

Recommendations for Implementation of the Third Decade (Cycle 3) of the National Water Quality Assessment (NAWQA) Program under the Current Funding Scenario

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Prepared by the Cycle 3 Implementation Planning Teams

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Chapter 1: Introduction

Planning for the third decade (Cycle 3) of the U.S Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program began in the fall of 2008 when a Cycle 3 Planning Team (C3PT) was formed and held two meetings to gather feedback regarding which current and emerging water-quality issues should be priorities for NAWQA over the next decade of assessment activities. The first meeting involved external stakeholders, largely members of the NAWQA National Liaison Committee; the second meeting involved USGS scientists and managers, mainly senior NAWQA scientists and managers, and other Water Discipline Program Coordinators. The outcome of these meetings was a list of eleven high-priority issues that were described in the [Rowe and others, \(2010\)](#). This report described each of the eleven issues, NAWQA's role in addressing these issues, described potential approaches and study designs, identified collaborative opportunities with other USGS Programs and external partners and provided guidelines for development the NAWQA Cycle 3 Science Plan.

A draft of the Cycle 3 Science Framework (hereafter Science Framework) was then distributed to USGS scientists and managers and NAWQA stakeholders in August 2009 with a request to provide input on the top 3-4 issues they felt were most important for NAWQA to address in Cycle 3. The Science Framework was also distributed to two technical advisory committees for review and comment. These were (1) the Cycle 3 Advisory Committee, an internal USGS advisory group chaired by Eric Evenson with representatives from each of the four USGS disciplines, and (2) the National Research Council (NRC) Committee on Preparing for the Third Decade (Cycle 3) of the National Water Quality Assessment (NAWQA) Program chaired by Dr. Don Siegel of Syracuse University. The external NRC Committee was asked to make recommendations regarding priority issues, provide guidance regarding Cycle 3 designs and approaches, and perform technical reviews of Cycle 3 planning materials.

Feedback from internal and external stakeholders, the Cycle 3 Advisory Committee, and the NRC Committee resulted in the selection of four issues that were (1) high priorities for all the stakeholders, (2) were nationally relevant, and (3) represented a good fit with USGS and NAWQA data collection, analysis, and modeling capabilities. The four issues selected were contaminants, excess nutrients, sediment, and streamflow alteration. Recommendations from the NRC Committee ([National Research Council, 2010](#)) and other stakeholders were to develop a science strategy that focused on understanding how large-scale drivers of environmental changes, such as changing climate and human activities on the landscape, affected these water-quality stressors, and in turn, how these stressors affect water-quality for human use and the condition of stream ecosystems.

The C3PT began preparing a Cycle 3 Science Plan (hereafter termed "Science Plan") to address this science strategy in summer 2010. The Science Plan is based on an evaluation of assessment progress by NAWQA and its partners during Cycles 1 and 2 (1991-2012) and an updated review of stakeholder priorities as captured in the Cycle 3 Science Framework (Rowe and others, 2010). The Cycle 3 plan maintains key characteristics essential to the Program's long-term success—such as national-scale relevance, method consistency, and partnerships—but also adjusts some of the approaches needed to face challenges driven by population growth, increasing demands for water, changing land use, and changing climate. An early draft of the Science Plan was reviewed by the NRC Committee in October 2010 and a letter report describing the Committee's review comments was sent to the USGS Director in January 2011 ([National Research Council, 2011](#)). A revised draft of the Science Plan was then released to USGS scientists, managers, the Mission Area Associate Directors, and the Regional Executives as well as members of the external NAWQA Liaison Committee on January 28, 2011 for comment. A final NRC Committee report on the NAWQA Program, based on the Committee's review of NAWQA accomplishments in Cycle 2 and the plans outlined in the January 2011 version of the Cycle 3 Science

Plan is scheduled to be published in March 2012. Please [click here](#) to access a pdf version of the draft Science Plan that was distributed on January 28, 2011.

As a reminder the four goals outlined for Cycle 3 in the Science Plan are:

- **Goal 1** –Assess the current quality of the Nation’s freshwater resources and how water quality is changing over time (**Status and Trends**)
- **Goal 2** – Continuing: Evaluate how human activities and natural factors, such as land use and climate change, are affecting the quality of surface water and groundwater (**Understanding Causes**)
- **Goal 3** –Determine the effects of contaminants, excess nutrients, sediment, and streamflow alteration on aquatic ecosystems (**Understanding Effects**)
- **Goal 4** –Predict the effects of human activities, climate change, and management strategies on water quality and ecosystem condition (**Forecasting**)

The first two goals represent consolidation of the original Cycle 1 and 2 Program Goals. Goals 3 and 4 represent new Goals for the Program that represent logical extensions of the scientific findings and directions established in the first two decades of NAWQA while also aligning well with scientific and resource management priorities identified by the USGS Science Strategy and NAWQA stakeholders.

Implementation Planning Process

Following review of the draft Science Plan, the C3PT developed a draft implementation strategy that laid out in broad terms activities and studies that would be conducted under different budget scenarios. The draft implementation strategy was delivered to the NAWQA Leadership Team (NLT) on June 28, 2011 and discussed at a NLT meeting held July 12-14, 2011 in Narragansett, Rhode Island. The outcome of the meeting was a decision to form five Implementation Planning Teams (IPTs) that would be responsible for developing a detailed implementation plan by February 2012. The implementation plan was to include identification of specific products and outcomes associated with Cycle 3 goals and objectives and a more detailed discussion of the approaches, resource requirements, staffing, budgets, and timelines necessary to achieve those outcomes. The plans were also asked to provide recommendations on where NAWQA monitoring and interpretative studies should be conducted. Details regarding the agreed upon implementation planning process including (1) identification of candidates to participate on the five IPTs, (2) the need to hold a face-to-face meeting of all five IPTs in October 2011, and (3) establishing a February 2012 deadline for completing the draft implementation plan, were issued in a memo from Bill Wilber dated July 25, 2011 (see Appendix 1).

A revised version of the draft implementation strategy was then presented to Water Senior Staff on August 19, 2011 following the Water Managers meeting held in Minneapolis, Minnesota. At this meeting participants were given a chance to weigh in on the draft implementation strategy, the implementation planning process, and the composition of the IPTs. Water Senior Staff approved the set of plans and proposed IPT teams and implementation planning began in earnest. The list of implementation planning team members, as well as key technical consultants and support staff that assisted with the planning effort, are listed in Table 1.1.

Purpose and Scope

The purpose of this document is to present the results of the implementation planning process described above. The plans described in this document are based on funding targets from the “Current Funding Scenario” (CFS) described later in this chapter. Although it was recommended at the July 2011 NLT meeting that a second implementation plan be developed using targets based on the “Science Plan”

funding scenario (see page 3) the February 2012 deadline set by the NLT left little time for development of a Science Plan version of the implementation strategy. However, such a plan could be developed relatively quickly because significant work has been done to identify and prioritize stream and river sites for the National Fixed Site Network, trend and new status groundwater networks, Integrated Watershed Study candidate basins, plans for new and upgraded surface-water and groundwater models used for status, trend, and forecasting applications have been made, and locations and objectives of Regional Synoptic Studies (RSS) that would be carried out to support status and trend and stressor effect goals have been identified. Therefore the plans described here could be quickly scaled up should additional funds become available or if the NLT determines it would like to have the full Science Plan version of the implementation strategy at their disposal for marketing purposes.

Implementation plans summarized in this document are the IPTs recommendations to the NLT for launching Cycle 3 and represent a starting point for generating the annual work plan guidance for FY13 and subsequent years. It is recognized that these plans need to be reviewed by USGS managers and scientists, both within and external to the Water Mission Area. This includes the Water Science Centers (WSCs), the Associate Directors (ADs), Regional Executives (REXs) and their staff, relevant Program Coordinators and their staff, and NAWQA personnel not involved in the implementation planning effort.

Table 1.1. Cycle 3 Implementation Planning Teams, Technical Consultants, and Support Staff

Component	Implementation Planning Team Members	Technical Consultants and Support Staff
Surface Water Assessment	Bob Gilliom (Chair) Charlie Crawford Greg Schwarz Jonathan Kennen Lori Sprague Jeff Deacon Greg Delzer Michelle Hladik	Bob Hirsh Mark Munn Skip Vecchia Naomi Nakagaki Denise Argue
Groundwater Assessment	Ken Belitz (Chair) Wayne Lapham Neil Dubrovsky Kevin Dennehy Bruce Lindsey Karen Burow Ward Sanford Tom Nolan Sandy Eberts	Gary Rowe Jim Tesoriero Bob Gilliom
Integrated Watershed Studies	Paul Capel (chair) Anne Hoos Hedeff Essaid Casey Lee Rich Alexander Jim Tesoriero Matt Miller Gary Rowe Terry Short	Nancy Baker Karen Burow Allen Gellis Jennifer Lanning-Rush Jason Roth Dave Wolock

Ecologic Effects Studies	Mark Munn (chair) Daren Carlisle Patrick Moran Chris Konrad Tom Cuffney Lisa Nowell Chris Schmitt	Ian R Waite Roxolana Kashuba Terry M Short Jonathan G Kennen Neil M Dubrovsky Bob Gilliom Pete VanMetre Skip Vecchia Naomi Nakagaki
Forecasting Studies	Dave Wolock (chair) Lauren Hay Leon Kauffman Dick Smith Peter Claggett Ian Waite Nate Booth Roxalana Kashuba	Karen Burow Greg Schwarz

Budget Scenarios

Two budget scenarios were included in the draft implementation strategy presented to Water Senior Staff last August, a **Science Plan Scenario** and a **Current Funding Scenario**. These two scenarios were used by the C3PT to develop component funding targets for each of the IPTs and both are presented here for completeness even though, as noted above, the IPTs devoted most of their effort towards developing implementation plans based on the CFS.

The **Science Plan Scenario** assumes that increased funding at levels sufficient to support the full “national needs” version of Cycle 3, as described in the Science Plan, is received early in Cycle 3 and that the Program receives approximately \$243 M per year with cost-of-living adjustments (COLAs) throughout the ten-year cycle. The cost estimates were not based on any preconceived funding targets or component ratios but instead are C3PT estimates of what the different data collection activities and interpretative and modeling studies described in the Science Plan would cost, based on C3PT and NLT’s collective experience from Cycles 1 and 2.

The **Current Funding Scenario** assumes the FY2013 appropriation is set at the FY2010 enacted level of \$66.5M per year, plus an additional \$2.8 M in NASQAN funding, and that this appropriation is constant throughout the 10-year planning period with no adjustment for inflation. This implies that funding targets decline by the expected amount of inflation each year. Year-by-year targets are based on an assumed inflation rate of 4 percent per year, which approximates the average annual rate of inflation for personnel, data collection, and study costs observed by the Program over the past 15 years.

The decision to use the FY10 appropriation of \$66.5M as the FY13 as opposed to the FY11 appropriation was due to the delay in Congress finalizing the FY11 appropriation and the lack of knowledge regarding what the FY12 appropriation would be at the time implementation planning began (March 2011). It was eventually learned that the FY11 appropriation would be \$64.23M and recently it was learned that the FY12 appropriation would be \$62.9M; however given the uncertainty surrounding the budget last fall the IPTs were told to proceed using targets based on an assumed FY13 appropriation of \$66.5M.

The overall impact of assuming no inflation adjustment at an inflation rate of 4 percent per year is about a 30 percent decrease in available funds between year 1 (FY13) and year 10 (FY22) of Cycle 3. This funding scenario means the IPTs must take into account the steady decrease in assumed funding over Cycle 3 when planning data collection activities or interpretative studies.

Component Funding Targets

Component funding targets for the two budget scenarios were established in the following categories:

- Bureau and Water Mission Area Science Support (set at 28 percent of gross funding)
- Program Management (NAWQA Leadership Team and support personnel)
- Goal 1 Surface Water Status and Trends Assessment
- Goal 1 Groundwater Status and Trend Assessment and Goal 2 Groundwater Modeling Studies
- Goal 2 Integrated Watershed Studies
- Goal 3 Effects of Stressors on Stream Ecosystem Studies
- Goal 4-Forecasting Studies
- Technical Support (database management, modeling and ancillary data support, etc).

For each budget scenario it was assumed that the percentage of funding retained for Water Mission Area Science support would remain fixed around 28 percent throughout Cycle 3. This may underestimate this cost in FY13 and remaining out years because the percentage of NAWQA funds allocated for Bureau and Water Mission Area science support percentage has increased over time ranging from 25.7 percent in FY03 to 29.6 percent in FY12 (ten-year average is 27.8 percent; Steve Moulton, written communication, Feb 1, 2012). The net funding available to support Cycle 3 assessment activities under the two budget scenarios after science support and management costs are deducted is given below (Table 1.2).

Table 1.2. Assumed fiscal year 2013 appropriations and net funding available for Cycle 3 activities under the two budget scenarios after science support and program management costs are deducted [all numbers are in millions of dollars].

Scenario	Assumed Appropriation ¹	Science Support ²	Program Management Costs	Net Funding
Science Plan	\$242.8	\$67.9	\$3.0	\$171.9
Current Funding	\$69.2	\$18.6	\$1.8	\$48.8

¹ Includes \$2.3 million in NASQAN funding and \$0.4M in National Monitoring Networks (NMN) funds because the Cycle 3 Surface Water Status and Trends design assumes integration of NAWQA, NASQAN, and NMN networks under a single National Fixed-Site Network

² Technical Support charge is applied to NAWQA funds only; not to NASQAN and NMN funding (\$2.7M).

Science Plan Scenario Component Targets

Target components for different Cycle 3 goals and major components are given in Table 1.3 and are based on cost estimates prepared prior to the October 2010 meeting with the NRC Committee, as documented in the Excel spreadsheet file "*Cycle 3 Cost Estimate_Full Plan Breakdown_NRC Meeting.20101026.xlsx*" (available upon request).

Table 1.3. Component funding targets under the Science Plan Scenario. All targets are in gross funds and each year of Cycle 3 is the same relative to FY13 cost estimates because adjustment for inflation is assumed. [SW, surface water; GW, groundwater; ST, status and trends; IWS, integrated watershed studies, all numbers in millions of dollars].

Goal 1 SW ST		Goal 1 GW ST		Goal 2 IWS	Goal 2 GW Models	Goal 3 Effects of Stressors Studies	Goal 4 Forecasting	Tech Support	Total
Data	Analysis	Data	Analysis						
\$55.5	\$27.4	\$15.0	\$5.0	\$34.0	\$12.0	\$13.0	\$4.0	\$6.0	\$171.9

Current Funding Scenario Component Targets

The CFS scenario assumes initial net funding of \$48.8M per year; this funding declines to \$33.7M by the end of the ten-year cycle in FY22 (Table 1.4). For Goal 1 Surface-Water and Groundwater Status and Trend activities the ratio of funding devoted to data collection versus analysis, interpretation, and reporting is about 3 to 1. The overall ratio of Surface Water to Groundwater Status and Trends data collection, analysis, interpretation and reporting is about 2:1. This is significantly higher than the ratio currently being used in Cycle 2 (approximately 1:1) although it should be noted that the total funds devoted to surface-water and groundwater data collection actually increase relative to Cycle 2. This represents an effort to restore NAWQA data collection in response to stakeholder concerns regarding the erosion of NAWQA monitoring networks throughout Cycle 2 because of flat funding and inflation. Similarly, the ratios for data collection relative to analysis/reports for this scenario are significantly higher than the current 1:1 ratio used for Cycle 2.

Table 1.4. Component funding targets under the Current Funding Scenario from FY13 through FY22. All targets are in gross FY13 dollars and assume a four percent inflation rate. [SW, surface water; GW, groundwater; ST, status and trends; IWS, integrated watershed studies].

Fiscal Year	Goal 1 SW ST		Goal 1 GW ST		Goal 2 IWS	Goal 2 GW Models	Goal 3 Effects of Stressors Studies	Goal 4 Forecasting	Tech Support	Total
	Data	Analysis	Data	Analysis						
FY13	\$17.20	\$6.00	\$7.50	\$2.50	\$4.00	\$4.00	\$4.00	\$2.00	\$1.50	\$48.80
FY14	\$16.17	\$6.00	\$7.20	\$2.40	\$3.84	\$3.84	\$3.84	\$1.92	\$1.44	\$46.75
FY15	\$15.28	\$6.00	\$6.91	\$2.30	\$3.69	\$3.69	\$3.69	\$1.84	\$1.38	\$44.88
FY16	\$14.43	\$6.00	\$6.64	\$2.21	\$3.54	\$3.54	\$3.54	\$1.77	\$1.33	\$43.09
FY17	\$13.60	\$6.00	\$6.37	\$2.12	\$3.40	\$3.40	\$3.40	\$1.70	\$1.27	\$41.36
FY18	\$12.82	\$6.00	\$6.12	\$2.04	\$3.26	\$3.26	\$3.26	\$1.63	\$1.22	\$39.71
FY19	\$12.06	\$6.00	\$5.87	\$1.96	\$3.13	\$3.13	\$3.13	\$1.57	\$1.17	\$38.12
FY20	\$11.33	\$6.00	\$5.64	\$1.88	\$3.01	\$3.01	\$3.01	\$1.50	\$1.13	\$36.60
FY21	\$11.20	\$5.44	\$5.41	\$1.80	\$2.89	\$2.89	\$2.89	\$1.44	\$1.08	\$35.13
FY22	\$11.20	\$4.77	\$5.19	\$1.73	\$2.77	\$2.77	\$2.77	\$1.39	\$1.04	\$33.73

Comparison of Goals, Organizational Structure, and Funds Flow

The Science Plan retains long-term NAWQA Program goals of assessing the status the Nation's streams and aquifers, trends in surface and groundwater quality, and understanding the factors that control water quality and aquatic ecosystem condition (Table 1.5). The draft Cycle 3 Science Plan recommended consolidating NAWQA's status and trend goals, retaining the goal of improving our understanding of

natural and human factors that affect water quality, and adding two new goals that explicitly address key stakeholder concerns: Goal 3 involves assessing the ecological effects of important water-quality stressors on aquatic biota, and (Goal 4) involves developing models that can forecast future changes in water-quality and stream ecosystems in response to changes in climate and human activities.

Table 1.5. Comparison of NAWQA goals for Cycles 1 and 2 versus goals recommended for Cycle 3.

Goal	Cycle 1 and 2 Goals	Goal	Cycle 3 Goals
1	Status	1	Status and Trends
2	Trends		
3	Understanding Natural and Human Factors	2	Understanding Natural and Human Factors
--	Not Applicable	3	Ecologic Effects of Stressors
--	Not Applicable	4	Forecasting Future Water-Quality Conditions

The Cycle 2 organizational structure features five general areas including: (1) Groundwater Status and Trends, (2) Surface Water Status and Trends, (3) Topical Studies, (4) National Synthesis, and (5) Technical Support (light blue boxes, Fig. 1.1). Distributed teams organized under these five topics had a range of responsibilities including operation of NAWQA status and trend networks, design and execution of focused topical studies, synthesis of NAWQA data and findings at the regional and national scales, support of NAWQA modeling activities, and operation of NAWQA water-quality and biological data bases (orange boxes, Fig. 1.1).

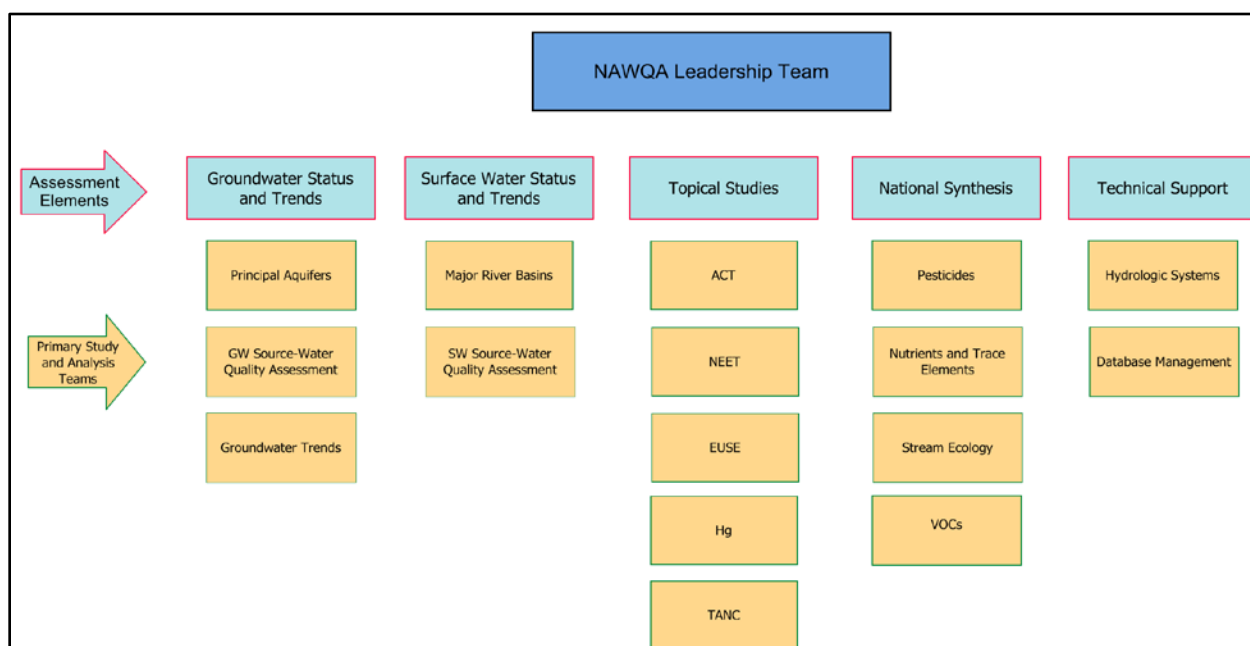


Figure 1.1. Organizational structure of NAWQA assessment elements and study teams at end of Cycle 2 (see text for details).

Because of fiscal constraints imposed by the limited resources inherent in the Current Funding Scenario, as well as the need to realign the core assessment and synthesis elements of the Program with the revised goals laid out in the Cycle 3 Science Plan, consolidation and reorganization of the NAWQA organizational structure is proposed (Fig. 1.2). The C3PT recommends ending the remaining Cycle 2 National Synthesis Teams for Pesticides, Nutrients, and Stream Ecology (VOC National Synthesis activities were ended several years ago) and, in their place, redistribute and integrate the synthesis

activities needed to support Cycle 3 goals and objectives directly into the four assessment and synthesis elements (blue boxes) where Cycle 3 work will be done. As part of previously established long-term NAWQA plans, the five Topical Studies started in Cycle 2 will end. In addition, teams organized in Cycle 2 to support modeling, data analysis, and report preparation at the regional scale (Major River Basin and Principal Aquifer teams) will also end; however, critical elements of the work those teams performed are retained under the implementation strategy described in this report. Last, C3PT recommends that the Study Unit terminology used throughout Cycle 1 and much of Cycle 2 be formally abandoned outside of its use to reference relevant Cycle 1 or Cycle 2 data, studies, or reports.

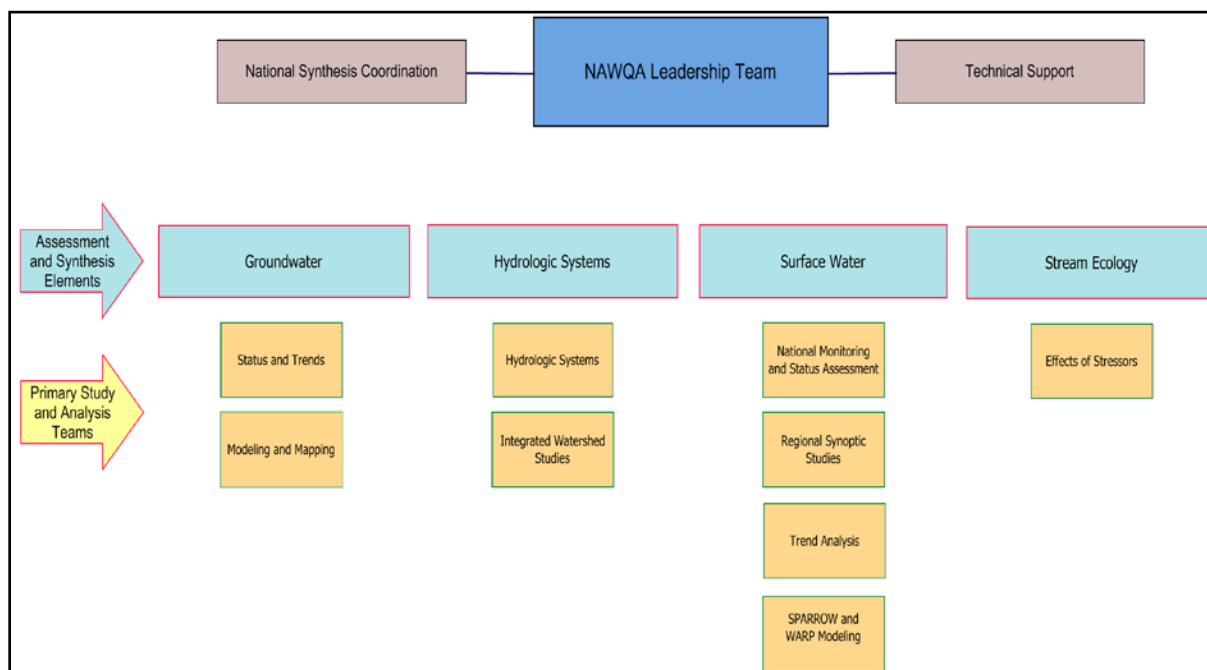


Figure 1.2. Proposed organizational structure for Cycle 3 (see text for details).

The organizational structure proposed by C3PT places study and analysis teams (yellow boxes) under four assessment and synthesis elements including Surface Water, Groundwater, Hydrologic Systems, and Stream Ecology Synthesis (fig. 1.2). Teams responsible for overseeing data collection, trend analysis, and status-related modeling of surface-water and groundwater-quality are directed by Coordinators that head the Surface-Water and Groundwater elements respectively. Most analytical, technical support, and synthesis functions of the Cycle 2 National Synthesis Teams for pesticides, nutrients, and trace elements will reside in the Surface Water and Groundwater study teams, for example, the Contaminant Toxicity and Properties Team (see Chapter 2 and Appendix 2A). The Cycle 2 Hydrologic Systems Team will be part of the Hydrologic Systems element which also includes the Goal 2 Integrated Watershed Studies. Teams responsible for evaluating the effects of important stressors on stream ecosystems are placed under the Stream Ecology assessment and synthesis element. Database management and other technical support functions will be formally overseen in Cycle 3 by the NLT and the four assessment and synthesis element coordinators.

National Synthesis coordination remains a critical feature of the Program in Cycle 3, but the nature of coordination will change from managing assessments and products by previous national synthesis topics (e.g. pesticides, nutrients, stream ecology), to managing national synthesis analyses and products that are more interdisciplinary and individually designed to address the most critical national issues. As plans for these analyses and products are developed, they will be carried out by national synthesis product

teams composed of selected team members from permanent Cycle 3 teams. The planning and formulation of these teams will be a collaborative effort of the National Synthesis Coordinator (member of NLT who has collateral duty to coordinate all synthesis activities) and coordinators for four Cycle 3 synthesis components (blue boxes in Figure 1.2).

With respect to funds flow, in Cycle 2 NAWQA used an annual work plan process to produce general targets for each of the five assessment categories. It was the responsibility of the Surface Water and Groundwater coordinators, National Synthesis Chiefs, Topical Team leaders, and others to break down the overall targets into individual study team and science center targets. These targets were sent to the field for vetting by the local Study-Unit Chiefs, technical team leads, and WSC management. If discrepancies were identified, the Regional NAWQA Coordinators (formally Associate Regional Hydrologists for NAWQA or ARHNs) worked with NAWQA staff, WSC management, and respective NAWQA component leaders to resolve the discrepancies. We envision a similar process being used in Cycle 3 with exception that NLT will work with the four coordinators for Surface Water, Groundwater, Hydrologic Systems, and Stream Ecology Synthesis to produce initial targets for the primary study and analysis teams and the WSCs are carry out water-quality monitoring, modeling and interpretative studies, and house NAWQA staff. Per recent practice, WSC Directors and REX office staff will be included in the annual work plan process.

Criteria for Prioritizing Cycle 3 Activities

The C3PT considered several criteria for ranking different Cycle 3 objectives and activities included in the Current Funding Scenario. These included:

- Does the product or outcome envisioned for a particular Cycle 3 objective address a nationally important issue in the form of policy-relevant data, scientific understanding, models, or decision support tools?
- Does NAWQA/USGS fill a unique niche or brings unique strengths to addressing the objective? (Can other agencies address the objective?)
- Does the research complement the agenda of other institutions and agencies?
- If the objective is dropped, will it cause significant distress among NAWQA stakeholders?
- Which Cycle 3 activities provide the most return on taxpayer investment in terms of important data gaps filled, information needs met, etc.?
- Can the activity be incentivized internally (Can NAWQA, Science Center, or Area funding be used to generate in-kind or matching funds for specific activities)?
- Can the activity be incentivized externally (Are there external partners who will support and share the burden to conduct a specific activity)?
- For new Cycle 3 design elements, what is the minimum amount of work we can do to produce a scientifically credible assessment?
- Are there Cycle 1 or 2 features of the NAWQA design that produce critical scientific data have to be maintained in all budget scenarios (example: SW-QW trend records at long-term fixed sites)?

These criteria and the long-held NAWQA approach of doing a few things well instead of spreading the Program too thin were used by the IPTs in developing the implementation plan. However, at the same time the C3PT and NLT felt strongly that NAWQA should begin to implement new studies that support high priority Cycle 3 Goal 2, 3, and 4 objectives to the extent possible under the Current Funding Scenario, even if it means piloting such studies in the early part of Cycle 3.

