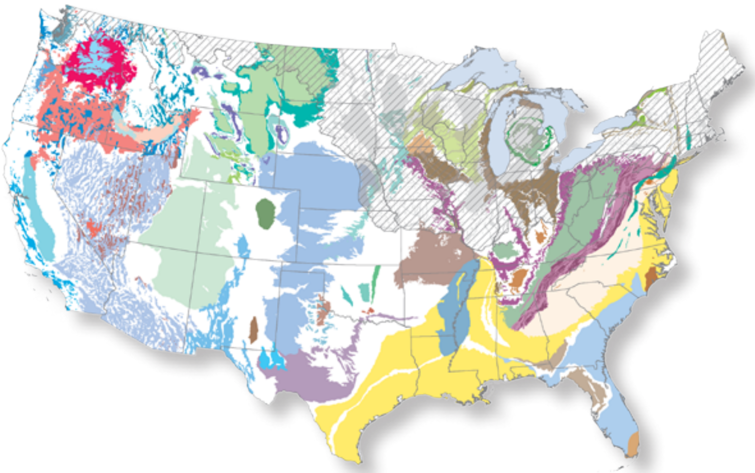
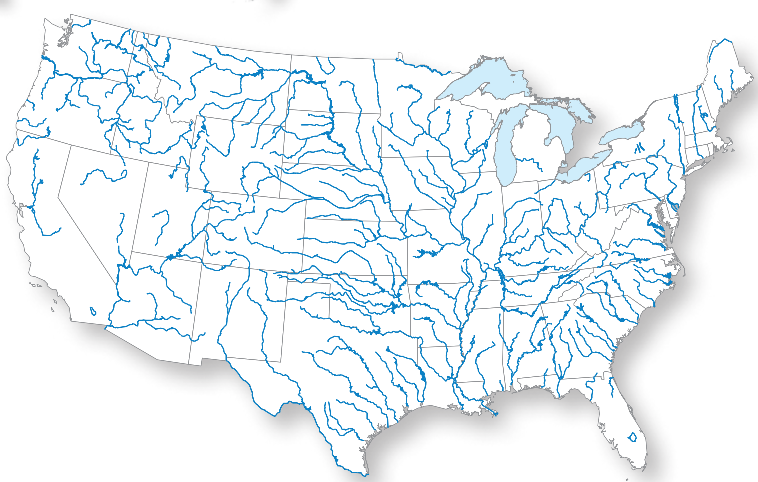
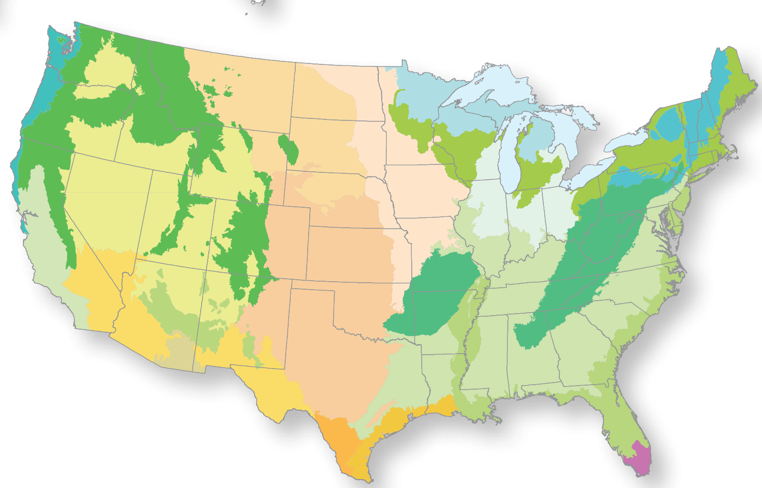
National Water-Quality Assessment Program

Design of Cycle 3 of the National Water-Quality Assessment Program, 2013–23:

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







Open-File Report 2013–1160

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

Cover: Maps illustrating national-scale design elements for Cycle 3 of the National Water-Quality Assessment Program including: (upper left)-principal aquifers of the conterminous U.S., (center)-major rivers of the conterminous U.S., and (lower right) level-2 ecoregions of the conterminous U.S.

Design of Cycle 3 of the National Water-Quality Assessment Program, 2013–23:

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

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

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Foreword

The United States has made major investments in assessing, managing, regulating, and conserving natural resources such as water, minerals, soils, and timber. Sustaining the quality of the Nation's water resources and the health of our ecosystems depends on the availability of sound water-resources data and information to develop effective, science-based policies. Effective management of water resources also brings more certainty and efficiency to important economic sectors. Taken together, these actions lead to immediate and long-term economic, social, and environmental benefits that make a difference to the lives of millions of people (*http://water.usgs.gov/nawqa/applications/*).

Two decades ago, the Congress established the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program to meet this need. Since then it has served as a primary source of nationally consistent information on the quality of the Nation's 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 related decision support tools, 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 critical to our future because the Nation faces an increasingly complex and growing need for clean water to support population, economic growth, and healthy ecosystems. For example, two thirds of U.S. estuaries are impacted by nutrients and dead zones that no longer fully support healthy fish and other aquatic communities. Forty-two percent of the Nation's streams are in poor or degraded condition compared to reference conditions. Eighty three percent of urban streams have at least one pesticide that exceeds criteria to protect aquatic life. Groundwater from about 20 percent of public and domestic wells—which serve almost 150 million people—contains at least one contaminant at a level of potential health concern.

This report presents a science plan for improved water-quality information and management for the third decade—Cycle 3—of the NAWQA Program.The science plan describes a 10-year strategy for national monitoring and assessment of the Nation's freshwater quality and aquatic ecosystems during 2013–23 and builds on a foundation of over 20 years of NAWQA data collection, interpretative studies, and modeling activities. It represents the consensus of USGS scientists and managers, NAWQA Program stakeholders, and a National Research Council technical advisory committee (*http://www.nap.edu/catalog.php?record_id=13464*).

Other recent NAWQA reports have focused on occurrence and distribution of nutrients, pesticides, and volatile organic compounds in streams and groundwater, the effects of contaminants and streamflow alteration on condition of aquatic communities in streams, and on the quality of untreated water from private domestic and public supply wells. Each report builds toward a more comprehensive understanding of the quality of regional and national water resources (*http://water.usgs.gov/nawqa/nawqa_sumr.html*). All NAWQA reports are available on-line at *http://water.usgs.gov/nawqa/bib/*.

The information in this report is intended primarily for those interested or involved in resource management and protection, conservation, regulation, and policymaking at regional and national levels. We hope this publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

William H. Werkheiser
Associate Director for Water
U.S. Geological Survey

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations and Acronyms

AGNPS	Agricultural Nonpoint Source Pollution Model
CADDIS	Causal Analysis/Diagnosis Decision Information System
CMAQ	Community Multiscale Air Quality Modeling System
DDT	dichlorodiphenyltrichlorethane
DSS	Decision Support System
E. coli	Escherichia coli
ELOHA	Ecological Limits of Hydrologic Alteration
ETN	Enhanced Trends Network
EUSE	Effects of Urbanization on Stream Ecosystems
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FPS	Flow-Path Study
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
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 Level
MOC3D	Method of Characteristics Solute Transport Model
MODFLOW	Modular Groundwater Flow Model
MODPATH	MODFLOW Particle Tracking Model
MOWS	Modeling of Watershed Systems
MRB	major river basin
MT3D	Modular 3-D Groundwater Solute Transport Model
NARS	National Aquatic Resource Surveys
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water-Quality Assessment
NEET	Effects of Nutrient Enrichment on Stream Ecosystems
NEON	National Ecological Observatory Network
NFSN	National Fixed-Site Network
NMN	National Monitoring Network
NOAA	National Oceanic and Atmospheric Administration
NRP	National Research Program
NTAS	NAWQA National Target Analyte Strategy
O/E	ratio of the observed value to the estimated reference condition value
PAA	Principal Aquifer Assessment
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
P-GWAVA	Process-based Groundwater Vulnerability Assessment
PRMS	Precipitation Runoff Modeling System
QPCR	quantitative polymerase chain reaction
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 Watersheds
STREON	Stream Experimental and Observatory Network
SWAT	Soil and Water Assessment Tool
TANC	Transport of Anthropogenic and Natural Contaminants to Supply Wells
TMDL	Total Maximum Daily Load
TOPMODEL	Topography-based Model
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WARP	Watershed Regressions for Pesticides
WaterSMART	Water (Sustain and Manage America’s Resources for Tomorrow)

About this Report

This report presents a science plan for improved water-quality information and management 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 2013–23 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 Cycle 3 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 in this report, 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 follows.

Introduction and Overview

The introduction 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, the information gained from Cycle 3 monitoring and modeling activities that can be used to improve, protect, and restore the Nation's 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.*"

Cycle 3 Design Elements

This section outlines the specific objectives associated with each of the four Cycle 3 goals and describes each of the major design elements for implementing Cycle 3. These individual design elements for surface water and groundwater are then applied to specific design components for each objective in subsequent sections. The NAWQA Program 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; greater contaminant coverage and application of continuous real-time water-quality monitoring; regional synoptic studies of specific topics; and integrated hydrologic and water-quality studies of representative large watersheds with local-scale intensive studies to answer specific questions. The groundwater design focuses on assessment of large principal aquifers, with a new goal of assessing groundwater 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 groundwater flow and contaminant-transport modeling done at a range of scales.

Objectives and Approaches for Addressing Cycle 3 Goals

Remaining sections of the report describe the objectives and assessment approaches for each of the four Cycle 3 goals including:

- objectives,
- products,
- policy and management relevance,
- progress during Cycles 1 and 2,
- study approaches,
- planned studies, and
- partnership opportunities

The objectives and approaches are presented somewhat differently for each of the goals, depending on the specific types of studies involved, their degree of integration, and the level of development for specific study designs.

Goal 1—Assess the Current Quality of the Nation's Freshwater Resources and How Water Quality is Changing Over Time

The Cycle 3 design for monitoring surface water and groundwater addresses gaps in the current assessment of the Nation's water-quality while also addressing issues identified by stakeholders as being important to maintaining or improving water quality in the future. A critical first step is to restore the NAWQA fixed-site network for monitoring water quality in the Nation's streams and rivers; this network has suffered substantial declines in the number of sites and the frequency at which the sites are sampled between Cycles 1 and 2 (from approximately 500 sites monitored in Cycle 1 to 113 sites in 2011). Substantial increases in the number of surface-water sites (113 to 313 sites), annual sampling (at all sites), and the use of continuous water-quality monitoring (at most sites) are key features of the enhanced Cycle 3 design.

In addition, several critical improvements that address key data gaps are included 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, reservoirs, and on 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) enhanced 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 monitoring activities described for Goal 1 are essential for identifying and explaining trends in water-quality and ecosystem conditions (Goal 2), understanding the effects of climate change and human activities on water quality and aquatic biota (Goals 2 and 3), and also are essential for development and validation of water-quality models (Goals 2, 3, and 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

Studies to address Goal 2 are focused on developing explanations for, and understanding of, the observed patterns and trends in water quality. Such 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 new management strategies and the effects of potential future land use and climate change of water-quality and ecosystem conditions will be explored through Goal 4.

Goal 3—Determine the Relative Effects, Mechanisms of Activity, and Management Implications of Multiple Stressors in Aquatic Ecosystems

Goal 3, which is receiving increased emphasis in Cycle 3, builds on 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 in Goal 4 to estimate the effects of future land use, climate change, and management strategies on aquatic ecosystems.

Goal 4—Predict the Effects of Human Activities, Climate Change, and Management Strategies on Future Water-Quality and Ecosystem Condition

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 that future changes in land use, water use, and climate may have 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 scale (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 conditions due to changes in climate, land and water use, and management practices.

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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 human activities and natural factors 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 report presents the science plan for improved water-quality information and management 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 2013–23. 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 (Rowe and others, 2010). Specifically, input on key water issues and science needs has been solicited, reviewed, and supported by the National Research Council (2010, 2011, or 2012) and more than 50 internal and external stakeholders who provided input during the first three years of the planning effort (2008–11).

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 adheres to this vision by serving as one of the largest and most comprehensive programs that provides 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 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 stressor-effects 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?*" requires a "targeted" design such as NAWQA's, which focuses on understanding the relations between water-quality conditions and human and natural factors that cause those conditions, including water sources, transport, seasonal differences, varying streamflow and groundwater contributions, and processes that control the movement of water. Information provided by NAWQA, as described further in this section of the report, complements information gathered by other national-scale water-quality programs, such as the U.S. Environmental Protection Agency (USEPA) National Aquatic Resources Surveys. The surveys assess water quality conditions in the Nation's streams, rivers, lakes, wetlands, and coastal waters use a probability-based statistical design 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 2013–23 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

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.

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 historical 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 important in shaping 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. Substantial progress towards cleaner water resulted from engineering improvements in manufacturing processes and wastewater treatment (Dubrovsky and others, 2010).

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, the cumulative long-term effects of the introduction of hundreds of synthetic organic compounds on humans or aquatic biota, how to manage and reduce nutrient delivery to inland and coastal waters, and how to balance flow requirements in our streams and rivers to minimize habitat degradation and meet the needs of both humans and aquatic ecosystems are still largely unknown.

What we do know, however, is that we face a litany of water-quality issues that continues to grow. Key examples

NAWQA's Unique Approach to National Assessment

The following describe unique aspects of NAWQA's 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 these sites 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 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, NAWQA 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.

include recognition that almost two-thirds of our major estuaries are affected by excess nutrients and related dead zones that no longer support fish and other life; 42 percent of our streams are impaired and not meeting beneficial uses, such as for drinking, recreation, and ecosystem health because of habitat degradation, nutrients, or sediment; 83 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 about 150 million people—contain at least one contaminant at levels of potential health concern (see sidebar: "Ever-Increasing Water-Quality Issues Face the Nation").

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 approximately 130 million people by 2050, to a total of almost 440 million (Vincent and Velkhoff, 2010). 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.

Increased climate variability and change (with associated changes in the amount and timing of precipitation and temperature) are expected in addition to increased stress on water quality related to human activities. The two pervasive factors that affect water-quality trends (changes

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, 2010b). 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 (U.S. Environmental Protection Agency, 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).

in land and water use with population growth, and climate variability) act simultaneously, but to varying degrees in different areas and at different times, sometimes the factors affect physical characteristics, such as streamflow, temperature, and sediment; sometimes they affect chemical characteristics; and sometimes both—but all factors ultimately affect the sustainability of available water supplies for current and future human and ecosystem needs.

The complexities of hydrologic systems and human activities on the landscape mean that we can no longer 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 human activities and natural factors that contribute to those conditions. Only by investing in improved monitoring and assessment will we be able to separate the effects of human activities from natural effects, 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 investments are essential 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 yr, 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 (2012) operates a “national” surface-water-trend network composed of 113 stream and river sites, only about 40 of which are monitored during any given year. This represents a substantial decline from the 1990s, when almost 500 sites were monitored by NAWQA. The lack of maintained monitoring sites parallels similar declines in the amount of surface- and groundwater-quality data collected by other Federal and State agencies (fig. 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

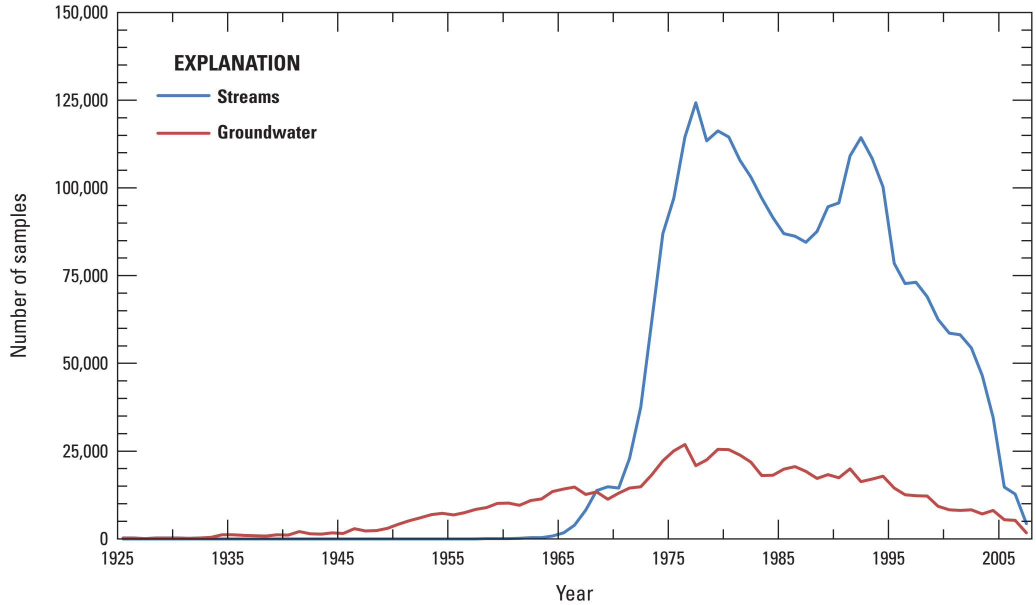


Figure 1. Numbers of nitrate samples from streams and groundwater illustrate the decline in monitoring by Federal and State agencies that has occurred over the past 20–25 years (yr), even for one of the most commonly monitored contaminants. Sample numbers are estimated from U.S. Environmental Protection Agency and U.S. Geological Survey (*http://waterdata.usgs.gov/nwis/qw*) databases and include nitrate and nitrite plus 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 10–15 yr (Jerad Bales, U.S. Geological Survey, written commun., December 2010).

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). In 2012, only 35 of those sites were still being monitored for model calibration. The sparseness of ongoing data collection by USGS and other Federal and State agencies may limit model applications and will increase the uncertainty associated with future versions of the models and the accuracy of spatial extrapolations and predictions of future water-quality change.

Of equal importance to the decline in water-quality data is that 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 substantially inadequate and out-of-date. This includes, for example, spatial data on factors such as use of pesticides, fertilizers, and other chemicals; land- and water-use; land-management practices; hydrologic settings; and fluxes of chemicals from point sources. Overall, understanding the factors responsible for observed water-quality and stream ecosystem condition will advance only 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 datasets as part of our investments in water-quality monitoring and science.

Scientific Foundation and Partnerships are Well Positioned to Make Rapid Progress

Fortunately, 20 yr 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 also 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. The National Aquatic Resources Surveys, done in collaboration with the states, help to answer key questions, such as "What are the most significant water-quality problems?," "Where are problems occurring?," and "Is water quality improving?" USEPA and the state environmental agencies use the NARS data to develop and evaluate water-quality standards, identify impaired waters, and prioritize monitoring and management needs. Nationwide, coastal, lake, wetland, and wadeable stream assessments have been completed and a new survey of wadeable streams is scheduled for 2013 (*http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm*).

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 additional details available in noted online sources.

Cycle 1:

During 1991–2001, the NAWQA Program focused on interdisciplinary baseline assessments of the quality of streams, groundwater, and aquatic ecosystems in 51 of the Nation's river basins and aquifers (referred to as "study units"). These assessments supported sampling of 505 stream sites and more than 6,000 wells. Each study-unit produced 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, 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 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 provided information that is needed to synthesize a broad understanding of how and why water quality varies regionally and nationally and enabled 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 included comprehensive national assessments of pesticides, nutrients, volatile organic compounds, and aquatic ecology at the national scale and data synthesis and comparative analysis at the study-unit scale *(http://water.usgs.gov/nawqa/nawqa_sumr.html)*.

Cycle 2

During 2002–2012, NAWQA built on the baseline study-unit assessments of Cycle 1 by increasing emphasis on assessment of long-term trends. This was done by adding topical studies of priority water-quality issues that evaluated hydrologic processes and human activities that affect the quality of streams and groundwater. Selected new status assessments were also conducted, 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 yr of consistent monitoring data available. 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/topical_studies.html)*. Each topical study included several nationally distributed study areas that ranged from a few square kilometers to a few hundred square kilometers that 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 groundwater. 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 the 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/)*.

The development and application of water-quality models has been integral to the success of the NAWQA Program in Cycle 2. 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 drivers that help to explain how water-quality conditions vary regionally and nationally. A variety of models have been used in Cycle 2, including statistical models, detailed simulation models, and hybrid models.

The surveys provide snapshots of water quality and ecosystem conditions that are not duplicated by NAWQA and provide information and data that are highly complementary to NAWQA. Integration of NAWQA and USEPA studies and data is an ongoing activity for 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, 2008).

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

- Established interdisciplinary baseline assessments of streams, groundwater, and aquatic ecosystems in 51 of the Nation's major river basins and aquifers;
- Synthesis of water-quality conditions for the Nation's streams and groundwater for nationally important water-quality concerns such as pesticides, nutrients, and volatile organic compounds VOCs;
- 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 important progress toward understanding (1) the interactions among sources of contaminants, and (2) physical, chemical, and biological processes that control the transport and transformation of contaminants through the hydrologic system; and
- Made important 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 striven to collaborate with Federal, state, and local governmental organizations, public interest groups, professional and trade associations, academia, and private industry to remain relevant to the needs and interests of these organizations. Such collaboration helps NAWQA address the most important water-resource issues facing our Nation, fill the most critical information niches, and get the most possible benefit from all available data and studies. The NAWQA 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 components of our water resources. Fortunately, such integration is increasingly possible as technology and expertise advance in the areas of 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 NAWQA 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 supporting healthy coastal waters and ecosystems.

The following ongoing or potential external NAWQA partnerships are highlighted, but more detailed information on specific partnerships being explored is provided later in relation to specific goals, objectives, and approaches:

- Partner with the 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;
- Partner with the National Ecological Observatory Network (NEON; *http://neoninc.org/*) to coordinate interdisciplinary monitoring for better understanding of nutrient processing in streams;
- Partner with the 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;
- Partner with the U.S. Department of Agriculture (USDA) to evaluate the effectiveness of conservation and management practices on water quality; and
- Partner with 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 support 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—Water (Sustain and Manage America's Resources for Tomorrow; *http://www.doi.gov/watersmart/*) Program. The science plan is also designed to deliver coordinated assessments of groundwater availabilitiy in specific aquifers by partnering with the Groundwater Resources Program (*http://water.usgs.gov/ogw/gwrp/*). The strategy also contributes to the development of a national reference watershed-monitoring network, which will support the Global Change Program (*http://www.usgs.gov/global_change/)*, Toxic Substances Hydrology Program (*http://toxics.usgs.gov/*), and Contaminant Biology Program.

Topics for collaboration 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 the following:

- ***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 change and climate variability.

- ***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; expanded collection of real-time data for temperature and other properties to differentiate short-term variability from long-term change; and development of models and decision-support tools that forecast 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 aquatic 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 the NAWQA Program, in Cycle 3 new emphasis will be placed 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 they consider important for NAWQA to address (Rowe and others, 2010). 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 large-scale "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 water resources for the health of humans and aquatic ecosystems (fig. 2).

Cycle 3 centers on four major goals that will guide development of the interdisciplinary studies that are needed to address the priority stressors and their effects 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 effects of human and natural factors on water-quality stressors. Goal 3 assesses the effects of these stressors on stream 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 on 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 that were initiated in 1991, which are to assess the status and trends in water-quality conditions and to evaluate the natural and human factors that affect those conditions. Although these broad goals have remained unchanged, greater emphasis has been placed since 2001 on evaluation of trends and

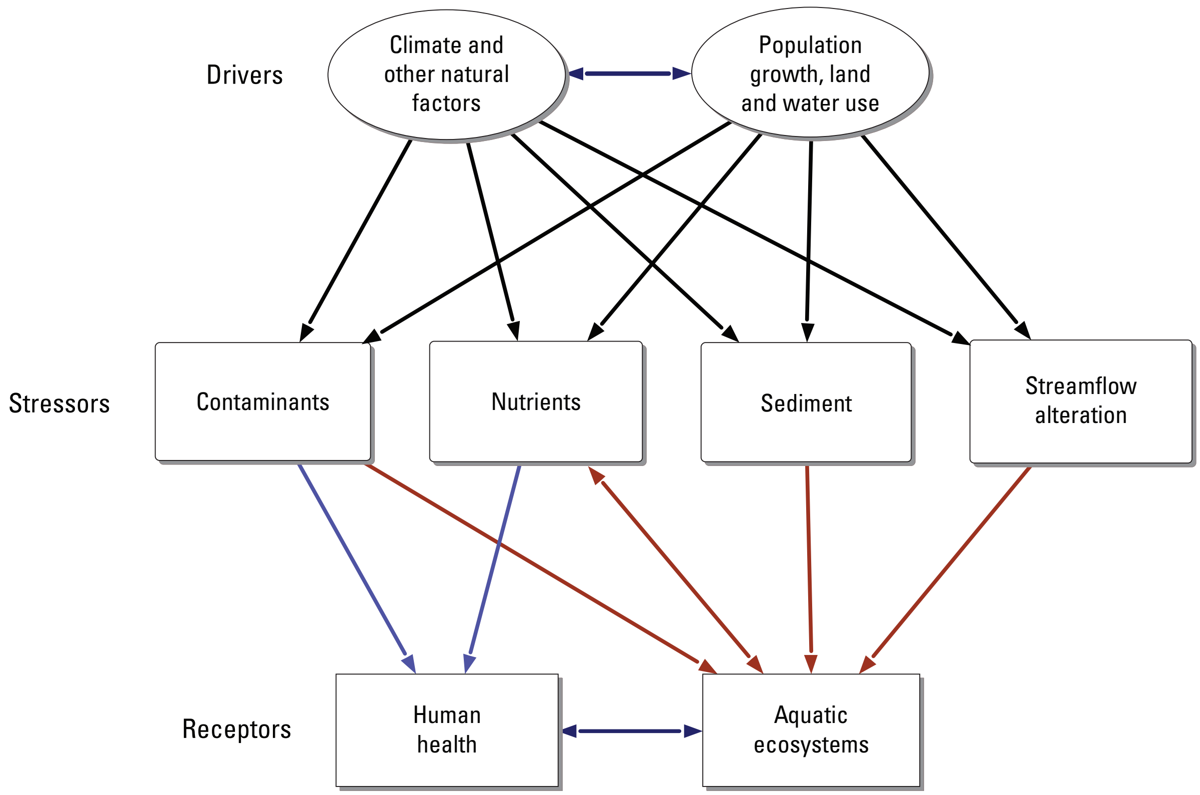


Figure 2. The Cycle 3 design is based on an interdisciplinary approach to determine where, when, and how the physical, chemical, and biological quality of water resources is affected by four major stressors: contaminants, nutrients, sediment, and streamflow alteration, all of which are simultaneously affected by large-scale environmental drivers related to climate and other natural features or are related to population growth, land and water use, and associated human activities. Additional feedback loops, exist between human activities and climate, and between aquatic ecosystems and individual stressors; for example, the effects of biological activity on nutrient concentrations in streams, rivers, and coastal estuaries. These large, indeed global-scale environmental drivers are most important with respect to governing the ultimate sustainability of available water resources for human health and healthy aquatic ecosystems.

identifying the factors responsible for observed trends. Additional shifts related to Goals 1 and 2 are included 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 nutrient and sediment 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: (1) determining the effects of multiple stressors on aquatic ecosystems and (2) forecasting future water-quality conditions. Examples of policy-relevant questions raised by water-resource managers and NAWQA stakeholders in relation to NAWQA Program goals established for Cycle 3 are listed below:

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

- 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 water-quality conditions changing over time?
- What are the freshwater inflows and loads of nutrients, sediment, and contaminants 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 the quality of surface water and groundwater.

- 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 nutrient, contaminant, and sediment loads delivered to estuarine ecosystems, the Great Lakes, and other receiving waters?

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

- 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?

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 areas identified by NAWQA stakeholders where Program resources should be directed over the next decade. Approaches used to achieve the four science goals will either depend on or affect products and outcomes from the other goals, as follows:

- ***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. These data are also essential for development and validation of water-quality models produced as part of 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 ecosystem condition, to the human and natural factors that affect water quality and aquatic ecosystem condition. 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 effects 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 ecosystem condition.
- ***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 ecosystem condition. 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 conducted as parts of 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.

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

- 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 as land use and climate change over time?
- 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 climate or to human activities at the land surface?

Introduction to the Cycle 3 Approach

Partners, stakeholders, and the National Research Council (2011) offered two recommendations to guide the updated strategy for Cycle 3. First, NAWQA should stay on course with the overall approach used for national assessment in Cycles 1 and 2 by 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 development of the capability to forecast future water-quality conditions.

Guiding Principles for Cycle 3 Design

- ***Maintain a priority on national-scale relevance:*** NAWQA achieves national-scale assessment by combining several interrelated approaches, including (1) cumulative interdisciplinary assessments of the most important hydrologic systems, (2) nationally consistent monitoring and data analysis that yield 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 conditions 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 important factors that affect observed water-quality conditions and trends. These goals remain the foundation for Cycle 3 design, although specific goals for each 10-yr 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 include 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 aligned and closely coordinated with many mission-critical activities 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 integrating NAWQA assessment activities with other USGS programs, other governmental agencies (Federal, State, regional, and local), nongovernmental organizations, industry, and academia. Such partnerships expand the abilities of NAWQA and the Nation to assess the status and trends in water-quality and biological conditions 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 during the past 20 yr. 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 significant design features and approaches for Cycle 3 are described in subsequent sections of the report but are introduced here with a focus on key aspects—some of which do not change for Cycle 3, while others do.

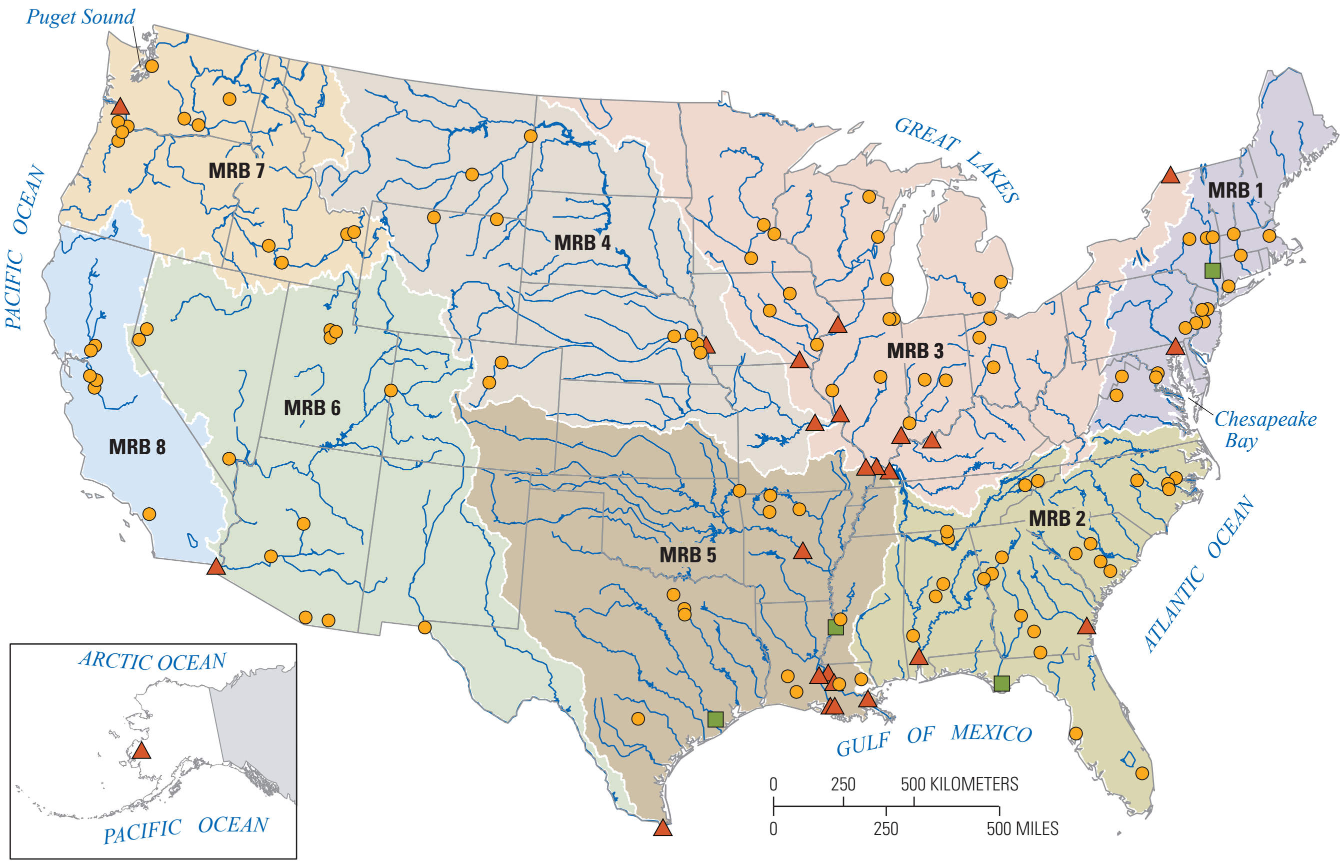
NAWQA will continue to assess the Nation's water quality using the following approaches that remain essential to successful national-scale water-quality assessment:

- Adequate spatial representation of the hydrologic and environmental settings of the Nation, as well as specific areas of concentrated water-use and ecosystem need;
- 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;
- Synthesis of national and regional information for important water-quality issues; and
- Development 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-monitoring networks that have been substantially reduced over the past decade due to fiscal constraints will be required. For example, the current (2012) NAWQA water-quality trend network for surface water monitors most sites only 1 yr out of every 4 yr. 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 science plan are the following:

- 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 of stream and river sites will change to every year instead of a 2- or 4-yr rotation, and real-time water-quality monitoring, including measurements of turbidity, will be added at most sites.
- Initiation of integrated watershed studies in selected 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 groundwater. Multi-scale monitoring and modeling approaches will be used to assess sources and transport.
- 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 ecosystem condition.
- Increased monitoring and modeling of deep aquifers including sampling of approximately 2,000 public-supply wells, the sampling of which was not emphasized in previous assessments. Overall, the number of groundwater samples collected in Cycle 3 will be twice the number collected during Cycle 2.
- Synoptic studies to assess regional biological conditions in streams across diverse environmental settings across gradients of key stressors (contaminants, nutrients, sediment, and streamflow alteration). Collected data 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 and estimates of model uncertainty, that can be used to assess the effectiveness of implemented or proposed regulatory policies and strategies, and potential effects of land-use and climate changes on water quality and ecosystem condition.

Although these assessment and study activities span a wide range of spatial scales, their implementation is highly interdependent. The locations selected for monitoring, modeling, and research will be 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, Alaska, and Hawaii (*http://water.usgs.gov/nawqa/studies/mrb*). The MRBs are used by NAWQA for regional-scale analysis and modeling of surface-water quality. In addition to geographic organization by MRBs 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. This network serves to provide broad geographic coverage within the Basins and to provide anchors of consistent long-term data collection on which other studies are built (fig. 3).



EXPLANATION

Major river basin (MRB)

MRB1 New England and Mid-Atlantic

MRB2 South Atlantic-Gulf and Tennessee

MRB3 Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainy

MRB4 Missouri

MRB5 Lower Mississippi, Arkansas-White-Red, and Texas-Gulf

MRB6 Rio Grande, Colorado, and Great Basin

MRB7 Pacific Northwest

MRB8 California

Surface-water quality monitoring site

National Water-Quality Assessment (NAWQA)—113 sites

National Stream Quality Accounting Network (NASQAN)—25 sites

National Monitoring Network (NMN)—4 sites

Figure 3. The Cycle 3 fixed-site network for monitoring surface-water quality will include approximately twice the number of sites in the Cycle 2 network, shown in this figure, which is a combination of NAWQA, National Stream Quality Accounting Network (NASQAN), and National Monitoring Network (NMN) 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 the selection of individual surface-water sites 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 other USGS programs or external stakeholders that are conducting ongoing monitoring or research; 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 and Puget Sound. Water-quality assessments also will 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 (PA; *http://water.usgs.gov/nawqa/studies/praq/*) and national scales. Principal aquifers represent large areas (10,000 to greater than 100,000 square kilometers (km^2)) with common lithostratigraphic and hydrogeologic characteristics (fig. 4). In Cycle 3, assessments are planned in 24 PAs; those PAs that account for the majority of current and future national groundwater use for drinking water will be selected. In each PA assessed, multi-scale geographic and temporal monitoring will be combined

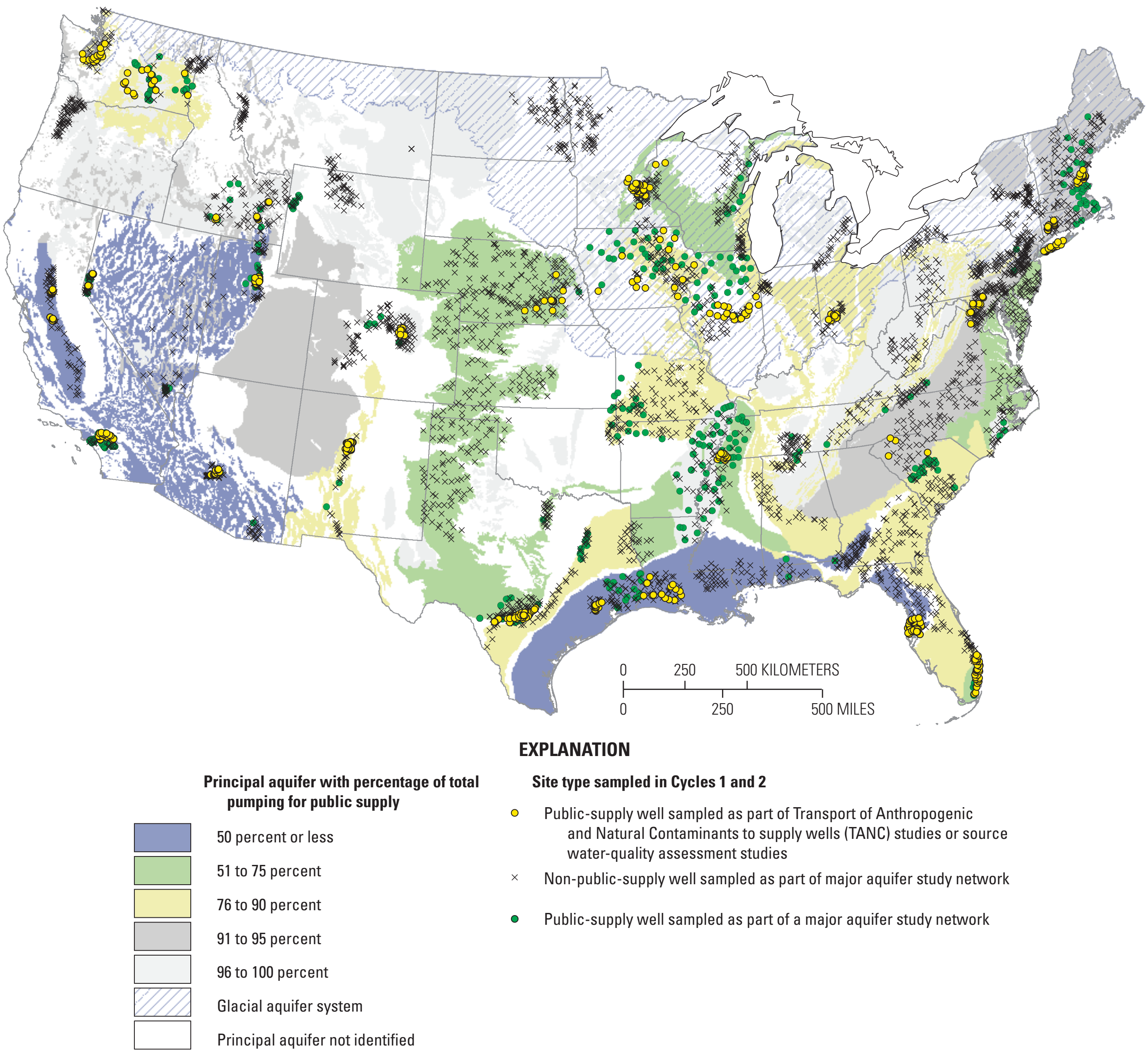


Figure 4. Groundwater monitoring and assessments are organized by principal aquifers, which are large areas (10,000 to greater than 100,000 square kilometers) with common lithostratigraphic and hydrogeologic characteristics. Those principal aquifers serving the majority of public drinking-water supplies (as indicated by the percentage by volume of pumping by public-supply wells in each aquifer and the distribution of public-supply wells samples by NAWQA in Cycles 1 and 2) are shown on this map and are described at *http://water.usgs.gov/nawqa/studies/praq/*.

