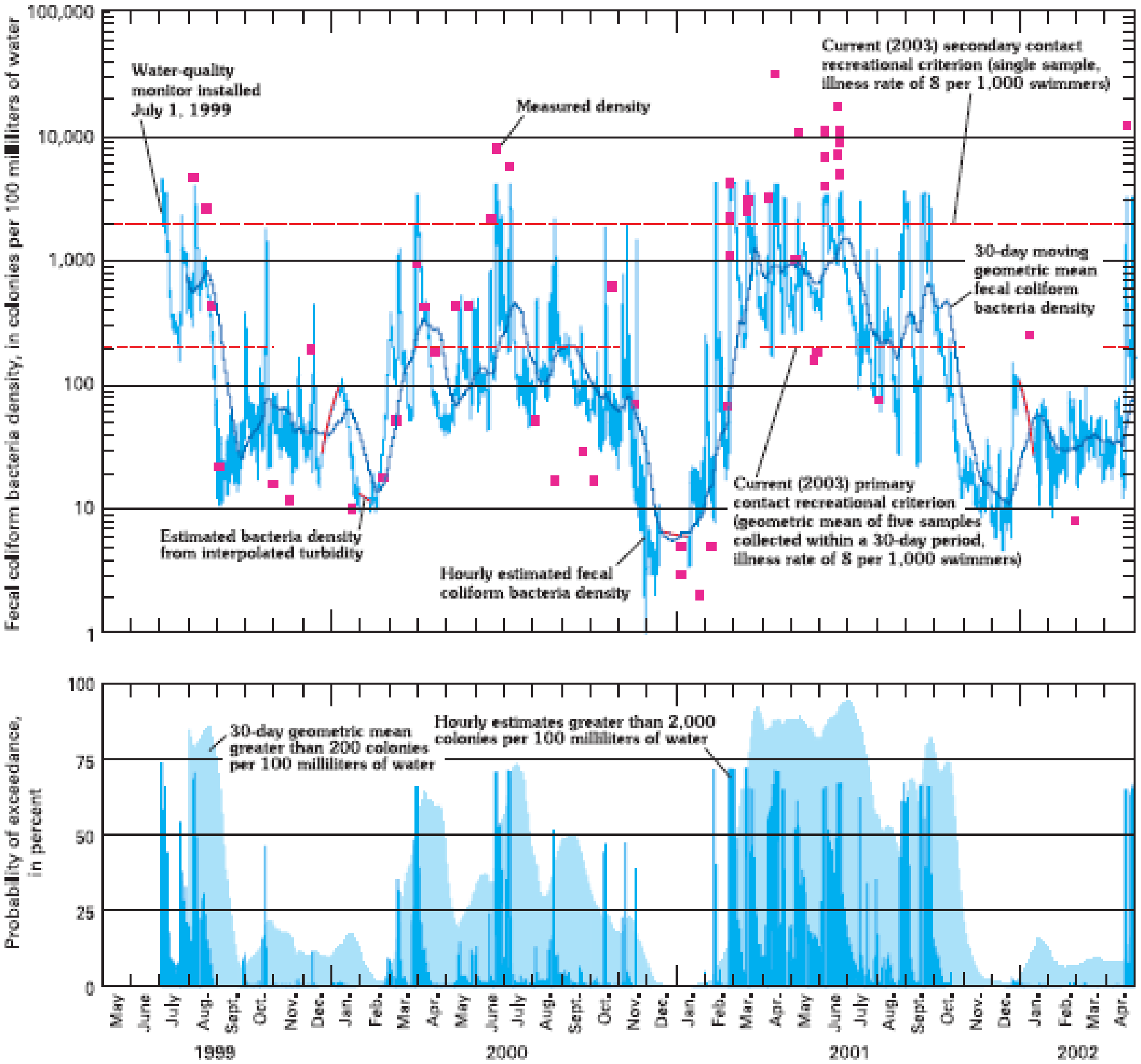


Figure 3.1. Comparison of measured and regression-estimated fecal coliform bacteria concentrations in the Kansas River at Desoto, Kansas May 1999 through April 2002 (upper plot) and the probability of exceeding recreational water-quality criteria established by Kansas Department of Health and Environment (from Rasmussen and Ziegler, 2003). Such plots are updated on a near real-time basis and made available on the web to the public via the USGS Water-Quality Watch website.

Approach

Overview

Currently advisories or closings for recreational waters are issued based on standards for concentrations of *Escherichia coli* (*E. coli*) or enterococci; these standards are based on criteria established in 1986 and include culture-based analytical methods that take too long to provide timely and accurate assessments. USEPA is required to develop new criteria that include rapid assessment methods that will start being implemented in 2012. As a result, research is being done by USEPA and others to test and standardize a rapid analytical method using quantitative polymerase chain reaction (QPCR) technology for *enterococci*. *E. coli*, and *Bacteroides* (*Bacteroides* is a bacterium abundant in the gut of warm-blooded animals and *Bacteroides* genes are often targeted for source tracking purposes). The QPCR method is a molecular method that involves expensive start-up and equipment costs and many technology-transfer obstacles, all of which USEPA is working to address. An alternate rapid method that is less costly and easier to use is immunomagnetic separation/adenosine triphosphate (IMS/ATP). USEPA and stakeholders at the state and local levels are interested in determining how well concentrations of indicators determined by rapid analytical methods compare to current culture methods as the transition to rapid methods is implemented over the next decade.

Stakeholders are also interested in developing continuous surrogates for indicators and pathogens. These methods depend on concurrent collection of ancillary water-quality and hydrologic data at the time of collection of a fecal indicator bacteria sample. Typically, fecal indicator bacteria concentrations have been found to be correlated with turbidity and discharge in streams, and several states now use these relations to predict when water is safe for recreational contact (fig. 3.1). Routine NAWQA sampling of multiple water-quality parameters is an excellent foundation for developing surrogate relations and potentially establishing simple regression models that link one or more surrogate measures with indicator bacteria concentration.

The monitoring approach will involve sampling a subset of 75 NFSN sites for key indicator bacteria using both traditional culture and new rapid analytical methods. Site selection criteria will include broad geographic coverage, variety of land-use types and sources of fecal contamination, different climates and watershed sizes, and the capability of study units to perform the specialized sampling. NFSN sites that represent streams or rivers designated for recreational activities will be included in the monitoring design as well as sites not designated as formal recreational sites (because many of these sites, especially wadeable streams, are used for recreation by children and others). Twenty-five of the 75 sites selected will be sampled 14 times per year over a three-year period, followed by rotation to 25 new sites. Sites will be sampled on an approximately monthly schedule with more intensive sampling from May through September with collection of two additional rain-event samples.

Contaminant Coverage

The indicator bacteria *E. coli, enterococci*, and *Bacteroides* (general*) species* will be determined by traditional membrane filtration culture techniques. *E. coli,* and *enterococci* will also be determined by QPCR and IMS/ATP rapid methods, whereas *Bacteroides* (human marker) will be done by QPRC only.

Critical Requirements for Technical Support and Data Support

Methods for *Bacteroides* (general*)* and *Bacteroides* (human marker) *species* by QPCR and for *E. coli,* and *enterococci* by QPCR are still being developed and will require approval prior to the start of fiscal year (FY) 2013 if they are going to be used in Cycle 3. Some of the methods development work is being done by USEPA and publication of an approved method by USEPA by FY 2013 is anticipated (*E. coli,* and *enterococci* by QPCR). Both rapid methods for *Bacteriodes species* will require approval by the USGS Office of Water Quality. Training of field crews on how to collect and process microbiological samples may also be needed.

Objective 1d: Determine the distributions and trends of contaminants of concern in aquifers needed for domestic and public supplies of drinking water.

NAWQA Progress in Cycles 1 and 2

In Cycles 1 and 2 NAWQA analyzed groundwater samples for both regulated and unregulated contaminants of potential human health concern using laboratory methods that provide low-level detections, often at concentrations orders of magnitude below regulatory thresholds. To place observed concentrations in a human-health context, data were compared to human-health benchmarks, either USEPA maximum contaminant limits (MCLs) for regulated contaminants or HBSLs for selected unregulated contaminants (mainly organic compounds). NAWQA also collected samples for various hydrologic tracers (stable isotopes), indicators of groundwater age (trace gases and radioisotopes) or indicators of geochemical conditions (pH and dissolved oxygen). These constituents provide a basis for interpreting the hydrologic and geochemical processes that affect groundwater quality and for tracing sources of contaminants derived from human activities.

NAWQA focused mostly on sampling shallow monitoring wells and domestic wells in Cycles 1 and 2, thus providing coverage for parts of the groundwater system (shallow) and user population (private domestic wells) that are not otherwise monitored (or regulated) on a systematic basis nationally. Both domestic wells and public supply wells were sampled at the point of extraction and prior to treatment rather than sampling at the tap, thus providing a direct assessment of the ambient groundwater resource.

Cycle 1 groundwater monitoring networks were implemented at multiple scales within the context of Study Units (52 SUs). Major Aquifer Studies (MAS), ~1000 km^2 to >100,000 km^2) were designed to provide a broad assessment of groundwater quality in areas with relatively similar geologic, hydrologic, and climatic conditions. Nationwide, groundwater samples were collected from about 3000 wells (~2000 domestic, ~500 public supply, and ~500 other well types, mostly irrigation) in about 100 MAS networks. Land-use studies (LUSs, ~100 km^2 to >1,000 km^2) were nested within MASs, and were designed to assess relations between shallow groundwater quality and overlying land use. About 2700 wells (primarily observation wells) were sampled in about 110 agricultural and urban land-use networks. Flow-path studies were designed to evaluate the hydrologic and geochemical processes affecting groundwater quality along a presumed flow path and were typically implemented at relatively short length scales (1-10 km). About 650 observation wells, installed in shallow to moderate depth well clusters, were sampled in about 40 FPS networks, most of which were nested within LUS networks. Additional wells, including reference wells, were sampled by Study Unit teams for various purposes to complement the MAS, LUS, and FPS networks.

In Cycle 2, 26 new MAS networks (~780 wells) and 18 new LUS networks (~540 wells) were sampled to fill spatial or specific land-use gaps, including areas outside of previously defined Study-Unit boundaries. Similar to surface water, studies of ambient groundwater quality were augmented by Source-Water Quality Assessments that involved sampling of selected groundwater supplies for about 280 organic contaminants, including analysis of both source and finished drinking water, to assess occurrence patterns in source water and to determine if these patterns also occurred in treated drinking water prior to distribution. For each groundwater system evaluated (about 30), samples were obtained from 15 high-volume supply wells.

In contrast to the significant reductions in number of sites operated and samples collected incurred by the NAWQA surface-water network, the number of groundwater networks sampled in Cycle 2 for status and trends assessments has largely adhered to the original implementation plan developed by Gilliom and others (2001). However, synthesis of status and trends data in Cycle 2 is being done at the Principal Aquifer (PA) scale with synthesis efforts focused on 19 of 62 principal aquifers (Lapham and others, 2005). The PA-scale assessments are based mostly on analysis of data from Cycle 1 MAS, LUS, and FPS networks, and results from Cycle 2 Source-Water Quality Assessments (preceding paragraph) and Transport of Anthropogenic and Natural Contaminant (TANC) large-scale studies.

With respect to groundwater trends, in Cycle 2, NAWQA resampled 33 MAS networks and 33 LUS networks (approximately 2000 wells) for the purposes of monitoring trends on a decadal time scale. Results of the first round of decadal-scale resampling focused on trends in nitrate and pesticides and pesticide degradates. Findings show significant increases in nitrate concentrations over the last 10-15 years, mainly in agricultural areas (Rupert, 2008). Detection frequencies of six frequently detected herbicides did not change; however, small but statistically significant decreases were observed in concentrations of two of the herbicides (atrazine and prometon) and one herbicide degradate (deethylatrazine) (Bexfield, 2008). Patterns in nutrient and pesticide concentrations over time generally reflect overall trends in fertilizer and pesticide use. Six Cycle 1 FPS networks were also resampled to assess changes in groundwater quality along a known flow path where rates of flow and contaminant loading to the local aquifer were known. Changes in recharge-water quality over the decadal time periods at the FPS sites generally reflected changes in land and chemical use at the local to regional scale (Rosen and others, 2008).

A subset of wells (5) from each of the LUS and MAS trends networks were selected for quarterly and biennial trends sampling in Cycle 2. Quarterly sampling was conducted for one year at a subset of 100 biennial trend wells. Rosen and others (2008) found that quarterly sampling over a one-year period was ineffective for assessing seasonal effects on groundwater quality. Based on this finding, the decision was made in mid-Cycle 2 to drop quarterly monitoring and devote the quarterly monitoring funds to increased groundwater age-dating and flow modeling. An evaluation of trends using the biennial data collected during the course of Cycle 2 has yet to be completed and it is not known how much information will be provided by the six samples (four biennial samples collected between the two decadal samples) regarding intra-annual variability in groundwater quality caused by year-to-year changes in climate, human activities, and contaminant loading.

Information needs not addressed during Cycles 1 and 2

- Spatial gaps from the perspective of Principal Aquifers: with few exceptions, Cycle 1 and 2 groundwater networks were located entirely within study-unit boundaries.
- Depth gaps – in many areas, NAWQA has adequately characterized water quality in shallow recharge areas and the depth zone used for domestic supply but the Program has not broadly assessed groundwater quality in the depth zone used for public supply.
- Contaminant gaps: Selected regulated and unregulated contaminants including anthropogenic organic chemicals (for example, pharmaceuticals, wastewater and HPV organics, radionuclides, and selected microbial pathogens.
- Ancillary data necessary to interpret changes in water quality at various scales (local, regional, national) if often lacking, especially at the temporal scales need to explain trends at the local and regional levels.

- A weakness of the decadal-scale resampling approach to analyzing trends in groundwater quality is that the hydrogeologic position of the wells in the local or regional flow system often isn't known, especially in the MAS networks. Knowing where the wells and networks are located with respect to local and regional flow systems would allow for a more informed interpretation of trends, or the lack thereof.
- Some insight into the relative hydrogeologic position of a well or network of wells is gained by age-dating groundwater. NAWQA made a conscious effort to collect as many age-dating samples as the program could afford in Cycle 2 at resampled trend networks. However, some gaps in age-dating coverage in existing networks still exist.
- To determine the validity of statistically determined decadal-scale trends in groundwater quality there is a still a need to evaluate how variable groundwater quality is at shorter time scales, especially in response to seasonal or annual changes in recharge, discharge, or contaminant loading.

NAWQA's Role in Cycle 3:

Given the importance of groundwater as a source of drinking water, it is vital for NAWQA to continue assessing groundwater quality in the principal aquifers considered most critical for domestic and public supply. This includes evaluating the occurrence, concentration and distribution of contaminants in groundwater using a monitoring design that captures the most relevant portions of the used resource. Cycle 3 groundwater assessments will focus on that part of the resource that is or potentially will be used for drinking-water supply, as the quality of groundwater used for drinking water is the highest priority from a human-health perspective.

With respect to changes in groundwater quality over time NAWQA is the only national-scale program that is evaluating trends in groundwater quality. Because groundwater residence times range from years to decades to millennia, changes in groundwater quality caused by either natural factors such as climate change, or human activities on the land surface, may not be reflected in changes in groundwater quality for years, decades, or longer. On the other hand, more rapid shifts in climate and human-induced changes in contaminant loading could accelerate changes in groundwater quality and it will be important to document those changes with data so models developed for extrapolation, forecasting, and scenario testing under Goals 2 and 4 can be calibrated and validated.

NAWQA's role in Cycle 3 is to (1) collect enough data to support development of predictive models at a range of temporal and spatial scales, (2) use flow models and other approaches to develop a better understanding of the hydrogeologic position of NAWQA wells and networks, (3) to assess the range of expected residence times and their relation to changes in key stressors that affect groundwater quality to better understand groundwater trends, and (4) selectively add new contaminants of potential human health concern when resampling trend networks to better evaluate their distribution in key water-supply aquifers and establish a foundation for future trends monitoring.

Planned Outcomes:

- Enhanced and updated occurrence and distribution assessments for present and potential groundwater sources of supply, which:
  - Build upon previous assessments by updating and expanding target contaminants (based on guidance from NTAS work group).
  - Improve spatial and depth coverage of key contaminants at the local to national scale.

- Exceedance maps produced by combining data generated under this objective with the modeling described in the Goal 2 chapter will be key product for Cycle 3 (see fig 3.2).
- Assessment of relations between groundwater quality, contaminant sources, and selected natural and human factors, such as climate and human activities at the land surface.
- Periodic national or regional reports on the status and trends of selected contaminants in groundwater from domestic and public supply wells.
- Regular, web-based reporting of trends in groundwater quality at scales ranging from individual networks, principal aquifers, and the Nation.
- Development of an Enhanced Trend Network (ETN) whose purpose is to provide short and long-term groundwater-quality trend information to the Nation in key hydrologic settings.
- Production of data sets that can be used to validate coupled groundwater flow and solute transport models used for extrapolation and forecasting.

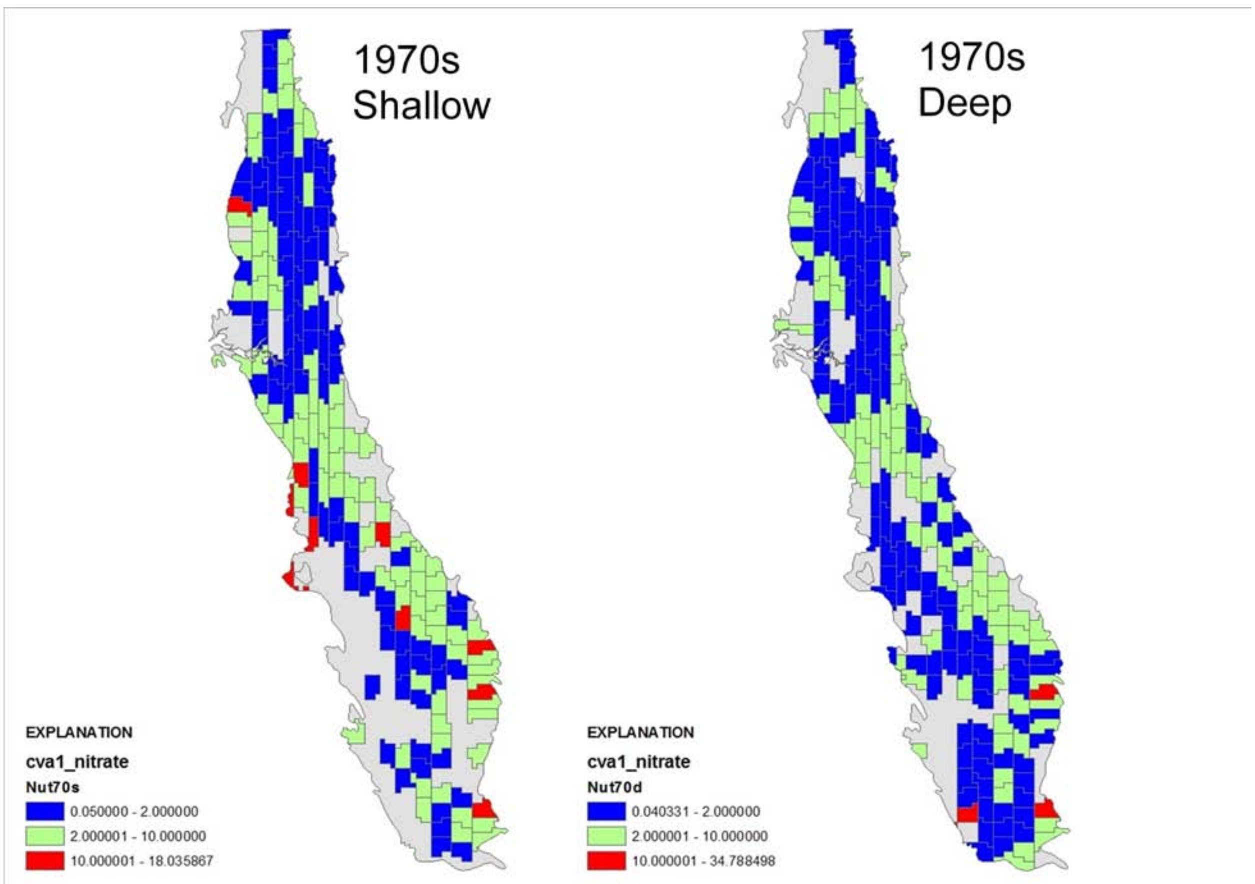


Figure 3.2. Nitrate exceedance maps for California's Central Valley Principal Aquifer based on nitrate samples collected in the 1970s. The map on the left shows the nitrate exceedance distribution based on data from shallow (mostly domestic supply) wells screened at depths less than 240 feet below land surface. The map on the right shows the nitrate exceedance distribution for deep (mostly public supply) wells that are screened at depths greater than 240 feet. Grid cells in red exceed the USEPA Maximum Contaminant Level (MCL) for nitrate of 10 milligrams per liter. The maps were created by using an equal area grid for the entire aquifer, compiling nitrate data from local, State, and Federal agency databases (approximately 21,000 wells), and by

partitioning available data for wells in the grid cells by decade (Karen Burow, U.S. Geological Survey, written communication, September 2010).

Approach

Overview

Within the context of a given Principal Aquifer, groundwater quality can vary as a function of position relative to the sources of recharge and/or relative to the areas of discharge; for the purposes of analysis, one can refer to this as hydrologic position. In turn, hydrologic position can be defined with respect to lateral location – for example proximal, intermediate or distal – and with respect to depth. From a depth and water-use perspective, the groundwater resource used for drinking water can be divided into two depth intervals: the depth zone pumped mostly for domestic supply and the zone primarily pumped for public supply. In some areas of the Nation, the two depth intervals overlap or coincide, and in other areas, the interval used for public supply is substantially deeper than the interval used for domestic supply. Two additional depth intervals can be defined: shallow groundwater (depth interval above the interval used for domestic supply) and deep groundwater (depth interval below the interval used for public supply.

Existing NAWQA networks (MAS, LUS) and a new network type, Principal Aquifer Surveys (PAS), will be used to characterize groundwater quality with respect to depth and hydrologic position in individual aquifers. PAS will consist primarily of public supply wells screened at depths typical of the zone tapped for public supply. PAS will follow the stratified random design used for MAS networks but the size of the area covered and number of wells sampled will be larger than a typical MAS network depending on water use patterns, the availability of non-USGS data to fill spatial and depth gaps, and the desire to increase coverage with respect to hydrologic position.

Principal aquifers will remain the primary organizational and design unit for Cycle 3 groundwater assessments. As discussed in Chapter 2, the plan is to assess groundwater quality in 24 of the 62 most important aquifer systems of the Nation based on water use for domestic and public supply, overall water use and population served, environmental setting, and relative vulnerability to contamination at varying levels of intensity. Where possible, NAWQA assessments will be done in collaboration with the USGS Groundwater Resources Program (GWRP) where the GWRP has built, or is building regional groundwater flow models. The goal of the collaboration will be to produce water availability assessments that combine NAWQA information on the quality of groundwater for human use with GWRP information on the quantity of groundwater available in the aquifer.

A major component of the Cycle 2 trends design that will be retained for Cycle 3 is decadal-scale resampling of FPS, LUS, and MAS networks (90 networks; see Table 3.3 for breakdown by network type). This represents an increase of 10 networks over the 81 trend networks resampled in Cycle 2; the increase in the number of trends networks reflects the addition of new networks during Cycle 2. However, existing groundwater age information and flow modeling results will be used to evaluate existing trend networks to determine if decadal-scale resampling of entire networks is warranted or if a reduction in the number of resampled wells should be considered. Biennial-well sampling, which began in Cycle 2 will continue through Cycle 3 in order to obtain information on the magnitude of year-to-year variability in groundwater quality relative to observed decadal scale trends.

A new monitoring component proposed for Cycle 3 is the Enhanced Trend Network (ETN) which will consist of 100 wells distributed across the 20 of the most important PAs, with an approximate distribution of five wells per PA. These wells would sampled bi-monthly over three, two-year periods (this equates to 12 discrete samples over two years—11 bimonthly samples plus one biennial sample). The wells would be equipped with data sondes capable of monitoring temperature, specific conductance, and water level; these sondes would be operated continuously over Cycle 3 to provide basic information on how the well is responding to human and natural factors. The continuous data will also be used to place the discrete bimonthly water-quality samples in a hydrologic context.

Numbers of networks and wells

A summary of the approximate number of networks, wells, and groundwater samples that would be included in the Cycle 3 assessment of the status and trends of the Nation's groundwater resources is as follows:

Table 3.3 Approximate Number of Cycle 3 Groundwater Networks and Wells

Network Type	Number of New Status Networks	Number of Trends Networks	Average Number of Wells per network	Total wells sampled	Total number of decadal samples	Total number trend (biennial or bimonthly) samples	Total number samples
Flow-Path Study	15	20	20	700	700	400	1100
Land-Use Survey (agricultural, urban)	15	40	30	1650	1650	800[c]	2450
Major Aquifer Survey	15	30	30	1350	1350	600[c]	1950
Principal Aquifer Network	55	0	50	2750	2750	--	2750
Finished water	--	--	--	*450*[b]	450	--	450
Enhanced Trend Network	--	*20*[a]	5	*100*[a]	--	3300[d]	3300
Totals	**100**	**90**	**- -**	**6450**	**6900**[e]	**5100**	**12000**

a Enhanced trend networks/wells not included in column totals; they are a subset of trends networks/wells.

b Finished water samples not included in column total; samples will be collected at wells that are within other networks: primarily new MAS or PAS.

c Biennial sampling: (5 wells per network) x (4 biennial samples) = 20 samples per trend network.

d Eleven bimonthly samples per two-year cycle (+ one biennial sample); three, two-year cycles; 6 years of data per well.

e 3,950 of the wells represent sampling of previously un-sampled wells in new networks and the remaining 2,950 represent decadal-scale resampling of wells in Cycle 2 trend networks.

Contaminant Coverage

Proposed contaminant coverage for this objective by network type is given in Table 3.4 and is based on data needs for this and other Cycle 3 objectives. The proposed addition of "new contaminants" to Cycle 3 monitoring for this objective is based on potential human health concerns identified by the NTAS work group and is subject to having approved analytical methods and adequate funding. A key step will be development of HBSLs, where possible, for any new unregulated contaminants that are to be monitored. This will be a key step in assessing which contaminants are of greatest potential concern and will be done in collaboration with the USEPA Office of Water.

Table 3.4 Water-quality constituents or contaminant groups to be monitored for characterizing groundwater quality for human health [P-indicates this class of contaminants will potentially be included in this network depending on study objectives, environmental setting, and funding constraints]

Network Type	Water Quality Constituents to be Monitored									
	Geochemical Indicators[a]	Age-Dating Tracers[b]	Major Ions and Nitrate	Trace Elements	Pesticides	Volatile Organic Compounds[c]	Human and Verterinary Drugs[d]	Semi-Volatile Organic Chemicals[e]	Radionuclides[f]	Pathogens[g]
Flow Path Study	✓	✓	✓	P	✓	P	P	P	P	P
Agricultural Land-Use Study	✓	✓	✓	P	✓		P		P	P
Urban Land-Use Study	✓	✓	✓	✓	✓	✓	✓	✓	P	
Major Aquifer Survey	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Principal Aquifer Network	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Finished Water Samples					✓	✓	✓	✓		
Enhanced Trend Network	✓[h]		✓							

[a] Geochemical indictors include basic water-quality properties such as temperature, specific conductance, pH, and indicators of redox condition such as dissolved oxygen.

[b] One or more potential age-dating tracers including tritium, tritium-helium-3, chloroflurocarbons (CFCs), and other trace atmospheric gases will be used to estimate the apparent recharge age of the water sample.

[c] Covers volatile organics, selected high production volume chemicals and disinfection byproducts of potential human-health concern per findings of the NTAS work group.

[d] Covers pharmaceuticals, antimicrobials, and hormones of potential human-health concern per findings of NTAS work group.

[e] Covers wide variety of trace organic chemicals including compounds found in personal-care products, detergents, flame retardants, and other organic contaminants of potential human-health concern per findings of the NTAS work group. Although some compounds may be of natural origin most are associated with household, industrial, and agricultural waste sources.

[f] Radionuclides of human health concern including uranium, radon, radium, lead and polonium. Selected radioisotopes would be assessed in aquifers where they were known or suspected to occur at levels approaching human health benchmarks.

[g] A subset of PAS supply wells (600 wells over course of Cycle 3) will be sampled for key microbial indicator organisms in vulnerable aquifer systems. Indicator organisms to be analyzed include total coliforms, E. coli, enterococci, somatic and F-specific coliphage, enteric viruses, and bacillus spores.

[h] Enhanced Trend Network wells would be equipped with transducers/data sondes for continuous measurement of water level, temperature, and specific conductance.

Resampled MAS and LUS trend networks will be sampled for the contaminant groups sampled in previous NAWQA Cycles; additional contaminants groups may be sampled to establish a baseline for future trends monitoring of previously unmonitored constituents or contaminant groups (Table 3.5). Trends wells that have not been sampled for groundwater age tracers will be sampled for those tracers in Cycle 3. This strategy applies to biennial trends wells although they will not be resampled for age tracers on a biennial basis. Bimonthly samples collected from wells in the Enhanced Trend Network will be analyzed for major ions and nutrients.

Expand compilation and analysis of non-USGS data

NAWQA will continue to selectively compile and analyze non-USGS water-quality data collected by the States and other organizations on contaminants in groundwater, especially for commonly measured contaminants of human health concern such as nitrate, arsenic, and selected pesticides and VOCs. Such data will be critical for producing aquifer exceedance maps at various spatial and depth scales as well as filling gaps in hydrologic position analyses.

There will be a continued need for regularly updated ancillary data regarding land, chemical, and water-use information in the vicinity of the well and at larger scales. Some of this information can be collected by NAWQA but other information will require collaboration with state or local agencies to help explain short-term (seasonal, annual) trends in groundwater quality.

Continue highly selective and targeted comparisons of source and finished water

A subset of wells (450) from the PA and MAS networks will be used to conduct source-water/finished-water comparisons with a goal providing a broad national coverage in a variety of hydrogeologic settings deemed vulnerable to anthropogenic organic contaminants.

Critical Requirements for Technical Support and Data Support

Ancillary hydrogeologic data regarding recharge and discharge rates (natural and human), hydrologic position (lateral and vertical), aquifer type, mineralogy, need to be compiled for each well sampled. Data on sources (and history) of contaminants and/or surrogates for those sources (land cover) in the vicinity of each well will also need to be compiled. Although NAWQA will compile much of this data at the national level, collaboration with other Federal, state, and local agencies will be required to gather key ancillary information.

Objective 1e: Determine the distributions and trends for contaminants, nutrients, sediment, and streamflow alteration that may degrade stream ecosystems.

NAWQA Progress during Cycles 1 and 2:

Substantial progress was made during Cycles 1 and 2 on assessing the occurrence and distribution of a broad range of contaminants and nutrients in stream water and relating time- or flow-weighted concentrations to (1) current biological condition as determined by evaluating the status of algae, macroinvertebrate, and fish communities, and (2) water-quality benchmarks for aquatic life. These data supported a variety of statistical analyses that related the degree of ecosystem impairment or frequency of exceeding benchmarks with concentrations of contaminants, nutrients, and suspended sediment. Findings indicate variable degrees of correlation, with aspects of some stressors highly correlated with ecosystem impairment, albeit with substantial uncertainty because of the concurrent high degree of influence by other stressors, such as habitat degradation and streamflow alteration, as well as natural variability.

Trends in flow-adjusted concentrations of selected constituents that can impair aquatic ecosystems, including dissolved solids, nutrients, suspended sediment, and pesticides, have been analyzed using data collected at NAWQA fixed sites that are part of the surface-water trends network. Flow-adjusted trends in surface-water quality vary widely across the country as a function of land use and environmental setting, with upward or downward trends likely to reflect changes in source terms, regulatory actions, or management practices.

The collection of suspended sediment concentration data by NAWQA in Cycles 1 and 2 has been ancillary to other potential stressors to aquatic ecosystems, and has primarily been for the purpose of characterizing trends in concentrations at NAWQA fixed sites and loads at NASQAN and NMN sites. Streambed-sediment samples were collected at approximately 500 sites across the country in Cycle 1 to characterize the occurrence and distribution of sediment-associated contaminants relative to land use setting and sediment-quality guidelines. NAWQA data were compared with other agency data and the results suggest continued declines in the concentration of bioaccumulative and toxic contaminants that were banned by USEPA in the 1970's and 1980s such as PCBs and various organochlorine pesticides like DDT. However, repeat sampling of streambed sediment monitoring sites was not conducted in Cycle 2. More detailed information on trends in sediment quality is obtained from sediment cores collected at lakes and reservoirs in urban, agricultural, and reference condition watersheds (see URL: http://tx.usgs.gov/coring/). Although the coring studies confirmed declining trends in most metals and a number of banned organic contaminants, they also showed that other contaminants of concern to aquatic ecosystems, principally PAHs, have increasing trends in recent decades and are frequently found at levels that exceed sediment quality guidelines in the youngest parts of the cores (Van Metre and Mahler, 2005). During Cycle 2, NAWQA scientists (in collaboration with scientists working with the City of Austin, Texas) identified a major, previously unrecognized urban source of PAHs – coal-tar-based pavement sealants. The importance of these sealants as a PAH source was recently confirmed by source-receptor modeling to 40 lakes which identified coal-tar sealants as the largest PAH source (Van Metre and others, 2010).

Evaluating the effect of streamflow alteration on aquatic ecosystems was not a major component of Cycle 1 or Cycle 2 studies. In Cycle 2 the effect of altered streamflow and related physical properties was partially addressed by two of the five NAWQA topical studies and as part of a national analysis of ecological data collected during Cycles 1 and 2. In the first topical study, the effects of urbanization on physical habitat and biota (fish, macroinvertebrates, and algae) were studied in multiple urban areas across the conterminous United States. The study found that streamflow, temperature, and physical habitat were altered by urbanization and that changes in biological condition of urban streams were correlated with changes in various streamflow metrics. In the second study, the effects of nutrient enrichment on stream ecosystems were studied in multiple agricultural areas across the conterminous United States. Here it was found that stream temperature and channel substrate have significant effects on macroinvertebrate community response and that groundwater discharge, as measured by a base-flow index, was inversely correlated with stream temperature in the agricultural streams studied.