Chapter 2: Recommendations for Surface Water

Introduction

One of the four goals of NAWQA Cycle 3—and a central goal of NAWQA since its inception—is to assess the current quality of the Nation’s freshwater resources and how water quality is changing over time. This status and trends goal pertains to both surface water and groundwater resources, but the approaches are quite different and are thus described separately. The national approach to surface water status and trends assessment is described in this section. The components of this approach will be closely coordinated with related Cycle 3 activities in Integrated Watershed Studies (Goal 2), Ecological Effects Studies (Goal 3), and Forecasting (Goal 4).

The Cycle 3 Science Plan describes 6 primary objectives and related approaches for assessing status and trends for surface water:

1. Determine the distributions and trends for contaminants, nutrients, sediment and streamflow alteration that may degrade stream ecosystems.
2. Determine the distributions and trends of contaminants in current and future sources of drinking water from streams, rivers, lakes, and reservoirs.
3. Determine contaminant, nutrient, and sediment loads to coastal estuaries and other receiving waters.
4. Determine trends in biological condition in relation to trends and changes in contaminants, nutrients, sediment, and streamflow alteration.
5. Determine mercury trends in fish tissue.
6. Determine the distributions and trends in microbial contaminants in streams and rivers used for recreation.

Compared to the Science-Plan Funding Scenario, the Implementation Plan for the Current Funding Scenario for Cycle 3 Surface Water Status and Trends, which is the focus of this chapter, is based on a scaled-back design with reduced scope and less extensive approaches to objectives 1-4, and elimination of objectives 5 and 6. Most aspects of streamflow alteration objectives are incorporated into the “Ecological Effects” design, which is described in the Implementation Plan for Goal 3.

The approach to the status and trends assessment for surface water relies on three primary sources of water-quality data: (1) the National Fixed Site Network (NFSN), principally NAWQA and NASQAN, (2) NAWQA regional synoptic studies (RSS), and (3) data from other USGS programs and state and federal agencies.

- The NFSN produces the common core of consistent information that other assessments rely on—it is the foundation for long-term national status and trends assessment. The CFS design integrates NAWQA and NASQAN networks, and the ultimate goal is to also integrate network designs with the Hydrologic Benchmark Network (HBN) and the National Monitoring Network (NMN).
- RSS are limited duration, geographic or issue-focused studies, which generally include a subset of fixed sites, but include additional sites that are specifically chosen to meet the specific study objectives and enhance geographic coverage. RSS play an especially critical role in the CFS because the NFSN is so sparse, especially for smaller streams, and these geographically extensive, short-duration RSS studies are needed to fill the gaps for status assessments.
- Data from other USGS programs and state and federal agencies have played an increasingly vital role in NAWQA assessments, particularly for some of the water-quality parameters that have been commonly and economically monitored for many years by a variety of programs and agencies. Such data have

greatly expanded the data for development of SPARROW models for nutrients and have potential to expand available data for modeling and trend assessment for other constituents as well.

The design of the NFSN and RSS will be closely coordinated to support Cycle 3 Integrated Watershed Studies, but the national and regional status and trends products are not highly dependent on smaller scale studies, especially under the current funding scenario. The RSS will be coordinated and designed in close collaboration with the Goal 3 ecological-effects synoptic studies. The models developed as part of the status assessment will be applied to meet Goal 4 forecasting objectives.

The budget targets for CFS implementation planning are from the allocation plan developed by the Cycle 3 Planning Team and the NAWQA National Leadership Team (NLT) (Tables 1.4 and 2.1). The CFS budget protects the NFSN data collection from inflation so that a consistent monitoring design can be implemented across the full Cycle if the program budget stays constant at the CFS level, but with no inflation adjustment increases. In addition, the total budget for Design, Analysis, and Reporting (essentially all staff time not directly involved in data collection) is also kept relatively constant to maintain steady staff support. The effect of inflation is incorporated into the RSS data collection budget, which results in a front-loaded series of synoptic studies during the first 5-6 years of the cycle.

Table 2.1. Cycle 3 budget targets for Goal 1 Surface Assessment components

Scenario	Goal 1 Surface Water Assessment Targets (Millions of dollars per year)			
	National Fixed-Site Monitoring Data Collection	Regional Synoptic Study Data Collection	Design, Analysis, and Reporting	Total SWST Funding
Science Plan Scenario	\$49.5	\$6.0	\$27.4	\$82.9
Current Funding Scenario (Millions of FY13 dollars per year)				
FY13	\$11.20	\$6.00	\$6.00	\$23.20
FY14	\$11.20	\$5.07	\$6.00	\$22.27
FY15	\$11.20	\$4.18	\$6.00	\$21.38
FY16	\$11.20	\$3.33	\$6.00	\$20.53
FY17	\$11.20	\$2.50	\$6.00	\$19.70
FY18	\$11.20	\$1.72	\$6.00	\$18.92
FY19	\$11.20	\$0.96	\$6.00	\$18.16
FY20	\$11.20	\$0.23	\$6.00	\$17.43
FY21	\$11.20	\$(0.00)	\$5.54	\$16.74
FY22	\$11.20	\$(0.00)	\$4.87	\$16.07

As part of implementation planning for the CFS, the budget allocation was refined to conform to major categories of work and to somewhat increase staffing for design, analysis, and reporting relative to data collection. For activities primarily related to the NFSN, all protected from inflation, the data collection budget was left unchanged at \$11.2 million/year. For RSS, which are front-loaded into the first 6 years, \$250k/yr was moved from data collection to design/analysis/reporting staffing.

The study team organization is summarized in Figure 2.1. Figure 2.1 includes only FTE funded from the Goal 1 planning allocations, with the understanding that some combined work within the scope of other goals will ultimately result in combined teams and staff, particularly for data management and GIS support. These estimates are approximate and based on an average gross annual funding of \$225k per FTE per year. In addition, there still may be some adjustments in staffing and scope of teams as the draft implementation plan moves through review.

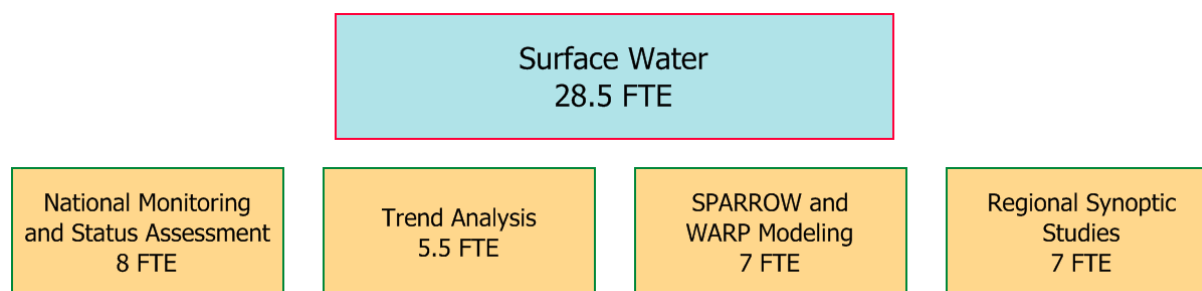


Figure 2.1 Organization of teams for Surface Water Assessment components. The FTE total for Surface-Water Assessment includes 1 FTE for the coordinator position.

The scope of each team is briefly summarized below and the Cycle 3 budgets and FTE allotments are provided in Tables 2.2 and 2.3.

- I. National Monitoring and Status Assessment Team:** Manages the NFSN, conducts Annual Reporting and Periodic Status Assessments, including integration with SPARROW and WARP model analyses, and works with other data managers to provide USGS and other-agency water-quality data to all Surface-Water Assessment teams. A long-term goal will be integrated operation of the NFSN with the HBN and NMN networks.
- II. Trend Analysis Team:** Conducts trend analysis for a wide range of water-quality parameters using all appropriate and qualifying data from USGS and other sources.
- III. SPARROW and WARP Modeling Team:** Develops and applies regional and national SPARROW and WARP models, working in collaboration the status analysis and Regional Synoptic Studies.
- IV. Regional Synoptic Studies Team:** Designs and manages all aspects of Regional Synoptic Studies.

The following sections describe the details of implementation for Surface Water Status and Trend Assessment, organized according to the four teams identified above.

In addition to the implementation details described for these four teams, there will also be integrated national synthesis analyses and related products that will be accomplished by product teams comprised of selected staff from the four primary teams summarized above. Some product teams for national synthesis will also include staff from other Cycle 3 components, such as Groundwater and Stream Ecology. Plans for specific national synthesis products will be developed by Cycle 3 component coordinators and team leaders in collaboration with the NLT.

Table 2.2. Refined budget targets, in millions of FY13 dollars [NFSN: National Fixed-Site Network].

Fiscal Year	National Monitoring and Status Assessment Team			Trend Analysis Team	SPARROW and WARP Modeling Team	Regional Synoptic Studies (RSS) Team	
	NFSN:,Data Collection	NFSN: Network Management	Status Assessments and Data Management			RSS: Data Collection	RSS: Design, Analysis and Reporting
FY13	11.2	1.1	0.7	1.1	1.6	5.9	1.6
FY14	11.2	1.1	0.7	1.1	1.6	5.0	1.6
FY15	11.2	1.1	0.7	1.1	1.6	4.1	1.6
FY16	11.2	1.1	0.7	1.1	1.6	3.3	1.6
FY17	11.2	1.1	0.7	1.1	1.6	2.4	1.6
FY18	11.2	1.1	0.7	1.1	1.6	1.6	1.6
FY19	11.2	1.1	0.7	1.1	1.6	0.9	1.6
FY20	11.2	1.1	0.7	1.1	1.6	0.2	1.6
FY21	11.2	1.1	0.7	1.1	1.6	0.0	1.0
FY22	11.2	1.1	0.7	1.1	1.6	0.0	0.4

Table 2.3. FTE allocations based on refined budget targets. Budget targets for non-data-collection components are converted to FTEs (bold) by assuming an approximate average cost of \$225k/FTE (some additional adjustments were made to balance staffing). [NFSN: National Fixed-Site Network; M, million]

Fiscal Year	National Monitoring and Status Assessment Team			Trend Analysis Team	SPARROW and WARP Modeling Team	Regional Synoptic Studies (RSS) Team	
	NFSN: Data Collection	NFSN: Network Management	Status Assessments and Data Management			RSS: Data Collection	RSS: Design, Analysis and Reporting
FY13	\$11.2M	5.0	3.0	5.5	7.0	\$5.9M	7.0
FY14	\$11.2M	5.0	3.0	5.5	7.0	\$5.0M	7.0
FY15	\$11.2M	5.0	3.0	5.5	7.0	\$4.1M	7.0
FY16	\$11.2M	5.0	3.0	5.5	7.0	\$3.3M	7.0
FY17	\$11.2M	5.0	3.0	5.5	7.0	\$2.4M	7.0
FY18	\$11.2M	5.0	3.0	5.5	7.0	\$1.6M	7.0
FY19	\$11.2M	5.0	3.0	5.5	7.0	\$0.9M	7.0
FY20	\$11.2M	5.0	3.0	5.5	7.0	\$0.2M	7.0
FY21	\$11.2M	5.0	3.0	5.5	7.0	\$0.0M	4.6
FY22	\$11.2M	5.0	3.0	5.5	7.0	\$0.0M	1.6

I. National Monitoring and Status Assessment

Introduction

National Monitoring and Status Assessment activities will be implemented by a national team that will have responsibility for five related activities and associated products:

1. **NFSN:** Managing the National Fixed Site Network.
2. **Annual Reporting:** Developing and producing consistent and timely online and routine annual reporting of water-quality conditions.
3. **Status Assessments:** Periodic interpretive status assessments for selected topics and geographic areas, including participation in national synthesis analyses that integrate monitoring and modeling results. .
4. **Data Management:** Aggregation, quality assurance, and management of USGS and non-USGS water quality data needed for support of all four Surface Water Assessment teams. These data management functions will be developed in coordination with related data management needs for all components of the NAWQA Cycle 3 design.
5. **Contaminant Toxicity and Properties:** Program-wide resource for Cycle 3 Surface Water and Groundwater studies. The Contaminant Toxicity and Properties Team will provide data and science assistance for planning and conducting evaluations of the potential significance of contaminant occurrence to human health and aquatic organisms, and for contaminant properties for modeling.

Each of these activities is described in more detail below, including relations to other NAWQA components, followed by an overview of the team composition.

A. National Fixed Site Network

NAWQA will characterize the status and trends of water quality and aquatic ecosystems by monitoring ambient water-quality and ecological conditions through a National Fixed Site Network (NFSN). The NFSN will be the primary source of data for timely tracking and systematic annual reporting of ambient conditions nationally. The NFSN will also be a primary source of data for periodic interpretive analysis of status and trends for selected topics and regions, but these more intensive interpretive analyses will also tap other sources of data, including compatible historical and current data from other monitoring networks and from NAWQA Regional Synoptic Studies.

Primary objectives to be addressed by the NFSN are:

1. Determine the status and trends in loads and concentrations of contaminants, nutrients, and sediment in the Nation's large rivers, including loads to selected major estuaries.
2. Determine the status and trends in concentrations of contaminants, nutrients, and sediment for case-study Wadeable streams in selected land-use and environmental settings.
3. Determine trends in ecological condition in relation to trends in contaminants, nutrients, sediment, and streamflow alteration for case-study Wadeable streams in selected land-use and environmental settings.

Site Selection

Relative to the NAWQA Cycle 2 NFSN design, the Cycle 3 NFSN will be modified to include:

- Every-year sampling at all sites, rather than the rotational schedule used in Cycle 2.
- Improved coverage of large river and coastal sites, including those in the National Stream-Accounting Network (NASQAN) and [National Monitoring Network](#) (NMN), as well as new or reactivated NAWQA sites in previously under-represented areas of the country.
- Reduced number of Wadeable stream sites in urban, agricultural, and reference watersheds.

- Addition of real-time monitoring at a subset of sites.

As described in this document, the new NFSN will include 19 large river coastal sites, 42 large river inland sites, 19 wadeable stream reference sites, 10 wadeable stream urban sites, and 10 wadeable stream agricultural sites. Some specific site-selection decisions are still under discussion; final decisions will be made in Spring 2012.

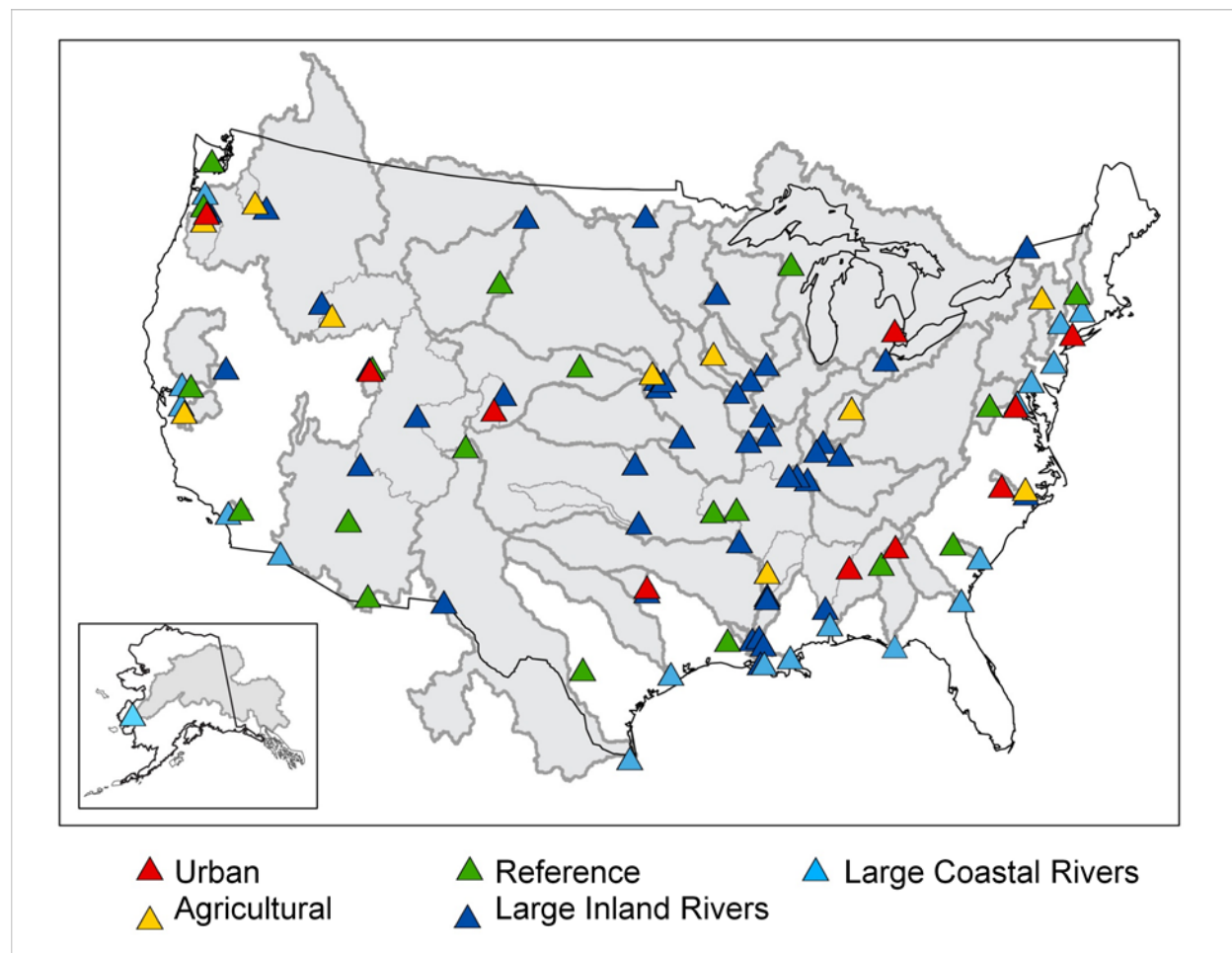


Figure 2.2. Locations of sites in the Cycle 3 National Fixed Site Monitoring Network. Drainage basin boundaries are outlined and shaded for all large river sites.

Large river sites

Monitoring sites on large coastal rivers and large inland rivers in the current funding scenario include most NAWQA Cycle 2 large river sites, plus all NASQAN and NMN sites. Table 2.4 summarizes the 61 large river sites in the Cycle 3 design. Coastal river sites are those that (1) are the most downstream site on a river draining directly to the coast and (2) represent 80 percent of the drainage area for a given river basin. (Note this is a change from the previous NASQAN definition of coastal sites, which defined coastal sites as those furthest downstream above head of tide that represented 90 percent of the drainage area for a given river basin.) All other sites are classified as inland rivers.

Table 2.4. Large river sites in the Cycle 3 National Fixed Site Network. Sites indicated as Co-op in the Cycle 2 affiliation are discussed further below.

Site number	Site name	Cycle 2 network affiliation ¹	Number of samples per year in Cycle 3
01184000	Connecticut River at Thompsonville, CT	NAWQA	18
01372043	Hudson River near Poughkeepsie, NY	NMN	14
01463500	Delaware River at Trenton, NJ	NMN	14
01578310	Susquehanna River at Conowingo, MD	NASQAN	14
01646580	Potomac River at Chain Bridge at Washington, DC ²	NAWQA	18
02089500	Neuse River at Kinston, NC	NAWQA	18
02175000	Edisto River near Givhans, SC	NAWQA	18
02226160	Altamaha River at Everett City, GA	NASQAN	14
02359170	Apalachicola River near Sumatra, FL	NMN	14
02469762	Tombigbee River near Coffeeville, AL	NAWQA	18
02470500	Mobile River at Mt. Vernon, AL	NASQAN	14
03303280	Ohio River at Cannelton Dam at Cannelton, IN	NASQAN	14
03374100	White River at Hazleton, IN	NAWQA	18
03378500	Wabash River at New Harmony, IN	NASQAN	14
03609750	Tennessee River at Highway 60 near Paducah, KY	NASQAN	14
03612500	Ohio River at Dam 53 near Grand Chain, IL	NASQAN	14
04193500	Maumee River at Waterville, OH	NAWQA	18
04264331	St. Lawrence River at Cornwall, Ontario, near Massena, NY	NASQAN	14
05082500	Red River of the North at Grand Forks, ND	Co-op	18
05331580	Mississippi River at Hastings, MN	NAWQA	14
05420500	Mississippi River at Clinton, IA	NASQAN	14
05465500	Iowa River at Wapello, IA	NASQAN	14
05490500	Des Moines River at Keosauqua, IA	NASQAN	14
05586100	Illinois River at Valley City, IL	NASQAN	14
05587455	Mississippi River Below Grafton, IL	NASQAN	14
06329500	Yellowstone River near Sidney, MT	NAWQA	14
06610000	Missouri River at Omaha, NE	NASQAN	14
06754000	South Platte River near Kersey, CO	NAWQA	18
06800500	Elkhorn River at Waterloo, NE	NAWQA	18
06805500	Platte River at Louisville, NE	NAWQA	14
06892350	Kansas River at DeSoto, KS	Co-op	14
06934500	Missouri River at Hermann, MO	NASQAN	14

07022000	Mississippi River at Thebes, IL	NASQAN	14
07144100	Lower Arkansas River near Sedgwick, KS	Co-op	18
07241550	North Canadian River near Harrah, OK	Co-op	18
07263620	Arkansas River at David D Terry Lock and Dam below Little Rock, AR	NASQAN	14
07288955	Yazoo River below Steele Bayou near Long Lake, MS	NAWQA	18
322023090544500	Mississippi River above Vicksburg, MS	NMN	14
07373420	Mississippi River near St. Francisville, LA	NASQAN	14
07374000	Mississippi River at Baton Rouge, LA	NASQAN	14
07374525	Mississippi River at Belle Chasse, LA	NASQAN	14
07381495	Atchafalaya River at Melville, LA ³	NASQAN	14
07381590	Wax Lake Outlet at Calumet, LA ⁴	NASQAN	14
07381600	Lower Atchafalaya River at Morgan City, LA ³	NASQAN	14
08057410	Trinity River below Dallas, TX	NAWQA	18
08116650	Brazos River near Rosharon, TX	NMN	14
08364000	Rio Grande at El Paso, TX	NAWQA	14
08475000	Rio Grande near Brownsville, TX	NASQAN	12
09163500	Colorado River near Colorado-Utah State Line	NAWQA	18
09380000	Colorado River at Lees Ferry, AZ	Former NASQAN, now Co-op	14
09522000	Colorado River at NIB, above Morelos Dam, AZ	NASQAN	12
10171000	Jordan River at Salt Lake City, UT	NAWQA	18
10350500	Truckee River at Clark, NV	NAWQA	18
11074000	Santa Ana River below Prado Dam, CA	NAWQA	18
11303500	San Joaquin River near Vernalis, CA	NAWQA	18
11447650	Sacramento River at Freeport, CA	NASQAN	14
12510500	Yakima River at Kiona, WA	NAWQA	18
13154500	Snake River at King Hill, ID	NAWQA	14
14211720	Willamette River at Portland, OR	NAWQA	18
14246900	Columbia River near Beaver Army Terminal, OR	NASQAN	12
15565447	Yukon River at Pilot Station, AK	NASQAN	7 (only 3 for pesticides)

¹ Five Co-op sites are currently being monitored through the Cooperative Water Program and were not monitored as part of NAWQA during Cycle 2. They are discussed in more detail below

² 78 percent of total drainage basin

³ Distributary of the Mississippi River

⁴ Distributary of the Atchafalaya River

Due to funding constraints, fifteen of the NAWQA Cycle 2 large river sites will not be included in the NFSN for Cycle 3. These sites were selected to be discontinued based on the following criteria: (1) drainage area less than 1,000 square miles, (2) location in the same HUC as another large river site, (3) marginal regional representation, and/or (4) short record of selected Cycle 3 target constituents (nutrients, pesticides, sediment, carbon) (Table 2.5). NASQAN and NMN sites were not considered for discontinuation, as they had been through earlier site screening and decision-making as part of the NASQAN ad hoc Technical Committee redesign in 2007.

Table 2.5. Cycle 2 NAWQA large river sites not included in the Cycle 3 National Fixed Site Network.

Site number	Site name	Rationale for discontinuing
01104615	Charles River near Watertown, MA	Drainage area is less than 1,000 square miles.
01357500	Mohawk River at Cohoes, NY	Site is in the same HUC6 as NMN site: 01372043 Hudson River near Poughkeepsie, NY
02318500	Withlacoochee River near Quitman, GA	Site is small and without large regional representation.
02338000	Chattahoochee River near Whitesburg, GA	Site is in the same HUC6 as NMN site: 02359170 Apalachicola River near Sumatra, FL
02424000	Cahaba River at Centreville, AL	Site is in the same HUC4 as NAWQA and NASQAN sites: 02469762 Tombigbee River near Coffeetown, AL 02470500 Mobile River at Mt. Vernon, AL Site has the shortest record of the three.
03467609	Nolichucky River near Lowland, TN	Site is small and without large regional representation.
03575100	Flint River near Brownsboro, AL	Drainage area is less than 1,000 square miles.
05532500	Des Plaines River at Riverside, IL	Drainage area is less than 1,000 square miles.
06279500	Bighorn River at Kane, WY	Site is in same HUC4 as NAWQA site 06329500 Yellowstone River at Sidney, which is larger and has a longer record.
06295000	Yellowstone River at Forsyth, MT	Site is in same HUC6 as NAWQA site 06329500 Yellowstone River at Sidney, which is larger and has a longer record.
07189000	Elk River near Tiff City, MO	Drainage area is less than 1,000 square miles.
08012150	Mermentau River at Mermentau, LA	Site is small and without large regional representation.
09517000	Hassayampa River near Arlington, AZ	Site is heavily influenced by WWTP effluent in Phoenix; atypical large river site.
10311400	Carson River near Carson City, NV	Drainage area is less than 1,000 square miles.
13056500	Henrys Fork near Rexburg, ID	Site is in same HUC6 as NAWQA site 13154500 Snake River at King Hill, ID, which is larger and has a longer record.

To provide coverage of geographic gaps, five new large river sites were selected for NAWQA support to be added as part of the NFSN (and are included in Table 2.4 with a Cycle 2 network affiliation as “Co-op”). These sites were selected by the following criteria: (1) coverage of a geographic gap in the NFSN, (2) long record of selected Cycle 3 target constituents, (3) location in a discontinued or never started NAWQA study unit, (4) discontinued NASQAN or NAWQA site, (5) cost-share potential, and (6) presence

of continuous monitors. The rationale for including each of these sites is summarized in Table 2.6. New Cycle 3 sites and discontinued Cycle 2 sites are shown in Figure 2.3.

Table 2.6-New large inland river sites added to improve geographic coverage in the Cycle 3 National Fixed Site Network

Site number	Site name	Rationale for including
05082500	Red River of the North at Grand Forks, ND	Fills geographic gap. Located in a discontinued NAWQA study unit. Long record, especially when cooperative data is included. Currently contains a supergage with continuous monitoring. Cost-share potential. Note: easier to sample than Red River of the North at Pembina, ND.
06892350	Kansas River at DeSoto, KS	Fills geographic gap. Located in a never started NAWQA study unit (the Kansas was a pilot study unit). Long record. Cost-share potential.
07144100	Lower Arkansas River near Sedgwick, KS	Fills geographic gap. Located in a never started NAWQA study unit. Long record. Cost-share potential.
07241550	North Canadian River near Harrah, OK	Fills geographic gap. Located in a never started NAWQA study unit. Long record. Cost-share potential.
09380000	Colorado River at Lees Ferry, AZ	Fills geographic gap. Discontinued NASQAN site (since 2000). Long record. Cost-share potential. Note: overlap with Water Census.

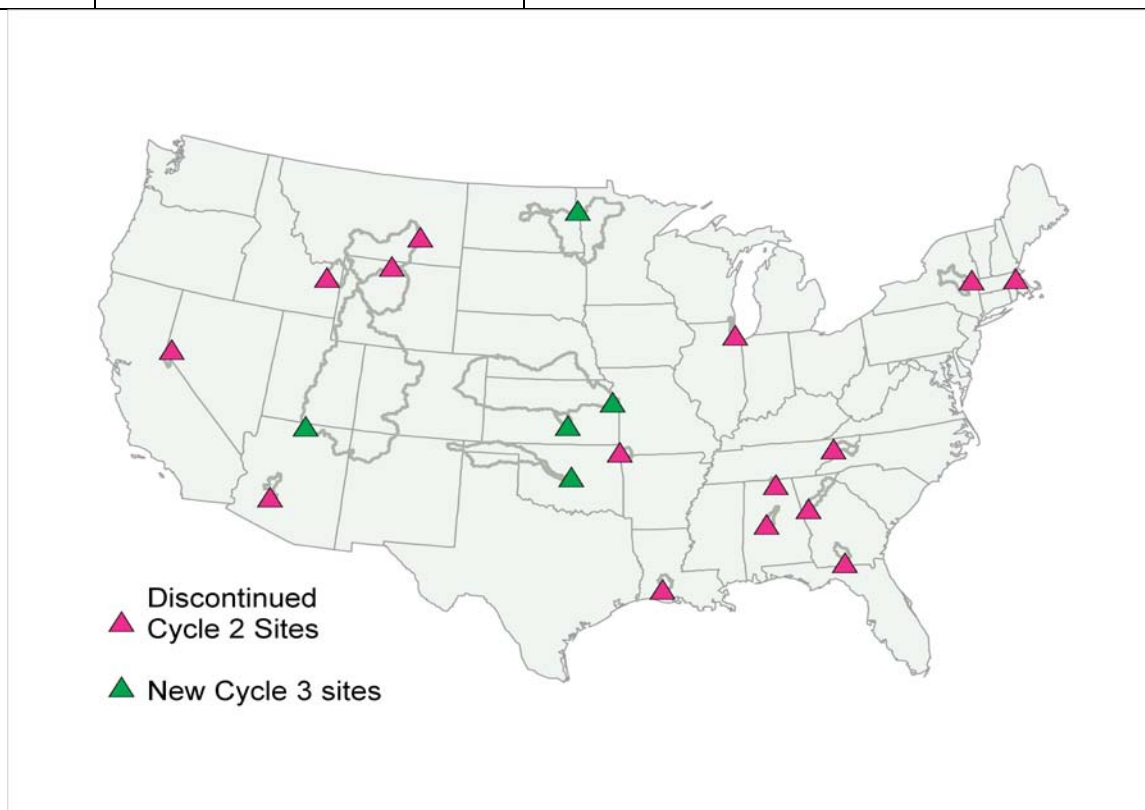


Figure 2.3.New Cycle 3 large river sites and discontinued Cycle 2 sites.