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 of the factors that affect groundwater quality in different settings.

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 natural and human 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 effects 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 human activities in 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 water-resource managers increasingly need rapid feedback on changing water-quality conditions. In addition to continuing national synthesis of multi-scale data and findings on nationally important topics such as nutrients and pesticides at regular (5- or 10-yr) intervals, the Program will regularly report key monitoring results and study findings by use 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 decisionmaking. Each product represents much-needed advances over our current (2012) knowledge and capabilities. Each general type of product described in this report will include scores of individual products that focus on specific water-quality issues within different geographic areas and with varying environmental settings. Although the details of these products are described later, a specific example of each category of Cycle 3 products is described to give the reader 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 assessments must be sensitive enough to detect trends at the time scales in which important changes in contaminant sources or management strategies occur (fig. 5). Timely feedback enables policy-makers and managers to rapidly respond to changes in water-quality conditions and improves evaluation of (1) progress toward water-quality goals and (2) 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, and for the collection of water-quality surrogate data in real time so that long-term trends typical of those caused by source changes or management strategies can be discerned and tracked relative to short-term changes caused by storms or other short-lived hydrologic events.

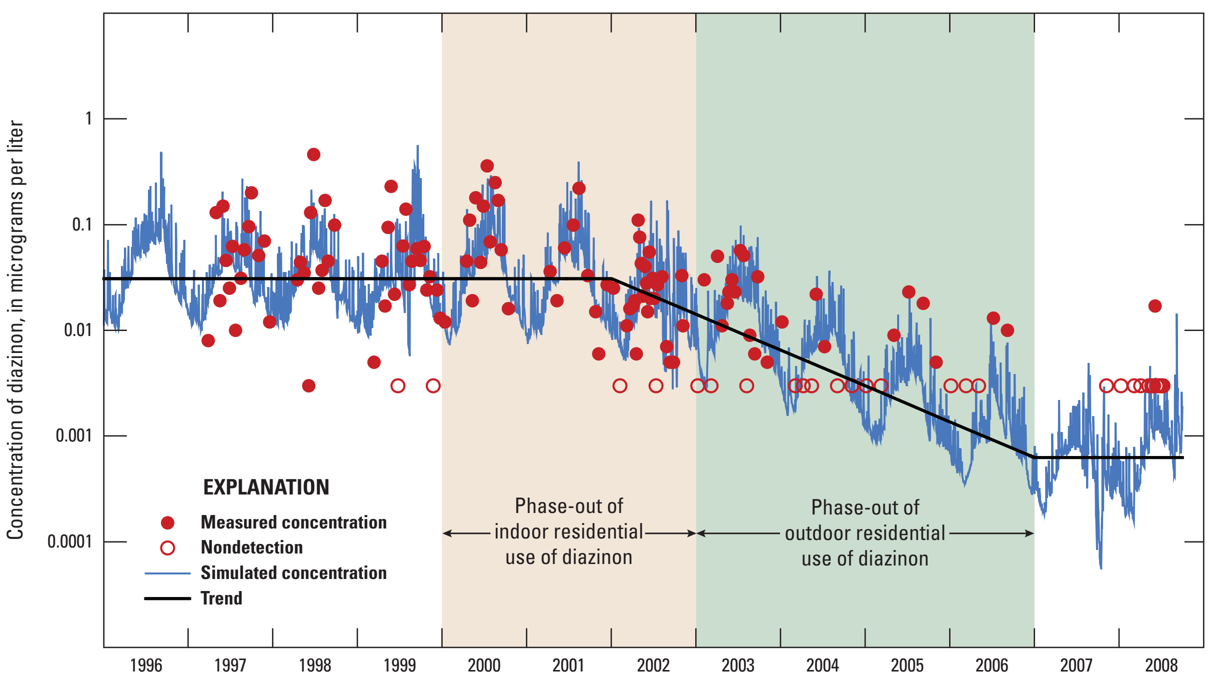


Figure 5. The trend analysis for the insecticide diazinon in Accotink Creek, an urban stream in Virginia, provides an example of the type of trend-analysis product that would result from implementation of the Cycle 3 design.

Every-year monitoring of diazinon concentrations since 1997 (with the exception of 2007) and continuous monitoring of flows throughout each year provided the data necessary to develop a time-series and trend model to simulate diazinon concentrations in Accotink Creek for 1996–2008. Every-year monitoring, as proposed in the Cycle 3 design, was the basis for the clear downward trend in diazinon concentrations during 2002–06, resulting in more than a 90-percent concentration decline. The decline corresponds to reduced residential uses resulting from a regulatory phase-out required by the 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 effects 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 several case-study areas and on the application of statistical and hybrid models that link causal factors to individual contaminant occurrence, such as the effect of intensive agriculture on atrazine and nitrate concentrations. 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 (fig. 6).

Factors used to represent nitrogen sources in the model 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, soil type, the presence of drainage ditches, and

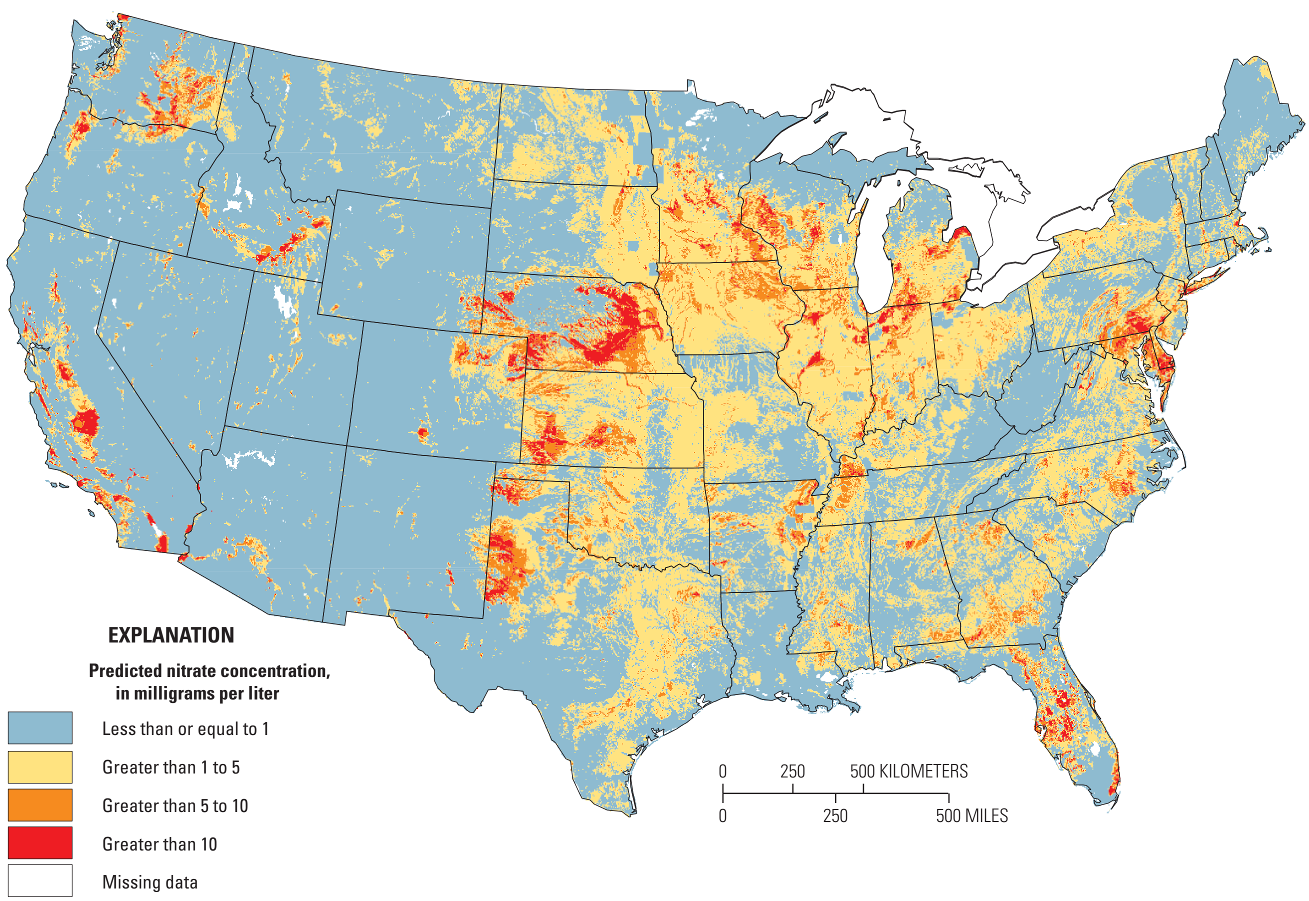


Figure 6. A model of nitrate concentrations in shallow groundwater was used to predict nitrate concentrations across the conterminous United States. The model was used to show that the highest concentrations are predicted to be in the High Plains, northern Midwest, Central Valley of California, and other 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. (Modified from Nolan and Hitt, 2006.)

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 created for other contaminants and specific regions, and models of shallow groundwater quality provide an important starting point for evaluating deeper parts of aquifers used for domestic and public supply. Last, they can be used to develop groundwater models that couple groundwater quality with groundwater flow to evaluate the distribution and transport of contaminants in aquifers.

Understanding the Effects of Stressors on Stream Ecosystem Condition

NAWQA Cycle 3 includes analysis of relations between specific water-quality stressors—contaminants, nutrients, sediment, and streamflow alteration—and their individual and combined effects 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 stressor effects 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. 7).

The atrazine Watershed Regressions for Pesticides model (WARP; Stone and Gilliom, 2008), which was developed from NAWQA Cycle 1 and 2 monitoring data (plus extensive data on atrazine use patterns, soils, precipitation,

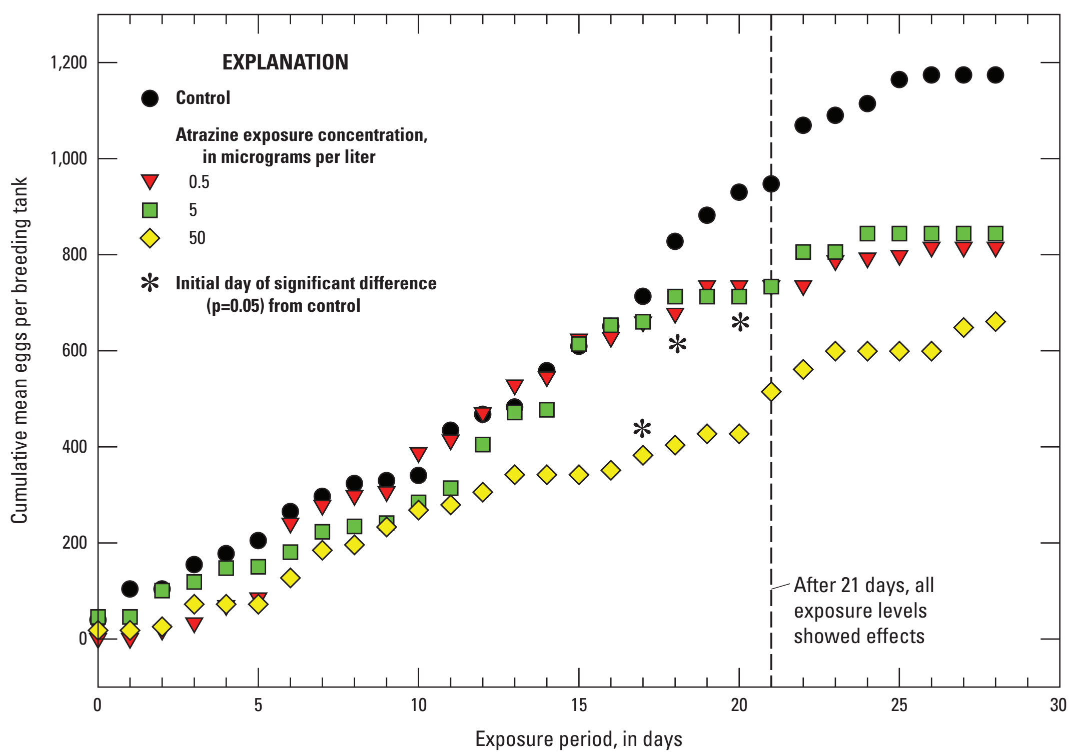


Figure 7. Results of laboratory tests showing reduced egg production in fathead minnows at atrazine concentrations as low as 0.5 microgram per liter with an exposure duration in the range of 21 days. These findings raised the question as to where such atrazine levels are found in streams and may, therefore, be a concern warranting further investigation. (Modified from Tillitt and others, 2010; p=0.05; p, or more specifically, the p-value is the probability of rejecting the null hypothesis in a statistical test, defined here at a significance level of 0.05 or five percent).

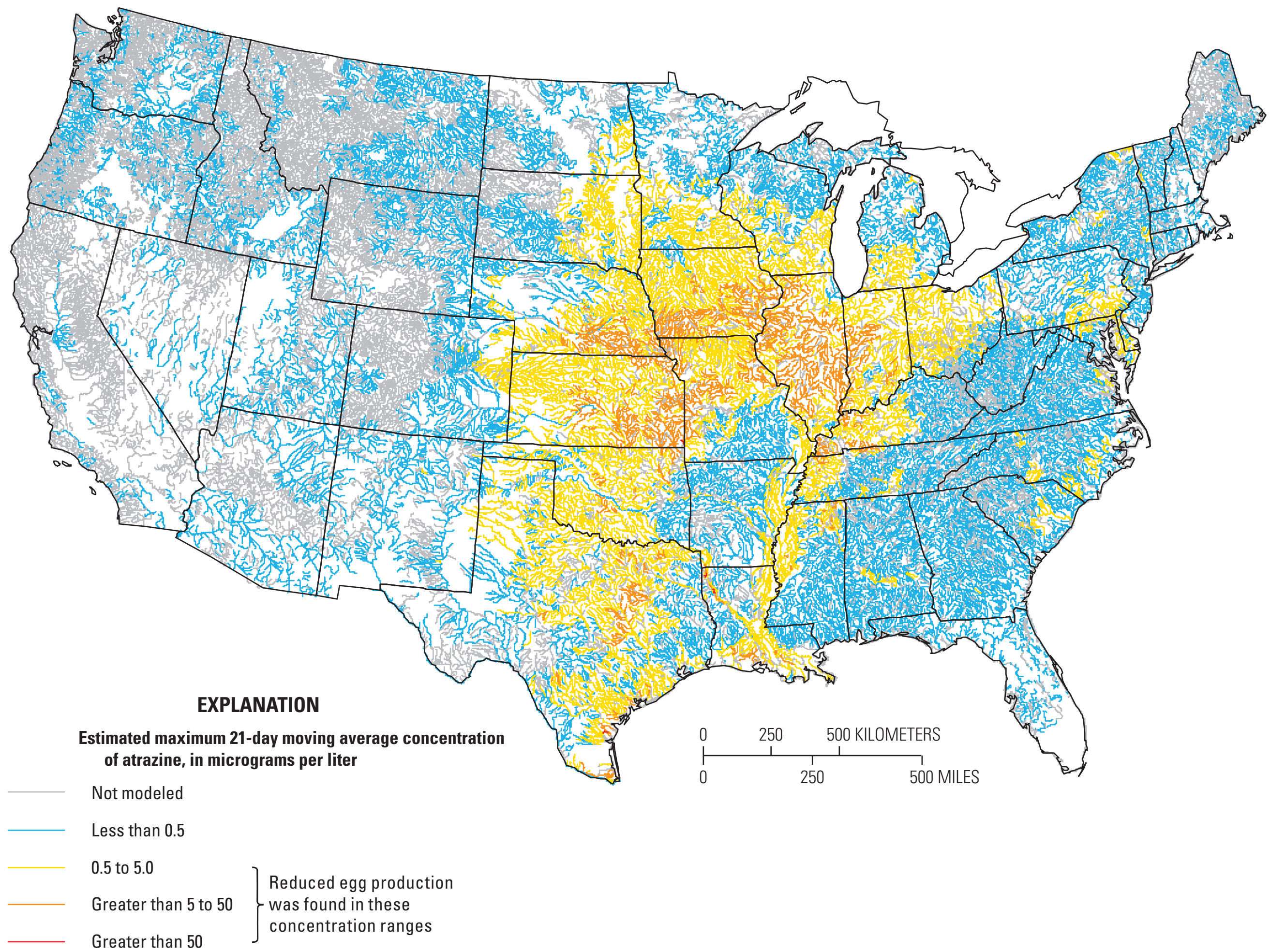


Figure 8. Predicted maximum 21-day average atrazine concentration in streams for concentration levels shown to affect egg production of fathead minnows in laboratory studies. (Modified from Stone and Gilliom, 2009.)

and agricultural practices), allows rapid estimation of what areas of the country have streams that are likely to 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. 8). This example illustrates one way in which new stressor-effects 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 and scenario-testing 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 Effects of a Reduction in Fertilizer Use on Nutrient Loadings

Cycle 3 assessments will apply hydrologic and statistical models to forecast how potential changes in climate, population, land-use, and other factors will affect groundwater 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 region included in the model. The SPARROW model can be used to provide information to address a variety of issues, including how changes in land

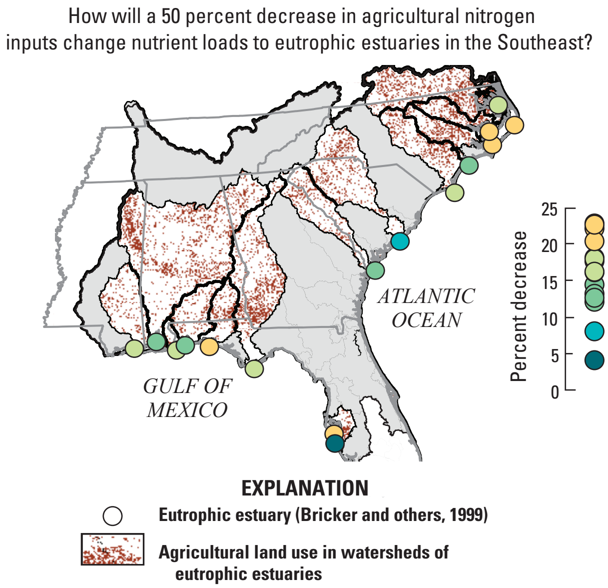


Figure 9. Map showing area of the southeastern United States for which the SPARROW model was used to predict nitrogen loads delivered to eastern Gulf of Mexico and South Atlantic estuaries based on a 50-percent reduction in agricultural nitrogen inputs. The graph shows that the SPARROW model was used to predict 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. (Map constructed from dataset included in supplemental materials for Hoos and McMahon, 2009.)

use or management actions, such as a 50 percent reduction in fertilizer usage, may affect water quality in the southeastern United States (fig. 9).

This example shows that—in terms of total annual nitrogen load—a reduction of agricultural sources alone may not markedly improve eutrophication in some of these estuaries (fig. 9). Cycle 3 will expand the capabilities of SPARROW and other models to include additional contaminants and to simulate changes in nutrient (or other contaminant) fluxes over time. In addition, Cycle 3 includes plans to 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.

Cycle 3 Design Elements

The science plan 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 occurred as Program resources declined over the past decade require that the Cycle 3 approach incorporate a substantial evolution in emphasis and an expanded scope to meet the Nation's current and future requirements for water-quality information. This section of the report lists specific objectives for each of the four major Cycle 3 goals and then provides a summary of recommended approaches and study components for the surface-water and groundwater design elements.

Goals and Objectives of Cycle 3

The approach was developed by defining specific science objectives for each of the four Cycle 3 goals. 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 for each of the four goals, 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.

The following are objectives for Goal 1:

1a. Determine the distributions and trends for 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 for 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; and

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

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.

The following are objectives for Goal 2:

2a. Determine how hydrologic systems—including water budgets, flow paths, traveltimes 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; and

2e. Evaluate how the effectiveness of current and historical 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 on aquatic ecosystems.

The following are objectives for Goal 3:

3a. Determine the effects of contaminants on degradation of stream ecosystems, determine 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; and

3e. Evaluate the relative effects 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.

The following are objectives for Goal 4:

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; and

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.

Study Components

Assessments of surface-water and groundwater quality 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 for the surface water and groundwater design elements are described in this section separately. Each objective is highly dependent on information derived from other objectives and, thus, all objectives for surface and groundwater will depend on having study components that are flexible but closely coordinated. The study components provide a consistent structure for organizing multi-purpose, interrelated assessments across multiple scales of investigation for surface water and groundwater. A common study component for all types of assessments will be review and analysis of existing data and information, which will be referred to as “retrospective analysis.” Following the overview of the individual surface water and ground water study components provided here, subsequent sections will describe how these components are applied to the design of studies that will meet each goal and its related objectives.

Surface Water

The design for surface-water quality assessment addresses 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, and to the entire Mississippi River Basin and the Nation; time scales of interest 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 in this section, involves several broad enhancements and changes to the Cycle 2 design that are needed to adequately address Cycle 3 goals and objectives. Individual components of the surface water design are briefly introduced in the following list and then explained in more detail in the following subsections, all as the foundation for explaining the specific approach to each goal and objective in subsequent parts of the report:

- ***The National Fixed-Site Network (NFSN)*** is a national network of monitoring sites that serves as the foundation for long-term 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 from Cycle 2 to improve trend analysis and to provide support for model development and validation, analysis of drinking-water sources, analysis of reference conditions and climate change, analysis of nutrient and contaminant loads to coastal ecosystems, and other specific analysis requirements.

- ***Regional Synoptic Study (RSS)*** is a short-term, targeted water-quality or biological assessment of specific regions or environmental settings. The RSS assessments are a flexible design component that help fill spatial gaps between national fixed-site monitoring and the geographically limited Integrated Watershed Study and Intensive Study assessments (described in the following bullets). The RSS assessments 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 in support of Goal 3. The RSS assessments were used to a limited degree in Cycles 1 and 2, but will take on a larger role in Cycle 3.

- ***Integrated Watershed Study (IWS)*** is a large-scale, holistic water quality assessment 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 IWSs will fill gaps in water-quality assessments that were created by the phase-out of Study-Unit investigations during Cycle 2.

- ***Intensive Study (IS)*** is a focused assessment that will be conducted at a few sites, reaches, or small watersheds, selected to investigate specific topics in comparative designs. The IS component is vital to meet Cycle 3 objectives for improving understanding of specific sources, processes, and stressor effects relationships in aquatic ecosystems. The IS were also an important part of the approach of NAWQA Topical Studies done in Cycle 2. In Cycle 3, the IS will be nested in IWS study areas to facilitate up-scaling of findings and to leverage monitoring, modeling, and ancillary data in the IWS study areas.

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 ensure success 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 subsections, more detailed descriptions are provided for the four surface-water study components. The NFSN is described most completely, although not with detailed specifics on factors such as site selection and analytical strategy, whereas the IWS, IS, and RSS components are illustrated with examples and will be highly dependent on design details developed by focused study implementation teams.

National Fixed-Site Network

The Cycle 3 National Fixed-Site Network 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 properties (selected sites). The Cycle 3 design relies on, and is composed of, monitoring sites and activities supported to varying degrees *http://www.usgs.gov/climate_landuse/*), and the interagency National Monitoring Network (NMN; *http://acwi.gov/monitoring/network/index.html*).

The NFSN produces the consistent and common core of information that is essential for other Cycle 3 components. Fixed-site monitoring has been a vital component of the NAWQA design since the beginning of Cycle 1. During Cycle 1, 505 sites were operated for varying periods of time during Study-Unit Investigations. By 2007, these sites were reduced to a national network of 113 sites, about three quarters of which (83) were sampled intensively only 1 yr out of every 4 yr. When combined with 25 NASQAN sites and 4 NMN sites, the fixed-site monitoring network operated during the latter half of Cycle 2 consists of 142 sites (fig. 10).

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

- Monitoring is planned to be conducted every year rather than using rotational schedules. Trend analysis of water-quality data from 1992–2008 has shown that important trends, such as those for many pesticides, are happening within a few years and are not adequately characterized with rotational sampling (see fig. 5).

- Continuous, real-time water-quality monitoring of selected water-quality properties is planned for most sites. Continuous monitoring of selected properties, 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 water-quality properties through correlation analysis. Continuous data also yield improved understanding of the effects of short-term hydrologic events (such as storms, floods, dam releases) on water quality and provide time-dense data for developing dynamic simulation models.

- Additional sites will be added 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, and this information from new sites is essential to meet Cycle 3 goals.

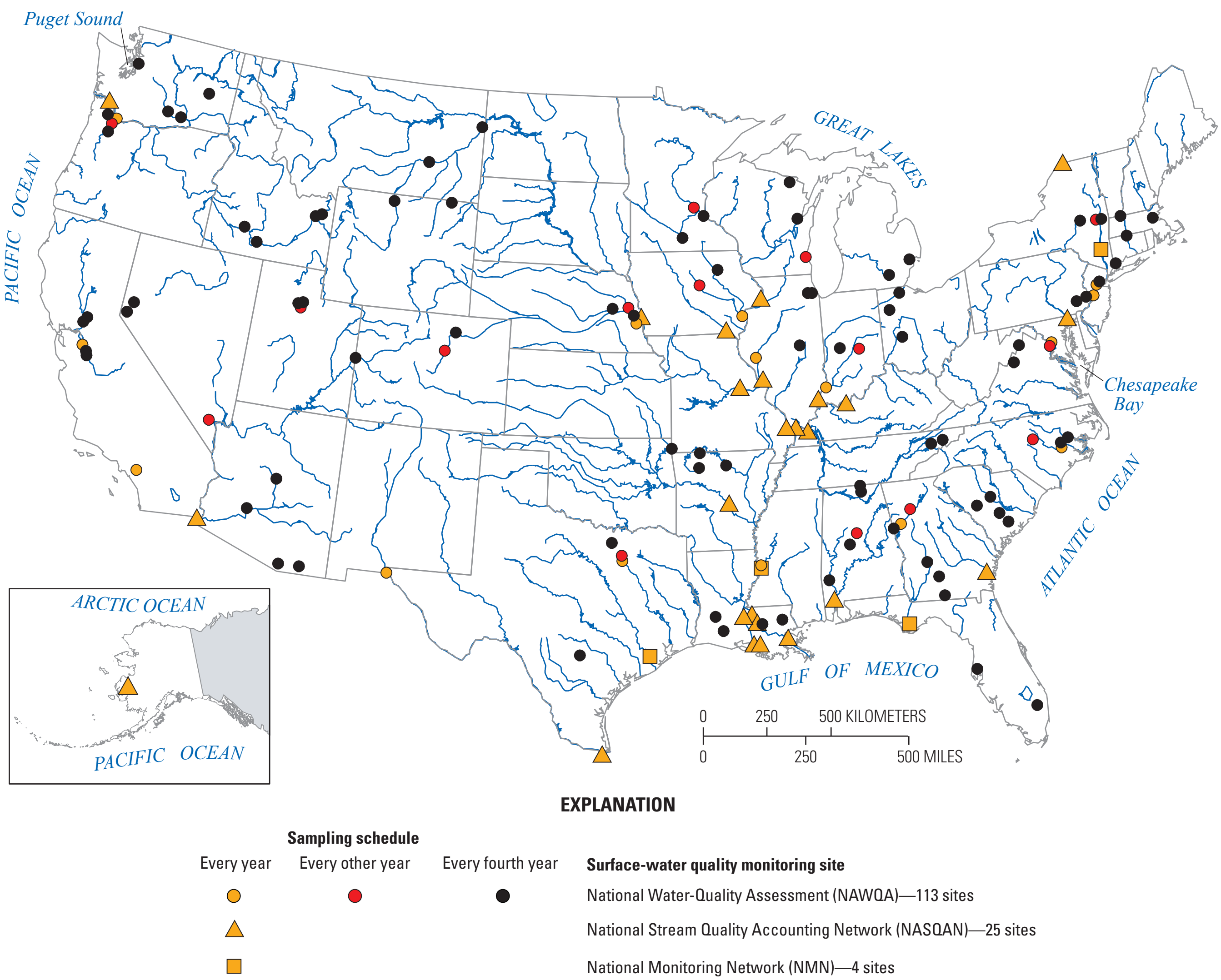


Figure 10. The Cycle 2 fixed-site network for monitoring surface-water quality is a combination NAWQA, NASQAN (National Stream Quality Accounting Network), and NMN (National Monitoring Network) sites. Of the 142 sites included in the combined network, only 44 are monitored every year; 15 sites are sampled one in every two years, and the remaining 83 sites are monitored only 1 out of every 4 years.

Specific Roles

The following are specific roles of the NFSN in the NAWQA Cycle 3 design:

- 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 IS assessments that have short-term study periods;
- Primary data source for assessing contaminant, nutrient, and sediment loading to coastal ecosystems;
- Primary data source for assessing the quality of surface-water sources of drinking water; and
- Primary source of reference watershed data for evaluating effects of changing climate and human activities on water quality and aquatic ecosystems.

Design Characteristics

The design of the NFSN for Cycle 3 is described in comparison to the Cycle 2 design in table 1; figures 11, 12, and 13 show the general distribution of large river, wadeable stream, and drinking-water intakes sites by land use. Site selection and site-specific sampling and analysis plans for NFSN monitoring sites 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.

Relation to Other Components

The following describe the relation of the NFSN to other surface-water and groundwater components:

- ***IWS component:*** On average, each IWS basin will contain from one to four NFSN sites that provide a core of consistent, long-term data at key locations.
- ***IS component:*** Most IS will be anchored by one or two NFSN sites that provides a longer-term temporal reference for the shorter-term intensive study.
- ***Regional Synoptic Study (RSS) component:*** Most RSSs will include 10 to 20 NFSN sites that will serve as long-term temporal references for the short-term synoptic approach of the RSS.
- ***Local Groundwater Study (LGS), Regional Groundwater Study (RGS), and Principal Aquifer Assessment (PAA) components:*** Most LGS, RGS, and PAA will include one or more NFSN sites that will be used to perform base-flow separation analyses to determine water-quality and quantity contributions from groundwater to monitored watersheds.

Regional Synoptic Study

The RSS component consists of 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 NFSN

Table 1. Changes from Cycle 2 to Cycle 3 in the National Fixed Site Network.

[NAWQA, National Water-Quality Assessment; NASQAN, National Stream Quality Accounting Network; NMN, National Monitoring Network]

Characteristic	Cycle 2	Cycle 3
Total sites	142 total sites consisting of: 113 NAWQA sites, 25 NASQAN sites, and 4 NMN sites)	313 total sites
Sampling schedule	Most sites every 2 or 4 years	All sites sampled all years
Sampling frequency	12–26 samples per year	6–26 samples per year
Real-time monitors	None	50 percent of sites
Ecological monitoring sites	58	88 (includes 30 new reference sites)
Reference sites	19	58 (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	7	56 sites
Contaminant analyses	Limited	Expanded
Suspended sediment	Limited	Suspended sediment and continuous turbidity monitoring

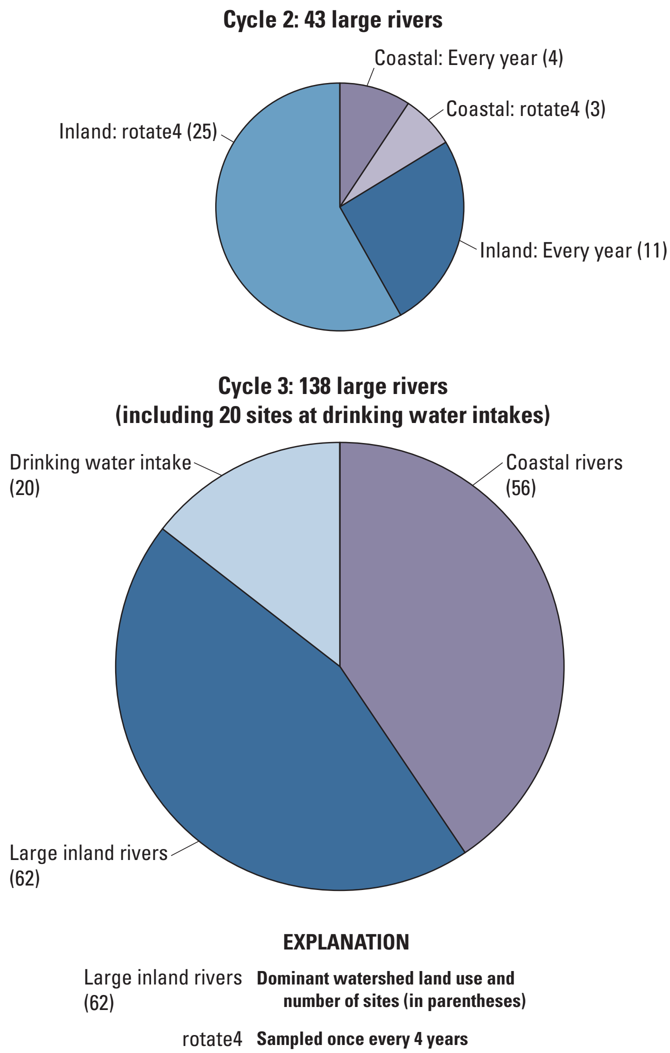


Figure 11. The number of National Fixed Site Network sites on large rivers (nonwadeable) increases from 43 sites in Cycle 2 to 138 sites in Cycle 3. Important changes in Cycle 3 include 53 additional coastal sites, 20 sites at drinking-water intakes, and annual monitoring at each site every year.

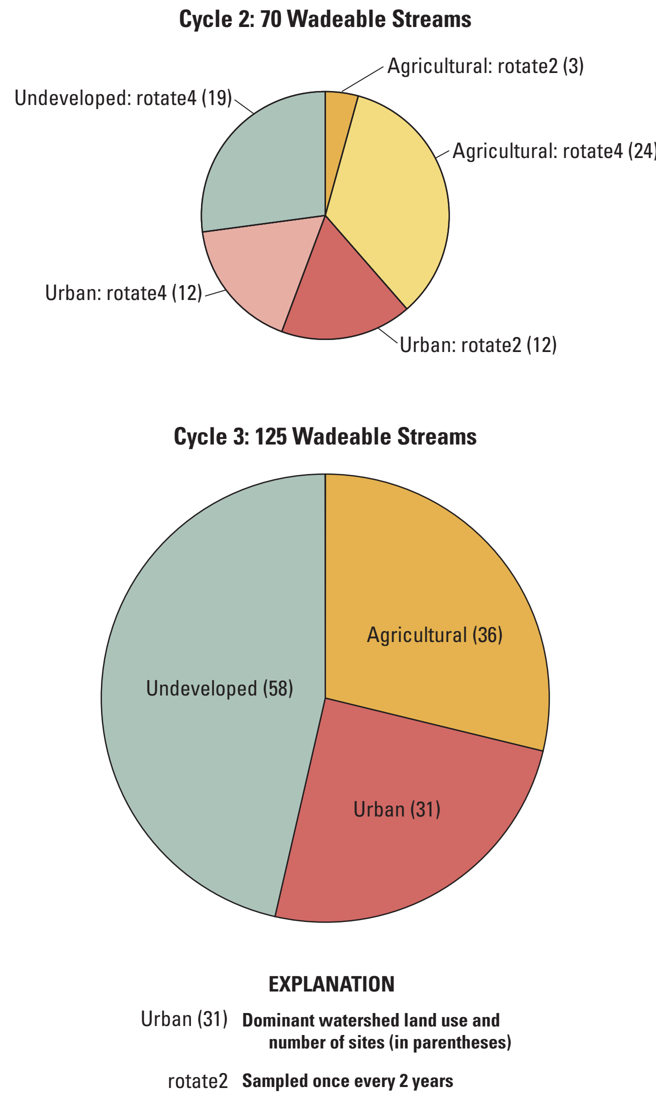


Figure 12. The number of National Fixed Site Network sites on wadeable streams increases from 70 sites in Cycle 2 to 125 sites in Cycle 3. Important changes in Cycle 3 include an increase in undeveloped reference sites from 19 to 58 sites and increased monitoring at each site throughout the year, every year.

sites in the same geographic area (typically in the range of 10 to 20 times more) depending on the scale characteristics and variability of natural and human features on the landscape. The RSS is a very flexible design component. Some RSS assessments may be unique, one-time studies aimed at specific topic in a region, such as the distribution of a specific contaminant in spring runoff within a particular setting such as row-crop agriculture. Others will be part of long-term rotational series of RSS assessments, such as geographic assessments of the biological condition of streams as related to a consistent set of important stressors, that are conducted using a similar design. Within such assessments, regions are rotated over time to build a national dataset on a particular set of scientific and management questions.