A national analysis of all NAWQA ecological data collected during Cycles 1 and 2 is currently ongoing. This analysis includes an assessment of the degree of streamflow and temperature alteration relative to reference conditions and how that relates to the condition of the aquatic ecosystem. Preliminary results indicate that high flow, low flow, and flow variability in streams are altered compared to reference conditions and that alteration of these flow characteristics is associated with impaired aquatic ecosystem condition. With respect to temperature it was found that removal of natural land cover generally results in increased stream water temperatures and that human-caused changes to stream temperature may be mitigated by natural influences such as groundwater inputs and riparian shading.

Information needs not addressed during Cycles 1 and 2:

- Potentially important contaminants were not measured in water including some pesticides especially those that are new or have recently increased in use), pesticide degradates and adjuvants, and other organic contaminants that are potentially toxic or hormonally active, such as personal care products, various dyes, surfactants, and other industrial chemicals.
- Similarly, potentially important contaminants were not measured in streambed sediment or lake sediment cores including hydrophobic organics that are toxic, bioaccumulative, or hormonally active and are potential endocrine disruptors. Examples include synthetic hormones, new pesticide compounds and their degradates, and various phenols, plasticizers, dyes, flame retardants, and other industrial and personal care products.
- Suspended-sediment sampling has generally been inadequate to describe how sediment concentrations vary spatially and temporally, especially at time scales relevant to aquatic ecosystems. It has also been inadequate to identify trends and how these trends are related to changes in upstream land-use or land management practices.
- Assessment of the extent, severity, and types of streamflow and temperature alteration and an evaluation of how dominant types of streamflow and temperature alteration vary among regions.
- Documentation of historical temporal changes in streamflow and temperature alteration and an evaluation of how human activities and natural factors affect spatial and temporal variability in observed streamflow and temperature.

NAWQA's Role in Cycle 3

There is a continuing need for NAWQA in Cycle 3 to monitor contaminants and nutrients in the Nation's streams and rivers to determine if concentrations are exceeding available aquatic health benchmarks for water and sediment. Because of the overall importance of suspended sediment as a source of aquatic ecosystem impairment there is longstanding unmet need to improve monitoring of this stressor in terms of the number of locations monitored and to improve the reliability of measurements of suspended sediment concentration over time.

NAWQA and the USGS are also well positioned to provide information to government agencies and non-governmental organizations regarding the effects of streamflow and temperature alteration on aquatic ecosystems. The USGS has been collecting consistent streamflow and water temperature information at a national scale for over a century, although the data are sparse in the early portion of the historical record, particularly for water temperature. NAWQA has been compiling national-scale information on aquatic ecosystem condition since the early 1990s. The program can leverage this historical information, together with new data collection and studies, to assess and better understand the direct and indirect effects of streamflow and temperature alteration on aquatic ecosystems.

Data collected under this objective will support evaluation of short-term variability in each of these key stressors across a range of environmental settings and help define long-term trends caused by changes in climate and land use (Goal 2). The data will also be critical for developing an improved understanding of how contaminants, excess nutrients, suspended sediment, and sediment-associate contaminants are affecting aquatic ecosystems (Goal 3).

Planned Outcomes:

- Enhanced and updated occurrence and distribution assessments of contaminant, nutrient, and suspended sediment concentrations in streams and rivers which:
  - Build upon previous assessments of water-quality by updating and expanding target contaminants (based on guidance from NTAS work group).
  - Improve geographic coverage of contaminant, nutrient, and sediment monitoring in streams and rivers to increase the reliability of assessments examining the effects of these stressors on aquatic ecosystem condition
  - Improve statistical models that extrapolate contaminant, nutrient, and suspended sediment concentrations in streams, rivers, lakes, and reservoirs used for public supply based on watershed characteristics, chemical use, and other relevant ancillary data.
- Comparison of observed contaminant, nutrient, and suspended sediment concentrations to existing aquatic-life guidelines, nutrient criteria, and related water-quality standards.
- Enhanced and updated occurrence and distribution assessment of sediment quality of new and emerging contaminants of concern in streambed sediment.
- Assessment of decadal-scale trends in new and emerging sediment-borne contaminants in urban, agricultural, and reference condition watersheds.
- Assessment of flow and temperature metrics for all USGS streamgages with sufficient periods of record. The statistics will include a variety of metrics that characterize the flow and temperature regime and will be calculated for the period of record and on a year-by-year basis.
- Identification of a subset of all streamgages that, from a flow perspective, represent least disturbed basins. The hydrologic regime at reference sites and non-reference sites can be compared to determine the severity of streamflow alteration.
- Classification of river types: All reference sites in the conterminous United States will be classified into river types, such as snow-melt dominated, intermittent flashy, or stable groundwater. The classification also will be done on a regional basis by ecoregion.
- Assessment of the severity of flow and temperature alteration will be determined for non-reference USGS streamgages that have sufficient streamflow record.
- Empirical models that can be used to estimate the reference flow regime and the degree of streamflow alteration at any location in the conterminous United States.
- Web-based tools that allow users to view, query, and analyze streamflow alteration datasets.

Approach

Overview

Characterization of the status and trends of contaminant, nutrient, and suspended sediment concentrations in water will be achieved by monitoring ambient water-quality conditions through the enhanced NFSN. Characterization of concentrations and trends in sediment-associated contaminants will be achieved by resampling selected Cycle 1 bed sediment locations and lake coring sites and by sampling additional sites in high-priority settings, for example, downstream from wastewater discharge.

Surface-Water Quality

Basic data regarding concentrations of contaminants, nutrients, and suspended sediment will be collected as part of the enhanced NFSN. Short and long-term information on how concentrations of these constituents vary through time will also be provided by the NFSN through a combination of fixed interval sampling conducted a frequency sufficient to characterize contaminant, nutrient, and suspended sediment concentrations over the seasonal and annual hydrograph combined with continuous monitoring of key water-quality properties like water temperature, specific conductance, dissolved oxygen, and turbidity. Increased monitoring associated with an enhanced NFSN will improve coverage of the concentrations of ecologically important contaminants, along with nutrients and suspended sediment both spatially and temporally. Coverage will also be enhanced with respect to different environmental settings.

Sediment Quality

Given the current lack of knowledge regarding the occurrence and distribution of many emerging contaminants of concern in sediment the preferred approach will be to conduct a reconnaissance study of streambed sediment, lake bottom sediment, and possibly stormwater pond sediments, for analysis of as broad a range of compounds as possible. Ideally, this sampling will include toxicity screening at all sites and an assessment of the benthic community, followed by toxicity identification and evaluation (TIE) studies where toxicity is indicated. The survey and subsequent TIE studies would be done in collaboration with the USGS Toxic Substances Hydrology Program and (or) the Contaminants Biology Program. The reconnaissance study will be conducted early in Cycle 3 with the goals of providing findings that are relevant to resource managers in a timely manner and of improving and focusing Cycle 3 studies of the health of aquatic ecosystems on the most important contaminant-related stressors.

Site selection will be based on an analysis of existing NAWQA, Toxics, and other sediment-quality data to determine predominant mixtures of sediment-associated contaminants that pose a threat to human health or ecosystem condition and their relation to predominant land-use and source types. Approximately 100-200 sites, primarily in urban and agricultural settings associated with key types of contaminant sources will be selected for sampling. A subset of the sites (10 percent) would be reference sites and an additional 10 percent of the sites would be paired with lake or reservoir core sites for trend analysis. All sites would be sampled once and analyzed for the range of high-priority sediment-associated contaminants recommended by the NTAS work group (see below).

Streamflow Alteration

Initial characterization of the current and historical degree of streamflow and water temperature alteration will be done by analyzing retrospective data sets for USGS streamgages that have sufficient periods of flow and temperature data (typically 10 years of continuous data). Currently there are approximately 8,000 streamgages with sufficient flow data and 5,000 sites with adequate temperature data. Following compilation of the available data, a set of least-disturbed references sites for both flow and temperature will be identified. Then a set of empirical models that predict components of the natural flow regime and another set that estimates metrics describing the altered flow regime are constructed.

The degree of streamflow alteration is determined by comparing observed flow and temperature metrics at altered sites against those estimated for reference or “least disturbed” sites within a geographic region (e.g. level 2 ecoregion. Explanatory variables in the reference condition models are restricted to natural (climate, geology, soils, terrain) watershed characteristics whereas those used for altered flow or temperature regime models would include both human and natural characteristics that influence flow or temperature. Only explanatory variables that are available across the conterminous United States will be used in model development. Once degrees of streamflow or temperature alteration have been assessed, the results will be analyzed for spatial patterns among regions.

Trends in the degree of flow or temperature alteration would then be developed by estimating the degree of alteration over time for selected time intervals (e.g. annual to decadal) for sites that have multi-decadal periods of record.

Contaminant coverage

Proposed contaminant coverage for sampling of ambient streams and rivers included in the NFSN is given in Table 3.2. Target contaminant groups for RSS will vary per individual RSS objectives. The addition of new contaminants to Cycle 3 monitoring for this objective is based on potential aquatic ecosystem health concerns identified by the NTAS work group and is subject to having approved analytical methods and adequate funding.

The NTAS work group has also provided a series of recommendations regarding contaminants in sediment that are considered a high priority from an aquatic ecosystem perspective. These include trace elements, pesticides including pyrethroids and organophosphates, and several important subclasses of hydrophobic organic compounds including PAHs, nonylphenols, alkyphenol ethoxylates, brominated flame retardants, and perfluorinated surfactants. For the reconnaissance study of sediment-associated contaminants described above, a mix of approved analytical methods, custom methods (developed by USGS but not yet approved), and non-USGS methods and laboratories will be used. Information from that study will be used to guide sediment methods development in the future.

Expand compilation and analysis of non-USGS data

NAWQA will continue to selectively compile and analyze non-USGS water- and sediment-quality data collected by USEPA, the States, and other organizations to improve spatial and temporal coverage of the NAWQA data.

Critical Requirements for Technical Support and Data Support

Upgrade or replace existing analytical methods for contaminants of potential aquatic health concern in water and sediment per recommendations of the NTAS work group. Compile historical datasets of land cover and land use, datasets describing stream channel modifications, and information regarding water withdrawals and use.

Objective 1f: Determine contaminant, nutrient and suspended sediment loads to coastal estuaries and other receiving waters

NAWQA Progress during Cycles 1 and 2:

Monitoring nutrient and sediment loads to estuaries and other large water bodies has not been a primary focus of the NAWQA Program, for several reasons. First, most of the nutrients and suspended sediment delivered to estuaries is transported by large rivers such as the Mississippi River whereas NAWQA monitoring and assessment in Cycles 1 and 2 has emphasized smaller tributary rivers and wadeable streams; large-river monitoring has been left to other programs such as NASQAN. Second, the surface-water sampling strategy for nutrients used in Cycles 1 and 2 was designed to produce accurate estimates of mean annual concentration rather than mean annual loading. Finally, efforts to accurately characterize either mean annual concentration or mean annual loading of sediment were abandoned early in Cycle 1 because of a lack of funding.

Despite these limitations, NAWQA monitoring and assessment activities in Cycles 1 and 2 produced a large body of nutrient data that has dramatically improved understanding of the factors that control transport and delivery of nutrients to streams, reservoirs and estuaries. (Dubrovsky and others, 2010). NAWQA scientists combined monitoring data from Cycles 1 and 2 with monitoring data from NASQAN and other State and Federal agencies to develop regression/geospatial models that can be used to extrapolate nutrient and suspended sediment loads to unmonitored locations throughout the Nation. The most relevant example of this approach is the SPARROW model (Smith and others, 1997; Schwarz and others, 2006) model, which has been applied at national and regional scales to estimate mean annual nutrient and suspended sediment loads for any reach in the national stream network based on watershed characteristics and to provide source-allocation estimates for modeled watersheds (Alexander and others, 2008; Schwarz, 2008).

In Cycle 2 NAWQA determined trends in nutrient concentrations and loads since 1993 at a national set of stream monitoring sites, and related trend results to changes in watershed characteristics and nutrient inputs (Sprague and others, 2009). At the majority of sites, nutrient concentrations and loads did not change significantly between 1993-2003; where significant changes did occur the trends were generally upward for total nutrient and total phosphorus, and generally downward for nitrate. NAWQA regional assessments of suspended-sediment concentrations and loads have found no significant change at most sites, despite documented reductions in field-scale erosion from improved soil controls. As noted previously, sites in NAWQA's trend assessments have not included many of the large rivers that deliver the majority of nutrient and sediment directly to the coast but instead focus on the smaller tributary streams and rivers.

Information needs not addressed during Cycles 1 and 2:

Documenting, understanding, and predicting how nutrient and suspended sediment loading to lakes, reservoirs, estuaries and other coastal waters are changing over time are critical national needs as identified by NAWQA stakeholders. Specific needs identified include:

- Coordination of nutrient and suspended sediment monitoring across USGS programs at large river and tributary sites across the country.
- Enhancing spatial coverage for assessing annual loads and trends of nutrients and suspended sediment in the Mississippi River Basin and a number of important estuaries.
- Enhancing temporal coverage for determining how nutrient and sediment loading responds to short (days to seasons) and long-term (years to decades) variations in climate
- A better understanding of whether management practices designed to control nutrient and sediment loading to adjacent receiving waters are effective in reducing downstream loading to lakes, reservoirs, estuaries, and other coastal waters.

NAWQA's Role in Cycle 3:

NAWQA's role under this objective is assess seasonal and annual loading of nutrients and suspended sediment to downstream aquatic ecosystems in lakes, reservoirs, estuaries, and other coastal waters at national and regional scales. NAWQA's contribution to these assessments is unique and builds upon the models and analyses developed in Goal 2 to link spatial and temporal patterns in nutrient and sediment transport to the natural and human factors that influence water quality, and to evaluate if, when, and how changes in natural factors such as climate and human activities have affected downstream transport. NAWQA's regional and national scales of assessing spatial and temporal patterns in nutrient and sediment loading are necessary to help evaluate whether the billions of dollars spent on nutrient management and soil conservation have been effective at reducing downstream transport. Information on nutrient and sediment loads will be used to support and enhance source and transport models such as SPARROW and transform current steady-state versions of these models to transient versions that can be used to forecast and predict nutrient and sediment loads over different time periods (Goals 2 and 4).

Planned Outcomes

- Annual publication of nutrient and suspended sediment loads delivered to reservoirs and estuaries monitored by the NFSN.
- Assessment at regular intervals (e.g., five years) of trends in loads of nutrients and suspended sediment to reservoirs and estuaries that can be linked to the NFSN, and relation of observed trends to changes in watershed conditions.
- Assessment at regular intervals (e.g. five years), based on monitoring and modeling, of nutrient and sediment loads delivered to the 141 catalogued estuary systems in the Nation. The estimates would include nutrient and sediment loads to the estuary and estimates of loads and source shares from major tributaries that flow into the estuary.

Approach

Overview:

As outlined in Chapter 2, a significant increase in the number of large river NFSN sites where nutrients and suspended sediment would be monitored is proposed for Cycle 3. This includes reactivation of a significant number of NASQAN and NAWQA sites that were discontinued. Selection of sites to be reactivated would be done in collaboration with resource management and regulatory agencies including USEPA, NOAA, and the States to maximize coverage of important reservoirs, estuaries, and other coastal waters. The minimum sampling frequency at NFSN sites will be increased to 18 samples per year to better characterize inter-annual and seasonal variability of nutrient and sediment loading. To further increase the accuracy of load estimates of sediment and sediment-associated constituents, continuous monitoring of turbidity and (or) other suspended sediment surrogates will be collected. In selected tributaries, continuous monitoring of nitrate may also be done.

To better characterize the spatial distribution and occurrence of suspended sediment in streams and rivers a significant retrospective data compilation and analysis will be undertaken at the start of Cycle 3. This analysis of historical USGS sediment data is necessary to (1) determine how historical sediment data vary with respect to sampling and analytical methods, (2) understand how biases/uncertainty associated with different methods affect computations of sediment concentration and flux, (3) characterize which sites and what data should be used to estimate sediment flux and characterize trends, and (4) use available data to conduct regional/national assessments of how environmental setting and human activities affect sediment loads in streams and rivers and to estuaries.

Contaminant Coverage

Analytes will include nitrogen constituents (nitrate plus nitrate, ammonia, and total nitrogen), phosphorus constituents (total and dissolved phosphorus, dissolved orthophosphate), carbon constituents (total and dissolved organic carbon) and suspended sediment. Grain-size analysis of suspended sediment samples will be done to improve correlations with surrogate measures of suspended sediment concentration determined by turbidity or other techniques.

Expand compilation and analysis of non-USGS data

NAWQA will continue to selectively compile and analyze non-USGS water-quality data collected by the States and other organizations on nutrients and suspended sediment in the Nation's streams and rivers. Significant progress on this task has been completed for nutrients, and to a lesser extent for suspended sediment, as part of the efforts to build regional SPARROW models. However, continued tracking of ongoing monitoring by other Federal, State, and local agencies, and subsequent compilation of data will be needed to augment NAWQA and USGS data collection efforts.

Critical Requirements for Technical Support and Data Support

There is an ongoing need to evaluate the use of continuous surrogate technology or in situ continuous measurement of selected nutrients for load estimation. There is a need to evaluate the utility of continuous nitrate sensors and other potential surrogates to estimate nutrient loads. While continuous turbidity measurement has proven effective at estimating fine-grained suspended-sediment, other measurement techniques, such as optical backscatter or hydroacoustic methods, may be used at sites with predominantly sand-sized sediment transport. Load calculation software will need to be updated to better handle conversion of continuous surrogate data for sediment into sediment load estimates. Additionally, retrospective analysis on historical sediment data is needed to determine where and when sampling was adequate to compute loads."

Objective 1g: Determine trends in biological condition at selected sites and relate observed trends to changes in contaminants, nutrients, sediment, and streamflow alteration.

NAWQA Progress during Cycles 1 and 2:

NAWQA biological assessments conducted at streams and rivers for trends assessment include collection of fish, macroinvertebrate, and algae community data, and in stream and riparian habitat data. In the original Cycle 1 design the primary focus of ecological sampling at NAWQA fixed sites was to compile a baseline assessment of current biological condition in the study units, not assessment of trends. Assessment of ecological trends under the Cycle 1 model was to be based on successive 3-year intensive phases as the study-units were resampled in subsequent decadal cycles. A decision was made to begin annual sampling of all ecological trend sites in 1998.

At the start of Cycle 2, 129 of the 145 sites in the surface-water status and trends network were deemed suitable for ecology sampling on an annual basis. However, as funding declined, the number of surface-water status and trend network sites was reduced from 145 to 84 and the number of sites designated for ecological trends sampling declined to 58 sites. At this time the NAWQA Program abandoned its goal of providing a national assessment of the "status" of the Nation's stream ecosystems, recognizing that biological data collected by the USEPA and the States would be better suited to address this objective at the national scale. With respect to trends, the NAWQA Ad Hoc Surface Water Status and Trends Redesign Committee noted that the 58-site network only allows a limited number of site-specific trend stories to be told and that extrapolation of trends observed in the network to regional or national scales would be in inappropriate. As a result, only limited trends analysis has been conducted to date on the NAWQA ecological data to date.

Information needs not addressed during Cycles 1 and 2:

- Sustained ecological trends monitoring at reference or "least disturbed" sites as these sites will be critical for assessing the effects of natural factors such as climate change on aquatic ecosystem condition.
- Sustained ecological trends monitoring at "transitional sites" or sites where changes in land, water, or chemical use are occurring or where management practices are actively being implemented.

NAWQA's Role in Cycle 3

In Cycle 3 NAWQA will focus on assessing ecological trends at a limited number of sites where consistent, long-term monitoring of stream ecosystems is combined with monitoring of physical, chemical, and biological aspects of water quality to gain a better understanding of how these ecosystems change in response to changes in key environmental drivers and stressors. Such long-term monitoring will provide temporal context for the more spatially extensive monitoring done by USEPA and the States and for assessing the effects of changing climate and land use on stream ecosystems

Planned Outcomes:

- A description of ecological trends in watersheds where human activities at the land surface are causing significant changes.
- A description of ecological trends associated with natural factors such as climate change (based on reference watershed monitoring).
- Incorporation of NAWQA trend sites in probabilistic surveys of ecosystem condition conducted by USEPA and the States to put results of the probabilistic survey results in a temporal context.

Approach:

Overview

A consistent set of ecologic data on important taxonomic groups (algae, macroinvertebrates, fish) will be collected at all NFSN ecology trend sites to provide a framework of information that is consistent in terms of ecological variables, methods, and sampling frequency. The framework serves multiple purposes that integrate with other stressor-related monitoring being performed at these sites and provides the response data upon which to address objectives listed under Goals 2 and 3.

A subset of NFSN sites where contaminant monitoring is being done will be selected for continued ecological monitoring to assess long-term ecological trends. These sites will support intensive studies with a core of high-quality time-series observations of biological conditions and stressors to support objectives laid out in Goals 2 and 3. All NFSN sites with ecological monitoring will be wadeable streams. The three major types of fixed sites for ecological trends monitoring are:

- **Trends in Streams with Developed or Developing Watersheds.** Assess long-term trends in biological conditions in relation to contaminants and other stressors for selected "example" streams distributed among a range of the most important environmental settings of the nation with respect to ecological impairment due to agricultural, urban, or other transitional land-use categories.
- **Reference Sites.** Assess the current status and long-term trends in biological conditions at least disturbed reference sites in order to evaluate the effects of natural factors such as climate change at

selected environmental settings. These sites would represent NAWQA's contribution towards a proposed national reference watershed and monitoring site network.

- **Intensive Study Sites.** Provide temporal assessment of biological conditions, as well as contaminants and other stressors, at sites included in the intensive study network (described in detail in Goal 2 below). These are expected to be primarily a subset of the transitional trend sites described above, although some new sites may be required to meet the design requirements of the intensive studies.

It will be necessary to evaluate characteristics of the 58 current NFSN ecology trend sites including the extent and quality of historic water quality and ecological data and their distribution relative to the locations of selected IWS and related intensive studies. The relative importance of the four stressors chosen for emphasis in Cycle 3 (contaminants, excess nutrients, sediment, and streamflow alteration) will also be factored into the evaluation and it may be necessary to include some new sites to address specific stressors or combinations of stressors. We will also evaluate the NFSN ecology sites relative to sites included in recent USEPA NARS wadeable stream surveys so we understand how NAWQA long-term monitoring sites relate to the USEPA sampling design. Per Chapter 2, approximately 40 sites would be reference sites with the majority of the remaining sites consisting of existing NAWQA trend sites located in developing watersheds.

- New reference sites will be selected in collaboration with the USGS Hydrologic Benchmarks and Global Change Program, USEPA Office of Water, U.S. Fish and Wildlife Service, and the National Park Service to support development of a new multi-agency national reference watershed and monitoring site network (Wilber and Deacon, 2010).

NFSN ecology sites would be sampled annually (no rotation) to ensure that monitoring of aquatic community status, contaminant exposure, and other stressors are sufficient to support analysis of trends in biological conditions and their relation to key stressors. Biological data would include annual sampling for in stream and riparian habitat, algae and macroinvertebrates; fish would be sampled biennially. Transitional and intensive study sites would be sampled for contaminants, nutrients, and suspended sediment per Table 3.2. Reference sites will be monitored less intensively for contaminants but basic water-quality properties (flow, temperature, specific conductance, and turbidity) will be monitored continuously and major ion and nutrient samples will be collected monthly.

Critical Requirements for Technical Support and Data Support

Review and update biological and habitat protocols to optimize the scientific utility and cost effectiveness of NAWQA ecologic assessments.

Partnerships for Goal 1

Monitoring the status and trends of the Nation's water resources is done by other USGS Programs and local, State, and Federal agencies. The goal of partnership with these entities is to coordinate and leverage assessment activities for the benefit of the country. Below are highlighted current or desired partnerships that are critical to achieving Goal 1 objectives for Cycle 3. They involve other USGS Programs, agencies, and organizations where initial discussions regarding collaborative activities have been initiated or are planned with prospective partners.

USGS Mission Areas and Programs

- Climate and Land Use Change: Data and assessment activities conducted under Goal 1 objectives support goals listed for the USGS Global Change Science Strategy in assessing how climate change and land use affect streamflow, sediment transport, surface and groundwater quality, and freshwater availability. The information will also support efforts to understand how climate and land use change affect aquatic ecosystems, particularly through Cycle 3 efforts to expand monitoring at reference watersheds.

- Energy and Minerals, and Environmental Health: Discussions with the Toxic Substances Hydrology Program have primarily focused on assessments of contaminant occurrence in source waters and finished drinking water and on joint methods development activities to increase USGS capabilities for analyzing new contaminants in water, sediment, and tissue samples. The Toxic Substances Hydrology and Contaminant Biology Programs are also important collaborators for evaluating the occurrence of contaminants in aquatic biota.
- Ecosystems: The NFSN provides a platform for long-term monitoring of aquatic ecosystem condition that includes evaluation of aquatic ecosystem structure and function and related ecosystem services and how stream ecosystem condition is changing over time.
- Water: NAWQA, through its data collection and statistical models, is envisioned to be the primary source of water-quality information for regional and national-scale assessments of water availability from a water quantity and quality perspective. This includes assessments of surface-water basins to be conducted by the USGS WaterSMART Program and assessments of groundwater availability in principal aquifers being conducted by the Groundwater Resources Program.

External Partnerships

National Water Quality Monitoring Council (NWQMC)

- Support implementation of National Monitoring Network (NMN): Collaborate with NWQMC and its member agencies and organizations to track water-quality conditions from headwater streams to coastal estuaries by monitoring physical, chemical, and biological characteristics of various hydrologic components. The NMN is, comprised of a "network of networks" and represents an integrated, multidisciplinary, and multi-organizational approach that leverages diverse sources of data and information, augments existing monitoring programs, and links observational capabilities in nine crucial environmental compartments from terrestrial to oceans—including estuaries, the near shore; offshore and the exclusive economic zone; Great Lakes; coastal beaches; rivers and coastal streams; wetlands; groundwater; and the atmosphere. Network data—including observations on biological, chemical, and physical features—help document inputs, sources, amounts, timing, and severity of natural and man-made stressors of coastal ecosystems such as freshwater, sediment, nutrients, and contaminants.

U.S Environmental Protection Agency

- Assess status and trends of aquatic ecosystem condition: The USEPA Office of Water National Aquatic Resource Surveys (NARS) use a probabilistic approach to characterize current water-quality and biological condition of wadeable streams, lakes and reservoirs, large rivers, wetlands, and coastal estuaries. Identified areas of mutual interest for NARS and NAWQA include development of a national reference watershed and monitoring site network (see below), monitoring of ecological trends in streams and rivers, and identification of causes of water-quality impairment.
- Assess risk of pesticides in the environment: The USEPA Office of Pesticide Programs is responsible for registration and re-registration of pesticide products and has frequently cited NAWQA information in its registration decisions. Identified areas of potential collaboration include

characterization of new pesticide compounds and their degradates in drinking water sources and supplies, development of methods to extrapolate pesticide concentrations in unmonitored areas, and evaluating the effects of individual pesticides or mixtures of pesticides on aquatic organisms (Goal 3). A key partner in this effort is SFIREG (State-FIFRA issues Research & Evaluation Group) a State-level group that advises USEPA on pesticide regulation issues.

- Assess microbiological contamination in recreational waters: The USEPA Office of Research and Development is developing recommendations for the USEPA Office of Water and the States regarding application of rapid analytical methods to recreational water-quality monitoring. There is a shared interest in testing these new methods in a wide range of environmental conditions and assessing their efficacy versus traditional culture-based methods.

American Water Works Association (AWWA), Administration of State Drinking Water Administrators (ASDWA), Centers for Disease Control (CDC), National Institute of Environmental Health Sciences (NIEHS), Agency for Toxic Substances and Disease Registry (ATSDR)

- Coordinate USGS monitoring of drinking water supplies: These organizations, along with USEPA have a shared interest in evaluating contaminant occurrence and exposure in source and finished drinking water as it relates to drinking water quality and human health. Individual water-supply systems and their professional associations, such as AWWA and ASDWA, would be asked to collaborate on site selection, identification of suppliers willing to participate in source and finished water comparison studies, and to facilitate retrieval of information regarding treatment processes. Agencies such as CDC, NIEHS, and ATSDR are potential partners for developing contaminant exposure estimates via modeling or add-on data collection. They would also be contacted about coordinating NAWQA water-quality monitoring with state or Federal epidemiologic studies.

National Oceanic and Atmospheric Administration, Integrated Ocean Observing System, and National Federation of Regional Associations

- Develop an integrated approach to watershed and coastal protection and management of sustainable ecosystems: NOAA's Coastal Management and Assessment Office manages the biological integrity of estuaries. The Nation's Integrated Ocean Observing System (IOOS) supports, through partnerships with governmental and non-governmental organizations, a coordinated national and international network of observations and data transmission; data management and communication; and, data analyses and modeling for coastal waters. Associated with IOOS are eleven strong regional associations that make up a broad community of data providers and users, including coastal states, Federal agencies, Tribes, researchers, and non-governmental organizations. NAWQA and NASQAN data, and SPARROW modeling of nutrient loads are used and are directly relevant to these partners in protecting and managing key estuaries. Collaborative efforts are ongoing in selected regions, including Chesapeake and Delaware Bays, the Great Lakes, and the Gulf of Mexico.

Chapter 4. Evaluate how human activities and natural factors, such as land use, water use and climate change, are affecting the quality of surface water and groundwater (Goal 2)

Outcome: An explanation of the causes of observed spatial patterns and temporal trends in water quality that leads to an understanding of the factors influencing watershed and aquifer system water-quality response to changes in hydrology, contaminant sources, and transport mechanisms and processes, caused by past and current human activities and natural factors.

Products:

1. Surface-water and groundwater models that relate observed contaminant, nutrient, sediment and streamflow concentrations, fluxes, and trends to human activities and natural factors that can be used to assess the potential for surface-water and groundwater-quality degradation.
2. Dynamic watershed-scale models that explain the combined factors that result in observed seasonal and annual concentrations and fluxes of water, contaminants, nutrients, and sediment as they move through a large, complex watershed.
3. Models that can be used to assess the effects and effectiveness of urban and agricultural management practices on water quality.
4. Updated web tools to access and visualize contaminant, nutrient, sediment and streamflow distributions and trends and their relation to human activities and natural factors.
5. Exceedance maps for selected natural and anthropogenic contaminants that impair the use of groundwater for drinking supply.

Connection to other Cycle 3 Goals

Data from NAWQA's ongoing, long-term, monitoring of water quality at multiple scales will be used in assessments of spatial patterns and temporal trends in water quality across the Nation, as detailed in Goal 1 above. A second vital role of NAWQA in assessing national water quality is to link the nature and distribution of water-quality conditions (status assessment), as well as changes and trends in water-quality conditions (trend assessment), to the anthropogenic and natural factors that influence water quality. Goal 2 is focused on developing explanations for, and understanding of, the observed patterns and trends in water quality identified by Goal 1 assessment activities. This understanding is critical for evaluation of the effectiveness of implemented management practices and the susceptibility of water quality to degradation. Modeling tools developed as part of this effort will be used in Goal 1 to extrapolate findings to unmonitored areas, and in Goal 4 to explore improved management strategies, as well as the influence of potential future land use and climate change. Water quality parameters and conditions that lead to degradation of stream ecosystems will be identified in Goal 3. Strategies to remediate and minimize these negative water quality effects on steam ecosystems will rely heavily on the understandings from Goal 2 that relate flow, sources, transport and transformation processes, driven by human activities and natural conditions, to water quality conditions and responses.

Background

Evaluating the causes of broad-scale water-quality problems requires an understanding of processes occurring at multiple scales, from small watersheds and contributing areas for individual supply wells to major river basins and principal aquifers. The multi-scale, interdisciplinary approach of NAWQA is well-suited to incorporating the optimal mix of investigations for each problem. For example, the recent effort by USEPA to develop nutrient criteria, combined with concerns about the ecological status of inland and coastal waters, underscores the need to better understand the role of watershed disturbance on the transport and effects of nutrients at the scale of major river basins, such as the Mississippi River Basin. However, it is understood that small headwater streams play an important role in reducing nutrient loading to surface waters due to instream processing and transformation and must be considered when evaluating large-scale transport of nutrients. It is also understood that nitrate currently stored in the unsaturated zone and shallow groundwater may be a source of loading to surface-water systems for an extended period of time into the future.

Explaining observed water-quality conditions and trends, and understanding their connection to human activities and natural factors will be achieved through analyses that integrate information regarding source loading with flow and transport studies, including identification of specific biogeochemical or abiotic transformation processes. These studies of stressor source, transport, and transformation will make use of simulation and statistical models to help explain historical and current water-quality conditions, to estimate the susceptibility of water resources to degradation, and to evaluate how the effectiveness of management practices is related to flow and transport. These models will rely upon historical data collected within and outside of NAWQA, as well as data collected through Cycle 3. The models and studies will be applied at scales ranging from the national scale, to the major river basin and principal aquifer scale, to the intermediate scale (integrated watershed and/or regional aquifer analysis), and ultimately to the intensive study scale (specific flow-path and/or reach-scale). Studies will be nested within each other and designed to provide results of relevance and benefit to models and studies conducted at alternative scales. The complexity of models will range from simple statistical representations to detailed process-oriented models, and will vary by issue and across scales of study.

Ecosystem services are the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005), with services categorized into provisioning (e.g., food and water), regulating (e.g., regulation of floods, drought, land degradation, water quality), supporting (e.g., soil formation, nutrient cycling and primary production), and cultural (e.g., recreational, educational). Increasing human demands for ecosystem services means that trade-offs must be made among services: conversion of forest to agriculture increases the service of food supply but diminishes the service of regulating floods and water quality. Increasing demands on water resources, including both quantity and quality, requires scientifically defensible information in order to make sound resource management decisions. Since its inception, the NAWQA program has addressed multiple water quality issues in surface and groundwater across the United States, many of which overlap with a number of specific ecosystem services. In Cycle 3, however, NAWQA is organized for the first time to evaluate and quantify the factors -- including indirect drivers (e.g., climate, land use) and direct drivers (e.g., nutrients and sediment) -- that control the capacity of ecosystem to provide services related to water quantity and quality. Studies that support this and subsequent goals will inform USGS and other agency efforts to better understand the factors that affect ecosystem services, particularly those performed by stream ecosystems.

Evaluating how surface water and groundwater quality responds to human activities and natural factors will be achieved through a Goal 2 study design that will integrate the regional and national scale data collected as part of Goal 1 with multi-scale analyses and models of flow, sources, transport and transformation processes that are supplemented with spatially and temporally intensive data collection, to address the following objectives:

Objective 2a: Determine how hydrologic systems—including water budgets, flow paths, travel times and streamflow alterations—are affected by land use, water use, climate, and natural factors.