NASQAN is presently sampling six sites in the lower Mississippi River Basin. Beginning with NASQAN II in 1996, the NASQAN program sampled only two sites in the Lower Mississippi River Basin [the Mississippi River near St. Francisville LA (site 07373420 at river mile 266) and the Atchafalaya River at Melville, LA (site 07381495 at river mile 107)]. During the review of NASQAN II basin work plans in 2000, some scientists began advocating that these NASQAN sampling sites be moved further downstream and(or) that there be expanded monitoring in this region of the Mississippi River Basin. After prolonged discussion, two additional downstream sites were added on both the Mississippi and Atchafalaya Rivers: at Baton Rouge (site 07374000 at river mile 231; added in 2004) and Belle Chasse (site 07374525 at river mile 76; added in 2006) on the Mississippi River and at Morgan City (site 07381600 at river mile 18; added in 2006) and Wax Lake Outlet (site 07381590; added in 2006) on the Atchafalaya River. The intention was to collect concurrent data at the six sites for several years and then, based on an analysis of the data, select sites that best meet the needs for monitoring nutrient delivery to the Gulf of Mexico (Aulenbach and others, 2007).

Recent analyses of data from these sites indicate that concentrations of sediment and sediment-associated constituents (principally total phosphorus) as well as orthophosphate are significantly different at the Mississippi River at St. Francisville compared to the Mississippi River at Baton Rouge and Belle Chasse sites. There are similar differences between the Mississippi River at Baton Rouge and Belle Chasse. Likewise there are differences between the sites on the Atchafalaya River at Melville and Morgan City and Wax Lake Outlet. Differences between the sites on Wax Lake Outlet and the Atchafalaya River at Morgan City are minimal, however. Therefore, we could consider dropping the sites on the Mississippi River at Baton Rouge and Wax Lake Outlet to free up resources for monitoring elsewhere, while keeping the remaining four sites in the Lower Mississippi River Basin. The Baton Rouge site is bracketed by the St. Francisville and Belle Chasse sites, while the water quality in Wax Lake is reasonably approximated by the site on the Atchafalaya River at Morgan City. In place of these two discontinued sites, other sites could be added for the same cost, improving the geographic coverage of the NFSN and NAWQA's ability to address other important policy issues. Alternatively, the funds could be used to cost share the operation of continuous monitors already located at NAWQA sites where future cooperator funding is uncertain.

Urban stream sites

Wadeable urban streams in the current funding scenario are limited to ten sites, selected from the Intensive Urban Indicator sites and Effects of Urbanization on Stream Ecosystems (EUSE) topical study sites monitored in Cycles 1 and 2. These sites will provide information on water-quality and ecological status and trends in urban areas. Fully representative national coverage is not possible with only ten sites, so examples of urban streams in major environmental settings across the nation were selected. Criteria used to identify the ten urban sites were: (1) broad geographic coverage, (2) long record of selected Cycle 3 target constituents, (3) former EUSE sites to build on insights gained in Cycle 2, (4) an overall mix of stable urban and urbanizing sites to allow for an examination of the impacts of both on-going urbanization in transitional urban areas and the implementation of urban management practices in established urban areas, and (5) geographic proximity to urban coring trend sites (Table 2.7).

Table 2.7. Urban stream sites included in the Cycle 3 National Fixed Site Network. Locations are shown on Figure 2.2.

Site Number	Site Name	% of basin in crop land use in 2006	% of basin in urban land use in 2006	Average % change in population (per decade), 1990-2010	Rationale for including	Number of samples per year in Cycle 3
01209710	Norwalk River at Winnipauk, CT	1.8	28.0	7.5	Long record.	24
01654000	Accotink Creek near Annandale, VA	0.4	72.1	11.6	Long record. Near urban coring site.	24
02087580	Swift Creek near Apex, NC	2.3	75.4	35.3	EUSE site with long record. Near urban coring site.	24
02335870	Sope Creek near Marietta, GA	0.7	76.7	7.1	EUSE site with long record. Near urban coring site.	24
0242354750	Cahaba Valley Creek at Pelham, AL	5.6	31.8	14.3	EUSE site with long record.	24
04161820	Clinton River at Sterling Heights, MI	9.4	48.8	8.5	Long record.	24
06713500	Cherry Creek at Denver, CO ¹	0.6	21.7	43.3	EUSE site with long record.	24
08057200	White Rock Creek at Dallas, TX	2.6	92.9	30.7	Long record. Overlap with urban coring site.	24
10168000	Little Cottonwood Creek at Salt Lake City, UT	0.1	29.1	0.0	Very close to EUSE site; long record. Near urban coring site.	24
14206950	Fanno Creek at Durham, OR	0.7	89.0	16.9	EUSE site with long record.	24

¹ Based on total, not contributing, drainage area

Agricultural stream sites

Wadeable agricultural streams in the current funding scenario are limited to ten sites, selected from the Intensive Agricultural Indicator sites and Agricultural Chemicals: Sources, Transport, and Fate (ACT) topical study sites in Cycles 1 and 2. These sites will provide case-study level information on water-quality and ecological status and trends in agricultural areas. Fully representative national coverage is not possible with only ten sites, so examples of agricultural streams in major agricultural and environmental settings across the nation were selected. Criteria used to identify the ten case-study agricultural sites were: (1) broad geographic and crop-type coverage, (2) long record of selected Cycle 3 target constituents, and (3) former ACT sites to build on insights gained in Cycle 2 (Table 2.8). Using the 2006 NLCD, some of these sites do not meet the commonly used NAWQA criteria for classification as an agricultural site (>25 percent agricultural land cover and <5 percent urban land cover) (Table 2.8). Because of changes in the processing of land-cover data since the 1990's (notably an apparent increase in the accounting of urban land area), NAWQA's approach to classifying agricultural sites will likely need to change to include sites with >25 percent agricultural land cover and <10 percent urban land cover. This change is supported by changes in the population data, which was measured consistently between 1990 and 2010 through the Census of Population. Population decreased at several sites where land-

cover data indicated an increase in urban area—this suggests that some part of the change in urban area at all sites was due to a change in processing of the land-cover data rather than an actual increase in urban area.

Table 2.8. Agricultural stream sites included in the Cycle 3 National Fixed Site Network. Locations are shown in Figure 2.2.

Site Number	Site Name	% of basin in crop land use in 2006	% of basin in urban land use in 2006	Average % change in harvested cropland (per 5 years), 1992-2007	Average % change in population (per decade), 1990-2010	Rationale for including	Number of samples per year in Cycle 3
01349150	Canajoharie Creek near Canajoharie, NY	59.7	6.2	-7.6	0.1	Long record.	24
02091500	Contentnea Creek at Hookerton, NC	43.9	9.5	-6.6	16.0	Excellent record for nutrients and sediment.	24
394340085524601	Sugar Creek at New Palestine, IN	84.7	7.6	0.7	9.3	ACT site with long record.	24
05451210	South Fork Iowa River near New Providence, IA	88.3	6.7	0.7	-9.1	ACT site with long record.	24
06800000	Maple Creek near Nickerson, NE	81.5	4.6	-0.8	-7.6	ACT site with long record.	24
07288650	Bogue Phalia near Leland, MS	87.5	4.3	-0.7	-4.3	ACT site with long record.	24
11274538	Orestimba Creek near Crows Landing, CA	86.8	7.4	-1.4	-14.5	Long record. Note: Site has smaller area and less complicated drainage than Merced River (which was an ACT site).	24
12505450	Granger Drain at Granger, WA	56.7	7.9	-1.7 ¹	11.6	ACT site.	24
13092747	Rock Creek at Twin Falls, ID ²	24.6	3.5	-1.2	29.7	Long record.	24
14201300	Zollner Creek near Mt. Angel, OR	87.9	7.2	-2.3	5.7	Long record.	24

¹ Excludes 1997 due to lack of data

² Based on total, not contributing, drainage area

Reference stream sites

Wadeable reference streams in the current funding scenario are undeveloped reference sites in the NAWQA Cycle 2 network and do not include the Cycle 2 relative reference sites, which included watersheds where some development is present but ecological communities are as undisturbed as could be found in the study unit. These Cycle 3 reference sites include three sites that are in the Hydrologic Benchmark Network (HBN) and some Cycle 2 ecology-only NAWQA reference sites. Table 2.9 lists the Cycle 3 reference sites.

Table 2.9. Reference sites included in the Cycle 3 National Fixed Site Network. Locations are shown on Fig. 2.2.

Site number	Site name	Cycle 2 site type	Number of samples per year in Cycle 3
01170100	Green River near Colrain, MA	rotate4	6
01610400	Waites Run near Wardensville, WV	rotate4	6
02172300	McTier Creek near Monetta, SC	rotate4	6
02338523	Hillbahatchee Creek near Franklin, GA	rotate4	6
04063700	Popple River near Fence, WI	rotate4, HBN	6
06324970	Little Powder River near Weston, WY	rotate4	6
06775900	Dismal River near Thedford, NE	ecology only	6
07055646	Buffalo River near Boxley, AR	rotate4	6
07060710	North Sylamore Creek near Fifty Six, AR	rotate4, HBN	6
08014500	Whisky Chitto Creek near Oberlin, LA	rotate4	6
08195000	Frio River at Concan, TX	ecology only	6
08227000	Saguache Creek near Saguache, CO	ecology only	6
09471000	San Pedro River at Charleston, AZ	rotate4	6
09505800	West Clear Creek near Camp Verde, AZ	rotate4	6
10172200	Red Butte Creek at Fort Douglas near Salt Lake City, UT	rotate4, HBN	6
11049400	Santa Ana River above Seven Oaks Dam, CA	ecology only	6
11335000	Cosumnes River at Michigan Bar, CA	ecology only	6
12056500	North Fork Skokomish River near Hdsprt, WA	ecology only	6
14205400	East Fork Dairy Creek near Meachan Corner, OR	rotate4	6

Data Collection

Water Chemistry

Laboratory schedules for sites in the NFSN in Cycle 3 will follow the NASQAN approach used during Cycle 2, with the addition of updated analytical methods. This approach includes more constituents than had previously been included at NAWQA sites in Cycle 2. Water-chemistry samples collected at all sites in the NFSN will include suspended sediment (concentration and sand/fine split), nutrients and organic carbon (lab schedules 997/1010/1069, with updates for the new nitrogen method currently in prove out), pesticides (replacement method for Schedule 2033, currently in development at the National Water-Quality Laboratory), major ions and miscellaneous trace elements (Schedule 998/1201), inorganic carbon and ultraviolet absorbing organic constituents (Lab code 8096 and 8097), and field parameters (including alkalinity). Pesticide samples will not be collected at reference sites.

At most NASQAN and NMN large river sites, plus the six NAWQA large river sites with drainage areas greater than 30,000 mi², a total of 14 water-quality samples per year will be collected (table 2.10)—six at bimonthly fixed intervals and eight at seasonally weighted fixed intervals during periods of high variability in concentration and load. [Samples will be collected twice per month (about every two weeks) during these periods of high variability.] The seasonally-weighted fixed-interval sampling scheme eliminates the bias that is introduced into trend analyses if samples are artificially inserted into the time series by specifically targeting high flows. The high-flow samples obtained will instead be a part of a seasonally random time series.

Table 2.10. Overview of Cycle 3 National Fixed Site Network sampling strategy by site type.

Site type	Samples per year	Sampling approach	Report table with sites
(1) Most NASQAN and NMN sites and (2) NAWQA large river sites with drainage areas > 30,000 mi ²	14	6 at bimonthly fixed intervals and 8 at seasonally weighted fixed intervals during periods of high variability in concentration and load	Table 2.4
Three NASQAN sites	12	6 at bimonthly fixed intervals and 6 at seasonally weighted fixed intervals during periods of high variability in concentration and load	Table 2.4
Yukon River at Pilot Station, AK	7	7 during warm season; pesticide analysis for 3 samples per year	Table 2.4
NAWQA large river sites with drainage areas < 30,000 mi ²	18	6 bimonthly at fixed intervals and 12 at seasonally weighted fixed intervals during periods of high variability in concentration and load	Table 2.4
Urban and agricultural sites	24	12 monthly fixed intervals and 12 at seasonally weighted fixed intervals during periods of (1) high variability in concentration and (2) fertilizer and pesticide application	Tables 2.7 and 2.8
Reference sites	6	6 bimonthly samples	Table 2.9

Four NASQAN large river sites will be sampled less frequently than described above. Only 12 water-quality samples per year will be collected at the most downstream sites on the Rio Grande, Colorado, and Columbia Rivers, where fewer samples are needed to represent the variability in concentration and load (Table 2.4). These 12 samples will be distributed as six at bimonthly fixed intervals and six at seasonally weighted fixed intervals during periods of high variability in concentration and load. In addition, because of seasonal access limitations, water-chemistry samples will be collected at the Yukon River site only seven times per year; however, pesticide samples will be collected only three times per year at the Yukon River site.

At the remaining NAWQA large river sites (those with drainage areas less than 30,000 mi²), a total of 18 water-chemistry samples will be collected each year (Table 2.4)—six bimonthly at fixed intervals and twelve at seasonally weighted fixed intervals during periods of high variability in concentration and load. The higher sampling frequency at these sites relative to the larger sites is due to greater expected variability in concentration throughout the year at the smaller large river sites.

At the urban and agricultural sites, a total of 24 water-chemistry samples will be collected each year (Tables 2.7 and 2.8)—twelve monthly fixed intervals and 12 at seasonally weighted fixed intervals during periods of (1) high variability in concentration and (2) fertilizer and pesticide application. These two periods will coincide in some areas but not others. Some sites might require more than 12 seasonally weighted fixed interval samples; monthly fixed interval sampling could be reduced to accommodate additional seasonally weighted samples or additional funds will need to be allocated.

At reference sites (Table 2.9), which are expected to have less variability in concentration, a total of 6 bimonthly water-chemistry samples will be collected. If costs allow, another sample coincident with ecology sampling should be added to provide additional information and flexibility for analyses of ecological stressors. No additional collection costs would be incurred for this seventh sample; the only additional cost would be for laboratory analysis (and this cost would exclude pesticides, which are not included in reference-site sampling).

Ecology

Ecological data collection at the 10 urban, 10 agricultural, and 19 reference sites will follow established NAWQA protocols outlined in Moulton and others (2002). These protocols were revised during Cycle 2 and will be implemented in Cycle 3 to maintain continuity between cycles. Richest Targeted Habitat (RTH) and Qualitative Multi-Habitat (QMH) invertebrate samples will be acquired at designated reaches at all agricultural, urban, and reference sites in Cycle 3. RTH algal samples, Chlorophyll A and ash-free dry mass will also be collected. All invertebrate samples will be sent to USGS National Water Quality Laboratory for analysis. The laboratory will use a quantitative fixed-count processing method to estimate the abundance of each taxon. Disposition of algal samples in Cycle 3 is yet to be determined. Fish will be sampled in each Cycle 3 stream reach following the standard NAWQA 2-pass methodology. Habitat samples will be collected in conjunction with ecological samples following the protocols outlined in Fitzpatrick and others (1998). Modifications to habitat protocols will be considered during Cycle 3; any changes will be communicated to Water Science Centers (WSCs). Ecological samples will be collected annually during pre-established index periods which last for 1.5 months and differ depending on latitudinal and longitudinal positioning.

Real-time monitors

Real-time monitors will be included at approximately 5 percent of the sites in the NFSN (Table 2.11).

Table 2.11. National Fixed Site Network locations with NAWQA-supported real-time monitors in Cycle 3.

Site number	Site name
01646580	Potomac River at Chain Bridge at Washington, DC ¹
03612500	Ohio River at Dam 53 near Grand Chain, IL
06934500	Missouri River at Hermann, MO
07022000	Mississippi River at Thebes, IL
07374000	Mississippi River at Baton Rouge, LA

¹ The real-time monitor is at the Potomac River near Washington DC 01646500

The instrumentation is already in place at these sites (or is being installed in FY 2012). Real-time temperature, dissolved oxygen, specific conductance, pH, nitrate, fluorescent dissolved organic matter (FDOM), and turbidity will be measured in Cycle 3. A primary goal of this real-time monitoring is to better identify the timing and magnitude of nutrient and sediment concentrations and loads from large coastal tributaries. In addition, all urban and agricultural stream sites will have real-time temperature monitoring.

Real-time monitoring will initially focus on 1) developing the necessary physical and cyber-infrastructure to efficiently manage sensors and make data available in real-time in NWIS, 2) implementing strategies and algorithms for dealing with potential instrument interferences (e.g. turbidity, color, and temperature), and 3) training local field staff and NAWQA personnel in sensor operation and maintenance. Currently in Cycle 2, plans are in place for development of an interpretive report comparing nitrate trends and loads for the first complete year using both discrete and continuous data in the Potomac River and Mississippi River. Based on these efforts, a USGS Techniques and Methods report for the operation of continuous optical sensors will be prepared early in Cycle 3 to support continued monitoring at the 5 percent of NFSN sites and any others that may be added to the network. This report will describe standard operating procedures for the maintenance and servicing of optical sensors, advanced techniques for data management and QA/QC of continuous water-quality data through the collection of “burst samples” at 15 minute sampling intervals, and data transmission through traditional USGS portals (e.g. loggers to NWIS) and cellular modems for real-time QA/QC and post-processing.

Limited continuous data currently are available from monitoring of dissolved oxygen, specific conductance, temperature, and pH at trend sites early in Cycle 3. Analysis of these data during FY2012 or early in Cycle 3 may provide additional insights into the benefits of continuous data; continuous monitoring of selected constituents at additional sites in the NFSN might be beneficial in Cycle 3. For example, recent work by Ward Sanford using specific conductance as a chemical tracer in the Chesapeake Bay watershed suggests that graphical separation techniques may underestimate groundwater discharge and therefore underestimate the lag time effect on nitrate delivery to streams. If these initial findings could be corroborated using the more geographically extensive data collected early in Cycle 3, continuous monitoring of specific conductance at more sites in the NFSN could be warranted in Cycle 3, particularly given the emphasis on groundwater inputs and lag times in multiple program components in Cycle 3.

In addition, a larger network of nitrate sensors in Cycle 3 could provide an early warning of problems to managers, allow for evaluation of long-term trends with improved accuracy, and establish additional capacity to evaluate the effects of management actions on water quality. Numerous national reviews have highlighted the need for such a network using advanced sensors to assess inland and coastal water quality, evaluate changes in nutrient and carbon cycling, and protect coastal resources (National Science

and Technology Council Committee on Environment and Natural Resources, 2007; US Commission on Ocean Policy, 2004). A network of in-situ nitrate sensors established and operated by the NAWQA program in collaboration with other programs could address this need.

According to NWISweb, additional real-time monitors for selected constituents are in place at other sites recommended for the NFSN; these monitors are funded by other programs (Table 2.12). If funding to support real-time monitoring were discontinued at these sites, NAWQA could consider providing supplemental funding. The cost would be relatively small (estimated at \$10,000-\$15,000 per site per year), as the instrumentation is already installed. In evaluating such options, however, the sources and stability of support for long-term operation need to be considered.

Table 2.12. Additional National Fixed Site Network sites with real-time monitors currently in place that are funded by other programs.

Site number	Site name
01463500	Delaware River at Trenton NJ
03374100	White River at Hazleton, IN
04063700	Popple River near Fence, WI
05082500	Red River of the North at Grand Forks, ND
05451210	South Fork Iowa River NE of New Providence, IA
05586100	Illinois River at Valley City, IL
06800500	Elkhorn River at Waterloo, NE
06805500	Platte River at Louisville, NE
07144100	Lower Arkansas River near Sedgwick, KS
07241550	North Canadian River near Harrah, OK
08364000	Rio Grande at El Paso, TX
09163500	Colorado River near Colorado-Utah State Line
09380000	Colorado River at Lees Ferry, AZ
11274538	Orestimba Creek at River Rd near Crows Landing, CA
11447650	Sacramento River at Freeport, CA
14206950	Fanno Creek at Durham, OR
14211720	Willamette River at Portland, OR

Quality-Assurance/Quality-Control Plan

The types and numbers of QA/QC samples to be collected in Cycle 3 will follow precedents established in Cycle 2. These will be specified in more detail in the surface-water plans disseminated with annual workplan guidance.

WSC personnel will be responsible for data review, rerun requests, and timely responses to contamination problems and other data issues. These personnel may not always be affiliated with other on-going NAWQA work. This is a change from Cycles 1 and 2 of NAWQA and has resulted from the move away from a study-unit based organization. NASQAN sampling, however, has always been coordinated directly with WSC personnel. Secondary review of data from the NFSN will be conducted by national

NAWQA staff through an automated program currently integrated into the NAWQA Data Warehouse. This program will be reviewed and revised as needed in FY12 or FY13.

Training

Sampling personnel from each WSC with sampling responsibility will be required to take Field Water-Quality Methods for Ground-Water and Surface-Water if they have not had any such training in the past, or Water Quality Field Methods Refresher if they have not had any field methods training in the last 5 years. Both classes will provide focused training on sampling methods that are new to NAWQA (including carbon sampling and new nutrient and pesticide methods). During the remainder of Cycle 2, the NAWQA program will coordinate with Office of Water Quality to ensure that needed updates to the classes are incorporated and that all students can be accommodated in FY13. This may necessitate offering additional field methods courses in FY13.

In addition, ecology-sampling personnel will be required to take the Ecology Field Methods Course if they have not had the training in the past 5 years. This may require the NAWQA program to invest in materials and staff time for course development and instruction in FY13.

Budget and Staffing

The annual funding target for data collection as part of the NFSN is \$11.2 million in FY13 dollars. This includes staff time and equipment/supply costs for water-quality and ecology sample collection and streamgauge operation (if not covered by a cooperator or non-USGS agency), as well as laboratory analyses. This target is from the allocation plan developed by the Cycle 3 Planning Team and the NLT. It protects the NFSN data collection from inflation so that a consistent monitoring design can be implemented across the full Cycle. Thus, in each subsequent year, the NFSN budget will be adjusted upward to incorporate increased costs due to inflation.

Water-quality and ecology samples will be collected by staff from the WSCs. For sites that were sampled during Cycle 2, these costs have already been established. For new sites, cost-share will be worked out with WSC staff prior to the start of Cycle 3. Management and data analysis staffing is summarized separately as part of the plan for the National Monitoring and Status Assessment Team.

B. Annual Reporting

The goal of the standardized annual reporting is to develop a consistent and timely set of products derived from the NFSN that provides basic information and data from the fixed sites on an annual basis on a NFSN web page. The annual reporting is a new product type for NAWQA for Cycle 3, but is closely related to products that have been initiated for NASQAN. The annual reporting products will not be highly interpretive, or based on in-depth analysis each year, and will be entirely or primarily based on data from the NFSN. Other compatible monitoring data collected by other programs and agencies may be selectively used, but the timeliness and consistency requirements for the annual products will constrain most uses of other data. Standardized information will be updated on an annual or semi-annual basis on the web. The initial product for the annual reports would include an annual data aggregation that would be the basis or the foundation of the web-based reports, and that would also provide timely public access to the complete dataset.

Standardized web-based reports - The standardized annual reports will include basic information on individual site characteristics and a series of graphics that display hydrologic conditions, concentrations, and loads for selected constituents. The following example is meant to convey a candidate approach for annual reporting for all sites in the NFSN—specific and final details for annual reporting will be developed early in Cycle 3. A standardized format would be developed for a set of consistent annual

products (turn key products) that are updated once a year with a strong emphasis on timeliness, soon after the water year or a season ends. Current NASQAN annual reporting and access to data will be used as a benchmark for developing Cycle 3 annual web-based products. This will be accomplished by expanding the NASQAN reporting by including more data summaries and a larger group of constituents. NASQAN currently focuses on nutrients; therefore, as part of the Cycle 3 annual reporting process, novel methods and approaches will be developed for reporting temporal and spatial patterns and distributions of concentration, annual frequency of benchmark exceedances, and reporting of additional contaminants, such as pesticides, sediment, salinity, and carbon collected at sites in the NFSN. Where appropriate, load estimates will be presented as well. Initial consideration for annual reporting on load estimates will be given to nitrogen, phosphorus, sediment, carbon, and silica.

On-line Annual Reporting Page-A link from the Cycle 3 web page to the NFSN network web page would be the access point for the on-line annual reporting page. One example would be to create a link from the annual-reporting page "site map" that would be designed to show information on each fixed site in the NFSN or on a subset of sites (defined by specific designation, such as by river basin or region or by site types, such as urban, agricultural, reference, large rivers, etc.) that represents the gateway to the more comprehensive annual report page for the individual or grouped sites. Such a page would include some basic information about the site, some characteristics about the basin and its predominant land uses and physical features, and general information on the hydrology or the streamflow characteristics for the current water year that just ended compared to previous years (fig. 2.4). Such information will allow a user to determine whether the current year was a wet, dry, or an average year. Showing general site characteristics is important because as users view the data or graphics that are developed for this type of on-line report, there is a need to put those data into context based on streamflow conditions.

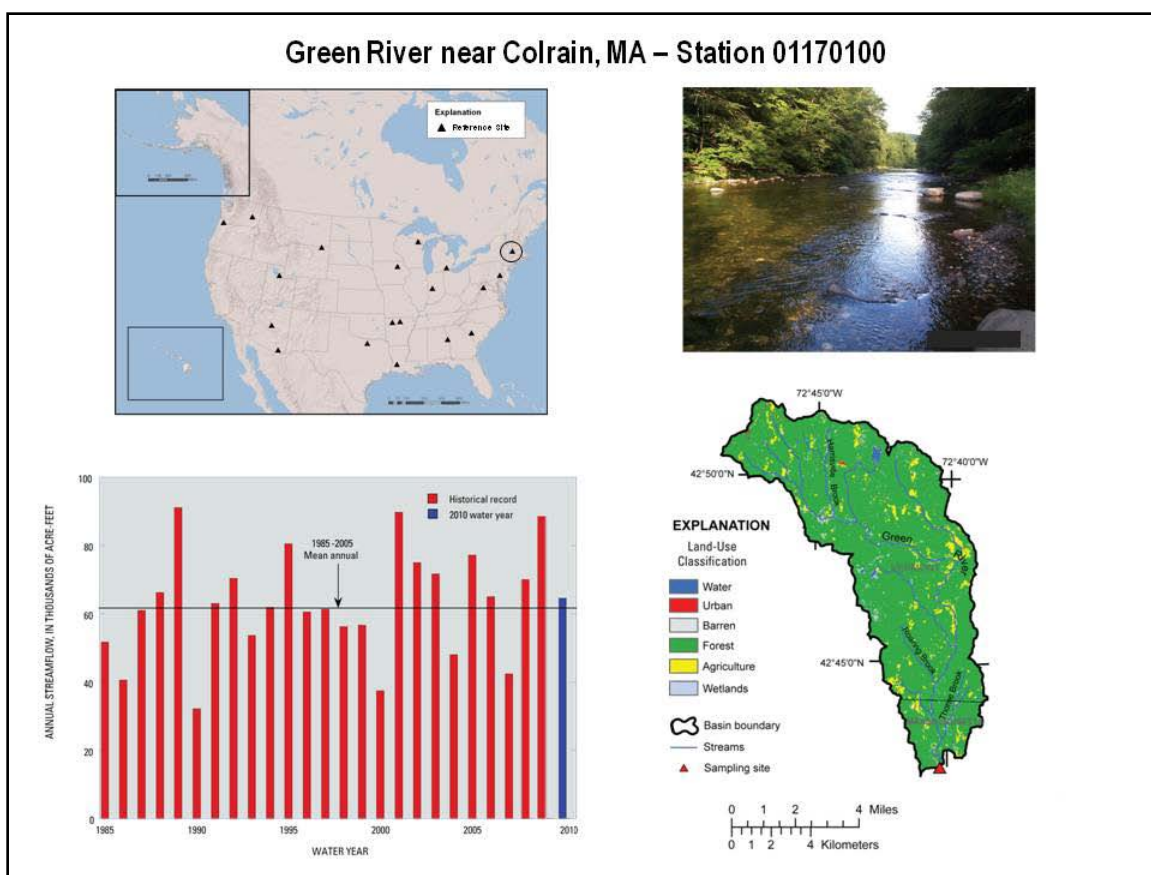


Figure 2.4-Example of a possible 'front page' to an annual report.