The RSS 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 primarily dominated by spatial variability more than temporal variability. The RSS assessments are particularly important for evaluating biological conditions and contaminants in bed sediments or fish tissue.

Specific Roles

The following are specific roles of the RSS assessments in the NAWQA Cycle 3 design:

- Expand geographic assessment for water-quality characteristics identified from other studies to be of

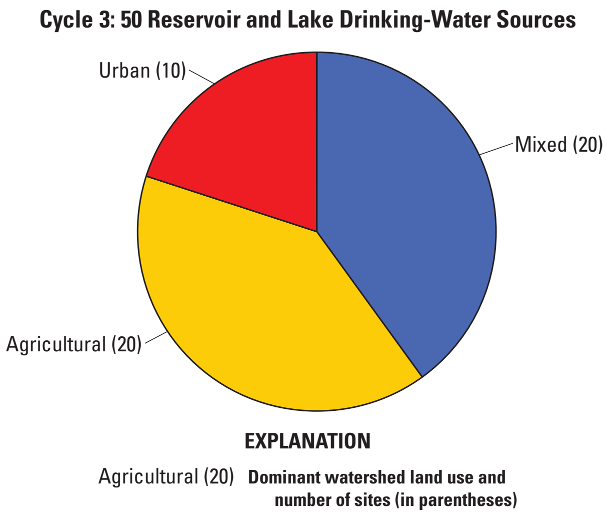


Figure 13. The Cycle 3 allocation of 50 National Fixed Site Network sites at lake or reservoir drinking-water intakes is a new assessment component that was not part of Cycle 2.

potential regional interest, particularly biological conditions; and

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

Relation to Other Components and Associated Analyses

The following items describe the relation between RSS assessments and other surface-water components:

- Point-in-time testing and verification of predictions for selected constituents and biological conditions from national and regional models developed from NFSN and RSS assessments; and

- Up-scaling of findings for selected constituents from IWS and IS assessments to a regional scale.

Integrated Watershed Study

The IWS component consists of long-term, interdisciplinary water-quality assessments of large watersheds. The IWS assessments are nationally distributed examples of regional environmental settings, each of which is characterized by a defined range of human activities and natural hydrologic settings. The IWS assessments consist of a stable set of 10–20 watersheds that are generally in the range of 5,000–50,000 km^2, depending on the scale characteristics and variability of the human and natural environmental setting in a particular region. Example candidate IWS locations are shown in figure 14 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 effects on water quality. Most, if not all, IWS assessments will be large watersheds selected from the NAWQA Cycle 2 trend network and will consist of either entire NAWQA Cycle 1 study units or one of their major sub-basins. Characterization and prioritization of IWS assessments will follow the same type of process and will use similar information as was used to prioritize study units and topical study areas for Cycle 2. There will likely be one or two IWS in each NAWQA Cycle 2 major river basin (MRB), but selection and implementation of IWS will be phased to coordinate with IS priorities, partnerships with other agencies, and available resources.

An important role of the IWS is to bridge the gap in scale between NFSN monitoring and the IS component so that large-scale and multi-scale source and transport objectives, predominantly for contaminants, nutrients, and sediment, can be addressed. In the context of the NAWQA Study-Unit -investigations that evolved through Cycle 1 (52 study units) and Cycle 2 (started with 42 study units but most activities were phased out), IWS can be considered to be more selective, more intensive, surface-water focused “study units.” Although primarily focused on surface water, the IWS watersheds also will be the primary locations where monitoring and modeling studies will examine relations between surface water and groundwater in different hydrologic settings.

Specific Roles

The following are specific roles of the IWS component in the NAWQA Cycle 3 design:

- Serves as focus areas for developing intensive and high-quality information on water-quality and hydrologic-system characteristics and the human and natural factors that affect water surface and groundwater quality, including data derived from continuous water-quality sensor technology;

- Provides a real-world laboratory 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. Ultimately, data obtained

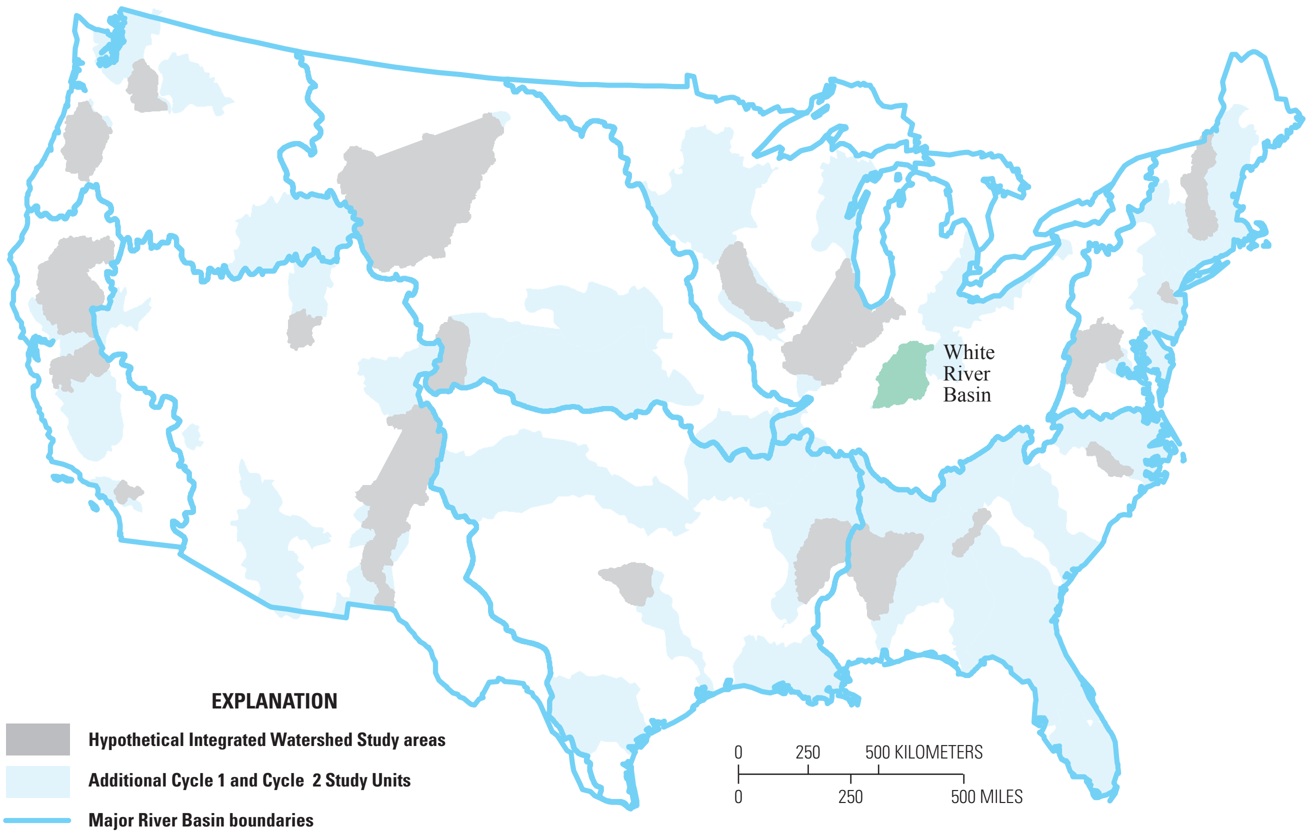


Figure 14. Hypothetical map of 20 possible Integrated Watershed Study watersheds distributed among the 8 NAWQA major river basins (fig. 3) in the conterminous United States. The actual number of Integrated Watershed Study assessments and timing of implementation will be determined based on coordination with Intensive Study 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 design features of an Integrated Watershed Study in the section on Goal 2. As illustrated here, the 20 hypothetical Integrated Watershed Study areas were selected from the 51 watersheds studied by NAWQA in Cycles 1 and 2; however additional watersheds with extensive water-quality data and models will be considered during the implementation phase.

from the IWS locations will be used for development and testing of predictive models used to forecast water-quality conditions under various scenarios of climate or land-use change;

- Defines the geographic areas for locating IS so that IS study areas are nested in a well-characterized large watershed for analysis of larger-scale significance and linkage to downstream waters;
- Contributes to evaluating the importance of land- and water-management practices to large-scale improvements in water quality by linking local-scale studies and land-use activities to effects on downstream systems in larger watersheds;
- Is 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. The IWS component thus spans a variety of research and management interests in key settings and is supported by NAWQA's monitoring and assessment infrastructure.

Design Characteristics

In general, each IWS will focus on a watershed that previously was 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 may occur if high-value partnerships can be formed between multiple agencies in watersheds that have large amounts of water-quality and ancillary data or that have 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, approximately 20-50 candidate IWS basins will be characterized using existing information, following a consistent approach. As Cycle 3 plans evolve, this will facilitate selecting IWS basins for detailed assessment.

Initial Characterization of Candidate Integrated Watershed Study Areas

The initial characterization of candidate IWS areas will serve as a well-defined starting point for a design that can be used to identify critical issues in each watershed as they relate to the Cycle 3 objectives, inventory the available information and critical gaps, and begin to explore potential partnerships. Initial characterization will include, but not be limited to, the review, update, and synthesis of readily available existing information, such as:

- Geographic characterization of human and natural characteristics;
- Land-use characteristics and distribution;
- Point-source discharges;
- Drinking-water intakes;
- Active streamgages and current monitoring programs;
- Current water-quality issues and stakeholders; and
- Information from other studies and related activities in progress in the IWS study area, such as other USGS studies, USDA Agricultural Research Service research sites (*http://www.ars.usda.gov/*), and Long Term Ecological Research (LTER) sites (*http://www.lternet.edu/sites/*).

Selection and Implementation of Integrated Watershed Study Assessments

All IWS assessments will not be implemented at the same time because of constraints on funding and personnel, as well as the timing of study priorities. A range of implementation options will be considered, but the favored approach to begin Cycle 3 is to implement approximately 6 to 10 IWS assessments within a 10-yr study period. The 10-yr study period for a comparatively small number of studies is preferred over the alternative of having more IWS assessments on a shorter rotational schedule. The 10-yr study period is essential for developing sustainable study partnerships and efficiently phasing in data collection and modeling. Although several specific issues warrant consideration regarding the number of IWS assessments that can be implemented at one time (which will not be resolved until later during the implementataion phase), examples of some of the primary factors that will determine priorities for implementation follow:

- Relevance to highest priority IS assessments;
- 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; and
- Likelihood of partnering with other USGS programs, Federal or state agencies, and academic researchers on shared scientific interests.

Core Assessment Activities

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

- Detailed updates and enhancements of ancillary information on all human activities in the watershed that affect water quality;
- Inventory of 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 one to four NFSN sites typically in an IWS with 10–12 additional sites that would be monitored using a similar sampling and analytical strategy as the NFSN sites. 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; and
- Development of water-quality models 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

The following items describe the relation between the IWS assessments and other surface-water and groundwater components:

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

Intensive Study

Intensive Study assessments are interdisciplinary studies ranging in scale from individual stream reaches to small (50–200 km^2) watersheds. The primary purpose of these assessments 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 of these studies include assessment of the following:

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

Design Characteristics

- The IS assessments 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 importance of groundwater/surface-water interactions. The IS will be nested inside the larger IWS, with one or two IS sites per IWS, depending on the specific questions being addressed. Similar to the IWS, the IS will be anchored by sites in the NFSN.
- The IS assessments provide an important scale for collaborative work with other USGS long-term programs like the National Research Program (*http://water.usgs.gov/nrp/*) and the Toxic Substances Hydrology Program (*http://toxics.usgs.gov/*) and are well suited for coordinating with NEON and other non-USGS programs.
- Each IS site will be selected primarily from sites or small watersheds that have been studied during Cycle 1 or 2 to take advantage of the amount of baseline data already available. Because monitoring for each IS assessment will be used to address different questions, no single design will necessarily work for all questions. Due to the variable levels of effort at these sites, IS assessments will rotate among the different IWS study areas, with some IS assessments lasting 2–4 yr and others lasting longer.

Relation to Other Components

The following items describe the relation between the IS assessments and other surface-water components:

- Include at least one NFSN site for each IS and locate within an IWS study area;
- Provide understanding of specific processes or cause-effect relations for interpreting findings from all other components; and
- 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 effect on ecosystem conditions. In Cycles 1 and 2, NAWQA implemented a targeted design that provided an opportunity to assess groundwater quality across a broad range of conditions representative of the Nation, with a particular focus on evaluating the relation between land use and shallow groundwater quality. In Cycle 3, NAWQA will implement an integrated design that uses data and models at multiple scales, with an emphasis on developing a three-dimensional view of groundwater quality in selected principal aquifers. The Cycle 3 groundwater design will complement and build on data and models developed by NAWQA during Cycles 1 and 2, by other USGS Programs, such as the National Cooperative Geologic Mapping Program (*http://ncgmp.usgs.gov/*), Groundwater Resources Program (*http://water.usgs.gov/ogw/gwrp/*), and Cooperative Water Program (*http://water.usgs.gov/coop/*), and other Federal and non-Federal entities.

In Cycle 1, NAWQA groundwater studies were implemented within study units (2000–10,000 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 (10,000–100,000 km^2), implemented topical studies designed to develop a better understanding of groundwater quality at local to regional scales (100–1,000 km^2), maintained a groundwater-sampling network for the purposes of assessing trends, assessed trends at multiple scales, and also built and sampled new networks to fill in data gaps from Cycle 1. During Cycle 1, NAWQA sampled about 2,700 observation wells, 3,000 domestic wells, approximately 500 public-supply wells, and 500 wells with other uses (mainly irrigation). Observation wells were installed in randomly selected locations at shallow depths, generally less than 50 feet (15 m) below land surface, in areas of specific land uses such as row-crop agriculture or urban areas as part of Land-Use Study (LUS) networks. Results were used to assess the effects of specific land uses on shallow groundwater quality. Existing domestic and public-supply wells randomly selected within the target aquifer were sampled as part of Major Aquifer Survey (MAS) studies; 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 national scales, and developed groundwater 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, rather than the study unit. Principal aquifers represent large areas (approximately 200,000 to greater than 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 Aquifer Assessments (PAA), 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 factors. The Cycle 3 study components for assessment of groundwater quality are briefly introduced in the following list and then explained in more detail in the following subsections:

- ***Principal Aquifer Assessment***: The PAA component will be the primary organizational unit for groundwater studies in Cycle 3, and PAA studies will be designed for assessment of status and trends at principal aquifer to national scales.

- ***Regional Groundwater Study:*** The RGS assessments will be nested within principal aquifers, and selected RGS assessments will be co-located with surface-water IWS areas. The RGS assessments will be designed for assessment of status and trends at regional scales with an emphasis on improving understanding of how human activities and natural factors affect groundwater quality.

- ***Local Groundwater Studies:*** The LGS assessments will be co-located with surface-water IS areas or nested within RGS areas, and are designed to improve understanding of the human activities and natural factors that affect groundwater quality at a more specific level of cause and effect than RGS assessments.

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. The following subsections provide detailed descriptions of each study component, followed by a description of initial plans for national implementation.

Principal Aquifer Assessment

The PAA studies will be designed for assessment of groundwater status and trends at the principal aquifer to national scales. Figure 4 shows the distribution of principal aquifers 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 principal aquifers. This plan also outlines two new types of monitoring networks for Cycle 3, the Principal Aquifer Survey (PAS) network and the Enhanced Trends Network (ETN). Data from PAS wells will be used to assess groundwater quality in aquifers 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 to gain a better understanding of short-term variability and long-term trends in groundwater quality. The 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 principal aquifer scale. Output from statistical modeling could take the form of constituent concentrations or probabilities associated with a constituent concentration exceeding a specified threshold, for example, a Maximum Contaminant Level (MCL) or a Health-Based Screening Level (HBSL) or some fraction thereof. Modeling studies will include three-dimensional groundwater-flow simulation (Harbaugh, 2005) and particle tracking (Pollock, 2012). Where available, NAWQA will use or build on models previously developed by the USGS Groundwater Resources Program (*http://water.usgs.gov/ogw/gwrp/*). Output from quantitative flow models, such as hydrologic position and residence time, may be used as explanatory factors in statistical models.

Regional Groundwater Studies

The Cycle 3 Regional Groundwater Study (RGS) assessments 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. The RGS assessments (with study areas of approximately 1,000 to greater than 100,000 km^2) were a major component of NAWQA during Cycles 1 and 2 and included LUS and MAS networks, large-scale networks sampled by the Transport of Anthropogenic and Natural Contaminants to Supply Wells topical study (TANC; *http://oh.water.usgs.gov/tanc/NAWQATANC.htm*), and networks of public supply wells sampled by the Source Water-Quality Assessments (*http://water.usgs.gov/nawqa/swqa/*). In Cycle 3, NAWQA will use existing data when available (retrospective data), continue to sample selected existing networks to evaluate trends in groundwater quality, implement additional networks where needed, and develop quantitative models. Additional networks will 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 principal aquifer 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. Where available, NAWQA will use or build on previously developed models, including those developed for large- and small-scale TANC studies or models produced by the USGS Cooperative Water Program (*http://water.usgs.gov/coop/*). Refinement of the models may include simulation of the flow system as a dual-domain system; this consists of a mobile domain where transport is dominated by advection and immobile pore space where advective transport does not occur, in order to better represent residence time and transport of contaminants. The RGS study areas will be nested within PAA study areas and may be co-located with surface-water IWS study areas. Knowledge gained from RGS assessments will provide a basis for extrapolating groundwater quality into unmonitored areas.

Local Groundwater Studies

Cycle 3 Local Groundwater Study (LGS) assessments 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 (FPSs) that examine how groundwater quality changes as groundwater flows from recharge to discharge areas at scales ranging from a few hundred meters to several kilometers. The LGS assessments also can be three-dimensional at scales ranging from tens to hundreds 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). The LGS assessments will use 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. The LGS study areas will be nested within surface-water Intensive Studies or RGS study areas.

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 principal aquifer-scale exceedance maps for selected constituents that have concentrations of concern; concentrations of concern will be defined relative to USEPA MCLs or USGS HBSLs (Toccalino, 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; these aquifers supply more than 90 percent of the groundwater used for domestic and public supply. About one third of the principal aquifers will be evaluated at a high level of intensity, one third at a moderate intensity, and one third at low intensity. High-intensity studies will involve sampling of about 200 PAS wells; implementation of two to four new MAS, LUS, or FPS networks; development of one to three regional-scale groundwater flow and particle-tracking models; development of a principal aquifer-scale groundwater-flow and particle-tracking model; and development of principal aquifer-scale statistical models for selected constituents. Regional-scale models of flow and solute transport may be implemented in two to four high-intensity PAA study areas, and local-scale models of coupled flow and reactive chemistry may be implemented in one or two high-intensity PAA study areas.

Moderate-intensity studies will involve sampling of about 100 PAS wells; may or may not include implementation of new MAS, LUS, or FPS networks; development of one or two regional-scale groundwater-flow and particle-tracking models; development of a principal aquifer-scale flow model (with or without particle tracking); and development of principal aquifer-scale statistical models for selected constituents. Low-intensity studies will involve sampling of about 50 PAS wells. The low-intensity studies also would involve development of principal aquifer-scale statistical models for selected constituents.

Enhanced Trend Network (ETN) wells could be located within any of the PAA study areas, but it is expected that ETN wells would mostly be located in high- or moderate-intensity PAA study areas. Criteria for selection of a PAA 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 previous data and models, and the geographic distribution of other PAAs. Details on the number of networks and wells proposed for the Cycle 3 design can be found in section “Objective 1d. Determine the Distributions and Trends of Contaminants of Concern in Aquifers Needed for Domestic and Public Supplies of Drinking Water” in the section on Goal 1.

Goal 1—Assess the Current Quality of the Nation's Freshwater Resources and How Water Quality is Changing Over Time

Objectives, approaches, and partnership opportunities that will be used to address the four Cycle 3 goals are described in this and subsequent sections. For each of the four Cycle 3 science goals and their associated objectives the following information is described:

1. Progress made during Cycles 1 and 2,
2. Data or information gaps not addressed during Cycles 1 or 2,
3. NAWQA role in Cycle 3
4. Planned outcomes,
5. Approach
6. Critical data or technical support requirements,
7. Partnerships and collaborative opportunities

In this section Goal 1 objectives and approaches are described individually; however, in subsequent sections on Goals 2, 3, and 4, study objectives are grouped together because of similar information requirements, and a description of the overall approach that will be used to achieve the science goal objectives is given.

Goal 1 Outcome: An updated and enhanced assessment of spatial patterns and temporal trends of the quality of the Nation's freshwater resources.

Products

The following are planned products for Goal 1:

1. Annual Web-based reports on contaminant, nutrient, and sediment concentrations and loads based on an expanded monitoring network of over 260 streams and large rivers with expanded analytical coverage per prioritization of constituents by the NAWQA National Target Analyte Strategy (NTAS) work group (see sidebar "NAWQA NationalTarget Analyte Strategy").
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 prioritization.
3. Annual Web-based reports on contaminant concentrations and trends in groundwater used for domestic and public supply with expanded analytical coverage per NTAS prioritization.
4. Continuous monitoring of selected water-quality properties and constituents (for example, temperature, specific conductance, dissolved oxygen, turbidity, and nitrate) or related surrogate water-quality constituents (salinity, nutrients, sediment, or bacteria) at a subset of NFSN 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 conditions at approximately 50 streams in watersheds undergoing rapid land-use change (urbanizing) and at approximately 40 reference-condition watersheds.
7. Exceedance maps for groundwater contaminants of human-health concern (for example, 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-yr) 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 yr).

Connections to other NAWQA Cycle 3 Goals

Data, analyses, models, and decision-support systems associated with the seven Goal 1 objectives described in the following subsections represent the continuation of the original NAWQA Program goals 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 Cycle 3 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 climatic conditions 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 stream ecosystem response to changing land-use and climatic conditions (Goal 4).

Policy and Stakeholder Concerns Driving Key Management Questions

Water-quality legislation enacted in this country at the Federal level has been prompted by two primary concerns: protection of human health and restoring and maintaining the chemical, physical, and biological integrity of the Nation's surface water 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 aquatic-ecosystem conditions. Because most of the concerns and related policies and regulations that prompted 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, the following subsections give a brief overview of those policies and concerns per the two major receptors of interest: human health 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 (1) threats related to consumption of aquatic organisms (primarily fish in freshwater) and (2) microbial contamination of waters used for

NAWQA National Target Analyte Strategy (NTAS)

A high priority for many stakeholders is for NAWQA to assess new or previously unrecognized contaminants that are currently unregulated but that may 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 the need to weigh the addition of new contaminants against the need to continue monitoring of Cycle 1 and 2 NAWQA contaminants as well as a need to upgrade NAWQA's existing analytical portfolio, the Cycle 3 Planning Team established a NTAS work group in spring 2009. The work group was instructed to prioritize constituents with respect to:

- Which current NAWQA contaminants are important for continued monitoring;
- Which contaminants could be dropped from lab schedules used by the NAWQA Program; and
- Which emerging contaminants should be added to monitoring plans, in view of current understanding of the national significance of different contaminants to Cycle 3 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 was dropped due to lack of data) with a focus on organic chemicals and trace elements. Microbial contaminants were evaluated separately. Several thousand candidate contaminants known to partition in either water or sediment were evaluated. Prioritization of candidate 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; and
- Other agency priorities such as a compound's presence on the USEPA Contaminant Candidate List 3 or the Unregulated Contaminant Monitoring Rule 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 to upgrade existing methods and develop new ones for the highest priority contaminants.

Information regarding the contaminants evaluated, their relative importance within specific contaminant groups, and the methods used to develop the NTAS work group's recommendations is described in Olsen and others (2013).

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; it accounts for about two thirds of the water used for public supply in 2005, and over 10,000 community water systems relied on surface-water sources for drinking water (Kenny and others, 2009). Reservoirs supply more than twice as much drinking water as rivers and streams (Hutson and others, 2004). Remaining drinking water for public supply is provided by water systems that rely on groundwater sources. In 2005, about 258 million Americans received their water from public suppliers; the remaining 43 million Americans 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 the SDWA thus applies to virtually all surface-water sources (very few are private). The SDWA 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 the 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 they provide to their customers. The Source Water Protection Program, established in a 1996 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 the SWDA, nor in most cases is it regulated by the states.

States are responsible for determining the need for and issuing of 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 (for example, see *http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/index.cfm*). Most advisories involve five contaminants known to bioaccumulate in the environment: mercury, polychlorinated biphenyls (PCBs), chlordane, dioxins, and dichlorodiphenyltrichlorethane (DDT). These 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 percent 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 SDWA. The Clean Water Act 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 the 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

The Clean Water Act 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 these waters can support high-quality aquatic ecosystems and the services those ecosystems provide. The statute uses 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 Clean Water 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 United States. This is the primary source used by the 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 that govern the status and trends in the quality of aquatic ecosystems is a national concern because of the present extent of impaired waters and the potential that the amount of impaired waters and associated ecosystems 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 were 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, concerns are increasing regarding the potential effects of less well understood threats to aquatic ecosystems, including endocrine disrupting chemicals, low-concentration mixtures of multiple 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 importance in affecting aquatic ecosystems. Without an understanding of the relative importance of contaminants and their relation to other stressors, management strategies aimed at improving aquatic ecosystems cannot be reliably and efficiently devised or implemented.

Management questions related to the Goal 1 status- and trend-assessment activities described throughout this section include the following examples:

- 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 the 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 a 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 that are identified in the following bullets 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 were not extensively assessed in surface water (not at all or only in a few, selected locations) including (1) many pesticides and their degradates and adjuvants; (2) numerous additional unregulated organic contaminants, including high-production volume chemicals and pharmaceuticals; (3) disinfection by-products; (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; and
- 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 data.

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 current 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 to supply drinking water, (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

The following are planned outcomes for Objective 1a:

- Enhanced and updated occurrence and distribution assessments for current and potential future source waters that (1) build on previous assessments by updating and expanding target contaminants (based on prioritization by the NTAS work group as described by Olsen and others, 2013); (2) expand the scope of assessment to include 50 lakes and reservoirs that currently or potentially supply drinking water; (3) improve geographic coverage of contaminant monitoring for streams and rivers to increase the reliability of assessments for the most important present and future drinking-water sources (importance determined by balancing vulnerability to contamination against population served); (4) 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; and (5) provide regular (annual and 5-yr 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. These assessments will feature improved tracking of the most critical contaminants in important surface-water supplies; and
- Periodic national reports on the status and trends of source-water quality.

Approach

Overview

Objective 1a will mostly be accomplished through expanded data collection conducted at NFSN sites, and, to a lesser extent, through data provided by RSS assessments and other agencies. The most significant changes for the NFSN in Cycle 3 include a return to perennial (each site monitored each year, every year) instead of rotational (sites monitored 1 yr out of every 2 or 4 yr) monitoring strategy and a recommendation to incorporate continuous water-quality sensor technology at 50 percent of the NFSN sites. Table 2 lists other components of the recommended monitoring strategy for the NFSN, including sampling frequency and constituents to be monitored using continuous water-quality sensors.

In addition to an upgraded network of ambient stream- and river-monitoring sites in which each monitoring site is sampled each year of Cycle 3, new monitoring components recommended to assess the suitability of surface-water sources for drinking-water supply include a sub-network of 20 stream and river sites that are at or near public-supply intakes. These sites would be selected to represent intakes that are most vulnerable to contaminants, based on watershed characteristics such as agricultural or urban land use. Blended water systems (that is, those systems with multiple surface-water sources or those that include a mix of surface water and(or) groundwater sources) would be avoided so that the sites are suitable for source-water/finished-water comparisons. The 20 sites would be distributed geographically across different environmental settings with locations weighted towards serving the greatest population and having the greatest exposure to contaminants. Locations will be selected to balance the 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. Site locations will also be nested within IWS areas to the extent possible.

To more fully assess a key source of the Nation's drinking water, NAWQA will create a new network of 50 lakes and reservoirs used for public supply. The focus will be on monitoring intake water quality (1 site per supply location) with a subset of 10–25 percent of sites selected for source-water/finished-water comparisons. The subset of sites selected for source-water/finished-water comparisons will focus on the most contaminated source waters in a variety of environmental and land-use settings based on an initial round of sampling. Subject to the above constraints, sites serving the largest number of people will be selected. Lake and reservoir studies will be strictly focused on water-quality monitoring and will not involve detailed studies of lake or reservoir hydrodynamics. Site-selection criteria will be similar to those used for the 20 stream sites.

Regional Synoptic Study assessments, in which a selected set of contaminants are targeted for sampling during specific periods of interest (for example, chemical application periods and specific climatic or hydrologic conditions) in water-bodies used for drinking-water supply may also be conducted to fill gaps in spatial or temporal occurrence. 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 a period of several months is warranted to fully characterize the concentrations of pesticides during spring application periods.

Table 2. Sampling strategy for National Fixed Site Network.

Site type	Number of sites	Site sampled every year?	Sampling frequency (samples per year)	Continuous water-quality monitoring constituents[a]				
				Streamflow	Temperature	Specific conductance	Turbidity	Dissolved oxygen
Ambient large river	118	Yes	6–18	Yes	Yes	Yes	Yes	Yes
Ambient wadeable stream	125	Yes	26	Yes	Yes	Yes	Yes	Yes
Stream or river drinking water intake	20	Yes	18	Yes	Yes	Yes	Yes	Yes
Lake or reservoir drinking-water intake	50	Yes	12	Possibly	Possibly	Yes	No	No

[a] Continuous water-quality monitoring sensors for the constituents listed will be installed in 50 percent of National Fixed Site Network sites.

Table 3. Water-quality constituents or contaminant groups to be monitored for characterizing surface-water quality for human health.

Site type	Water-quality constituents to be monitored								
	Major Ions	Nutrients (nitrogen, phosphorus, carbon)[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	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Ambient wadeable stream	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Large river drinking-water intake	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Lake or reservoir drinking-water intake	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No

[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 NAWQA Target Analyte Strategy (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 or wastewater.

[e]Pathogen monitoring is proposed for a subset of the National Fixed Site Network sites under Objective 1c.

Contaminant Coverage

Proposed contaminant coverage for Objective 1a by site type is given in table 3 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 prioritiziation by the NAWQA National Target Analyte Strategy (NTAS) work group (see sidebar) and is subject to having approved analytical methods and adequate funding. A key step will be continued development of HBSLs (Toccalino, 2007) for new contaminants that are added to NAWQA analytical schedules. Development of new HBSLs, which is critical for assessing which contaminants are of greatest concern, will continue to be done in collaboration with USEPA.

Use of continuous-monitoring technology that yields real-time water-quality information for basic properties such as temperature, specific conductance, dissolved oxygen, turbidity, and other related constituents is an integral feature of the NFSN monitoring design (table 2). It is recommended that such sensors be installed at 50 percent of NFSN sites. Data from such monitoring will provide information regarding short-term (minutes to days) responses of water quality to hydrologic, climatic, or human effects and will provide an improved understanding of stressor-effects relations and will also 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 water use. 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 that are 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.

Critical Requirements for Technical Support and Data Support

An initial design requirement for Objective 1a will be a reliable analysis 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 the 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 described in the section on Goal 2) 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 concentrations of organic contaminants in whole fish (approximately 1,000 sites were sampled nationally), which resulted in national assessments that yielded statistical-extrapolation models for key individual contaminants. However, trace elements, including mercury, were assessed in fish livers and other organisms such as Asiatic clams; the presence of these elements in these types of samples is difficult to relate to human consumption. From 1998 through 2005, NAWQA and the Toxic Substances 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 a 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 evaluation of mercury trends in fish (Chalmers and others, 2011).

Information Needs Not Addressed During Cycles 1 and 2

Information needs that are noted in the following bullets include those needs 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.

- A 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, is lacking;
- New or emerging contaminants were not extensively assessed in fish tissue;
- Cycle 1 assessments of mercury 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; and
- Cycle 1 tissue sites were not resampled for trend analysis.

NAWQA's Role in Cycle 3

The role of NAWQA with respect to addressing potential concerns with human consumption of contaminated fish is to build on existing regulatory monitoring of edible fish tissues such as the USEPA National Fish Contaminants Survey (*http://water.epa.gov/scitech/swguidance/fishstudies/overview.cfm*) and to address information needs that are most critical to long-term protection of human health from contaminants that bioaccumulate in fish. Given that the USEPA and the states monitor contaminants responsible for consumption advisories, and that an extensive assessment of a variety of contaminants in fish of lakes, rivers, and coastal waters is being done by USEPA as part of the National Aquatic Resource Surveys Program (*http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm*), 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

The following are planned outcomes for Objective 1b:

- Annual updates of trends in mercury in fish tissue within a selected set of watersheds that represent a range of mercury deposition and methyl-mercury production rates will be reported on the Web; and
- A substantial investment in the proposed national mercury monitoring network will be provided (MERCNET; see *http://nadp.sws.uiuc.edu/mercnet/*).

Approach

Overview

The basic approach is to annually monitor mercury concentrations in fish in a network of stream and river sites over the duration of Cycle 3. Site selection will be based on the extent and quality of historical data and on coverage of a variety of watershed characteristics that have been shown to be important in methyl-mercury production and bioaccumulation in fish consumed by humans such as mercury deposition rates, percentage of wetlands, organic carbon in streambed sediment, dissolved sulfate, and pH. Candidate sites would include NFSN sites, USGS Biomonitoring of Environmental Status and Trends Program (*http://www.cerc.usgs.gov/data/best/search/*) and National Contaminant Biomonitoring Program (*http://www.cerc.usgs.gov/pubs/center/pdfDocs/90341.PDF*) sites, and NAWQA lake-coring sites. The total number of sites to be monitored would range from 100 to 200 sites, with a minimum 25-percent overlap with NFSN sites, especially those selected for ecosystem-trends monitoring. Mercury trend sites would be sampled annually, and one or more targeted fish species would be sampled that represent the top predator sport fish and 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 mercury in fish tissue. The primary reason to do so is to improve spatial and temporal coverage of mercury 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, continued improvement on data sharing and infrastructure is needed to allow for more efficient and collaborative aggregation of state, Federal, and tribal fish mercury monitoring data.

Objective 1c. Determine the 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 datasets that were collected. A strategy for monitoring microbial contaminants in Cycle 2 developed by Francy, Myers, and Helsel (2000) was not implemented because of lack of funding, although a pilot study to evaluate the occurrence of several indicator organisms in streams and groundwater was conducted in the latter part of Cycle 1 (Francy, Helsel, and Nally, 2000).