As water moves through the hydrologic cycle, its suitability for human use and aquatic ecosystems changes. These changes occur at the land surface, where water interacts with the natural and human landscape, and in the subsurface, as water moves through shallow and deep groundwater flow systems. The magnitude and timing of changes in water quality will depend on how long it takes for the water to flow from one point to another as well the as the interactions that occur along flow paths. Thus, a critical step in understanding water-quality responses to human activities and natural factors is a better understanding of the hydrologic system, as characterized by water budgets, flow paths, travel times, and streamflow alteration.

Objective 2b: Determine how sources, transport, and fluxes of contaminants, nutrients and sediment are affected by land use, hydrologic system characteristics, climate and natural factors.

Understanding the effects of land use, climate, and natural factors on the Nation's water quality requires identifying sources of contaminants, nutrients and sediment, how they are introduced to the ecosystem by human activity and natural factors, and how they are transported and transformed within the hydrologic system. Sources can be categorized as nonpoint sources, such as precipitation, pesticide use, fertilizer use, and runoff from urban land, or as point sources, such as discharges from wastewater treatment plants or from confined feeding operations, and leaking waste storage facilities. Combining knowledge of hydrology and sources with observed concentrations and ecosystem processing will allow better understanding of how and why the loads of contaminants, nutrients (nitrogen, phosphorus, carbon; N, P, C) and sediment to rivers, reservoirs and coastal waters (estuaries and coastal oceans), and fluxes into, within, and out of aquifers, are changing over time and space in response to human and climate induced changes and differences.

Objective 2c: Determine how nutrient transport through streams and rivers is affected by stream ecosystem processes.

Nutrient transport in surface water is a complex issue that requires evaluating the interactions and feedback mechanisms between the stream ecosystem and nutrient concentrations and loads. The key to understanding the factors influencing nutrient enrichment in streams is to take a systems approach where one examines simultaneous influences of the various controlling factors and how these interactions change over space and time. For example, stream habitat modification can affect nutrient transport and processing, and nutrient transport and ecosystem function may change over time in response to changes in land use practices and climate change.

Objective 2d: Apply understanding of how land use, climate, and natural factors affect water quality to determine the susceptibility of surface-water and groundwater resources to degradation.

Sustaining water quality for human use and aquatic ecosystems requires that water-quality conditions and flows in current and potential sources of water meet designated standards and criteria. Understanding the distribution of water-quality and flow conditions in relation to land use and other causes is a critical step in developing strategies for protecting and improving water supplies. Furthermore, knowledge of sources, transport, and transformation processes will be used to evaluate the susceptibility of water resources to degradation caused by land use, climate and natural factors.

Objective 2e: Evaluate how the effectiveness of current and historic management practices and policy is related to hydrologic systems, sources, transport and transformation processes.

The effectiveness of management practices is determined, in part, by characteristics of the hydrologic system where the practice is implemented. Scientific findings will be compiled into outcomes and products that demonstrate the connections between changing water quality, hydrologic setting, and regional and national management practices and policy.

Policy and Stakeholder Concerns Driving Key Management Questions:

Continuing population growth will cause increases in urbanization, agricultural activity, natural resource development, and water demand. Large-scale changes in land use and associated activities—driven by increased population, economic changes, and management strategies implemented to mitigate water quality problems—lead to changes in the quality of water for aquatic ecosystems and humans through alteration of flow conditions and changes in the sources and transport of contaminants, nutrients, and sediment. The magnitude and timing of flow and water-quality responses to these modifications will vary with climate, landscape, geology, geochemistry and hydrology. Surface-water systems dominated by overland or tile-drain flows are expected to respond rapidly to these perturbations, whereas groundwater systems are expected to respond more slowly. Evaluating the effectiveness of policy and management strategies to sustain and/or improve water quality is dependent on understanding the influence of these factors on contaminants, nutrients, sediment, streamflow, and groundwater recharge and discharge as well as on understanding the variable sensitivity of different regions, watersheds, and aquifers to such changes. Understanding the causes of patterns and trends in water-quality degradation is essential for improving management. Selected examples of management-relevant questions illustrate the broad range of applications:

- Are the most important point and nonpoint sources of contaminants being addressed by current management strategies?
- Are protection, conservation, and remediation programs working effectively to control sources and transport of contaminants?
- What strategies are needed to protect sources of drinking-water?
- What areas should be targeted for more intensive monitoring, protection, or remediation?
- What are the sources and transport processes controlling nutrients, contaminants, and sediment delivery to estuarine ecosystems, the Great Lakes, and other receiving waters?

NAWQA Progress during Cycles 1 and 2

Cycle 1 of NAWQA was organized into Study Unit Investigations to identify water-quality problems and relate them to local conditions and management practices. Analyses were based on a mixture of quantitative and descriptive approaches, depending on the extent of data available. Cycle 2 of NAWQA moved towards integration of findings across broad regions of the Nation, with models being a key tool in this effort. The modeling approaches included:

- Broad-scale national and regional regression/geospatial source and transport SPARROW models (Schwarz and others, 2006) for nutrients (N, P and C), salinity, and sediment (Preston and others, 2009, Schwarz, 2008). These models incorporated steady-state accounting of nutrient and sediment loads to estimate a mass balance based on average hydrologic conditions and spatially variable inputs from difference sources.
- National regression/geospatial models, without mass-balance accounting, were developed to predict pesticide concentrations in water and in fish tissue (WARP; Stone and Gilliom, 2009).
- Process-simulation watershed models, such as TOPMODEL (Beven and others, 1995) and SWAT (Neitsch and others, 2005), were developed for small basins in some topical studies to improve understanding of the role of flow paths in contaminant transport.
- Groundwater flow and particle-tracking models were developed at scales ranging from an individual supply well 1-10 km^2 to regional groundwater systems (100’s to 1,000’s km^2).
- National regression/geospatial models were developed to estimate groundwater vulnerability to pesticide and nitrate contamination (Nolan and Hitt, 2006; Stackelberg and others, 2005).

Cycle 2 also initiated small-scale detailed topical studies, to complement these large-scale studies, geared towards making the connection between the effects of human activities and water quality. These studies have led to increased understanding of the processes and factors that control water-quality responses to agricultural practices, urbanization, and mercury deposition in selected areas representative of major settings in the Nation.

An illustration of complementary large- and small-scale studies in Cycle 2 is provided by NAWQA’s activities aimed at understanding the factors that control transport and delivery of nutrients to streams, reservoirs, and estuaries, and evaluating the response of instream nutrient loads to changes in land use, source inputs, and land management practices. At the national scale, trends in nutrient concentrations and loads of stream monitoring sites since 1993 were related to changes in watershed characteristics and nutrient inputs (Sprague and others, 2009). NAWQA also combined monitoring data collected during Cycles 1 and 2 with monitoring data from other agencies and statistical and/or hybrid models to extrapolate water-quality conditions in unmonitored parts of the country. The results of simulations made with SPARROW models that have been used to prioritize watersheds for implementation of conservation and management practices as part of the Mississippi River Basin Healthy Watershed Initiative (U.S. Department of Agriculture, 2009). SPARROW estimates of mean loading of nitrogen to estuaries throughout the Nation (Smith and others, 1997) were used in NOAA’s 1999 assessment of effects of terrestrial nutrient sources on estuarine ecosystem condition (Bricker and others, 1999).

Detailed stream-reach studies conducted as part of the Nutrient Enrichment of Stream Ecosystems (NEET) topical study addressing nutrients in agricultural streams found that (1) concentrations of nitrogen and phosphorus in agricultural streams often exceed proposed USEPA Regional Nutrient Criteria although algal biomass was often less than expected due to habitat alterations; (2) benthic algae showed a more rapid response to initial increases of nutrients than did macroinvertebrates or fish, and overall may be a better indicator of nutrient conditions; (3) agricultural streams often were heterotrophic and may have limited nutrient processing capacity, resulting in high nutrient export; (4)

denitrification rates in surface water were less than 5 percent of surface-water nitrate loading rates and were unable to significantly reduce downstream transport of nitrate; and (5) legacy nitrate from fertilizer applied years or decades ago in groundwater discharging to streams can a source of nitrogen to streams for an extended period (years to decades).

In Cycle 1, NAWQA groundwater quality studies were implemented at multiple scales within the context of Study Units. About 100 Major Aquifer Studies (MAS, ~1,000 km^2 to >100,000 km^2) were designed to provide a broad assessment of water quality in areas with relatively similar geologic, hydrologic, and climatic conditions. About 110 LUS networks were sampled in agricultural and urban settings and were designed to evaluate the relation between shallow groundwater quality and overlying land use; LUS networks were, with few exceptions, nested within MAS networks. About 40 flow-path studies (FPSs) were conducted; these studies were generally nested within LUS networks and were designed to evaluate the hydrologic and geochemical processes affecting groundwater quality. In Cycle 2, NAWQA groundwater data and interpretative investigations were organized, in part, by principal aquifers (or groups of PAs), into 11 regional areas (~200,000 km^2 to ~3,000,000 km^2), to assess groundwater quality from a regional geologic, hydrologic, and climatic perspective.

In addition, two topical studies completed in Cycle 2 had a significant groundwater focus. The TANC study examined contaminant transport to public supply wells at the scale of the contributing area and at the scale of the larger groundwater flow system (~100 km^2 to ~ 5,000 km^2). TANC studies were implemented in 10 representative areas distributed across the Nation. The Agricultural Chemicals Transport (ACT) study examined transport of contaminants through the entire hydrologic cycle from a watershed perspective, and was implemented using a nested design in seven representative areas (~10 km^2 to ~1000 km^2). The TANC and ACT studies were field intensive, made use of quantitative groundwater flow modeling, and were designed to understand the hydrologic and chemical processes affecting water quality.

NAWQA'S Role and Future Directions in Cycle 3

Evaluating the influences of human activities and natural factors on water-quality patterns and trends will be achieved in Cycle 3 by integrating findings from studies conducted across multiple and nested spatial scales, as described in Chapter 2 (fig 4.1). Modeling will be a key component of all analyses of source and transport processes, with the complexity of the models being tailored to the scale and scope of the analysis. For example, complex process-simulation models will be applied at the most detailed scale of study, with the goal of providing information that can be used in more simplified broader-scale models, and vice versa. A key evolution in modeling in Cycle 3 will be to develop dynamic models that include temporal variability caused by time-varying source inputs, climate variability, and hydrology. The construction and calibration of these models will require the collection of data at a sufficient frequency and coverage to fulfill these modeling goals. Data collection strategies and design components outlined in Part III for status and trends assessments are also designed to support these process and modeling studies. In addition, these models will rely heavily on water-quality and ancillary data collected by other agencies. The models and understanding developed in this effort provide the basis of forecasting studies in Goal 4.

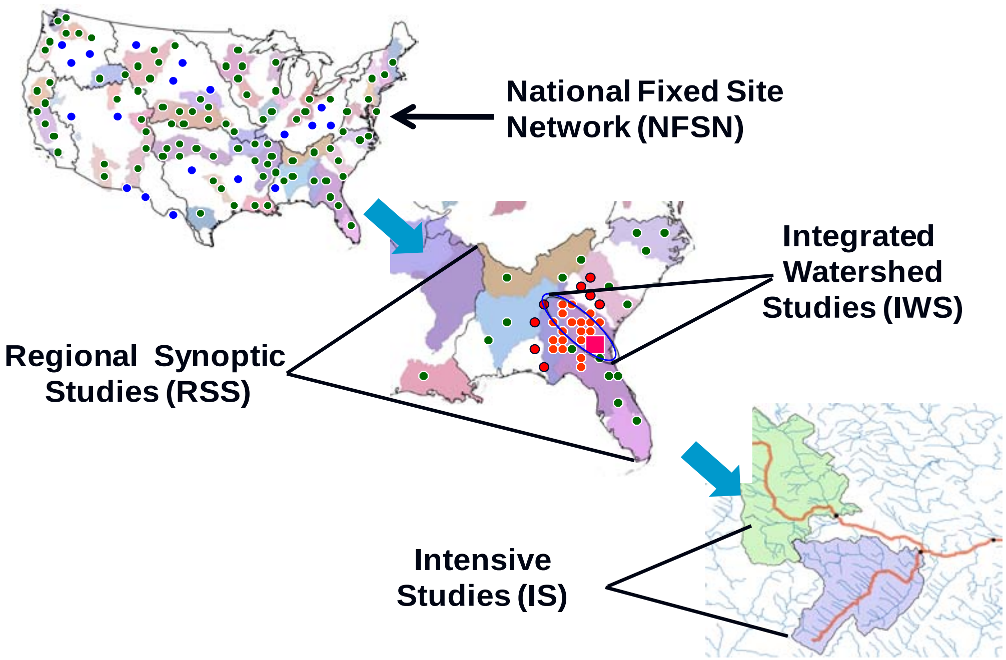


Figure 4.1-Schematic diagram illustrating nested spatial scales for Cycle 3 surface-water studies. The shaded areas in the national map indicate Cycle 1 and Cycle 2 study areas.

Approach

Goal 2 studies are designed to evaluate how ongoing human activities and natural factors result in observed distributions and trends in surface-water and groundwater quality identified through Goal 1 efforts. Although meeting the objectives of Cycle 3 will require integrated multidisciplinary studies, each different stressor, as well as surface water and groundwater, has unique characteristics that affect study approaches. For simplicity, the description of the Cycle 3 Goal 2 approaches is organized into (1) surface water studies described by stressor, (2) an example of an Integrated Watershed Study, (3)an example of an Intensive Study, and (4) groundwater studies. The studies described within each of these categories include examining connections across scales, and between surface water and groundwater as highlighted within the explanations of each individual design and approach.

Surface-Water Studies

Cycle 3 national and regional studies will continue to refine and improve regional and national modeling tools developed using the NFSN data sets integrated with information and data from other State and Federal agencies to extrapolate water-quality information to unmonitored areas, evaluate delivery of contaminants, nutrients, and sediment to downstream areas, and determine the relative contributions of sources and management areas to downstream transport. RSS will be undertaken in conjunction with model development when more data are required for model improvement. The general direction of model enhancement will be to move towards dynamic models that can account for storage and loss of contaminants, nutrients, and sediment over time. Such models can be used to simulate seasonal and annual trends in water-quality conditions and loads. NFSN data collection is designed to support these modeling efforts. Likewise, smaller-scale Integrated Watershed Studies (IWS) and Intensive Studies (IS) will be designed to provide process understanding that can be used to enhance dynamic national and regional models and reduce prediction uncertainty.

The IWS are designed to provide information at the intermediate scale, nested between the much larger national and regional analyses and the much smaller scale Intensive Studies. The IWS will integrate surface water and groundwater hydrology with source, transport, and transformation analyses for the range of stressors of concern in the watershed. These studies aim to provide a holistic scientific understanding of the fate of contaminants, nutrients, and sediment as they are transported through the watershed, and the human activities and natural factors that influence the sources, transport, and transformations they undergo. Concentrations and fluxes at critical locations within the watershed and at the outlet will be related to urban and agricultural management practices, as well as watershed characteristics. Dynamic models developed at this scale will be the first products and will be the foundation for models developed at regional and national scales that will be released later in Cycle 3.

Embedded within each IWS will be one or more detailed IS that focus on very specific scientific objectives that will improve NAWQA's ability to simulate contaminant, nutrient, and sediment transport at the IWS scale (fig 4.2). One goal of the IWS design described above is to better understand the role of watershed disturbance on the transport, transformations, and effects of contaminants, nutrients, and sediment at the watershed scale. The IWS analysis will provide an opportunity to scale-up IS findings and to determine their relative importance within the larger watershed. Cycle 3 Intensive Studies related to Goal 2 will initially focus on nutrient and sediment transport and fate. As Cycle 3 studies progress, priority contaminants and streamflow alteration may be integrated into the nutrient and sediment design, or added through additional Intensive Studies.

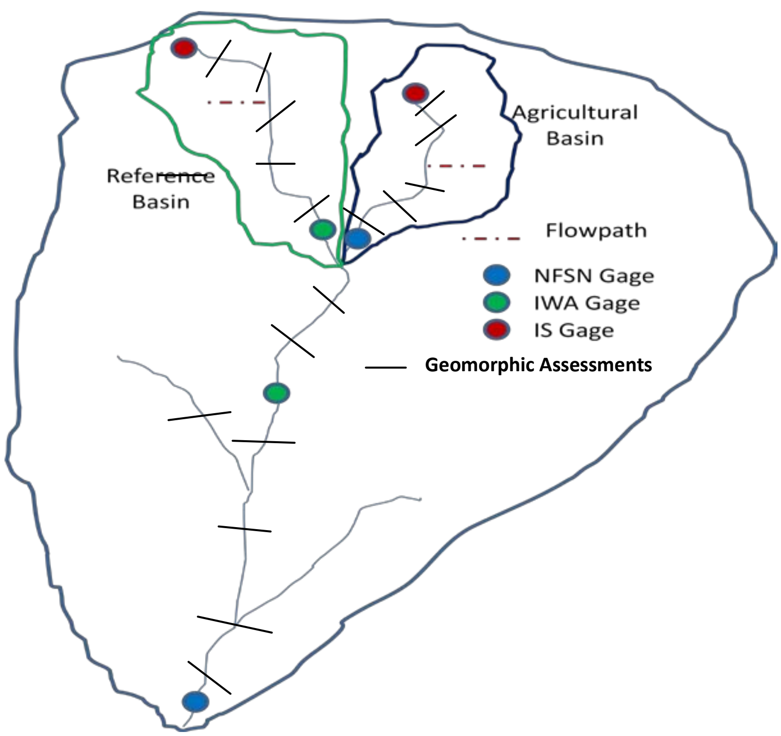


Figure 4.2. Example of an Integrated Watershed Study (IWS) design with an embedded Intensive Study (IS) that uses a paired-watershed design for comparing sediment and nutrient sources, transport, and transformations. The IS will be conducted in a reference or least disturbed watershed and an agricultural basin and related to the downstream effects observed in the IWS. For example, periodic geomorphic assessments (along with collection of sediment flux and analysis of ancillary data) will be conducted to characterize sediment sources and sinks from headwater to downstream channels. Note that local-scale groundwater flow-path studies are nested within the IS and IWS watersheds to examine groundwater/surface-water interactions. A National Fixed Site Network monitoring site at the base of the watershed anchors the IWS.

Planned study designs and outcomes are detailed below for each type of stressor.

Contaminants:

Approach

Broad-scale national and regional models of contaminant distributions will be developed for surface-water systems. Surface-water regression/geospatial models developed in Cycle 2 such as WARP will be expanded to include additional contaminants or contaminant mixtures of concern; refined regional models that are based on all regional data sources, even when these data are not available nationally; improved representation of critical sources and processes; and development of temporally dynamic (seasonal and annual) models that simulate the effects of time-varying sources and transport processes at the time period of greatest relevance. Also, mechanistic understanding of transport pathways and transformation processes developed from process-based watershed and reach-scale transport models will be used to improve the broad-scale hybrid models. National and regional contaminant studies will focus on those contaminants of widespread human and ecosystem concern, for example, atrazine in agricultural areas, insecticides in urban areas, salinity in arid areas, and mercury nationwide, including reference areas.

Planned Outcomes:

The modeling tools developed to explain observed contaminant distributions and trends in surface water will be used to:

- Identify primary sources of priority contaminants found in surface water and their relation to human activities and natural factors
- Understand the factors that limit, or enhance, the seasonal and annual fluxes of critical contaminants to downstream receiving waters
- Analyze and interpret the transport pathways and transformation processes for selected contaminants in river and stream networks and how they impact the effectiveness of implemented management practices
- Evaluate national and regional susceptibility of drinking-water resources to water-quality degradation, and the relation of susceptibility to human activities and natural factors

Nutrients:

Approach:

Considerable effort was devoted to monitoring and modeling sources of nutrients and how they move through the environment in Cycle 2, with the greatest emphasis on nitrogen and phosphorous. Cycle 3 modeling and analysis efforts will be geared towards shifting from the steady-state source and transport models of Cycle 2 to dynamic models that can represent seasonal and annual variability in nutrient transport. Additional emphasis will be given to carbon transport in watersheds to complement ongoing studies of carbon sequestration and carbon cycling being conducted by the USGS Global Change Program and to complement goals laid out by the USGS Climate and Land Use Change Strategic Science Planning Team.

Existing nutrient models will be refined to include temporal variability (seasonal and annual) and improved representations of water-quality management practices. For example, answering questions such as “Are regulatory and non-regulatory actions in the Mississippi River Basin making a difference in riverine nutrient loading to the Gulf of Mexico?” requires improved understanding and prediction of how fluxes of nutrients and the timing of their delivery to downstream water bodies (reservoirs, estuaries) responds to implemented practices. A major obstacle is the challenge of discerning whether changes observed in nutrient delivery are due to implemented management practices, or to natural climatic variation (or even human-induced climate change).

To address this challenge, load prediction models such as SPARROW that were developed in Cycles 1 and 2 will need to be modified or coupled with other models to simulate the effect of specific conservation practices as well as annual and seasonal variation in nutrient loading. This will require assembly of ancillary data characterizing nutrient source inputs at seasonal and annual time steps, and adapting the models to account for nutrient storage and sinks. The development of realistic, dynamic models of regional nutrient transport can progress only if our understanding of nutrient processing at smaller scales is improved. This will be achieved through model development and testing at the IWS scale and improved representation of important processes identified from IS results.

Planned Outcomes:

The modeling tools developed to explain observed nutrient loads and concentration distributions and trends in surface water will be used to:

- Relate trends in concentrations and loads of nutrients to changes in watershed conditions and distinguish trends related to human activities from those related to natural factors (based on modeling).
- Improve estimates of nutrient delivery to critical water bodies, including inter-annual and seasonal variability including
  - Periodic assessment, based on combined monitoring and modeling, of nutrient loads (annual, seasonal) for important estuaries in the Nation.
  - Maps for each estuary of tributary watersheds showing estimated nutrient loads delivered to the estuary, and source shares for specific time periods (seasonal, annual)
- Evaluate the effect of specific ecological resources, such as wetlands and forested riparian areas, on nutrient loads delivered to downstream targets, which in turn supports valuation of ecosystem services in relation to nutrient processing.

Sediment:

Approach

NAWQA has a unique capability to conduct broad-scale evaluations of how changes in land use and land management have affected sediment transport in streams and rivers. Although attention to sediment transport was minimal in Cycles 1 and 2, the USGS is the only agency with the infrastructure (i.e. streamgages, nationally consistent sampling and analytical methods, and historical data) with which to conduct regional and national assessments of sediment concentrations, loads, and transport. Development and improvements in use of continuous suspended-sediment surrogates over the past decade afford NAWQA an opportunity to more accurately quantify sediment concentrations and loads at fine temporal resolutions and across multiple spatial scales. Analysis of spatial and temporal patterns in sediment concentrations and loads is necessary to better understand how natural factors and human disturbance affect sediment transport, and to evaluate whether the billions of dollars spent on soil conservation have resulted in improved downstream water quality.

Basin-scale analysis of factors affecting the erosion, transport, and deposition of sediment is needed to better understand the timescales at which climate, land use, and land management affect suspended-sediment concentrations and loads in streams and rivers. NAWQA data and assessments will be used to improve existing SPARROW models and also to test watershed models currently used by State and Federal agencies such as Soil and Water Assessment Tool (SWAT; Neitsch and others, 2005) or the Hydrological Simulation Program-Fortran (HSPF; Bicknell and others, 1997). The models will be used to analyze how various drivers affect sediment movement in streams and rivers. Knowledge of the extent to which instream sediment transport has been altered from its natural condition is necessary to help governmental and non-governmental agencies identify and manage the effects of altered sediment transport on aquatic ecosystems. These goals will be achieved as follows:

- Continuous sediment surrogates (i.e. turbidity, optical backscatter, or acoustic sensors) will be installed, and periodic suspended-sediment and stream-habitat data will be collected at stream and river sites in the NFSN as specified in Goal 1. Sites will include a substantial number of reference sites to better quantify sediment flux from relatively pristine, small basins in different geographic regions.
- Flux will be computed at each site using statistical software that can utilize hourly, sediment surrogate data to compute flux and uncertainty (USGS LOADEST model or adaptation; http://water.usgs.gov/software/loadest). Sediment loads and differences in the magnitude, frequency, and duration of historical and current sediment concentrations will be evaluated across regions, land-use settings, and through time, to assess how climate, environmental setting, and human activities affect the movement of sediment in streams and rivers.
- Geomorphic assessments and GIS-derived analyses of channel stability will be conducted to characterize in-channel sediment erosion and deposition from headwater to downstream reaches.
- Sediment sources can be characterized through comparison of chemical and radiochemical signatures of end-member sediment sources (such as surface and channel-bank soils) to signatures in suspended-sediments.
- National/regional SPARROW models will be improved using surrogate-derived sediment flux and updated ancillary data

Planned Outcomes:

- Updated web tools to access and visualize historical suspended-sediment and ancillary data
- Databases and web tools that characterize river types based on GIS and geomorphic survey-derived factors affecting stream stability and sediment transport (such as segment slope, valley type, geologic setting, streambed substrate, historical land use and channel change)
- Long-term, continuous sediment-surrogate and ancillary data that improve current and future ability to identify changes in sediment transport and streamflow pathways
- Assessment of trends and spatial patterns in sediment concentrations and loads relative to environmental setting, human disturbance, and erosion controls
- Assessment of how natural factors and human disturbance affect the sources, transport, and deposition of suspended sediment in specific environmental settings

- Improved national/regional SPARROW models based on existing and future data collection that characterizes variability in sediment transport relative to natural factors and human disturbance

Streamflow Alteration:

Approach:

Natural patterns in the magnitude and timing of streamflow are major controlling factors of water quality and ecosystem integrity (Postel and Richter 2003) and have been extensively altered by human activities throughout the United States (Graff 1999, Carlisle et al., 2010). NAWQA's expertise in hydrologic and geospatial analysis will enable the program to clarify how human activities and natural factors affect the flow regime. This effort will rely on characterization of major patterns in streamflow alteration at gaged sites developed in Goal 1. For example, we expect major differences in streamflow alteration among different climatic regions, land uses, and water management activities. Using this characterization, empirical models that predict components of the natural flow regime and another set that estimates metrics describing the altered flow regime will be developed. Predictive models will be used to extrapolate estimates of streamflow alteration to ungaged river segments across each region. Observed annual flow regime metrics will be compared to the streamflow metric values estimated for reference conditions by calculating the ratio of the observed value to the reference condition value (O/E) to summarize the frequency distribution of O/E values by region and time period and to identify sites with abrupt or gradually changing values of O/E. These patterns and trends will be explained in relation to changing human activities and natural factors, and will be related in Goal 3 to aquatic ecosystem habitat and health.

Planned Outcomes:

NAWQA will produce datasets, models, analysis tools, maps, and reports that will assist the agencies and organizations responsible for maintaining the integrity of aquatic ecosystems.

Example of an Integrated Watershed Study

Integrated Watershed Studies (IWS) play an important role in furthering our understanding of the effects of human activities and natural factors on water-quality conditions. IWS will incorporate small-scale intensive studies that facilitate understanding of water-quality processes, but will focus on improving our understanding of fate and transport processes at a scale much larger than that typically assessed by traditional research studies. IWS basins will nested within nationally important regional watersheds, such as the Mississippi River Basin, to leverage ongoing data collection and modeling activities (for example, Mississippi River Healthy Watersheds Initiative areas, NEON studies, and WaterSMART watersheds).

Approach:

Each IWS will build upon Cycle 1 and 2 studies, will incorporate local information collected by other agencies and entities, and will be supplemented by further data collection during Cycle 3. An example watershed where considerable work has already been conducted, the White River Basin, Indiana, is used to illustrate the approach and objectives of an IWS (fig. 4.3). The goal of the IWS is to combine previous data and analyses with additional monitoring in critical locations into a comprehensive hydrologic systems understanding of how human activities and natural factors have influenced sources, transport pathways and transformation processes and resulted in observed water-quality distributions and trends. The first steps in an IWS analysis will include:

- Aggregating historical NAWQA findings from Cycle 1 study unit analyses, regional SPARROW models, PA studies, Cycle 2 topical studies, and studies by other agencies and organizations to develop a broad conceptual understanding of the watershed system. An illustration of the kind of information available from previous NAWQA work in the White River Basin includes estimates of nitrogen and atrazine loads across the watershed produced by national SPARROW and WARP models, respectively (figs 4.3 A and B).
- Compiling detailed current and past land use, water use, climate, source, and management practice information. For example, land use, nitrogen fertilizer applications and wastewater discharge points for the White River Basin are shown in Figures 4.3 C and K, illustrating that the IWS scale will encompass a wide range of land-use categories and a range of source inputs. This is important for analyzing how water quality changes in response to changing land use.
- Characterization of watershed/aquifer characteristics that influence flow, transport, time lags, and transformations. For example, spatially detailed hydrologic analysis of the surface-water system is now possible with the National Hydrography Dataset-Plus database (fig. 4.3 G)

A key element of the IWS is the analysis of fluxes of contaminants, nutrients, and sediment across important interfaces within the watershed (i.e. surface-water/groundwater interface, interior sub-basins, watersheds with drinking-water intakes) and relating fluxes to sources, specific land uses, and natural factors. Comparison of watershed source loading and export predicted by water-quality models will be conducted at multiple nested spatial scales using a longitudinal design to discern how these processes change as stream size increases and water moves through the watershed (fig. 4.4). Time-varying load estimates will also be compared to changing sources and changing human activities and climate for both short-term seasonal effects and long-term trends. The percentage of streamflow derived from groundwater discharge to the stream will be determined by either groundwater flow modeling or by base-flow separation analysis. These estimates can be coupled with estimates of the average age and contaminant concentration of discharging groundwater to provide an estimate of contaminant loading from the aquifer to the watershed. IWS studies will rely on a subset of NFSN sites for long-term monitoring, with the addition of a number of short-term monitoring sites that will be needed to complete the longitudinal design. This enhanced monitoring network will be needed to measure and analyze water budgets, and contaminant, nutrient, and sediment mass budgets. Selection criteria for these additional monitoring sites will need to consider the flow system, land use, active gaging stations and sites where other programs are collecting water-quality data.

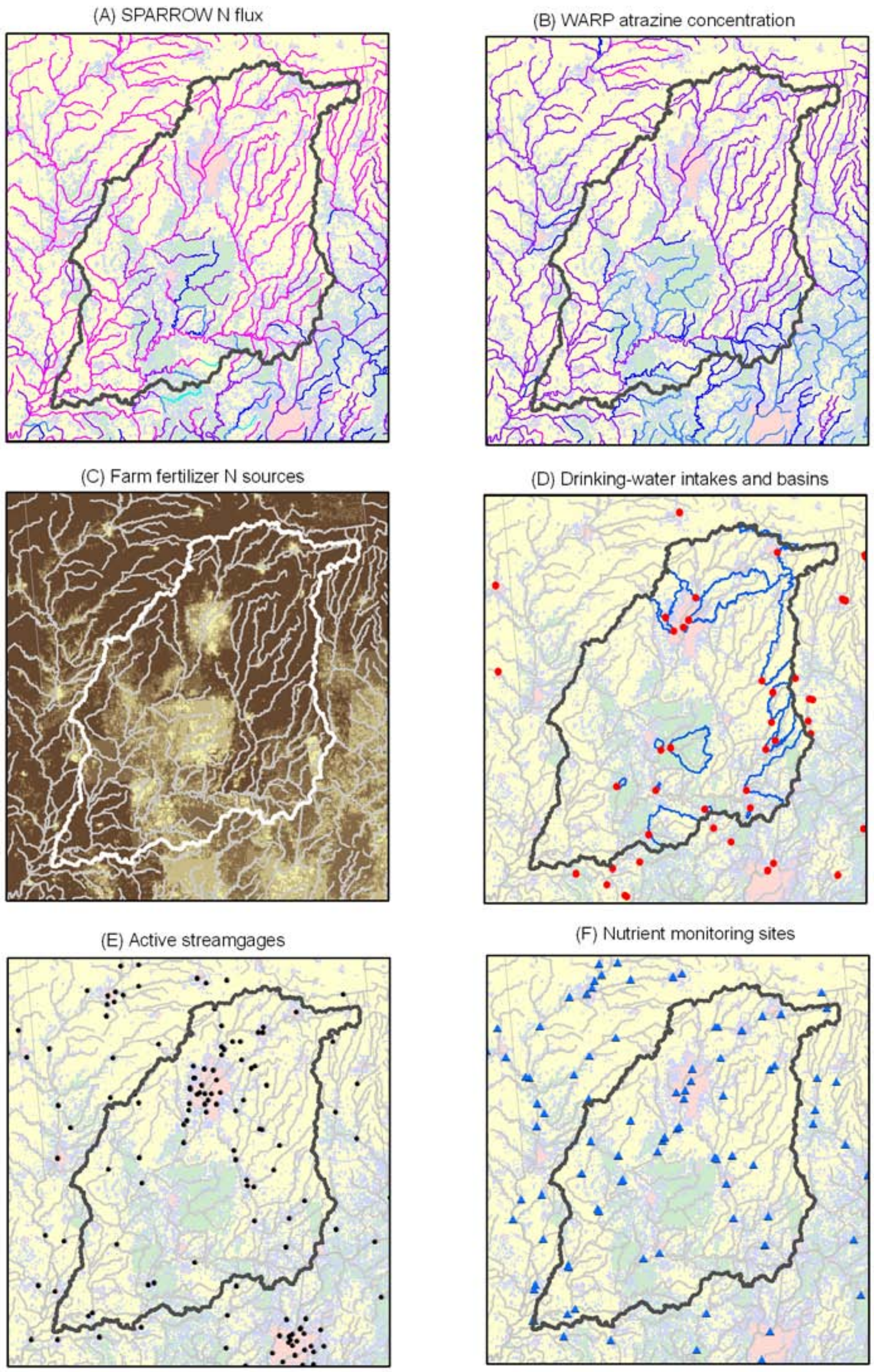


Figure 4.3. Examples of geospatial information available for the White River Basin that would be of use in an Integrated Watershed Study (all maps include land use in the background): (A) estimates of total nitrogen flux in streams from national SPARROW model, (B) estimates of atrazine concentration from national WARP model, (C) farm fertilizer inputs of nitrogen, (D) locations of drinking-water intakes and associated contributing basins, (E) locations of active streamgages, (F) locations of nutrient monitoring sites (USGS and other agency sites).