Flow and Water-Quality Information Page—Besides general site characteristics (fig. 2.4), the next series of information or data that could be presented in an on-line annual report could take on an appearance similar to that presented in Figure 2.5. This enhanced annual on-line data reporting would include information on the sample distribution throughout time, season, and the flow regime, and the results of water-quality samples collected that year (for example, concentrations of total nitrogen or chloride). Water-quality samples could be plotted along a flow duration curve to indicate correspondence to changes in flow characteristics across the water year or to identify flow conditions when specific samples were taken (fig. 2.5). Two examples are shown in Figure 2.5 which displays the concentrations of total nitrogen and chloride. In the total nitrogen example (fig. 2.5C), concentrations are plotted relative to streamflow but are also compared to the historic data for total nitrogen at this site. This allows a user to compare the concentrations of a specific constituent for the current year with that of a previous year and evaluate how concentrations differ in response to streamflow conditions. The chloride example (fig. 2.5D) is a time-series plot displaying monthly concentrations compared to an existing USEPA recommended water-quality criterion. Chloride in streams is a concern for many State water-resource managers and policy makers, especially in the northeast where road salting and its effects on aquatic biota are a source of impairment. Depending on constituents of interest, this kind of data reporting could be targeted to support regional scale issues based on a subset of sites in the NFSN. For example, pesticide concentrations at agricultural sites in the Midwest could be compared to pesticide toxicity indices and provide managers with insight concerning concentrations of pesticides that might be of concern from an ecological standpoint.

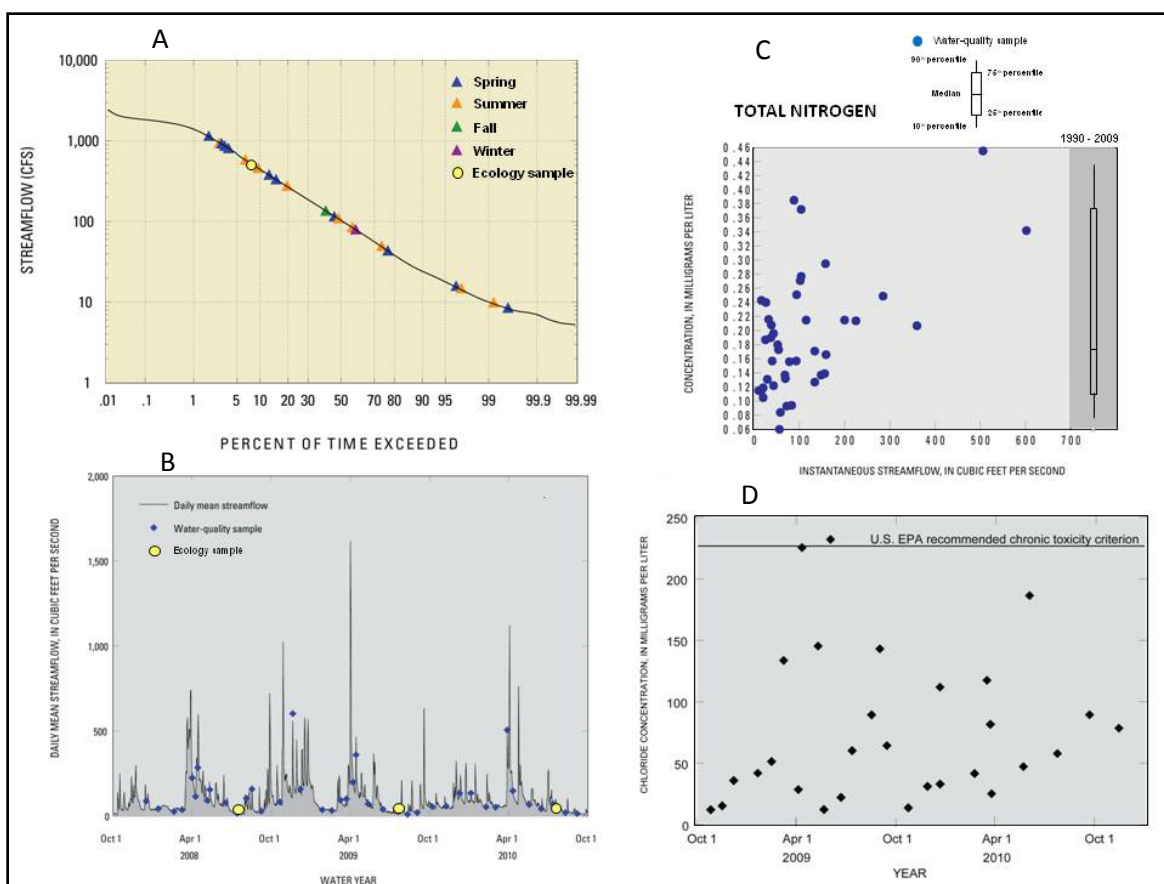


Figure 2.5. Example graphics page illustrating patterns in the sampling distribution and in concentration.

Constituent Load Estimates Page—Loads of selected constituents will be reported for coastal and upstream tributary sites. The loads from inland tributaries would be used to assist with characterizing the relative importance of different source areas, information that is crucial to the targeting of restoration or remediation activities. Figure 2.6 is an example of a product that has impact and relevance to resource managers and represents the type of graphics that could be used for displaying changes in annual nutrient loads. In particular, the data used to develop the graphic in Figure 2.6A displays the month of May's dissolved nitrate load to the Gulf of Mexico, which, on the third axis is displayed as being directly related to the extent of hypoxia in the Gulf. The lower time series graphic (fig. 2.6B) shows the variability in total nitrogen loads from 1998 to 2010 relative to the long-term moving average and a nitrogen reduction target. This is the type of annual reporting that has already been identified as being of high value and impact. This type of reporting may have the greatest impact in specific regions within, for example, the Mississippi River basin.

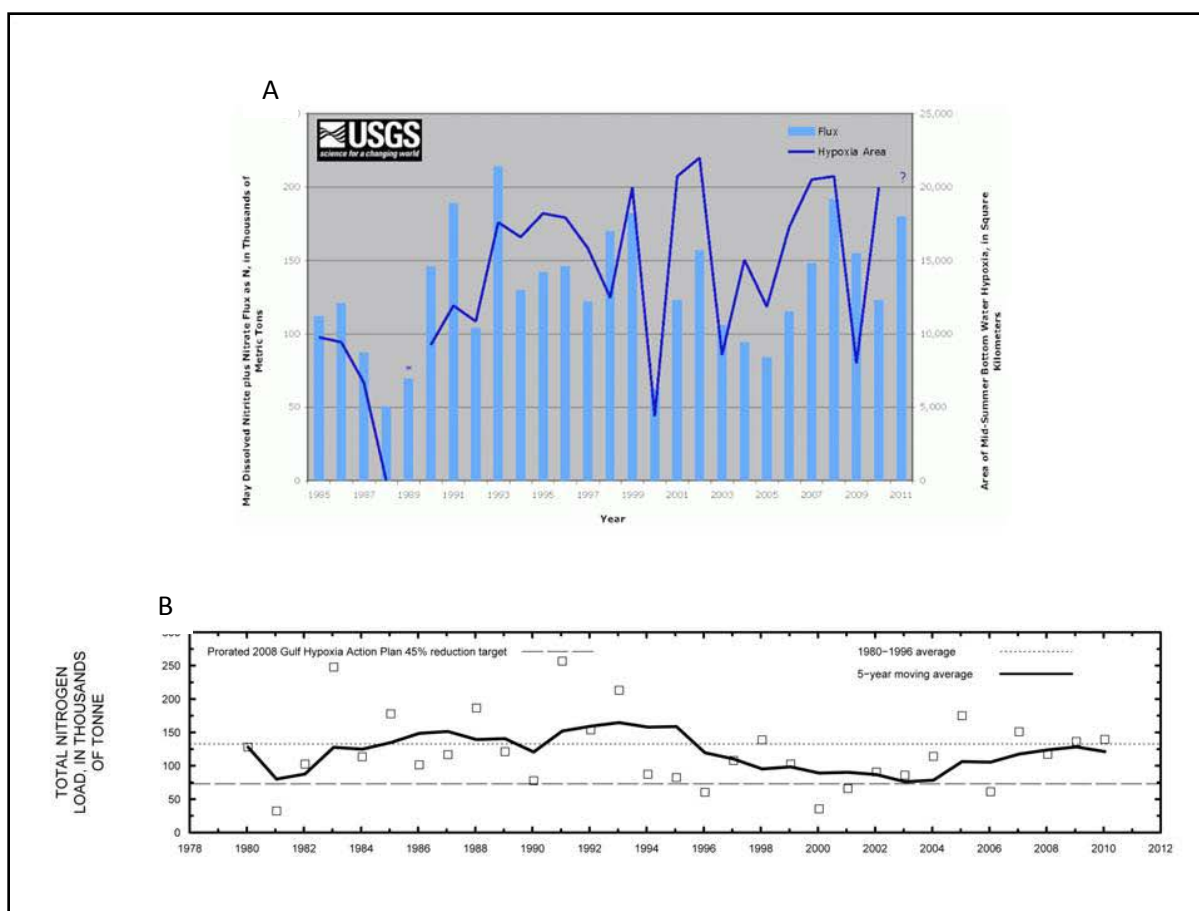


Figure 2.6. Example of graphics page illustrating constituent load characteristics.

Ecological Data Page—Web based annual reporting of ecological data collected at the NFSN sites could be represented, as shown in Figure 2.7, using a combination of taxonomic metrics and complementary physical/chemical variables. For example, the plots shown in figures 2.7A and B depict trends at two urban sites and show the relation between assemblage metrics and hydrologic variables. Little Neshaminy Creek (fig. 2.7A) shows an association between declining “intolerant” fish species and a decline in the magnitude of monthly low flows for May. The month of May is a critical time for fish life cycles and a decline in low flows during that period could potentially effect spawning, reproduction, and migration. For Lisha Kill Creek (fig. 2.7B), there is distinct decline in the percent of EPT taxa from the early 1990’s to 2008. During this period, the magnitude of high flows for June has increased which may indicate that this stream is becoming flashier and there is a higher potential for scouring to occur. Hydrologic disturbance is known to directly affect the life history and survival of sensitive fauna such as those included in the EPT metric. These plots represent a possible example of how ecological data could be incorporated into annual reports by using simple metrics. The metrics selected for use in the annual reports could vary from year-to-year based on annual hydrologic conditions and changes in the relation between assemblage metrics and physical/chemical variables. Because this type of analysis will require regular re-interpretation, it will be difficult to automate and may therefore be limited to selected sites.

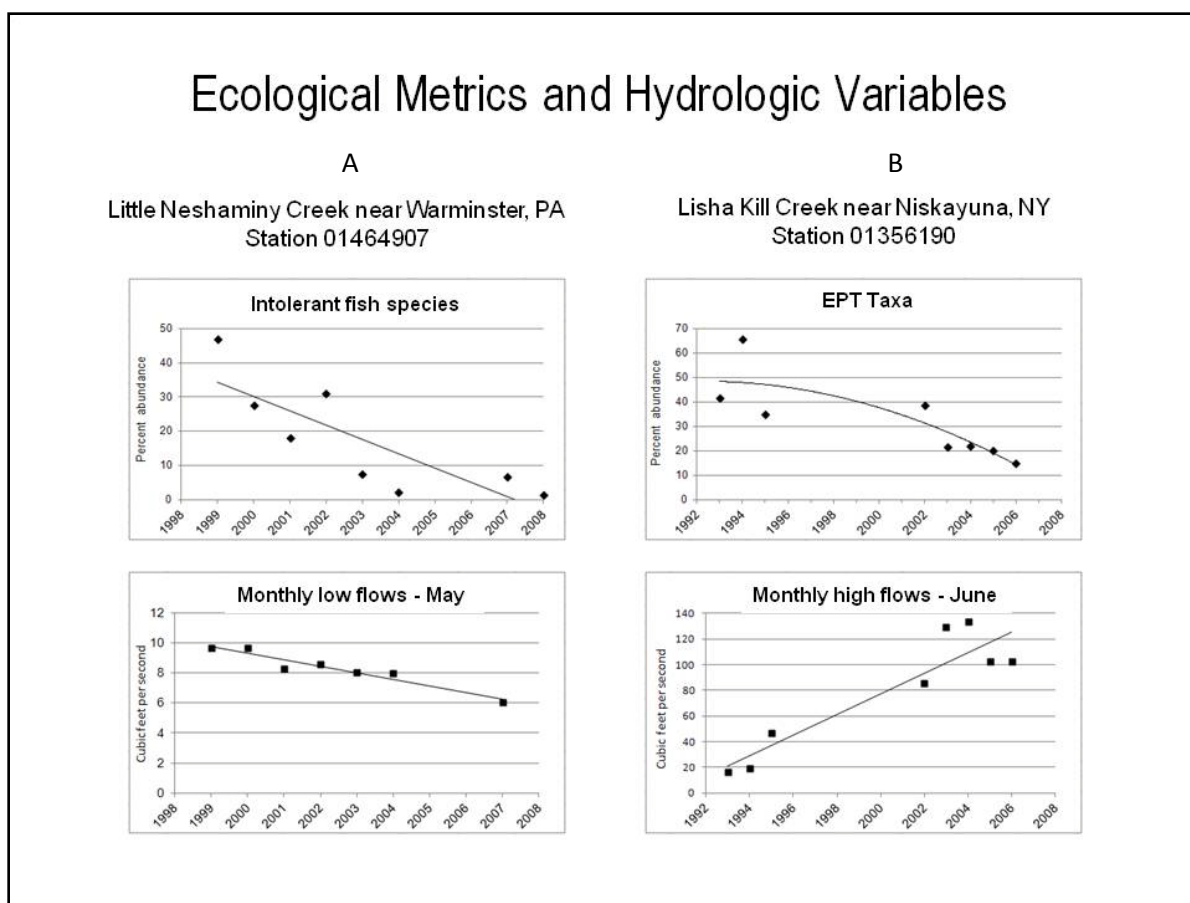


Figure 2.7. Example of the type of ecological metrics that could be included in annual reporting.

Access to the NFSN data that is used to generate these annual reports could be in the form of a web portal, linked to NWIS, which directly accesses NFSN data. The NASQAN program worked collaboratively with the Center for Data Analytics in the Wisconsin Water Science Center to develop a very simple way of retrieving data specific to NASQAN program needs. This approach does not rely on a separate data set; rather, it uses a subroutine to extract the specific data that needs to be aggregated for production of web-based graphical products. This type of interface is highly user friendly, adaptable and makes a seamless connection between data retrieval and the creation of easily interpretable graphical products that not only can be annually updated, but can be served directly to the public.

Site specific web-based reports page—For a subset of sites, a series of annual updates would be produced for site specific trends that could be used as a basis to support water resource management needs. The focus of these updates would be interpretations of water-quality conditions for a given year in the context of past years. Although there would be some information on the actual measured concentrations in the samples collected during the year, the focus would be on the characteristics estimated (using those samples, the flow data, and inferences based on samples from past years) to describe the time history and probability distribution of the concentration and(or) load values throughout the year. These inferences will require the use of a statistical model such as LOADEST, WRTDS, or other simpler models. Care needs to be taken to assure that the model is appropriate to the data set being considered. This will involve exploratory analysis and diagnostic plotting to determine the appropriate models to be used in each case.

An example of one approach that can be used to for annual web-based reporting of status and trends information is given in Figures 2.8 and 2.9 for nitrate in the Missouri River at Hermann, Missouri. In this example, data from long-term monitoring sites that meets the current WRTDS requirements of >20 years of water-quality and streamflow record and >200 water-quality observations is plotted along with WRTDS generated trend lines. It assumes that there are no major gaps in the water-quality record. However, the approach may be equally applicable for data sets with existing gaps (currently being assessed). The graphs depict a substantial and rather rapid change in nitrate concentrations occurring from 2005 to 2009. This rapid increase marks the end of a period of generally stable conditions (as characterized by flow-normalized concentration and flux, fig. 2.8) followed by a distinct period of rapid change. The web-based reports will include figures and interpretation; however, it will be assumed that the reader has a conceptual understanding of what a "flow-normalized concentration" is relative to a "flow-normalized flux" as these concepts would be used throughout a web-based report based on WRTDS results. A common status and trends primer will be developed to present these concepts in a simple manner and linked to the site web pages.

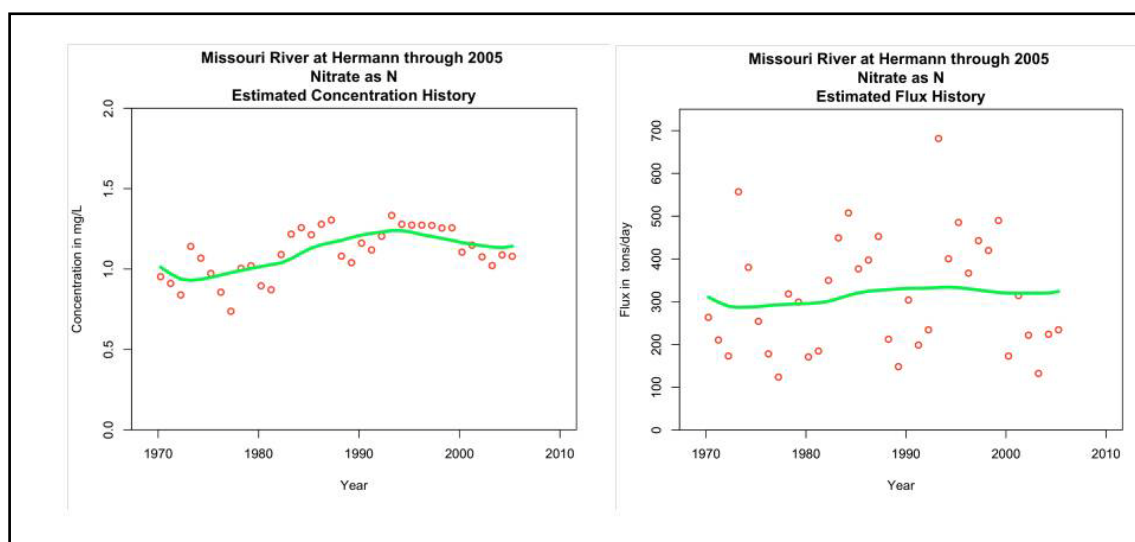


Figure 2.8. Estimated nitrate concentration and flux in water year 2005

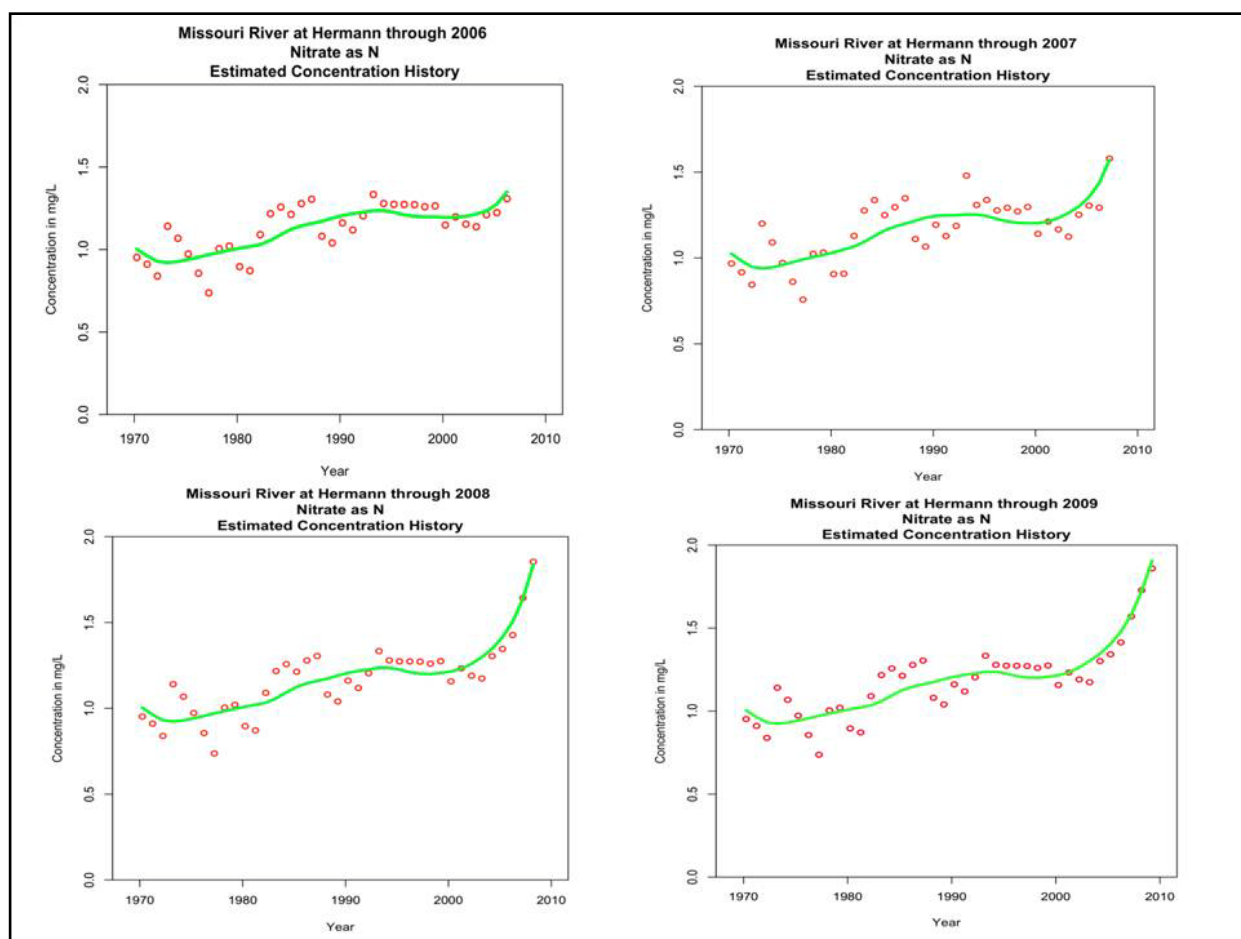


Figure 2.9. Estimated nitrate concentration in water year's 2006 - 2009.

Additionally, this type of analysis could also be completed for a specific portion of the year (for example, the months of April, May, and June). The computations and resulting illustrations used for a web-based report could be quite similar to what is depicted in Figures 2.8 and 2.9, but would focus on critical parts of the water year. For the Missouri River case study, the water years 1980-1996 represent the baseline period used by the Mississippi River/Gulf of Mexico Watershed Nutrient (Hypoxia) Task Force to assess progress toward nutrient management goals. Similar approaches of particular interest to key stakeholders could be used at other sites.

C. Status Assessments

In addition to providing data for the annual web-based reporting of ambient conditions nationally, the NFSN will also be a primary source of data for periodic interpretive analyses of status and trends for selected topics and regions. These more intensive interpretive analyses will also tap other sources of data, including compatible historical and current data from other monitoring networks and from NAWQA Regional Synoptic Studies. Trend analyses are described separately within the scope of the Trend Analysis Team, which has some unique requirements regarding statistical methods and data requirements. Periodic status assessments, described below, will include data-driven analyses (e.g. based directly on monitoring data from the NFSN, Regional Synoptic Studies, and other sources) but will

also feature relevant results from WARP and SPARROW products that have extrapolated the monitoring data spatially.

Interpretive data-driven status assessments will compliment annual reporting by providing concise updates on selected priority topics, such as pesticide or nutrient concentrations or load that reflect changes in pesticide use data, fertilizer use data, point source discharge data, agricultural management practices, changes in land use, and other ancillary variables. These status assessments will be foundational analyses for national synthesis products that integrate status and trends findings with understanding sources and causal factors.

These data-driven status assessments and reports will be broad based and national or regional in scope. For example, the pesticide national synthesis Circular developed in Cycle 2 included data through 2001, so an update to the status of pesticides in the Nation's rivers and streams would be relevant at the beginning of Cycle 3. However, the Circulars developed in Cycle 2 provide extensive background information for the development of these status reports in Cycle 3. Therefore, the scope of some Cycle 3 status reports would be smaller and more modest than the Circulars developed in Cycle 2, yet still integrated with trend analyses and selected modeling results as part of national synthesis reports. With available resources, one of these modest status updates could be completed about every 3 to 4 years.

Status Products

Planning the scope and timing of status products, including the integration of these products with trend analyses and other results to produce national synthesis products, will be one of the early tasks of the National Monitoring and Status Assessment Team, in collaboration with the other surface-water assessment teams and other Cycle 3 components. The examples below provide a sense of initial candidates and their characteristics, but this is meant to be just a starting point for the team effort to develop detailed product plans.

- Pesticides in the Nation's Streams and Rivers, 2002-2012—A SIR or short Circular that updates the surface-water status assessment for pesticides included in Circular 1291 for 1992-2001. The analysis will be a national synthesis product that parallels parts of Chapter 4 in Circ 1291 (Occurrence and Distribution in Streams and Groundwater) and will mainly be a data-driven assessment, but may be selectively supplemented by WARP model predictions.. Topics included will be (1) comparisons between decades for pesticides measured in both (2) comparisons between decades for discontinued and new pesticides that were not analyzed in both decades, and (3) a basic status assessment for the 2002-2010 decade with comparisons to use patterns and without the constraints of consistency with the 1992-2001 data. This status assessment may be integrated with SEAWAVE trend analyses for the most frequently detected pesticides.
- Retrospective analysis of suspended-sediment in U.S. streams and rivers, 1900-2010 - An SIR or journal article accompanied by an interactive webpage that describes patterns in suspended-sediment concentrations, loads, and grain size relative to time, streamflow, and landscape conditions.
- Nutrients in the Nation's Streams and Rivers, 2006-2016—A SIR or short Circular that updates the surface-water status assessment for nutrients included in Circular 1350 for 1992-2001. The analysis would parallel parts of Circ 1350 and would mainly be a data-driven assessment (not dependent on updated SPARROW models). Topics included would be (1) comparisons between decades, (2) comparisons to nutrient criteria established by States after 2004, and (3) a basic status assessment for the 2002-2010 decade with comparisons to use patterns.
- Site-Specific Assessment of Aquatic Assemblages in Select Streams and Rivers of the Conterminous US—A SIR or long fact sheet that reports on ecological condition and associated environmental drivers at a selected number of urban, agricultural, and reference study sites throughout the US. These reports will mainly be a data driven assessment that will rely on rapid updates of environmental attributes, and a fast

turn-around in processing time of ecological samples at the NWQL and contract labs. The analyses will parallel and extend those in many recent NAWQA publications from Cycle 2. Topics included will be (1) comparisons of the condition of fish, aquatic invertebrate, and algal assemblages, (2) modeling relations between aquatic assemblages and environmental drivers within or among different land use types, and (3) a broader summary of aquatic assemblage condition for the 2002-2010 decade (or later in the cycle, depending on timing).

D. Data Management

Water-Quality Data

At the start of Cycle 3, non-NAWQA water-quality and streamflow data of appropriate quality to support periodic status and trends assessments will be identified, compiled, and blended. A significant part of this effort will be QA/QC of the non-USGS data. Traditional QA/QC using blanks, replicates, or spikes will not be possible with all non-USGS data; rather, the effort will focus on verifying and vetting (to the extent possible) the field and analytical methods used over the period of record and checking for possible entry errors and duplication. These issues are of particular importance for trend analysis. Non-NAWQA data will be used to (1) supplement data at the NFSN sites if the data were collected at the same location, (2) support data-driven status assessments and SAPROW and(or) WARP model calibration through inclusion of appropriate additional sites, and(or) (3) evaluate trends at key sites that are not in the NFSN. These new data may allow for the inclusion of a larger number of sites with long-term data (longer than the 10-15 years of data currently available at many NAWQA sites)—long-term data from these sites can provide crucial insight into changes in water-quality conditions. Non-NAWQA sites identified through this effort will not be added to the annual web-based reporting, but they may support specific data-driven status assessments, model calibration, or trends analyses if the data meet minimum data requirements. Ultimately, all of the data directly used in status and trends assessments will be made available on-line through a web portal similar to that currently offered by the NASQAN program. The current NASQAN data portal will be refined early in Cycle 3 to support the expanded data collection and analysis efforts in Cycle 3.

Plans are still being developed for how the scope of effort described above will be integrated as part of the NAWQA-wide data management plan. For initial planning purposes for Surface Water Assessment, team resources have been included to accomplish a significant portion of the work, but its completion would still be dependent on additional support for long-term management of the master database.

Ancillary Data

In addition to water-quality data, new ancillary data will be needed to support annual reporting and interpretive products. A few specific examples of ancillary data products include:

- Updated use data (for example, pesticide, fertilizer, manure, atmospheric deposition, and biological fixation);
- Point-source discharge data (this would expand on current efforts for SPARROW, which includes mostly major dischargers for 1992, 1997, and 2002, to include earlier and more recent years plus additional minor dischargers that may be important in the drainages of sites in the NFSN);
- Agricultural management practices (for example, Conservation Reserve Program (CRP) acreage, conservation tillage, and others).

Comprehensive and coordinated development of a wide range of ancillary data is a NAWQA-wide need in order to support study design, analysis, and modeling. For initial planning purposes for Surface Water Assessment, team resources have been included to accomplish a portion of this work within the scope

of individual teams, but would be highly dependent on additional support from other program components. Appendix 2B describes additional details regarding the requirements for ancillary data.

E. Contaminant Toxicity and Properties

A Contaminant Toxicity and Properties Team (CTPT) will be managed as part of the National Monitoring and Status Assessment Team, but also will be a Program-wide resource for Cycle 3 Surface Water and Groundwater studies. The CTPT will provide data and science assistance for planning and conducting screening-level assessments in order to evaluate the potential significance of contaminant occurrence to human health and aquatic organisms, and staff will participate in assessments of priority human-health and aquatic-life topics. These roles will be vital to incorporating appropriate and relevant information on the properties and risks of contaminants into a wide range of NAWQA products, particularly national synthesis products.

The CTPT will be the primary source for up-to-date toxicity and physical-chemical properties data that are critical for conducting contaminant modeling and screening-level assessments. The primary responsibilities of the CTPT are in three main categories: (1) Benchmark and Database Maintenance—maintain and update human-health and aquatic-life benchmarks and physical-chemical property and related databases, (2) Emerging Topical Studies—conduct assessments on priority topics related to potential effects of contaminants, including the development of new benchmarks for emerging contaminants and the characterization and significance of chemical mixtures to humans and aquatic life as required for Cycle 3 studies, and (3) Status Assessments—participate in surface water and groundwater status assessments as project team members or leaders, with a particular focus on human health or aquatic ecosystem significance. Appendix 2A gives additional detail about the activities of the CTPT.