Information Needs Not Addressed During Cycles 1 and 2

Newer, molecular, and polymerase-chain-reaction 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 can cause nearly instant illness to people that are exposed to an infective dose. Water-borne diseases from microorganisms are readily understood by most people, and outbreaks of water-borne diseases, although not as widespread or deadly as in undeveloped countries, are relatively common in the United States as reported by the Centers for Disease Control and Prevention (*http://www.cdc.gov/healthywater/surveillance/index.html*). Beaches, lakes, and reservoirs used for recreation are monitored by USEPA, the states, and local health departments. However, although many people participate in recreational activities such as swimming, boating, or water skiing 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, where a high degree of bodily contact with the water is likely, for example, swimming, water skiing, or tubing, (2) evaluate relations between rapid analytical methods that provide results within 4 hours to culture-based methods that take at least 18 hours to obtain results, 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

The following are planned outcomes of Objective 1c:

- In streams and rivers, 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 assessed using state-of-the-art monitoring technology and analytical methods;

- A determination will be made of whether 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 possible that state and local health departments tasked with monitoring recreational water quality will adopt these methods into state monitoring programs; and

- Statistical models would be developed and refined; these models 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 will be placed on the USGS Water-Quality Watch Web site (*http://waterwatch.usgs.gov/wqwatch/*) on a near real-time basis (fig. 15)

Approach

Overview

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

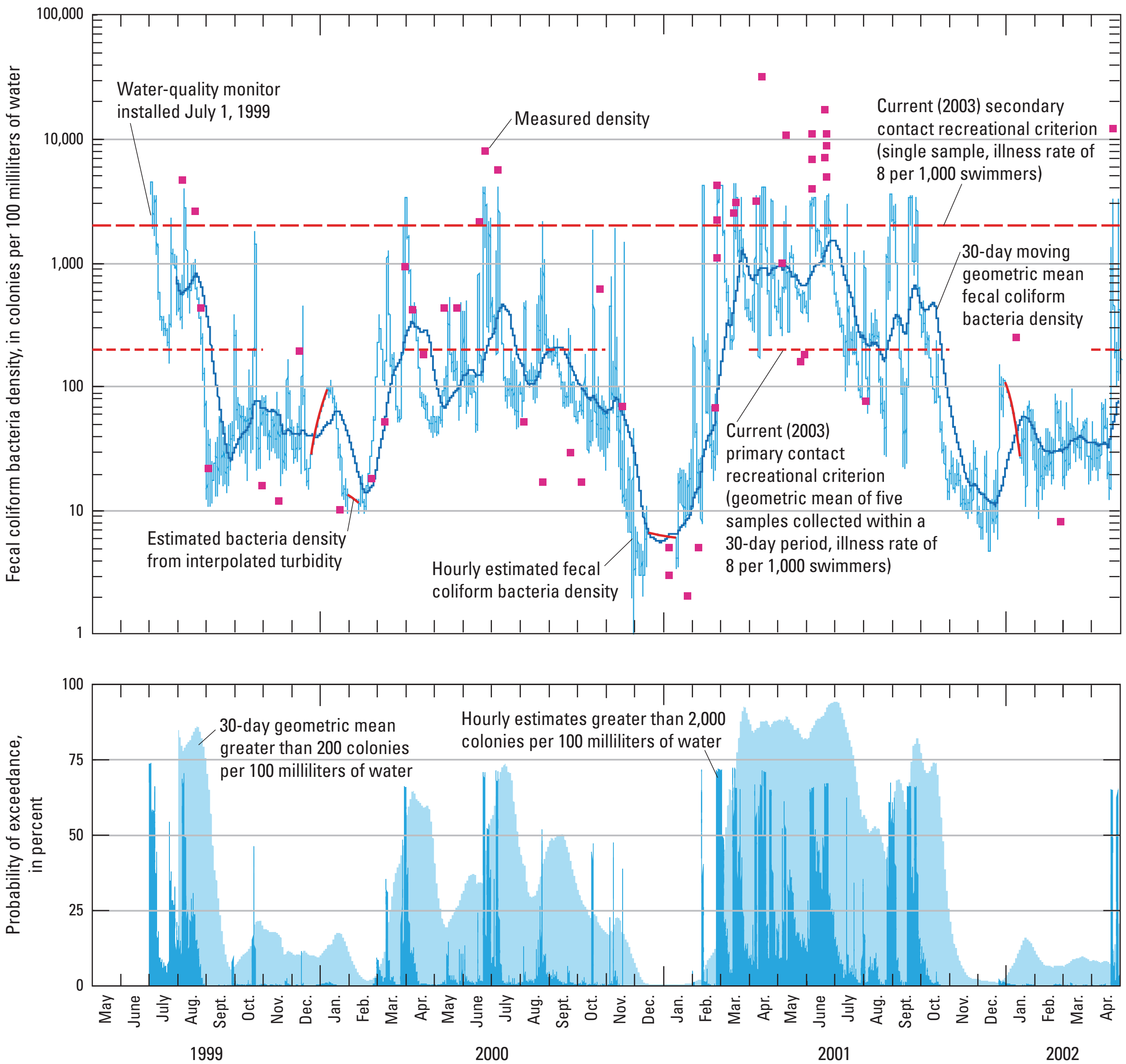


Figure 15. Comparison of measured and regression-estimated fecal coliform bacteria concentrations in the Kansas River at Desoto, Kansas, for May 1999 through April 2002 (upper plot) and the probability of exceeding recreational water-quality criteria established by the Kansas Department of Health and Environment (from Rasmussen and Ziegler, 2003). Such plots are updated on a near real-time basis and made available to the public through the USGS Water-Quality Watch Web site (*http://waterwatch.usgs.gov/wqwatch/*).

established in 1986 and include culture-based analytical methods that take too long to provide timely and accurate assessments. In 2012, the USEPA developed new recreational water quality criteria that include a rapid assessment method for *Enterococcus* spp., along with culture methods for *E. coli* and enterococci (USEPA, 2012a).

Research is being done by the USEPA and others to test and standardize rapid analytical methods using quantitative polymerase chain reaction (qPCR) technology for *E. coli*, enterococci, and *Bacteroides* (*Bacteroides* is a bacterium abundant in the gut of warm-blooded animals, and *Bacteroides* genes commonly are 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. Immunomagnetic separation/adenosine triphosphate (IMS/ATP) is an alternate rapid method that is less costly and easier to use (Bushon and others, 2009). USEPA and stakeholders at the state and local levels are interested in determining how well concentrations of indicator organisms determined by rapid analytical methods compare to current culture methods as the transition to rapid methods is implemented over the next decade.

Stakeholders also are 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 streamflow in streams (Rasmussen and Ziegler, 2003), and several states (Kansas, Georgia, Maryland) now use these relations to predict when water is safe for recreational uses (fig. 15; *http://waterwatch.usgs.gov/wqwatch/faq?faq_id=4*). Routine NAWQA sampling of multiple water-quality constituents is an excellent foundation for developing surrogate relations and potentially establishing simple regression models that link one or more surrogate measures with indicator bacteria concentrations.

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, a variety of land-use types and sources of fecal contamination, different climates and watershed sizes, and the capability of USGS personnel 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). Twenty-five of the 75 sites selected will be sampled 14 times per year over a 3-yr 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 storm samples.

Contaminant Coverage

The indicator bacteria *E. coli* and *enterococci* will be determined by traditional membrane filtration culture techniques. *E. coli* and *enterococci* also will be determined by IMS/ATP and qPCR rapid methods, whereas *Bacteroides* will be done by qPCR only.

Critical Requirements for Technical Support and Data Support

The qPCR method for enterococci (Method 1611) has been published and validated (USEPA, 2012b). Methods for *Bacteroides* (USEPA, 2010a) by qPCR and for *E. coli* by IMS/ATP have not been validated and will require USGS approval prior to the start of Cycle 3. Training of field crews on how to collect and process microbiological samples will 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, commonly at concentrations one to three 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 Levels (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), and 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 Study-Unit Investigations). MAS studies, which had areas of approximately 1,000 to greater than 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 3,000 wells (approximately 2,000 domestic, 500 public-supply, and 500 other well types, mostly irrigation) in about 100 MAS networks. LUS networks, which were approximately 100 to greater than 1,000 km^2, were nested within MAS study areas and were designed to assess relations between shallow groundwater quality and overlying land use. About 2,700 wells (primarily observation wells) were sampled in about 110 agricultural and urban land-use networks. Flow-Path Study (FPS) assessments 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 Investigation teams for various purposes to complement the MAS, LUS, and FPS networks.

In Cycle 2, 26 new MAS networks (with approximately 780 wells) and 18 new LUS networks (with approximately 540 wells) were sampled to fill spatial or specific land-use gaps, including a few areas outside of previously defined Study-Unit Investigation boundaries. Similar to surface-water studies, studies of ambient groundwater quality were augmented by Source Water-Quality Assessments (*http://water.usgs.gov/nawqa/swqa/*) 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 substantial reductions in the number of sites operated and samples collected that were incurred by the NAWQA surface-water network, the number of groundwater networks sampled in Cycle 2 for status and trends assessments largely adhered to the original implementation plan developed for Cycle 2 by the NAWQA National Implementation Team and described by Gilliom and others (2001). However, synthesis of status and trends data in Cycle 2 is being done at the principal aquifer scale with synthesis efforts focused on 19 of 62 principal aquifers (Lapham and others, 2005). The principal aquifer-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 2,000 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 yr, mainly in agricultural areas (Rupert, 2008). The 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 also were 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 5 wells 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 1 yr at a subset of 100 biennial trend wells. Rosen and others (2008) found that quarterly sampling over a 1-yr 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

The following information needs were not addressed for Objective 1d during Cycles 1 and 2:

- Spatial gaps exist from the perspective of principal aquifers because, with few exceptions, Cycle 1 and 2 groundwater networks were located entirely within Study-Unit boundaries;
- Depth gaps exist in many areas; although NAWQA has adequately characterized water quality in shallow recharge areas and the depth zone used for domestic supply, the Program has not broadly assessed groundwater quality in the depth zone used for public supply;
- Contaminant gaps exist for selected regulated and unregulated contaminants, including anthropogenic organic chemicals (for example, pharmaceuticals, wastewater and high production volume chemicals), radionuclides, and selected microbial pathogens;
- Ancillary data necessary to interpret changes in water quality at various scales (local, regional, national) is lacking, especially at the temporal scales needed 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 is unknown, 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 of trends;
- Some insight into the relative hydrogeologic position of a well or network of wells is gained by age dating the groundwater. NAWQA collected a significant number of age-dating samples in Cycle 2; however, gaps in age-dating coverage in existing trend networks still exist; and

- An evaluation of how variable groundwater quality is at shorter time scales, especially in response to seasonal or annual changes in recharge, discharge, or contaminant loading, is needed to determine the validity of statistically determined decadal-scale trends in groundwater quality

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 and changes in groundwater quality over time 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 parts 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 shallow 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 tested and validated.

NAWQA's role in Cycle 3 is to (1) collect enough data to support development of predictive models at a variety 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) assess the range of expected groundwater-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

The following are planned outcomes for Object 1d:

- Enhanced and updated occurrence and distribution assessments for present and potential groundwater sources of supply that (1) build on previous assessments by updating and expanding target contaminants (based on the NTAS work group recommendations described by Olsen and others, 2013), and (2) improve spatial and depth coverage of key contaminants at the local to national scale;
- Exceedance maps produced by combining data generated under Objective 1d with the modeling described in section on Goal 2 (see fig. 16);
- 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 and principal aquifers to the Nation;
- Development of an ETN whose purpose is to provide short and long-term groundwater-quality trend information to the Nation in key hydrologic settings; and
- Production of datasets that can be used to validate coupled groundwater flow and solute transport models used for extrapolation and forecasting.

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 or relative to the areas of discharge; for the purposes of analysis, this can be referred to 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 and LUS) and a new network type, PAS, will be used to characterize groundwater quality with respect to depth and hydrologic position in individual aquifers. The PAS network will consist primarily of public-supply wells screened at depths typical of the zone tapped for public supply. The PAS network design will follow the stratified random design used for MAS networks, but the

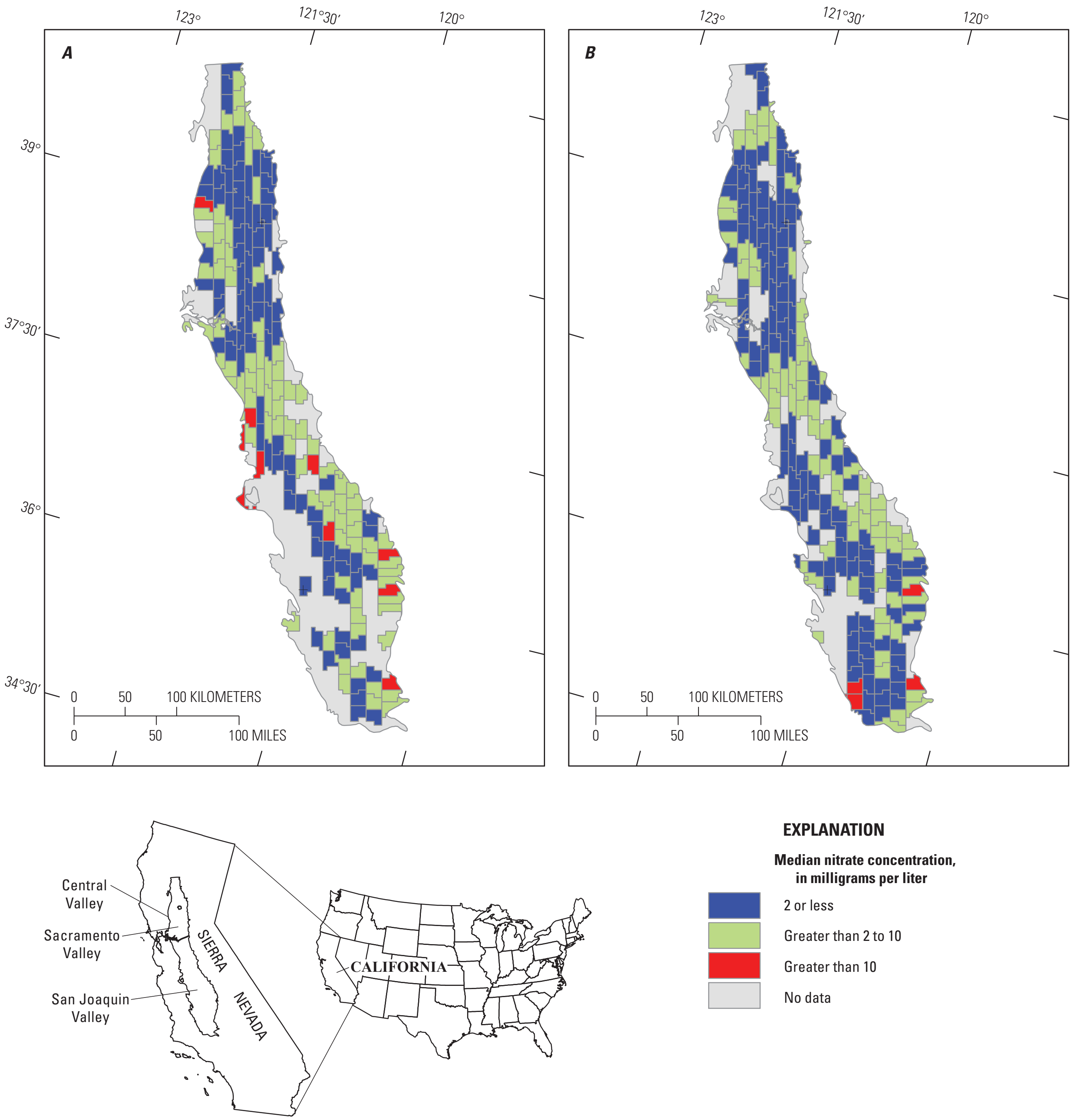


Figure 16. Nitrate exceedance maps for California's Central Valley principal aquifer based on nitrate samples collected in the 1970s. The map on the left shows the nitrate exceedance distribution based on data from shallow (mostly domestic supply) wells screened at depths less than 73 meters (m) (240 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 73 m. Grid cells in red exceed the U.S. Environmental Protection Agency's Maximum Contaminant Level (MCL) of 10 milligrams per liter for nitrate. 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 commun., September 2010).

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 described earlier, 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; *http://water.usgs.gov/ogw/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 4 for breakdown by network type). This represents an increase of 9 networks over the 81 trend networks resampled in Cycle 2; the increase in the number of trend 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 warrants consideration.

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.

The ETN is a new monitoring component proposed for Cycle 3; it will consist of 100 wells distributed across 20 of the most important principal aquifers, with an approximate distribution of five wells per principal aquifer. These wells would be sampled bi-monthly over three 2-yr periods (this equates to 12 discrete samples over 2 yr—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 during Cycle 3 to provide basic information on how the well is responding to human and natural factors. The continuous data also will 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 presented in table 4.

Contaminant Coverage

Proposed contaminant coverage for Objective 1d by network type is given in table 5 and is based on data needs for this and other Cycle 3 objectives. The proposed addition of

Table 4. Approximate number of Cycle 3 groundwater networks and wells. (--, no data)

Network type	Number of new status networks	Number of trends networks	Average number of wells per network	Total number of wells sampled	Total number of decadal samples	Total number of trend (biennial or bimonthly) samples	Total number of samples
Flow-Path Study	15	20	20	700	700	400[a]	1,100
Land-Use Study (agricultural, urban)	15	40	30	1,650	1,650	800[a]	2,450
Major Aquifer Survey	15	30	30	1,350	1,350	600[a]	1,950
Principal Aquifer Survey	55	0	50	2,750	2,750	--	2,750
Finished water	--	--	--	450[b]	450	--	450
Enhanced Trend Network	--	20[c]	5	100[c]	--	3,300[d]	3,300
Totals	100	90	--	6,450	6,900[e]	5,100	12,000

[a] Biennial sampling: (5 wells per network) × (4 biennial samples) = 20 samples per trend network.

[b] Finished water samples are not included in column total; samples will be collected at wells that are within other networks: primarily new Major Aquifer Survey or Principal Aquifer Survey networks.

[c] Enhanced Trend Network wells are not included in column totals; they are a subset of trends networks/wells.

[d] Eleven bimonthly samples per 2-year cycle (plus one biennial sample); three 2-year cycles; 6 years of data per well.

[e] 3,500 of the wells represent sampling of previously unsampled wells in new networks and the remaining 3,400 represent decadal-scale resampling of wells in Cycle 2 trend networks.

"new contaminants" to Cycle 3 monitoring for this objective is based on potential human-health concerns identified by the NTAS work group (Olsen and others, 2013) and is subject to having approved analytical methods and adequate funding. Continued development of HBSLs for unregulated contaminants that will be monitored in Cycle 3 is a key step in assessing which contaminants are of greatest potential concern.

Samples from wells that are part of NAWQA MAS and LUS trend networks will be analyzed for the contaminant groups sampled in previous NAWQA Cycles to continue monitoring for changes in groundwater quality; additional contaminant groups may be analyzed to establish a baseline for previously unmonitored constituents or contaminant groups (table 5). Trend network wells that have not been sampled for groundwater-age tracers will be sampled for those tracers in Cycle 3. This strategy applies to biennial trend network wells although they will not be resampled for age tracers on a biennial basis. Bimonthly samples collected from wells in the ETN 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 volatile organic compounds. Such data will be critical for producing aquifer exceedance maps at various spatial and depth scales as

Table 5. Water-quality constituents or contaminant groups to be monitored for characterizing groundwater quality for human health.

[P, indicates this contaminant group 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]	Radio-nuclides[f]	Pathogens[g]
Flow-Path Study	Yes	Yes	Yes	P	Yes	P	P	P	P	P
Agricultural Land-Use Study	Yes	Yes	Yes	P	Yes	No	P	No	P	P
Urban Land-Use Study	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	P	No
Major Aquifer Survey	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Principal Aquifer Survey	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finished water	No	No	No	No	Yes	Yes	Yes	Yes	No	No
Enhanced Trend Network	Yes[h]	No	Yes	No	No	No	No	No	No	No

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

[b] One or more potential age-dating tracers including tritium, tritium-helium-3, chlorofluorocarbons, 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 by-products of potential human-health concern per findings of the NAWQA National Target Analyte Strategy (NTAS) work group.

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

[e] Covers a 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 concentrations approaching human-health benchmarks.

[g] A subset of Principal Aquifer Survey supply wells (600 wells over the course of Cycle 3) will be sampled for key microbial indicator organisms in vulnerable aquifer systems. Indicator organisms to be analyzed include total coliforms, *Escherichia 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.

well as filling gaps in hydrologic position analyses. Regularly updated ancillary data will be needed 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 450 wells from the PAA and MAS networks will be used to conduct source-water/finished-water comparisons. The goal of these comparisons is to provide a broad national coverage in a variety of hydrogeologic settings deemed vulnerable to anthropogenic organic contaminants. The objective of collecting finished water samples is to understand occurrence patterns in source water and determine (1) if these patterns also occur in finished water prior to distribution and (2) how those patterns vary as a function of different treatment types.

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, and mineralogy need to be compiled for each well sampled. Data on sources (and history) of contaminants or surrogates for those sources (land cover) in the vicinity of each well also will need to be compiled. Although NAWQA will compile much of these data at the national level, collaboration with other Federal, state, and local agencies (such as the Advisory Council on Water Information Subcommittee on Groundwater) will be important 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 variety 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 to 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, unmeasured effects of 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 monitoring 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 reflecting changes in source terms, regulatory actions, or management practices.

The collection of suspended-sediment data by NAWQA in Cycles 1 and 2 has been secondary to data on other potential stressors and has primarily been for the purpose of characterizing trends in suspended-sediment concentrations at NAWQA fixed sites or 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. Streambed sediment data collected by NAWQA were compared with USGS and other agency data, and the results indicate continued declines in the concentration of bioaccumulative and toxic contaminants that were banned by USEPA in the 1970s and 1980s such as organochlorine pesticides like DDT (Gilliom and others, 2006). However, repeat sampling at 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 *http://tx.usgs.gov/coring/*).

Although the coring studies confirmed declining trends in most metals and several banned organic contaminants, they also showed that concentrations of other contaminants of concern to aquatic ecosystems, principally polycyclic aromatic hydrocarbons (PAHs), have increased in recent decades and frequently are found at concentrations that exceed sediment-quality guidelines in the youngest parts of the cores (Van Metre and Mahler, 2005). In 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 Mahler, 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 (EUSE study; Coles and others, 2012). The EUSE 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 were studied in multiple agricultural areas across the conterminous United States ecosystems (NEET study; *http://wa.water.usgs.gov/neet/)*. The NEET study showed that stream temperature and channel substrate have substantial 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 (Riseng and others, 2011). Also, Carlisle and others (2010b) found 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.

Information Needs Not Addressed During Cycles 1 and 2

The following information needs for Objective 1e were not addressed during Cycles 1 and 2:

- Potentially important contaminants not measured in water during Cycles 1 and 2 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 those used in personal-care products, various dyes, surfactants, and other industrial chemicals (Olsen and others, 2013);
- Potentially important contaminants not analyzed in streambed sediment or lake sediment cores during Cycles 1 and 2 including hydrophobic organic compounds 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 (Olsen and others, 2013);
- Suspended-sediment sampling generally has been inadequate to describe how sediment concentrations vary spatially and temporally, especially at time scales relevant to aquatic ecosystems. The sampling also has been inadequate to identify trends and describe how these trends are related to changes in upstream land-use or land management practices;
- An assessment of the extent, severity, and types of streamflow and temperature alterations and an evaluation of how dominant types of streamflow and temperature alteration vary among regions; and
- 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 a 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.

The USGS and NAWQA also are 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 more than a century, although the data are sparse in the early historical record (particularly for water temperature). National-scale data on aquatic ecosystem condition has been collected by NAWQA since the early 1990s. The NAWQA 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 as part of Objective 1e will support evaluation of short-term variability in each of the 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 also will be critical for developing an improved understanding of how contaminants, excess nutrients, suspended sediment, and sediment-associated contaminants are affecting aquatic ecosystems (Goal 3).

Planned Outcomes

The following are planned outcomes for Objective 1e:

- Enhanced and updated occurrence and distribution assessments of contaminant, nutrient, and suspended-sediment concentrations in streams and rivers that (1) build on previous assessments of water-quality by updating and expanding target contaminants based on guidance from the NTAS work group as described in Olsen and others (2013); (2) 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; and (3) 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 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 watersheds. 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 snowmelt 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; and
- Web-based tools that allow users to view, query, and analyze streamflow alteration datasets.

Approach

Overview

The status and trends of contaminant, nutrient, and suspended-sediment concentrations in water will be characterized by monitoring ambient water-quality conditions through the enhanced NFSN. Concentrations and decadal-scale change in sediment-associated contaminants will be characterized by resampling selected Cycle-1 streambed-sediment locations and lake coring sites and by sampling additional sites in high-priority settings (for example, downstream from wastewater discharges).

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 also will be provided by the NFSN through a combination of fixed-interval sampling conducted at 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 concentrations of nutrients and suspended sediment both spatially and temporally. Coverage also will 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 large a set of ecologically important 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 studies where toxicity is indicated. The survey and subsequent toxicity identification and evaluation studies would be done in collaboration with the USGS Toxic Substances Hydrology Program (*http://toxics.usgs.gov/*), the USGS Contaminant Biology Program, or both. The reconnaissance study will be conducted early in Cycle 3 with the goals of (1) providing findings that are relevant to resource managers in a timely manner and (2) 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, Toxic Substances Hydrology Program, 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 subset (10 percent) of the sites would be paired with lake or reservoir core sites for trend analysis. All sites would be sampled once and samples would be analyzed for the high-priority sediment-associated contaminants identified by the the NTAS work group (see following subsection “Contaminant Coverage”).

Streamflow Alteration

Initial characterization of the current and historical degree of streamflow and water temperature alteration will be done by analyzing retrospective datasets for USGS streamgages that have sufficient periods of flow and temperature data (typically 10 yr of continuous data). Based on an assessment done in 2011, approximately 8,000 streamgages have sufficient flow data and 5,000 streamgages have adequate temperature data for a retrospective analysis. 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 or temperature regimes will be constructed.

The degree of 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 (for example, a USEPA 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 affect 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 (for example, annual to decadal) for sites that have multi-year or multi-decadal periods of record.

Contaminant Coverage

Proposed contaminant coverage for the sampling of ambient streams and rivers included in the NFSN is given in table 3. Target contaminant groups for Regional Synoptic Study (RSS) assessments 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 (Olsen and others, 2013) and is subject to having approved analytical methods and adequate funding. Contaminants that are considered a high priority from an ecosystem health perspective 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 in the previous subsection "Sediment Quality," 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 the reconnaissance 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

Critical requirements for technical support and data support include upgrading or replacing existing analytical methods for contaminants of potential aquatic-health concern in water and sediment per findings of the NTAS work group (Olsen and others, 2013). Historical datasets of land cover and land use, datasets describing stream channel modifications, and information regarding water withdrawals and use also will be needed.

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 have emphasized smaller tributary rivers and wadeable streams; large-river monitoring has been covered by other USGS programs such as NASQAN (*http://water.usgs.gov/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 the mean annual concentration or mean annual loading of suspended 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), 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 most sites, nutrient concentrations and loads did not change significantly between 1993 and 2003; where significant changes did occur, the trends were generally upward for total nutrient and total phosphorus concentrations and generally downward for nitrate concentrations. NAWQA regional assessments of suspended-sediment concentrations and loads indicate 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 changes over time is a critical national need as identified by NAWQA stakeholders. The following specific needs have been identified for Objective 1f:

- 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 several 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; and
- A better understanding of whether management practices designed to control nutrient and sediment loading to adjacent streams and rivers are effective in reducing downstream loading to lakes, reservoirs, estuaries, and other coastal waters.

NAWQA's Role in Cycle 3

NAWQA's role under Objective 1f is to 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 on the models and analyses developed in Goal 2 to link spatial and temporal patterns in nutrient and sediment transport to the human and natural factors that affect water quality, and to evaluate if, when, and how changes in human activities and natural factors such as climate have affected downstream transport. The regional and national scales of assessing spatial and temporal patterns in nutrient and sediment loading used by NAWQA are necessary to help evaluate whether the large amount of funds spent on nutrient management and soil conservation have been effective in reducing downstream transport. Information on nutrient and sediment loads will be used to support and enhance source and transport models such as SPARROW and to 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

The following are planned outcomes of Objective 1f:

- Annual publication of nutrient and suspended-sediment loads delivered to reservoirs and estuaries monitored by the NFSN;
- Assessment at regular intervals (for example, 5 yr) 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; and
- Assessment at regular intervals (for example, 5 yr), 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 described previously, a substantial 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 many of the 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 most NFSN sites will be increased to 18 samples per year to better characterize inter-annual and seasonal variability of nutrient and sediment loading (table 2). To further increase the accuracy of load estimates of sediment and sediment-associated constituents, continuous monitoring of turbidity or other suspended-sediment surrogates will be done at 50 percent of the NFSN sites. At a subset of NFSN sites, continuous monitoring of nitrate may also be done using new nitrate sensor technology (Pellerin and others, 2012).

To better characterize the spatial distribution and occurrence of suspended sediment in streams and rivers, an important 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 suspended sediment data vary with respect to sampling and analytical methods, (2) understand how biases/uncertainty associated with different methods affect computations of suspended sediment concentrations and loads, (3) characterize which sites and what data should be used to estimate suspended sediment loads and analyze trends, and (4) use available data to conduct regional/national assessments of how different environmental settings and human activities affect suspended sediment loads in streams and rivers and resulting sediment delivery to estuaries.

Contaminant Coverage

Proposed contaminant coverage includes 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 sensors or other continuous 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. Substantial 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

The need to evaluate the use of surrogate technology for continuous measurement of suspended sediment or nutrient concentrations for load estimation is ongoing. Evaluation of the utility of continuous nitrate sensors and other potential surrogates to estimate nutrient loads is needed. Although continuous turbidity measurement has proven effective at estimating fine-grained suspended-sediment concentrations, other measurement techniques, such as optical backscatter or hydroacoustic methods, may be used at sites with predominantly sand-sized sediment transport (Gray and Gartner, 2010). Load-calculation software will need to be updated to better handle conversion of continuous surrogate data into sediment-load estimates. Additionally, retrospective analysis of historical sediment data is needed to determine where and when sampling was adequate to compute historical 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 the current biological condition in the study units, not an assessment of trends. Assessment of ecological trends under the Cycle 1 model was to be based on successive 3-yr 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 trend 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 decreased 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 had been conducted as of 2011 on the NAWQA ecological data.

Information Needs Not Addressed During Cycles 1 and 2

The following bullets describe information needs for Objective 1g that were not addressed during Cycles 1 and 2:

- Sustained ecological trends monitoring at reference or "least-disturbed" sites, because these sites will be critical for assessing the effects of natural factors such as climate change on aquatic-ecosystem condition; and

- 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 few 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 stream 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

The following are planned outcomes for Objective 1g:

- A description of ecological trends in watersheds where human activities at the land surface are causing substantial changes;
- A description of ecological trends associated with natural factors such as climate change (based on reference-condition watershed monitoring); and
- 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 on 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 follow:

- ***Trends in Streams in Transitional or Developing Watersheds:*** Assess long-term trends in biological conditions in relation to contaminants and other stressors for selected “example” streams distributed among a variety of the most important environmental settings of the Nation where ecological impairment is related 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 to evaluate the effects of natural factors (such as climate change) at a range of 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 (IS) network (described in detail in section on Goal 2). The IS sites 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 historical water-quality and ecological data and their distribution relative to the locations of selected IWS areas and related Intensive Studies. The relative importance of the four stressors selected for emphasis in Cycle 3 (contaminants, excess nutrients, sediment, and streamflow alteration) also will be factored into the evaluation, and it may be necessary to include some new sites to address specific stressors or combinations of stressors. The NFSN ecology sites also will be evaluated relative to sites included in recent (2008) USEPA NARS (*http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm*) Wadeable Streams Assessment to better understand how NAWQA long-term monitoring sites relate to sites sampled by USEPA. Per Table 1 the NFSN would add 30 new reference sites; the remaining sites would be a mix of 48 existing NAWQA trend sites in developing watersheds and 10 long-term NAWQA reference sites.

The 30 new reference sites will be selected in collaboration with the USGS Hydrologic Benchmark Network (*http://ny.cf.er.usgs.gov/hbn/*), the USGS Global Change Program (*http://www.usgs.gov/global_change/)*, the USEPA Office of Water, the U.S. Fish and Wildlife Service, and the National Park Service as part of an effort sponsored by the Advisory Committee on Water Information’s National Water-Quality Monitoring Council to support development of a collaborative and multipurpose national network of reference watersheds and monitoring sites for freshwater streams in the United States *(http://acwi.gov/monitoring/workgroups/wis/National_Reference_Network_for_Streams_rev2.pdf).*

Ecology sites will 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 will include annual sampling for in-stream and riparian habitat, algae, and macroinvertebrates; fish will be sampled biennially. Transitional and Intensive Study (IS) sites would be sampled for contaminants, nutrients, and suspended sediment per table 3. 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

Critical requirements for technical support and data support for Objective 1g include the review and update of 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 many 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. The following subsection highlights current or desired partnerships that are critical to achieving Goal 1 objectives for Cycle 3. These partnerships 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

The following USGS mission areas and programs are potential partners for Goal 1 of Cycle 3:

- ***Climate and Land Use Change Mission Area:*** Data and assessment activities conducted under Goal 1 objectives support goals listed for the USGS Global Change Science Strategy (Burkett and others, 2011) in assessing how climate change and land use affect streamflow, sediment transport, surface and groundwater quality, and freshwater availability. The information also will 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 Mission Area:*** 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 fish tissue samples. The Toxic Substances Hydrology and Contaminant Biology Programs also are important collaborators for evaluating the occurrence of contaminants in aquatic biota.

- ***Ecosystems Mission Area:*** 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 Mission Area:*** 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 watersheds to be conducted by the USGS WaterSMART Program *(http://water.usgs.gov/watercensus/WaterSMART.html)* and assessments of groundwater availability in principal aquifers being conducted by the Groundwater Resources Program (*http://water.usgs.gov/ogw/gwrp/*).

External Partnerships

The following external agencies and organizations are potential partners for Goal 1 of Cycle 3:

- ***National Water Quality Monitoring Council:***
    - Support implementation of the National Monitoring Network (NMN; *http://acwi.gov/monitoring/*) by collaborating with the National Water Quality Monitoring Council 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 composed 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: 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:*** Collaboration with the USEPA could involve the following areas:
  - Assess status and trends of aquatic ecosystem condition: The USEPA Office of Water's NARS (*http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm*) uses a probabilistic approach to characterize current water-quality and biological conditions 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, 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 (*http://www.epa.gov/pesticides/index.htm*) 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 to 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 the State FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) Issues Research and Evaluation Group, or SFIREG, which is a state-level group that advises USEPA on pesticide regulation issues.
  - Assess microbiological contamination in recreational waters: The USEPA Office of Research and Development (*http://www.epa.gov/ord/*) is developing recommendations for the USEPA Office of Water and the states regarding application of rapid analytical methods for recreational water-quality monitoring. There is a shared interest in testing these new methods in a variety of environmental conditions and in assessing their efficacy compared to traditional culture-based methods.
- ***American Water Works Association, Administration of State Drinking Water Administrators, Centers for Disease Control and Prevention, National Institute of Environmental Health Sciences, Agency for Toxic Substances and Disease Registry:***
  - Coordinate USGS monitoring of drinking-water supplies by collaborating with these organizations. 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 the American Water Works Association and Administration of State Drinking Water Administrators, would be asked to collaborate on site selection, identify suppliers willing to participate in source- and finished-water comparison studies, and facilitate retrieval of information regarding treatment processes. Agencies such as Centers for Disease Control and Prevention, National Institute of Environmental Health Sciences, and Agency for Toxic Substances and Disease Registry 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 through collaboration with these agencies and organizations. The Office of Ocean and Coastal Resource Management at NOAA (*http://coastalmanagement.noaa.gov/*) manages the biological integrity of estuaries and coasts. Through partnerships with governmental and non-governmental organizations, the Nation's Integrated Ocean Observing System (*http://www.ioos.gov/*) supports 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 the Integrated Ocean Observing System are 11 regional associations that make up a broad community of data providers and users, including coastal states, Federal agencies, tribes, researchers, and non-governmental organizations (*http://www.usnfra.org/*). Data from the NAWQA and NASQAN Programs and SPARROW modeling of nutrient loads are used by 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.

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

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 affecting the response of watersheds and aquifers to changes in hydrology, contaminant sources, transport mechanisms, natural factors, and past and current human activities.

Products

The following are planned products for Goal 2:

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 degradation of surface-water and groundwater quality.
2. Dynamic watershed-scale models that explain the combined factors that affect observed seasonal and annual concentrations and fluxes of water, contaminants, nutrients, and sediment as they move through a large, complex watershed or aquifer system.
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 contaminants of human or natural origin that impair the use of groundwater for drinking supply.

Connections to other NAWQA 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 described in the section on Goal 1 activities. A second vital role of NAWQA in assessing national water quality is to link the nature and distribution of water-quality conditions (status assessment) and changes and trends in water-quality conditions (trend assessment) to the human and natural factors that affect water quality. Goal 2 is focused on the development of explanations for, and the understanding of, observed patterns and trends in water quality identified by Goal 1 assessment activities. This understanding is critical for evaluating the effectiveness of management practices in reducing contaminant concentrations or loads and for evaluating 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 and to evaluate the effects of potential changes in land use or climate. Water-quality properties and environmental conditions that lead to degradation of stream ecosystems will be identified in Goal 3. Strategies to remediate and minimize adverse water-quality effects on steam ecosystems will rely heavily on the understanding achieved by Goal 2 monitoring and modeling studies.

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 for 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 effects 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 are important in reducing nutrient loading to surface waters due to in-stream processing and transformation, and therefore warrant consideration when evaluating large-scale transport of nutrients. It also is understood that nitrate currently stored in the unsaturated zone and shallow groundwater may be a source of nitrogen loading to surface-water bodies for years or decades into the future Dubrovsky and others (2010).

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 on historical data collected by the NAWQA Program and other agencies, as well as data to be collected during Cycle 3. Models and studies will be done at scales ranging from the national scale, to the major river basin and principal aquifer scale, to the intermediate scale (integrated watershed and regional aquifer analysis), and ultimately to the Intensive Study scale (reach and local flow-path scales). Studies will be nested within each other and designed to provide relevant results that can be used to benefit models and studies conducted at other 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 (for example, involving food and water), regulating (involving regulation of floods, drought, land degradation, and water quality), supporting (involving soil formation, nutrient cycling, and primary production), and cultural (involving recreation and education). Increasing demands for ecosystem services means that trade-offs must be made among services; for example, conversion of forest to agriculture increases the service of food supply but diminishes the service of regulating floods and water quality. Increasing demand on water resources, including both quantity and quality, requires scientifically defensible information to make sound resource management decisions. Since its inception, the NAWQA Program has addressed multiple water-quality issues in surface water and groundwater across the United States, many of which overlap with several specific ecosystem services. In Cycle 3, however, NAWQA is organized for the first time to evaluate and quantify the factors—including indirect factors (for example, climate and land use) and direct factors (for example, nutrients and sediment)—that control the capacity of ecosystems 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. These studies will be supplemented with spatially and temporally intensive data collection, to address the five objectives described in the following sections.

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 landscape, and in the subsurface, as water moves through shallow and deep aquifers. 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 and on the interactions that occur along flow paths. Thus, a critical step in understanding water-quality responses to human activities and natural factors is to gain a better understanding of the hydrologic system, as characterized by water budgets, flow paths, traveltimes, 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 how the combined effects of hydrologic setting, land use, climate, and natural factors affect water quality requires identifying sources of contaminants, nutrients, and sediment; how they are introduced to the environment; 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 (1) discharges from wastewater-treatment plants or confined feeding operations and (2) leaking waste storage facilities. Combining knowledge of the hydrologic characteristics of different parts of the country and sources of contaminants with observed concentrations and ecosystem processing will allow a better understanding of how and why loads of contaminants, nutrients, and sediment change, both temporally and spatially in response human and natural factors.

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 affecting nutrient enrichment in streams is to use a systems approach where the simultaneous effects of the various controlling factors and how these interactions change over time and space are examined. 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.