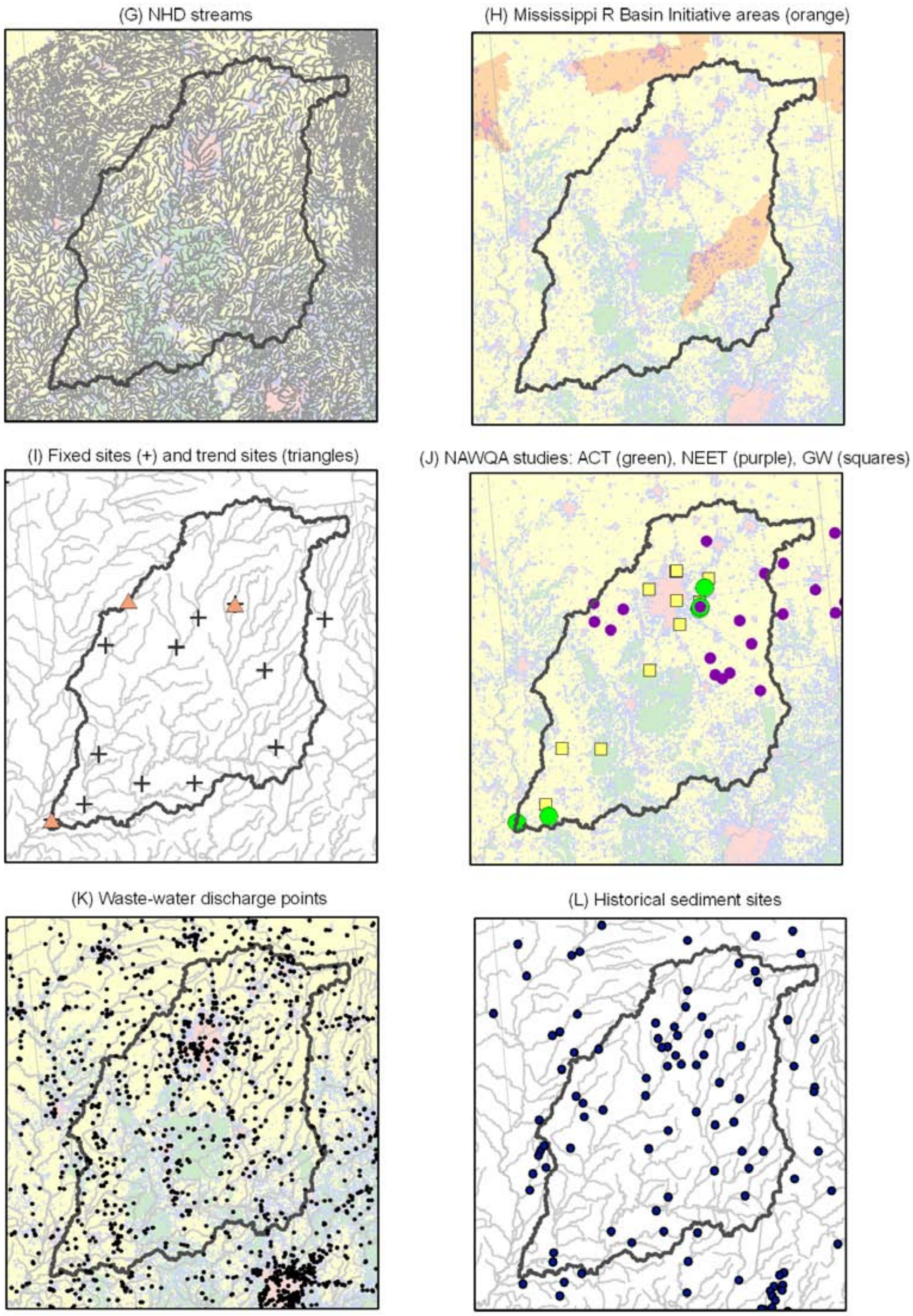


Figure 4.3 (continued)-Examples of information available for the White River Basin that would be of use in an Integrated Watershed Study (all maps include land use in the background): (G) high resolution National Hydrography Dataset (NHD) stream network that can be used to enhance models, (H) location of the U.S. Department of Agriculture Mississippi River Basin Initiative (U.S. Department of Agriculture,, 2009) area located within the White River IWS area, I) locations of fixed and trend monitoring sites, (J) locations of prior NAWQA studies including ACT and NEET topical study sites, flow-path studies, and wells from land-use study networks, (K) location of wastewater discharge points, and (L) sediment monitoring sites .

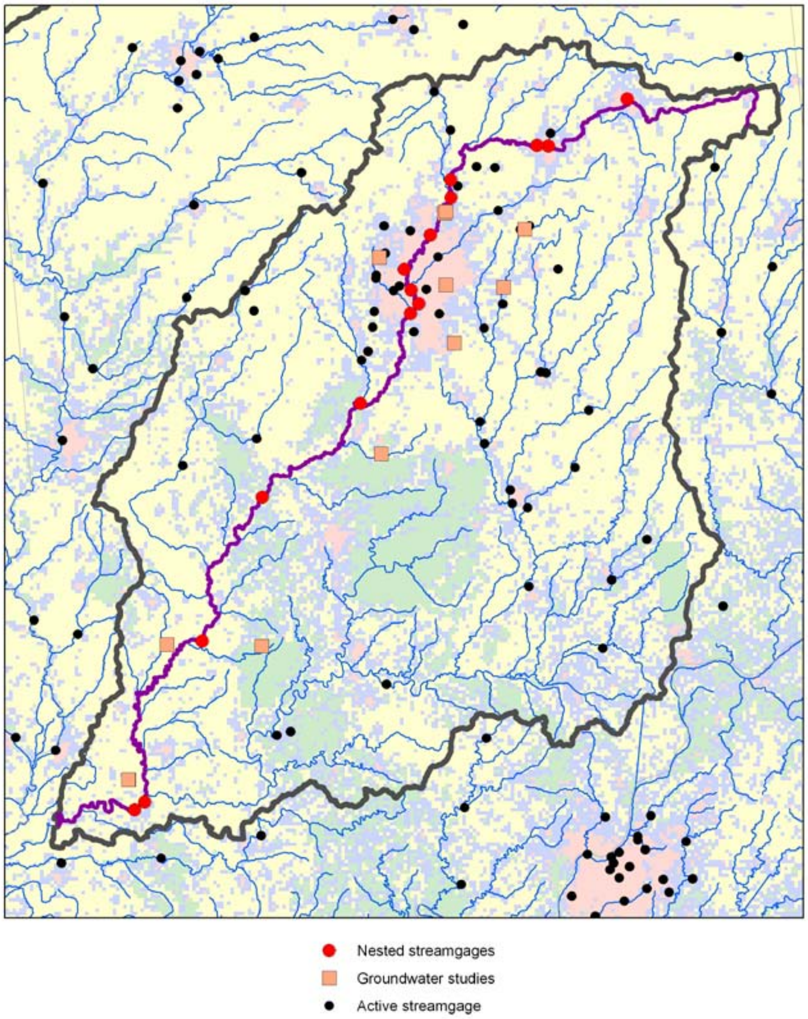


Figure 4.4. Map of the White River Basin showing proposed nested streamgages (red) that could be added to the water-quality monitoring network and used to track fluxes along a river corridor (purple) and to deduce the impact of varying land use, management practices, and watershed characteristics on the fate of contaminants, nutrients, sediment, and streamflow. Local groundwater flow-path studies and regional model results will be used to determine the influence of groundwater processes and fluxes on surface water quality.

The enhanced IWS monitoring network would provide the opportunity to:

- Compile water budgets, and contaminant, nutrient, and sediment mass budgets along the river corridor
- Examine how the fluxes of selected contaminants, nutrients, and suspended sediment differ with land use and natural factors
- Evaluate how the flow regime changes in response to human activities and natural factors
- Evaluate how changes in the flow regime affect transport and fluxes of contaminants, nutrients, and sediment

- Compile regularly updated (monthly, seasonal, annual) data on chemical or nutrient application rates, water use, and other human activities or natural factors that change on a regular basis

Applying and developing modeling tools will be a key element of the IWS analysis. Modeling efforts will include:

- Examining the reliability of national and regional scale NAWQA regression/geospatial models such as SPARROW and WARP, as well as USDA watershed models such as SWAT and AGNPS (Bingner and Theurer, 2001), that have been developed to track sources of contaminants, their relation to land use and natural factors, and the relative contributions of basins to contaminant and nutrient processing, and sediment erosion/deposition. As illustrated in Figures 4.3 A and B, predictions of nitrogen flux and atrazine concentrations for detailed river networks are available from national and regional-scale regression/geospatial models. These predictions represent average values based on many years worth of monitoring data at a limited number of sites across the nation. Enhanced data collection within the IWS areas will make it possible to examine the local uncertainty in these average predictions, the causes of uncertainty, the range of deviation of annual and seasonal variability from average predictions. This analysis will identify the enhancements needed to reduce uncertainty in model predictions, and also indicate the factors that must be incorporated into the models to provide dynamic predictions of annual and seasonal variations in fluxes and concentrations.
- Improving representations of groundwater contributions, management practices, and watershed storage and transformation processes in regression/geospatial models, based on results of above analysis, to develop the ability to predict annual and seasonal trends in water quality. NAWQA has been successful in estimating average fluxes of nutrients through large-scale river networks and identifying the sources of these nutrients using SPARROW. A goal of Cycle 3 is to develop SPARROW-like dynamic regression/geospatial models that have the capability to estimate annual and seasonal fluxes, and to identify the factors controlling the temporal variability in fluxes and concentrations. The data collections and conceptual understandings developed in the IWS areas will be used for the development and testing of these models. Ultimately, the goal is to take these models that have been tested in the IWSs and apply them across the Nation. Estimates of groundwater flows and fluxes will be determined using a range of techniques including baseflow separation and output from regional groundwater models.
- Applying and testing the ability of watershed-scale process models such as Precipitation Runoff Modeling System (PRMS; Leavesley and others, 1983) and Coupled Ground-Water and Surface-Water FLOW model (GSFLOW; Markstrom and others, 2008) to reproduce system behavior at multiple-scales within the IWS (including the IS as explained below). These models will be used to help identify the key processes and factors that influence watershed water-quality responses at multiple scales. This knowledge will be used to identify the key factors and processes that must be incorporated into the dynamic regression/geospatial models. The role of surface water-groundwater interactions on watershed water-quality will be examined as part of these modeling efforts.
- Using regression/geospatial and watershed process models to understand the human activities and natural factors that result in observed patterns and trends within the IWS. These models will be tools for integrating knowledge of flow systems, sources, transport and transformation processes into a conceptual and quantitative understanding of how land use, water use, management practices, climate and watershed characteristics are related to historic and current water quality patterns and trends observed in the IWS.

Planned Outcomes:

- Understanding of the fate of contaminants, nutrients, and sediment as they move through a large, complex watershed.
- An understanding of the watershed characteristics that determine the water-quality response of a watershed to applied stressors.
- Dynamic watershed-scale models that explain the combined factors that result in observed seasonal and annual concentrations and fluxes for sub-basins within the watershed, and the aggregate at the outlet.
- Assessing the effects and effectiveness of urban and agricultural management practices on water quality (using models).
- Annual reports summarizing data collected, progress made, and any publications released.

Example of an Intensive Study for Sediment and Nutrient Transport

Previous studies have shown that headwater streams play a dominant role in reducing nutrients due to in-stream processing and transformation. Thus, a detailed understanding of the factors controlling contributions of headwater streams to downstream nutrient and sediment transport must be part of our watershed studies. The IS for sediment and nutrients is designed to answer the following questions:

- What are the dominant pathways responsible for the transport of nutrients to streams and how have land-use practices influenced these pathways?
- How do stream habitat and riparian modifications affect nutrient and sediment transport and nutrient processing?
- How are nutrient and sediment transport and ecosystem processes influenced by management practices, and can the outcomes of changes in management practices that either increase or decrease landscape alteration be predicted?
- What watershed characteristics influence nutrient pathways and processes, and are these characteristics effective predictors of the susceptibility of streams to nutrient enrichment?
- What watershed characteristics influence the erosion, transport, and deposition of suspended sediment?

Questions will be addressed using a combination of paired IS in small watersheds (50-150 km^2) that are nested within a larger IWS basin (fig. 4.2). The paired basins will include one small watershed that is relatively undisturbed and one in which landscape practices have altered nutrient and sediment loading. Due to the complexity and time required to address this question, this study will be done in only three IWS but for an extended period of time (5-10 years). The advantages of focusing on a few long-term sites are: (1) there is a substantial investment in monitoring infrastructure at startup, (2) several years of operation will facilitate compilation and analysis of retrospective data on chemical use, fertilizer and manure application, sedimentation, and land-use practices, (3) maintaining a long-term focus on a particular watershed will facilitate partnering with other USGS programs (NRP, Toxics, etc) and external agencies (USEPA, USDA, NEON, Universities) on collaborative studies, and (4) such sites may be useful in assessing gradual, longer-term trends, such as climate change or sustained development.

Three pairs of IS watersheds will be established in three IWS basins that span a variety of physiographic areas with varying levels of landscape development. The study will include looking at antecedent conditions in the watershed and how land use, flow, and sediment and nutrient loading have potentially changed ecosystem condition. Although specific IWS have not yet been identified, there will be a western, central, and eastern IWS in settings that capture a representative range of climatic conditions and land-use practices and that have high transfer value. Intensive studies will be have high and low-intensity phases and will be implemented on a rotational basis.

Approach

The paired basins for the sediment and nutrient transport IS will have reaches that extend for 2-5 km and will be gaged near the upper end of the basin and at the mouth (fig. 4.2). A longitudinal design will also be incorporated to discern how these processes change as water moves from small headwater systems into larger river systems. Due to the complexity of this study, more detailed studies will be done in the smaller IS and lower levels of data collection will be done at downstream sites. The larger river gaged sites and some of the IWS gaged sites will be NFSN sites, which will enable findings from the IS study to be put in context with findings at other IS sites.

IS in the small watersheds will characterize the hydrology, sediment sources and transport, surface water and groundwater nutrient transport, nutrient transformations, assessments of stream-channel form and stability, and ecological interactions with nutrient processing. Intensive investigations will be repeated periodically at a site in order to elucidate temporal patterns and better understand changing processes. Data collection will be maintained at a lower level between intensive investigations. Continuous data collected at the gaged sites will include flow, turbidity, conductivity, and dissolved oxygen whereas samples for analysis of suspended sediment concentrations and nutrients (N, P, C) will be collected approximately monthly in order to calculate a suspended sediment and nutrient mass balance in each of the two IS paired basins. The amount and type of data collection may vary according to region-specific factors affecting nutrient and sediment transport and ecosystem processes.

The influence of groundwater on nutrient transport and transformations will be characterized by the use of flow-path studies in each IS to determine the quantity, age of groundwater and the quantity and rate of transport of nutrients from groundwater to surface water. These studies will be complemented by instream piezometer studies to determine nutrient exchange with shallow groundwater. The fraction of nutrients derived from groundwater will be determined by coupling estimates of base flow with measured nutrient concentrations in groundwater. Water levels will be measured at wells throughout the IS portion of the IWS as input for the development of local groundwater flow models.

Instream studies to address nutrient transformations and ecological processes include sediment denitrification experiments, biogeochemical cycling of N, P, and C, stream metabolism, and other process-related measures. Several methods will be used to study the interactions of nutrient processes and biota, including primary and secondary production, trophic interactions, and the food quality of primary producers using lipid analysis methods. The influence of nutrients on biological condition will be assessed using natural and artificial substrates. While nutrients in the water column are an important part of this study, nutrients in sediment will also be assessed due to their effect on macrophyte growth.

Studies to address sediment transport through IS and IWS basins will utilize retrospective data compilation and collection of new data on suspended-sediment concentrations and loads, stream stability and floodplain deposition, and analysis of sediment sources. Retrospective and GIS data will categorize stream segments in relation to natural factors that influence sediment transport processes (i.e. slope, valley type, sinuosity, soils, geology, etc). Historical aerial photography and changes in stream geometry (at existing USGS streamgage locations or other historical surveys) will be analyzed to better understand how historical land-use practices and climate may have influenced sediment loading and stream-channel migration. Concentrations of suspended sediment in water samples collected periodically at streamgage locations will be related to continuous measurements of turbidity to produce hourly (or smaller) estimates of suspended-sediment concentration and load, and will be compared to concentrations in historical sediment samples to identify potential trends. Periodic stream geomorphic surveys will be conducted to characterize areas of sediment erosion and deposition in relation to hydrologic condition. Predominant sediment sources can be characterized at headwater and downstream locations by comparing chemical and radiochemical signatures of suspended sediments to hypothesized sediment sources (such as surface and channel-bank soils).

A longitudinal design will be used to integrate the small-scale IS basins with the larger-scale IWS basin. This will permit a better understanding of how nutrient and sediment transport and transformations change as stream size increases. The longitudinal approach will also permit an assessment of how riparian and near-stream land uses influence nutrient and sediment transport along the stream system. Studies at larger streams will rely more heavily on modeling water chemistry and stream discharge (e.g., LOADEST, metabolism, base-flow index).

Planned Outcomes:

- Develop coupled groundwater and surface-water models to predict the effect of climate and land-use changes on the stream and groundwater quality.
- Assist SPARROW modeling efforts by determining rates of nutrient transport and retention. These rates will be used to improve parameter estimates used in SPARROW models for headwater basins.
- Assess the effectiveness of management practices on the processing and export of nutrients and sediments along a river corridor.
- Determine the age distribution of nitrate in streams and how it varies as a function of stream order (longitudinally) and land-use alteration.
- Develop a methodology for assessing the vulnerability of streams to legacy sources using the process-based understanding of nutrients transport.

Groundwater Studies

In Cycle 3, NAWQA will focus on groundwater resources needed for public and domestic drinking supply, and groundwater contributions to surface water. Evaluating the susceptibility of aquifers used for drinking-water supply to water-quality degradation caused by human activities and natural factors requires an understanding of the groundwater flow system, the loading history of anthropogenic contaminants; the mineralogy, redox state, and pH within the aquifer system, and the distribution of groundwater residence times. Additional complications can arise because supply wells can draw water from different parts of the aquifer system, thereby producing a mixture of waters that may not reflect a linear combination of the sources. Given these complexities, Cycle 3 studies will be conducted from a hydrogeologic-systems perspective that considers the three-dimensional and temporal character of groundwater flow systems, and will be conducted over a range of nested, spatial scales (local to regional to Principal Aquifer; fig. 4.5). These studies will incorporate data previously collected by NAWQA and others; will provide for collection of new data as needed; will utilize quantitative groundwater flow and transport modeling; and will utilize statistical relations between groundwater quality and hydrogeologic characteristics. Groundwater simulation models developed at regional scales and statistical-regression/geospatial models developed at national scales in Cycle 2 will provide the basis for modeling contaminant distributions in Cycle 3.

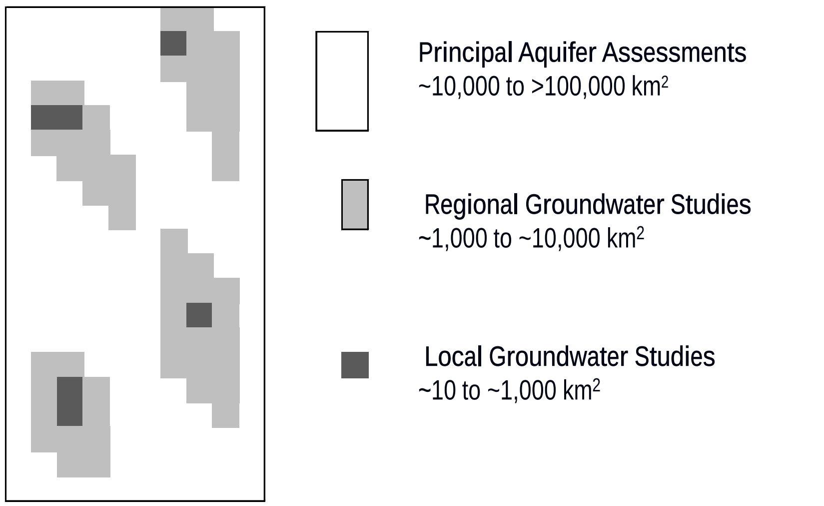


Figure 4.5-Nested spatial scales for Cycle 3 groundwater studies. Principal Aquifers (or groupings of Principal Aquifers) will be the primary organizational unit, with Regional Groundwater Studies and Local Groundwater Studies conducted within the Principal Aquifers.

In Cycle 3, NAWQA groundwater studies will address key scientific questions in five topical areas:

- Trends in Groundwater Quality: How is groundwater quality changing in the depth interval used for domestic supply? How is groundwater quality changing in the depth interval used for public supply? What are the hydrologic and geochemical processes responsible for attenuating or exacerbating these changes?
- Legacy Contamination: To what extent will legacy contaminants, such as nitrate and solvents, impair the continued use of groundwater at depth intervals used for domestic and public supply?
- Vulnerability of Groundwater to Degradation: What is the vulnerability of aquifers used for domestic and public supply to contaminant sources introduced at the land-surface? What is the vulnerability of these aquifers to natural contaminants? (Vulnerability is defined as the likelihood of detecting a contaminant at a concentration greater than human-health benchmarks or at some ratio deemed protective of human health from a monitoring perspective such as one tenth or one hundredth of a human health benchmark).
- Effects of Hydrologic Changes: How does groundwater quality change in response to changes in the hydrologic cycle, and over what times scales do those changes occur? Hydrologic changes can include increases in recharge due to the use of imported surface water, acceleration of the movement of water through the hydrologic cycle resulting from groundwater pumping and irrigation, artificial recharge, aquifer storage and recovery, and, water reclamation and reuse.
- Interactions of Groundwater and Surface Water: How do groundwater contributions to surface water affect stream-water quality? Groundwater can be a significant source of water to streams, particularly during base-flow conditions, and can be a source of contaminants to those streams. In general, the volume of water in the groundwater system is large relative to the volume of water in

streams, and therefore groundwater can be a long-term source of contaminants to surface water systems. For example, in many areas of the Nation nitrate has accumulated in groundwater over a period of several decades and the contaminated groundwater may contribute nitrate to streams over a period of decades to centuries.

The above questions will be addressed by developing a hydrogeologic systems approach for evaluating groundwater quality that will account for the three-dimensional and temporal character (groundwater residence time) of groundwater flow systems, and the external driving forces on, and internal characteristics of, groundwater flow systems. External driving forces include hydrologic and contaminant inputs. Internal characteristics include physical properties, aqueous-phase chemical properties, mineral composition, etc. Models are a key part of this approach. Four levels of model sophistication will be used. For each level of sophistication, field data would be used to develop and calibrate the model(s):

- Regression/geospatial models -- NAWQA has successfully used regression/geospatial models for evaluating the distribution of contaminant concentrations in groundwater. An important aspect of those models is incorporation of spatially distributed explanatory factors. In Cycle 3, regression models will also include hydrologic position and groundwater residence time as explanatory factors for groundwater quality and as surrogates for other factors that can affect groundwater quality, such as redox state. In turn, this will require development of straightforward methods for estimating hydrologic position and residence time.
- Groundwater flow and particle tracking models-- These models would be based, to a large extent, on models previously developed by NAWQA and the USGS Groundwater Resources Program. The models would provide estimates of hydrologic position and residence time.
- Groundwater flow and solute transport.-- These models can directly simulate the transport and transformation of contaminants of concern, such as salinity, or can simulate factors that affect groundwater quality such as groundwater age.
- Simulation models of groundwater flow and reactive transport-- The reactive transport component could be simplistic, treating sets of reactions as if they followed simple rate laws, or the reactive transport component could be fully simulated.

Approach

In Cycle 3, NAWQA will implement multi-scale studies that use monitoring data, process-simulation models, and statistical-regression/geospatial models to develop an understanding of the relation between contaminant concentrations and the sources and processes affecting groundwater quality.

Monitoring data will include contaminant concentrations, indicators of geochemical condition (e.g. redox state, pH), tracers of groundwater age (residence time), and surrogates for contaminant source (e.g. land use, fertilizer application history). Process-simulation models will include one-dimensional vadose zone transport (P-GWAVA; Nolan and Hitt, 2006), groundwater flow with particle tracking (MODFLOW/MODPATH; Harbaugh, 2005), solute-transport (MOC3D; Konikow and others, 1996; MT3D; Zheng, 1990), dual-domain transport (MT3DMS; Zheng and Wang, 1999), and coupled models of flow and reactive transport.

Multi-scale groundwater investigations will be conducted as follows:

- Implement multi-scale studies at a sufficient number of locations that are representative of the Nation. At each location, the scale will range from local (~10 km^2 to ~ 100 km^2) to regional (MASs, ~1,000 km^2 to ~10,000 km^2) to Principal Aquifer (Principal Aquifers and groupings of Principal Aquifers, ~10,000 km^2 to >100,000 km^2) (fig. 4.5).
- Develop statistical-regression/geospatial and process-simulation models at local, regional, and Principal Aquifer scales. The level of model sophistication will depend on scale: it is anticipated that coupled flow and reactive transport models will be developed only at local scales, whereas flow and particle tracking would be developed at all scales. Information gained from process-simulation at a given scale will be used in the development of regression models at larger scales.
- Develop exceedance maps for selected anthropogenic and natural contaminants at the depth interval used for domestic supply, and at the depth interval used for public supply. The maps would be developed using statistical-regression/geospatial and process-simulation models at local, regional and Principal Aquifer scales. Multiple maps would be produced for each depth interval of interest at each of the multi-scale study areas. In some areas, the depth interval for domestic wells corresponds to the depth interval for public supply wells.
- For a given modeling approach (regression or process simulation), compare exceedance maps produced at the different scales of spatial resolution. These comparisons would provide a measure of the uncertainty introduced with representing groundwater flow systems at decreasing levels of resolution.
- For a given spatial scale (local, regional, Principal Aquifer), compare exceedance maps produced by the different modeling approaches. These comparisons would provide insight into the relative benefits of using more sophisticated modeling approaches.
- For the study areas where flow and reactive transport models are developed, the comparative evaluations would include this third modeling approach. Comparisons of flow and transport model results with water-quality data and estimates of groundwater age could be used to evaluate the limitations of using regression/geospatial models.

In addition, in Cycle 3, NAWQA will use local and regional scale models to address the issue of how groundwater contamination affects surface water quality. Local groundwater studies will be implemented along groundwater flow paths that terminate at streams; the scale of these studies will likely range from 1 km to 10 km. The primary goal of these studies will be to identify the physical and chemical processes affecting the subsurface transport of contaminants, including nitrate. A secondary goal would be the development of simplified models that account for the major processes affecting contaminant transport and transformation. Regional groundwater studies and models will include the streamflow network, and output from these models will include the location and quantities of groundwater that flows into (or out of) streams. The estimated groundwater volumes can be combined with estimated concentrations to estimate contaminant loads. These estimates can be used with other watershed regression/geospatial and process models being developed by NAWQA in Cycle 3.

Planned Outcomes:

In Cycle 3, NAWQA Groundwater Studies will provide:

- Exceedance maps (fig. 3.1) for selected natural and anthropogenic contaminants that impair the use of groundwater for drinking supply at the depth interval tapped by domestic wells and at the depth interval tapped by public supply wells (fig. 4.6). Exceedance maps would indicate the likelihood of detecting concentrations relative to human-health benchmarks such as MCLs or HBSLs. The maps would be developed at a broad-scale of resolution for the Nation, and at more detailed scales of resolution for selected local areas and PAs. The maps would incorporate existing and newly acquired chemical data, and would be generated by models developed for this purpose. Resource managers and planners will be provided with information on the extent to which groundwater might or might not be available to meet the demands of current and growing populations, and a context for understanding how groundwater quality in their area compares to water quality in other areas.

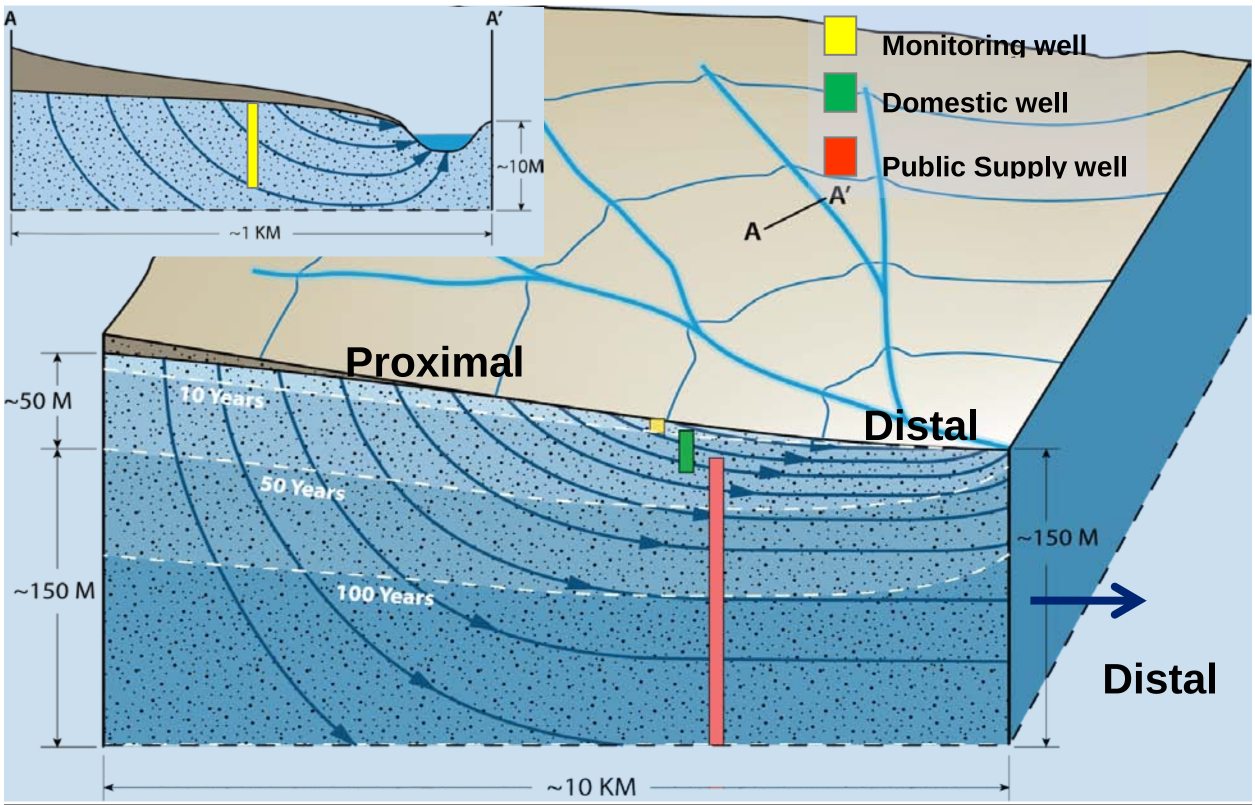


Figure 4.6-Three-dimensional representation of a groundwater flow system illustrating the depth intervals sampled by monitoring, domestic and public supply wells; flow paths and groundwater ages; and, proximal and distal regions of the aquifer. Inset at upper left illustrates small-scale flow path study along transect A-A'.

- Systematic approaches and modeling tools for evaluating groundwater quality from a hydrogeologic-systems perspective. These approaches and tools will be applicable at multiple scales; would utilize hydrogeologic, climate, land-use, contaminant, and water-use data; and will be calibrated with available chemical data. NAWQA will evaluate groundwater quality, not only from a Cartesian (and temporal) perspective, but also from a "parameter-space" perspective. The properties could include lateral hydrologic position (proximal/distal), depth, groundwater age, mineralogy, redox, and pH. Local and regional agencies will be able to use these approaches and tools to develop exceedance maps within their areas.
- For representative areas (and depths) within important Principal Aquifers, evaluation of the magnitude of seasonal (and annual) variability as compared to long-term trends in groundwater

quality. Resolving the magnitude of water-quality responses on different time scales is important for assessing the effectiveness of management decisions and policies.

Technical and Data Support for Goal 2

All activities in Goal 2 have the objective of making the connection between observed water quality and the current and historical human activities and natural factors. This can be achieved only if the spatial and temporal data sets describing the impacts of human activities and natural factors can be assembled. These include (1) historical and current land use, (2) historical and current source inputs, (3) historical and current water budgets, (4) historical and current agricultural and urban practices, (5) historical and current climate, (6) watershed characteristics, (7) aquifer characteristics, and (8) geochemical conditions.

Partnerships for Goal 2

The objectives of Goal 2 for assessing sources, transport, and transformation of key stressors in surface water and contaminants in groundwater and how water quality is affected by human activities and climate change offer significant opportunities for scientific collaboration on study design, sampling and analytical methods, advances in data analysis and modeling applications. Below are highlighted current or desired partnerships that are critical to achieving the Goal 2 objectives outlined for Cycle 3.

USGS Mission Areas and Programs

- Climate and Land Use Change: Research studies conducted under Goal 2 objectives support the USGS Global Change Science Strategy in assessing how climate change and land use affect the four stressors. Findings regarding how climate and land use affect key hydrologic processes, which in turn directly affect key stressors, also support efforts to develop mechanistic and process-based models, understand how climate and land use change affect aquatic ecosystems, particularly through Cycle 3 efforts to expand monitoring at reference watersheds.
- Energy and Minerals, and Environmental Health: Regional Synoptic Studies, Integrated Watershed Studies, Intensive studies, and Local Groundwater Studies will be conducted at scales conducive for partnering with the Toxic Substances Hydrology Program to improve understanding of contaminant transport and transformation in watersheds and aquifers.
- Ecosystems: Integrated Watershed Studies and Intensive Studies will provide scientific infrastructure for leveraging additional research on how aquatic ecosystems respond to important stressors with the following Ecosystem Mission Area Programs (1) Status and Trends of Biological Resources, 2) Terrestrial, Freshwater and Marine Ecosystems, and 3) Fisheries: Aquatic and Endangered Resources. Mass-balance and hydrologic studies that examine nutrient transport and processing have implications for assessing how climate and human activities affect ecosystem services in different watersheds.
- Water: Goal 2 studies represent the logical intersection of NAWQA and National Research Program (NRP) research that is conducted at a variety of scales and in various hydrologic settings built on the foundation of extensive NRP involvement in Cycle 2 topical studies. Considerable expertise exists within NRP that can be leveraged in Cycle 3 of NAWQA. This expertise includes the development and application of new analytical techniques, field methods, modeling tools, and data analysis approaches.