Composition of the National Monitoring and Status Assessment Team

The National Monitoring and Status Assessment Team, as described above, will have responsibility for five main areas of related activities and products: Managing the National Fixed Site Network, Annual Reporting, Status Assessments, Data Management, and Contaminant Toxicity and Properties. For convenience in describing primary Team functions, each of these areas was described separately, while also noting the considerable interdependencies with other activities. Table 2.13 summarizes all of the positions on the team. As noted in the brief position descriptions, there will be extensive collaboration among activities within the scope of this team and most team members will be involved in more than one of the five main areas of activities and products.

Table 2.13. Composition of the National Monitoring and Status Assessment Team. Some positions may be comprised of part-time commitments of more than one person.

Position	Grade(s)	FTE	Duration	Position Description
Lead Scientist	GS-15	1.0	FY13-FY22	Provides scientific leadership, management, and coordination, of NAWQA SW monitoring, including for the National Stream Quality Accounting Network and the National Monitoring Network, and development of status assessment products. Coordinates NAWQA monitoring with HBN and other national networks, with other components of NAWQA Cycle 3 and USGS, and with other agencies.
Assistant Lead Scientist and Data Analyst	GS-13/14	1.0	FY13-FY22	Assists the Lead Scientist, including development of work plans and budgets, and guidance for collection, analysis, and reporting of data. Analyzes data and designs and prepares status reports and internet based annual reports summarizing information collected at NAWQA fixed sites. Serves as liaison between the NAWQA National Fixed Site Network and the USGS Hydrologic Benchmark Network and the National Water Quality

				Monitoring Council Interagency National Reference Site Network.
Network Management Assistant and Data Analyst	GS-12/13	1.0	FY13-FY22	Assists with work plans and guidance for the collection, analysis, and reporting of data. Works with NAWQA data managers to revise and update quality control screening software as needed and does second tier quality control of NFSN data via the NAWQA data warehouse routines. Analyzes and interprets data and helps prepare status reports and internet based annual reports summarizing information collected at NFSN sites.
Quality Control Specialist, Data Aggregator, Data Analyst	GS-13/14	1.0	FY13-FY22	Analyzes quality control data collected at NFSN sites. Serves as principle liaison between National Monitoring and Status Assessment Team and the USGS National Water Quality Laboratory and NAWQA Data Synthesis and Data Warehouse teams. Aggregates surface water data sets of all collected constituents for fixed sites on an annual basis for use by National Monitoring and Status Assessment Team as well as other NAWQA program components.
Large River Specialist and Data Analyst	GS-13/14	0.5	FY13-FY22	Responsible for field-level quality assurance of sample collection at large rivers (e.g. Ohio, Mississippi, Yukon, etc.). Periodically visits and reviews techniques of crews collecting samples from large rivers. Participates in designing and preparing status and annual reports, especially as they relate to large rivers.
Contaminant Transport/Load Computation Specialist	GS-12/13	0.5	FY13-FY22	Computes annual and monthly constituent loads for stations in the NFSN using standardized techniques. Works with other team members contributing to status assessment and annual reporting products.
Data Management Specialist	GS-11/12/13	1.0	FY13-FY22	Manages large data hydrologic sets (e.g. data sets too large to be managed with Microsoft Excel or Access). Compiles data from other USGS programs and other state and Federal agencies. Screens data for information usable by NAWQA tasks (i.e. status reporting, trends analysis, and SPARROW modeling). Provides these data to other members of the National Monitoring and Status Assessment Team as well as other NAWQA program components. Provides database support as necessary to users of data provided.
GIS Specialist for Annual Reporting and Status Assessments	GS-12/13	0.5	FY13-FY22	Approximately 80 percent of the time in this position will be spent on preparing ancillary data to support status studies and annual reporting; the remaining 20 percent will be spent on taking primary responsibility for management and support for one or more national GIS data sets for NAWQA-wide use.
Programming and Web Support Specialist	GS-12/13	0.5	FY13-FY22	Writes and maintains computer programs to automate processing of annual internet based reports and posting of same to the internet.
Human Health and Aquatic Effects Specialist	GS-13/14	0.5 ¹	FY13-FY22	Lead scientist of the Contaminant Toxicity and Properties Team (CTPT). Prioritizes and directs activities. Participates in analysis and interpretation of data and prepares reports and articles. Coordinates with task leaders of other components of NAWQA Cycle 3. The CTPT is planned for approximately 30-40 percent time on Benchmark and Database Management, 20-30 percent on Emerging Topical Studies, and 30-50 percent on participation in Status Assessments for surface water and groundwater. Interfaces with external agencies and organizations as needed on the development of benchmarks and new science directions.
Contaminant Properties Specialist	GS-12/13	0.5 ¹	FY13-FY22	Contaminant Toxicity and Properties Team. Compiles and manipulates large data sets and analyzes and interprets water-quality data in the context of human health and aquatic life. Evaluates data sources on contaminant toxicity and related information to develop and maintain databases of water-quality benchmarks and contaminant properties. Provides toxicity and physical-chemical property data to status and trends teams. Provides analytical and writing support to authors of status and trends reports, prepares reports and articles for the Contaminant Toxicity and Properties Team, and participates in status assessments.

¹ These positions will be full-time positions but they will be supported by three Cycle 3 components: 0.25 FTE by Groundwater Status and Trends; 0.25 FTE by Regional Synoptic Studies; and 0.5 FTE by National Status and Trends Monitoring.

Trend Analysis

The Trend Analysis Team will develop and apply trend analysis methods to suitable data from USGS and others to produce a series of topical and geographic trend assessment products through Cycle 3, including national synthesis of trend analysis. Initial steps necessary for the periodic trend assessments include (1) an evaluation of the suitability of existing statistical methods for analysis of different constituents and data-set characteristics and (2) a determination of how output from the different methods can be reported as seamlessly as possible. These steps will be completed early in Cycle 3, prior to any new trend analyses. Subsequent periodic trend assessments will cover priority topics and(or) geographic regions. Due to funding constraints, some constituents, some areas of the country, and(or) some ecological responses won't be featured in individual interpretive reports. This will, among other things, limit options for synthesis/capstone products. Trend reports will need to be staggered, with the later reports potentially including trend results from 5 to 6 years earlier.

Methodology and reporting guidance

Methodology and reporting guidance will be developed to guide the selection of methods most appropriate for the range of constituents and data-set characteristics that will be included in the periodic trend analyses. For example, evaluation of the suitability of existing methods such as LOADEST, SEAWAVE-Q, and WRTDS for varying constituents (for example, nutrients, pesticides, sediment, salinity, carbon) and differing data-set characteristics (for example, sampling frequency, historical data, continuous monitoring data) would be conducted to support development of this guidance. Evaluating the sensitivity of each method to the addition of one year of new data will provide a greater understanding of year to year variability in trend response. For example, the interpretation of results based on a time series of estimated and flow-normalized loads and concentrations or a single trend over time could change with the addition of new data.

Ancillary Data Needs

New ancillary data needed to support the interpretive trends products will need to be developed. A time series of key ancillary variables will assist in determining the causes of trends, giving the NAWQA program a greater ability to explain trends than was possible in Cycle 2. Specific examples of ancillary data products include:

- Updated use data (for example, pesticide, fertilizer, manure, atmospheric deposition, and biological fixation);
- Point-source discharge data (this would expand on current efforts for SPARROW, which includes mostly major dischargers for 1992, 1997, and 2002, to include earlier and more recent years plus additional minor dischargers that may be important in the drainages of sites in the FSN);
- Agricultural management practices (for example, Conservation Reserve Program (CRP) acreage, conservation tillage, and others);
- Changes in irrigated type and acreage;
- Changes in crop type/acreage;
- Changes in livestock numbers;
- Changes in commodity prices;
- Changes in agricultural policies;
- Changes in tile drained area;
- Changes in urban stormwater practices and impervious area;
- Changes in land use (expanding on current data to include earlier and more recent years).

Trend Analysis Products

Once the methods development and data aggregation are completed early in Cycle 3, trend analysis will begin. This analysis is likely to cover a time period that extends through 2012 or 2013. These trend results will be published in a series of USGS Open-File Reports or Scientific Investigations Reports; there may be separate reports for nutrients, pesticides, sediment, ecology, and carbon/salinity. These reports will document the trend methods used and tabulate the trend (and load, if applicable) results, but no interpretation of individual or collective trends will be included. The primary purpose of these reports is to support subsequent interpretive studies that rely on the tabulated results. These foundational reports will be developed twice in Cycle 3, at 5 year intervals.

Using selected results from the foundational reports, journal articles (or short USGS SIRs) that focus on key national or regional findings will be developed. These reports will not be simple summaries of trend results from the foundational reports—they will require additional analysis and interpretation (for example, to identify important causative factors and/or to investigate lag effects). Due to resource constraints, journal articles produced within each 5-year interval will need to be staggered, with the later reports potentially including trend results from 5 to 6 years earlier when they are published. Moreover, not all sites and constituents will be considered in a detailed interpretive trends report.

The content of the journal articles and the specific design of capstone synthesis products will, in large part, be driven by the trend results; therefore, a full accounting of all reports to be produced throughout Cycle 3 is not possible in advance of the analyses. Given national and regional priorities as well as science questions identified during Cycle 2, however, several likely topics can be identified at this point. These are listed here as examples.

- Report 1: Changes in total and dissolved phosphorus in agricultural areas—Trends in total and dissolved phosphorus concentration and load at long-term agricultural sites will be evaluated to determine if more phosphorus is being transported in the dissolved than total phase in recent years because of soil saturation and/or implementation of agricultural management practices.
- Report 2: Nutrient, contaminant, and sediment loading to coastal estuaries in the United States – Changes in loading from coastal rivers (including those monitored by NAWQA and others with data of adequate quality) will be determined and compared. Because of the size of these watersheds and the number of sites likely to be included, the focus will not be on interpreting the causes of observed trends, but on comparing changes among receiving water bodies.
- Report 3: Comparative effects of agricultural management on nutrient and pesticide trends in agricultural areas – Changes in use, management practices, and hydrology will be determined at the 10 agricultural sites. Differences or similarities in how they affect nutrients and pesticides will be evaluated. Other agricultural sites may be added to the analysis if cost-effective quantification of watershed changes at a larger number of sites is possible.
- Report 4: Effects of extreme hydrologic events on water-quality and ecological response—Using the longest data sets, changes in water-quality conditions (peaks, relations with streamflow, watershed export) and ecological conditions after extreme events such as floods and droughts will be examined. Results will be put in context of multi-year to multi-decade perturbations. Though this is not a direct examination of the impact of climate change, results can be used to predict likely responses to hydrologic changes that may occur with future climate change.
- Report 5: Lagged response of nutrients in rivers to changes on the landscape—Estimates of residence/lag times as well as updated time series of key changes on the landscape will be used to estimate lagged response of rivers to changes in their watersheds. Lag times will be compared among regions. Because of the large number of sites that could be included in this national analysis, the analysis will focus on the lag

time issue rather than on a comprehensive evaluation or comparison of the trends. Where there is overlap, this analysis will be coordinated with analyses conducted by the IWS (Chapter 4).

- Report 6: Trends in aquatic assemblages at urban and agricultural sites—Changes in aquatic assemblages over time and their relation to changes in physical and chemical stressors will be evaluated. Key stressors will be identified and compared among urban and agricultural sites.
- Report 7: Changes in nutrient concentration and load in the Mississippi River Basin—Changes in loading to the Gulf of Mexico and from upstream contributing areas will be evaluated and compared to large-scale changes in the watershed, such as changes in use, crop patterns, management practices, etc.
- Report 8: Changes in salinity in the southwestern United States—Changes in salinity in the arid Southwest will be evaluated and compared to natural and anthropogenic changes to determine the regional efficacy of salinity control practices. A complete analysis will be contingent upon our ability to quantify changes in major salinity control practices.
- Report 9: Effects of climate and land-use changes on pesticide runoff from large rivers—Pesticide runoff from the watersheds of large inland and coastal river sites will be compared to changes in climate (primarily precipitation) and land-use (primarily large-scale changes such as changes in cropping patterns, tile drainage, major urbanization, etc.). The annual percent of pesticide applied that ends up as runoff will be related to variables computed using available precipitation data (e.g., total precipitation during the application season, largest weekly precipitation total during the application season, etc.) and the potential effects of climate change (such as increased frequency of large precipitation events) will be evaluated. Major changes that cannot be attributed to precipitation will be related to potential land-use changes that would be expected to affect pesticide runoff. This product could be timed in conjunction with a similar study for evaluating changes in nutrient loadings for large rivers. Where there is overlap, this analysis will be coordinated with IWS in Goal 2 (Chapter 4) and forecasting in Goal 4 (Chapter 6).
- Report 10: Evaluating the sensitivity of ecological trend response to the addition of new data—Changes in the trajectory of a trend response with the addition of new data and the effect on trend interpretation will be assessed. Such an assessment could provide further insight into the relative robustness of ecological trend data and expand our understanding of the overall significance of an identified response.

Work on several trend studies that began toward the end of Cycle 2 also will be completed during the first part of Cycle 3. These include:

- Changes in total and dissolved phosphorus concentration and flux from 1980 to 2010 at sites in the Mississippi River Basin (this is a pilot analysis for the above-described national analysis)
- Inter-Regional Synthesis of Temporal Trends and Drivers of Trends in Biological Assemblages at NAWQA Sites in Major River Basins 1-8—This report was supported by the Surface Water Status and Trends component of NAWQA for FY12 and represents the last of a series of ecological trend studies to be completed as part of Cycle 2. Previous ecological trends studies focused on site specific (that is, case study) temporal trends. This effort has been designed to synthesize common biotic and abiotic characteristics across the four MRBs where trends reports have been done and it uses of inter-regional synthesis to better understand temporal changes at a scale relevant to a national program. The goal of the proposed project is to describe inter-regional patterns and trends in biotic (algae, invertebrates, and fish) groups across the country, and to identify commonalities among the physical and biological characteristics in different land use settings. Specifically, this study will summarize commonalities in the patterns and processes associated with ecological trends and the findings will help to identify (1) the extent to which temporal trends vary among regions, (2) how temporal trends differ among biotic groups and whether trends vary as a function of regional specific abiotic drivers or collectively at the inter-regional scale, and (3) which aquatic assemblages are most useful for evaluating ecological trends. These findings will be used to provide recommendations to resource managers that are relevant to the management of stream ecosystems at the regional and national scale.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Lead scientist (1 FTE)	Methods dev, trend analysis					Trend analysis				
		National summary OFR				National summary OFR				
			Lead Report 1				Journal article			
			Coauthor Report 2							
				Lead Report 5				Journal article		
				Co-author Report 6						
					Integrative summary				Capstone summary	
Hydrologist/Chemist (1 FTE)	Methods dev, trend analysis					Trend analysis				
		National summary OFR				National summary OFR				
			Lead Report 2				Journal article			
			Coauthor Report 3							
				Lead Report 7				Journal article		
				Co-author Report 5						
					Integrative summary				Capstone summary	
Hydrologist/Chemist (1 FTE)	Methods dev, trend analysis					Trend analysis				
		National summary OFR				National summary OFR				
			Lead Report 3				Journal article			
			Co-author Report 4							
				Lead Report 8				Journal article		
				Co-author Report 7						
					Integrative summary				Capstone summary	
Ecologist (0.5 FTE)	Methods dev, trend analysis					Trend analysis				
		National summary OFR				National summary OFR				
			Lead Report 4				Journal article			
				Lead Report 6				Journal article		
					Integrative summary				Capstone summary	
Hydrologist - analysis/report support (1 FTE)	Methods dev, trend analysis					Trend analysis				
		National summary OFR				National summary OFR				
			Co-author Report 1				Journal article			
				Co-author Report 8				Journal article		
					Integrative summary				Capstone summary	
Geographer - GIS support	Provide GIS and report writing support as needed.									

Figure 2.10. Preliminary timeline for trend-assessment products. Report titles shown during 2015-2017 are examples used for illustration of team responsibilities; actual timeline and report topics will be confirmed early in Cycle 3.

Composition of the Trend Analysis Team

The trend analysis team will be responsible for periodic trends assessments of nutrients, pesticides, carbon, salinity, sediment, and aquatic assemblages, including contributions to the initial development of annual web-based reporting by providing examples of the kind of water quality and(or) ecology trend assessments that could be developed at a small number of key sites for inclusion in web-based reporting. Team members would be responsible for coordinating with SPARROW modelers on load estimation. Team composition is summarized in Table 2.14. Because the analysis of trends is expected to require complex and on-going statistical development throughout Cycle 3, it would be ideal to also have a high-level statistician on the team to provide statistical and analytical support.

The team will work on methods development, data screening, trend analyses, and results compilation in the foundational USGS reports during 2013 and 2014 (figure 2.10). In 2015-2017, the focus will shift to journal articles built from the foundational USGS reports. To encourage interdisciplinary interaction, it is likely that each scientist will be lead author on two reports and co-author on at least one other report during this period. All team members will collaborate on integrative products summarizing key results from the trends reports during 2017 and 2018. In 2018, the second round of trend analysis will begin.

Table 2.14. Composition of Trend Analysis Team. Some positions may be comprised of part-time commitments of more than one person.

Position	Grade(s)	FTE	Duration	Position Description
Lead Scientist	GS-13/14	1.0	FY13-FY22	Coordinates SW Trends Team and oversees and participates in methods development activities, national and regional trend analyses, and preparation of related publications.
Trend Analyst: Contaminants, nutrients, sediment	GS-12/13/14	1.0	FY13-FY22	Conducts trend analysis of concentrations and loads, writes interpretive reports, and presents results to technical and nontechnical audiences. Requires strong background in statistical analysis and interpretation of surface-water chemistry, sediment and hydrologic data. Works with other trend analysis team members to ensure effective interdisciplinary analysis and interpretation.
Trend Analyst: Contaminants, nutrients, sediment	GS-12/13/14	1.0	FY13-FY22	Conducts trend analysis of contaminant concentrations and loads, writes interpretive reports, and presents results to technical and nontechnical audiences. Requires strong background in statistical analysis and interpretation of surface-water chemistry, sediment and hydrologic data. Works with other trend analysis team members to ensure effective interdisciplinary analysis and interpretation.
Trend Analyst: Ecology	GS-12/13/14	0.5	FY13-FY22	Conducts trend analysis of ecological conditions, writes interpretive reports, and presents results to technical and nontechnical audiences. Requires strong background in statistical analysis and interpretation of ecological data. Works with other trend analysis team members to ensure effective interdisciplinary analysis and interpretation.
GIS Specialist for Trend Analyses	GS-11/12/13	1.0	FY13-FY22	Approximately 80 percent of the time in this position will be spent on preparing ancillary data to support trend studies and the remaining 20 percent will be spent on taking primary responsibility for management and support for one or more national GIS data sets for

				NAWQA-wide use.
Data Management Specialist	GS-11/12/13	1.0	FY13-FY22	Manages large data sets (e.g. data sets too large to be managed with Microsoft Excel or Access). Compiles data from other USGS programs and other state and Federal agencies. Screens data for information usable by NAWQA tasks (i.e. status reporting, trends analysis, and SPARROW modeling). Provides these data to other members of the National Monitoring and Status Assessment Team as well as other NAWQA program components. Provides database support as necessary to users of data provided.

SPARROW and WARP Modeling

Introduction

A key challenge for water-quality assessment is to extrapolate water-quality conditions determined at a few monitored locations to other, unmonitored basins. To address this need, NAWQA has increasingly relied on empirical models of water quality developed from water-quality data in combination with a wide range of basin attribute variables. Two principal models have been used in these efforts: the SPAtially Referenced Regression on Watershed attributes (SPARROW) model and the WATershed Regressions for Pesticides (WARP) model. Each of these models characterizes different aspects of the water-quality condition and approach the extrapolation issue in different ways. Both models are similar, however, in that they can be readily applied at large spatial scales, and the statistical methodology used to estimate them provides a rigorous framework for model evaluation and an assessment of accuracy. Below, SPARROW and WARP models are described specifically in relation to their roles in Cycle 3 status assessments, which will be implemented by the SPARROW and WARP Modeling Team. Appendix 2B describes data infrastructure issues associated with implementation of the Cycle 3 plan for modeling in support of surface water assessment. Additionally, SPARROW model activities related to surface water assessment are contained in other sections of the Cycle 3 plan, including a description of developments in SPARROW model methodology in the plan for the Hydrologic Systems Team (HST), and the planned application of dynamic SPARROW models under Integrated Watershed studies.

Modeling for Status Assessment

The plan for model assessment can be divided into two scales of analysis: national models and regional models. National models are necessary to provide a broad perspective on water-quality conditions. A national scale is also needed to empirically identify factors having important effects on water quality at the regional scale, such as climate. Conversely, regional models provide an opportunity to introduce region-specific processes and sources into the models. Some regions may have special data sets to address specific water-quality concerns. For example, millponds have recently become a concern as a source of sediment in the Northeast and special data sets identifying their location have been created. Because these data sets may not be available nationally, it will not be possible to use them in a national analysis. Regional models also provide an opportunity for USGS personnel to gain specific understanding of the water-quality problems arising in individual basins and to develop modeling strategies for addressing these concerns. Consequently, regional models may generate more interest from regional water-quality stakeholders than a national model, particularly if these stakeholders have some influence in suggesting modifications to the analysis.

To meet demands for timely information, the plan calls for model updates to be generated as frequently as the ancillary data used for model estimation will allow. Effort will be made to make updates

“backward compatible” so that results from previous and recent models can be directly compared. In some cases, this may require revisions of previous models.

As models are updated and refined during Cycle 3, as well as expanded to new stressors, model analyses and extrapolations will play an increasingly critical role in status assessment products and national synthesis of status and trends. Cycle 3 products will bring a new focus to the integration of data-driven status assessments and empirical models.

SPARROW Models

The SPARROW model is used to describe mean conditions for instream contaminant loads, employing a mass balance approach that accounts for simple, spatially-defined processes affecting the transport of contaminants from their source locations to downstream monitoring sites. The spatial infrastructure used for referencing is provided by a reach network consisting of tens to hundreds of thousands of individual reach segments and associated catchments. Model estimation requires an extensive network of monitoring sites combined with numerous, spatially explicit ancillary variables to describe a comprehensive set of contaminant sources and the factors affecting overland and instream transport. The statistical method of weighted nonlinear least squares is used to estimate a set of model coefficients that mediate the effects of the explanatory variables on water quality. Extrapolation of model results to specific stream locations is achieved using the ancillary variables referenced to the reach network. The SPARROW methodology is fully documented, complete with a guide to using the software (Schwarz and others, 2006).

To date, national models have been developed for total nitrogen and phosphorus, suspended sediment, and organic carbon, and regional models have been developed for total nitrogen and phosphorus, dissolved solids, and suspended sediment (Table 2.15 summarizes all existing SPARROW models). SPARROW has also been used to model water quality in other countries (see table 2.15). Recently, a set of regional models for total nitrogen and total phosphorus have been developed for selected major river basins of the conterminous U.S. The national models described above have all made exclusive use of USGS water-quality data; the regional models have augmented USGS data with extensive non-USGS data collected by State and other agencies. SPARROW information has been used in numerous applications, including an evaluation of contaminant discharge to coastal areas (Alexander and others, 2008), the importance of atmospheric deposition for water quality (Alexander and others, 2001), a characterization of nitrogen background conditions (Smith and others, 2003), the ranking of basins for nutrient reduction (Robertson and others, 2009), and the role of headwater streams in downstream water quality (Alexander and others, 2007). An online decision support system (DSS) has recently been developed (Boothe and others, 2011) that uses SPARROW model results to generate predictions of water-quality conditions for alternative management scenarios.

Table 2.15. List of existing national, regional and foreign SPARROW models, summarizing model features and references to documentation. (NWIS represents the U.S. Geological Survey's National Water Information System; STORET represents the U.S. Environmental Protection Agency's Storage and Retrieval database; NRWQN represents New Zealand's National River Water Quality Network.)

Spatial extent	Base Year	Source data	Number of monitoring stations	Model Root Mean Squared Error	Reference
Total Nitrogen					
Conterminous U.S.	1987	NWIS	414	0.674	Smith, and others, 1997
Conterminous U.S.	1987	NWIS	374	0.660	Alexander and others, 2000
Conterminous U.S.	1992	NWIS	425	0.553	Alexander and others, 2008
Conterminous U.S.	1992	NWIS	425	0.498 (regionalized ¹) 0.505 (hybrid ²)	Schwarz and others, 2011
Chesapeake Bay basin	1987	NWIS, State agencies	79	0.409	Preston and Brakebill, 1999
New England	1992	NWIS, State agencies	65	0.400	Moore and others, 2004
Northeastern and Mid-Atlantic U.S.	2002	NWIS, STORET, and State agencies	363	0.35	Moore and others, 2011
Southeastern U.S.	2002	NWIS, STORET, and State agencies	331	0.32	Hoos and McMahon, 2009
Upper Mississippi, Great Lakes, Red/Souris basins	2002	NWIS, STORET, and State agencies	708	0.408	Robertson and Saad, 2011
Missouri basin	2002	NWIS, STORET, and State agencies	193	0.744	Brown and others, 2011
South-Central U.S.	2002	NWIS, STORET, and State agencies	344	0.552	Rebich and others, 2011

Spatial extent	Base Year	Source data	Number of monitoring stations	Model Root Mean Squared Error	Reference
Pacific Northwest U.S.	2002	NWIS, STORET, and State agencies	178	0.640	Wise and Johnson, 2011
Waikato basin, New Zealand	1993-1998	NRWQN	37	0.377	Alexander and others, 2002
New Zealand	1996-1999	NRWQN	77	0.330	Elliott and others, 2005
Total Phosphorus					
Conterminous U.S.	1987	NWIS	381	0.841	Smith, and others, 1997
Conterminous U.S.	1992	NWIS	425	0.762	Alexander and others, 2008
Conterminous U.S.	1992	NWIS	425	0.689 (regionalized ¹) 0.726 (hybrid ²)	Schwarz and others, 2011
New England	1992	NWIS, State agencies	67	0.480	Moore and others, 2004
Northeastern and Mid-Atlantic U.S.	2002	NWIS, STORET, and State agencies	457	0.65	Moore and others, 2011
Southeastern U.S.	2002	NWIS, STORET, and State agencies	370	0.54	Garcia and others, 2011
Upper Mississippi, Great Lakes, Red/Souris basins	2002	NWIS, STORET, and State agencies	810	0.493	Robertson and Saad, 2011
Missouri basin	2002	NWIS, STORET, and State agencies	311	1.01	Brown and others, 2011
South-Central U.S.	2002	NWIS, STORET, and State agencies	442	0.743	Rebich and others, 2011
Pacific Northwest U.S.	2002	NWIS, STORET, and State agencies	228	0.693	Wise and Johnson, 2011

Spatial extent	Base Year	Source data	Number of monitoring stations	Model Root Mean Squared Error	Reference
Waikato basin, New Zealand	1993-1998	NRWQN	37	0.381	Alexander and others, 2002
New Zealand	1996-1999	NRWQN	77	0.580	Elliott and others, 2005
Suspended Sediment					
Conterminous U.S.	1992	NWIS	1,828	1.414	Schwarz, 2008
Chesapeake Bay basin	2002	NWIS, STORET and State agencies	129	0.96	Brakebill and others, 2011
Dissolved Solids					
Southwestern U.S.	1974-2003	NWIS	315	0.71	Anning and others, 2007; Anning, 2011
Upper Colorado basin	1991	NWIS	218	0.51	Kenney and others, 2009
Organic Carbon					
Conterminous U.S.	1970-2008	NWIS, STORET	1,125	0.540	Shih and others, 2010

¹ “Regionalized” corresponds to a national analysis with fixed-effects coefficients for three regions.

² “Hybrid” corresponds to a national analysis with constrained fixed-effects coefficients for three regions.

National SPARROW Models

The plan for national SPARROW modeling in Cycle 3 calls for a series of updates of existing models for nutrients, suspended sediment, dissolved solids, and organic carbon. SPARROW models are highly dependent on a wide range of ancillary data that are typically infrequently revised. Principal among the infrequently revised data is the NLCD land cover, which was recently revised for 2006 (Fry and others, 2011) and is scheduled for another revision for 2012, these revisions typically come with a 5-year production lag. Other important agricultural data are revised on a five-year interval, with updates for 2012 and 2017 and an expected production lag of only two years (the publication date of the updated 2007 Census of Agriculture is December, 2009; U.S. Department of Agriculture, National Agricultural Statistics Service, 2009).

The Cycle 3 plan calls for national model updates to coincide with scheduled revisions to the agricultural data; development of new models would target the years 2012 and 2017. As discussed below in the plan for the regional SPARROW models, the 2012 national models will be produced after completion of the regional models, thereby facilitating the incorporation of data from the nutrient and suspended sediment regional models into the respective national models. The historical lag in the development of NLCD data makes it unlikely the 2012 land cover data will be available for the 2012 models. As a contingency, the 2012 nutrient models will use the 2006 NLCD data to allocate 2012 agricultural information. The suspended sediment, dissolved solids and organic carbon models will be produced later in the planning period and may have access to updated 2012 NLCD data.

The updated models will use thinned resolution of the NHDPlus spatial infrastructure. Because the existing national models are for the E2RF1 reach network, there are potential problems with compatibility of the Cycle 3 models with existing models. An effort will be made to transfer the existing 1992 national nutrient models to the thinned NHDPlus; the other existing national models are considered preliminary and will not be revised. The national model updates will be for mean annual load and, pending successful development of the SPARROW multiple contaminant model, will include a description of mean seasonal loads that accounts for seasonal storage effects.