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 factors 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 Historical 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—affected by increased population, changing economic conditions, and management strategies implemented to mitigate water quality problems—lead to changes in the quality of water for aquatic ecosystems and humans by 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 improve water quality is dependent on understanding the effect of these factors on contaminants, nutrients, sediment, streamflow, and groundwater recharge and discharge as well as on understanding the varying sensitivities 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 of resources. 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 available data. 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 following modeling approaches were included in Cycle 2:

- Broad-scale national and regional SPARROW models of regression/geospatial source and transport (Schwarz and others, 2006) for nutrients (nitrogen, phosphorus, and carbon), 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, based on watershed properties and chemical use estimates without mass-balance accounting, were developed to predict pesticide concentrations in water and fish tissue (WARP models; Stone and Gilliom, 2009).
- Process-simulation watershed models, such as TOPMODEL (Topography-based Model; Beven and others, 1995) and SWAT (Soil and Water Assessment Tool; Neitsch and others, 2005), were developed for small watersheds in some topical studies to improve understanding of the importance of flow paths in contaminant transport.

- Groundwater flow and particle-tracking models were developed at scales ranging from individual supply wells (1–10 km^2) to regional aquifer systems (hundreds to thousands of square kilometers) (Paschke, 2007).

- National regression/geospatial models were developed to estimate groundwater vulnerability to nitrate and pesticide contamination in shallow groundwater (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 bioaccumulation in stream ecosystems 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 (1) NAWQA's activities aimed at understanding the factors that control transport and delivery of nutrients to streams, reservoirs, and estuaries, and (2) evaluating the response of in-stream nutrient loads to changes in land use, source inputs, and land-management practices. At the national scale, trends in nutrient concentrations and loads since 1993 at stream monitoring sites were related to changes in watershed characteristics and nutrient inputs (Sprague and others, 2009). NAWQA also integrated monitoring data collected during Cycles 1 and 2 with monitoring data from other agencies into statistical models to extrapolate water-quality conditions in unmonitored parts of the country. The results of simulations made with SPARROW models 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). Estimates of mean loading of nitrogen to estuaries throughout the Nation derived from SPARROW models (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 Effects of Nutrient Enrichment on Stream Ecosystems (NEET; *http://wa.water.usgs.gov/neet/*) topical study examining nutrients in agricultural streams found that (1) concentrations of nitrogen and phosphorus in agricultural streams commonly exceed proposed USEPA Regional Nutrient Criteria although algal biomass commonly was 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 commonly 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 substantially reduce downstream transport of nitrate; and (5) legacy nitrate from fertilizer applied years or decades ago in groundwater that discharged to streams can be 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 MAS assessments (with study areas of approximately 1,000 to greater than 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 FPSs were conducted; these studies generally were 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 principal aquifers) into 11 regional areas (approximately 200,000 to 3,000,000 km^2) to assess groundwater quality from a regional geologic, hydrologic, and climatic perspective.

Two topical studies completed in Cycle 2 had a large groundwater focus. The Transport of Anthropogenic and Natural Contaminants (TANC) study (*http://oh.water.usgs.gov/tanc/NAWQATANC.htm*) examined contaminant transport to public-supply wells at the scale of the contributing area and at the scale of the larger groundwater flow system (approximately 100 to 5,000 km^2). TANC studies were implemented in 10 representative areas distributed across the Nation. The Agricultural Chemicals Transport (ACT) topical study (*http://in.water.usgs.gov/NAWQA_ACT/*) examined transport of contaminants through the entire hydrologic cycle from a watershed perspective and was implemented using a nested design in seven small watersheds each approximately 10 to 1,000 km^2. The TANC and ACT studies were field intensive, made use of quantitative groundwater-flow modeling, and were designed to facilitate understanding of the hydrologic and chemical processes affecting water quality.

NAWQA'S Role in Cycle 3

Evaluating the effects 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 the section on Cycle 3 design elements and shown in fig. 17. 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 with the relation reversed. A key advance for modeling in Cycle 3 will be to develop dynamic models that include temporal variability caused by time-varying source and water 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 the section on Goal 1 assessment activities also are 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 for Goal 4.

General 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 Goal 2 approaches is organized into (1) surface-water studies described by stressor, (2) an example of an IWS, (3) an example of an IS, and (4) groundwater studies. The studies described within each of these categories examine connections across scales, and between surface water and groundwater, as described by the explanations of each individual design and approach.

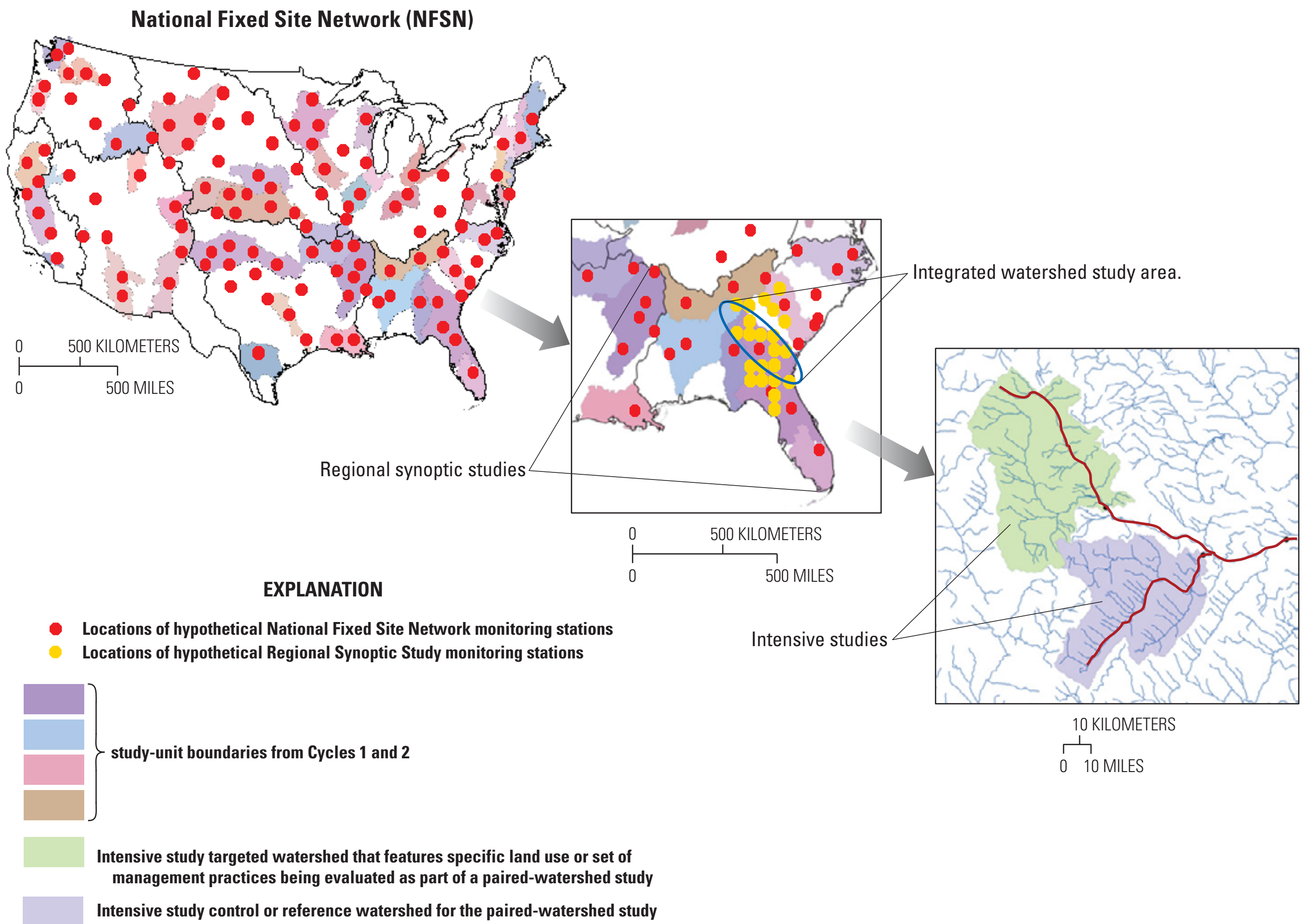


Figure 17. Schematic diagram illustrating nested spatial scales for Cycle 3 surface-water studies. The national map shows hypothetical monitoring stations for the National Fixed Site network (red dots), the middle inset shows a close up of the southeastern U.S. showing location of NFSN monitoring sites with the geographic extent of a Regional Synoptic Study indicated by hypothetical RSS sampling locations (yellow dots). The area encompassed by a typical Integrated Watershed Study is shown by the oval outline. In the last inset, two watersheds that would be monitored as part of a paired watershed Intensive Study are shown. The shaded areas in the national map indicate Cycle 1 and Cycle 2 study unit areas (*http://water.usgs.gov/nawqa/studies/study_units.html*).

Surface-Water Studies

Goal 2 surface-water studies will be used to continue to refine and improve regional and national modeling tools developed using the National Fixed-Site Network (NFSN) and other agency datasets to extrapolate water-quality information to unmonitored areas; evaluate delivery of contaminants, nutrients, and sediment to downstream areas; and determine the relative contributions of different contaminant sources to downstream receiving waters. Regional Synoptic Study (RSS) assessments will be done in conjunction with model development when more data are needed to improve existing water-quality models. The general direction of model enhancement will be towards dynamic models that can account for storage and loss of water, contaminants, nutrients, and sediment over time. Such models can be used to simulate seasonal and annual trends in contaminant concentrations and loads. Collection of NFSN data is designed to support these modeling efforts. Likewise, smaller-scale IWS and IS assessments will be done to provide process-level understanding that can be used to improve model accuracy and predictive capabilities.

The IWS assessments are designed to provide information at the intermediate scale, nested between the much larger national and regional analyses and the much smaller scale IS assessments (fig. 17). The IWS assessments will integrate surface water and groundwater hydrology with source, transport, and transformation analyses for the stressors of concern in the watershed. These studies aim to provide a holistic scientific understanding of the fate of nutrients, sediment, and other contaminants as they are transported through the watershed, and of the human activities and natural factors that affect these constituents as they move through the watershed or aquifer. Concentrations and fluxes at critical locations within the watershed and at the basin outlet will be related to urban and agricultural management practices, as well as to watershed characteristics. Dynamic models developed at this scale will be the first modeling products and represent the foundation for larger regional- and national-scale models that will be released later in Cycle 3.

Embedded within each IWS area will be one or more detailed IS areas that address specific scientific questions, the answer to which will improve NAWQA's ability to simulate contaminant, nutrient, and sediment transport at the IWS scale (fig. 18). One goal of the IWS design is to better understand the effects of watershed disturbance on sources, transport, and transformation of important constituents at the watershed scale. The IWS analysis will provide an opportunity to scale-up IS findings and determine the relative importance of IS-scale processes within the larger watershed. IS assessments will initially focus on nutrient and sediment transport and fate. As Cycle 3 studies progress, other priority contaminants and (or) the effects of streamflow alteration on aquatic biota may be integrated into the nutrient and sediment design or added through additional IS assessments.

Planned study approaches and outcomes are described in the following subsections for each type of stressor: contaminants, nutrients, sediment, and streamflow alteration.

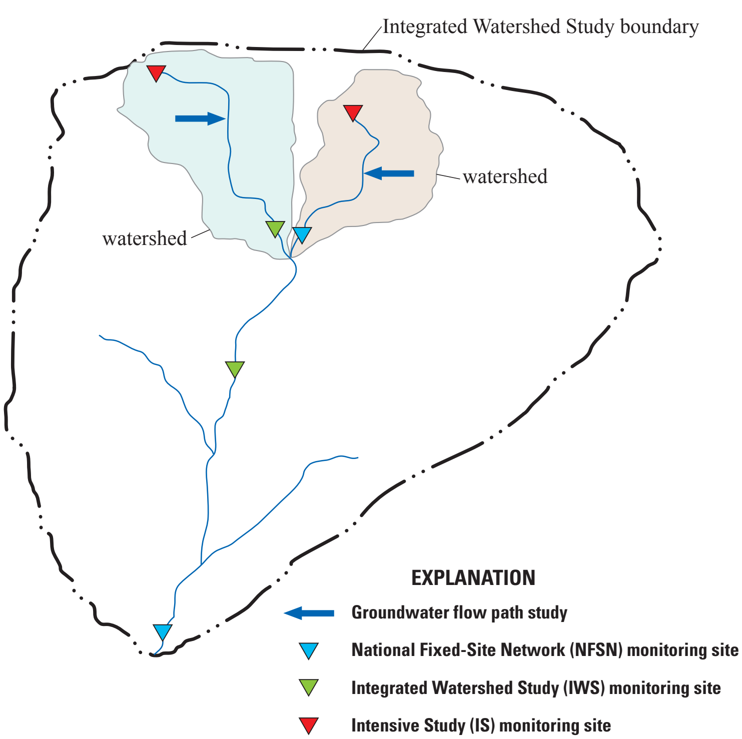


Figure 18. Example of an Integrated Watershed Study (IWS) design with an embedded Intensive Study (IS) that uses a paired-watershed design for comparing sediment and nutrient sources, transport, and transformations. The IS will be conducted in a small reference or least-disturbed watershed and in an agricultural or urban watershed and related to the downstream effects observed in the IWS. For example, periodic geomorphic assessments (along with the collection of sediment data and analysis of sediment flux and explanatory ancillary data) will be conducted to characterize sediment sources and sinks from headwater to downstream channels. Local-scale groundwater flow-path studies will be nested within the IS and IWS watersheds to examine surface-water/groundwater interactions. A National Fixed-Site Network monitoring site at the outlet of the basin anchors the IWS.

Contaminants

Contaminants that will be considered for Goal 2 studies include constituents or chemicals that are commonly detected in streams and rivers and, if present at high enough concentrations, can degrade drinking water-quality or affect ecosystem health. Example constituents include selected high-use pesticides, dissolved solids (salinity), and mercury. These constituents contain well-defined sources, are commonly detected in the environment, and can be tracked as they move through a watershed and in and out of shallow groundwater systems. The following sections describe the approach and planned outcomes for contaminants in surface-water studies.

Approach

Broad-scale national and regional models of contaminant concentration distributions will be developed for surface-water systems using Goal 1 data from the expanded NFSN as well as retrospective data where available. Surface-water-quality regression/geospatial models developed in Cycle 2 such as WARP (Stone and Gilliom, 2009) 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 periods of greatest relevance. Also, a 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 and wastewater compounds 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 affect implemented management practices; and
- Evaluate national and regional vulnerability of drinking-water resources to water-quality degradation and the relation of vulnerability to human activities and natural factors.

Nutrients

Nutrients to be monitored in Cycle 3 include nitrogen, phosphorus, and carbon. The following subsections describe the approach and planned outcomes for nutrients in surface-water studies.

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 year-to-year 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 (*http://www.usgs.gov/global_change/)* and to complement goals laid out by the USGS Climate and Land Use Change Strategic Science Planning Team (Burkett and others, 2011).

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 an improved understanding and prediction of how fluxes of nutrients and the timing of their delivery to downstream water bodies (including reservoirs and 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, water-quality models such as SPARROW (Smith and others, 1997) 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 variations 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 to distinguish trends related to human activities from those related to natural factors;
- Improve estimates of nutrient delivery to critical water bodies, including year-to-year and seasonal variability, which includes (1) periodic assessment, based on combined monitoring and modeling, of nutrient loads (annual, seasonal) for important estuaries in the Nation; (2) maps for each estuary of tributary watersheds which show estimated nutrient loads delivered to the estuary; and (3) estimates of the relative contribution of nutrients from different sources for specific time periods (seasonal, annual); and
- 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

Suspended sediment and selected surrogates will be monitored in Cycle 3 to assess sediment concentrations, loads, and transport. The following subsections describe the approach and planned outcomes for sediment in surface-water studies.

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 (that is, 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 sensor technology that can measure suspended-sediment surrogates such as turbidity in real time 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.

Watershed-scale analysis of factors affecting the erosion, transport, and deposition of sediment is needed to better understand the time scales 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 the 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 factors affect sediment movement in streams and rivers. Knowledge of the extent to which in-stream 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 suspended sediment surrogates (that is, turbidity, optical backscatter, or acoustic sensors) will be installed, and periodic suspended-sediment and stream-habitat data will be collected at selected stream and river sites in the NFSN. Sites will include many reference sites to better quantify sediment flux from relatively pristine, small watersheds in different geographic regions;
- Suspended sediment loads will be computed at each site using statistical software that can incorporate hourly sediment surrogate data to compute loads and uncertainty (USGS LOADEST (Load Estimator) 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 and 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 analyses derived from GIS datasets for 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 (Gellis and Walling, 2011); and
- National/regional SPARROW models will be improved using surrogate-derived sediment loads and updated ancillary data.

Planned Outcomes

The following are planned tools to explain sediment concentrations, loads, and transport in surface water:

- Updated Web tools to access and visualize historical suspended-sediment and ancillary data;
- Databases and Web tools derived from geographic information systems and geomorphic surveys that characterize river types based on 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 our ability to identify current and future 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 human disturbance and natural factors affect the sources, transport, and deposition of suspended sediment in specific environmental settings; and

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

Streamflow Alteration

Streamflow alteration will be evaluated in Cycle 3. The following subsections describe the approach and planned outcomes for streamflow alteration in surface-water studies.

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 (Graf, 1999; Carlisle and others, 2010a). Scientific expertise in hydrologic and geospatial analysis will enable NAWQA scientists 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 streamgages determined for Goal 1. For example, major differences in streamflow alteration are expected 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 of models that estimates metrics that describe 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 estimated 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 O/E values. 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 Study assessments are a critical design component for furthering our understanding of the effects of human activities and natural factors on water-quality conditions. IWS assessments will incorporate small-scale IS assessments 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 areas will be nested within nationally important regional watersheds (such as the Mississippi River Basin or Chesapeake Bay) to leverage ongoing data collection and modeling activities; for example, USDA's Mississippi River Basin Healthy Watersheds Initiative areas (U.S. Department of Agriculture, 2009), the National Ecological Observatory Network (NEON; *http://neoninc.org/*), the Chesapeake Bay Program (*http://www.chesapeakebay.net/*), and WaterSMART Program (*http://water.usgs.gov/watercensus/WaterSMART.html*) focus area watersheds such as the Colorado and Delaware River Basins.

Approach

Each IWS will build on Cycle 1 and 2 studies, will incorporate local information collected by other agencies and entities, and will be supplemented by additional 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. 19). The goal of the IWS assessments 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 affected 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, PAA 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. 19*A* and *B*) (Smith and others, 1997; Stone and Gilliom, 2009).

- Cataloging existing monitoring infrastruction including stream gages (fig. 19*E*), locations of NAWQA monitoring sites or studies (figs. 19*I* and 19*J*), and locations where other long-term nutrient or sediment datasets were collected (respectively figs 19*F* and 19*L*).

- Compiling detailed current and past land-use, water-use, climate, contaminant-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 19*C* and 19*K*. This illustrates that the IWS scale will encompass a variety of land-use categories and source inputs. This is important for analyzing how water quality changes in response to changing land use; and

- Characterizing watershed and aquifer characteristics that affect 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 dataset (*http://nhd.usgs.gov/*; fig. 19*G*).

A key element of the IWS is the analysis of fluxes of contaminants, nutrients, and sediment across important interfaces within the watershed (for example, surface-water/groundwater interface, interior sub-basins, and watersheds with drinking-water intakes (fig. 19*D*) and relating fluxes to sources, specific land uses, and natural factors). A 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. 20). Time-varying load estimates also will 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 assessments will rely on a subset of NFSN sites for long-term monitoring, with the addition of several 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 include considerations for the flow system, land use, active streamgages, and sites where other programs are collecting water-quality data.

Enhanced IWS monitoring will 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 varying 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; and
- 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 the following:

- 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 the Agricultural Nonpoint Source Pollution Model (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 watersheds to contaminant and nutrient processing, and sediment erosion and deposition. As illustrated in figures 19*A* and 19*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 of monitoring data at sparse 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, and the deviation of annual and seasonal variability from average predictions. This analysis will identify the enhancements needed to reduce uncertainty in model predictions, and also identify the factors that warrant incorporation 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 analysis described in the previous bullet, 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 in identifying the sources of these nutrients using the SPARROW model. 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 collection and conceptual understanding resulting from the IWS will be used to develop and test these models. Ultimately, the goal is to take these models that have been tested in the IWS assessments and apply them across the Nation. Estimates of groundwater flows and fluxes to streams and rivers within the IWS will be determined using a variety of techniques including base-flow separation and output from regional groundwater flow models;

- Applying and testing the ability of watershed-scale process models such as the Precipitation Runoff Modeling System (PRMS; Leavesley and others, 1983) and the Coupled Ground-Water and Surface-Water FLOW model (GSFLOW; Markstrom and others, 2008) to reproduce system responses at multiple-scales within the IWS (including the IS as explained in the following section “Example of an Intensive Study for Sediment and Nutrient Transport”). These models will be used to help identify the important hydrologic processes and factors that affect watershed water-quality responses at multiple scales that warrant incorporation into the dynamic regression/geospatial models. The importance of surface-water/groundwater interactions on watershed water quality will be examined as part of these modeling efforts; and

- Using regression/geospatial and watershed process models to improve understanding of how human activities and natural factors affect 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 historical and current water-quality patterns and trends observed in the IWS.

Planned Outcomes

The following are planned outcomes from the IWS assessments:

- An 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 affect observed seasonal and annual concentrations and fluxes for sub-basins within the watershed, and the aggregate at the outlet;

- Assessment of the effects and effectiveness of urban and agricultural management practices on water quality (using models); and

- 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 are important in reducing nutrients through in-stream processing and transformation. Thus, a detailed understanding of the factors controlling contributions of headwater streams to downstream nutrient and sediment transport will be part of the planned watershed studies. The Intensive Study (IS) assessments 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 affected 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 affected by management practices, and can the outcomes of changes in management practices that either increase or decrease landscape alteration be predicted?

- What watershed characteristics affect nutrient pathways and processes, and are these characteristics effective predictors of the susceptibility of streams to nutrient enrichment?

- What watershed characteristics affect the erosion, transport, and deposition of suspended sediment?

Questions will be addressed using a combination of paired IS watersheds in small watersheds (50–150 km^2) that are nested within a larger IWS watershed (fig. 18). The paired IS watersheds will include one small reference 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, these paired IS assessments will be done in only three IWS areas but for an extended period of time (5–10 yr). The advantages of focusing on a few long-term sites are to (1) maximize use of sites because substantial investment in monitoring infrastructure occurs at startup; (2) facilitate compilation and analysis of retrospective, current, and future data on chemical use, fertilizer and manure application, sedimentation, and land-use practices through long-term site operation; (3) maintain a long-term focus on a particular watershed, which will facilitate partnering with other USGS Programs (for example, National Research Program and Toxic Substances Hydrology Program) and external partners (for example, USEPA, USDA, NEON, and universities) on collaborative studies; and (4) gain additional data from such sites that could 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 areas that span a variety of physiographic areas with varying levels of landscape development. The IS assessments will include evaluating antecedent conditions in the watershed and determining how land use, flow, and sediment and nutrient loading have potentially changed ecosystem condition.

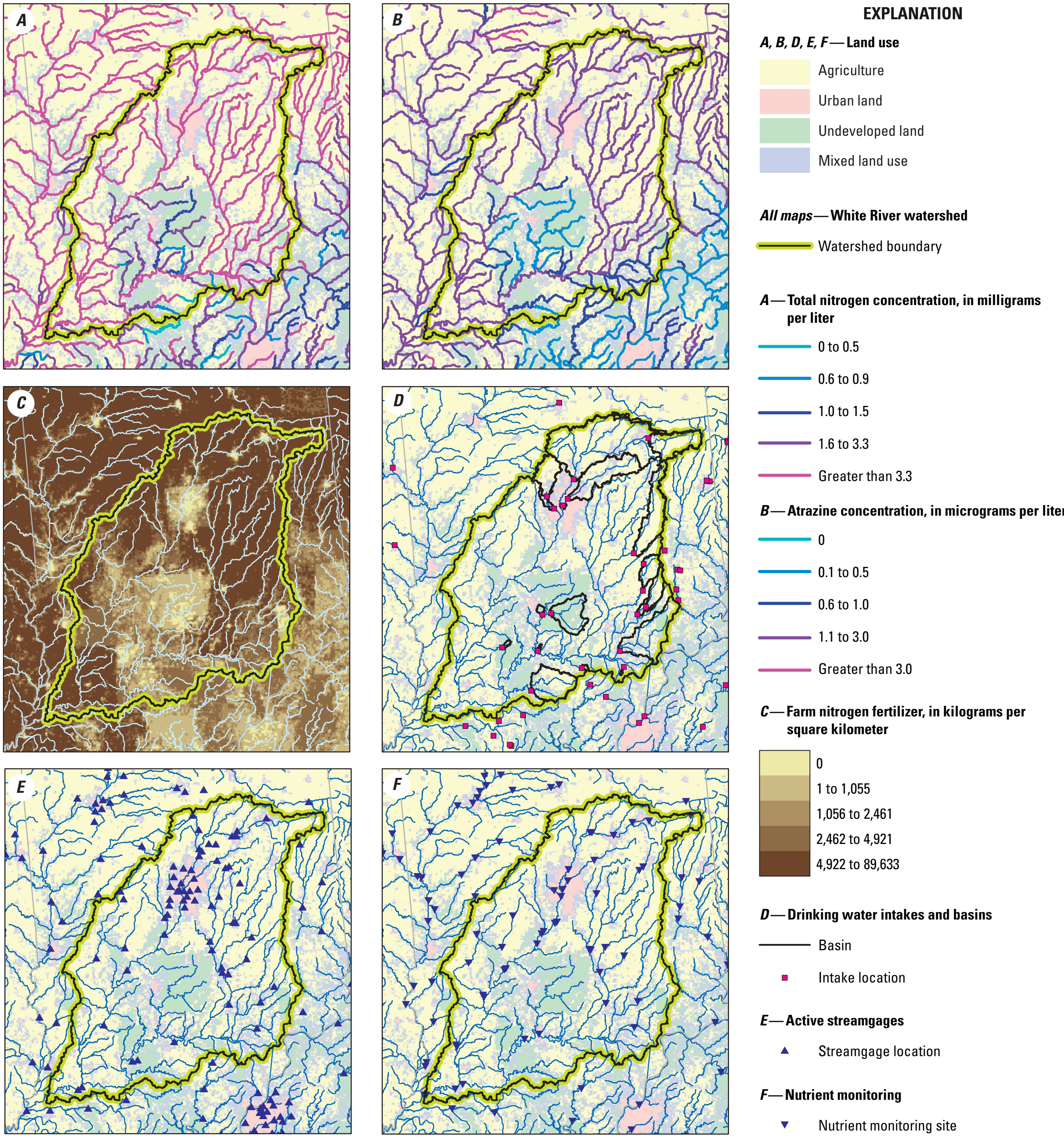


Figure 19 (facing pages). Examples of geospatial information available for the White River Basin in Indiana that would be of use in an Integrated Watershed Study: *A*, estimates of total nitrogen flux in streams from national SPARROW model (Smith and others, 1997); *B*, estimates of atrazine concentration from national WARP model; (Stone and Gilliom, 2009) *C*, farm fertilizer inputs of nitrogen (Gronberg and Spahr, 2012); *D*, locations of drinking-water intakes and associated contributing watersheds (Curtis Price, U.S. Geological Survey, written communication, 2012); *E*, locations of active streamgages; *F*, locations of nutrient monitoring sites (U.S. Geological Survey and other agency sites);

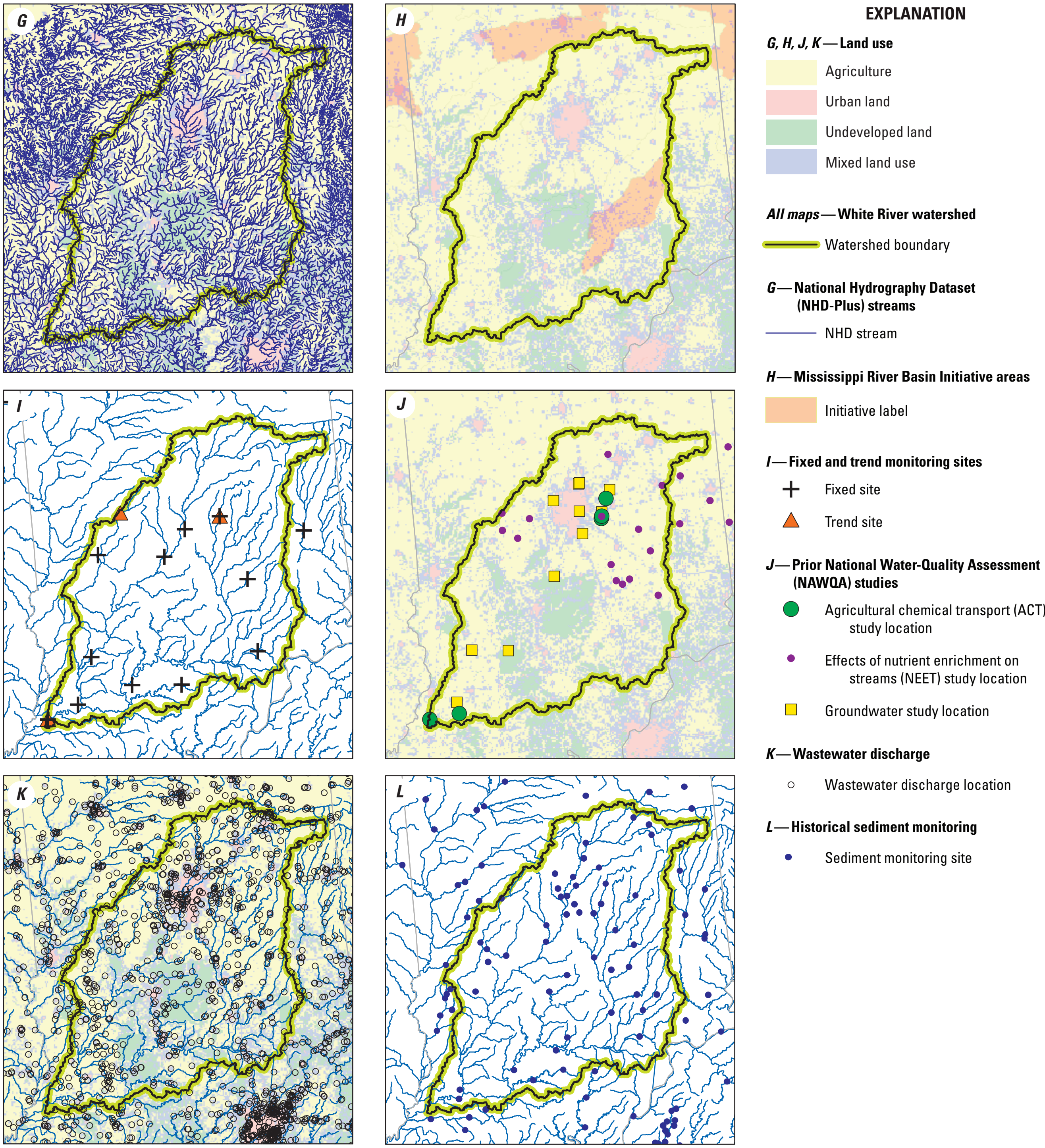


Figure 19 (facing pages)—Continued. *G*, high-resolution National Hydrography Dataset-Plus stream network that can be used to enhance models; *H*, location of the U.S. Department of Agriculture Mississippi River Basin Initiative (U.S. Department of Agriculture, 2009) areas within and adjacent to the White River Basin IWS area; *I*, locations of National Water-Quality Assessment Program surface-water-quality monitoring sites; *J*, locations of previous National Water Quality Assessment studies including Agricultural Chemicals Transport study (ACT, *http://in.water.usgs.gov/NAWQA_ACT/*), Effects of Nutrient Enrichment on Stream Ecosystems (NEET, *http://wa.water.usgs.gov/neet/*), topical study sites, and groundwater studies; *K*, location of wastewater discharges; and L, historical sediment monitoring sites.

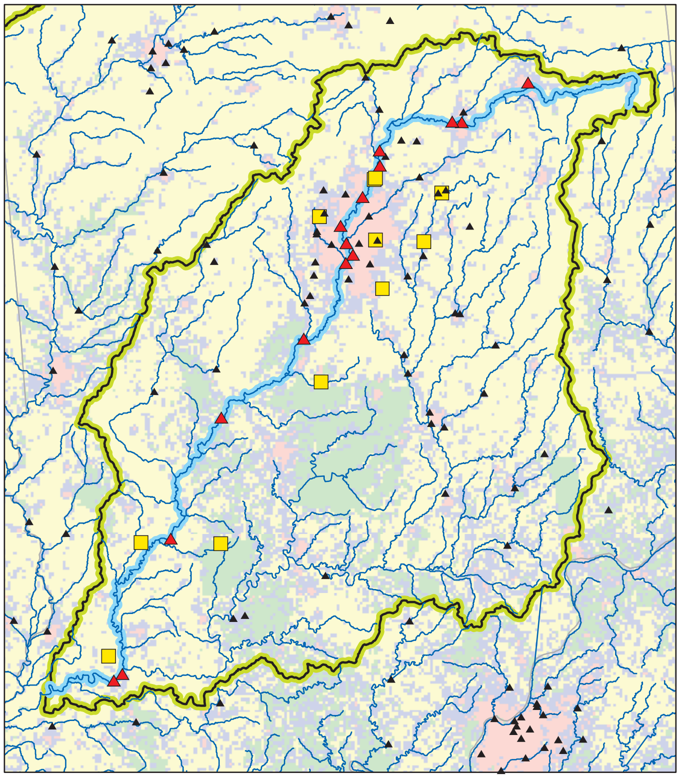


Figure 20. The White River Basin in Indiana showing nested streamgages that could be added to the water-quality monitoring network and used to track fluxes along a river corridor and deduce the effects of varying land uses, management practices, and watershed characteristics on the fate of contaminants, nutrients, sediment, and streamflow. Local groundwater studies and regional model results will be used to determine the effect of groundwater processes and fluxes on surface-water quality.

Although specific IWS areas 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 have high- and low-intensity phases and will be implemented on a rotational basis.

Approach

The paired IS watersheds for the sediment and nutrient transport assessments will have reaches that extend for 2–5 km and will be gaged near the upper end of the watershed and at the mouth (fig. 18). 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 the sediment and nutrient-transport assessments, more detailed studies will be done in the smaller IS watersheds, and lower levels of data collection will be collected at downstream sites.

The IS assessments 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. The IS assessments will be repeated periodically at a site to identify temporal patterns and better understand changing conditions and processes. Data collection will be maintained at a lower level in between individual IS assessments. Continuous data collected at the streamgages will include flow, turbidity, conductivity, and dissolved oxygen, whereas samples for analysis of nutrients (nitrogen, phosphorus, and carbon) and suspended-sediment concentrations will be collected approximately monthly to calculate nutrient and suspended-sediment mass balances in each of the paired IS watersheds. The amount and type of data collection may vary according to region-specific factors affecting nutrient and sediment transport and ecosystem processes.

The effect of groundwater on nutrient transport and transformations will be characterized by data from a network of FPS wells in each IS watershed that will be used to determine the quantity and age of groundwater and the quantity and rate of nutrient transport from groundwater to surface water. The FPS will be complemented by in-stream 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 watersheds nested within the IWS area as input for the development of local groundwater-flow models.

In-stream studies to address nutrient transformations and ecological processes include sediment denitrification experiments; biogeochemical cycling of nitrogen, phosphorus, and carbon; stream metabolism; and other process-related measures. Several methods will be used to study the interactions of nutrient processes and biota, including methods to assess primary and secondary production, trophic interactions, and the food quality of primary producers. The effect of nutrients on biological condition will be assessed using natural and artificial substrates. Although nutrients in the water column are an important part of this study of sediment and nutrient transport, nutrients in sediment also will be assessed because of their effect on macrophyte growth.

Studies to address sediment transport through IS and IWS watersheds will use retrospective data compilation and collection of new data on suspended-sediment concentrations and loads, stream stability and flood-plain deposition, and analysis of sediment sources. Retrospective and geographic information-system data will be used to categorize stream segments in relation to natural factors that affect sediment transport processes (for example, slope, valley type, sinuosity, soils, and geology). Historical aerial photography and changes in stream geometry (at existing USGS streamgages or other historical survey locations) will be analyzed to better understand how historical land-use practices and climate may have affected sediment loading and stream-channel migration. Concentrations of suspended sediment in water samples collected periodically at streamgages will be related to continuous measurements of turbidity to produce hourly (or more frequent) 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 (Gellis and Walling, 2011) .

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

Planned Outcomes

The following are planned outcomes from the Intensive Study (IS) assessments:

- 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 change; and
- Develop a methodology for assessing the vulnerability of streams to legacy sources using the process-based understanding of nutrient transport.

Groundwater Studies

In Cycle 3, NAWQA will focus on groundwater resources needed for public and domestic drinking supply and on groundwater contributions to surface water. Evaluating the vulnerability 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 man-made 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 characteristics of groundwater-flow systems over a range of nested, spatial scales (local to regional to principal aquifer scales; fig. 21). These studies will incorporate data previously collected by NAWQA and others, provide for collection of new data as needed, use quantitative groundwater flow and transport modeling, and use statistical relations between groundwater quality and hydrogeologic characteristics. Groundwater-flow 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.

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.

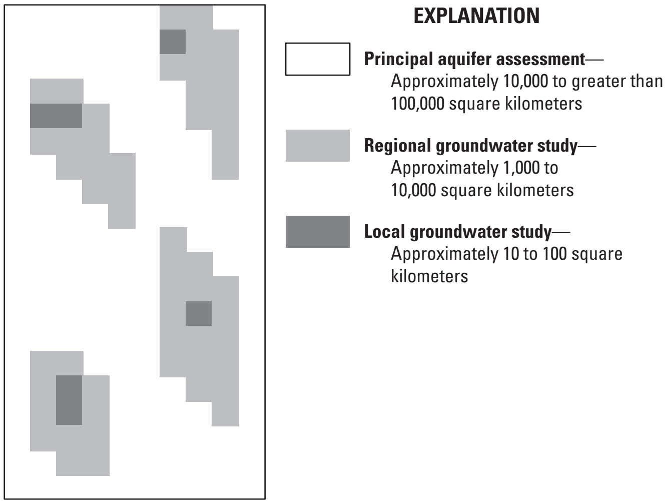


Figure 21. Nested spatial scales for Cycle 3 groundwater studies. Principal aquifers (or groupings of principal aquifers) will be the primary organizational unit, with regional groundwater studies and local groundwater studies conducted within the principal aquifers.