- The “follow-the-water” design of the Integrated Watershed Studies is also compatible with the “focus area study” concept of the WaterSMART Program. There are also good opportunities for NAWQA and WaterSMART to conduct joint collaborative work on ecologic flow requirements.

USGS Groundwater Resource Program (GWRP)

- Assess water availability in important water-supply aquifers: One goal of the GWRP is to provide information regarding the quantity of groundwater available in the Nation’s major aquifer systems. This complements NAWQA objectives of characterizing the Nation’s groundwater quality and plans are being developed to couple GWRP flow models with NAWQA water-quality data to develop water availability estimates that factor in information on groundwater quantity and quality. Results of such modeling can be used to evaluate how groundwater quality may change in response to natural and human stresses.

U.S. Environmental Protection Agency, U.S. Department of Agriculture, and National Oceanic and Atmospheric Administration

- Coordinate modeling of nutrient and sediment transport from source areas to receiving waters: A common goal expressed by strategic plans of all three agencies is to develop models that can identify sources of nutrients and sediments to receiving waters and predict changes in nutrient or sediment delivery over time and space in response to changing environmental conditions. A secondary goal is to link models constructed at different scales. The focus of collaboration would be to link other agency data and models to NAWQA models done as part of the Integrated Watershed Studies, as well as larger scale regional and national models.

U.S. Department of Agriculture

- Evaluate the effects of agricultural management practices on water quality: Through its Conservation Effects Assessment Project (CEAP), the USDA has developed large-scale models to quantify the effects of historical and current conservation practices and programs on the environmental quality of agricultural landscapes. Evaluation of the uncertainty in USDA and NAWQA model estimates will benefit from the comprehensive data-collection efforts of the IWS. The goal of partnering would be to compare modeling approaches, reduce uncertainty in model results, and to provide improved estimates of the effectiveness of past and current management practices at a range of scales.

National Science Foundation National Ecological Observatory Network (NEON) Program

- Assess how biological processes affect the transport of nutrients to stream ecosystems: The STReam Experimental and Observatory Network (STREON) component of NEON is designed to study how stream ecosystems respond to eutrophication and features long-term dosing experiments that complement proposed Cycle 3 nutrient transport studies. Co-location of STREON and NAWQA nutrient studies in one or more IWS is the desired outcome of this partnership.

Chapter 5. Determine the relative effects, mechanisms of activity, and management implications of multiple stressors in aquatic ecosystems (Goal 5).

Outcome: Improve our understanding of the effects of multiple stressors on aquatic ecosystems in regards to their relative influence and how they interact to cause degradation, and how management practices can be used to reduce the effects of stressors.

Products

1. Journal papers on individual stressors, combined effects of stressors, and on the influence of management practices.

2. Regional or national-scale map products where predicted contaminant, nutrient, or sediment concentrations, or the degree of streamflow alteration, are at levels capable of adversely affecting aquatic biota and (or) stream ecosystems (for example, fig. 1.8).

3. Water-quality indicators that can be used to predict the initiation of ecological impairment in response to specific stressors or combinations of stressors.

4. Regional predictive models that incorporate the influence of land use and (or) management practices on the interaction of key environmental stressors and how these stressors affect stream ecosystem condition.

Connections among NAWQA Cycle 3 Goals:

Goal 3 builds upon Goals 1 and 2 by incorporating ecosystem processes and condition into water-quality assessment, understanding, and management. Goal 1 provides the national network for assessing status and trends of water quality, primarily focused on stressor conditions, and Goal 2 builds upon Goal 1 by linking water quality stressors to the anthropogenic and natural factors that influence water quality stressors. Goals 1 and 2 provide the foundation for understanding the complex interactions of land use, climate, management practices, and major stressors (contaminants, nutrients, sediment, and streamflow alteration) and the water-quality or biological measures (indicators) that are best correlated with degraded stream ecosystems. The development of regionally-based predictive models in Goal 3, which predict the effects of stressors and management practices on ecosystem condition, will be applied in Goal 4 to predict the effects of future land use, climate change, and management strategies on stream ecosystems.

Background

Incorporating ecosystem condition into water quality assessments is important for two primary reasons. First, the Clean Water Act lists biological integrity as a key part of water quality and therefore regulatory agencies and resource managers are incorporating biological endpoints into their water quality programs for assessing present condition and for tracking changes due to management practices. In addition, biological processes are key determinants of water-quality conditions in that they influence both the chemical and physical nature of surface waters. For example, initial increases of nutrients often cause an increase in plant production; however, as plant biomass increases it begins to reduce nutrient concentrations and loads due to uptake, along with influencing in-stream habitat (Munn et al. 2010). When stream habitat is altered such that the biological system does not function normally, nutrients will remain elevated in the stream and be transported to downstream systems (Duff et al. 2008). Therefore, in order to effectively manage water quality it is important to understand the interactions of the biological system within the physical and chemical environment, and how management practices influence these interactions. Regionally-based models which can describe and predict the effect of these interactions are needed by resource agencies tasked with managing local water-quality issues. However interactions among multiple drivers, stressors, and ecosystem endpoints represent a substantial challenge toward the development of these models in Cycle 3.

There are several unique challenges for assessing the relative roles of stressors—contaminants, nutrients, sediment, and streamflow alteration—in affecting aquatic ecosystems. Sediment, streamflow variation, and nutrients are essential parts of a natural, healthy stream ecosystem and therefore are not, in and of themselves, detrimental to ecosystem condition. However, when any of these are altered due to human or natural perturbations and deviate from their natural condition, degradation of the stream ecosystem may result. Contaminants differ from the other stressors in that although there are some natural contaminants (e.g. trace elements), most are derived from human activities, and through toxic or endocrine-disrupting effects have the potential to directly affect aquatic life. In order to efficiently manage water resources it is important to know when an individual or combination of stressors causes the initial decrease in biological condition (e.g. threshold) and at what point ecosystem condition moves through identified categories of concern (fig. 5.1). These types of analysis are presently common within specific regions and stressors, but have not been addressed at larger spatial scales or with multiple stressors. Predictive models will be developed at regional scales because there are regional differences in stressors, management practices, and biogeography. Model development and validation will require that stressors be examined through both individual and multi-stressor approaches.

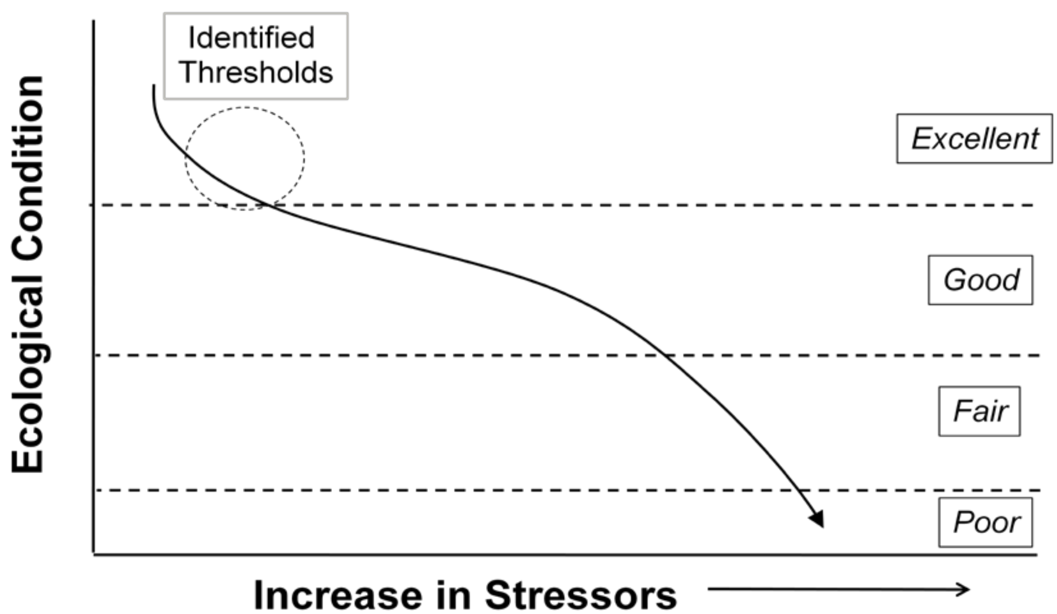


Figure 5.1. Schematic diagram showing the decrease in biological condition as stressors increase.

Objective 5a: Determine the effects of contaminants on degradation of stream ecosystems, which contaminants have the greatest effects in different environmental settings and seasons, and evaluate which measures of contaminant exposure are the most useful for assessing potential effects.

Understanding the effects of contaminants on ecosystem condition is a major challenge in Cycle 3. Contaminants, either individually or as mixtures, are known to occur in streams at levels that pose a threat to aquatic ecosystems. However, the complexity of contaminant mixtures and variable spatial and temporal exposure patterns has resulted in an insufficient understanding of their actual ecological effects, particularly in combination with other stressors. Cycle 3 activities will focus on identifying the appropriate tools for measuring exposure to contaminant mixtures, and determining what the ecological thresholds are for early detection of effects. Studies to address this objective will rely primarily on field based studies, but will use some laboratory testing to select the appropriate measure of contaminant exposure and to guide model development.

Objective 5b: Determine the levels of nutrient enrichment that initiate ecological impairment, what ecological properties are affected, and which environmental indicators best identify the effects of nutrient enrichment on aquatic ecosystems.

Nutrients continue to be a major concern for water-resource managers due to the scale of the problem and the complexity of nutrient cycling and effects. The severity of the problem has led the USEPA to begin developing regional-based nutrient criteria. It is well documented that nutrients can lead to eutrophication, with its associated effects of low dissolved oxygen, increased macrophyte plant growth, and harmful algal blooms. However, there is a general lack of information on what indicators provide an early warning of nutrient enrichment, and how nutrients affect ecosystems through interactions with other stressors. In Cycle 3, NAWQA will focus on determining what measures are most appropriate for use as early warning indicators and how responses differ among regions and their interaction with other stressors. Results from this objective will also be integrated with the nutrient process component of Goal 2, which evaluates how biological processes influence nutrient cycling and loads. Nutrient enrichment indicators will also be included in the predictive models as response variables to enrichment.

Objective 5c: Determine how changes to suspended and depositional sediment impair stream ecosystems, which ecological properties are affected, and what measures are most appropriate to identify impairment.

Sediment has long been cited as an important and widespread cause of stream ecosystem degradation. Changes in the amount of sediment supplied to streams can alter critical streambed habitat and reduce light penetration to benthic communities, thereby affecting primary and secondary production. What is not well understood is (1) if, where, and how streams are impaired with regard to sediment, (2) what measures of suspended or depositional sediment are optimal for quantifying sediment-related impairments on ecosystems, and (3) at what point of sediment disturbance are ecosystems first impacted (e.g., dose-response). Monitoring and studies in Goal 1 and 2 will characterize how legacy and ongoing activities have altered the movement of sediment in streams, but further intensive and regional work is needed to identify indicators of sediment impairment that can be consistently applied and to characterize how these impairments affect various measures of ecosystem condition.

Objective 5d: Determine the effects of streamflow alteration on stream ecosystems and the physical and chemical mechanisms by which streamflow alteration causes degradation.

While assessment of streamflow conditions has always been an important part of NAWQA, particularly in relation to contaminant and nutrient transport, Cycle 3 will assess the effect of streamflow alteration on biological condition at a regional and national scale. This will be done by analyzing data from USGS streamgages across the Nation as well as data from multiple programs, including NAWQA, USEPA, and States. This objective will be addressed using a multi-regional implementation of an established framework for evaluating the Ecological Limits of Hydrologic Alteration (ELOHA, Poff et al. 2010). The ELOHA framework provides a consistent and scientifically-recognized approach to understanding the relationships between altered streamflow and biological condition. The NAWQA study is unique in its application of the ELOHA approach, in a uniform manner, on a national level at thousands of sites.

Objective 5e: Evaluate the relative influences of multiple stressors on stream ecosystems in different regions that are under varying land uses and management practices.

The four individual stressor objectives above provide the building blocks for assessing multiple stressors and developing regional-based predictive models. Addressing this multiple stressor objective will be accomplished by collecting key measures of the four stressors and biological response measures. Quantifying how the four stressors vary across space and time at key locations (such as through paired basin studies and at land-use change thresholds), at multiple spatial scales, and in different environmental settings will allow NAWQA to characterize the relative importance of the various stressors on ecosystem condition. This will help managers better understand how the stressors interact, which are most important in causing degradation in different hydrologic or land-use settings, and which management practices may help in reducing the effects of the stressors. The primary approach for addressing this objective will be by use of statistical modeling; several different approaches will be used to identify the relative influence of different stressors in affecting specific measures of ecosystem condition, as well as relating the magnitude of the stressor effect on ecosystem condition to land use, management practices, or natural factors.

Policies and Stakeholder Concerns Driving Key Management Questions

Although the ultimate motivation driving management questions is to protect and improve the quality of aquatic ecosystems, management strategies focus on the control of stressors and, thus, stakeholder concerns are often expressed in terms of specific stressors.

Contaminants in water and sediment can result in lethal toxicity, potentially causing fish kills, elimination of sensitive species, or reduced diversity. Alternatively, contaminants may cause sub-lethal effects, such as endocrine disruption, reproductive impairment, growth inhibition, or increased susceptibility to disease. Both lethal and sub-lethal effects can cause impairment of ecosystems compared to natural conditions. Yet, lack of suitable data on contaminants in USEPA and State 305(b) surveys has prevented examination of the same kinds of linkages to biological effects as has been possible with other, more commonly measured stressors.

In streams and rivers, adverse ecological effects of nutrient enrichment include increased algal and macrophyte biomass, which can result in periodic reductions in dissolved oxygen, loss of fish habitat, release of toxic metals from sediments, and increases the availability of substances like ammonia. Nutrients are also associated with the occurrence of harmful algal blooms, which can produce toxins that affect fish and human health. As nutrients move downstream they create problems for coastal waters, resulting in hypoxia and toxic algal blooms. The spread of dead zones (areas of low dissolved oxygen) in coastal estuaries is considered a key stressor on marine ecosystems and thus an issue of global concern; formation of these areas is directly linked to increased fluxes of nutrients from rivers.

The 2004 Clean Water Act 305(b) report lists sediment as the sixth leading cause of impairment to streams and rivers in the United States. Sediment is related to the five other leading causes of stream impairment in that (1) sediment transports pathogens, organic matter, and nutrients (the first, third, and fifth most reported impairments), and (2) sediment is a principal cause of habitat alteration and biological impairments (the second and fourth most reported impairments). In addition to the physical impact of alterations to sediment transport, sediments are a primary transport mechanism for phosphorus, trace elements, and a variety of organic contaminants (Horowitz, 1991; Rasmussen and Ziegler; 2003, VanMetre and Mahler, 2005). Altered sediment transport is also a known or suspected cause of habitat degradation to endangered mussel, fish, and bird species.

A national assessment of streamflow alteration found that nearly 90% of monitored sites experienced altered magnitudes of minimum flows, maximum flows, or flow variability (Carlisle and others, 2010). There is abundant indirect evidence that physical habitat alteration is commonly the ultimate cause of ecological impairment. Indeed, at least one-third of ecologically impaired (as designated by state assessments) rivers and streams across the Nation are affected by modified physical habitat, water temperature, and streamflow (U.S. Environmental Protection Agency, 2008). In addition, more than half of impaired rivers and streams are affected by excessive sediment and nutrients and oxygen depletion (U.S. Environmental Protection Agency, 2008), which are often caused or exacerbated by altered streamflows (Bunn and Arthington, 2002).

With a backdrop of clear-cut documentation of widespread biological impairment of streams, but uncertain assignment of specific causes in many situations, each type of stressor needs to be characterized and understood in relation to its relative role in affecting aquatic ecosystems. Without an understanding of the role of each type of stressor, their relative importance compared to each other, and their interactions, management strategies aimed at improving aquatic ecosystems cannot be reliably and efficiently devised or implemented.

Understanding the relative importance of different stressors on ecosystem condition, related ecosystem services, and developing predictive models that relate stressors to effects is essential for improving management. Selected examples of management-relevant questions illustrate the broad range of applications:

- What is the importance of various physical and chemical stressors on ecosystem condition, and which are most important to control?
- Which management strategies will most effectively improve and protect ecosystem condition?
- What ecological measures are most appropriate as early warning indicators for assessing ecosystem degradation due to physical or chemical stressors and for monitoring recovery after changes in management practices?

- What levels of stressors can be tolerated by aquatic ecosystems and how can this information be used to develop regional thresholds for use in management issues such as nutrient criteria?

NAWQA Progress in Cycles 1 and 2

The majority of work in Cycle 1 focused characterizing the occurrence and distribution of nutrients and contaminants (mainly pesticides) in the Nation's streams. Ecological studies included the collection of algae, macroinvertebrate, and fish communities at ecological status and trend sites; these data provided insight regarding current stream condition and how aquatic communities change over time in relation to habitat or chemical measures. Synoptic studies targeting various ecological questions were done within individual study units to provide broader spatial or temporal information on a specific stressor or hydrologic condition (e.g. spring runoff). The degree to which a specific biological study integrated water chemistry into the study varied greatly; however, these studies provide important insight into the response of algae, macroinvertebrate, and fish assemblages to varying land uses, in-stream habitat, and some chemical measures, such nutrients or pesticides. Cycle 1 provided the ecological data for the beginning of modeling efforts that greatly expanded in Cycle 2.

New ecological efforts in Cycle 2 included two topical studies on urban and agricultural streams, along with a major push in the development of regional and national statistical models. The topical team efforts included a study called Effects of Urbanization on Stream Ecosystems (EUSE) (http://water.usgs.gov/nawqa/urban/), which examined urbanization and the quality of aquatic ecosystems in metropolitan areas. This study showed that urban impairment is the result of a suite of co-occurring stressors that change over the urban gradient, but in different ways among various regions of the country. The second topical study was the NEET study and its primary focus was examining the effects of nutrients on the ecology of agricultural streams (http://wa.water.usgs.gov/neet/). The NEET study found that (1) concentrations of nitrogen and phosphorus in agricultural streams often exceed proposed USEPA Regional Nutrient Criteria and thus indicate potential eutrophication, yet algal biomass is often less than expected due to habitat alterations; (2) benthic algae show a more rapid initial response to increases of nutrients than macroinvertebrates or fish, and overall may be a better indicator of nutrient conditions; (3) denitrification rates in surface water were less than 5 percent of surface-water nitrate loading rates and were unable to significantly reduce downstream transport of nitrate; and (4) legacy groundwater inflow can continue to be a source of nitrogen to streams years after nutrient applications to cropland is stopped.

Large-scale modeling efforts were included as part of the two ecological topical studies, as part of the surface water status and trends program within Major River Basins, and at the National scale as part of ecological synthesis. A brief summary of each effort is presented below.

- Urban Modeling: The Urban Ecology Topical Team is involved in several ecological modeling activities. Bryant and Carlisle (in review) used regression approaches to identify multiple stressor models for predicting condition of algae, invertebrates, and fish communities and how responses differ among varying urban areas (fig. 5.2). Qian and others, (2010), Cuffney and others, (in review), Kashuba and others, (2009), and Kashuba and others, (2010) used hierarchical modeling to examine the effect of regional scale processes on the relation between watershed-scale urbanization and stream macroinvertebrates. Last, Kashuba and others (in review) used a Bayesian network modeling approach to link watershed and reach scale stressors with biological condition.

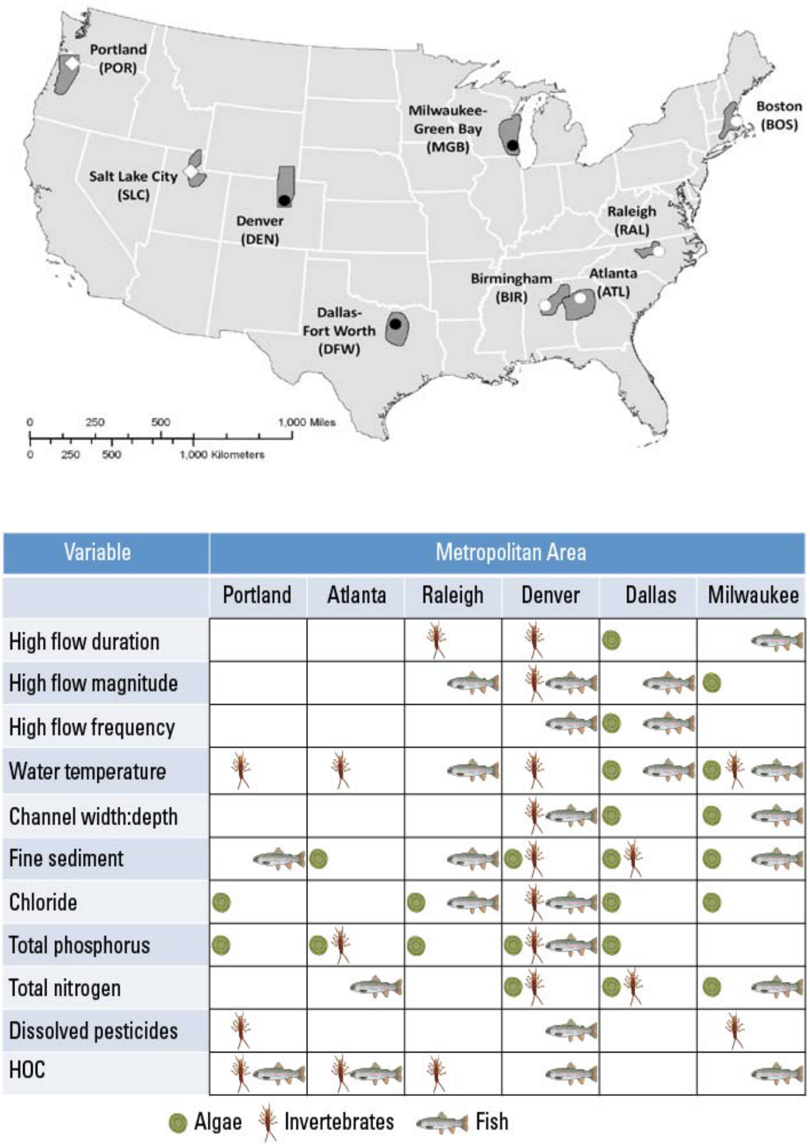


Figure 5.2. Location of Effects of Urbanization on Stream Ecosystem (EUSE) studies and results of multiple regression modeling for identifying influence of multiple stressors on algae, invertebrate and fish communities in six urban areas (Bryant and Carlisle in review). Figure indicates which of the three taxa (algae, invertebrates or fish) respond to varying stressors in different urban settings.

- Nutrients in Agricultural Streams: The Effects of Nutrient Enrichment on Stream Ecosystems (NEET) Topical Team has been focusing on the use of Structural Equation Modeling (SEM) for examining the relationships between land use activities, riparian characteristics, nutrients, and in-stream biological conditions. SEM was used to develop a set of causal models and examine the direct, indirect, and total effects of agriculture on biological integrity acting via different nutrient and habitat pathways (Riseng et al. in review). The SEM work was done using 226 sites distributed across eight NAWQA study units (fig. 5.3 top). The national model (fig 5.3, bottom) provided an integrated view of the relationship between crop cover, riparian cover, and biological integrity. Cropland primarily affects benthic communities by altering stream habitat and secondarily by imposing water quality stresses, particularly nutrients. This national model provides managers with a better understanding of the relationship between land use, nutrients and biota, as well as a tool for assessing the influence of land use/riparian management on water quality and biological integrity. Regional models (West, Midwest, and East) were also developed which provide more specific interactions and management implications. These models can be used to predict how changes in land use/riparian practices or in-stream conditions can influence biological conditions.

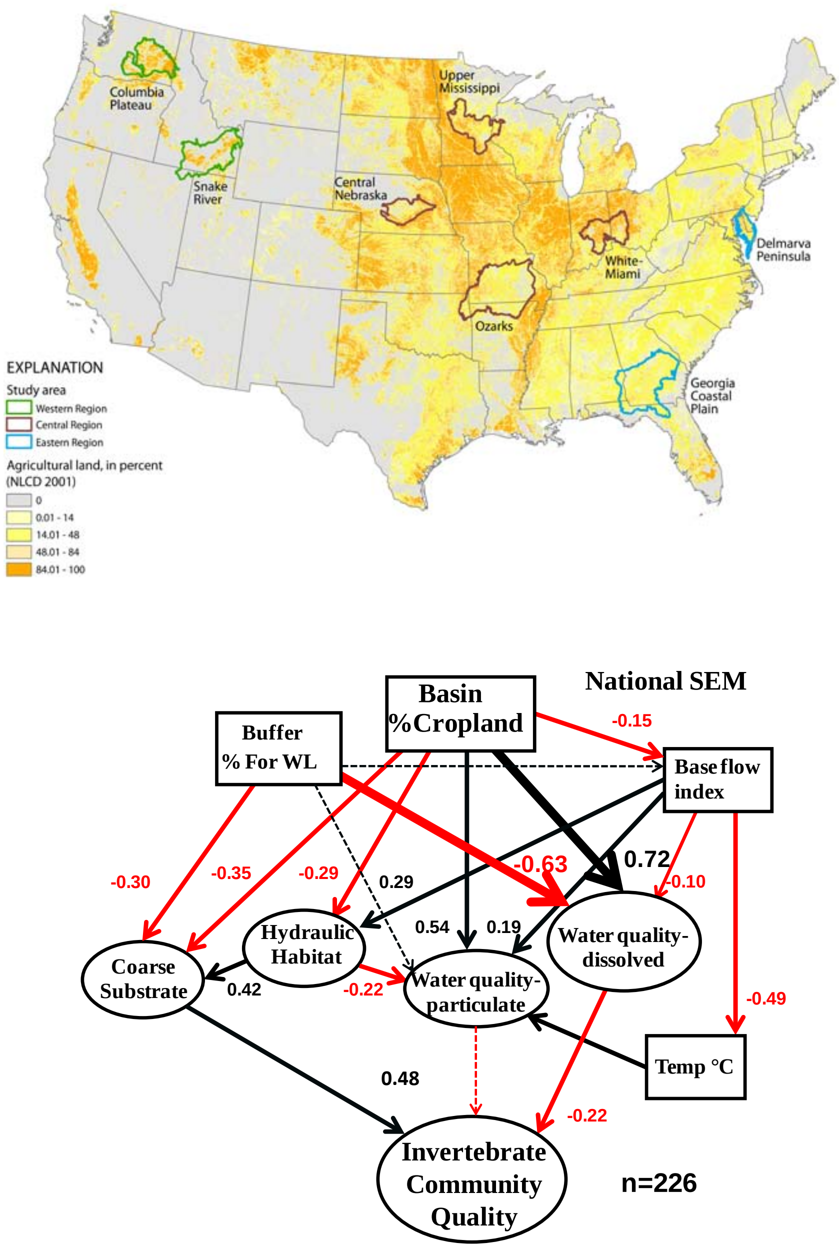


Figure 5.3. Location of the eight agriculturally dominated NAWQA study units included in the Nutrient Effects on Stream Ecosystems topical study (top), and the National SEM (Structural Equation Model) (bottom) developed from data collected at the eight study sites. Values between environmental variables are calculated correlations (negative correlation = red; positive correlation = black) (Buffer for % WL = percent forested wetland in buffer area).

- Major River Basins/Regional Studies: Ecological modeling in Major River Basins is diverse due to the differences among the regions and the variety of ecological questions being addressed. Two recent papers illustrate this diversity. Kennen et al. (2010) used a variety of multivariate statistical analysis to assess the effects of landscape and streamflow alteration on stream macroinvertebrates in northeastern streams. Results indicated that urbanization patterns alter streamflow sufficiently to negatively impact stream biota. Waite et al. (2010) compared several watershed disturbance predictive models for stream invertebrates in the western United States. The study concluded that only a few explanatory variables were required to develop significant models and that all models required a combination of land use and natural explanatory variables.

- National-scale Streamflow: A recent study found that human impacts on hydrology are widespread, with up to 86% of streams having altered flow patterns (fig. 5.4). Results showed that diminished flow magnitudes were the primary predictors of macroinvertebrate and fish condition with the streams (Carlisle et al. 2010). Annual and seasonal cycles of water flows — particularly the low and high flows — shape ecological processes in rivers and streams. An adequate minimum flow is important to maintain suitable water conditions and habitat for fish and other aquatic life. High flows are important because they replenish floodplains and flush out accumulated sediment that can degrade habitat.

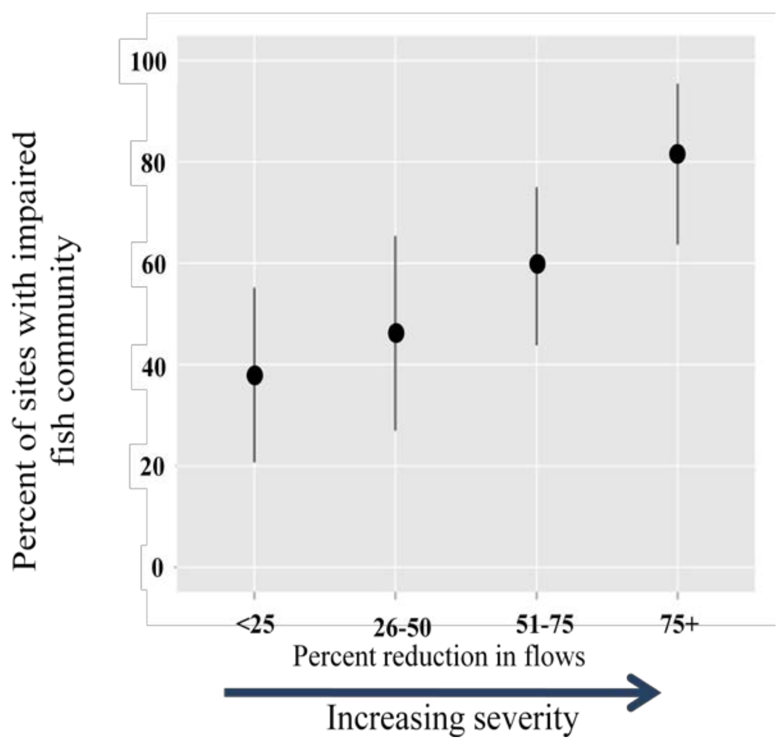


Figure 5.4. Relation between percent reduction in in-stream flow and the percentage of stream sites with impaired fish communities. The graph shows a positive correlation between percent reduction in flow increases and the number of streams with impaired fish communities.

These examples provide a sample of the many efforts that have either been published or are presently in progress. These efforts are the building blocks for the development of predictive models in Cycle 3.

NAWQA's Role and Future Direction in Cycle 3

Although NAWQA, USEPA, States and academics have made large gains in understanding the influence of individual stressors on ecological systems, there is a lack of understanding of which stressors are most detrimental under different conditions, the interactions and effect mechanisms of the stressors, and the influence of various management practices in reducing impacts of stressors on aquatic ecosystems. Therefore, Goal 3 studies will focus on research that will result in the development of ecologically-based predictive models that will assess the interactions of different stressors in various environmental settings and predict how specific management practices will influence ecosystem condition.

Approach

Goal 3 objectives will be addressed using a combination of IS, IWS, and RSS studies. Findings from Goal 3 will provide the needed information for explaining the ecological status and trends in Goal 1 and the influence of the four stressors on ecological processing in Goal 2. In combination, the IS and RSS will provide the data and understanding needed to develop models for predicting the influence of the four stressors on ecosystem condition, the mechanisms by which they function, and what management practices are most likely to improve stream ecosystem condition.

Design Features

Previous studies have demonstrated that the most appropriate scale for developing ecological models is at the regional scale due to a combination of biogeography and differences in natural and anthropogenic factors. Therefore, Goal 3 will adopt a regional-based design using the five design elements below.

Identify Geographic Regions for Assessment and Modeling

There are numerous strategies for dividing the United States into geographically distinct regions. The first step in Goal 3 will be to identify the most appropriate regional scale to use for the development of predictive models, with 10-20 regions being optimal. The process will start with examining the USEPA Level II Ecoregions (fig. 5.5) because it contains the major geographic regions and has been shown to be

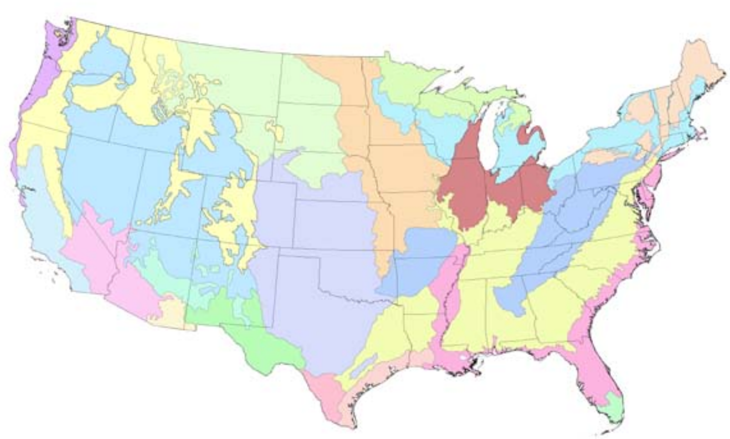


Figure 5.5. Map showing U.S. Environmental Protection Agency Level 2 ecoregions (Commission on Environmental Cooperation, 2008).

one of the better geographic based classification systems at the larger scale. The regions will then be ranked based upon a number of criteria, including representation of a wide range of stressor conditions and reference sites, as well as containing a sufficient number of NAWQA NFSN sites and having some overlap with Integrated Watersheds. Where possible, regions will selected to take advantage of collaborative opportunities with other USGS programs and (or) Federal, State, or academic studies (such as the National Science Foundation STREON Program).

Develop conceptual model:

While it is common to develop a conceptual model as part of an ecological study, this step is particularly critical to Goal 3. A conceptual model (fig. 5.6) will be developed for each region selected for study based upon a combination of NAWQA findings from Cycles 1 and 2, and consultation with USEPA, State, or local experts. The conceptual model will incorporate drivers (land use) and associated stressors (streamflow alteration), their interactions, and how they influence selected measures of biological condition. The actual measures of biological condition will vary depending on the stressors examined. The development of these conceptual models is critical to the refinement of stressor-related questions specifically for the selected region, to assist in prioritizing information gaps, and in evaluating what study approaches are most appropriate. Whereas the conceptual model is important for the overall design of a study, it will also be used as the starting place for the development and testing of a predictive model. For example, some modeling approaches, as in structural equation modeling, require that a conceptual model be developed in order to test the hypothesis that the model is based upon.