All national models will be analyzed to determine the importance of regional effects using methods developed by Schwarz and others (2011). Statistically or physically significant regional effects will be incorporated into model results using either the Schwarz and others methodology, or by adoption of a hierarchical error specification. Regional-specific data sets may be incorporated into the regionalized national model if these data do not bias model results in other regions.

National SPARROW Products

SPARROW model products for Cycle 3 include regular updates of the national models and regional models, which are separately described below. A timeline summarizing the active development and completion of each model is given in table 2.16. The sequencing of activities is dictated by staffing constraints imposed by the size of the SPARROW modeling team (see the section describing the SPARROW modeling team and their responsibilities) and the varying degree of effort required to develop regional data due to different region sizes (see figure 2.11, below).

Table 2.16. Timeline for completion of the regional and national SPARROW models planned for Cycle 3. Light green cells indicate regional data compilation for the 2017 national models. [NE, Northeast; SE, Southeast; MW, Midwest; and W, West regions].

Year	2012 Regional Models								National Models							
	Nutrients				Suspended Sediment				Nutrients		Suspended Sediment		Dissolved Solids		Organic Carbon	
	NE	SE	MW	W	NE	SE	MW	W	2012	2017	2012	2017	2012	2017	2012	2017
2013																
2014																
2015																
2016																
2017																
2018																
2019																
2020																
2021																
2022																

A number of products are envisioned for the updated national SPARROW models. Each model will be documented via journal publications. Due to the similarities in the total nitrogen and phosphorus models, these models will be produced and documented simultaneously. Although the suspended sediment and dissolved solids models are inherently different in terms of sources and processes, together these two models represent the total amount of continental erosion so there is justification for their combination in publication. The carbon model will be reported separately.

All water-quality data, load estimates (with NWIS references to the streamflow data), and ancillary data spatial coverages will be made available online through dedicated web sites. Each model will be ported to the DSS to provide users access to detailed model results and the ability to perform simulations. As explained above, the nutrient models will be made backward compatible with existing models, which will require the generation of new versions of these models for 1992 (and possibly for 2002 models, if such models become available in Cycle 2) to account for changes in the reach network. The remaining models may require revisions to the 2012 updates in order to be compatible with the 2017 updates.

The results of the national models, as stressed above, will be primary contributions to status assessment and national synthesis products produced by NAWQA in Cycle 3. In their contributions to national synthesis products that integrate status and trends, SPARROW models will provide insights into the sources of trends determined as part of Cycle 3 trend studies. The model results may also be useful as stressor information for the extrapolation of ecological models (Chapter 5) developed in Cycle 3.

Regional SPARROW models

The NAWQA program has invested significant resources in the development of regional SPARROW nutrient models. Models for total nitrogen and total phosphorus for 2002 were created for seven of the eight Major River Basins (MRBs, regions 1-5, 7 and 8), and a dissolved solids model was updated for MRB 6. Most of the original models were developed for the E2RF1 reach network (models for MRBs 1 and 8 were originally developed for NHDPlus), but all models will eventually be produced for NHDPlus as part of completing Cycle 2 modeling.

In Cycle 3, the regional models will be updated to a base year of 2012 for total nitrogen and total phosphorus, and new 2012 models for suspended sediment will be developed. Limitations placed on resources for Cycle 3 prevents the full continuation of the MRB regional modeling program. In its place, there will be a simplified geographic strategy that reduces the number of regions to four, as shown in figure 2.11: the Northeast (currently MRB 1), the Southeast (currently MRB 2, minus the Tennessee River basin), the Midwest (combined MRBs 3, 4 and 5, and the Tennessee River basin from MRB 2), and the West (combined MRBs 6, 7 and 8).



Figure 2.11. Four Cycle 3 SPARROW modeling regions in relation to the eight Major River Basins used in Cycle 2.

The plan for Cycle 3 calls for completion of the 2012 regional models prior to commencing work on the 2012 regionalized national models. This scheduling allows the effort expended to produce the regional models to be used to support development of the national models. Thus, the regional model load estimates derived from USGS and non-USGS water-quality data, and the contaminant source, NHDPlus and NLCD data sets, validated to work for the regional models, will also be used in the national models, although the national models will use a thinned version of these data. Regional model development could identify region-specific contaminant source and transport-process defining data sets. These data will be incorporated into the national models if such data do not create biased predictions for the other regions of these models.

Resource constraints limit the regional models to a single update for 2012. Regional specificity for 2017 will be attained by regionalizing the 2017 national models using methods developed by Schwarz and others (2011) or by employing new capabilities for hierarchical error specification through the development of an enhanced error structure for SPARROW models. As with the national models, the regional models will report estimates of mean seasonal loads, based on contaminant storage, in addition to the estimates of mean annual load.

The shifting of priorities towards national models for the 2017 updates is not expected to have a great effect on the accuracy of model predictions at the regional level, or on the relative importance of different sources or transport processes. Schwarz and others (2011) have examined the national nutrient models for regional effects and found that regionalization does not greatly improve model fit (reduction in the root mean squared error of predicted load is less than 10 percent of its value) or produce many coefficient estimates that differ significantly across regions.

Although the shift to national models for the 2017 updates is expected to work, as described above, an important component of the Cycle 3 plan is that the experience with development of both regional and regionalized national models for 2012 will be used to help decide if there are meaningful differences between approaches that need to be accounted for in development of 2017 models.

Although explicit regional models for 2017 will not be developed, the 2017 national models will require regionally validated water-quality and ancillary data, implying regional effort is essential to the successful completion of the national models. It is expected that the intensive effort of building regional models for 2012 will have payoffs for the 2017 national model in terms of an improved data infrastructure and a better understanding of regional processes. Additionally, regional effort is explicitly budgeted to support the 2017 national models. This effort could also be used as leverage to develop 2017 updates to select regional models, pending additional support due to improved NAWQA budget support or from outside cooperators.

The dependence of the regional models on non-USGS water-quality data raises a concern regarding the likely continued availability of these data in coming years, which could affect model performance depending on the number and configuration of the maintained stations. To address this concern, an analysis was done to evaluate the sensitivity of the existing MRB 3 (the Upper Mississippi/Great Lakes/Souris-Red-Rainy region) nutrient models to alternative configurations of the monitoring network. The analysis shows that the MRB 3 SPARROW models are relatively robust to changes in the network, with the primary effect coming from changes in the number of stations, rather than the spatial configuration of the stations.

Regional SPARROW Products

The principal SPARROW-specific products to be generated from the regional models will be journal articles documenting the nutrient and suspended sediment models (one journal article will document the nutrient models; a second article will document the suspended sediment model). Additionally, each model will be ported to the DSS for online dissemination and simulation capability. In accordance with the national models, the 2002 nutrient models will be revised to be consistent with the new models for 2012. For the Midwest and Western regions, this will require re-estimation of the previous models by merging 2002 load estimates from multiple MRB models. The revised models will be made available through the DSS. No regional models for suspended sediment currently exist so there are no issues of backward compatibility for these models.

The regional models will likely generate interest from regional stakeholders for special applications of the models. Due to limited resources, the Cycle 3 plan does not budget resources for undertaking these applications. It is implicit in the plan, therefore, that any applications generated from the regional models will require external funding.

WARP Models

WARP (Watershed Regressions for Pesticides) models are designed to estimate the annual or seasonal frequency distribution of pesticide concentrations, including specific concentration statistics, at a particular location on a stream or river. The method has been applied to pesticides in both water and bed sediment and can also be applied to other contaminants. Each WARP model consists of a set of equations, each relating a different concentration percentile or other concentration statistic to a set of upstream, whole-basin attributes. An extensive network of monitoring locations (approximately 50-150 sites), with intensive sampling at each site for one or more years, is required for model development. To accommodate censored observations, which are common in pesticide data, the model is estimated using the statistical method of maximum likelihood. Extrapolation of model results to unmonitored basins is achieved by a straightforward evaluation of the set of estimated equations using whole-basin attributes available for any specified location.

WARP can be used to assess concentration statistics for any basin determined to be within the range of model development conditions. The model can also be used to evaluate expected differences in exposure conditions under alternative source management scenarios. The methodology has been applied primarily to pesticides in water (Crawford, 2001; Larson and Gilliom, 2001; Larson and others, 2004; Stone and others, 2008; Stone and Gilliom, 2009), with a special emphasis on modeling atrazine and other individual pesticides exhibiting frequent detection in water-quality samples. Most studies have used NAWQA data exclusively for model estimation. A regional model for atrazine has recently been developed for the Corn-Belt region using mostly non-USGS data (Stone and Gilliom, 2011). A national multi-compound model has been developed by Crawford and others (in preparation). Nowell and others (2009) developed WARP-type models for organochlorine pesticides in fish tissue. The methodology has recently been extended to model nutrients (Spahr and others, 2010).

National WARP Models

The existing national WARP models will be updated approximately on a five-year interval, supplemented by special-purpose updates to report results for new contaminants and additional concentration statistics. The updated models will incorporate new site years from available monitoring data and incorporate improvements in predictor variables made with time. Improvements in predictor variables will be implemented in selected previous models to insure compatibility of the models across different updates.

There will be increased focus on development of updated and improved national multi-compound WARP models, which incorporate physical and chemical properties of individual pesticides to enable a single model to make predictions for many different pesticides.

Products

The results of the updated WARP models, and comparisons with previous results, will be documented by journal articles. As discussed for SPARROW, modifications will be made to allow import of the WARP model to the DSS to provide public access to model results and to use the model to simulate alternative source management scenarios.

WARP extrapolations to nationwide streams will be incorporated into status assessment products and national synthesis products that summarize status and trends in relation to causes.

Regional WARP Models

The Cycle 3 plan includes several Regional Synoptic Studies of contaminants in streams, including pesticides (see following section on Regional Synoptic Studies). All or most of these studies are expected to provide sufficient data to develop a regional multi-compound WARP model for the conditions measured. A RSS team formed during Cycle 3 will determine the details of these planned studies, including the specific regions to be analyzed. The particular design elements for each of the RSS will be customized to address specific study objectives, including a determination of critical contaminant exposure conditions. Methods will be developed to extrapolate exposure conditions, typically expressed as a seasonal concentration statistic, to streams throughout each study region.

Products

Results of the RSS studies, including WARP extrapolation assessments, will be documented through journal articles. WARP estimates will be used to extend sampling results to characterization of all streams in the study region and are incorporated into RSS product plans.

Composition of the SPARROW and WARP Modeling Team

Implementation of the Cycle 3 plan for surface water assessment using SPARROW and WARP requires a team of four SPARROW modelers, a WARP modeler, a data manager, and a GIS specialist, as summarized in Table 2.17. The four SPARROW modelers have responsibility for producing all national and regional model updates. This group will compile water-quality data from USGS and non-USGS sources, determining which data are suitable for load estimation, and compute all load estimates used in the regional and national SPARROW nutrient and suspended sediment assessment models. This group is also responsible for validating the contaminant source (principally the point source file), NHDPlus and NLCD data sets, and for identifying unique regional data sets used in the regional models.

The four modelers will be physically located in each of the four modeling regions, providing an essential link to users of the regional models. The modelers' expertise will improve the specification of the regional models and ensure that the models address the major water-quality concerns of each region. Each member of the modeling team will be responsible for constructing and documenting the regional models for the region they represent. Collectively, this group will also specify, estimate and document the national model updates, providing as much regional specificity as possible with national data sets and employing regional data sets to identify regional factors affecting water quality, as long as the incorporation of these regionally-specific data do not bias the national model.

The WARP modeler will oversee the development of the pesticide use data, produce the national model updates and regional synoptic models, and write journal and USGS publications describing their

research. The WARP modeler will identify important factors affecting pesticide use in agricultural and urban settings, and use the WARP model to evaluate the pervasiveness and persistence of pesticides in aquatic environments. The modeler will remain informed of literature describing the human and ecological health impacts of pesticides and their degradation products, and disseminate the results of their research to the appropriate regulators of these chemicals.

The data manager and GIS specialist will work in coordination with the modelers to build the spatial data sets necessary to estimate and predict with the SPARROW and WARP models. Some of the data sets may require extensive statistical methods for their construction and modelers in the Hydrologic Systems Team will help guide the data specialists in these methods. An important component of the data specialists' duties will be development of automated algorithms so that updated data sets remain current with the most recent version of the NHDPlus reach network. The specialists will document all data sets they create and serve as authoritative sources for the proper use and interpretation of the data.

Table 2.17. Composition of SPARROW and WARP Modeling Team. Some positions may be comprised of part-time commitments of more than one person.

Position	Grade(s)	FTE	Duration	Position Description
Lead Scientist	GS-13/14	1.0	FY13-FY22	Coordinates the development of the 2012 regional models. The leader will also have responsibility for producing and documenting the 2012 nutrient and suspended sediment models for one of the regions (see regional modeler responsibilities below). The team leader will coordinate other regional modelers to compile water-quality data for the development of the 2017 national model updates and acquire of all data necessary to produce 2017 regionalized national models for nutrients, suspended sediment, dissolved solids and organic carbon.
Regional SPARROW Modeler	GS-12/13/14	1.0	FY13-FY22	Responsible for data acquisition, model specification, and documentation of the 2012 regional models for nutrients and suspended sediment for one of four regions. Each modeler will have a detailed understanding of the major water-quality issues occurring in their respective region, and will network with regional water-quality managers of other agencies to remain current on these issues. Regional modelers will provide and develop water-quality and ancillary data for the production of the 2012 and 2017 national models for nutrients, suspended sediment, dissolved solids and organic carbon.
Regional SPARROW Modeler	GS-12/13/14	1.0	FY13-FY22	Responsible for data acquisition, model specification, and documentation of the 2012 regional models for nutrients and suspended sediment for one of four regions. Each modeler will have a detailed understanding of the major water-quality issues occurring in their respective region, and will network with regional water-quality managers of other agencies to remain current on these issues. Regional modelers will provide and develop water-quality and ancillary data for the production of the 2012 and 2017 national models for nutrients, suspended sediment, dissolved solids and organic carbon.

Regional SPARROW Modeler	GS-12/13/14	1.0	FY13-FY22	Responsible for data acquisition, model specification, and documentation of the 2012 regional models for nutrients and suspended sediment for one of four regions. Each modeler will have a detailed understanding of the major water-quality issues occurring in their respective region, and will network with regional water-quality managers of other agencies to remain current on these issues. Regional modelers will provide and develop water-quality and ancillary data for the production of the 2012 and 2017 national models for nutrients, suspended sediment, dissolved solids and organic carbon.
WARP Modeler	GS-12/13/14	1.0	FY13-FY22	The WARP modeler will develop and document national WARP models and updates and coordinate the development of the regional WARP models associated with synoptic studies. Coordinates the development of the pesticide use database for program-wide applications.
GIS Specialist for Model Support	GS-11/12/13	1.0	FY13-FY22	Approximately 80-90 percent of the time in this position will be spent on preparing ancillary data to SPARROW and WARP models, and the remaining 10-20 percent will be spent on taking primary responsibility for management and support for one or more national GIS data sets for NAWQA-wide use.
Data Management Specialist	GS-11/12/13	1.0	FY13-FY22	Manages large data hydrologic sets (e.g. data sets too large to be managed with Microsoft Excel or Access) in support of SPARROW and WARP modeling. Compiles data from other USGS programs and other state and Federal agencies. Screens data for useful information.

Regional Synoptic Studies

Introduction

A Regional Synoptic Study (RSS) is a short-term, targeted water-quality assessment of a region or issue. The overall objectives of the RSS are to:

- Determine contaminant, nutrient, and sediment concentrations in relation to land use and chemical use in selected regions.
- Determine links between contaminant, nutrient, and sediment conditions and ecological impairment.
- Evaluate significance of contaminant distributions and levels to sources of drinking water.
- Develop models of contaminant and nutrient concentrations for streams in unmonitored areas.
- Each individual RSS will have refined specific objectives and products.

Regional Synoptic Studies are typically 1-2 year studies that target a specific seasonal period of interest. Generally, the number of sampling sites for a RSS in a particular region is much greater than the number of NSFN sites in the same geographic area, typically in the range of 10 to 20 times more, depending on the scale characteristics and variability of the natural and anthropogenic features of the region. RSS are a very flexible design component. Some may be unique, one-time studies aimed at specific topic in one region, such as the distribution of a specific contaminant in spring runoff within a particular agricultural region. Others may be part of long-term rotational series of RSS, such as geographic assessments of

biological conditions in regions that are assessed using the same design, rotating regions over time to build a national data set on a particular topic.

Most RSS will be designed to address a combination of Goal 1 (status and trends of stressors) and Goal 3 (ecological effects of stressors) objectives. Some RSS specifically address an issue, such as contaminants in sources of drinking water, that does not have a significant ecological aspect, or an issue, such as flow alteration, that does not have a significant contaminant stressor aspect. The scope of stressors for status and trends objectives includes contaminants, nutrients, sediment, and streamflow alteration. Goal 3 is to “assess the effects and interactions of sediment, streamflow alteration, nutrients and contaminants on stream ecosystems within selected environmental settings and implications for management”, with a primary focus on Wadeable Streams. Thus, the RSS that are aimed at understanding regional-scale distributions of stressors and their relation to ecological conditions will predominantly focus on multiple stressors in Wadeable Streams and will be co-designed and executed to meet Goal 1 status and trends objectives and Goal 3 ecological effects objectives.

A typical RSS aimed at linking stressors to ecological effects will sample water at 50-100 sites across a region multiple times for up to one year, usually including bed sediment once during low flow, and therefore will augment the limited spatial coverage of the NFSN. Data from the NFSN, although geographically sparse, will serve to define the multi-year temporal context. Generally, water samples will be analyzed for contaminants and suspended sediment, and bed sediment samples will be analyzed for contaminants. Depending on the study, analyses may include toxicity assays and other biologically related assessments. Due to the importance of flow information for assessing streamflow alteration and contaminant fluxes, gauged sites will be sought to the extent possible while still meeting the design needs. The results will be used to describe contaminant occurrence in relation to land use and chemical use and to develop models of contaminant occurrence at unsampled stream reaches for the region. Measured and modeled contaminant occurrence at sites where ecological community and habitat sampling are conducted will provide information needed to evaluate the role of contaminant stressors in ecological impairment and be used in the development of ecological-response models.

Regarding the Goal 1 objective to “determine the distributions and trends of contaminants in current and future sources of drinking water from streams, rivers, lakes, and reservoirs”, the RSS will contribute in two main ways. First, all RSS that include contaminant analyses for stream water within a region contribute to understanding the quality of current and potential sources of drinking water. In each RSS, this understanding will be enhanced by considering, as part of the sampling design, the locations and nature of drinking water intakes in the region—when possible, sampling sites will be chosen to increase relevance of the results to the assessment of drinking water sources. Second, one RSS will be specifically designed to address a wide range of contaminants in reservoirs used for water supply with a focus on the most vulnerable, small reservoirs with urban and agricultural lands in their watersheds.

The Goal 1 RSS will support Goals 2 and 4 by providing contaminant occurrence in many Wadeable Streams under high- and low-flow (base flow) conditions. This information will help support regional- and national-scale models, such as WARP (and potentially dynamic SPARROW models), and add a contaminants component to Integrated Watershed Studies of groundwater—surface-water interactions. Finally, to the extent that RSS study areas include Cycle 1 and Cycle 2 monitoring sites, these sites will be re-sampled to add a trends component to the RSS. This also could improve our spatial understanding of trends seen at the NFSN sites in the region, at least for very pronounced trends such as those caused by shifts in the pesticides used (e.g. introduction of pyrethroids).

Approach to Selecting Regional Synoptic Studies

Each RSS will be a multi-disciplinary, intensive study of water quality at a large scale, generally ranging between the EPA level 3 and level 2 ecoregion scale. The implementation plan includes five RSS. Three additional high-priority RSS that were not selected are identified as candidates if funding becomes available. The RSS planned for implementation are “front loaded” in Cycle 3, with all sampling occurring during FY13 – FY18.

Three primary criteria were used to define and prioritize regions for selection as a Cycle 3 RSS:

1. **Stressor Levels:** Prioritize regions with (1) large areas and proportions of stream miles potentially affected by high use, discharge, or occurrence of contaminants and (2) full gradients of stressor conditions from low to high levels.
2. **Importance of Resource to Receptors:** Prioritize regions based on the significance of streams (or reservoirs for the drinking water RSS) to aquatic ecological resources and to human uses, including surface water supplies of drinking water.
3. **Representative Setting/Distribution:** To the extent possible, distribute RSS to cover major geographic regions of the U.S. and major agricultural and urban types (e.g. western irrigated agriculture, Midwest corn and soybean belt, etc.).

Each of these criteria is described in more detail below. Although an individual RSS may include both agricultural and urban sites (as well as reference sites), most RSS will have a dominant focus on agriculture or urbanization. To simplify prioritization, and because data available for evaluating occurrence of agricultural and urban contaminants are very different, potential RSS were evaluated separately for agricultural- and urban-focused regional studies. Agricultural regions were evaluated using the intersection of EPA level 2 ecoregions (ECO2) and Farm Resource Regions (FRR) with (ECO2/FRR) as approximations of study area boundaries (Figure 2.12, Supporting Information Table S-1: Table summarizing characteristics of possible ECO2/FRR for study). ECO2 regions take similarity of biological communities into account and the FRR take similarity of agricultural land use (e.g. dominant crop types, extent of irrigation, etc.) into account. Urban regions considered for study were defined for the purpose of prioritization by evaluating urbanization within EPA level 3 ecoregions (ECO3) or combinations of two or more adjacent ECO3 (Figure 2.13 and Table S-2). Twelve ECO3s that contain substantial urbanization and stream resources were identified for further consideration (Supporting Information Table S-2). The criteria used to prioritize regions for study are described below.

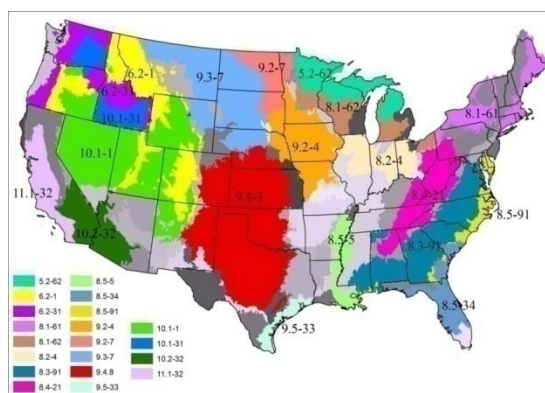


Figure 2.12. Intersection of Farm Resource Regions (FRR) and EPA Level 2 Ecoregions (ECO2). Selected FRR/ECO2 areas were identified as candidate study areas as indicated on the figure, and list of these with land-use and other characteristics is in Table S-1.

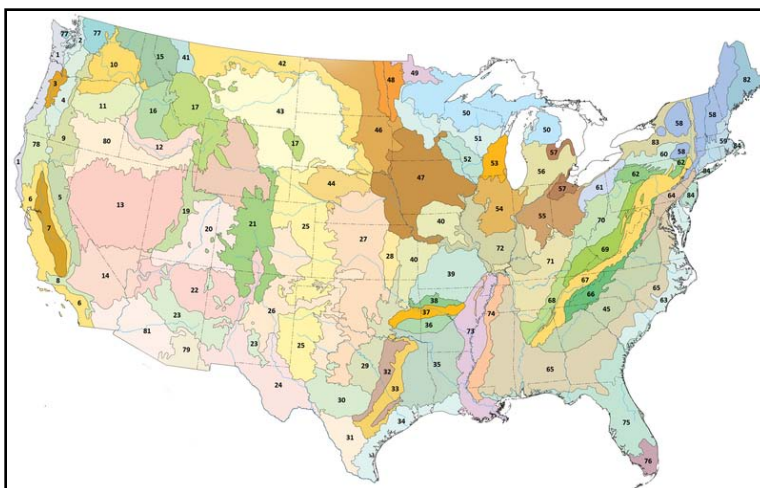


Figure 2.13. EPA Level 3 Ecoregions used as a decision tool for evaluation of urban-focused RSS

Stressor Levels

Two tests were applied to evaluate stressor levels: (1) magnitude and distribution (or gradient) of contaminant sources and (2) contaminant occurrence. The available data to address these tests differed between agricultural and urban settings. In agricultural regions, the magnitude and distribution of pesticide sources was evaluated using toxicity-weighted use (TWU) scores at the HUC10 scale. The TWU is calculated by dividing the use of each pesticide by its toxicity index value, from Pesticide Toxicity Index scores (Munn and others 2008), for each of three species groups (benthic invertebrates, cladocerans, and fish), then summing those results for each HUC10 and dividing by the HUC10 area (Figure 2.14). The distribution of TWU within regions was assessed and regions were given higher priority if they had a sufficient number of HUCs across the whole range in TWU (range determined for all of the regions together) and had lower urban land use in each decile, with special emphasis on the low and high ends of the TWU distribution (Figure 2.15). The objective of this evaluation was to find those regions with a wide distribution of stressor levels, high potential for adverse effects (the high end), and availability of stream with reference conditions (the low end).

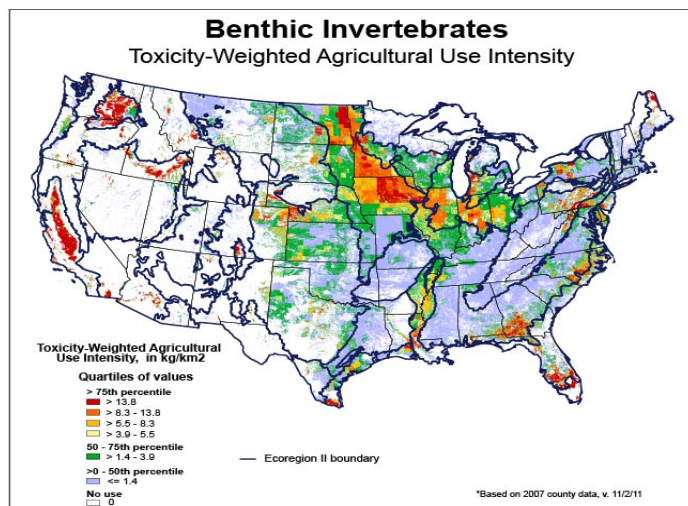


Figure 2.14. Toxicity-weighted use for agricultural pesticides relative to benthic invertebrates.

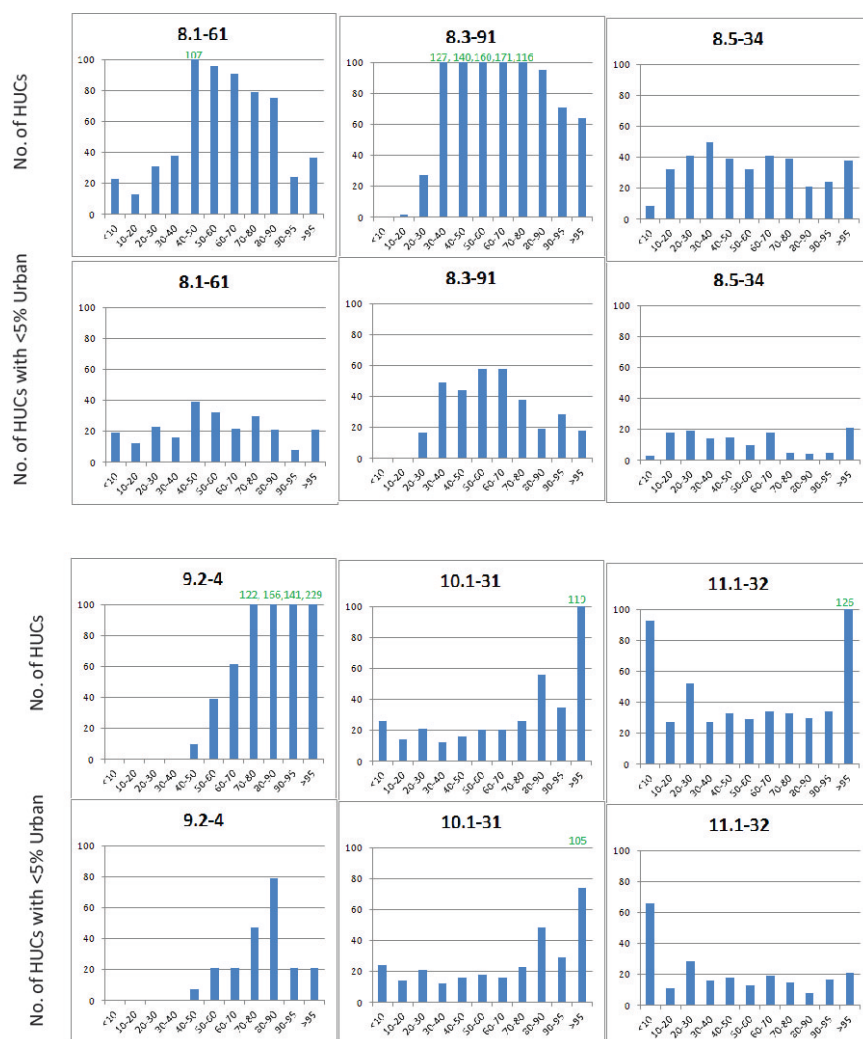


Figure 2.15. Distribution of Toxicity-Weighted Use (TWUbi) values (percentile of all TWU and HUCs nationally) for selected ECO2/FRR.