- ***Interactions of groundwater and surface water:*** How do groundwater contributions to surface water affect stream-water quality? Groundwater can be a substantial 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 variability of groundwater flow in aquifers, the external factors affecting aquifers, and the internal characteristics of studied aquifers. External factors include hydrologic and contaminant inputs. Internal characteristics include physical properties, aqueous-phase chemical properties, and mineral composition. Models are a key part of this approach. Four levels of model sophistication will be used. For each level of sophistication, field data will 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 at regional and national scales. An important aspect of those models is incorporation of spatially distributed explanatory factors. In Cycle 3, regression/geospatial models also will 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. This in turn will require development of straightforward methods for estimating hydrologic position and residence time.

- ***Groundwater-flow and particle-tracking models:*** These models will be based, to a large extent, on models previously developed by NAWQA and the USGS Groundwater Resources Program. The models will provide estimates of hydrologic position and residence time.

- ***Groundwater-flow and solute-transport models:*** These models can directly simulate the transport and transformation of contaminants of concern, such as salinity, or simulate factors that affect groundwater quality such as redox conditions.

- ***Simulation models of groundwater flow and reactive transport:*** The reactive-transport component could be simplistic, whereby sets of reactions are treated 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 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 (for example, redox state and pH), tracers of groundwater age (residence time), and surrogates for contaminant source (for example, land use and fertilizer application history). Process-simulation models will include one-dimensional vadose zone transport using the Process-based Groundwater Vulnerability Assessment model (P-GWAVA; Nolan and Hitt, 2006), groundwater flow with particle tracking using the Modular Groundwater Flow Model (MODFLOW) and the related particle-tracking model MODPATH (Harbaugh, 2005; and Pollock, 2012), solute-transport using the Method of Characteristics Solute Transport Model (MOC3D; Konikow and others, 1996) and the Modular 3-D Groundwater Solute Transport Model (MT3D; Zheng, 1990), dual-domain transport using the MT3DMS model (Zheng and Wang, 1999), which is the successor to MT3D, 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 important water-supply aquifers found throughout the Nation. At each location, the scale will range from local (approximately 10–100 km^2) to regional (MAS assessments; approximately 1,000–10,000 km^2) to principal aquifer and groupings of principal aquifers (PAS assessements and PAA studies, approximately 10,000 to greater than 100,000 km^2) (fig. 21);

- Develop 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 will be developed at all scales except national. 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 contaminants of human and (or) natural origin at the depth interval used for domestic supply and at the depth interval used for public supply. The maps will be developed using regression/geospatial and process-simulation models at local, regional, and principal-aquifer scales. Multiple maps will 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 can provide a measure of the uncertainty introduced with representing groundwater-flow systems at decreasing levels of resolution and can be used to evaluate the limitations of using regression/geospatial models for exceedance mapping while also providing more quantitative estimates of error and the reliability of predicted exceedance values.

- 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; and

- 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, NAWQA will use local and regional scale models in Cycle 3 to address the issue of how groundwater contamination affects surface-water quality. Local Groundwater Study (LGS) assessments will be implemented along groundwater flow paths that terminate at streams; the scale of these studies likely will range from 1 to 10 km. The primary goal of these LGS assessments 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 Study (RGS) assessments 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. Model-derived groundwater volumes can be combined with estimated contaminant concentrations to estimate contaminant loads. Resulting estimates of groundwater-derived contributions to streams at local or regional scales can be input into other watershed regression/geospatial and process models being developed to examine contaminant loads in streams and rivers, such as SPARROW.

Planned Outcomes

In Cycle 3, NAWQA groundwater studies will provide:

- Exceedance maps (fig. 16) for selected human and natural 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. 22). Exceedance maps will indicate the likelihood of detecting concentrations relative to human-health benchmarks such as MCLs or HBSLs. The maps would be developed at a coarse resolution for the Nation and at finer scales of resolution for selected local areas and principal aquifers. The maps will incorporate existing and newly acquired water-quality data and will be generated by models developed for this purpose. Resource managers and planners will be provided with (1) information on the extent to which groundwater might or might not be available to meet the demands of current and growing populations and (2) a context for understanding how groundwater quality in their area compares to water quality in other areas;

- Systematic approaches and modeling tools for evaluating groundwater quality from a hydrogeologic-systems perspective. These approaches and tools will be applicable at multiple scales; will use 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 time and space perspective, but also from a "parameter-space" perspective in which variation in key groundwater system properties ("parameters") along a flow system (such as lateral hydrologic position, depth, groundwater age, mineralogy, redox, or pH) would be related to groundwater quality. Local and regional agencies will be able to use these approaches and tools to develop exceedance maps within their areas; and

- 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.

Critical Requirements for Technical Support and Data Support

All activities in Goal 2 have the objective of understanding the relation between water-quality and current and historical human activities and natural factors that determine the observed water-quality. This can be achieved only

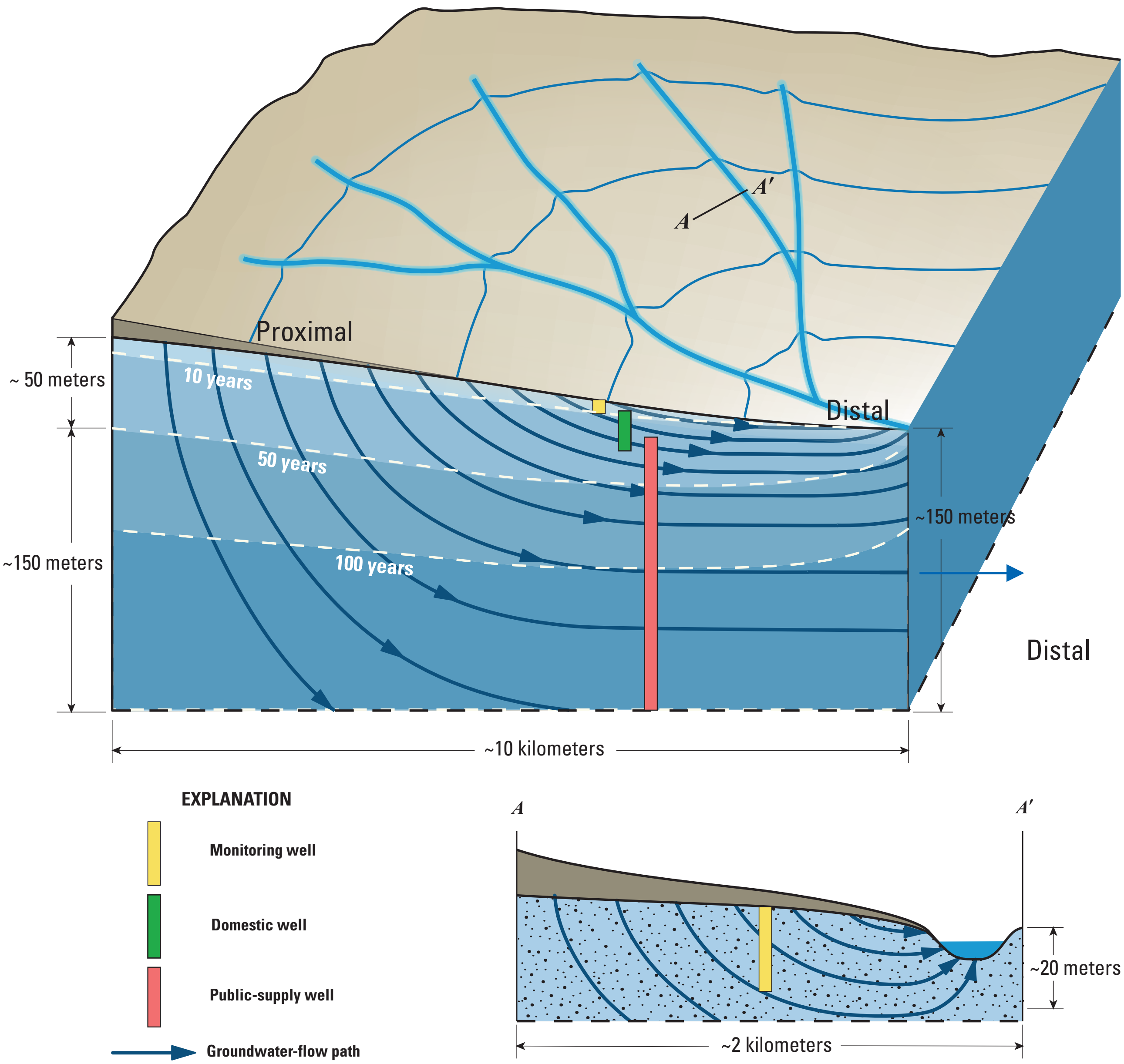


Figure 22. Three-dimensional representation of a groundwater-flow system illustrating the depth intervals sampled by monitoring, domestic, and public-supply wells; flow-path studies, and groundwater ages; and proximal and distal regions of the aquifer. The hydrologic systems approach described in the text involves sampling the aquifer at key locations along the flow system, from recharge to discharge areas (proximal to distal) and with depth (shallow to deep) to better characterize how groundwater quality changes with flow and increased residence time. Inset at lower right illustrates small-scale flow-path study along transect A-A′. (~, approximately)

if the spatial and temporal datasets describing the effects 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 important opportunities for scientific collaboration on study design, sampling and analytical methods, advances in data analysis, and modeling applications. The following section highlights current or desired partnerships that are important to achieving the Goal 2 objectives outlined for Cycle 3.

USGS Mission Areas and Programs

The following USGS mission areas and programs are potential partners for Goal 2 of Cycle 3:

- ***Climate and Land Use Change Mission Area:*** Research studies conducted under Goal 2 objectives support the USGS Global Change Science Strategy (Burkett and others, 2011) in assessing how climate change and land use affect the four stressors. Findings regarding how climate and land use affect hydrologic processes, which in turn directly affect stressors, also support efforts to develop mechanistic and process-based models and 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 Mission Area:*** RSS, IWS, IS, and LGS assessments will be conducted at scales conducive for partnering with the Toxic Substances Hydrology Program, in order to improve understanding of contaminant transport and transformation in watersheds and aquifers.
- ***Ecosystems Mission Area:*** The IWS and IS assessments will provide scientific infrastructure for leveraging additional research on how aquatic ecosystems respond to important stressors with the following Ecosystem Mission Area Programs (*http://www.usgs.gov/ecosystems/*): (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 Mission Area:*** 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.
- ***WaterSMART Program***: The “follow-the-water” design of the IWS assessments also is compatible with the “focus area study” concept of the WaterSMART Program. Opportunities also exist for NAWQA and WaterSMART to conduct joint collaborative work on ecologic flow requirements.
- ***Groundwater Resource Program***: 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. Plans are being developed to couple GWRP flow models with NAWQA water-quality data to develop groundwater-availability estimates that combine information on groundwater quantity and quality. Coupling water-quality models with flow models can be used to evaluate how groundwater quality may change in response to natural and human stresses.

External Partnerships

The following external agencies and organizations are potential partners for Goal 2 of Cycle 3:

- ***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 the sources of nutrients and sediment delivered to receiving waters and predict temporal or spatial changes in nutrient or sediment delivery in response to changing environmental conditions. A secondary goal is to link models that have been constructed at different scales. The focus of collaboration would be to link other agency data and models to NAWQA models developed as part of the IWS assessments, as well as to 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; *http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/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 assessments. The goal of partnering would be to compare modeling approaches, reduce uncertainty in model results, and provide improved estimates of the effectiveness of past and current management practices at a range of scales; and

- ***National Science Foundation National Ecological Observatory Network Program***: Assess how biological processes affect the transport of nutrients to stream ecosystems. The STReam Experimental and Observatory Network (STREON; *http://www.neoninc.org/science/experiments*) 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. The desired outcome of this partnership is co-location of STREON and NAWQA nutrient studies in one or more IWS watersheds.

Goal 3—Determine the Relative Effects, Mechanisms of Activity, and Management Implications of Multiple Stressors in Aquatic Ecosystems

Goal 3 Outcome: Improve understanding of the effects of (1) multiple stressors on stream ecosystems and how stressors act, alone or in combination, interact to cause degradation and (2) how management practices can be used to reduce the effects of stressors.

Products

The following are planned products for Goal 3:

1. Journal articles on individual stressors, combined effects of stressors, and the effect of management practices;
2. Regional- or national-scale map products that show where predicted contaminant, nutrient, or sediment concentrations (or the degree of streamflow alteration) are at levels capable of adversely affecting aquatic biota or stream ecosystems (for example, fig. 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 effects of land use and management practices on the interaction of key environmental stressors and how these stressors affect stream ecosystem condition.

Connections to other NAWQA Cycle 3 Goals

Goal 3 builds on 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 that primarily focus on stressor conditions, and Goal 2 builds on Goal 1 by linking water-quality stressors to the human and natural factors that affect water quality. 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 regional-scale 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 ecosystem condition.

Background

Incorporating knowledge of an ecosystem's 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 incorporate biological endpoints into their water-quality programs to assess current condition and to track changes due to management practices. Second, biological processes are key determinants of water-quality conditions in that they can affect both the chemical and physical quality of surface waters. For example, initial increases of nutrients commonly cause an increase in plant production; however, as plant biomass increases it begins to reduce nutrient concentrations and loads due to uptake, while also affecting in-stream habitat (Munn and others, 2010). When stream habitat is altered such that the ecosystem doesn't function normally, nutrients will remain elevated in the water column and be transported to downstream receiving waters (Duff and others, 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 affect these interactions. Regional-scale models that can describe and predict the effect of these interactions are needed by agencies tasked with managing local water resources. However, accurately simulating interactions among multiple factors, stressors, and ecosystem endpoints represent a substantial challenge to the development of reliable models in Cycle 3.

Several unique challenges are faced when assessing the relative importance 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 stressors 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 some are natural contaminants (for example, trace elements), most are derived from human activities and have the potential to directly affect aquatic life through toxic or endocrine-disrupting effects. Hence it is important to know when an individual stressor or combination of stressors causes the initial decrease in biological condition (for example, threshold) and at what point ecosystem condition moves through identified categories of concern (fig. 23). These types of analyses are currently 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 of 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 to address the five objectives described in the following sections for Goal 3.

Objective 3a. Determine the Effects of Contaminants on Degradation of Stream Ecosystems, Determine 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 concentrations 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.

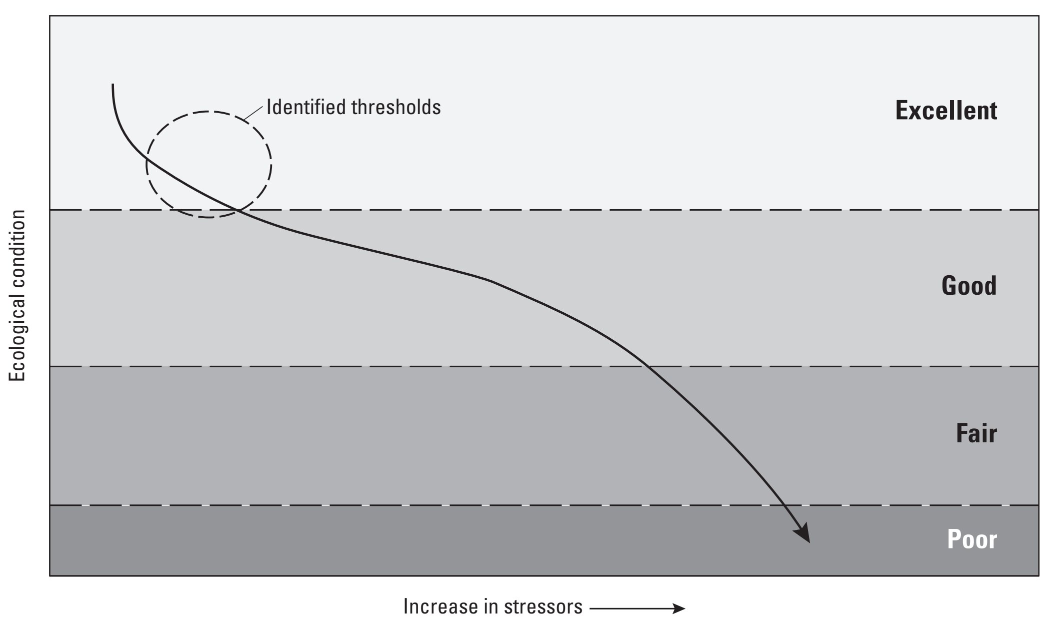


Figure 23. Schematic diagram showing the decrease in biological condition as stressors increase.

Objective 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

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 excess nutrients can lead to eutrophication, with its associated effects of low dissolved oxygen, increased macrophyte plant growth, and harmful algal blooms. However, general information is lacking on what indicators provide an early warning of nutrient enrichment and on 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 also will be integrated with the nutrient process component of Goal 2, which evaluates how biological processes affect nutrient cycling and loads. Nutrient-enrichment indicators also will be included in the predictive models as response variables to enrichment.

Objective 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

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 affected (for example, dose-response). Monitoring and studies for Goals 1 and 2 will be used to characterize how legacy and ongoing activities have altered the movement of sediment in streams, but additional 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 3d. Determine the Effects of Streamflow Alteration on Stream Ecosystems and the Physical and Chemical Mechanisms by Which Streamflow Alteration Causes Degradation.

Assessment of streamflow conditions has always been an important part of the NAWQA Program, particularly in relation to contaminant and nutrient transport. The effect of streamflow alteration on biological condition at a regional and national scale will be assessed in Cycle 3 by analyzing data from USGS streamgages across the Nation and data from multiple programs, including NAWQA, USEPA, and states. Objective 3d will be addressed using a multi-regional implementation of an established framework for evaluating the Ecological Limits of Hydrologic Alteration (ELOHA; Poff and others, 2010). The ELOHA framework provides a consistent and scientifically recognized approach to understanding the relations 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 3e. Evaluate the Relative Effects of Multiple Stressors on Stream Ecosystems in Different Regions that are Under Varying Land Uses and Management Practices.

The four individual stressor objectives (Obejctives 3a–3d) provide the building blocks for assessing multiple stressors and developing regional-scale 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 spatially and temporally at key locations (such as through paired IS assessments 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 stressors 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 Objective 3e will be by use of statistical modeling; several different approaches will be used to identify the relative effects of different stressors on specific measures of ecosystem condition and to relate the magnitude of the stressor effect on ecosystem condition to land use, management practices, or natural factors.

Policy and Stakeholder Concerns Driving Key Management Questions

Although the ultimate motivation guiding management questions is to protect and improve the quality of aquatic ecosystems, management strategies focus on the control of stressors, Thus, stakeholder concerns are commonly 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 such as nutrients, sediment, or metals.

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 (hypoxia), loss of fish habitat, release of toxic metals from sediments, and increases in the availability of substances like ammonia. Nutrients also are associated with the occurrence of harmful algal blooms, which can produce toxins that negatively 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 (Bricker and others, 1999; Diaz and Rosenberg, 2008; Rockstrom and others, 2009).

The 2004 Clean Water Act 305(b) report (*http://water.epa.gov/lawsregs/guidance/cwa/305b/2004report_index.cfm*) lists sediment as the seventh leading cause of impairment to streams and rivers in the United States. Sediment is related to the six other leading causes of stream impairment in that (1) sediment transports pathogens, organic matter, nutrients, and metals (the first, third, fifth, and sixth most reported impairments, respectively), 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 effects of sediment transport, suspended sediments are a primary transport mechanism for phosphorus, trace elements, and a variety of hydrophobic organic contaminants (Horowitz, 1991; Rasmussen and Ziegler; 2003, VanMetre and Mahler, 2005). Altered sediment transport also is a known or suspected cause of habitat degradation to endangered mussel, fish, and bird species.

A national assessment of streamflow alteration found that about 86 percent of monitored sites experienced altered magnitudes of minimum flows, maximum flows, or flow variability (Carlisle and others, 2010b). Abundant indirect evidence indicates that physical habitat alteration is commonly the ultimate cause of ecological impairment. Indeed, at least one-third of ecologically impaired rivers and streams (as designated by state assessments) across the Nation are affected by modified physical habitat, water temperature, and streamflow (U.S. Environmental Protection Agency, 2008). In addition, more than one-half of impaired rivers and streams are affected by excessive sediment and nutrients and oxygen depletion (U.S. Environmental Protection Agency, 2008), which are commonly 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 importance in affecting aquatic ecosystems. Without an understanding of the effects 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, understanding related ecosystem services, and developing predictive models that relate stressors to effects are 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 stream ecosystem condition, and which are most important to control?
- Which management strategies will most effectively improve and protect stream ecosystem condition?
- What ecological measures are most appropriate as early warning indicators for assessing stream 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 stream 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

Most of work in Cycle 1 focused on characterizing the occurrence and distribution of nutrients and contaminants (mainly pesticides) in the Nation’s streams. Ecological studies included assessment of the condition 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 (for example, spring runoff). The degree to which a specific biological study integrated water chemistry 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 as 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 effort to develop regional and national statistical models. The first topical study, called Effects of Urbanization on Stream Ecosystems (EUSE, *http://water.usgs.gov/nawqa/urban/*), 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 (Coles and others, 2012).

The Effects of Nutrient Enrichment on Stream Ecosystems topical study, examined the effects of nutrients on the aquatic communities in agricultural streams (*http://wa.water.usgs.gov/neet/*). This study found that (1) concentrations of nitrogen and phosphorus in agricultural streams commonly exceed proposed USEPA Regional Nutrient Criteria (U.S. Environmental Protection Agency, 2002) and thus indicate potential eutrophication, yet algal biomass commonly is less than expected due to habitat alterations; (2) benthic algae show a more rapid initial response to increases of nutrients than do macroinvertebrates or fish, and overall benthic algae 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 substantially 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 (see MRB in fig. 3), and at the national scale as part of ecological synthesis. A brief summary of each effort is presented below.

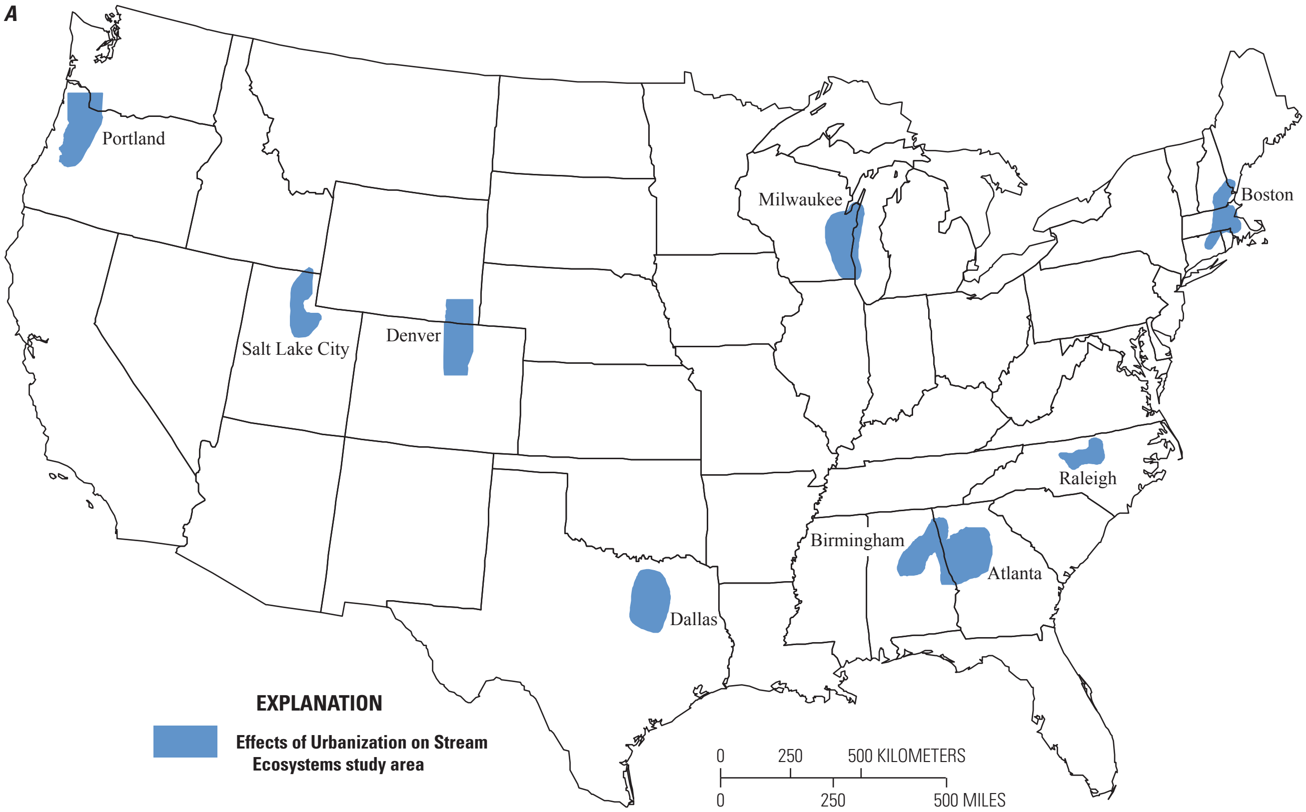
- ***Urban modeling:*** The EUSE topical study (*http://water.usgs.gov/nawqa/urban/*) has been involved in several ecological modeling activities. Bryant and Carlisle (2012) used regression approaches to identify multiple stressor models for predicting condition of algae, invertebrates, and fish communities and how responses differ among varying urban areas (fig. 24). Qian and others (2010), Cuffney and others (2011), 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 (2012) used a Bayesian network modeling approach to link watershed and reach-scale stressors with biological condition.

- ***Nutrients in agricultural streams:*** The NEET topical study focused on the use of structural equation modeling for examining the relations between land-use activities, riparian characteristics, nutrients, and in-stream biological conditions. Structural equation modeling was used to develop a set of causal models and examine the direct, indirect, and total effects of agriculture on biological integrity acting through different nutrient and habitat pathways (Riseng and others, 2011). The structural equation modeling was done using 226 sites distributed across eight NAWQA study units (fig. 25A). The national model (fig. 25B) provided an integrated view of the relations between crop cover (basin percent cropland), riparian cover (buffer percent of wetland), and biological integrity (invertebrate community quality). 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 relations between land use, nutrients and biota, as well as a tool for assessing the effects of land use/riparian management on water quality and biological integrity. Regional models (West, Midwest, and East) were also developed that 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 affect biological conditions.

- ***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 and others (2010) used a variety of multivariate statistical analyses 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 affect stream biota. Waite and others (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 the "best" multiple linear regression models for a region and that all models required a combination of land use and natural explanatory variables.

- ***National-scale streamflow:*** A recent study by Carlisle and others (2010b) found that human effects on hydrology are widespread, with as much as 86 percent of streams having altered flow patterns (fig. 26). Results showed that diminished flow magnitudes were the primary predictors of macroinvertebrate and fish condition with the streams. Annual and seasonal cycles of water flows—particularly the low

A



B

Factor	Metropolitan Study Area					
	Portland	Atlanta	Raleigh	Denver	Dallas	Milwaukee
High flow duration			Invertebrates	Invertebrates	Algae	Fish
High flow magnitude			Fish	Invertebrates, Fish	Fish	Algae
High flow frequency				Fish	Algae, Fish	
Water temperature	Invertebrates	Invertebrates	Fish	Invertebrates	Algae, Fish	Algae, Invertebrates, Fish
Width:depth ratio				Invertebrates, Fish	Algae	Algae, Fish
Sand/silt in streambed	Fish	Algae	Fish	Algae, Invertebrates	Algae, Invertebrates	Algae, Fish
Chloride	Algae		Algae, Fish	Invertebrates, Fish	Algae	Algae
Phosphorus	Algae	Algae, Invertebrates	Algae	Algae, Invertebrates, Fish	Algae	
Nitrogen		Fish		Algae, Invertebrates	Algae, Invertebrates	Algae, Fish
Dissolved pesticides[1]	Invertebrates			Fish		Invertebrates
HOC toxicity[2]	Invertebrates, Fish	Invertebrates, Fish	Invertebrates	Fish		Fish

EXPLANATION

Algae

Invertebrates

Fish

[1]Pesticide Toxicity Index for cladocerans, which combines information on exposure of aquatic biota to pesticides (measured concentrations of pesticides in streamwater) with toxicity estimates (results from laboratory toxicity studies) to produce a relative index value for a sample.

[2]Toxicity of hydrophobic organic compounds (HOC) based on the p450 bioassay, which is a measure of the activity of an enzyme system important in detoxifying some contaminants.

Figure 24. *A*, Location of Effects of Urbanization on Stream Ecosystems study areas and *B*, results of multiple regression modeling for identifying effects of multiple stressors on algae, invertebrate, and fish communities in six metropolitan study areas (Bryant and Carlisle, 2012). This figure indicates which of the three taxa (algae, invertebrates, or fish) respond to varying stressors in different urban settings.

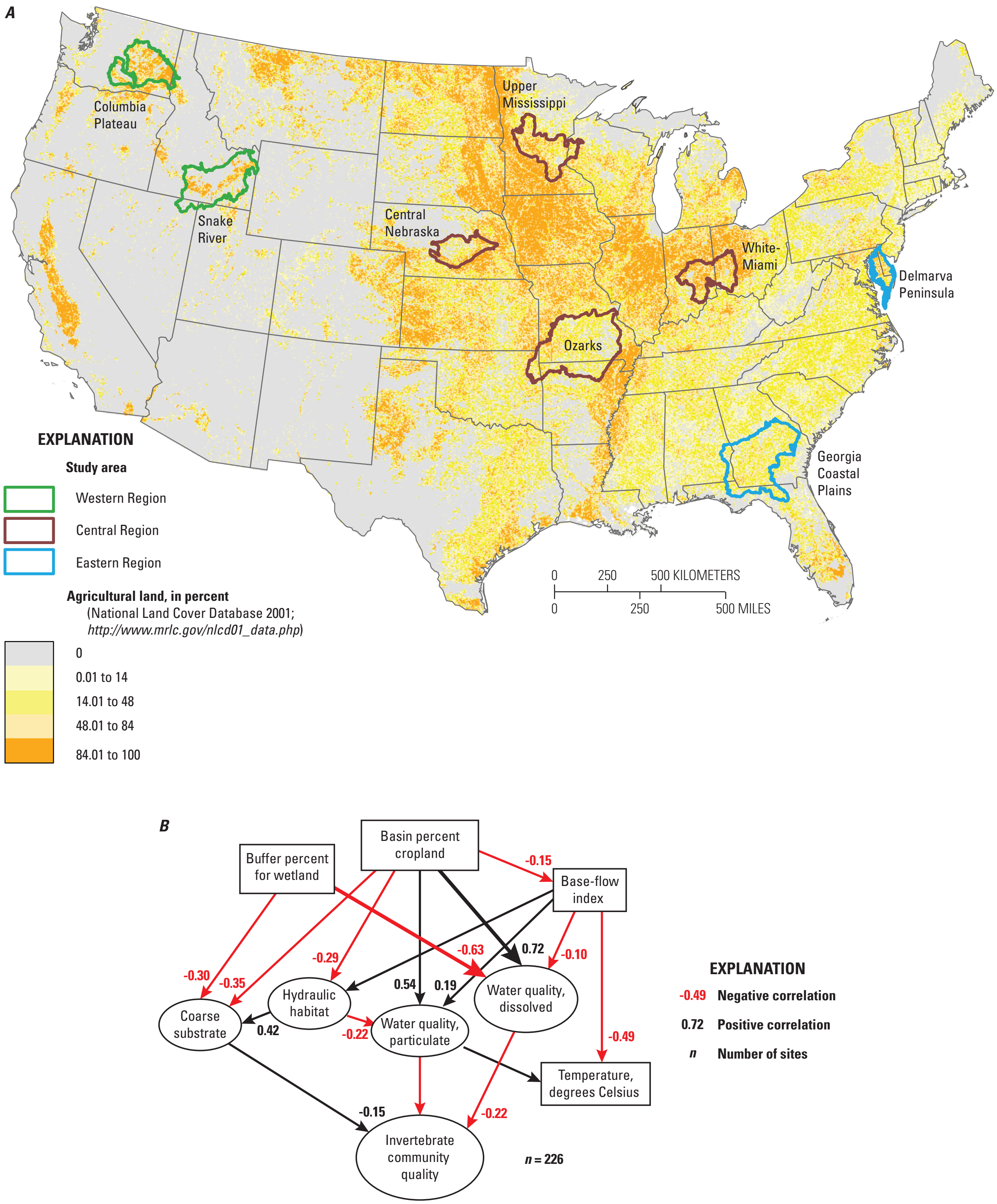


Figure 25. *A*, Location of the eight agriculturally dominated NAWQA study units included in the Effects of Nutrient Enrichment on Stream Ecosystems (NEET) topical study, and *B*, the national structural equation model developed from data collected at the eight study sites. Values between environmental variables are calculated correlations.

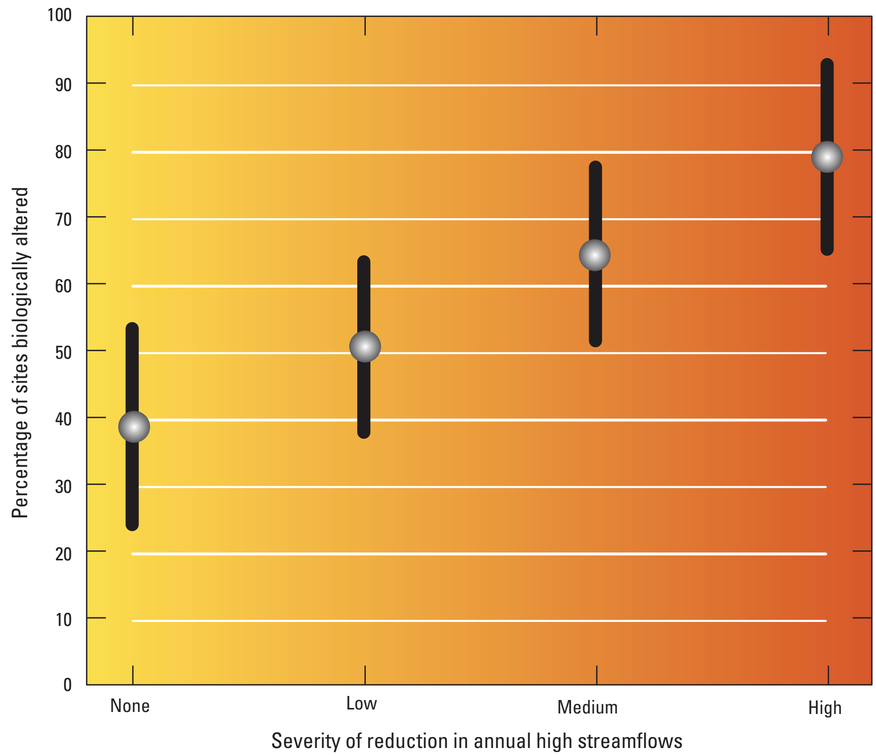


Figure 26. Relation between percent reduction in in-stream flow and the percentage of stream sites with impaired fish communities (from Carlisle and others, 2010b). The graph shows a positive correlation between increases in percent reduction of flow and the number of streams with impaired fish communities. This study provides an example 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.

and high flows—affect 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 flood plains and flush out accumulated sediment that can degrade habitat.

NAWQA's Role in Cycle 3

Although NAWQA, USEPA, States, and universities have made large gains in understanding the effects of individual stressors on ecological systems, they continue to lack understanding of which stressors are most detrimental under different conditions, the interactions and effect mechanisms of the stressors, and the effectiveness of various management practices in reducing the 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 affect ecosystem condition.

Approach

Goal 3 objectives will be addressed using a combination of IS, IWS, and RSS assessments. Findings from Goal 3 will provide the needed information for explaining the ecological status and trends in Goal 1 and the effect of the four stressors on ecological processing in Goal 2. In combination, the IS and RSS assessments will provide the data and understanding needed to develop models for predicting the effect 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 human and natural factors. Therefore, Goal 3 will have a regional-based design using the five design elements described in the following subsections.

1. Identify Geographic Regions for Assessment and Modeling

Numerous strategies are available 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. Having 10–20 regions subdividing the conterminuous United States will be considered optimal. The process will start by examining the USEPA Level 2 Ecoregions (USEPA, 2010b; fig. 27) because those ecoregions encompass major geographic regions and because the Level 2 ecoregions have been shown to be one of the better geographic-based classification systems at larger scales. The regions will then be ranked based on several criteria, including representation of a variety of stressor conditions, number of reference sites, and containing a sufficient number of NFSN sites and having some overlap with IWS areas. Where possible, regions will be selected to take advantage of collaborative opportunities with other USGS programs and Federal, state, or academic studies (such as the STREON Program).

2. Develop Conceptual Model

Although 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. 28) will be developed for each region selected for study based on a combination of NAWQA findings from Cycles 1 and 2 and consultation with USEPA, state, and local experts. The conceptual model will incorporate factors (land use) and associated stressors (e.g., nutrient enrichment, temperatures, hydrologic regime), their interactions, and how they affect selected measures of biological condition. The actual measures of biological condition will vary depending on the stressors examined. The development of a conceptual model 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. In addition to being important for the overall design of a study, the conceptual model also will be used as the starting place for the development and testing of a predictive model. For example, some modeling approaches, like structural equation modeling, require that a conceptual model be developed in order to test the hypothesis on which the model is based.