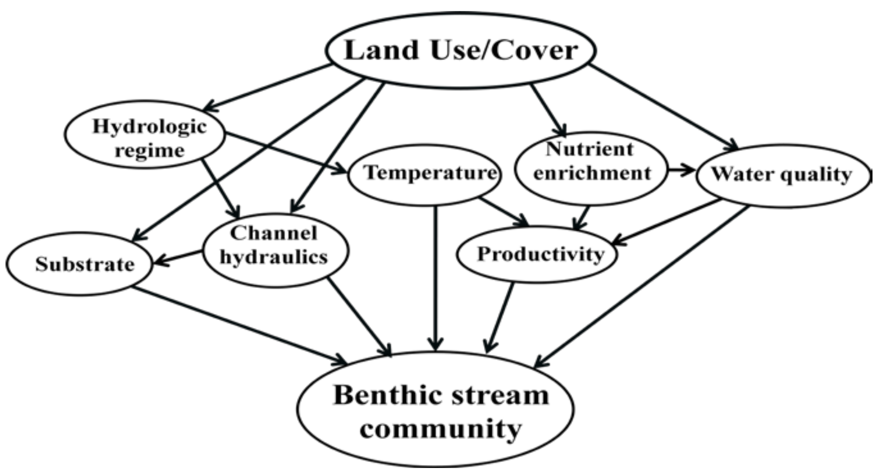


Figure 5.6. Example of a regional-scale conceptual model based upon existing studies and expert knowledge.

Intensive Studies:

Once a region is selected and a conceptual model is developed, the next step will be to establish an IS study. IS are the smallest scale study in Cycle 3 (fig. 4.2) and will be within an IWS basin which is the primary scale for studies addressing Goal 2. The primary purpose of the IS is to fill critical knowledge gaps about specific stressors, refine the conceptual model, and assist in the selection of the best measures of stressor and ecological endpoints. Therefore the IS are a critical first step in designing regional-based studies for the development of predictive models. The time period for IS may vary depending on the specific questions being addressed. For Goal 3, some of these studies will continue for 1-3 years in order to address specific stressor and methods questions, whereas for other questions, as in

Goal 2, the IS may continue for longer periods (5-10). Goal 3 Intensive sites will be selected to span a range of stressor conditions. The types of studies may differ among regions and stressors. For example, in some areas it may be important to focus more on identifying useful metrics of contaminant effects due to a lack of information on contaminant conditions and what endpoints are most relevant to biological systems. The IS have two critical roles that are not addressed by other design components:

- The level of study intensity and employment of multiple methods will enable a more refined and complete answer to questions than possible using more general-purpose monitoring data.
- They serve to test and determine the most effective new methods and approaches that may be adapted to fixed-site monitoring or Regional Synoptic Studies.

Regional Synoptic Studies:

The Regional Synoptic Studies, which are the third largest study scale in Cycle 3 (fig 4.1), are the scale at which data will be used for the development and application of predictive ecological models. Once an IS is completed, the original conceptual model will be updated to reflect study findings and the knowledge gained from the Intensive Study will be used to select key measures of individual stressors and biological endpoints that will be incorporated into a larger, regional-based study. The selection of a small number of key measures for the regional assessment is important because regional-based ecological models will commonly require a large number of sites (50-150). The actual number of sites selected is an important part of the statistical design of the RSS prior to the collection of data, and will vary depending upon the region and modeling approach selected. Whereas the RSS will likely be based upon short-term synoptic studies, they may also include some temporal sampling in order to assess how stressors influence biological endpoints over time. This will provide insight into how and to what extent individual stressors influence ecosystem condition, and will also provide a more complete understanding about the relative and combined influence of the four stressors. Sites selected will also include a gradient of watershed management practices within a region, so that models developed can address the influence of various management practices on both stressor and ecosystem conditions.

Develop ecologically-based predictive models:

Ultimately, a primary purpose of studies addressing Goal 3 objectives is to develop and test regional models for predicting the effects of various stressors on ecosystem condition, and to test scenarios of how changes in stressors, land use, climate or management practices may influence ecosystem condition. One of the tasks for Cycle 3 will be to assess what types of models will be most appropriate for the regional-scale assessments. NAWQA made significant progress in Cycle 2 using a variety of ecologically based statistical models, including Bayesian network models in the EUSE urban study and SEM models in the NEET nutrient effects study. These models greatly improved our ability to understand ecological interactions in both urban and agricultural streams, and to make predictions of how biological communities are influenced by land use and instream factors. The development and testing of ecological models will an outcome of Goal 3, and will be a critical part of Goal 4 efforts to develop forecasting models for prediction of ecosystem response.

Study designs and outcomes for each individual stressor.

Contaminants

NAWQA has done numerous studies on the occurrence and distribution of contaminants, including specialized studies of source, transport and transformations. Contaminant studies have included trend assessments, transport to agricultural, urban, and reference streams, transport to groundwater, and transport to individual supply wells. As noted earlier, contaminant concentrations have been compared to concentration benchmarks to assess potential toxicity, with results indicating frequent levels of potential concern, but no direct information suitable for evaluating cause and effect relations. In Cycle 3, NAWQA will more directly address the effects of contaminants on ecosystem condition.

Approach:

As mentioned earlier in this section, contaminants differ from other stressors in that they consist of a diverse array of inorganic and organic compounds of natural (trace elements) and anthropogenic (pesticides, PAHs) origin that occur in various combinations depending on the environmental setting and time period. Furthermore, contaminants can have a wide range of ecological effects, some of which are severe and easily measured (acute toxicity) whereas others produce long-term chronic effects that are very difficult to measure and assess. It is this vast array of chemical mixtures and potential effects that make assessing contaminant effects a challenge at larger scales.

The use of a combination of IS and RSS studies, each described previously in this section, is an ideal approach for addressing several contaminant-related stressor issues. Potential causes of contaminant effects include a wide range of factors, such as land use, wastewater contaminants, or a specific individual contaminant, and effects span a wide range of indicators, such as reduced species diversity or differences between reference and observed conditions. The use of several sites along a gradient of contaminant influence within an IS is the practical way to make definitive inroads toward understanding contaminant cause-and-effect relations. The use of the IS sites will permit clarification of several key elements of contaminant effects. First, it will provide an assessment of the types, concentrations, and timing of the various contaminants in each region. Second, based upon improved understanding of the contaminants of concern, instream ecosystem condition can be compared with various laboratory toxicity tests to determine if contaminants in water or sediment are toxic to aquatic life and if these contaminants actually influence natural communities. This information is critical prior to designing a RSS because it will be important to know what contaminant-related measures are most appropriate for assessing biological condition. It is important to note that it is likely that the contaminant indicator measures selected may vary depending on the specific features of the region. Once the contaminants effects indicators are selected, then a RSS can be completed in order to develop a predictive model.

Planned Outcomes:

- Integrated laboratory and field methods for assessing potential toxicity of contaminants to aquatic organisms. Ecological measures could include some traditional approaches, as in species-specific measures, to non-traditional measures of ecosystem function (e.g. stream metabolism).
- Development of models for predicting potential toxicity of contaminants, or mixtures of contaminants (for example the Pesticide Toxicity Index; Munn and others, 2006), to aquatic life under various land use or management scenarios.

Nutrients

It is well documented that severe eutrophication causes ecological impairment, but there are three specific aspects of nutrient enrichment in streams that require additional study. First, it is still common to address nutrient-related issues by measuring concentrations of nutrients, even though studies have shown a poor connection between ecosystem condition and concentrations due to biological activity. Studies are needed to provide a more accurate understanding of how stream ecosystems respond to various levels of nutrients in different regions and under different environmental conditions. Second, agencies are developing various monitoring programs to address USEPA-initiated nutrient criteria. Most state and local agencies are relying on existing methods; however, there is a growing need to determine what ecological endpoints are most appropriate for assessing the early onset of nutrient enrichment and for tracking improvements after changes in management practices. Last, there remains a general lack of knowledge on how various management practices influence the source, transport, and biological effects of nutrients in streams.

Approach

The effects of nutrients (nitrogen, phosphorus, and carbon) on biological condition will be assessed primarily by the IS/RSS design presented above. Effects of nutrient enrichment are not tied directly to the concentrations of nutrients, but instead are a function of ecological changes within the stream. For example, an increase in nutrients commonly results in an increase in plant production, which can alter dissolved oxygen levels and habitat (e.g., instream physical habitat and riparian), both of which can become major stressors to aquatic species.

NAWQA has historically addressed specific aspects of nutrient effects using established protocols for assessing habitat and biological communities. Although habitat and biological assessments of nutrient effects may utilize components of the existing protocols, adoption/development of different methods for assessing habitat and ecosystem structure/function will likely be based upon what has been learned in Cycles 1 and 2. Examples of new assessment techniques that may be used include: (1) primary and secondary production, (2) food web analysis, (3) food quality analysis, (4) role of sediment-bound nutrients in community composition, and (5) influence of nutrient cycling on plant and animal communities. IS will be used to assess various measures of nutrient enrichment and how biological indicators respond to increased nutrients. Findings from the IS will be used to select the most appropriate indicators of nutrient enrichment and biological endpoints for regional-based studies.

Planned Outcomes:

- A habitat-based stream classification system for predicting ecological response to nutrient enrichment.
- Determination of the timing and magnitude of elevated nutrient concentrations required to initiate excessive plant growth in streams.
- Environmental indicators for identifying early onset of ecological impairment due to nutrient enrichment.
- Information on how specific management practices influence nutrient effects.

Sediment

Assessment of sediment-related impairments to ecosystems is challenging in that suspended and streambed sediment varies naturally in different regions and through time. Sediment has been identified by the USEPA as one of the most widespread stressors to aquatic ecosystems (U.S. Environmental Protection Agency, 2006a). Sediment-related effects can be divided into those caused by changes in the concentrations of suspended sediment and those caused by alteration of streambed substrates. Suspended-sediment effects are typically related to changes in light penetration, which alter primary productivity and affect sight-feeding fish, but also include abrasion of macroinvertebrate communities. Alteration of streambed substrates can be caused by changes in upstream sediment supplies, or by changes in shear stress related to alteration of streamflow or channel conditions. Fining or coarsening of streambeds can affect stream ecosystems in many ways, including burial or scour of macroinvertebrate habitat and fish spawning beds (Waters, 1995).

Approach

Because ecosystems are adapted to natural sediment transport and streambed substrates, characterization of sediment impairments will rely on understanding developed in goals 1 and 2 and local knowledge to develop hypotheses as to if and how sediment-related impairments may affect ecosystem condition. Intensive studies will focus on assessing and developing measurements of suspended and depositional sediment along with indicators of ecosystem condition that are potentially affected by sediment disturbance. The magnitude, frequency, and duration of suspended-sediment concentrations will be evaluated through time and across hydrologic conditions through periodic sample collection and computation of suspended-sediment concentrations at hourly or finer temporal scales using surrogate technologies. In regard to streambed sediment, aquatic community response can be evaluated using representative measures of habitat quality identified as important during Cycles 1 and 2, and measures utilized by regional or national agencies, such as the relative bed stability index developed by USEPA (Kaufmann and others, 2008). The relative importance of sediment-related impairments to aquatic ecosystems will be evaluated with respect to both temporal and spatial variability in suspended and streambed sediments; an emphasis will be placed on reference sites as well as sites in which ecosystem degradation from contaminants are hypothesized to be minor. Ecological variables to be considered include aquatic macrophyte beds, biological assemblages (algae, macroinvertebrates and fish), primary production, and potentially other indicators.

Intensive study results will be used to evaluate indicators of sediment-related impairments for incorporation into regional synoptic studies. These studies will result in a predictive ecological model that will assess the relative importance of sediment-related impairments on stream ecosystems. This model will also provide insight into the importance of sediment-related management practices to the health of stream ecosystems.

Planned Outcomes:

- Identification of the predominant mechanisms by which changes to sediment transport affect stream habitat and aquatic ecosystems in different environmental settings
- Evaluation of existing, and development of new environmental indicators of sediment-related impairments to aquatic ecosystems
- Regional assessments of the importance of sediment-related impairments to aquatic ecosystems

Streamflow

Although streamflow alteration has been of concern for some years, it has recently become a major focus of many agencies and environmental groups due to its importance in sustaining a healthy stream ecosystem from a physical habitat perspective and its overall influence on stream quality. The recent concern around water withdrawals and competing needs for both human uses and biological condition has only intensified the need for a better understanding of how streamflow alteration influences biological condition. There is a demand from environmental policy makers and managers for information that quantifies relations between severity of streamflow alteration and degree of biological impairment. In addition, the scientific literature points out significant gaps in our knowledge of the mechanisms by which streamflow alteration affects aquatic ecosystems. Filling these gaps will improve our effectiveness in managing water resources to both satisfy human needs and maintain healthy ecosystems.

Approach

Streamflow alteration is unique among stressors because of the wealth of historical and current streamflow information collected and maintained by the USGS. There are more than 8,000 streamgages in the Nation with at least 20 years of flow record and about the same number of real-time streamgages currently in operation. Drainage basins for these streamgages have been delineated, which allows for characterization of many natural and human-affected watershed features. This rich dataset has enabled the development of statistical models that predict the expected baseline (i.e., natural) and the altered streamflow condition for any stream in the Nation. The three complementary methods summarized below take advantage of this predictive capability to quantify relations between streamflow alteration and ecosystem condition.

1. Data from the existing stream gaging network will be used to develop statistical models that estimate streamflow alteration at sites where biological condition data previously have been collected by Federal and State monitoring activities, but where streamflow data do not exist. The USEPA, for example, through its National River and Streams Assessment (NRSA), quantified physical and chemical habitat, along with biological condition, at almost 1400 sites across the Nation. The assessment, however, did not include any aspects of streamflow alteration. The statistical models developed by NAWQA will be applied to the NRSA sites to estimate streamflow alteration metrics. These streamflow alteration metrics will be combined with the data collected by the USEPA to assess relations between the habitat measures, streamflow alteration, and biological condition. Similar studies will be conducted at the State level where appropriate biological and habitat data have been collected by State agencies.
2. NAWQA will measure multiple potential stressors (contaminants, nutrients, sediment, habitat, streamflow alteration) and biological condition over time at many gaged long-term sites across the Nation. An analysis of the temporal variability among the stressors and biological condition will provide insight into covariance among the stressors and their effects on biological condition.
3. Statistical tools will be used to select streamflow sites within a region, such as a level II ecoregion, to control for possible confounding effects of other stressors. Biological condition will be measured at these sites to determine the effects of specific types of streamflow alteration. Measurements of other stressors will be made to confirm that streamflow alteration effects have been isolated.

In addition to the approaches described above, which rely on statistical analyses, the effects of streamflow alteration on biological condition will also be addressed within the context of the study outlined for assessing contaminants, nutrients, and sediment. Including consideration of streamflow in an intensive study will permit a better understanding of the mechanisms by which streamflow influences contaminants, nutrients, and sediment as stressors. Streamflow can also be assessed to determine what aspects of streamflow influence biological systems, including habitat features (for example, wetted perimeter), water temperature, and sediment effects (for example, scour). It will also permit an assessment of how various streamflow metrics affect various biological endpoints. For example, it is important to understand the role of streamflow alteration on plant biomass accrual and production, which structures the overall types of communities that can reside in a stream. In the IS study design, hydrodynamic and process-oriented watershed models will be used to improve predictions of stream channel hydraulic characteristics and daily streamflow at ungaged sites.

Planned Outcomes:

- Predictions of the effects of streamflow alteration on biological condition, and the mechanisms of how streamflow alteration influences biological systems at regional and national scales.

Example designs for integrated intensive and regional studies assessing stressors in urban and agricultural settings.

This section presents example study designs for an urban and agricultural setting, with the urban example presenting all components of the study design from conceptual model to regional model and application. The agricultural example provides a second example of model development and application.

Urban Example

"*How are contaminants, nutrients, sediment, and streamflow alteration affecting aquatic ecosystem condition in urban streams?"*

In Cycle 2, the EUSE topical team reported that ecosystem condition generally became degraded with watershed urbanization, but the relations between degree of watershed urbanization and degree of degradation varied among different natural environmental settings. EUSE results also yielded a multi-level hierarchical model that relates degree of urbanization and climatic variables to ecosystem condition. However, EUSE was not designed to assess the relative importance of different stressors as a function of land use, water use, chemical loading, or other natural factors. Therefore, Cycle 3 will focus on assessing the influence of contaminants, nutrients, sediment, and streamflow alteration on biological condition and will develop a regional-scale predictive model for important landscape features, in this case, specifically for urban lands. Whereas this example focuses on urban settings, Cycle 3 will also feature stressor studies conducted in agricultural settings.

Study Questions

- Which stressors are causing ecosystem degradation as a watershed becomes urbanized?
- How do the relative roles of different stressors change with degree of urbanization?
- How do stressor-effect relations vary among different natural settings?

Approach

Regional settings (10-20) will be ranked according to the urban and agricultural settings of greatest interest. Urban regional environmental settings will be assessed in light of Cycle 2 EUSE findings to determine if major urban areas can be combined into a single region. One example would be to combine Raleigh and Atlanta because they occur in a single USEPA Level 3 ecoregion.

Conceptual model: Modeling efforts by EUSE combined with additional information from other NAWQA studies, studies by others, and local expertise will be used to construct a conceptual model of how land use influences the four stressors identified, and how these stressors would likely influence specific indicators on ecosystem condition (fig. 5.7).

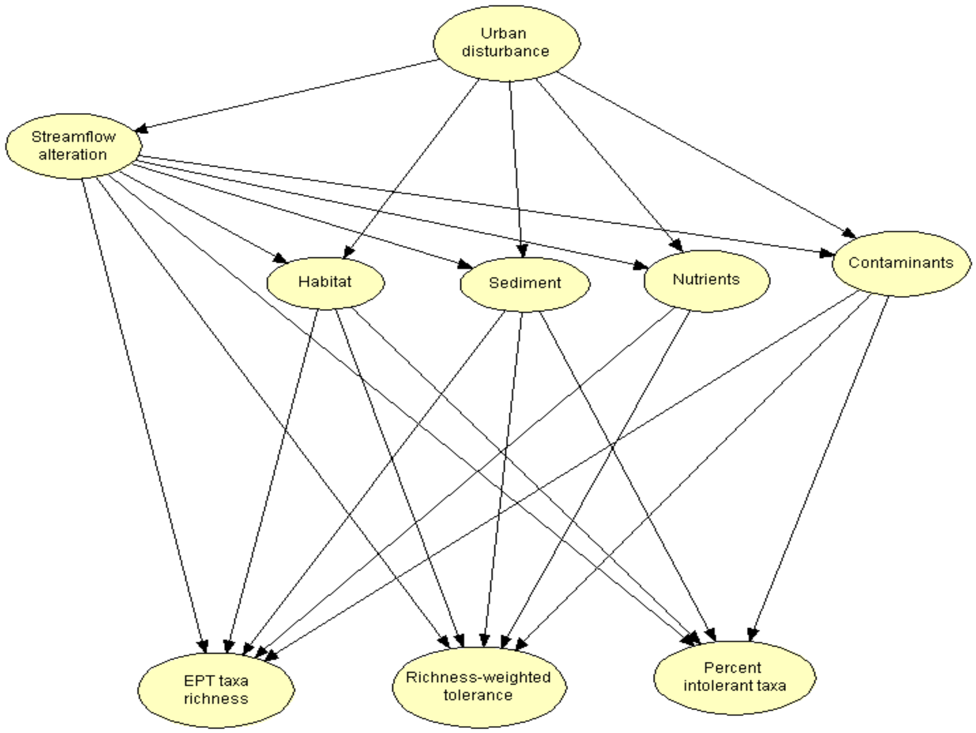


Figure 5.7. Hypothetical conceptual model showing the primary stressors that determine ecosystem condition in an urban stream ecosystem.

Intensive Study: Based upon the conceptual model above, several Intensive Sites could be selected, for example, within the Raleigh-Durham, North Carolina urban area, with three sites selected to represent low, medium and high urban intensity (fig. 5.8). These sites would be gaged and studied over a 1-3 year period to assess what stressors are most important and what endpoints and methods will be most useful for a regional-based study. With respect to toxic contaminants, the Intensive Sites will monitor for a suite of ecologically-important contaminants known or suspected to occur at urban sites to determine their concentrations and seasonal exposure patterns and the effects the contaminants have on biota. Measurements will be used to construct predictive indicators of potential toxicity, including the Pesticide Toxicity Index (PTI; Munn and others, 2006) for water, and the Probable Effects Concentration Quotient (PECQ; MacDonald and others, 2000) for sediment. Toxicity testing will be highly targeted and selective, using a variety of bioassay methods and other techniques based upon the types of contaminants indicated to be most important. Methods will include a combination of field and laboratory measures, including both acute and chronic toxicity tests. Additional details regarding the approach used to evaluate the effects of other stressors can be found on pages 108-111.

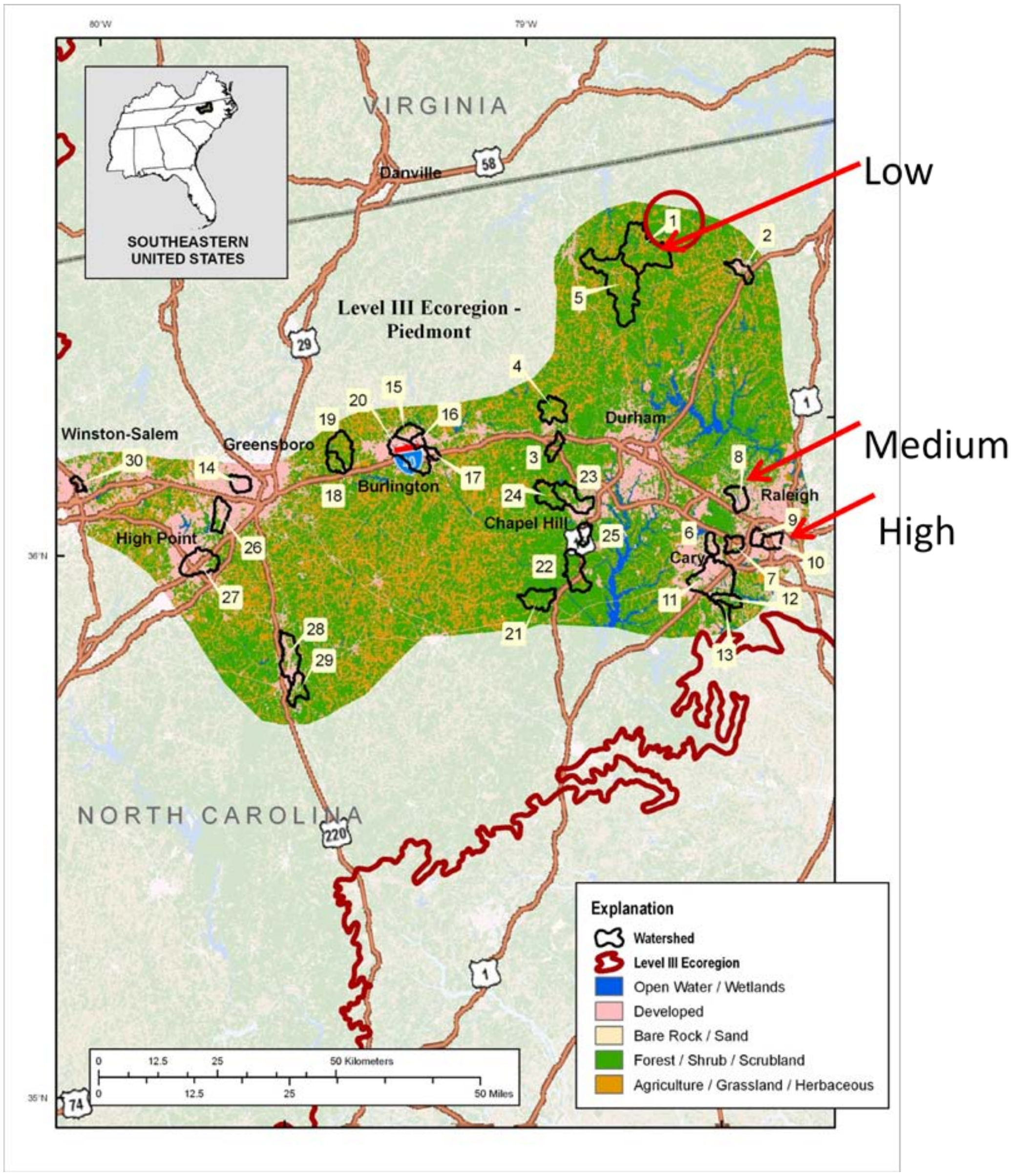


Figure 5.8. Map showing study sites included in the Cycle 2 Effects of Urbanization on Stream Ecosystems (EUSE) study in the Raleigh-Durham metropolitan area with the hypothetical locations of three Intensive Study sites where detailed stressor studies would be conducted.

Regional Synoptic Study: Results from the IS studies will be used to design a RSS that collects key variables of stressors and indicators of ecosystem condition. The RSS would include 50-100 sites across the identified metropolitan area with data used to develop a regional-scale urban predictive model. Figure 5.9 shows an USEPA Level III Ecoregion that encompasses two NAWQA urban areas. RSS sites will be established to capture a range of urban settings along with a range in the dominant stressors identified. Results from the regional study will then be used in the development of a regional-based model.

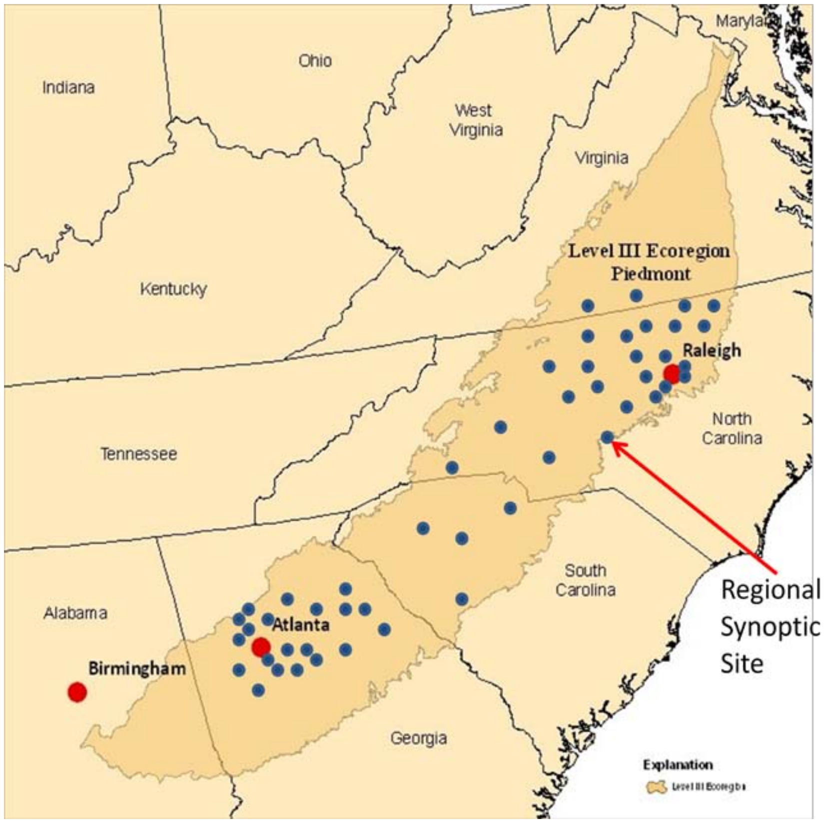


Figure 5.9. Map illustrating regional synoptic study design for assessing key stressors and biological response.

<u>Develop ecologically-based predictive models:</u> The data collected as part of the RSS will be used to develop a regional model. For example, the Bayesian network model shows the probabilities that a stream would have properties associated with each of the categories for each model node (fig. 5.10). For example, if it is known with 100 percent certainty that a stream is located in a watershed with 31-100% urban land cover, this model predicts that stream will have a 50 percent chance of having high flashiness (greater than 4 rises above median in a year), about a 48 percent chance of having low generic richness (less than 15 total taxa), and slightly over a one percent chance of achieving Biological Condition Gradient Tier 1 (equivalent to natural biological condition). Managers can set the known or desired value of any node in the model and it will predict the likely values of all other nodes in the system.

This model can be used to evaluate the impacts of various management actions on the probability of achieving desired levels of a biological condition standard. For example, managers could change the level of urban disturbance in the model to determine the degree to which a shift in urbanization influences key stressors and how biological condition is affected.

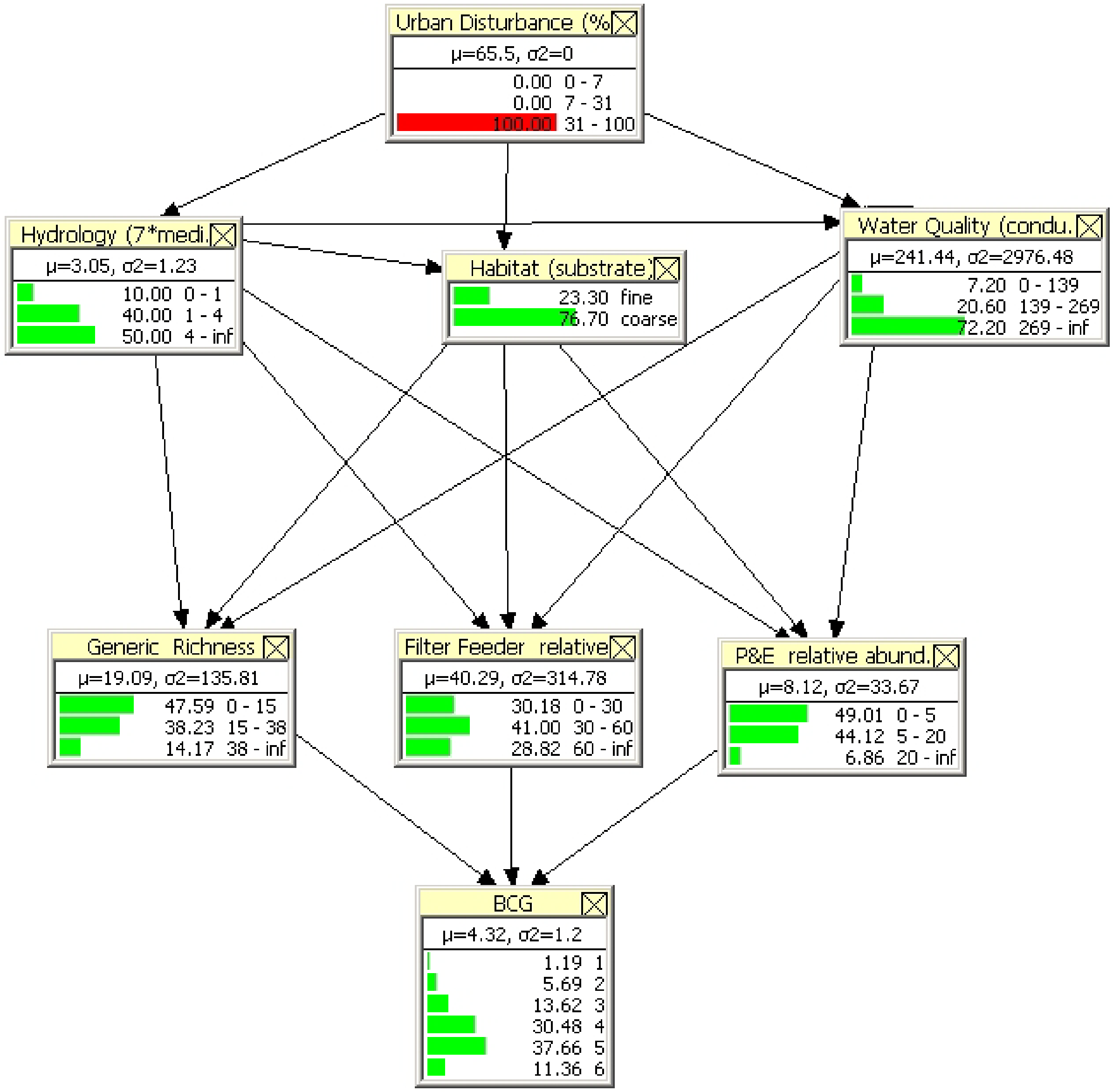


Figure 5.10. Bayesian network model for urban study showing the probabilities that a stream would have properties associated with each of the categories for each model node.

Agricultural Example

Along with urbanization, there continues to be substantial interest in agricultural lands and how management practices are influencing water quality and biological condition. This example focuses on agricultural lands and is based upon ongoing studies by the Nutrient Effects Topical Team.

Study Questions

- Which stressors are causing ecosystem degradation in response to specific agricultural practices?
- How do the relative roles of different stressors change with agricultural intensity?
- How do stressor-effect relations vary among different agricultural settings?

Approach

Development of Conceptual Model: Once a regional setting is selected, a conceptual model is developed that provides a hypothesis of how stressors and management practices influence stream biota. This model can incorporate both natural and anthropogenic factors, along with specific management practices. A conceptual model for agricultural lands, with an emphasis placed on how land use and cover influence flow, substrate, temperature, and water chemistry (primarily nutrient chemistry) (fig 5.11). Specific contaminants, as in pesticides, could be added to this example if necessary.

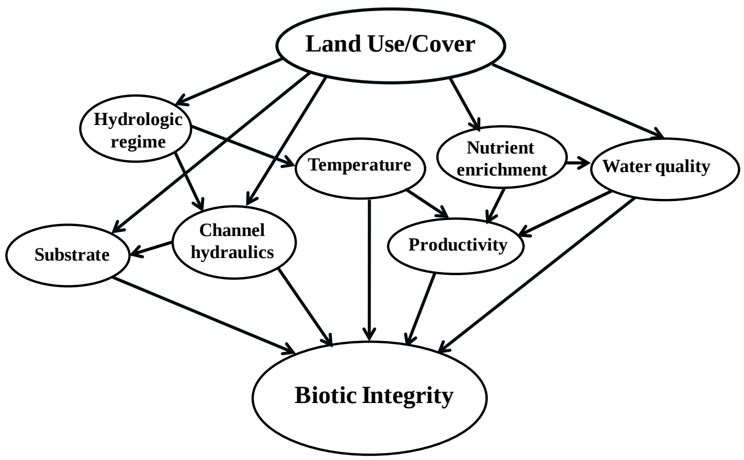


Figure 5.11. Conceptual model for testing the effects of land use, habitat and nutrients on biological integrity in an agricultural setting.