Lacking urban pesticide use information, and recognizing the occurrence of many other contaminants in urban settings, contaminant stressor levels were evaluated in potential urban study regions on the basis of measured contaminant occurrence and percent urban land use. Population density and percent urban land use have been shown to correlate to concentrations of a variety of contaminants (Chalmers and others 2007). Population (2010 census) and percent urban land use (NLCD06) were determined for HUC10s in each of the ECO3 (or combinations of ECO3s). The first screening step was to eliminate from further consideration those ECO3 lacking significant urbanization, as indicated by total population of less than 100,000 or with fewer than 10 HUC10s with greater than 70 percent urban land use. The distribution of stressor levels within the remaining regions was evaluated using the number of HUC10s in each potential study region falling in deciles of percent urban land use. Regions with better representation across the gradient in urban land use were given higher priority, for example in Level 2 ecoregions 8.4 and 8.5.

Contaminant occurrence, the final stressor criteria, was qualitative and was based on the Urban Stream Bed Sediment Study (USBS) and Contaminant Trends in Lake Sediments (CTLS) studies. Regions where

USBS results indicated higher potential toxicity from pyrethroids and regions where CTLS results indicate higher potential toxicity from PAH contamination were prioritized higher.

Significance of Resource to Receptors

Four factors were considered to assess the significance of the resource and the approach did not distinguish between predominantly agricultural and urban study regions. The first factor was the length (stream miles) and density of Wadeable streams in the region. Regions with more stream miles were prioritized. The second factor was the number of at-risk species. We used maps of at-risk fish and mussel species to assign potential regions in categories of low, medium, and high numbers of at-risk species (<http://www.epa.gov/bioiweb1/aquatic/freshwater.html>). The third factor was the number and density of surface water intakes for drinking water supply. This factor is obvious for selection of the drinking-water focused RSS, but was also considered in prioritizing selection of all RSS. The final factor considered for significance of the resource was the relative importance of the region nationally in terms of agricultural production or total population. Major agricultural regions and large population centers were given greater priority to increase the national significance of the RSS. In addition to contaminants, the three other stressor categories; streamflow alteration, nutrients, and sediment, will be ranked and considered in conjunction with the contaminants approach outlined here. More detail on the scoring and ranking of all four stressors, and their influence in overall design and regional and site selection can be found in the Goal 3 discussion of this Implementation Plan (Chapter 5).

Representative Setting/Region

This criterion was included to ensure that (1) the most important land-use settings from the national perspective were studied and (2), given the limited resources, similar land-use settings and regions were not studied more than once. With only five RSS included in the Goal 1 Surface Water Assessment implementation plan, it is important to cover major regions/settings of the country as efficiently as possible. For application to agriculture-focused studies, four major agricultural settings were identified: irrigated west, Midwest corn and soybean belt, south/southeastern U.S., and northeast. Each FRR/ECO2 considered was assigned to one of these agricultural settings on the basis of crop groups, crop diversity, climate, extent of irrigation, and geographic location (Table 2.18). Then the decision criteria previously described (related to stressor levels and significance of natural resources), was used to rank regions (FRR/ECO2) within each of the four major agricultural settings. The agriculture-focused RSS were selected from among the top priority FRR/ECO2 in each of the major agricultural settings. Ultimately, the number of settings that can be studied will depend on the funding level, but the representative setting approach can be used to select additional agriculture-focused RSS.

Table 2.18. High ranking potential agriculture-focused RSS within each of four major agricultural settings of the Nation. Potential RSS are ordered from higher to lower priority in each setting.

Major agricultural settings and potential study regions.			
Western irrigated ag	Midwest corn and soybean	Southeast	Northeast
Columbia Plateau (ECO2 10.1, Fruitful Rim NW)	NARS study (ECO2 8.2, 9.2; FRR Heartland, No Great Plains)	Miss-Alluvial (ECO2 8.5; Fruitful Rim SE, Miss Portal, So. Seaboard E)	Mixed Wood Plains (FRR/ECO2 8.1-61; No. Crescent E-W)
Central Valley (11.4-Fruitful rim W)	So Central Semi-arid Prairie (ECO2 9.4; No Great Plains, Prairie Gateway)	SE Plains (ECO3 8.3.5, So. Seaboard E)	
		TX-LA Coastal Plains (ECO2 9.5; Fruitful Rim TX)	

For application to urban-focused RSS, each potential study area (ECO3 or combination of adjacent ECO3s) was assigned to one of eight urban settings on the basis of its (1) rate and magnitude of population change and (2) climate/geography. The eight possible urban settings represent stable urban and rapidly urbanizing areas in each of four geographic areas, west/southwest, central, south, and northeast (Table 2.19). Within each urban setting, study regions are prioritized on the basis of stressors and resources as described above. Ideally, urban-focused RSS would represent both stable and urbanizing settings in all four geographic areas.

Table 2.19. Potential urban-focused RSS defined by ECO3 boundaries, ranked within each of four major regions of the U.S. The HUC10s column shows the number of HUC10s in the ecoregion that have (both) greater than 10 percent urban land use and less than 25 percent agricultural land use.

ECO3	Region	HUC10s	Population
West			
11.1.1	California Coastal	210	46,218,265
7.1.7	Strait of Georgia/Puget Lowland	55	3,970,906
Central			
8.2.2	Huron/Erie Lake Plains	25	2,818,923
8.2.3	Central Corn Belt Plains	17	6,088,283
8.2.1	Southeastern Wisconsin Till Plains	13	884,054
8.2.4	Eastern Corn Belt Plains	9	1,868,618
Northeast			
8.1.7	Northeastern Coastal Zone	126	17,758,860
8.1.1	Eastern Great Lakes Lowlands	37	2,163,792
South/Southeast			
8.5.3	Southern Coastal Plain	142	9,978,662
8.3.4	Piedmont	109	9,991,888
8.3.5	Southeastern Plains	81	5,941,766
8.5.1	Middle Atlantic Coastal Plain	53	2,902,797
8.3.1	Northern Piedmont	45	8,538,682

Regional Synoptic Study Prioritization Results

Regional prioritization as described above resulted in candidates for agricultural-focused studies in each of four major agricultural regions of the country and candidates for urban-focused studies in each of four geographic regions of the country (Tables 2.18 and 2.19). Using this ranking, four Goal 1+3 RSS and one Goal 1 only RSS (drinking water) are proposed. In two cases, a Goal 1+3 study will include urban and agricultural sites, allowing us to cover each land-use setting (urban and ag) in three regions of the country. Briefly, the five proposed RSS, their relative timing, and the rationale for their selection are:

1. **Midwest (NAWQA/NARS)(FY13-14)** – primarily agricultural focus, but also including mixed land-use sites typical of the region, and sites in suburban Chicago and Milwaukee to allow for assessment of contaminant status in rapidly growing and stable urban settings in the Central U.S. Collaborative study by NAWQA and the USEPA National Aquatic Resource Survey Program.

***Rationale:** This study was selected because it is one of the largest and most economically important agricultural region of the country, has high levels of pesticide and nutrient use and occurrence in streams, is important for contaminant loading to the Mississippi River and Gulf of Mexico, has several major urban areas (some of which are rapidly expanding), and is a high priority at the state and national levels in assessing the effects of agricultural management practices on water quality. The study will be in collaboration with the USEPA National Aquatic Resource Surveys (NARS) Program (ecology of wadeable streams) to be done in FY13 and FY14. The region has a great many miles of wadeable streams, some endangered aquatic species, and a high density of drinking water supply intakes. All of these factors combine to make this study a high priority for NAWQA. It is anticipated that as many as 100 sites will be sampled, with perhaps 75 percent of these in predominantly agricultural and reference settings and about 25 percent in urban and mixed land use settings. In this way, a large-scale agricultural and a moderate-scale urban characterization will be realized.*

2. **Southeast urban and agriculture (FY14-15)** – urban focus in the Piedmont (ECO3 8.3.4, Atlanta to Raleigh), to be designed in collaboration with the Goal 3 team, combined with an agriculture-focused study of the SE Coastal Plain (part of ECO3 8.3.5). The latter is ranked second for ag settings in the southeast region, but the advantages of combining the study with the Southeast Urban study outweigh the advantages of the Mississippi embayment area, which is ranked higher.

***Rationale:** The East coast Piedmont from Georgia to Virginia (ECO3 8.3.4) has been one of the nation's most rapidly urbanizing areas for the past several decades and has the advantage that much of the urbanization taking place is in encroaching on forested and light agricultural lands. The southeast Coastal Plain (ECO3 8.3.5, east from Alabama) is an intensive agricultural area growing a wide variety of crops with high levels of pesticide and nutrient use. The southeast, like the Midwest, is a major (and distinct) agricultural and climatic region of the country. The current plan is for the Ecological Effects RSS (Goal 3) to focus on urbanization in this region (mostly the Piedmont) and for the Contaminant RSS (Goal 1) to include urban and agricultural sites (Piedmont and Coastal Plain). This means that the contaminant characterization will be over a wider area than the ecological study and, therefore, not all ecological sampling sites will have the full chemical characterization. This disadvantage (which will happen in most RSS to some degree because of funding limitations) is balanced by the benefit of five RSS representing three major and diverse agricultural regions of the country (southeast, Midwest, and far west) and three major and diverse urban regions of the country (southeast, Midwest, and TBD).*

3. **Drinking water reservoirs (FY14-15)** – focus on water supply reservoirs in the Midwest and southeast, overlapping, to the extent possible (in space and time), with the Midwest NAWQA-NARS and Southeast urban studies.

***Rationale:** This RSS does not have a direct link to Goal 3 stream ecology objectives, but it will be closely integrated with the Midwest and Southeast RSS identified above. The Midwest (especially the eastern and southern portions of the planned Midwest/NARS RSS) and the Piedmont rely heavily on surface water for supply. Streams with drinking water intakes and streams that flow into drinking water reservoirs will be prioritized, to the extent possible, during site selection for those two RSS. Drinking water reservoirs that are downstream from other stream RSS sites (or NAWQA fixed stations) will be prioritized for sampling in the drinking water RSS. Drinking water reservoirs will be chosen mostly or solely from regions where streams are sampled by the Midwest and southeast RSS. In the Midwest, the drinking water RSS will start in FY14, allowing the drinking-water RSS planning team to benefit from contaminant occurrence data from the Midwest RSS collected in FY13. Sampling in the southeast by the stream RSS and the drinking-water RSS will be done in FY14 and FY15, allowing for co-location of some stream and reservoir sites. This integration will add valuable information on sources and timing of contaminant loading to drinking water reservoirs.*

4. **Western Irrigated Ag (FY16)** – either the Columbia Plateau or the Central Valley of California; both rank highly. Both have high intensity use of pesticides and good distribution of potential sites over the gradient in contaminant stressors. Both are of high national significance economically and in terms of aquatic resources.

***Rationale:** This RSS represents the third of the three largest and most distinctive agricultural settings of the country, irrigated western agriculture. Both of these areas are very intensively farmed for a wide variety of crops and both are important nationally for food production and economic output. Both also have experienced significant adverse ecological effects of agricultural and water-resources development, including potential effects on several species of salmon that are listed as endangered species.*

5. **Urban TBD (FY17-18)** – There are four good candidates for this study: Pacific NW, Central Texas, eastern Great Lakes, and New England. Final selection will consider regional balance, differences in contaminant occurrence (e.g. PAHs and pyrethroids), rate of urbanization, and priorities of Ecological Effects RSS (Goal 3).

***Rationale:** This study is yet to be decided, although several options have been identified. Given that we will have done a moderate-scale urban study in the Midwest and an intensive study in the southeast, we see four possible settings that will compliment these: New England (ECO3 8.1.7+8.5.4), Eastern Great Lakes (8.1.1), Central Texas (ECO3 9.4.7+8.3.8), and the Pacific Northwest (ECO3 7.1.7+7.1.9).*

A preliminary RSS timeline for planning, data collection, and analysis and report writing is given in Table 2.20.

Table 2.20. Tentative timeline for Regional Synoptic Studies. P is the planning year. The number in tan is an approximate number of sites sampled each year. R is the reporting years.

Year	Midwest (NARS)	Goal 1and3 RSS	Drinking water	Goal 1and3 RSS	Goal 1and3 RSS
2012	P				
2013	100	P	P		
2014	R	50	30		
2015	R	45	20	P	
2016		R	R	50	P
2017		R	R	R	30
2018				R	20
2019					R
2020					R
2021					
2022					

Regional Study Designs

The initial scope and approach for each of the first three RSS, as preliminarily selected, are described below, but most design specifics will be developed during the planning year of each study, and some broader aspects of scope and approach as outlined here could change. The first RSS, currently being planned in collaboration with EPA is certain, whereas the specific nature and scope of RSS2 and RSS3 are still very preliminary and are provided as examples of likely possibilities. With the exception of the Drinking Water Reservoir study, the RSS will have the broad objectives of characterizing water quality and providing contaminant, nutrient, and sediment stressor information to relate to ecological metrics, and all will be conducted within the following general framework:

- Select sites to cover a wide range in expected stressor conditions and a wide range in potential explanatory variables, such as pesticide application rates and agricultural management practices.
- Sample as many Cycle 1 and Cycle 2 NAWQA sites as possible that are consistent with the RSS design criteria in order to benefit from historical information and to add a trends component.
- Sample as many sites relevant to a drinking water supply intakes or reservoirs as possible.
- Characterize water-column chemistry and sediment for an index period leading up to ecological sampling.
- Characterize bed-sediment chemistry with one sample at each site collected about the same time as ecological and toxicity sampling.
- Characterize toxicity at many sites where water and sediment chemistry are measured.

Regional Synoptic Study 1- Upper Midwest

Short Title: Temperate Plains Synoptic (TPS)

Overview of Program Roles: This project is a collaboration of the USGS National Water Quality Assessment (NAWQA) and Columbia Environmental Research Center (CERC), and the USEPA NARS Program. NAWQA and CERC will primarily focus on assessment of stressor conditions, particularly contaminants, nutrients, and sediment. NARS will primarily focus on assessment of ecological

conditions, and both programs will collaborate on assessing relations between biological conditions and concentrations of contaminants and nutrients. Study team members from both programs will work together on study design, execution of sampling and analysis, and data interpretation and reporting.

Objectives:

- 1. Assess the geographic distribution of spring-summer seasonal conditions of contaminant, nutrient, and sediment concentrations**
 - a. Assess the geographic distribution and toxicity of selected contaminants in water and sediment
 - b. Assess the geographic distribution of nutrient and sediment concentrations in water
 - c. Assess the seasonal levels and temporal variation, within the 3-6 month period prior to ecological sampling, of contaminants, nutrients, and sediment in water
 - d. Extrapolate contaminant and nutrient “exposure” estimates to all stream and river segments in the study region.
- 2. Assess relations between biological conditions and concentrations of contaminants, nutrients, and sediment.**
 - a. Assess relations between nutrient levels, concentrations of specific contaminants, and contaminant indices (e.g. pesticide toxicity index) and biological condition.
 - b. Evaluate the relative importance of contaminants, nutrients, and sediment in influencing biological impairment.
 - c. To the extent possible, use stressor-biota relations and spatial extrapolations of exposure to identify stream segments where contaminant stressors are likely to be affecting biological condition.

Study Area: The study area is most of the Temperate Plains Region, as defined for NARS, with the omission of the Red River of the North drainage and some smaller subareas. The TPS study area boundaries (Figure 2.16) were specifically determined by combining the following Level III Ecoregions: 8.2.1, 8.2.2, 8.2.4, 8.3.2, 9.2.3, and 9.2.4 (excluding the southern section in KS, MO and OK).

This study area was selected because it is one of the largest and most economically important agricultural regions in the country, has high levels of pesticide and nutrient use and occurrence, is important for contaminant loading to the Mississippi River and Gulf of Mexico, has several major urban areas, and is a high priority at the State and national levels in assessing the effects of agricultural management practices on water quality and aquatic ecosystems.

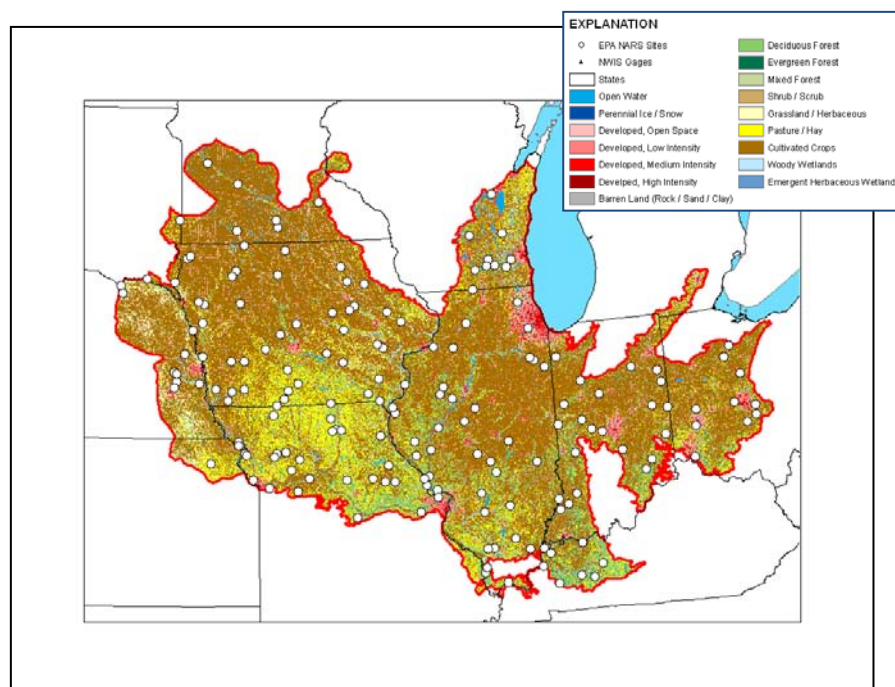


Figure 2.16. Study area for Temperate Plains Synoptic Study. White dots are EPA NARS sites from 2008-9 with watersheds less than 1,000 km² (n=121).

Targeted Stream and River Sizes: The TPS will allocate 75 percent of sites to stream orders 1-4 and 25 percent to stream with orders 5 or higher. Compared to NARS this places a higher weight on sites in orders 1-4. TPS staff will work with the states during site reconnaissance to ensure that only perennial streams are sampled. This might exclude some very small basin sites that EPA sampled in the past.

Overview of Site Selection Approach: The general approach to the TPS will be to combine the NARS probabilistic survey of biological conditions in streams and rivers with the NAWQA regional synoptic study of contaminants, nutrients, and sediment in streams and rivers and their relation to biological conditions. The approach has two specific goals that affect site selection: (1) make statistically-valid inferences about stream quality and the relative importance of contaminants to ecosystem status regionally; and (2) provide data to evaluation stressor-ecology relations and to develop regression models of contaminant occurrence capable of spatially-explicit extrapolations. The first goal requires that USGS contaminant sampling be linked to the probabilistic sampling sites of the EPA. The second goal requires that USGS sites be sampled to optimize coverage of gradients in explanatory variables of water quality.

Two specific approaches to site selection will be applied and evaluated:

- A. Supplement a portion of NARS sites with additional sites for TPS:
 - a. develop the NARS sampling strategy as usual, without *a priori* influence of the TPS site selection considerations,
 - b. select as many of these as possible that will meet TPS study requirements, and
 - c. add additional sites as needed to meet requirements of the TPS, either by hand-picking sites or by using a stratified random site selection constrained by TPS requirements.
- B. Integrate TPS sites into NARS probabilistic design:
 - a. determine site-selection criteria for the TPS and characterize all candidate basins in the study area with respect to these criteria, and

- b. integrate these criteria into the probability design for the NARS survey to yield the selected sample sites.

Both of these approaches require specification of the sampling design for the TPS.

Sampling Overview

Water-column sampling for TPS will be designed to characterize contaminants, nutrients, and sediment for a 6-12 week index period prior to ecological sampling. The range in length of the index period reflects the reality that the timing of the ecological sampling in some states will be decided by the states or contractors, will spread over several weeks or more, and will be subject to weather and other logistical factors. For these reasons, we will maximize the length of the water-quality sampling period prior to the ecological survey (minimum of 6 weeks but preferably 9-12 weeks), with no gap in sampling before the ecological survey, and with a consistent 12-week period of monitoring at all sites.

1. Water column: ~12 samples over an about 3 month index period prior to ecological sampling. Analyze for ~300 pesticides and degradates, nutrients, suspended sediment, and Cl (and possibly other major ions).
2. Bottom sediment: one sample at each site collected about when the ecological sampling takes place. At non-urban sites (urban < 5 percent) analyze for major and trace elements, organic carbon, and ~120 current use pesticides. At mixed and urban land use sites, add PAHs and halogenated compounds (chlorinated and brominated compounds including PCBs and organochlorine pesticides).
3. Toxicity: one sample at each site collected coincident with the bottom sediment sample for chronic toxicity testing. It is likely both sediment and water testing will be done.

Data Interpretation and Report Products

Details of data analysis and report plans and responsibilities will be developed by national and regional project leaders from all program partners.

Regional Synoptic Study 2-Southeast

As currently envisioned, the Southeast RSS will have two land-use objectives from the stressor- status-assessment perspective (Goal 1), only one of which will be an objective of the associated ecological-effects study (Goal 3). The common objective will be to characterize the effects of urban stressors on stream ecology and will focus on ECO3 8.3.4, including greater Atlanta, Georgia, and Raleigh-Durham, North Carolina. A second land-use characterization objective of Goal 1 is the intensive agricultural southeast coastal plain (ECO3 8.3.5). More sites in the southeast (contaminant assessment) RSS will be devoted to the urban-focused study than to the agricultural-focused study to provide adequate contaminant stressor data to the ecological study. A subset of sites in both ECO3 regions will be reference sites.

The decision to devote a substantial portion of the sites in the southeast RSS to agriculture outside of the scope of the Goal 3 RSS means that not all of the sites where ecological sampling is planned will have full contaminant characterization. At those sites, contaminant occurrence will be estimated using limited water-quality sampling for indicator compounds as part of the ecological effects study and possibly with statistical models (e.g. WARP or land-use regression based models). There are important benefits to extending the Goal 1 study to agricultural settings in the southeast. Mixed land-uses settings are common in all parts of the country and their implications for stream quality are not well understood. Extending the southeast RSS study area into a major agricultural area means that various mixtures of reference, agriculture, and urban land uses will be sampled, similar to the benefits of extending the

Upper Midwest RSS into mixed and urban land-use watersheds. More importantly, this expansion of the southeast RSS to include agriculture, and the inclusion of urban lands in the Upper Midwest RSS, will mean that three major agricultural and three major urban regions of the country will be sampled during Cycle 3.

Regional Synoptic Study 3-Drinking water

The primary purpose of this study is to provide information on the occurrence of a broad range of regulated and unregulated anthropogenic organic contaminants in source water of community water systems (CWSs) supplied by reservoirs. A secondary purpose is to understand occurrence patterns in source water and determine if these patterns also occur in finished water prior to distribution. The study is an extension of the Source-Water-Quality Assessment study conducted during Cycle 2 that focused on systems solely supplied by streams or groundwater. Only CWSs that are supplied solely by a reservoir will be considered for sampling; candidate reservoirs for RSS 3 occur across the country but are concentrated in the East and Midwest (fig. 2.17). Systems that blend reservoir water with groundwater or other surface water sources will not be selected for sampling. This provides the greatest opportunity for comparing source-water quality to finished-water quality. In addition, CWSs supplied by reservoirs considered to be the most vulnerable to anthropogenic organic contaminants will receive priority for sampling over those considered less vulnerable. To the extent possible, reservoirs may be located within study areas or downstream from other contaminant-based RSS activities to strengthen scientific understanding of links between land use and contaminant occurrence in source streams with contaminant occurrence in water-supply reservoirs.

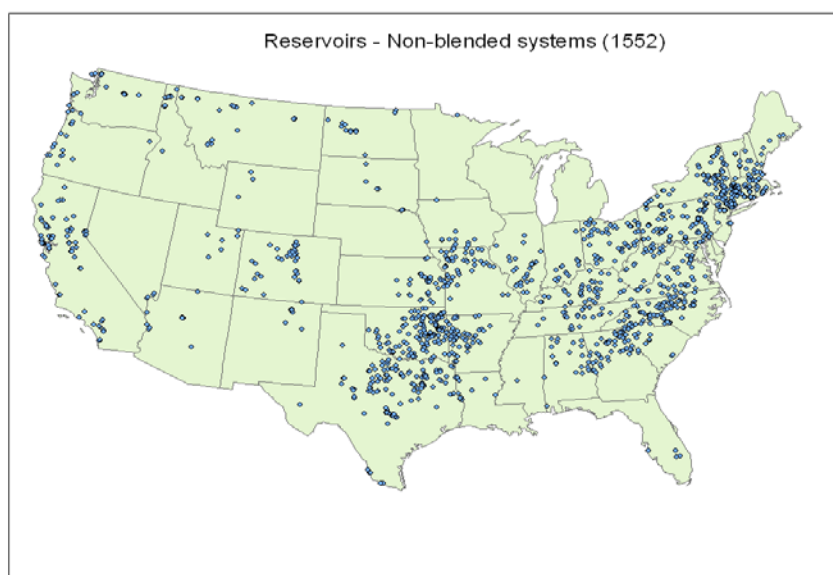


Figure 2.17. Possible locations of reservoirs used by community water systems that do not blend with groundwater or other surface-water sources.

Sampling activities are planned over a two-year period (tentatively, 2014 and 2015) wherein a larger percentage of reservoirs would be studied during the first year and a smaller percentage the following year, for example, 60 percent studied the first year and 40 percent the second year. The actual number of reservoirs to be sampled, the sampling frequency, and the percentage of finished-water samples analyzed will be determined during the detailed planning phase. To illustrate a possible design, 100 reservoirs used by CWSs that do not blend with other water sources are shown on Figure 2.17. These reservoirs were selected primarily based on those having the smallest watersheds (less than 1,900 km²)

with the largest amount of agricultural or urban land use within the watershed. Five reservoirs with the smallest amount of agricultural or urban land use within their watershed were selected and considered to be reference sites.

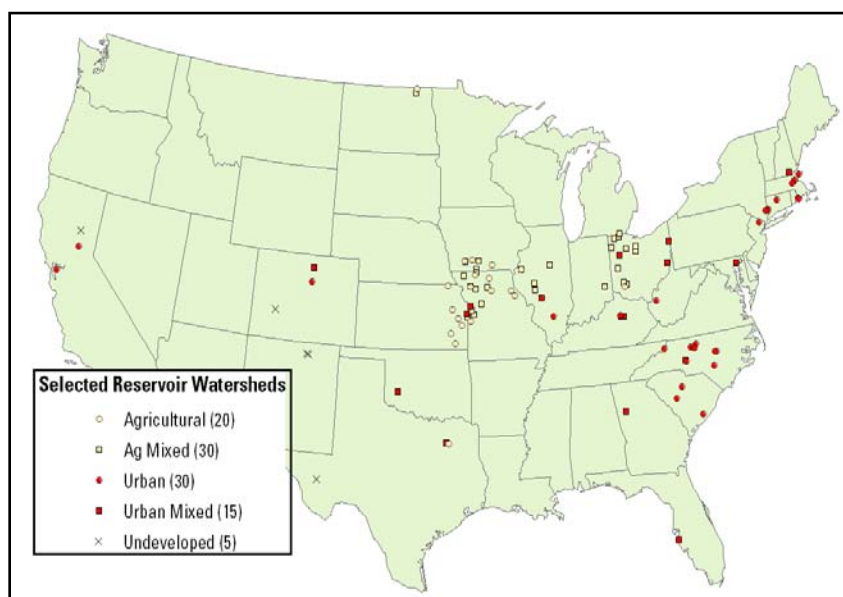


Figure 2.18. Possible locations of 100 reservoirs used by community water systems that are considered to be the most vulnerable to anthropogenic organic contaminants.

In addition to the broad objectives of characterizing the occurrence of anthropogenic organic contaminants in source and finished water of CWSs supplied by reservoirs, there are additional, more specific objectives. These include:

1. Chlorine oxidation of anthropogenic organic contaminants. No model currently exists that can predict the removal or transformation of organic contaminants by chlorine disinfection (Susan Richardson, Disinfection By-Product Research Chemist, U.S. Environmental Protection Agency, National Exposure Research Laboratory; written communication). A better understanding of the potential oxidation and transformation of these contaminants is important, in part, because little is known about the human-health significance of degradation products. Characterizing contaminants that are more or less susceptible to chlorine oxidation may provide valuable information to guide future research in determining toxicity values for parent contaminants and degradates of parent contaminants found to occur frequently in source water treated with chlorine. Additionally, an improved understanding of contaminants found to degrade and (or) transform in the presence of free chlorine may be significant in consideration of additional contact time in the distribution system of community water systems which may result in smaller concentrations than found in source water.
2. Algal toxins. There is no national-scale database for algal toxin occurrence in reservoirs. However, there have been anecdotal reports of adverse health effects on humans and poisonings of pets or wildlife from at least 36 states making it a national issue (Jennifer Graham, USGS Kansas Water Science Center, written communication). There have been some regional studies conducted and several states monitor for algal toxins in reservoirs used heavily for recreation. In addition, the U.S. Environmental Protection Agency included microcystins in the 2007 NARS National Lake Assessment. Combining information from these sources may provide a general indicator of algal toxin occurrence on a regional basis and facilitate targeting reservoirs or watersheds with consistent problems and high concentrations as well as areas of the country lacking information. Finally, the study of algal toxins in reservoirs would provide significant information for a better understanding of nutrient effects and eutrophication. A national map of acute

cyanotoxin poisonings in recreational freshwaters of the United States that may be of interest is provided here: <http://ks.water.usgs.gov/studies/qw/cyanobacteria/LLsummer-graham2.pdf>.

3. Nutrients and eutrophication. Nutrient enrichment of reservoirs and the resulting increases in algal growth can have direct effects not only on the water quality within the reservoir but also on CWS water-treatment operations. For example, nutrient enrichment increases particulate and dissolved organic substances, increases pH, and depletes oxygen within the reservoir. These factors tend to hinder flocculation, increase clogging of filters, and increase the chlorine demand necessary to treat the water for human consumption (Walker, 1983).