3. Intensive Studies

Once a region is selected and a conceptual model is developed, the next step will be select an IS watershed. The IS assessments are the smallest scale study in Cycle 3 (figs. 17 and 18) and will be nested within an IWS watershed, which is the primary scale for studies addressing Goal 2. The primary purpose of the IS assessments 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 assessments are a critical first step in designing regional-based studies for the development of predictive models. The time period for IS assessments may vary depending on the specific questions being addressed. For Goal 3, some of these IS assessments will continue for 1–3 years to address specific stressor and methods questions, whereas for other questions, as in Goal 2, the IS assessment may continue for longer periods (5–10 yr). The IS sites for Goal 3 will be selected to represent a variety of stressor conditions. The types of IS assessments 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 assessments have two critical roles that are not addressed by other design components:

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

4. Regional Synoptic Studies

The RSS assessments, which are the third largest study scale in Cycle 3 (fig. 17), are the scale at which data will be collected 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 IS 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 few key measures for the regional assessment is important because regional-based ecological models commonly will 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 assessments prior to the collection of data and will vary depending on the region and modeling approach selected. Although the RSS assessments likely will be based on short-term synoptic studies, these assessments also may include some temporal sampling in order to assess how stressors affect biological endpoints over time. This will provide insight into how and to what extent individual stressors affect ecosystem condition and will also provide a more complete understanding about the relative and combined effect of the four stressors. Sites selected also will include a gradient of watershed management practices within a region, so that models developed can address the effects of various management practices on both stressor and ecosystem conditions.

5. Develop Ecologically-Based Predictive Models

Ultimately, a primary purpose of studies addressing Goal 3 objectives is to develop and test regional models for

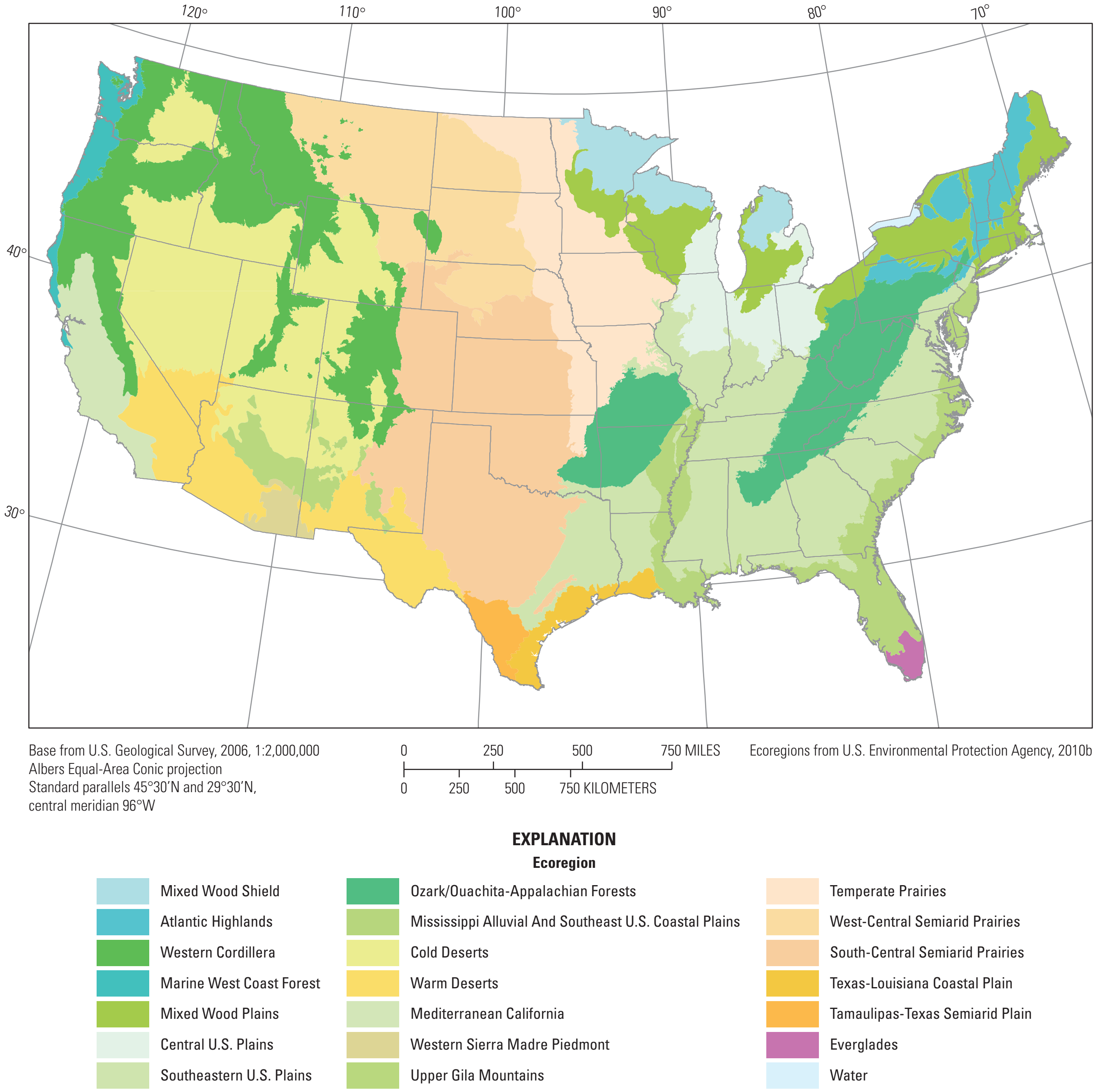


Figure 27. Map showing U.S. Environmental Protection Agency Level 2 Ecoregions (Commission for Environmental Cooperation, 2008). Ecoregion definitions are available at *http://www.epa.gov/wed/pages/ecoregions/na_eco.htm.*

predicting the effects of various stressors on ecosystem condition and to test scenarios of how changes in stressors, land use, climate, and management practices may affect 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. During Cycle 2, NAWQA made substantial progress using a variety of ecologically-based statistical models, including Bayesian network models in the EUSE topical study and structural equation models in the NEET topical study. These models improved understanding of ecological interactions in both urban and agricultural streams, and enhanced predictions of how biological communities are affected by land use and in-stream factors. The development and testing of ecological models is a planned outcome of Goal 3, and will be a critical part of Goal 4 efforts to develop forecasting models for prediction of ecosystem response.

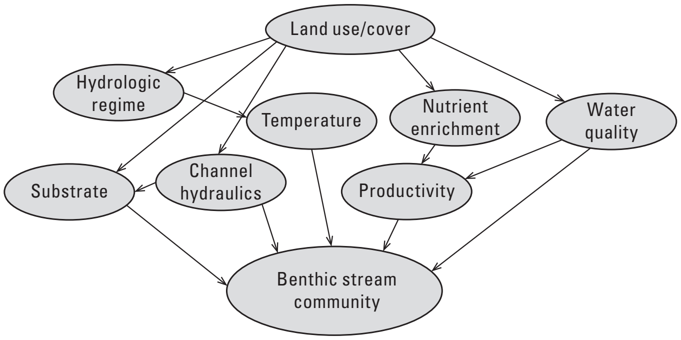


Figure 28. Example of a regional-scale conceptual model based on existing studies and expert knowledge that relates various environmental features and stressor characteristics to the condition of benthic stream communities.

Study Designs and Outcomes for Each Individual Stressor

Study designs and outcomes for Goal 3 are described relative to the four stressors affecting stream ecosystems: contaminants, nutrients, sediment, and streamflow alteration.

Contaminants

NAWQA has completed numerous studies on the occurrence and distribution of contaminants, including specialized studies of source, transport, and transformations in both Cycles 1 and 2. Contaminant studies have included trend assessments; transport to agricultural, urban, and reference streams; transport to groundwater; and transport to individual supply wells. Contaminant concentrations have been compared to concentration benchmarks to assess potential toxicity, with results indicating concentrations of potential concern are frequently exceeded in the environment, but no direct information suitable for evaluating cause-and-effect relations has been collected to date. In Cycle 3, NAWQA will more directly address the effects of contaminants on ecosystem condition.

Approach

Contaminants differ from other stressors in that they consist of a diverse array of inorganic and organic compounds of natural (trace elements) and human (pesticides and PAHs) origin that occur in various combinations depending on the environmental setting and time period. Furthermore, contaminants can cause a variety 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 assessments, each described previously in this section, is an ideal approach for addressing several contaminant-related stressor issues. Potential causes of contaminant effects include a variety of factors, such as contaminants from different sources, mixtures of contaminants, or effects caused by a specific individual contaminant. Effects of these factors can be shown through a variety of indicators, such as reduced species diversity or differences between reference and observed conditions. The use of several sites along a gradient of contaminant effects within an IS is a practical way to improve understanding of contaminant stressor effects relations.

The use of the IS assessments will aid clarification of several key elements of contaminant effects. First, IS assessments will provide an assessment of the types, concentrations, and timing of the various contaminants in each region. Second, based on improved understanding of the contaminants of concern, in-stream 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 affect natural communities. This information is needed before designing a RSS, because it will be important to know what contaminant-related measures are most appropriate for assessing biological condition. Contaminant indicator measures selected may vary depending on the specific features of the region. Once the contaminants effects indicators are selected, then an RSS assessment can be completed in order to develop a predictive model.

Planned Outcomes

The following are planned outcomes of Goal 3 studies of contaminants:

- Integrated laboratory and field methods for assessing potential toxicity of contaminants to aquatic organisms. Ecological measures could include some traditional approaches (for example, species-specific measures) and non-traditional measures of ecosystem function (for example, stream metabolism); and
- 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 three specific aspects of nutrient enrichment in streams 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. For example, the NEET topical study found that concentrations of nitrogen and phosphorus in agricultural streams commonly exceed proposed USEPA

Regional Nutrient Criteria (U.S. Environmental Protection Agency, 2002) and thus indicate potential eutrophication, yet algal biomass commonly is less than expected due to habitat alterations. 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, the 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 is growing. Third, a general lack of knowledge remains on how various management practices affect 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 previously in this section. 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 concentrations and habitat (for example, in-stream physical habitat and riparian), both of which can become major stressors to aquatic species.

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

Planned Outcomes

The following are planned outcomes of Goal 3 studies of nutrients:

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

Sediment

Assessment of sediment-related impairments to ecosystems is challenging because 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, 2006). Sediment-related effects can be divided into three categories: (1) those caused by changes in the concentrations of suspended sediment, (2) those caused by alteration of streambed substrates, and (3) those caused by bedload and suspended sediment which can alter the physical structure or morphology of the river. Suspended-sediment effects typically are 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). In streams with undisturbed flow, channel morphology is in equilibrium with streamflow, sediment (bedload and suspended sediment), and channel slope. Alterations of any of these parameters can lead to changes in channel morphology, which in turn, can affect the habitat of aquatic organisms living in the stream.

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 related to if and how sediment-related impairments may affect ecosystem condition. The IS assessments will focus on assessing and developing measurements of suspended and depositional sediment along with indicators of ecosystem condition that potentially are 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 (Pellerin and others, 2012). In regards 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 used by regional or national agencies, such as the relative bed stability index developed by USEPA (Kaufmann and others, 2008; Kaufmann and others, 2009). 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 and on 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.

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

Planned Outcomes

The following are planned outcomes of Goal 3 studies of sediment:

- 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; and
- Regional assessments of the importance of sediment-related impairments to aquatic ecosystems.

Streamflow Alteration

Although streamflow alteration has been of concern for many years, it has recently become a major focus of many agencies and environmental groups because of its importance in sustaining a healthy stream ecosystem (from a physical habitat perspective) and its overall effect on stream quality. The recent concern regarding 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 affects biological condition. Information that quantifies relations between severity of streamflow alteration and degree of biological impairment is critically needed by environmental policy makers and managers. In addition, the scientific literature points out large gaps in our knowledge of the mechanisms by which streamflow alteration affects aquatic ecosystems (Carlisle and others, 2010a and 2010b). Filling these information 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. More than 8,000 streamgages across the Nation have at least 20 yr of flow record, and about the same number of real-time streamgages currently (2012) are in operation. Drainage basins for these streamgages have been delineated, which allows for characterization of many watershed features, whether natural or affected by humans. This rich dataset has enabled the development of statistical models that predict the expected baseline (that is, 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 streamgage 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 Rivers and Streams Assessment (*http://water.epa.gov/type/rsl/monitoring/riverssurvey/index.cfm*), quantified physical and chemical habitat, along with biological condition, at almost 1,400 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 National Rivers and Streams Assessment sites to estimate streamflow-alteration metrics. These streamflow-alteration metrics will be combined with the data collected by the USEPA to assess relations among 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, and streamflow alteration) and biological condition over time at many long-term streamgages 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 USEPA Level 2 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 on the status of aquatic communities. Measurements of other stressors will be made to confirm that streamflow alteration effects have been isolated.

In addition to the three methods described above, which rely on statistical analyses, the effects of streamflow alteration on biological condition also will be addressed through intensive studies designed to assess the effects of contaminants, nutrients, and sediment. Including consideration of streamflow in IS will permit a better understanding of the mechanisms by which streamflow affects contaminants, nutrients, and sediment as stressors. Streamflow also can be assessed to determine what aspects of streamflow affect biological systems, including habitat features (for example, wetted perimeter), water temperature, and sediment effects (for example, scour). The IS assessments also will enable evaluation of how various streamflow metrics affect various biological endpoints. For example, it is important to understand the effects of streamflow alteration on plant biomass accrual and production, which form the overall types of communities that can reside in a stream. In the IS 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

The following are planned outcomes of Goal 3 studies of streamflow alteration:

- Predictions of the effects of streamflow alteration on biological condition; and
- Mechanisms of how streamflow alteration affects 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

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 (Coles and others, 2012). The EUSE study also yielded a multi-level hierarchical model that relates degree of urbanization and climatic variables to ecosystem condition (Kashuba and others, 2010). However, the EUSE study 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 effects 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. The example described in this section focuses on urban settings; however, Cycle 3 also will feature stressor studies conducted in agricultural settings.

Study Questions

The example urban study will address the following questions:

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

Approach

The example urban study will use the following 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 on the basis 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, North Carolina (N.C.), and Atlanta, Georgia (Ga.), because they occur within the same USEPA Level 3 Ecoregion.

Conceptual model: Modeling efforts by EUSE combined with additional information from other NAWQA studies, studies by other agencies, and local expertise will be used to construct a conceptual model of how land use affects the four stressors identified and how these stressors likely would affect specific indicators on ecosystem condition (fig. 29).

Intensive Study: Based on the conceptual model above, several Intensive Study (IS) sites could be selected; for example, within the Raleigh-Durham, N.C., urban area, where three streams draining low-, medium-, and high-density urban/surburban watersheds could be selected (fig. 30). These sites would be gaged and studied over a 1–3 yr period to assess what stressors are most important and what endpoints and methods will be most useful for a regional synoptic study. With respect to toxic contaminants, the IS sites will monitor a suite of ecologically important contaminants known or suspected to occur at urban sites to determine their concentrations, 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 (Munn and others, 2006) for water, and the Probable Effects Concentration Quotient (MacDonald and others, 2000) for sediment. Toxicity testing will be highly targeted and selective, using a variety of bioassay methods and other techniques based on 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.

Regional Synoptic Study: Results from the IS assessments will be used to design a RSS for which key variables of stressors and indicators of ecosystem condition will be collected. The RSS would include 50–100 sites across the identified metropolitan area(s) with data used to develop a regional-scale urban predictive model. Figure 31 shows an

USEPA Level 3 Ecoregion that encompasses two urban areas previously studied by NAWQA (Raleigh, North Carolina, and Atlanta, Georgia). The RSS sites will be established to capture gradients ofurbanization and dominant stressors identified for that region. Data and findings from the RSS will then be used in the development of a regional-based model.

Develop ecologically-based predictive models: 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. 32). For example, if it is known with 100-percent certainty that a stream is located in a watershed with 31–100 percent urban land cover, this model predicts that stream will have a 50-percent chance of having high flashiness (greater than four streamflow rises above the median flow in a year), about a 48-percent chance of having low generic richness (less than 15 total taxa), and slightly more than a 1-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 the model can be used to predict the likely values of all other nodes in the system.

This model can be used to evaluate the effects 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 affects key stressors and how biological condition is affected.

Agricultural Example

Along with urbanization, there is substantial interest in how agricultural management practices are affecting water quality and biological condition. This agricultural example focuses on agricultural lands and is based on ongoing NEET studies.

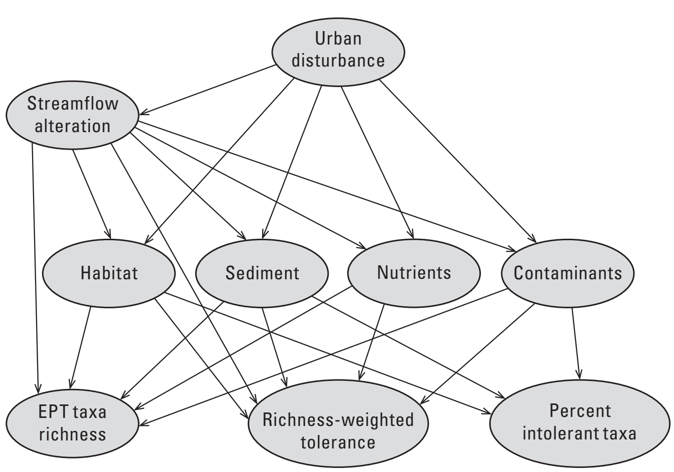


Figure 29. Hypothetical conceptual model showing the primary stressors that determine ecosystem condition in an urban stream ecosystem [EPT, Ephemeroptera sp.(mayfly), Plecoptera sp. (stonefly), and Trichopera sp. (caddisfly)].

Study Questions

The example agricultural study will address the following questions:

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

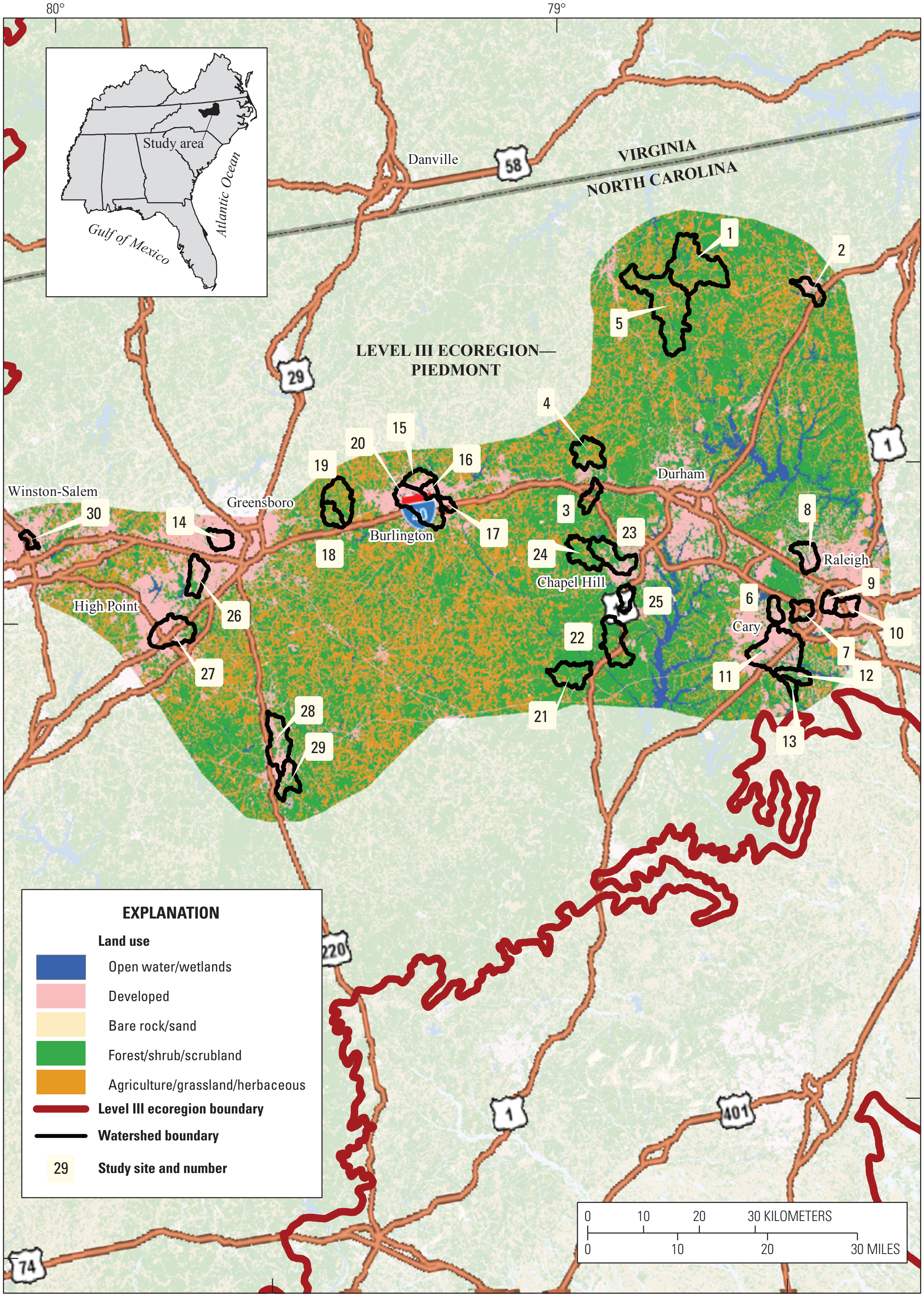
Approach

Development of conceptual model: Once a regional setting is selected, a conceptual model will be developed that provides a hypothesis of how stressors and management practices affect stream biota. This model can incorporate both human and natural factors, along with specific management practices. For the conceptual model for agricultural lands, emphasis will be placed on how land use and cover affect flow (hydrologic regime), substrate, and water chemistry, primarily nutrient enrichment (fig. 33). Specific contaminants, such as pesticides, could be added to this example if necessary.

Intensive and Regional Studies: As in the urban example, IS watersheds will be selected for assessment of the effects of the various stressors and to refine the selection of indicators for use in a regional study. Once this is completed, an RSS is initiated for which data are collected at multiple sites throughout the region. Data collected will include measures of key stressors and ecological endpoints that can be used for the development of a model.

Development of regional model: In contrast to the urban example, which relies on a Bayesian network model, this agricultural example illustrates the use of a structural equation model, which is used to develop a set of causal models and to examine the direct, indirect, and total effects of agriculture on biological integrity acting through different nutrient and habitat pathways (Riseng and others, 2011). For example, in the Coastal Plains ecosystem, cropland tends to be located on well-drained upland areas separated from streams by undisturbed riparian flood plain and wetland habitats resulting in lower nutrient concentrations in many of its streams. In the Coastal Plain structural equation model developed by Riseng and others (2011), riparian forested wetland had substantial positive effects on the invertebrate community by reducing dissolved nitrate, total phosphorus, and suspended sediment

Figure 30 (facing page). Study sites included in the Cycle 2 Effects of Urbanization on Stream Ecosystems (EUSE) study in the Raleigh-Durham metropolitan area in North Carolina. Hypothetical locations of three Intensive Study sites where detailed stressor studies would be conducted in watersheds with low, moderate, or high degrees of urbanization could include streams draining watersheds labeled numbers 1, 14, and 28, respectively.


80°
79°
36°
35°
Study area
Atlantic Ocean
Gulf of Mexico
Danville
VIRGINIA
NORTH CAROLINA
LEVEL III ECOREGION—
PIEDMONT
Winston-Salem
Greensboro
Burlington
Durham
Chapel Hill
Raleigh
Cary
High Point
EXPLANATION
Land use
Open water/wetlands
Developed
Bare rock/sand
Forest/shrub/scrubland
Agriculture/grassland/herbaceous
Level III ecoregion boundary
Watershed boundary
29 Study site and number
0 10 20 30 KILOMETERS
0 10 20 30 MILES

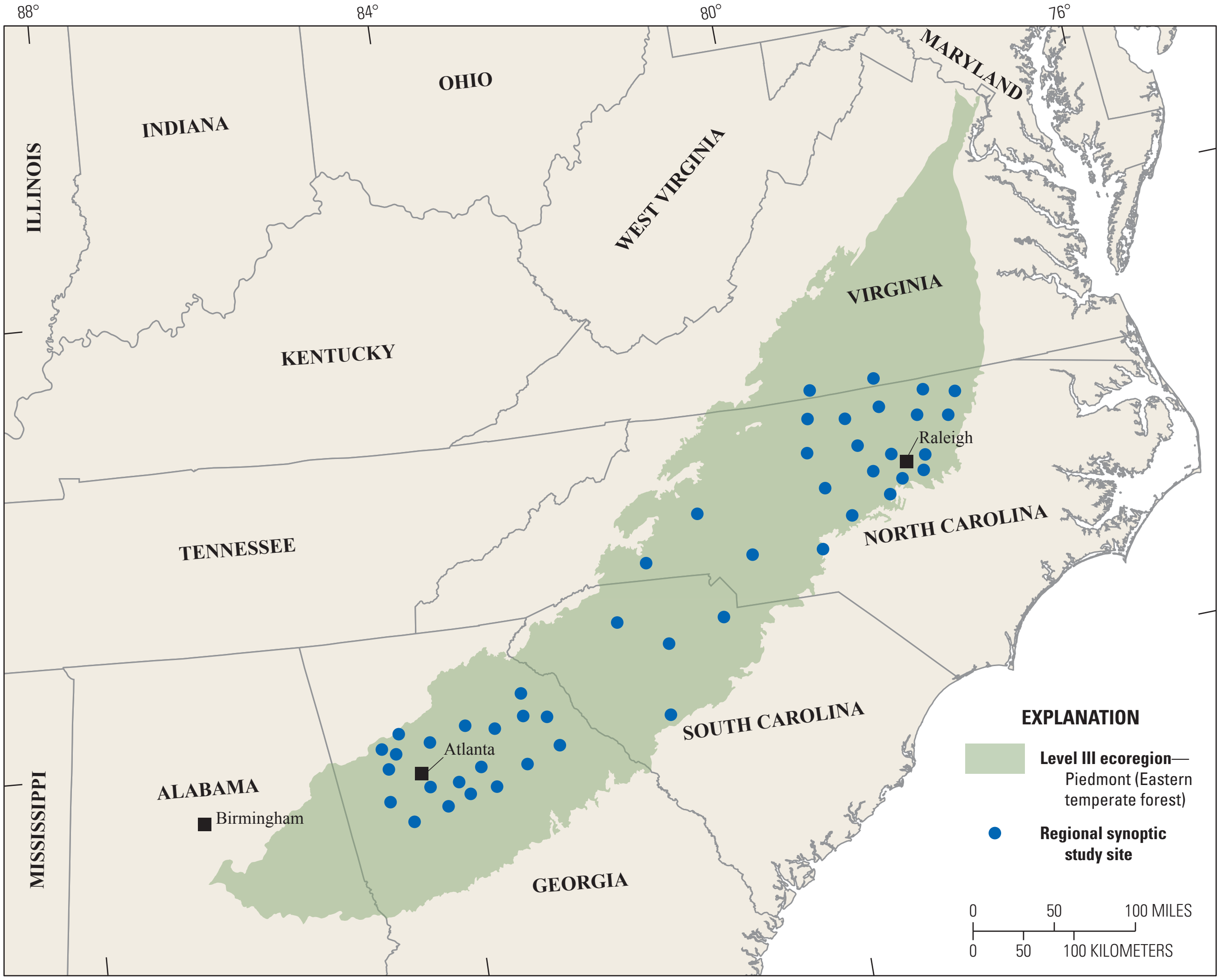


Figure 31. Regional Synoptic Study design for assessing key stressors and biological response.

concentrations and providing a coarse substrate habitat (woody debris) that far outweighed the negative effects of agriculture. The results indicated the importance of intact riparian flood plains and wetlands for maintaining biotic integrity in the Coastal Plains ecosystem (fig. 34).

This regional model can be used to evaluate the effects 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 affects biological condition.

Critical Requirements for Technical Support and Data Support

The following critical requirements for technical support and datasets are needed for Goal 3:

- ***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 earlier in this Section. 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, current (2012) protocols may need to be modified and updated for Cycle 3 (1) based on experience gained in Cycles 1 and 2 and (2) to facilitate the rapid collection of key variables from a large number of sites at the regional scale. Furthermore, some stressors, such as 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.

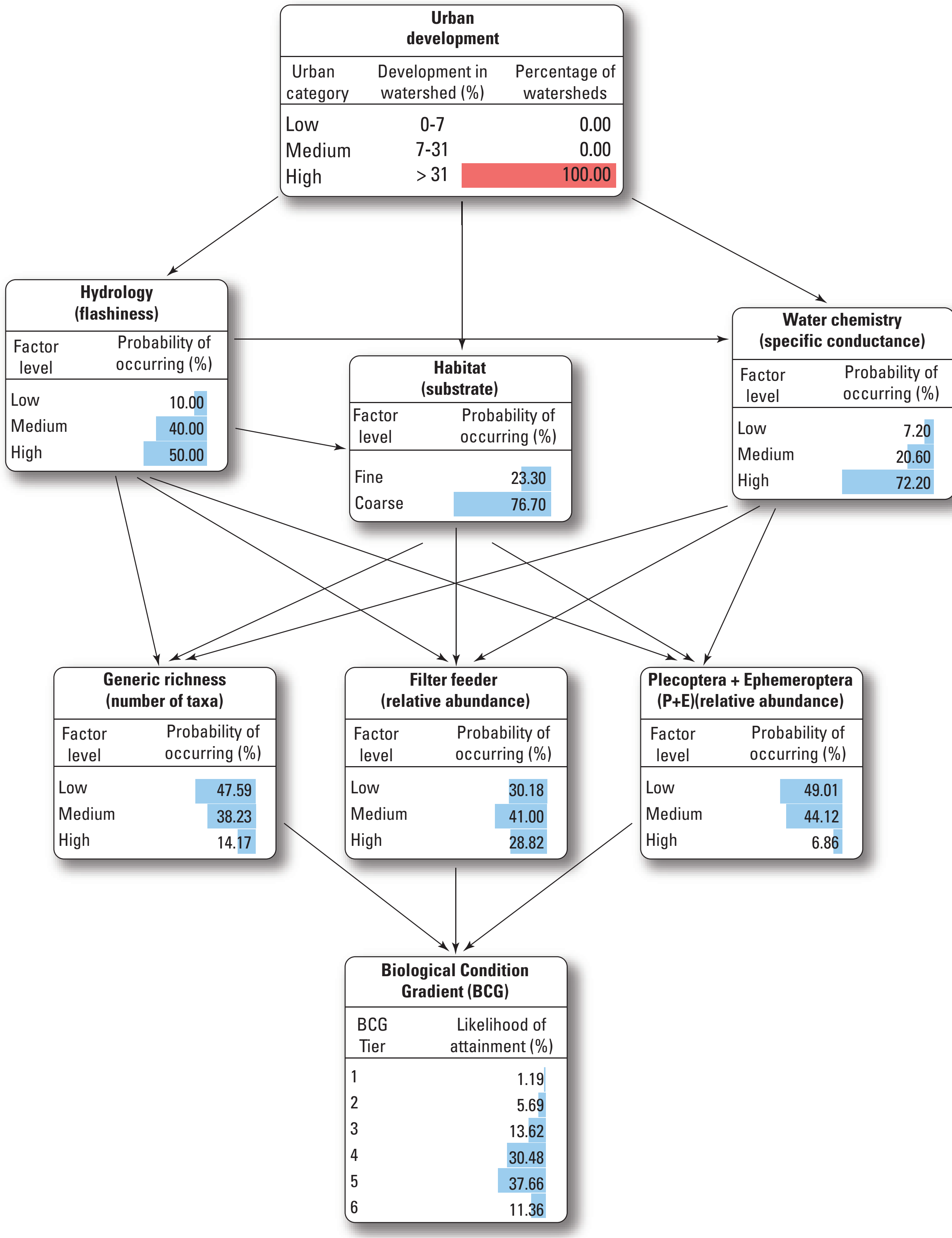


Figure 32. Example of a Bayesian network model showing the prior predictive probabilities that a stream would have properties associated with each of the categories for each model node under high urban development. Probabilities are represented as percentages, numerically and graphically (horizontal colored bars represent percent probability for each category, factor, or tier) (modified from Kashuba and others, 2012).

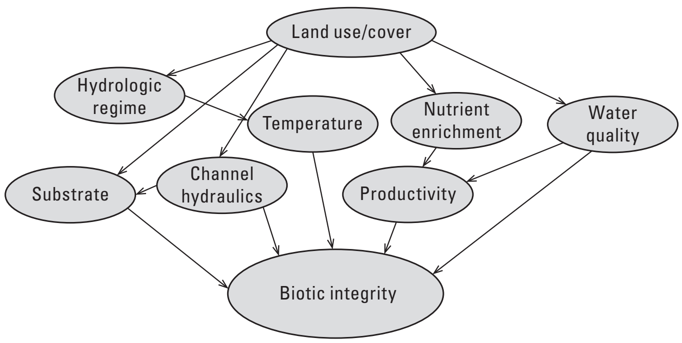


Figure 33. Conceptual model for testing the effects of land use, habitat, and nutrients on biological integrity in an agricultural setting.

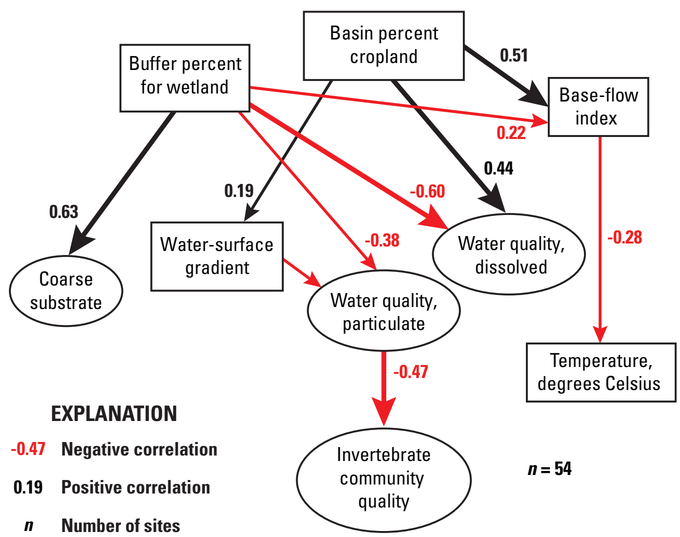


Figure 34. Example of a structural equation model of a coastal plain agricultural setting showing relations between land use (cropland, wetland buffer), habitat (substrate), water quality, and invertebrate community quality. Values shown are similar to correlation coefficients (modified from Riseng and others, 2011).

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. The following sections provide some specific examples of current or desired partnerships.

USGS Mission Areas

The following USGS mission areas and programs are potential partners for Goal 3 of Cycle 3:

- ***Energy and Minerals, and Environmental Health Mission Area:*** 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 on aquatic organisms using laboratory and field methods.

- ***Ecosystems Mission Area:*** Three programs within the Ecosystems Mission Area have potential for collaborative work with the NAWQA Program in Cycle 3. These programs are (1) Status and Trends of Biological Resources, (2) Terrestrial, Freshwater and Marine Environments (*http://ecosystems.usgs.gov/ecosystems/*), and (3) Fisheries: Aquatic and Endangered Resources. Additional discussions are planned to assess collaborative opportunities.

- ***Water Mission Area:*** 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 (NRP; *http://water.usgs.gov/nrp/*) 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 Mission Area:*** Activities within the Climate and Land Use Change Program (*http://www.usgs.gov/climate_landuse/*) are directly related to Cycle 3 NAWQA activities, especially mutual goals of assessing relations between land-use change and water-quality and biological conditions. Goals listed in the Climate and Land Use Change strategic science plan (Burkett and others, 2011) address how climate change will affect 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

The USEPA is a potential partner for Goal 3 as described in the following bullets:

- ***USEPA National Aquatic Resource Surveys and Office of Research and Development:*** NAWQA has a long history of working with the USEPA National River and Streams Assessment (*http://water.epa.gov/type/rsl/monitoring/riverssurvey/index.cfm*) and has collaboratively published with the USEPA on the biological condition of surface waters. This collaborative effort will continue in Cycle 3 in regards to all four of the stressors. NAWQA and USEPA are currently (2012) working on streamflow alteration as a major stressor of biological condition and on collaborating on the next USEPA National Aquatic Resource Survey of the Nation's streams and rivers scheduled for 2013.

- ***USEPA Causal Analysis/Diagnosis Decision Information System (CADDIS) Program:*** The CADDIS Program (*http://www.epa.gov/caddis/*) assists scientists and engineers in the regions, states, and tribes to conduct causal assessments in aquatic systems. The CADDIS Program is based on identifying the dominant stressors within a stream or watershed for taking management action. Scientists within the CADDIS Program are very interested in collaborative efforts with NAWQA because of joint interest in identifying and understanding stressors in stream environments.

Goal 4—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 water-quality and ecosystem condition in the future under different environmental scenarios.

Products

The following are planned products for Goal 4:

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 to other 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 (Goal 4). 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 (that is, stressors). In Goal 3, water-quality and hydrologic conditions that lead to degradation of stream ecosystems are to 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 ecosystem conditions.

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 indicated a slow response in nitrate concentrations of streams and groundwater to changes in fertilizer use, even for a scenario where a total ban in fertilizer application is implemented (fig. 35). The example illustrates the importance of understanding the hydrologic system that governs the transport of nitrogen in both surface water and groundwater when making science-based forecasts. Continued development of such understanding is an important component of Cycle 3 studies.

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 patterns or wastewater treatment technologies; regulatory changes; and management practices. In some cases—such as agricultural and urban best management practices—changes or implementation of these practices may result in improvements in water quality (for example, decreasing concentrations of pesticides and nutrients in streams). In other cases, increased demands on agricultural land uses to support food and energy requirements may yield increases in the concentrations and fluxes of agricultural chemicals, nutrients, and sediment to streams and rivers, adversely affecting stream quality and ecosystem condition.

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 science plan for the USGS Climate and Land Use Change Mission Area (Burkett and others, 2011). Changes in air temperature will affect water temperature and, thereby, also affect algal blooms, eutrophication, microbiological processes, and overall ecosystem condition. 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 condition.