Intensive and Regional Studies: As in the urban example, IS basins are established to assess the influence of these various stressors and to refine the selection of indicators for use in a regional study. Once this is completed, a RSS is carried out at multiple sites throughout the region. Data collected would include measures of key stressors and ecological endpoints that can be used for the development of a model.

Development of Regional Model: Whereas the urban example above relies on a Bayesian network model, this agricultural example illustrates the use of a Structural Equation Model (SEM), which is used to develop a set of causal models and examine the direct, indirect, and total effects of agriculture on biological integrity acting via different nutrient and habitat pathways (Riseng et al. in review). In the Coastal Plains ecosystems, cropland tends to be located on well-drained upland areas separated from streams by undisturbed riparian floodplain and wetland habitats resulting in lower nutrient concentrations in many of its streams. In the Coastal Plain model, riparian forested wetland had significant positive effects on the invertebrate community mediated through dissolved (including NO_3) and particulate (including total P and sediment) components of water quality and coarse substrate (woody debris) that far outweighed negative impacts of agriculture, suggesting the importance of intact riparian floodplains and wetlands for maintaining biotic integrity in CP systems (fig. 5.12).

This model can be used to evaluate the impacts of various management actions on habitat, nutrients, and invertebrate community quality. For example, managers could determine to what degree increasing the percent of buffer that is wetland habitat influences biological condition.

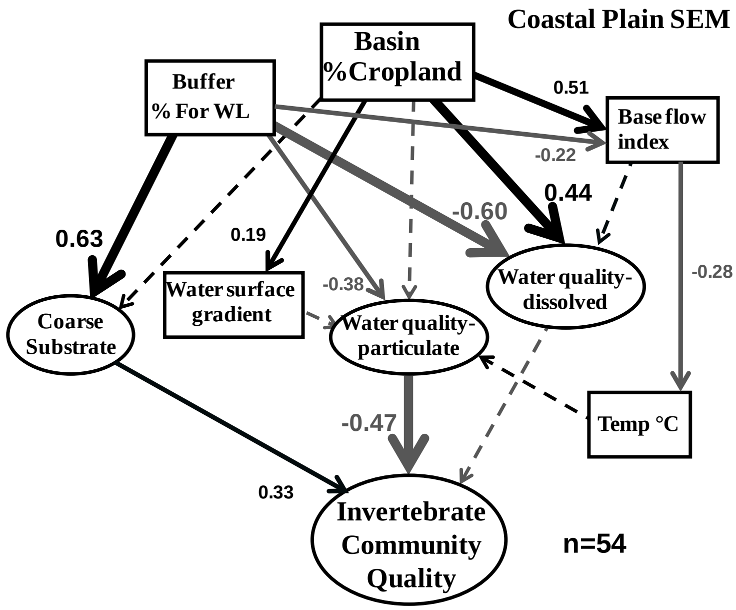


Figure 5.12. Structural equation model of coastal plain agricultural setting showing relations between land use, habitat, water chemistry, and invertebrate community condition. Values shown are similar to correlation coefficients, and are expressed as either positive (black) or negative (gray) (Buffer for % WL = percent forested wetland in buffer area).

Critical requirements for technical support and datasets

- Existing biological data

  — Numerous local, State and Federal agencies are collecting biological and habitat data as part of their existing monitoring and assessment programs. Obtaining and incorporating these data into a common database is important for addressing specific stressor objectives. For example, biological data collected near USGS streamgages are critical for addressing some of the streamflow alteration questions presented above. This activity will assist NAWQA in working with other agencies to address common questions on stressors and ecological effects.

- Evaluate existing or newer assessment tools

  — NAWQA has existing protocols for the collection of habitat and stream biological assemblages (algae, macroinvertebrates, and fish). However, Cycle 3 may require current protocols to be modified and updated based upon what has been learned in Cycles 1 and 2, and in order to facilitate the rapid collection of key variables from a large number of sites at the regional scale. Furthermore, some of stressors, as in toxic contaminants, will require methods not previously used in the NAWQA Program. These include field and laboratory toxicological tools that are important for the assessment of contaminant effects.

Partnerships for Goal 3

Goal 3 offers substantial opportunities for collaboration with other USGS programs and agencies. These partnerships are critical for achieving Goal 3 objectives outlined above. Below are some specific examples of present or desired partnerships.

USGS Mission Areas

- Energy and Minerals, and Environmental Health: The Toxic Substances Hydrology and Contaminant Biology Programs are important collaborators for evaluating the effects of contaminants on ecosystems. NAWQA has begun discussions on how the programs can work together on topics such as methods development and combined studies that examine the effects of chemical stressors using laboratory and field methods.

- Ecosystems: There are three programs within Ecosystems that have potential for collaborate work with the NAWQA program in Cycle 3. These include: 1) Status and Trends of Biological Resources, 2) Terrestrial, Freshwater and Marine Ecosystems, and 3) Fisheries: Aquatic and Endangered Resources. Further discussions are planned to assess collaborative opportunities.

- Water: A specific goal of the WaterSMART Program is to develop models and tools to evaluate the effects of streamflow on aquatic biota and developing methods for estimating ecologic flow requirements for different hydrologic and climatic settings. Cycle 3 streamflow alteration studies are designed to enhance and complement planned work by the WaterSMART Program on ecologic flow issues. The National Research Program also conducts studies evaluating the effects of various stressors on aquatic ecoystems and will continue to be an important part of the NAWQA program in Cycle 3.

- Climate and Land Use Change: Activities within the Climate and Land Use Change Program are directly related to Cycle 3 NAWQA activities, especially mutual goals of assessing relations between land use change and water quality and biological condition. There are also goals listed in the Climate and Land Use Change strategic science plan that address how climate change will influence various water-quality and ecosystem stressors, such as streamflow and temperature, which have strong connections to NAWQA plans for Cycle 3.

U.S. Environmental Protection Agency

- USEPA National Aquatic Resource Surveys and Office of Research and Development: NAWQA has a long history of working with USEPA National River and Streams Assessment and has published with the program on the biological condition of surface waters. This effort will continue in Cycle 3 in regards to all four of the stressors. NAWQA and USEPA are presently working on streamflow alteration as a major stressor of biological condition.

- USEPA CADDIS Program (Causal Analysis/Diagnosis Decision Information System): This program assists scientists and engineers in the Regions, States and Tribes to conduct causal assessments in aquatic systems. It is based upon identifying the dominant stressors within a stream or watershed for taking management action. Scientists within the CADDIS program are very interested in collaborative efforts due to our joint interest in identifying and understanding stressors in stream environments.

Chapter 6. Predict the effects of human activities, climate change, and management strategies on future water quality and ecosystem condition (Goal 4).

Outcome: Improved understanding of how human activities, climate change, and management strategies might affect future water quality and ecosystem conditions.

Products:

1. Models that predict how the use and management of land and water, together with climate change, are likely to affect future water quality and ecosystem conditions.

2. Model-based decision-support tools for managers and policy makers to evaluate the effects of changes in climate and human activities on water quality and ecosystems at watershed, state, regional, and national scales.

3. Reports describing studies at selected watersheds that assess the potential effects of future climate and land-use change on water quality and ecosystem condition.

Connections among NAWQA Cycle 3 Goals

The objectives, approaches, and products described in this section are tightly integrated with, and dependent on, the studies and assessments associated with the other goals. In Goal 1, data from NAWQA's ongoing, long-term, monitoring of water quality will be used in assessments of temporal trends in water quality across the Nation. These water-quality data will be used to develop and evaluate the models used to understand historical trends (in Goal 2) and forecast future changes in water quality (this goal). Goal 2 is focused on developing understanding of the observed spatial patterns and temporal trends in water quality. Modeling tools developed to explain historical trends will be applied in Goal 4 to predict the effects of potential future changes in land use, water management, and climate on water quality conditions (i.e., stressors). In Goal 3, water-quality and hydrologic conditions that lead to degradation of stream ecosystems will be identified and incorporated into regional ecological models. These models, which predict the effects of stressors on ecosystem condition, will be applied in Goal 4 to predict the effects of future land use, climate change, and management strategies on stream ecosystems.

Background

NAWQA has been addressing three broad questions since the program started: "What is the current condition of the Nation's water quality?", "Has the quality of water been getting better or worse?", and "What human or natural factors are responsible for current water-quality conditions?". A critical next question is "How do we expect water quality to change in the future?"

An example forecasting question is "How will nitrate in streams and public-supply wells change in the future under different scenarios of fertilizer use?" This question was addressed during Cycle 1 in southern New Jersey by using the groundwater-flow model MODFLOW and NAWQA water-quality data for streams and supply wells in the area (Kauffman and others, 2001). Simulations suggested a slow response in nitrate concentrations of streams and groundwater to changes in fertilizer use, even if a total ban in fertilizer application is implemented (fig. 6.1). The example illustrates the importance of hydrologic understanding in making science-based forecasts. Continued development of such understanding is an important component of Cycle 3 studies.

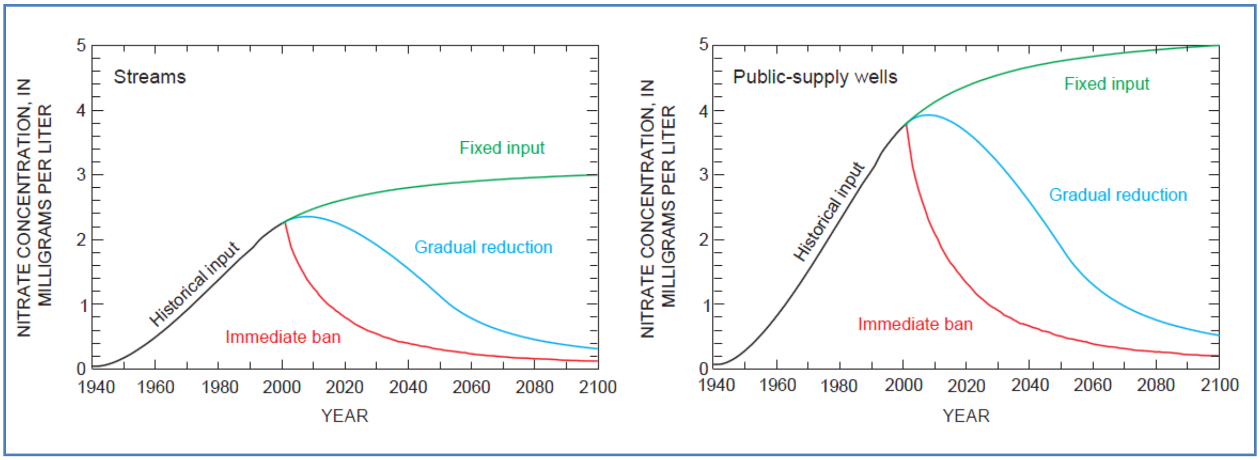


Figure 6.1. Simulated nitrate concentrations in streams and public-supply wells (Kauffman and others, 2001)

Policy and stakeholder concerns driving key management questions

Forecasts of future water quality and ecosystem conditions are essential information for policy makers and water managers. The primary factors that might cause future changes in water quality include changes in climate; population; land, water, and energy use; changes in water use or wastewater treatment technologies; regulatory changes; and management practices. In some cases—such as agricultural and urban best management practices—changes in these factors may result in improvements in water quality (for example, decreasing concentrations of pesticides and nutrients in streams). In other cases—such as possible increases in corn acreage for production of biofuels—the concentrations and fluxes of agricultural chemicals and sediment may increase.

Predicting the effects of climate change on future water quality is one of the highest priorities among NAWQA's stakeholders and is directly aligned with goals outlined in the draft science plan for the USGS Climate and Land Use Change Mission Area. Changes in air temperature would be expected to affect water temperature and, thereby, also affect algal blooms, eutrophication, microbiological processes, and aquatic ecosystem conditions. Precipitation and temperature affect streamflow which, in turn, affects many factors related to water quality. Increases in streamflow in areas experiencing wetter climate could dilute point sources of contaminants but also could increase erosion and downstream flux of sediment and sediment-bound contaminants. Decreases in streamflow in areas that become drier also would affect contaminant fluxes and concentrations. In addition, streamflow and temperature conditions are crucial components of the aquatic ecosystem habitat, and changes in these physical features of the environment would likely affect biological conditions.

Examples of management questions related to forecasting include:

- How will projected changes in climate, population, land use, water use, management actions, and other human activities affect water quality for future beneficial uses?
- Which strategies will most effectively improve and protect biological communities and ecosystem conditions?

- Which management strategies are most cost effective?
- What are the expected lag times between implementation of management practices and beneficial outcomes?
- Is water quality more sensitive to changes in land-use practices or climate?

NAWQA progress during Cycles 1 and 2

Forecasting future water-quality conditions was not a program goal in Cycles 1 and 2, but NAWQA monitoring and studies during the first two cycles provided much of the foundation required to address this objective. The work in assessing status and trends, together with focused topical studies and development of models across a range of scales, led to an improved understanding of how natural factors and human activities affect water quality in streams and aquifers. Forecasting future water-quality conditions requires that this understanding be integrated with predictions of how these factors and activities might change in the future.

The increased emphasis in Cycle 2 on the integration of monitoring with modeling led to the development of modeling tools and required ancillary datasets that will form the basis of the Cycle 3 forecasting approaches. For example, spatial extrapolation models that provide estimates of water-quality conditions in both streams and groundwater throughout the conterminous U.S. were developed or enhanced. Statistical relations between spatial variability in environmental factors and water-quality conditions form the basis of these models; some of these models (Table 6.1) can be adapted to evaluate temporal changes in water conditions as environmental drivers such as climate and land use change over time.

Table 6.1. Water-quality models to be used in Cycle 3 for prediction and forecasting. See references and web links for more information. Note that nutrients include nitrogen, phosphorous, and carbon.

Model	Model type	Drivers	Stressors	Receptors	Water resource
MODFLOW	Process	Climate, land use	Contaminants	Human needs	Groundwater
SPARROW	Geospatial /Process /Statistical	Population growth, climate, land and water use	Nutrients, sediment	Aquatic ecosystems	Streams and rivers
WARP	Geospatial /Statistical	Climate, land use	Contaminants	Aquatic ecosystems Human needs	Streams and rivers
RZQM2	Process	Climate, land and water use	Contaminants	Human needs	Shallow groundwater
Generic	Statistical	Population growth, climate, land and water use	Streamflow alteration, contaminants, nutrients	Aquatic ecosystems Human needs	Streams and rivers, shallow groundwater

The objectives of model applications in Cycles 1 and 2 can be viewed in the context of the driver/stressor/receptor conceptual model (fig. 6.2). Cycle 1 and 2 studies used process-based (MODFLOW), hybrid conceptual/statistical/geospatial (WARP and SPARROW), and more conventional statistical models to assess how land use (a driver) affects the fluxes and concentrations of contaminants and nutrients (stressors) to human uses and aquatic ecosystems (receptors). The relevance of pesticide concentrations to human uses and aquatic ecosystems was determined by comparison to water-quality benchmarks developed by the USEPA, USGS, and others. In addition, the effect of streamflow alteration and land use (e.g., urbanization) on aquatic ecosystem health was quantified with regression models.

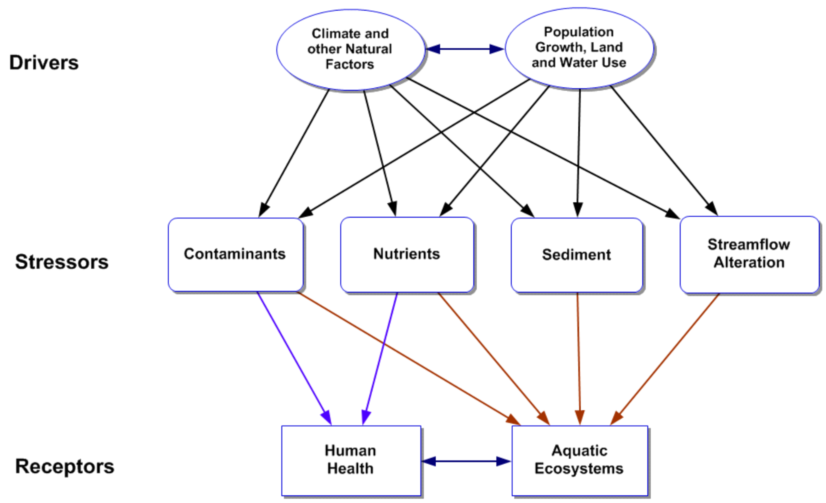


Figure 6.2. Conceptual model of the connections between environmental drivers, stressors, and receptors

Significant progress also was made in development of web-based decision-support tools. A "view and query" tool was constructed to enable users to explore and download input data and atrazine concentration predictions from WARP models. Also, a decision-support system (DSS) for national and regional SPARROW nutrient models is close to completion. The SPARROW DSS provides functionality for user-controlled predictions, scenario testing, and regulatory assessment. The only software requirements for the DSS are an internet connection and a web browser.

NAWQA's role in Cycle 3

In Cycle 3, NAWQA will develop tools for water-resource managers and policy makers to forecast the effects of future changes in land use, water use, and climate on stressors and the suitability of water for human and aquatic ecosystem needs. These tools will be based on models and decision-support systems that have already been developed in the NAWQA program. An important role for NAWQA is to evaluate which of the existing models are most suitable for estimating, with quantified uncertainty, changes over time in water quality and ecosystem condition due to changes in climate, land and water use, and management practices. In addition to the development of modeling tools, NAWQA will assess and report on the effects of changes in climate, land use, and water use on water quality and ecosystem condition at selected study areas.

Objective 4a: Evaluate the suitability of existing water-quality models and enhance as necessary for predicting the effects of changes in climate and land use on water quality and ecosystem conditions.

Appropriate NAWQA models, other USGS models, and established models developed by others will be used "as is" or will be enhanced to improve their utility for forecasting (see Chapters 4 and 5 for a description of the approaches to assessing suitability and required enhancements). Most existing NAWQA models provide only steady-state predictions of stressor or aquatic ecosystem condition based on steady-state driver conditions. Some of these models can be modified so that they vary with time and, therefore, estimate transient conditions. Such dynamic representation of processes can yield more realistic predictions as a function of time. In addition, models may need to be modified to include representation of the variables expected to change in the future.

SPARROW, for example, is a steady-state model that predicts mean-annual stressor flux throughout a river network as a function of sources applied to the land surface, land-to-stream delivery factors, and in-stream attenuation factors. In the SPARROW model for nitrogen, mean-annual nitrogen flux is a function of sources (including land use, fertilizer, atmospheric deposition, wastewater discharge), land-to-water delivery factors (precipitation, temperature, soil permeability, extent of tile drainage), and attenuation factors (instream decay). Regression coefficients that represent the strength of the delivery and attenuation factors are determined through calibration of model-estimated fluxes to measured fluxes at or near streamgages. After the model has been calibrated, scenarios of changes in land use or management practices can be evaluated by increasing or decreasing specific sources or delivery factors. Results from this type of model application indicate the long-term steady-state effect of a specified land use or management change. This type of scenario application, however, does not provide any information about the lag time between a change in land-use management and its subsequent effect on water quality.

Many of the existing NAWQA models, including SPARROW and WARP (Table 6.1), are calibrated to match the spatial pattern of water quality measured in a monitoring network across a broad geographic area. The calibrated model coefficients reflect the spatial pattern, not the temporal patterns, of the monitoring data and the explanatory variables. Using a spatial model to represent changes over time is valid only if variations over time in the forcing variables have the same effect as differences across space. This restriction does not apply to a dynamic model; therefore, one of the objectives in Goal 2 in Cycle 3 is to develop transient versions of SPARROW models. This would require adding storage compartments to the models that can "hold and release" chemicals (such as nutrients or sediment) and also specifying input time series such as monthly or seasonal values for fluxes of water and chemicals.

Certain non-transient models may also be used to evaluate changes in water quality over time due to changes in land or water use. For example, the steady-state version of MODFLOW predicts spatial patterns of flow paths and statistical distributions of travel times; these variables can be used to evaluate time lags required for a change at the land surface (such as fertilizer application) to propagate through the system and provides the capability to generate forecasts of future conditions (fig. 6.1).

NAWQA models that will be used to forecast future stressor and aquatic ecosystem conditions in response to changes in climate and land use require the following characteristics:

- Applicability at regional and/or national scale
- Explanatory or input variables that represent environmental drivers or stressors
- Dependent variables that represent stressors or receptors
- Quantifiable uncertainty

Descriptions of these models, the evaluation approach, and enhancements are given in Chapters 4 and 5 of this report.

Objective 4b: Develop decision-support tools for managers, policy makers, and scientists to evaluate the effects of changes in climate and human activities on water quality and ecosystems at watershed, State, regional, and national scales.

One of the primary Goal 4 products is model-based decision-support tools for scientists, managers, and policy makers. A web-based decision support infrastructure is being developed to provide access to NAWQA models of stream water-quality conditions and to offer sophisticated scenario testing capabilities for research and water-quality planning via a graphical user interface. This Decision Support System (DSS) is provided through a web browser over an Internet connection, making it widely accessible to the public in a format that allows users to easily display water-quality conditions and to describe, test, share modeled scenarios of future conditions, and generate maps illustrating model predictions at various scales.

The DSS and underlying software framework are intended to make running sophisticated model simulations easier by combining familiar website user interface controls with a powerful computer server infrastructure. This paradigm places new capabilities in the hands of decision makers and water-quality planners and managers in ways that previously were not available. The DSS takes advantage of innovations in the information technology field that allow for a flexible and robust web-based decision support framework for most NAWQA models. The DSS removes desktop software dependencies, simplifies scenario testing and provides a map interface.

Some of the functionality of a DSS is illustrated by the preliminary SPARROW sediment model for the conterminous United States (fig. 6.3 to fig. 6.7; Schwarz, 2008), which has been incorporated in a graphical system for viewing, querying, and scenario testing developed by the USGS Center for Integrated Data Analysis (CIDA). Through the user's web browser, maps of model results—such as the total suspended sediment load in streams and rivers (fig. 6.3) and the mass per unit area delivered to the stream from individual areas (fig. 6.4)—are displayed.

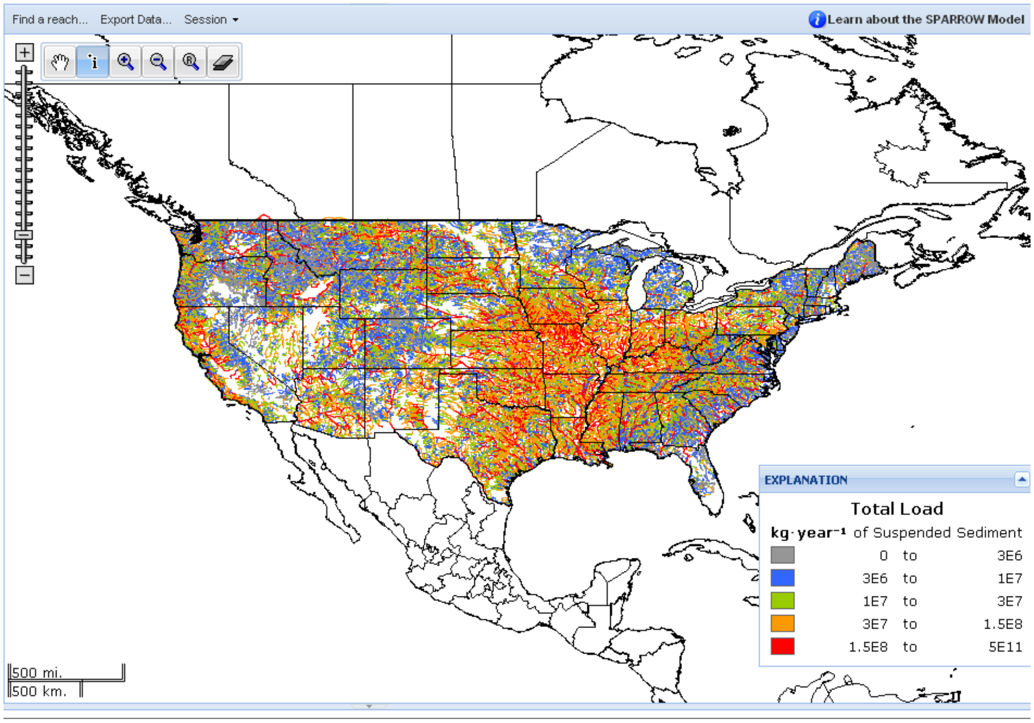


Figure 6.3. Total suspended sediment load estimated with SPARROW (Schwarz, 2008)

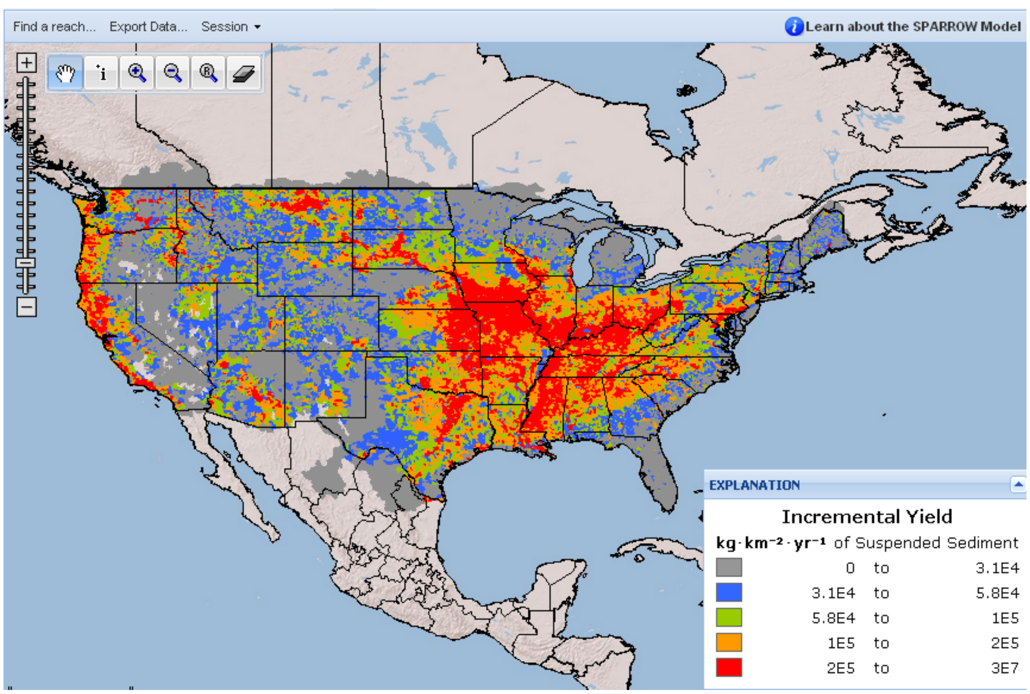


Figure 6.4. Sediment transported to streams and rivers from catchments, expressed on a per unit area basis (Schwarz, 2008)

The NAWQA DSS can be used to generate tables summarizing the sources of stressor loads, for example, estimated sources of suspended sediment at the downstream end of the Kansas River (fig. 6.5). This specific river reach was selected by using the pan and zoom features of the DSS. The table is viewed through the user's web browser and includes several tabs of information. The model results indicate (not surprisingly) that the primary source of sediment in the basin is agricultural land (fig. 6.5)

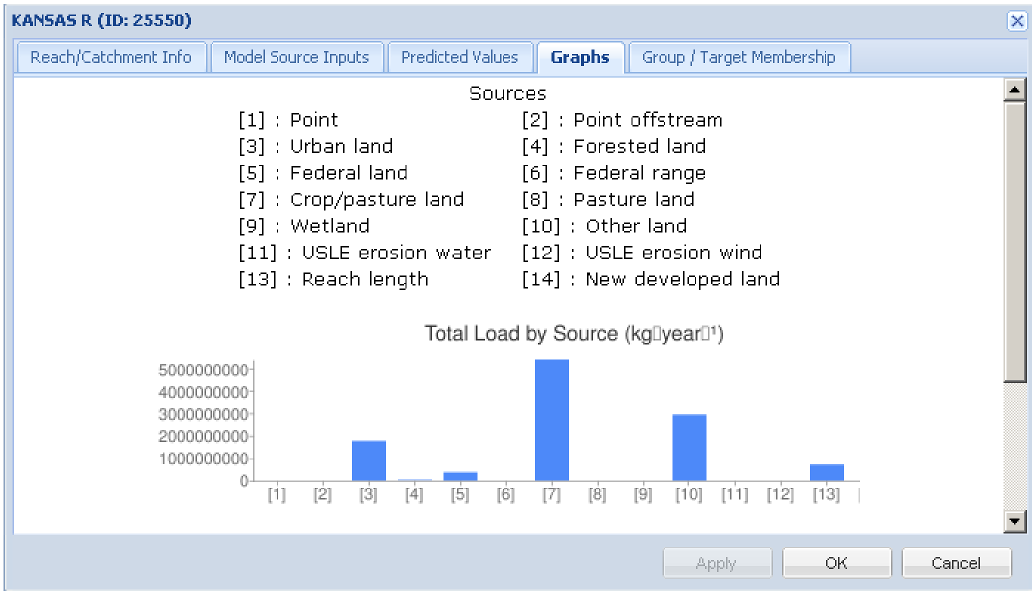


Figure 6.5. Sources of sediment in the Kansas River basin

User-controlled scenarios of changes in sources can be evaluated in the DSS. The Trinity River in Texas is displayed on the map with the Dallas metropolitan area indicated by a maroon-colored arrow and Lake Livingston indicated by a black arrow (fig 6.6). This lake is used for recreation and water supply for Houston.

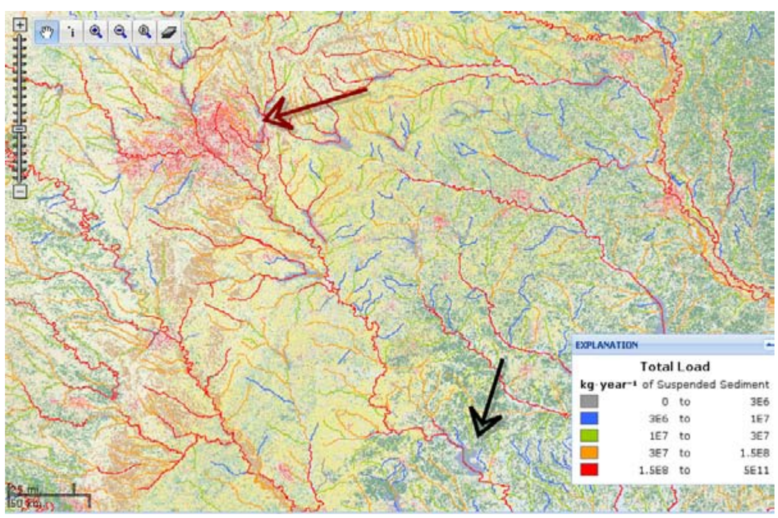


Figure 6.6. Total sediment load in streams and rivers in south-central Texas overlaid on land use classes. The land-use categories shown are urban (red), agriculture (yellow), forest (green), and water (blue). The maroon and black arrows indicate the location of Dallas and Lake Livingston, respectively. Lake Livingston is used as a water supply for Houston.

Mean-annual sediment load flowing into the lake is estimated by SPARROW to be about 5 million tons per year. The model indicates that almost half of the load originates in urban areas. (See light blue bars in fig 6.7).

The DSS can be used to evaluate scenarios of land-use change. For illustration, a prescribed scenario of a 50 percent decrease in sediment transported from urban land in the upper Trinity River basin—assumed to result from sediment control measures—was evaluated in terms of its impact on sediment delivery to Lake Livingston. This scenario resulted in a 45 percent decrease in urban sources of sediment to Lake Livingston but only a 21 percent decrease in total sediment flux to the lake. It should be noted that this type of analysis does not consider the elapsed time between implementation of management practices and desired outcomes. The length of this lag time can be many years.

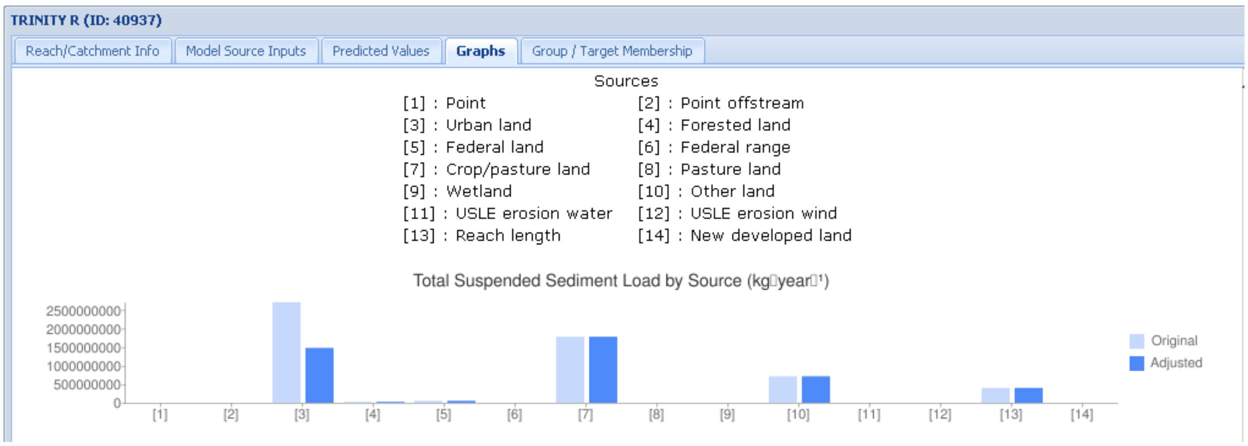


Figure 6.7. Sources of sediment in the Trinity River basin upstream of Livingston Lake.

Currently, NAWQA's DSS includes only steady-state river water-quality models: SPARROW nutrient and sediment models and the WARP atrazine model. The most crucial enhancements to the DSS for Cycle 3 are (1) support of additional models, (2) explicit depiction of predictive reliability, and (3) seamless access to land-use and climate change scenarios.