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 stream ecosystem condition?
- 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 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 provide a strong foundation for addressing this goal in Cycle 3. The work in assessing status and trends, together with focused topical studies and development of models across a range of scales, has led to an improved understanding of how human activities and natural factors 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 United States 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) can be adapted to evaluate temporal changes in water conditions as environmental drivers such as climate and land use change over time.

The objectives of model applications in Cycles 1 and 2 can be viewed in the context of the driver/stressor/receptor conceptual model (fig. 36). Cycle 1 and 2 studies

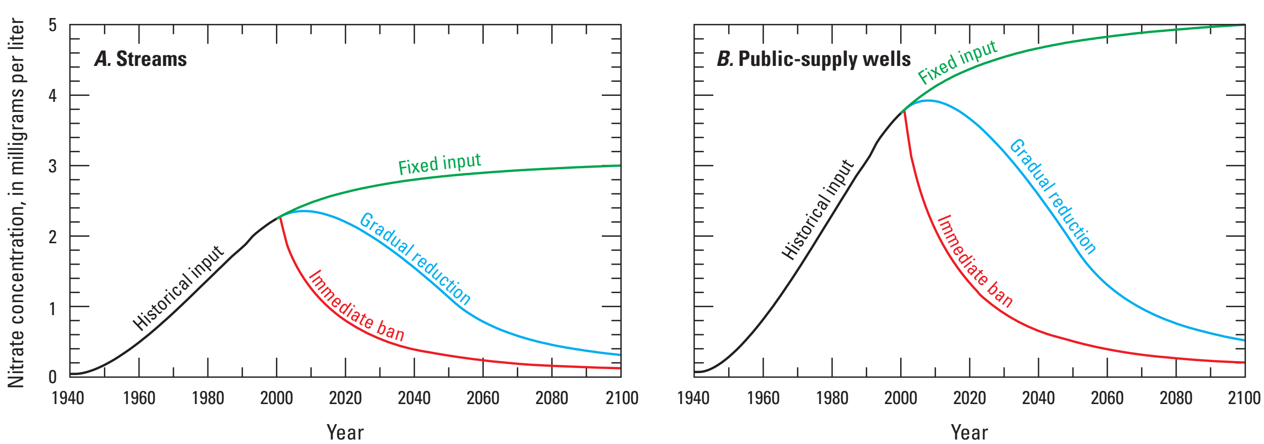


Figure 35. Simulated nitrate concentrations in *A*, streams, and *B*, public-supply wells (Kauffman and others, 2001).

used process-based models such as MODFLOW (Harbaugh, 2005), hybrid conceptual/regression/geospatial models such as WARP and SPARROW (Stone and Gilliom, 2009; Schwarz and others, 2006), 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, the USGS, and others. In addition, the effect of streamflow alteration and land use (for example, urbanization) on aquatic-ecosystem health was quantified with regression models.

Substantial 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 available at *http://cida.usgs.gov/sparrow/*. The SPARROW DSS (Booth and others, 2011) 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 as outlined in the following sections for the three objectives for Goal 4. 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 conditions 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 conditions 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. Most existing NAWQA models provide only steady-state predictions of stressor or aquatic-ecosystem conditions based on steady-state factors. 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.

The SPARROW model, 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 (table 6), 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 (in-stream 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), 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 temporal variations in the forcing variables have the same effect as spatial differences. 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" target chemicals or constituents (such as nutrients or sediment) and also require specifying input time series, such as monthly or seasonal values, for fluxes of water and chemicals.

Certain non-transient models also may be used to evaluate temporal changes in water quality due to changes in land or water use. For example, the steady-state version of MODFLOW (table 6) predicts spatial patterns of flow paths and statistical distributions of traveltimes; 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. 35).

NAWQA models that will be used to forecast future stressor and aquatic-ecosystem conditions in response

Table 6. Water-quality models to be used in Cycle 3 for prediction and forecasting.

[Nutrients include nitrogen, phosphorous, and carbon]

Model	Model type	Factors	Stressors	Receptors	Water resource
MODFLOW [a]	Process	Climate, land use	Contaminants	Human needs	Groundwater
SPARROW [b]	Geospatial/process/ statistical	Population growth, climate, land and water use	Nutrients, sediment	Aquatic ecosystems	Streams and rivers
WARP [c]	Geospatial/statistical	Climate, land use	Contaminants	Aquatic ecosystems, human needs	Streams and rivers
RZWQM2 [d]	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

[a] Harbaugh, 2005, (*http://water.usgs.gov/nrp/gwsoftware/modflow.html*).

[b] Schwarz and others, 2006, (*http://water.usgs.gov/nawqa/sparrow/*).

[c] Stone and Gilliom, 2009, (*http://infotrek.er.usgs.gov/warp/*).

[d] Ma and others, 2012, (*http://www.ars.usda.gov/Main/docs.htm?docid=17740*).

to changes in climate and land use require the following characteristics:

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

Descriptions of these models, the evaluation approach, and enhancements are given in the sections on Goals 2 and 3 of this report.

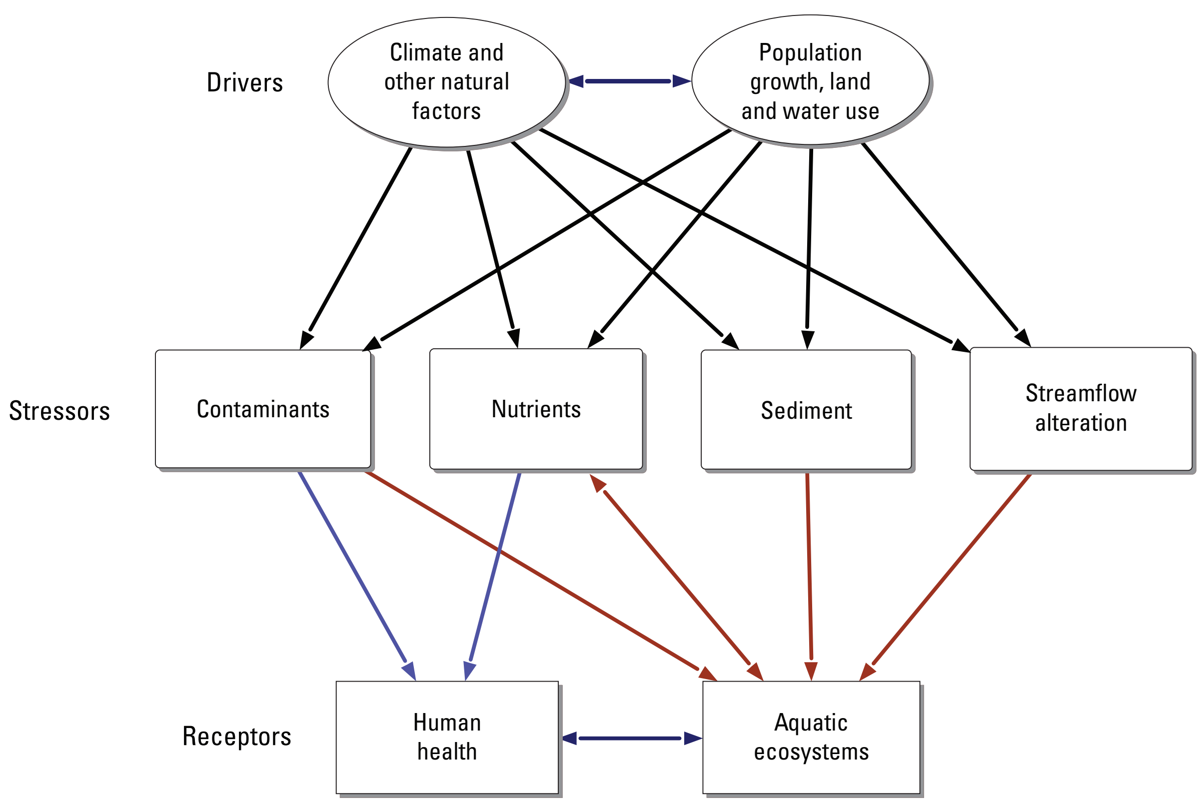


Figure 36. Conceptual model of the connections between environmental drivers, stressors, and receptors.

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 DSS and the underlying software that supports it has been 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 through a graphical user interface (*http://cida.usgs.gov/sparrow/*). The DSS (Booth and others, 2011) 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, and share simulated scenarios of future conditions and to 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 Web site user interface controls with a powerful computer server infrastructure. This paradigm places new capabilities in the hands of decisionmakers 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 (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 (*http://cida.usgs.gov/*) (figs 37–41). Through the user's Web browser, maps of model results—such as the total suspended sediment load in streams and rivers (fig. 37) and the mass per unit area delivered to the stream from individual areas (fig. 38)—are displayed.

The SPARROW 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. 39). This specific river reach was selected by using the pan and zoom features of the DSS. The table can be viewed through the user's Web browser and includes several tabs of information. The model results indicate that the primary source of sediment in the basin is agricultural (crop/pasture) land (fig. 39).

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 and Lake Livingston (fig. 40). This lake is used for recreation and water supply for Houston.

Mean annual sediment load flowing into Lake Livingston estimated by using the SPARROW model is about 5 million tons per year. The model indicates that almost one-half of the load originates in urban areas (see the blue section of the upper pie chart in fig. 41).

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 effect on sediment delivery to Lake Livingston. This scenario resulted in a 22-percent decrease in urban sources of sediment to Lake Livingston but only an 11-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.

Currently, the DSS offered on the NAWQA website 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 uncertainty, and (3) seamless access to land-use and climate change scenarios.

Enhancements for the support of additional models include

- Models previously developed by NAWQA (table 6) with enhancements for prediction and forecasting;
- New SPARROW models for carbon, temperature, dissolved oxygen, pesticides, and salinity; and
- Models developed and supported outside of the NAWQA Program, such as PRMS (Leavesley and others, 1983) and SWAT (Neitsch and others, 2005), that provide functionality unavailable in NAWQA models.

Predictive reliability enhancements include quantification of model reliability, which is crucial for meaningful model predictions. Placing model predictions within a reliability/uncertainty context is essential to avoid overconfidence or misinterpretation by the DSS user. Approaches for quantifying predictive reliability are described in the sections on Goals 2 and 3.

Seamless access to climate and land-use change scenarios will involve two USGS projects (the Center for Integrated Data Analysis and the Modeling of Watershed Systems Project that 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 website 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 or land-use changes on water-quality and aquatic-ecosystem conditions. Climate and land-use change scenarios are constantly evolving, and several sources of scenarios that could provide the basis for transient water-quality or ecological models are listed in table 7.

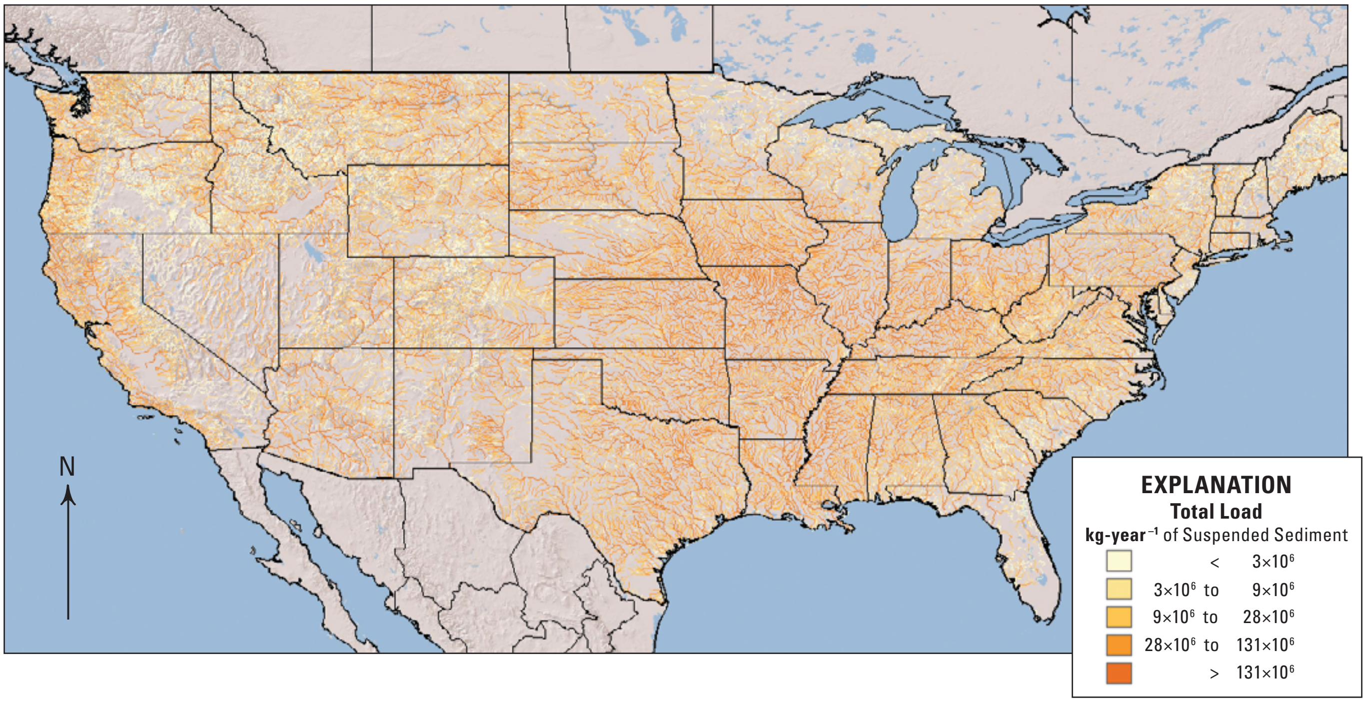


Figure 37. Total suspended sediment load estimated by using the SPARROW model from Schwarz (2008). (kg, kilograms; year^{-1}, per year)

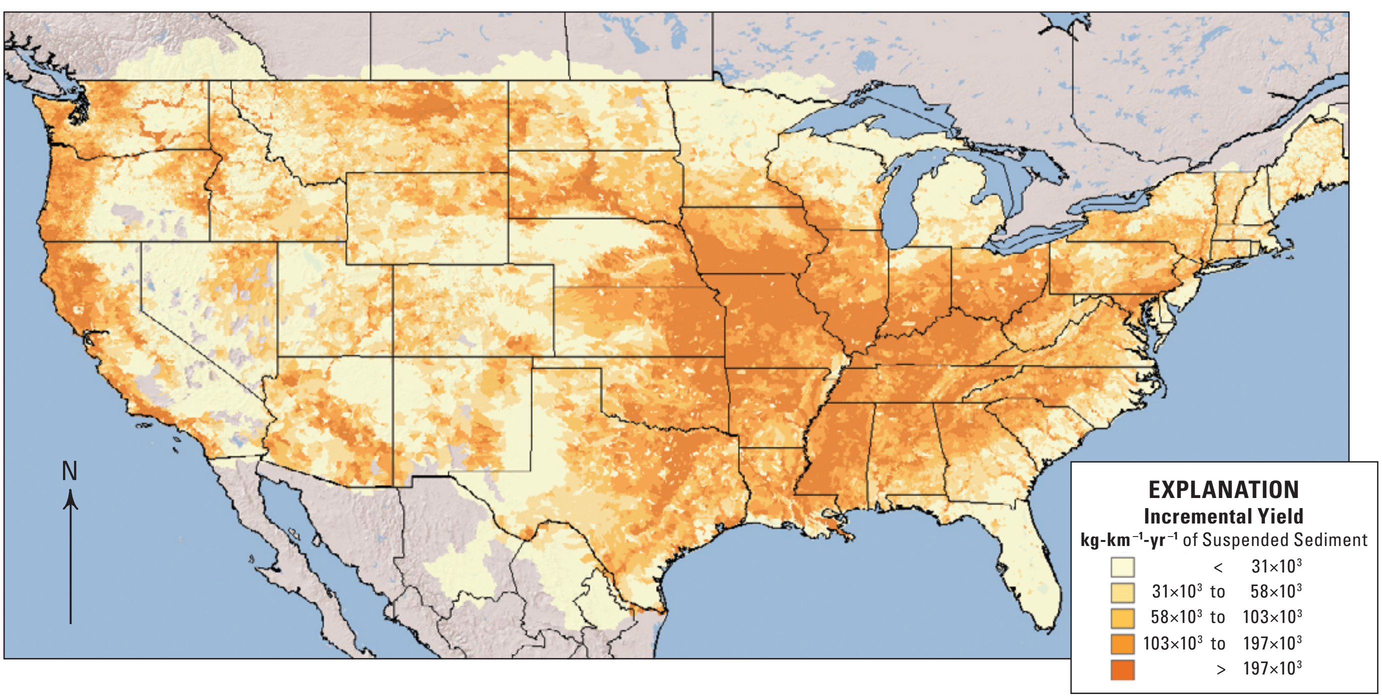


Figure 38. Estimated yield of sediment transported to streams and rivers from catchments, expressed on a per unit area basis, by using the SPARROW model from *Schwarz (2008)*. (kg, kilograms; km^{-2}, square kilometers; year^{-1}, per year)

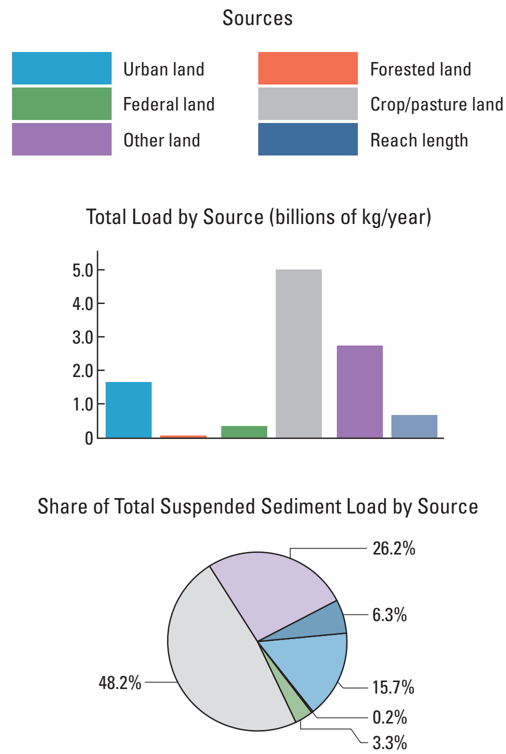


Figure 39. Sources of sediment in the Kansas River Basin estimated using the SPARROW Decision Support System (*http://cida.usgs.gov/sparrow/*). (kg, kilograms)

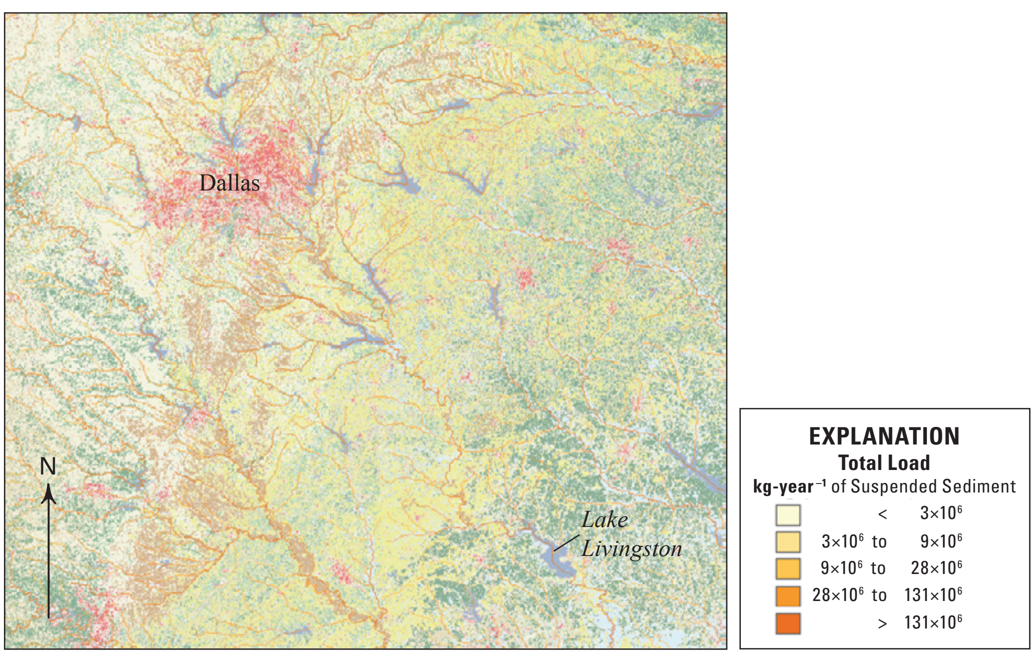


Figure 40. Total sediment load in streams and rivers in south-central Texas overlaid on land-use classes. The land-use categories shown are urban (red), agriculture (yellow), forest (green), and water (blue). Lake Livingston is used as a water supply for Houston. (kg, kilograms; year^{-1}, per year)

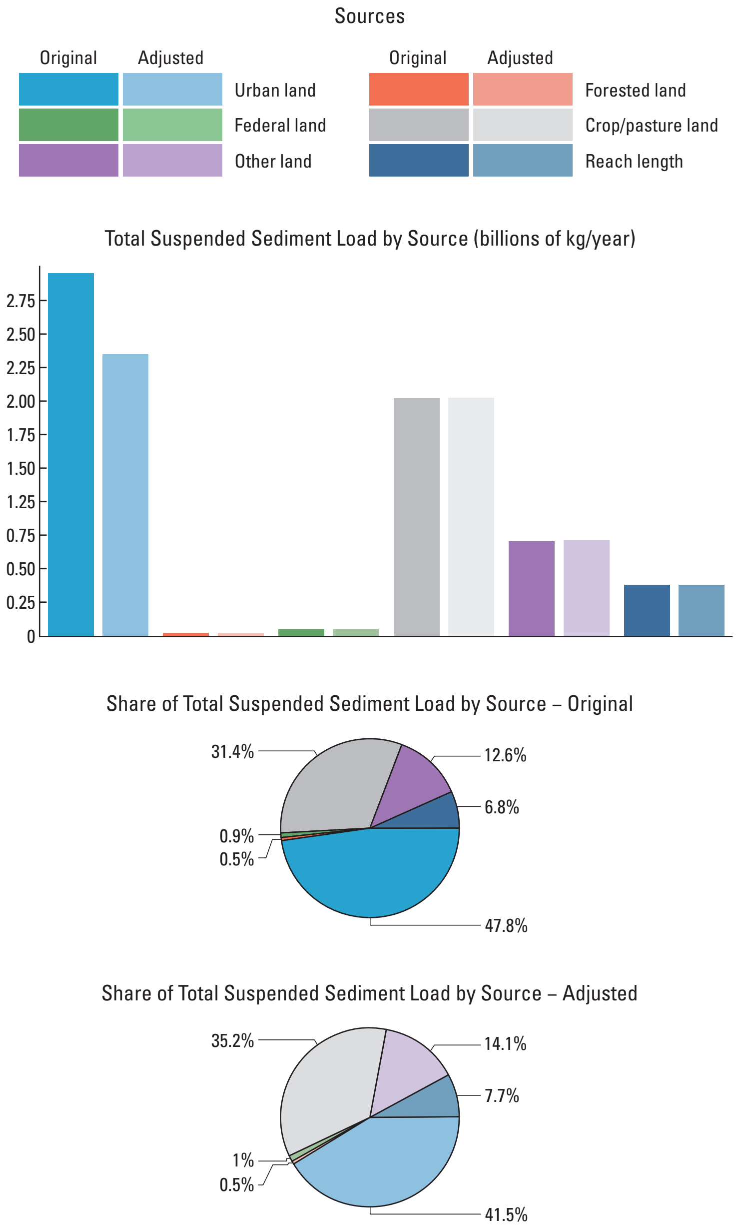


Figure 41. Sources of sediment in the Trinity River basin upstream of Livingston Lake estimated using the SPARROW Decision Support System (*http://cida.usgs.gov/sparrow/*). (kg, kilograms). Source loads for two scenarios are shown: Original (Orig.) indicating no adjustment to sediment transport and Adjusted (Adj.) in which sediment transport from urban land in the Upper Trinity River Basin is decreased by 50-percent. Comparison between the original and adjusted scenarios is depicted in two ways. The bar chart shows differences between the two scenarios in the estimated mass of sediment per year delivered to the lake. The pie charts show the same information expressed as percentages or “shares” of the total suspended sediment load.

Table 7. 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; National Oceanic and Atmospheric Administration, (*http://data1.gfdl.noaa.gov/*) and National Aeronaturic and Space Administration, (*http://www.giss.nasa.gov/projects/gcm/*) 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, U.S. Geological Survey (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 (*http://egsc.usgs.gov/currentscienceprojects.html*), the National Ecosystem Assessment and Forecasting Consortium, the Land Cover Dynamics and Environmental Processes Project (*http://egsc.usgs.gov/dynamicsandprocesses.html*), the Land Cover Trends Project (*http://landcovertrends.usgs.gov/*), and Project Gigalopolis (*http://www.ncgia.ucsb.edu/projects/gig/*). The U.S. Environmental Protection Agency is estimating future land cover in its Future Midwestern Landscapes Study (*http://www.epa.gov/AMD/Research/Ecosystems/Exposure_Application_Studies/fml.html*), and the U.S. Department of Agriculture (USDA) is generating future agricultural land-use scenarios (*http://www.srs.fs.usda.gov/pubs/39404*).
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 (*http://rff.org/Pages/default.aspx*) and the USDA Economic Research Service (*http://www.ers.usda.gov/*) to obtain necessary technical support.

The *WARP* web-mapper, (*http://infotrek.er.usgs.gov/warp/*), illustrates how model reliability information can be included in a decision-support tool. Figure 42 shows WARP predictions of annual mean atrazine concentration estimated for rivers and streams in the conterminous United States. The regression analysis that WARP predictions are based on also estimates model reliability/uncertainty metrics for the pesticide concentration predictions. If a meaningful contaminant concentration threshold—such as a human-health benchmark—is available, then the probability of exceeding the threshold can be estimated. Figure 43 shows such a map of exceedance probabilities for WARP-estimates of annual mean atrazine concentrations in the context of a threshold of 3 micrograms per liter, which is the USEPA Maximum Contaminant Level for atrazine (*http://water.epa.gov/drink/contaminants/index.cfm*).

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 associated decision-support systems (Objective 4c), NAWQA will complete selected studies in high priority areas (table 8) 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 that will be identified by one of NAWQA's partners.

A brief hypothetical study is described in the following section to illustrate how NAWQA could forecast the effects of both climate and land-use change on water quality.

Hypothetical Study in Chesapeake Bay

The objective of this hypothetical study is to evaluate the potential effects of climate and land-use change on the transport of nutrients to the Chesapeake Bay, which is the largest estuary in the United States. Chesapeake Bay borders Delaware, Maryland and Virginia. The general approach would be adapted to the individual study area. The brief description of the hypothetical study illustrates how NAWQA and its partners could forecast the effects of both climate and land-use change on water quality.

The Chesapeake Bay watershed SPARROW model would be used with climate and land-use change scenarios to estimate potential future nutrient loads to the bay. The following steps outline the approach for this hypothetical example:

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

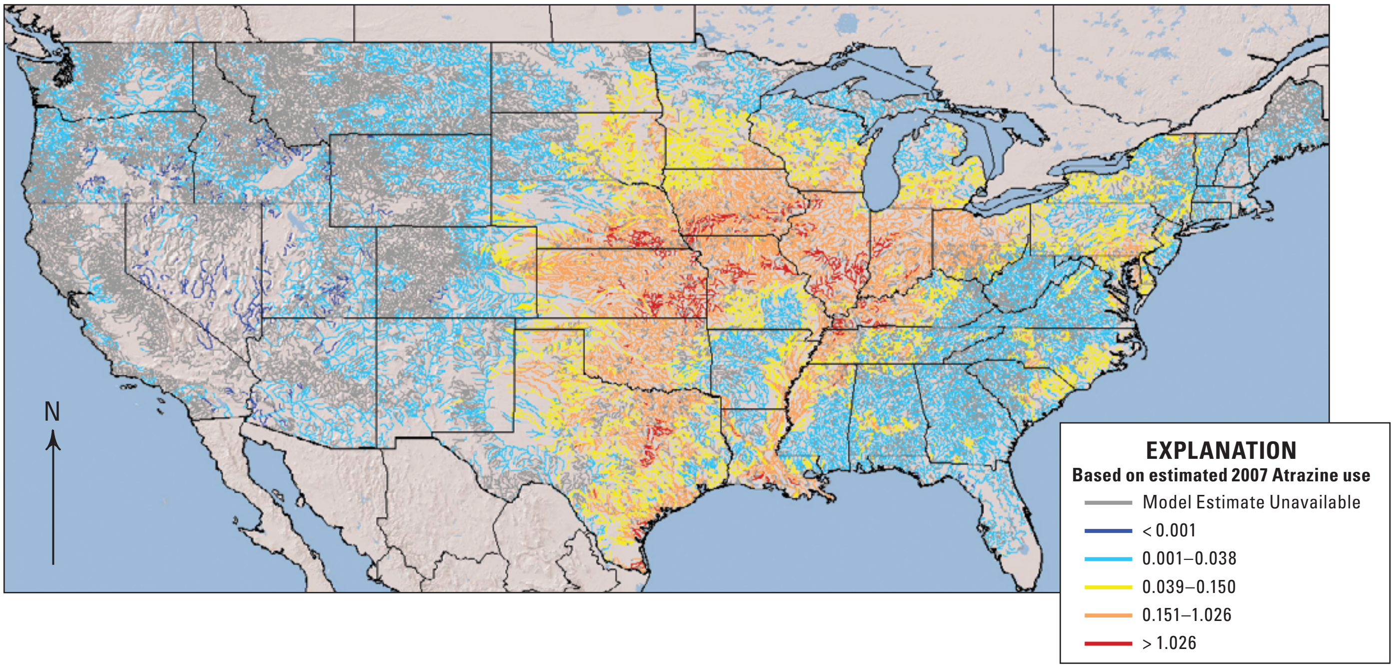


Figure 42. Estimated annual mean atrazine concentration for conterminous U.S. streams based on 2007 atrazine use. The highest atrazine concentrations are shown in red and the lowest concentrations are dark blue. Only streams with substantial agriculture use in their drainage basins are shown.

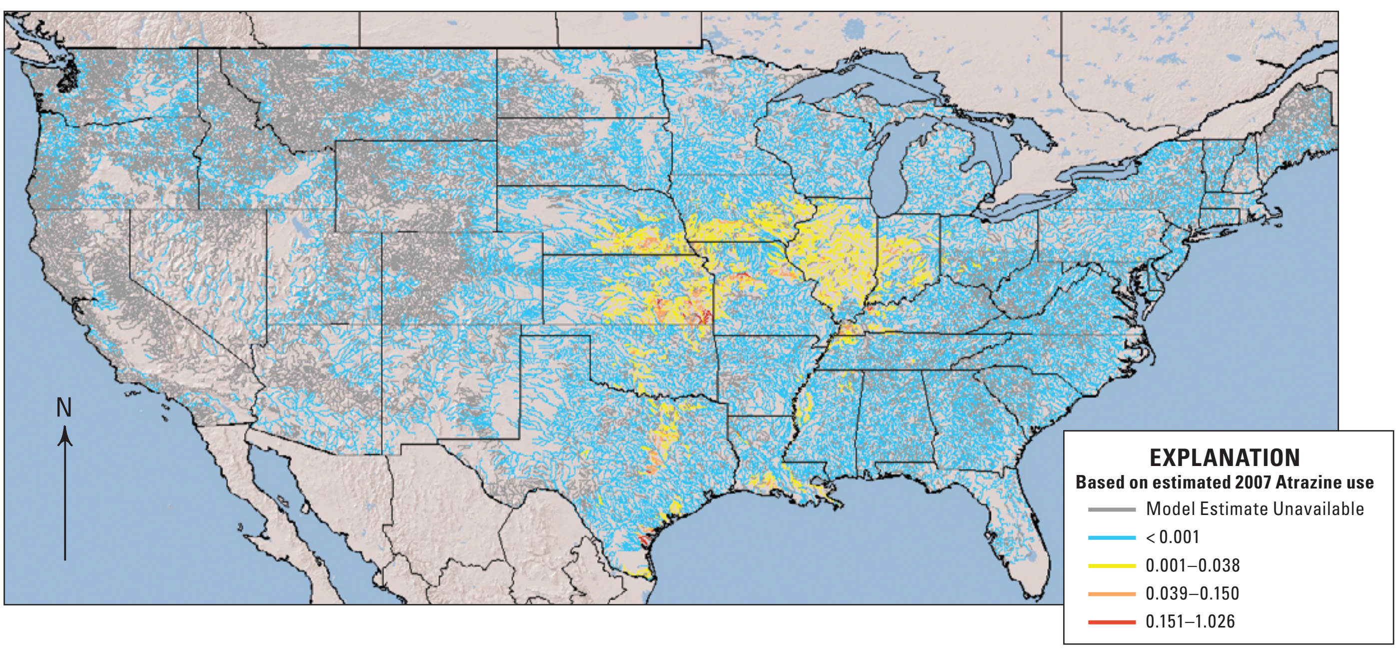


Figure 43. Probability that the estimated annual mean atrazine concentration exceeds 3 micrograms per liter. This Maximum Contaminant Level is a water-quality benchmark established by the U.S. Environmental Protection Agency for public drinking-water supplies.

Table 8. Potential climate and land-use change effects study areas. Note that additional study areas are likely to be added.

Watershed study areas	Primary partnerships
Chesapeake Bay	U.S. Geological Survey 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

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 for 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 for 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.

The approach described above uses a steady-state version of the SPARROW model, not a transient version. 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 or so based on age-dating analyses indicating typical traveltimes of water from the land surface through subsurface flow paths to streams and rivers is about 10 yr (Denver and others, 2010), or in the case of sediment or sediment-bound contaminants, possibly much longer. Thus, model simulations using land-cover and climate projections for the year 2030 may be predictive of stream-nutrient loads expected to occur in 2040 or later.

Potential products for this hypothetical example would 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.

Partnerships for Goal 4

Activities related to forecasting future water-quality conditions are being conducted by several USGS programs and Federal agencies. Like the NAWQA Program, a few of these efforts involve developing the capability to predict the effects of climate and land-use change on water-quality and ecosystem conditions. To not be redundant it is crucial 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

The following USGS mission areas are potential partners for Goal 4 of Cycle 3:

- ***Climate and Land Use Change Mission Area:*** Forecasting the effects of climate and land-use change on water-quality and ecosystem conditions is clearly aligned with this mission area. Examples of complementary goals include carbon sequestration, monitoring water quality and quantity, understanding and simulating the effects of climate and land-cover changes on ecosystems and other natural resources, geographic analysis and monitoring, and science applications and decision support. These are further described in the following bullets:

    - ***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 (*http://www.globalchange.gov/*) and the President's Climate Change Research Initiative (*http://www.climatescience.gov/about/ccri.htm*). These federally supported programs include a variety of activities related to forecasting changes in water quality. Some of the planned activities include long-term streamflow monitoring to detect effects 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 /University of California at Santa Barbara's Project Gigalopolis (*http://www.ncgia.ucsb.edu/projects/gig/*) 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 Mission Area:*** 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 water-quality policy makers and managers and will aid in analysis and decisionmaking. This goal is clearly 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; and

  - ***Couple water-quality models with USGS watershed models:*** The USGS National Research Program project Modeling of Watershed Systems (MOWS; *http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/index.html*) is designed to develop and support hydrologic simulation models at the watershed scale and currently is involved in simulating the effects of climate and land-use changes on flow in streams and groundwater. In addition, the MOWS project 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 conditions will facilitate forecasting water-quality and ecosystem conditions for MOWS-generated scenarios.

External Partnerships

The external agencies and organizations described in the following subsections are potential partners for Goal 4 of Cycle 3.

U.S. Department of Agriculture

The following are potential areas of collaboration between NAWQA and the USDA:

- ***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; and

- ***Evaluating the effects of agricultural management practices on water quality:*** Through its *Conservation Effects Assessment Project* (*http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap*), the USDA is quantifying the effects of conservation practices and programs on the environmental quality of agricultural landscapes. The Conservation Effects Assessment Project includes both monitoring and modeling projects at watershed and national scales. Recently (2012), 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 (*http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/?cid=nrcs143_014161*).

U.S. Environmental Protection Agency

The following is a potential areas of collaboration between NAWQA and USEPA:

- **Model response of water-quality to clean air regulation:** The NAWQA Program and USEPA can potentially collaborate on a model of water-quality response to clean air regulation. Through ongoing development of secondary standards for nitrogen dioxide and sulfur dioxide, USEPA is assessing the relation between regulatory emission control scenarios for nitric oxide and nitrogen dioxide, air quality, atmospheric nitrogen deposition, and nutrient enrichment of aquatic ecosystems. The Community Multiscale Air Quality modeling system (*http://www.epa.gov/AMD/Research/RIA/cmaq.html)*, developed by USEPA and NOAA, links emission-control scenarios to predictions of atmospheric nitrogen deposition. Identifying the levels of emission control that result in restoring healthy ecosystems in nitrogen-sensitive aquatic resources is of particular interest to the USEPA and the NAWQA Program. The goal of the collaboration would be to link the predictions from the Community Multiscale Air Quality modeling system 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

The following are potential areas of collaboration between NAWQA and NOAA:

- ***Forecast water-quality at National Weather Service forecast sites:*** As part of NOAA's *Next Generation Strategic Plan* (*http://www.ppi.noaa.gov/ngsp/*), NOAA proposes to pilot short-term (hours to days) water-quality forecasting at existing National Weather Service forecast sites. In this pilot program, the Office of Hydrologic Development (*http://www.nws.noaa.gov/oh/*) will produce a system for forecasting temperature to assist fisheries management.

- ***Forecast nutrient delivery to estuaries:*** Within NOAA's *Coastal Hypoxia Research Program* (*http://www.cop.noaa.gov/stressors/pollution/current/chrp/default.aspx*), 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.

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