- Support of additional models:
  - Models previously developed by NAWQA (Table 6.1) with enhancements for prediction and forecasting
  - New SPARROW models for carbon, temperature, dissolved oxygen, pesticides and salinity
  - Models developed and supported outside of NAWQA, such as PRMS and SWAT, that provide functionality unavailable in NAWQA models
- Predictive reliability:
  - Quantification of model reliability is crucial for meaningful model predictions. Placing model predictions within a reliability/uncertainty context is essential to avoid over confidence or misinterpretation by the DSS user. Approaches for quantifying predictive reliability are described in the Goal 2 and Goal 3 sections of this document.
- Seamless access to climate and land-use change scenarios:
  - Two USGS projects—the Center for Integrated Data Analysis and the Modeling of Watershed Systems Project—are collaborating to develop seamless access to a variety of climate and land-use change

scenarios. The term "seamless" indicates that a user accessing the DSS web site through the internet would be able to choose, in an intuitive and straightforward way, both a change scenario and model to evaluate the effects of climate and land-use change on water quality and aquatic ecosystem condition. Climate and land-use change scenarios are constantly evolving, and several sources of scenarios that could be used to drive transient water-quality or ecological models are listed in Table 6.2.

The WARP web-mapper illustrates how model reliability information can be included in a decision support tool. Figure 6.8 shows WARP predictions of annual mean atrazine concentration estimated for rivers and streams in the conterminous U.S. The regression analysis that comprises WARP also estimates model reliability/uncertainty metrics for the pesticide concentration predictions. If a meaningful contaminant concentration threshold—such as a USEPA human-health benchmark—is available, then the probability of exceeding the threshold can be estimated. Figure 6.9 shows such a map of exceedance probabilities for WARP-estimates of annual mean atrazine concentrations in the context of a 3 ug/L (a USEPA benchmark) threshold.

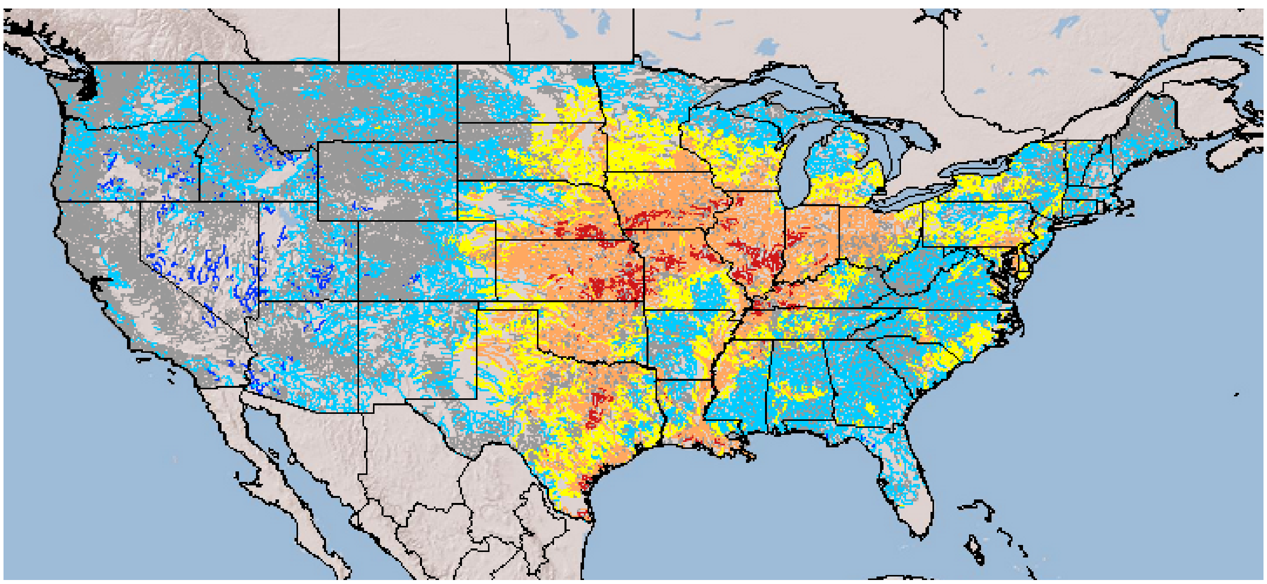


Figure 6.8. Estimated annual mean atrazine concentration [ug/L] for conterminous U.S. streams based on 2007 atrazine use. The highest atrazine concentrations are shown in red and the lowest concentrations are dark blue. Only streams with significant agriculture in their drainage basins are shown.

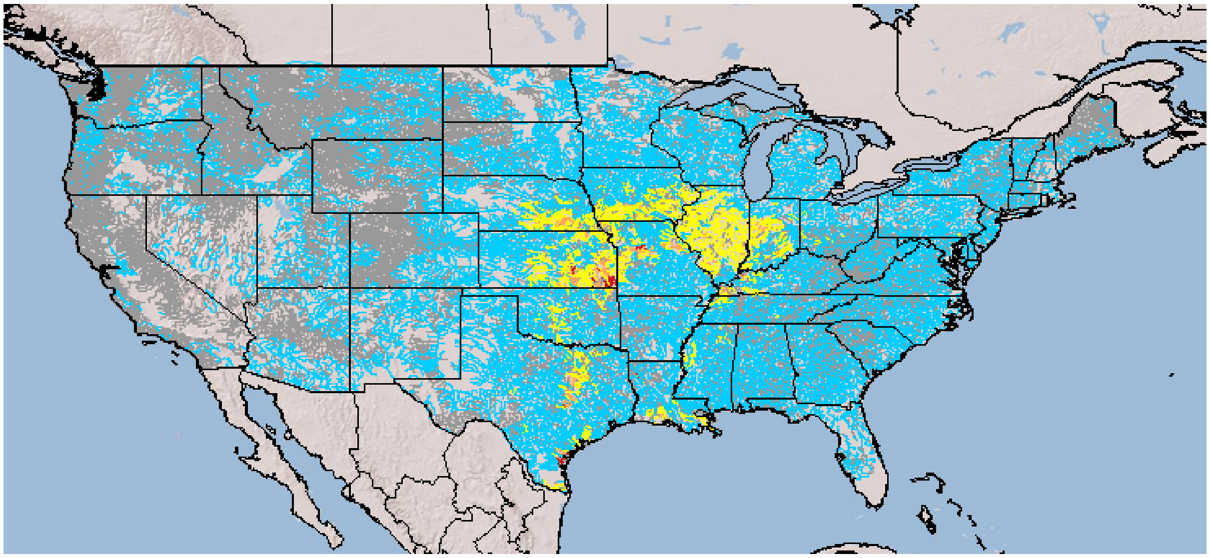


Figure 6.9. Probability that the estimated annual mean atrazine concentration exceeds 3 ug/L. This maximum contaminant level (MCL) is a water-quality benchmark established by the USEPA for public drinking water supplies. The color scheme for exceedance probability values is blue (<5%), yellow (5-25%), orange (26-50%), and red (>50%).

Table 6.2. Scenarios for forecasting changes in land use and climate

Climate-change scenarios
— Global climate models (GCMs) have been constructed at many universities and agencies around the world; NOAA and NASA are examples of agencies actively producing GCM simulations. GCMs are downscaled (the spatial resolution of the climate predictions is enhanced) using approaches developed at the Bureau of Reclamation, USGS, Texas Tech University, and Penn State University.
— Paleoclimate reconstructions of decadal-to-multidecadal (D2M) ocean climate modes can be used to estimate probability distribution functions of future shifts in climate and streamflow. Examples of D2M climate indices are the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO). Measurement of current and recent climate indices enables a probabilistic forecast of future ocean climate regimes and associated continental climate and streamflow condition.
Land-cover change scenarios
— Several Federal agencies and research institutions are developing methods to generate scenarios of future land-cover change. The USGS is supporting land-cover modeling projects including the National Land-Change Community Modeling System, the National Ecosystem Assessment and Forecasting Consortium, the Land Cover Dynamics and Environmental Processes Project, the Land Cover Trends Project, and Project Gigalopolis. The USEPA is estimating future land cover in its Future Midwestern Landscapes Study, and the USDA is generating future agricultural land-use scenarios.

Economic (cost-benefit) considerations in forecasting
— Economic analyses can be an important component of forecasting the effects of climate and land-use change on water resources for human and ecosystem needs. Examples of such analyses would include: an evaluation of the costs and benefits of implementing agricultural best management practices; or an economic assessment of costs associated with water-quality degradation due to climate change. NAWQA will continue to collaborate with economists from the organization Resources for the Future (RFF) and the USDA Economic Research Service (ERS) to obtain necessary technical support.

Objective 4c: Predict the physical and chemical water-quality and ecosystem conditions expected to result from future changes in climate and land use for selected watersheds.

In addition to providing models (Objective 4b) and an associated decision-support system (Objective 4c), NAWQA will complete selected studies in high priority areas (Table 6.3) of the potential effects of climate, land use, and water use changes on water quality and ecosystems. Within each study area, the study will focus on a crucial issue which will be identified by one of NAWQA's partners.

Table 6.3. Potential climate and land-use change effects study areas. Note that additional study areas are likely to be added.

Basin study areas	Primary Partnerships
Chesapeake Bay	Chesapeake Bay Program
Mississippi River	Gulf of Mexico Watershed Nutrient Task Force, Louisiana Universities Marine Consortium
Delaware River	WaterSMART
Colorado River	WaterSMART
Apalachicola-Chattahoochee-Flint Rivers	WaterSMART
Great Lakes	Great Lakes Restoration Initiative, Great Lakes Commission

A brief hypothetical study is described here to illustrate how NAWQA could forecast the effects of both climate and land-use change on water quality. This general approach would be adapted to the individual study area. A brief description of a hypothetical study is given below to illustrate how NAWQA and its partners could forecast the effects of both climate and land-use change on water quality.

Objective: Evaluate the potential effects of climate and land-use change on the transport of nutrients to the Chesapeake Bay.

Approach: Use the Chesapeake Bay watershed SPARROW model with climate and land-use change scenarios to estimate potential future nutrient loads to the Bay.

1. The steady-state version of the Chesapeake SPARROW nutrient model serves as the baseline condition.

2. A land-cover change scenario for the Chesapeake Bay watershed, selected by the Chesapeake Bay Program, is used to alter the land-cover dependent inputs to the baseline model. The baseline model is then rerun to simulate stream nutrient loads under future land-cover conditions.

3. A climate-change scenario also selected by the Chesapeake Bay Program is input to a water-balance model to estimate future streamflows throughout the watershed. The estimated flows are used to estimate future nutrient loads at existing monitoring sites, and the estimated future nutrient loads are used to calibrate a new steady-state SPARROW nutrient model. This model simulates stream nutrient loads under future climate conditions but present-day source conditions.

4. The land-cover change scenario is used to alter the land-cover dependent inputs to the model developed in step 3, and that model is rerun to simulate nutrient loads under future land-cover and climate conditions.

5. SPARROW results from the three change scenarios and the baseline condition are compared to infer the relative effects of climate and land-use change on nutrient loads to the Bay.

Products: These will be determined by the Chesapeake Bay Program and would likely include a report and web-accessible output from the model in the form of data and maps.

Caveats: The approach described above uses a steady state, not a transient, version of SPARROW. The results do not describe the lag time between changes in land use and changes in water quality; that lag time is expected to be on the order of a decade (based on age-dating analyses suggesting typical travel times of water from the land surface through subsurface flow paths to streams and rivers is about 10 years), or in the case of sediment or sediment-bound contaminants, possibly much longer. Thus model simulations using year 2030 land-cover and climate projections may be predictive of stream-nutrient loads expected to occur in 2040 or later.

Partnerships for Goal 4

Activities related to forecasting future water-quality conditions are being conducted in several USGS programs and a number of Federal agencies. A few of these efforts are, like NAWQA, are developing the capability to predict the effects of climate and land-use change on water-quality and ecosystem condition. It is crucial, in order to not be redundant, for Cycle 3 activities to complement, and not duplicate, these other efforts. This requires that NAWQA partner and plan with the programs and agencies listed below.

USGS Mission Areas

- <u>Climate and Land Use Change</u>: Forecasting the effects of climate and land-use change on water quality and ecosystem condition is clearly aligned with this Mission Area. Examples of complementary goals include: carbon sequestration; monitoring water quality and quantity; understanding and modeling the impacts of climate and land-cover change on ecosystems and other natural resources; geographic analysis and monitoring; and science applications and decision support.

— Model effects of climate change on water quality and aquatic ecosystems: The U.S. Climate Change Science Program oversees the U.S. Global Change Research Program (USGCRP) and the President's Climate Change Research Initiative (CCRI). These Federally supported programs include a variety of activities related to forecasting changes in water quality. Some of the planned activities are: long-term streamflow monitoring to detect impacts of climate and land-use change on water-quality and aquatic ecosystem conditions; integration of global climate models with ecological habitat models to develop management response options in the context of a changing climate; and an assessment of the potential of carbon sequestration to mitigate climate change.

— Forecast effects of urban growth, future urban planning scenarios, and resulting land cover change in urban areas on water quality and stream ecosystems: The long-term goal of the USGS Urban Dynamics Program /UC Santa Barbara's Project Gigalopolis is to predict urban growth patterns on a regional and continental scale to guide both local and regional community planners in achieving sustainable urban growth. Recent modeling work incorporates land conservation scenarios in the coupled models of urban growth and land-use change, creating a set of scenarios that can be used to experiment with alternative futures. The goal of the collaboration would be to link NAWQA models that relate urban land cover to stream ecological effects with Project Gigalopolis forecasts of land cover under different scenarios of urban growth and urban land planning and conservation.

- Water: NAWQA's goal is to be a leading source of scientific information for the development of effective policies and management strategies by providing objective and reliable data, water-quality models, and scientific studies that characterize where, when, how, and why the Nation's water quality is degraded—and what can be done to improve and protect it. The model-based decision-support tools developed in Goal 4 will deliver scientific information directly to the analysis and decision-making by water-quality policy makers and managers. This goal clearly is aligned with the Water Mission Area. Goals of other Water programs that complement Goal 4 include:

— Forecasting availability of water: A goal of the WaterSMART program is to develop an improved ability to forecast the availability of water for future human, economic and environmental uses . The program includes a systematic examination of the ecological effects of flow alteration, and definition of the flow alteration – ecological response relations for the various types of streams. The goal of the collaboration with WaterSMART would be to link NAWQA models that predict the severity of flow alteration to Water Census studies that relate ecological effects to degree of flow alteration.

— Couple water-quality models with USGS watershed models: The USGS National Research Program (NRP) Modeling of Watershed Systems (MOWS) project develops and supports hydrologic simulation models at the watershed scale and is currently involved in simulating the effects of climate and land-use change on flow in streams and groundwater. In addition MOWS will serve as a central distribution point for climate and land-use change scenarios produced by the USGS and other agencies. Linking MOWS model output and NAWQA models of water-quality and ecosystem condition models with allow forecasting water-quality and ecosystem conditions for MOWS-generated scenarios.

External Partnerships

U.S. Department of Agriculture

- Assessing the effects of biofuel development on water quality: The USDA is estimating the effects of biofuel development in the Midwest by coupling scenarios of land use and cropping patterns with a watershed model. These forecasts will show how increasing corn acreage and associated agricultural chemical use could affect nutrient and pesticide concentrations in streams.

- Evaluating the effects of agricultural management practices on water quality: Through its Conservation Effects Assessment Project (CEAP), the USDA is quantifying the effects of conservation practices and programs on the environmental quality of agricultural landscapes. CEAP includes both monitoring and modeling projects at watershed and national scales. Recently (June, 2010), the USDA released a description of a modeling study for the Upper Mississippi River Basin that focused on the effects of conservation practices on sediment, nutrient, and pesticide losses from farm fields.

U.S. Environmental Protection Agency

- Model water-quality response to clean air regulation: Through its ongoing development of the Nitrogen Dioxide (NO_2) and Sulfur Dioxide (SO_2) Secondary Standards, USEPA is assessing the relation between regulatory emission control scenarios for NO_x, air quality, atmospheric N deposition, and nutrient enrichment of aquatic ecosystems. The Community Multiscale Air Quality (CMAQ) modeling system, developed by USEPA and NOAA, links emission-control scenarios to predictions of atmospheric N deposition. Of particular interest is identifying the levels of emission control that result in restoring healthy ecosystems in nitrogen-sensitive aquatic resources. The goal of the collaboration would be to link the CMAQ predictions with NAWQA models (SPARROW) that predict nitrogen inflows to nitrogen-sensitive aquatic resources to identify levels of emission control that result in restoring healthy ecosystems.

National Oceanic and Atmospheric Administration

- Forecast water-quality at NWS forecast sites: As part of NOAA's Next Generation Strategic Plan (NGSP), the agency proposes to pilot short-term (hours to days) water-quality forecasting at existing NWS forecast sites. In this pilot program, the Office of Hydrologic Development (OHD) will produce a system for forecasting temperature to assist fisheries management.

- Forecast nutrient delivery to estuaries: Within NOAA's Coastal Hypoxia Research Program (CHRP), the USGS, Smithsonian Environmental Research Center, University of Michigan, and Cornell University have developed models to predict the effects of land-use and climate change on delivery of nutrients to estuaries.

References Cited

Alexander, R.B., Smith, R.A., Schwarz, G.E., Boyer, E.W., Nolan, J.V., and Brakebill, J.W., 2008, Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin, Environmental Science & Technology, Vol. 42, No. 3, p. 822-830.

Beven, K., Lamb, R., Quinn, P., Romanowicz, R., and Freer, J. 1995. TOPMODEL, in Singh, V. P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publication, Colorado, pp. 627-668

Bexfield, Laura M., 2008, Decadal-Scale Changes of Pesticides in Ground Water of the United States, 1993-2003, J. Environmental Quality, Vol. 37, pp. 226-239.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological Simulation Program--Fortran: User's manual for version 11: U.S.Environmental Protection Agency, National Exposure Research Laboratory, Athens, Ga., EPA/600/R- 7/080, 755 p.

Bingner, R. L. and F. D. Theurer, 2001, AGNPS 98: A Suite of water quality models for watershed use. In Proceedings of the Sediment: Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference, Reno, NV, 25-29 March 2001: Subcommittee on Sedimentation of the Interagency Advisory Committee on Water Data, p. VII-1 - VII-8.

Blomquist, J.D., Denis, J.M., Cowles, J.P., Hetrick, J.A., Jones, R.D., and Birchfield, N.B., 2001, Pesticides in selected water-supply reservoirs and finished drinking water, 1999–2000—Summary of results from a pilot monitoring program: U.S. Geological Survey Open-File Report 01-456, 65 p.

Bricker S.B., Clement C.G., Pirhalla D.E., Orlando S.P., Farrow D.R.G., 1999, National estuarine eutrophication assessment; effects of nutrient enrichment in the Nation's estuaries, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, Maryland, 71 p.

Brigham, M.E., Wentz, D.A., Aiken, G.R., and Krabbenhoft, D.P., 2009, Mercury cycling in stream ecosystems. 1. Water column chemistry and transport: Environmental Science and Technology, v. 43, no. 8, p. 2720-2725.

Bunn, S.E., A.H. Arthington, 2002, Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity, Environmental Management, 30:492-507.

Bryant and Carlisle (in review) The relative importance of physicochemical factors to stream biological condition in urbanizing basins: evidence from multi-model inference

Carlisle, D.M., D.M. Wolock, and M.R. Meador, in press Hydrologic alteration of U.S. rivers and the potential implications for biological diversity,

Carlisle, Daren M., Wolock, David M., and Meador, Michael R., **2010**, *Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment*: Frontiers in Ecology and the Environment (e-View), 11 p., online. doi:10.1890/100053 **Available Online**

Carlisle, D.M., J. Falcone, D.M. Wolock, M.R. Meador, and R.H. Norris, 2009, Predicting the natural flow regime: Models for assessing hydrological alteration in streams, River Research and Applications DOI: 10.1002/rra.1247

Chasar, L.C., Scudder, B.C., Stewart, A.R., Bell, A.H., and Aiken, G.R., 2009, Mercury cycling in stream ecosystems. 3. Trophic dynamics and methylmercury bioaccumulation: Environmental Science and Technology, Vol. 43, No. 8, p. 2733–2739. available for free download from ES&T via AuthorChoice.

Chalmers, A.T., Argue, D.M., Gay, D.A., Brigham, M.E., Schmitt, C.J., and Lorenz, D., 2010, Mercury trends in fish from rivers and lakes in the United States, 1969-2005: Journal of Environmental Monitoring and Assessment, published online June 10, 2010 in advance of print. doi: 10.1007/s10661-010-1504-6

Commission for Environmental Cooperation (Lead Author);Mark McGinley (Topic Editor), 2008, Ecoregions of North America-Level II (CEC): in Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth April 15, 2008; Last revised Date April 15, 2008; Retrieved October 21, 2010 <http://www.eoearth.org/article/Ecoregions_of_North_America-Level_II_(CEC)>

Cuffney, Thomas F., Kashuba, Roxolana, Qian, Song S., Alameddine, Ibrahim, Cha, YoonKyung, Lee, Boknam, Coles, James F., and McMahon, Gerad. Multilevel regression models describing regional patterns of invertebrate and algal responses to urbanization across the United States (in review).

DeSimone, L.A., Hamilton, P.A.., and Gilliom, R.J., 2009, Quality of water from domestic wells in principal aquifers of the United States, 1991-2004 - Overview of major findings: U.S. Geological Survey Circular 1332, 48 p.

Diaz, R.J. and Rosenberg, R, 2008, Spreading dead zones and consequences for marine ecosystems. Science 321:926-928

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 174 p.

Duff, J.H., Tesoriero, A.J., Richardson, W.B., Strauss, E.A., and Munn, M.D., 2008, Whole-Stream Response to Nitrate Loading in Three Streams Draining Agricultural Landscapes: Journal of Environmental Quality, v. 37, p. 1133 - 1144

Francy, Donna S., Helsel, Dennis H., and Nally, Rebecca A., 2000b, Occurrence and distribution of microbiological indicators in ground water and stream water: Water Environment Research, vol. 72, no. 2, p. 152-161. doi: 10.2175/106143000X137220

Francy, Donna S., Myers, Donna N., and Helsel, Dennis R., 2000a, Microbiological monitoring for U.S. Geological Survey National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 00-4018, 34 p.

Gilliom, R.J., Barbash, J.E., Crawford, C.G., Hamilton, P.A., Martin, J.D., Nakagaki, N., Nowell, L.H., Scott, J.C., Stackelberg, P.E., Thelin, G.P., and Wolock, D.M., 2006, The quality of our Nation's waters—

Pesticides in the Nation's streams and ground water, 1992–2001: U.S. Geological Survey Circular 1291, 172 p., http://ca.water.usgs.gov/pnsp/pubs/circ1291/

Gilliom, R.J., Bencala, K., Bryant, W., Couch, C.A., Dubrovsky, N.M., Franke, L., Helsel, D., James, I., Mueller, D., Stoner, J., Sylvester, M.A., Wilber, W.G., Wolock, D.M., and Zogorski, J., 2001. Study-unit design guidelines for Cycle II of the National Water Quality Assessment (NAWQA). U.S. Geological Survey NAWQA Cycle II Implementation Team. Revised Draft (6/28/2001), 193 p.

Graf, W.L.. 1999, Dam Nation: A Geographic Census of Large American Dams and Their Hydrologic Impacts, Water Resources Research 35: 1305-1311.

Herbage, A.W., 2005, MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, 253 p.

Horowitz, A.J., 1991, A primer on trace metal-sediment chemistry (2nd ed): Ann Arbor, Michigan, Lewis Publ. Co., 136 p.

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004, Estimated use of water in the United States in 2000: U.S. Geological Survey Circular 1268, 46 p.

Kashuba, R., Cuffney, T.F., McMahon, G., Reckhow, K., Gerritsen, J., and Davies, S. Linking urbanization to the Biological Condition Gradient (BCG) in the Northeast United States using a Bayesian network approach (in review). [Submitted to Environmental Modelling & Software last month.]

Kashuba, R., Cuffney, T., Qian, S., Reckhow, K. Combining expert knowledge with data to develop a Bayesian network describing the impact of urbanization on aquatic macroinvertebrate communities in the southeast United States. U.S. Geological Survey Scientific Investigations Report 2010-XXXX, XXp. (In review)

Kashuba, Roxolana, Cha, YoonKyung, Alameddine, Ibrahim, Lee, Boknam, and Cuffney, T.F., 2010, Multilevel hierarchical modeling of benthic macroinvertebrate responses to urbanization in nine metropolitan regions across the conterminous United States: U.S. Geological Survey Scientific Investigations Report 2009–5243, 88 p.

Kaufmann, P.R., Faustini, J.M., Larsen, D.P., and Shirazi, M.F., 2008, A roughness-corrected index of relative bed stability for regional stream surveyss: Geomorphology, v. 99, pp. 150-170.

Kaufmann, P.R., Larsen, D.P., and Faustini, J.M., 2009, Bed stability and sedimentation associated with human disturbances in Pacific Northwest Streams: Journal of the American Water Resources Association, v. 45, no. 2, pp. 434-459.

Kauffman, L.J., Baehr, A. L., Ayers, M. A., and Stackelberg, P. E., 2001, Effects of land use and travel time on the distribution of nitrate in the Kirkwood-Cohansey aquifer system in southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 01-4117, 49 p.

Kennen, J.G., Riva-Murray, K., and Beaulieu, K.M. 2010. Determining hydrologic factors that influence stream macroinvertebrate assemblages in the northeastern US. Ecohydrology. 3:88-106.

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p.

Konikow, L.F., Goode, D.J., and Hornberger, G.Z., 1996, A Three- Dimensional Method-of-Characteristics Solute-Transport Model (MOC3D): U.S. Geological Survey Water-Resources Investigations Report 96-4267, 87 p.

Lapham, W.W., Hamilton, P.A., and Myers, D.N., 2005, National Water-Quality Assessment Program - Cycle II - Regional assessments of aquifers: U.S. Geological Survey Fact Sheet 2005-3013, 4 p.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-Runoff Modeling System: User's Manual: U.S. Geological Survey Water-Resources Investigations Report 83-4238, 207 p.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW-Coupled Ground-water and Surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

Marvin-DiPasquale, M., Lutz, M.A., Brigham, M.E., Krabbenhoft, D.P., Aiken, G.R., Orem, W.H., and Hall, B.D., 2009, Mercury cycling in stream ecosystems. 2. Benthic methylmercury production and bed sediment-pore water partitioning: Environmental Science and Technology, v. 43, no. 8, p. 2726–2732.

MacDonald, D.D., Ingersoll, C.G., and Berger, T.A., 2000, Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems, Archives Environmental Contaminant Toxicology, v. 39 p 20-31.

Millennium Ecosystem Assessment, 2005, Ecosystems and Human Well Being: Synthesis, Island Press, Washington D.C., 137 p.

Munn, M.D., Gilliom, R.J., Moran, P.W., and Nowell, L.H., 2006, Pesticide toxicity index for freshwater aquatic organisms, 2nd Edition: U.S. Geological Survey Scientific Investigations Report 2006-5148, 81 p. **Available Online**

Munn, M., Frey, J., and Tesoriero, A., 2010, The influence of nutrients and physical habitat in regulating algal biomass in agricultural streams: Environmental Management, DOI 10.1007/s00267-010-9435-0.

Neitsch, S.L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2005. Soil and Water Assessment Tool theoretical documentation version 2005. Available at: http://swatmodel.tamu.edu/media/1292/SWAT2005theory.pdf. Accessed 6 October 2010.

Nolan, B.T. and Hitt, K.J., 2006, Vulnerability of shallow ground water and drinking-water wells to nitrate in the United States: Environmental Science and Technology, vol. 40, no. 24, p. 7834-7840.

Qian, S.S., Cuffney, T.F., Alameddine, Ibrahim, McMahon, Gerard, and Reckhow, K.H., 2010, On the application of multilevel modeling in environmental and ecological studies, Ecology, v. 91, no. 2 p. 355-361.

Poff N.L., Richter B., Arthington A.H., Bunn S.E., Naiman R.J., Kendy E., Acreman M., Apse C., Bledsoe B.P., Freeman M., Henriksen J., Jacobson R.B., Kennen J., Merritt D.M., O'Keeffe J., Olden J.D., Rogers K., Tharme R.E. & Warner A. 2010. The Ecological Limits of Hydrologic Alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology v. 55, pp. 147-170.

Postel, Sandra and Richter, Brian, 2003, Rivers for life: managing water for people and nature: Island Press, Washington DC.

Preston, S.D., Alexander, R.B., Woodside, M.D., and Hamilton, P.A., 2009, SPARROW MODELING—Enhancing Understanding of the Nation's Water Quality: U.S. Geological Survey Fact Sheet 2009–3019, 6 p.

Rasmussen, P.P., and Ziegler, A.C., 2003, Comparison and continuous estimates of fecal coliform and Escherichia coli bacteria in selected Kansas streams, May 1999 through April 2002: U.S. Geological Survey Scientific Investigations Report 2003-4056, 80 p.

Riseng, C.M., Wiley, M.J., Black, R.W. and Munn, M.D. Impacts of agricultural land use on biological integrity: a causal analysis. Ecological Indicators. (in review)

Rockstrom, J., Steffen, W., Noone, K., Persson, A., and others, 2009, A safe operating space for humanity, Nature, v. 461, p. 472-475.

Rosen, M.R., Voss, F.D., and Arufec, J.A., 2008, Evaluation of Intra-annual Variation in U.S. Geological Survey National Water Quality Assessment Ground Water Quality Data: Journal of Environmental Quality, 37 (5), p. S199-S208. doi: 10.2134/jeq2007.0055

Rowe, G.L., Jr., Belitz, Kenneth, Essaid, H.I., Gilliom, R.J., Hamilton, P.A., Hoos, A.B., Lynch, D.D., Munn, M.D., and Wolock, D.W., 2010, Design of cycle 3 of the National Water-Quality Assessment Program, 2013–2023: Part 1—Framework of water-quality issues and potential approaches: U.S. Geological Survey Open-File Report 2009–1296, 54 p.

Rupert, Michael G., 2008, Decadal-Scale Changes of Nitrate in Ground Water of the United States, 1988-2004: J. Environ. Qual., Vol. 37, No. 5 Supplemental, pp. 240-248.

Schwarz, G.E., 2008, A Preliminary SPARROW model of suspended sediment for the conterminous United States: U.S. Geological Survey Open-File Report 2008–1205, 8 p., available only online at http://pubs.usgs.gov/of/2008/1205.

Schwarz, G.E., Hoos, A.B., Alexander. R.B., and Smith, R.A., 2006, The SPARROW surface water-quality model—Theory, application, and user documentation: U.S. Geological Survey Techniques and Methods Report, book 6, chap. B3, 248 p., available online at http://pubs.er.usgs.gov/usgspubs/tm/tm6B3.

Scudder, B.C., Chasar, L.C., Wentz, D.A., Bauch, N.J., Brigham, M.E., Moran, P.W., and Krabbenhoft, D.P., 2009, Mercury in fish, bed sediment, and water from streams across the United States, 1998-2005: U.S. Geological Survey Scientific Investigations Report 2009-5109.

Smith, R.A., Schwarz, G.E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data: Water Resources Research, December 1997, vol. 33, no. 12, p. 2781-2798.

Sprague, L.A., Mueller, D.K., Schwarz, G.E., and Lorenz, D.L., 2009, Nutrient trends in streams and rivers of the United States, 1993-2003: U.S. Geological Survey Scientific Investigations Report 2008-5202, 196 p.

Stackelberg, P.E., Gilliom, R.J., Wolock, D.M., and Hitt, K.J., 2005, Development and application of a regression equation for estimating the occurrence of atrazine in shallow ground water beneath agricultural areas of the United States, U.S. Geological Survey Scientific Investigations Report 2005-5287

Stone, W.W.,and Gilliom, R.J., 2009, Update of watershed regressions for pesticides (WARP) for predicting atrazine concentration in streams: U.S. Geological Survey Open-File Report 2009–1122, 22 p.

Toccalino, P.L., 2007, Development and application of health-based screening levels for use in water-quality assessments: U.S. Geological Survey Scientific Investigations Report 2007-5106, 12 p.

Toccalino, P.L., and Hopple, J.A., 2010, The quality of our Nation's waters - Quality of water from public-supply wells in the United States, 1993-2007 - Overview of major findings: U.S. Geological Survey Circular 1346, 58 p.

U.S. Department of Agriculture, 2009, Mississippi Basins Healthy Watershed Initiative Fact Sheet, available online at http://www.nrcs.usda.gov/programs/pdf_files/mrbi_factsheet.pdf, Accessed 6 October 2010.

U.S. Environmental Protection Agency, 2006, Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams, EPA 841-B-06-002. (http://www.epa.gov/owow/streamsurvey/)

U.S. Environmental Protection Agency, 2008, Watershed Assessment, Tracking & Environmental Results (http://iaspub.epa.gov/waters10/attains_nation_cy.control)

U.S. Environmental Protection Agency, 2009, National water quality inventory: report to congress, 2004: EPA 841-R-08-001, pp. 1-37.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017: U.S. Geological Survey Circular 1309, x + 70 p.

Van Metre, Peter C., and Mahler, B.J., 2005, Trends in hydrophobic organic contaminants in urban and reference lake sediments across the United States, 1970-2001: Environmental Science and Technology, vol. 39, no. 15, p. 5567-5574. doi: 10.1021/es0503175 **Available Online**

Van Metre, P. C.; Mahler, B. J., Contribution of PAHs from Coal-Tar Pavement Sealcoat and Other Sources to 40 U.S. Lakes. Sci. of the Total Environ., 2010, v.409, 334-344.

Waite, I.R., Brown, L.J., Kennen, J.G., May, J.T., Cuffney, T.F., Orlando, J.F., and Jones, K.A., 2010, Comparison of watershed disturbance predictive models for stream benthic macroinvertebrates for three distinct western ecoregions: Ecological Indicators, Ecological Indicators v. 10, p. 1125–1136 (Also available at http://dx.doi.org/10.1016/j.ecolind.2010.03.011).

Waters, T.F., 1995, Sediment in streams—Sources, biological effects, and control: American Fisheries Society, Monograph 7, 251 p.

Wilber, W. G., and Deacon, J.R., (in prep), Establishing a Collaborative and Multipurpose Long-Term National Network of Reference Watersheds and Monitoring Sites for Freshwater Streams in the United States, U.S. Geological Survey Fact Sheet 10-xxxx, 4 pg.

Wilcove, D.S., D Rothstein, J. Dubow, A. Phillips, and E. Losos, 1998, Quantifying threats to imperiled species in the United States, BioScience, 48:607-615.

Zheng, Chunmiao, 1990. MT3D, A modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems, Report to the U.S. Environmental Protection Agency, 170 p.

Zheng, Chunmiao, and P. Patrick Wang, 1999, MT3DMS, A modular three-dimensional multi-species transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems; documentation and user's guide, U.S. Army Engineer Research and Development Center Contract Report SERDP-99-1, Vicksburg, MS, 202 p.