As specific plans for this RSS are developed, several outstanding issues will need to be addressed:

- Additional funding to support data collection to address objectives 2 and 3 above (algal toxins and nutrients/eutrophication) will need to be identified via partnerships with other agencies or programs within the USGS. Alternatively, the degree to which these two objectives will be satisfied needs to be determined and which will subsequently impact the overall scope of the study.
- Reach consensus on how to characterize the “vulnerability” of reservoirs (percentage of agricultural/urban land use versus relationships between surface area of the reservoir and the watershed).
- Reach consensus on the number of reservoirs to be sampled, sample frequency, and percent of finished-water samples to be collected.
- Identify specific CWSs based on reservoir vulnerability and obtain sampling permissions.
- Determine if this study should focus only on reservoirs in the eastern United States.
- Use of continuous water-quality measurements to identify timing of algal blooms in studied reservoirs.

Composition of Regional Synoptic Study Team

Staffing will be organized at two main levels: a national RSS team and RSS-specific teams composed of selected national team members, a regional project leader, and data-collection staff from WSCs in the study region. The national RSS team for the Goal 1 aspects of the RSS will require 7 FTE. Regional project leaders for individual RSS will require an additional 0.5 to 2 FTE per year, depending on the year and how many studies are in progress. A scientist from the national team will be a co-project leader with the regional project leader for each of the RSS-specific studies. The national team will provide continuity among the RSS through co-leadership, participate as staff for the RSS-specific teams (in collaboration with the Goal 3 team), assist with design, interpretation, and reporting of each RSS, provide data base and GIS support to all RSS, and participate with other Cycle 3 teams in contributing to status and trends products, particularly to national synthesis products. The five planned RSS each have unique aspects of setting, water-quality issues, and expected products, different degrees of coordination with ecological-effects RSSs, and each is on a different timeline, although they will overlap in time.

There are several objectives in this approach to staffing. One is to have continuity among the RSS, which will be provided by the national RSS team. Another is to ensure that sampling and products from each RSS will be completed in a coordinated and timely manner by having co-leadership of each RSS study by a “local” regional project leader and a co-leader from the national RSS team. A third is to facilitate collaboration between the other NAWQA study teams and Programs in the Water and other USGS Mission Areas. This link will be made by including an ecologist on the national RSS team and by having ecologists and water-quality specialists working together on each study. The composition of the RSS national team and the regional project leader role is summarized in Table 2.21. This is followed by a description of the field teams for data collection, which are not included in Table 2.21.

Table 2.21. Composition of the national team for Regional Synoptic Studies, including regional project leaders. Some positions may be comprised of part-time commitments of more than one person.

Position	Grade(s)	FTE	Duration	Position Description
Lead Scientist	GS-13/14	1.0	FY13-FY22	Coordinates all RSS Contaminant Studies and participates in design, study coordination, interpretation, and reporting for all RSS. RSS studies will include water and sediment chemistry, toxicity, and the development of linkages to ecological response. The RSS team leader will be responsible for strategic planning for the RSS in collaboration with other NAWQA program leaders and for ensuring effective incorporation of RSS findings into national synthesis products.
Ecologist: Toxicology and Modeling	GS-12/13/14	1.0	FY13-FY22	Aquatic ecologist with an ecological modeling and/or toxicological background. Works with RSS team members to ensure effective integration of ecological-effects objectives and leads the application of toxicological tests and ecological modeling, sometimes arranging and coordinating part-time contributions from other ecologists. Experience with statistical data analysis and report writing is essential. The RSS Ecologist will be a key participant in all RSS with an ecological component, and will serve as the RSS team leader for at least one RSS.
Water-Quality Specialist: Contaminants, Nutrients, Sediment, Data Analysis	GS-12/13/14	1.0	FY13-FY22	Hydrologist or chemist with an interdisciplinary background in contaminant chemistry and environmental behavior for surface water, combined with broad knowledge of water quality, including working familiarity with nutrients and sediment. Experience with statistical data analysis and report writing is essential. Works with RSS team members to ensure effective integration of information on contaminant and other water-quality characteristics and behavior into study designs and interpretation. Will be a key participant in all RSS and will be co-leader of at least one RSS.
Water-Quality Specialist: Contaminants, Nutrients, Sediment, Data Analysis	GS-12/13/14	1.0	FY13-FY22	Hydrologist or chemist with an interdisciplinary background in contaminant chemistry and environmental behavior for surface water, combined with broad knowledge of water quality, including working familiarity with nutrients and sediment. Experience with statistical data analysis and report writing is essential. Works with RSS team members to ensure effective integration of information on contaminant and other water-quality characteristics and behavior into study designs and interpretation. Will be a key participant in all RSS and will be co-leader of at least one RSS.
Data Analyst: Statistics and Modeling	GS-12/13/14	1.0	FY13-FY22	Hydrologist or chemist with a broad background in statistical analyses for water-quality assessments, particularly including statistical aspects of sampling design, development of multiple regression models, and other multivariate methods. Works with RSS team members to ensure effective application of statistics in data analysis and develops regional WARP models. Will be a key participant in all RSS and may serve as team leader for one RSS.
Regional Project Leaders	GS-12/13/14	0.5 to 2	FY13-FY20	Regional project leaders will work in cooperation with a co-project leader from the national RSS team. Major duties will include: • Collaboration in study design, including site selection, sampling strategy, and analytical strategy • Liaison with WSCs and agencies in the study region • Leadership in managing data collection, including arrangement and coordination of field program involving multiple WSCs • Direction of data management and QA/QC • Participation in data analysis and report preparation, including

				public presentations of results Requires expertise in interdisciplinary SW quality studies, thorough familiarity with the study region, and experience and skill in coordinating complex field operations with multiple agencies involved.
GIS Specialist for Model Support	GS-11/12/13	1.0	FY13-FY22	GIS specialist with strong technical background and experience with applying GIS to water quality assessment and managing and manipulating a wide range of geographic data. This position will be approximately 80-90 percent involved with planning and analyzing RSS and about 10-20 percent on taking primary responsibility for management and support for one or more national GIS data sets for NAWQA-wide use.
Data Manager and Analyst	GS-11/12/13	1.0	FY13-FY22	Manages the collection and QA/QC of water quality data, and manages water quality databases. Past field experience is desirable so that there is an understanding of the data collection issues. Backgrounds in statistics and graphical analysis are desirable. These hydrologists will work with RSS teams to ensure that the entry, quality, and management of data works smoothly for each project and will be involved to varying degrees in a range of data analysis roles.

Field Teams

The other staffing requirement needed to carry out the RSS is the field teams. Each RSS will require a large-scale, short-term field effort. It is estimated, for example, that RSS 1, will require 10 crews of two technicians each to be in the field for 3 months during spring and early summer 2013. Those crews and supervisory and supporting personnel will be pulled from numerous WSCs. The field staff required will vary somewhat for each RSS, depending on number of sites, frequency of sampling, and parametric coverage. Staffing of a hypothetical field team needed to conduct a 100-site RSS similar in scale to the Upper Midwest study (RSS 1) was used to estimate FTE requirements (9 FTE during FY13) and the average per-sample costs.

Products

Specific data and publication products will be designed for each RSS as plans are developed. A preliminary idea of the nature and scope of products, examples is provided below. RSS team members also will participate in development of synthesis products that combine RSS findings with national status and trends assessments.

Data Product Examples

- Geo-referenced online data report, including methods. This will provide documentation of the approach and methods and make the data widely available. It also will be the basis of most interpretive products (e.g. journal articles). Audience: scientific community, water-management and regulatory agencies.
- Data to support other program Goals. Audience: the rest of NAWQA.

Interpretive Product Examples

- Occurrence and model of pesticides in streams (e.g. updated WARP model for agricultural pesticides in the Midwest). Journal article. Audience: scientific community, EPA and state environmental agencies in the region, U.S. Department of Agriculture National Resource Conservation Service (USDA-NRCS), agricultural and pesticide industry interests, general public.
- Occurrence and models of sediment contaminants in streams (could be urban or ag or both). Likely will require development of new statistical models. Journal article and possibly on-line presentation and

interactive tools. Audience: scientific community, USEPA and state environmental agencies, urban planners, cities, some industries, and the general public.

- Relations between contaminants in water and sediment to toxicity. Journal article. Audience: scientific community, USEPA and state environmental agencies, industries, (less to) general public.
- Relations between land-use management factors and contaminant occurrence (e.g. ag management practices and pesticides in Midwestern streams). Journal article. Other factors to be investigated are degree and type of urbanization (e.g. use of pavement sealants), density of tile drains in the watershed, soil type, rainfall, etc. Audience: scientific community, EPA and state environmental agencies in the region, NRCS, agricultural and pesticide industry interests.
- Trends in contaminant occurrence. Journal article. Look for major shifts in pesticide and PAH occurrence at sites sampled by NAWQA in cycles 1, 2 and 3 (this RSS). Cycle 1 and 2 sites (e.g. BSandT and FS) will be prioritized in RSS site selection. Audience: scientific community, EPA and state environmental agencies in the region, some industry interests, general public.
- Sources of contaminants in streams (e.g. forensic modeling analysis of PAH sources in urban water bodies). Journal article.
- Relations between stream chemistry and genotoxicity (or other measures of potential effects beyond traditional toxicity testing). Journal article.
- New methods (e.g. new sampling strategies and equipment). Journal article.
- One capstone product is anticipated for each RSS, with the nature and scope to be designed as plans and implementation progress.
- National synthesis capstone products will also be planned that synthesize findings from multiple RSS or are part of broader syntheses of findings from multiple NAWQA components.

Chapter 3-Recommendations for Groundwater

In Cycle 3, NAWQA groundwater assessment activities will focus on the quality of groundwater resources needed for public and domestic drinking supply, and on the contribution of contaminants from groundwater to streams. This focus is expressed in the following five objectives derived from the Science Plan:

1. Determine the distributions and trends of contaminants of concern in aquifers needed for domestic and public supplies of drinking water.
2. Determine how hydrologic systems—including water budgets, flow paths, travel times and baseflow contributions to streams—are affected by land use, water use, climate, and natural factors.
3. Determine how sources, transport, and fluxes of contaminants to and within aquifers are affected by land use, hydrogeologic characteristics, climate and other natural factors.
4. Apply understanding of how land use, climate, and natural factors affect water quality to determine the susceptibility of groundwater resources to degradation.
5. Evaluate how the effectiveness of current and historic management practices and policy is related to hydrologic systems, sources, transport and transformation processes.

Introduction

During Cycle 3, NAWQA's assessment of groundwater quality will contain two major components: Status and Trends (Goal 1) and Groundwater Quality Modeling and Mapping (Goal 2). The planned budget allocations for the two goals are provided in Table 3-1. Over the 10 year Cycle (FY13-FY22, Table 3-1), the groundwater budget will be split approximately 50 percent for data and 50 percent for analysis, modeling, mapping, and reporting. The budget for data is "front-loaded" to maximize the number of samples collected and to provide an opportunity for NAWQA staff to analyze the data collected during Cycle 3.

NAWQA Groundwater studies will include a National Team for Status and Trends, a National Team for Modeling and Mapping, and 4 Principal Aquifer (PA) Modeling Teams (Figure 3-1). Two additional teams will be formed: Synthesis of Data and Models, and Decision Support and Forecasting. In addition, NAWQA will rely on personnel in Water Science Centers (WSCs) to collect groundwater data, and participate in trend analysis, interpretative studies, and development of modeling and mapping products, the latter as members of the three teams identified above. The funding for the WSC personnel involved in data collection is incorporated into the Goal 1 Data budget (Table 3-1). The funding for Modeling and Mapping, PA Modeling, and Decision Support and Forecasting is shown in the Goal 2 budget.

The Status and Trends team will be responsible for operation of the recommended trends networks, design and implementation of new networks, and analysis and reporting of data at National and PA scales. The Status and Trends team will include 4 critical positions: "Regional PA Coordinators" (alternatively, PA network analysts) who will be led by a Lead Scientist. The PA coordinators, working with WSC personnel, will be responsible for data collection and assessment within their regions. The 4 PA coordinators will also be members of the PA modeling teams, and where appropriate, will coordinate with NAWQA staff conducting groundwater data collection and modeling components of the Integrated Watershed Studies (Chapter 4).

The National Modeling team will be responsible for developing models and maps at the National-scale, and for providing leadership and technical assistance to the PA Modeling Teams. The team will be led by a Lead Scientist and will include staff with technical expertise in statistical methods (e.g. logistic regression and nonlinear regression) and process modeling (e.g. flow and transport modeling).

The Principal Aquifer Modeling teams (4 total) will be responsible for developing models and maps at PA, regional, and local scales. Each PA modeling team will be led by a Team Chief for a period of six years, with the size of the team (FTEs) varying during the six-year period. The PA Modeling Team will coordinate with the National Modeling Team and with a PA coordinator. Where needed, PA modeling Teams will coordinate with and support IWS Teams.

The Decision Support and Forecasting Team will be responsible for development and application of tools that allow users to test how groundwater quality would respond to changing contaminant sources, climate, or land use at different locations in modeled zones of the aquifer including how long it would take for contaminants to reach specific receptors (streams, supply wells). The team will be primarily active in the latter part of the Cycle: team members will likely be drawn from PA modeling teams as the PA teams wind down, and the tools and forecasts will be based on and utilize models developed by the PA modeling teams.

The Synthesis of Data and Models Team will be responsible for bringing together NAWQA results from data collection and modeling at PA and National scales. The team will only be active in the last four years of the Cycle, its members will likely come from other NAWQA groundwater components, and the products will represent the culmination of what NAWQA has learned about the Nation's groundwater quality.

Table 3.1. Cycle 3 budget targets for Goal 1 and 2 Groundwater studies. Projected allocation assumes that inflation adjustments are not received and that all years get funded at the FY13 level in current-year dollars. Budget targets are shown discounted to equivalent FY13 dollars.

Fiscal Year (FY)	Goal 1		Goal 2 Models	Goal 1 and 2 Total	Projected Allocation
	Data Collection	Assessment			
FY13	\$ 8.38	\$ 2.47	\$ 2.13	\$ 12.98	\$ 14.00
FY14	\$ 7.96	\$ 2.47	\$ 3.07	\$ 13.50	\$ 13.44
FY15	\$ 6.62	\$ 2.47	\$ 3.77	\$ 12.86	\$ 12.90
FY16	\$ 5.43	\$ 2.47	\$ 4.24	\$ 12.14	\$ 12.39
FY17	\$ 4.84	\$ 2.47	\$ 4.48	\$ 11.78	\$ 11.89
FY18	\$ 4.88	\$ 2.47	\$ 4.01	\$ 11.36	\$ 11.42
FY19	\$ 4.53	\$ 2.94	\$ 3.54	\$ 11.01	\$ 10.96
FY20	\$ 4.66	\$ 2.94	\$ 3.07	\$ 10.67	\$ 10.52
FY21	\$ 4.53	\$ 3.41	\$ 2.48	\$ 10.42	\$ 10.10
FY22	\$ 3.65	\$ 3.41	\$ 2.24	\$ 9.30	\$ 9.70
FY13-FY22	\$ 55.51	\$ 27.50	\$ 33.02	\$ 116.02	\$ 117.31

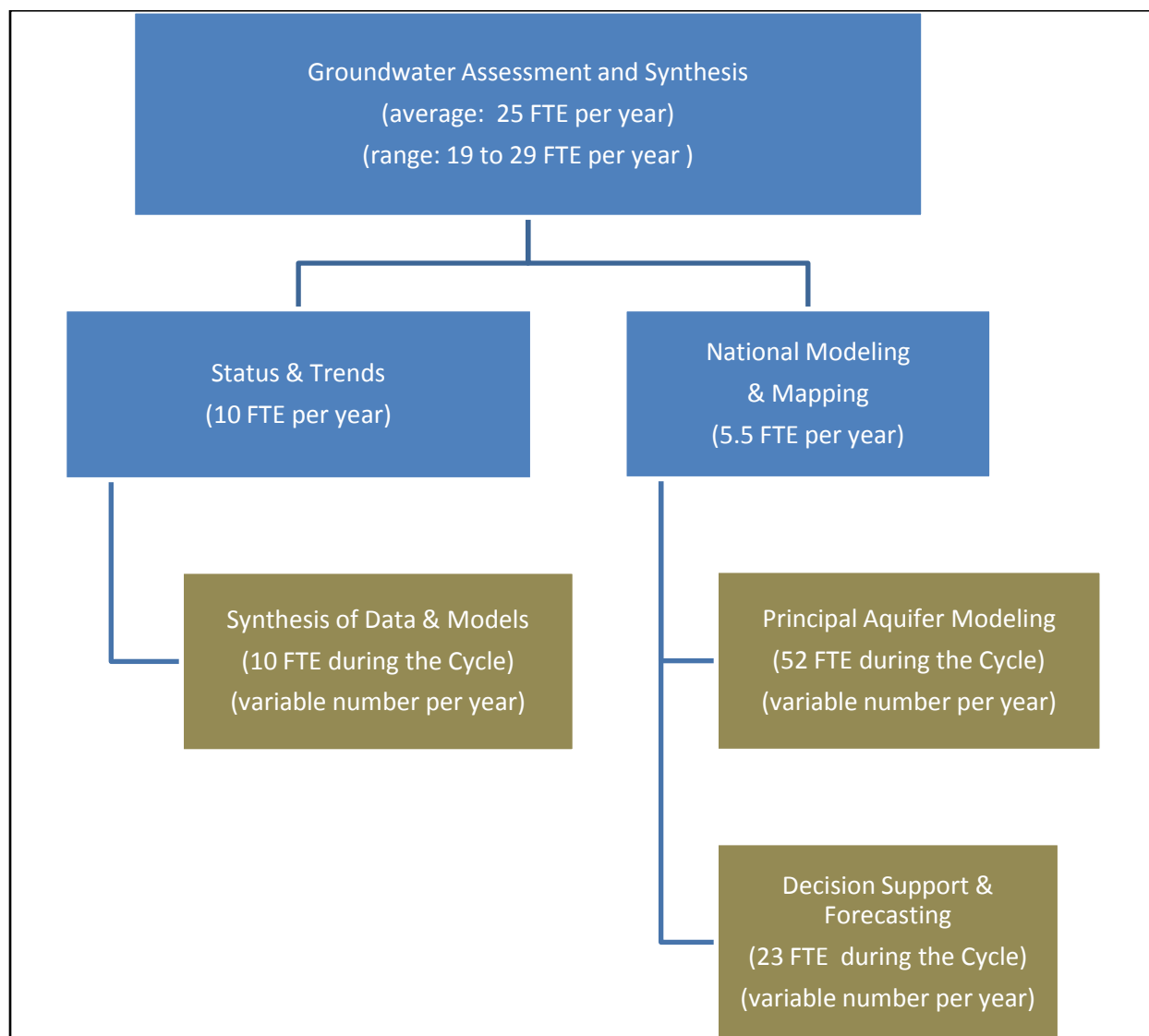


Figure 3.1. Organization of teams for Goal 1 (Status and Trends) and Goal 2 (Modeling and Mapping) components. The number of FTEs allocated for Principal Aquifer Modeling, Decision Support and Forecasting, and Synthesis of Data and Models, varies with time. The FTE total for Groundwater Assessment includes 1 FTE for the coordinator position.

Approach: Status and Trends

Evaluation of groundwater quality in Cycle 3 focuses on multiple scales from local to regional to Principal Aquifer (PA) to National. The scope of work includes sampling of existing networks (“trends networks”), and the creation of new network types (Table 3-2). The PA is the primary organizational unit for collection of groundwater data in Cycle 3.

Principal Aquifer Surveys (PAS) represent a new type of network for NAWQA in Cycle 3 and are used to assess groundwater quality in parts of the aquifer tapped primarily by public supply wells. In many aquifers this represents depths deeper than those tapped by domestic wells. Scale is regional to Principal Aquifer (PA) scale. The PAS is a new network type for NAWQA. There will be 4 PAs sampled at High Intensity (120 wells each) and 12 PAs sampled at Low Intensity (80 wells each). These data will be analyzed at the PA scale, and will be used to develop models and maps at National and PA scales. Sampling of these networks will occur early in the Cycle to allow for the analysis of these data and their incorporation into models.

Major Aquifer Surveys (MAS) are used to assess ground-water quality in parts of the aquifer tapped primarily by domestic or private supply wells. Scale is subregional to regional. NAWQA will maintain 30 existing MAS networks and anticipates implementation of 6 new networks. Some existing MAS networks will not be re-sampled during Cycle 3. The new MAS networks will be coordinated with the implementation of the PAS networks in H PAs. The MAS data will be used for decadal-scale trends assessment, to support modeling at PA and regional scales, and to support models and maps at National and PA scales. Sampling of existing networks will occur at a steady rate throughout the Cycle. Sampling of four new networks will occur early in the Cycle (Table 3-3) to allow for the analysis and incorporation of these data into models, and two new networks will be sampled at the end of the Cycle (Table 3-3) based on budgetary constraints.

Land Use Studies (LUS) are used to assess the effects of specific land uses (agricultural, urban) on shallow groundwater quality. Scale is subregional (nested within MAS and PAS networks). NAWQA will maintain 50 existing LUS networks. Some existing LUS networks will not be re-sampled in Cycle 3. These data will be used for decadal-scale trends assessment, to support modeling at PA and regional scales, and to support models and maps at National and PA scales. Sampling of these networks will occur at a steady rate throughout the Cycle (Table 3-3).

Flow Path Studies (FPS) are used to study the interaction of contaminant sources, transport processes, and contaminant fate at various receptors (streams, supply wells, domestic wells etc). Scale is local to regional and FPS studies will generally be nested within Regional Flow Model boundaries and Integrated Watershed Study boundaries. FPS will also be used for decadal-scale trends assessment and examination of SW-GW interactions and will also provide hydrogeologic and water-quality data for Local-Scale Coupled Flow and Reactive Chemistry Models. Sampling of existing networks will occur at a steady rate throughout the Cycle, and sampling of new networks will occur early in the Cycle to allow for the analysis and incorporation of these data into models (Table 3-3).

Enhanced Trends Networks (ETN) represent the second new network type recommended for Cycle 3 groundwater assessment and are used to address the question: "Over what time-scales does groundwater quality change?" The answer to this question will provide context for assessing observed changes in the decadal networks. ETN activities will include continuous water-quality monitoring, bi-monthly water-quality sampling for major ions, nutrients, and one organic schedule for a period of 4 years and biennial sampling for the remaining part of the decadal cycle. Four networks (3 wells per network) will be sampled on a bimonthly basis during the first part of the Cycle (FY13-FY16) and four additional networks (3 wells each) will be sampled on a biennial basis in the latter part of the cycle (FY18-FY21). Wells selected for the ETN network will be a subset of wells that are parts of other trend networks and will be sampled throughout Cycle 3 (Table 3-3).

National Reference Network (NRN) is used to establish reference conditions for evaluating groundwater quality. In previous Cycles, these wells were established as part of other networks. In Cycle 3, data from these wells will be consolidated at national and regional scales. Sampling of this network will occur at a steady rate throughout the Cycle (Table 3-3).

Table 3.2. Number of networks maintained by NAWQA during Cycle 3, the number of wells within those networks, and the number of samples obtained from those wells. The number of samples is based on an average sampling cost of \$11,000 (includes drilling costs for replacement wells in LUS networks). Implementation of a targeted analytical approach could allow for an increase in the number of samples. The number of Enhanced Trends networks is not included in the number of networks because they are a subset of other networks.

Network Type	Number of New Status Networks	Number of Trends Networks	Average Number of Wells per network	Total wells sampled	Total number of decadal samples	Total number biennial samples	Total number bimonthly samples	Total number samples
Principal Aquifer Survey	16	0	90	1440	1440	--	--	1440
Major Aquifer Survey	7	31	30	1140	1140	--	--	1140
Land-Use Survey	0	47	30	1410	1410	--	--	1410
National reference		1		100	100			100
Flow-Path Study	8	8	20	320	320	--	--	320
Enhanced Trends		8	3	24	--	60	576	636
Totals	31	87	--	4410	4410	60	576	5046

Table 3.3. Number of groundwater samples collected by NAWQA, by year and network type. The number of samples is based on an average sampling cost of \$11,000 (includes drilling costs for replacement wells in LUS networks). Implementation of a targeted analytical approach could allow for an increase in the number of samples [PAS, Principal Aquifer Survey; LUS, Land-Use Survey; MAS, Major Aquifer Survey; FPS, Flow-Path Study; NRN, National Reference Network; ETN, Extended Trends Network].

Year	PAS	TRENDS LUS, MAS, FPS, NRN	New MAS	New FPS	ETN	Total Samples
2013	360	260	30	40	72	762
2014	280	260	60	40	84	724
2015	220	260	30	20	72	602
2016	120	260	30	0	84	494
2017	140	260	0	40	0	440
2018	80	260	0	20	84	444
2019	80	260	0	0	72	412
2020	80	260	0	0	84	424
2021	80	260	0	0	72	412
2022	0	260	60	0	12	332
2013-2022	1440	2600	210	160	636	5046

Approach: Groundwater Modeling Studies

NAWQA will implement a multi-scale, multi-model approach for the assessment of groundwater quality. Three categories of models will be developed, with one or more model type developed at four different

scales. The multi-scale, multi-model approach is designed to support National and PA-scale mapping of groundwater quality at the depths used for domestic and public supply, and to support the modeling of groundwater contributions of nutrients or other contaminants to streams and rivers in watershed-scale models of surface water quality (for example, SPARROW models).

Statistical Regression/Geospatial (SRG) Models will be constructed at National and PA scales, and will be used to develop maps of groundwater quality at the depth used for domestic supply and the depth used for public supply. Two types of maps will be developed: “exceedence” maps (the probability that the concentration of a selected constituent exceeds a human health or water-quality benchmark) and concentration maps. National-scale SRG models will be developed by the National Modeling Team, and will rely on spatially distributed datasets for variables that can be mapped at the land surface (for example, land use), and on groundwater quality data collected by NAWQA and others.

PA-scale SRG models will be developed only for the 4 High Intensity PAs. The PA-scale SRG models, like the National-scale models, will rely on spatially distributed datasets and on groundwater quality data collected by NAWQA and others. In addition, the PA-scale SRG models will incorporate variables generated by PA-scale groundwater flow models. One goal of the PA-scale SRG modeling will be to identify surrogates for variables generated by groundwater flow models (flow system characteristics such as hydrologic position); in turn, these surrogates would then be incorporated into the National-scale models. PA-scale SRG models will be developed by the PA modeling teams.

Flow and Particle-Tracking (FPT) Models will be constructed at PA and regional scales, and will be used for two purposes: (1) mapping the quality of groundwater needed for domestic and public supply (see discussion of SRG models); and (2) estimating the flux of contaminants from groundwater to streams. FPT models will only be developed for High Intensity PAs, and where possible, will rely on models previously developed by the USGS Groundwater Resources Program and (or) the USGS Cooperative Water Program. Regional-scale models will generally be nested within PA-scale models, and where appropriate, in collaboration with the IWS Team and others developing watershed-scale surface-water quality models. It is anticipated that there will be 2 regional-scale models nested within each of the 4 High Intensity PAs. In some cases, it may be necessary to adjust the nested design. FPT models will be developed by PA modeling teams, with support and guidance from the National Modeling Team.

Process and Process-Mimicking Models will be developed at regional and local scales, and will be used to evaluate contaminant fluxes from the land surface to groundwater, within the groundwater flow system, and from groundwater to supply wells or streams. Process Models could include Solute Transport (ST) Models or Flow and Reactive Chemistry (FRC) Models. ST and FRC models will generally be coordinated with FSS and IWS studies, and will be designed to support these studies. Modeling could include complex numerical simulation, lumped-parameter models, or representative/conceptual mass balance models. Numerical models might be calibrated or might be uncalibrated. It is anticipated that many of the FRC models will not be numerical models. In some cases, process-mimicking “meta-models” will be developed that allow for extrapolation from the local (or) regional-scale to the PA scale; in turn, output from the meta-models would be used in PA-scale SRG models. The goal of the meta-modeling would be to improve the fit of the SRG models. ST, FRC, and meta-models will be developed by the National Modeling Team.

Approach: Timing

Some aspects of NAWQA groundwater studies will operate at a relatively constant rate, while others will be operational at variable rates. The National Status and Trends Team and the National Modeling and Mapping Team will operate at a constant rate during Cycle 3 (10 FTE and 5.5 FTE, respectively [Figure 3-1]). Trends (MAS, LUS, FPS, and NRN) and ETN sampling will also be conducted at relatively constant

rates (Table 3-3). In contrast, PAS sampling will occur at a higher rate in the early part of the Cycle (Table 3-4). Sampling of the 4 High Intensity PAs occurs early to allow for incorporation of that data into the PA modeling efforts. Sampling of the Low Intensity PAs is timed to allow for analysis and reporting of results, and as the budget permits. Each PA Modeling Team will be operational for a period of 6 years with a variable number of FTEs during that period (Table 3-4). The first PA Modeling Team will begin in FY13, and the three subsequent teams will begin in FY14, FY15, and FY16, respectively. The Decision Support and Forecasting Team will be operational for the duration of the Cycle, but the bulk of the work will be accomplished in the latter half (Table 3-6); its size (FTEs) will increase as the size of PA modeling teams decrease. The Synthesis of Data and Models Team will be operational only for the last four years of the Cycle (Table 3-6), and will ramp up as other groundwater studies wind down.

Table 3.4. Number of wells sampled as part of the Principal Aquifer Survey (PAS). For the purposes of planning and data management, the Nation is divided into 4 regions. Within each region, there will be one PA studied at a high (H) level of intensity (120 wells per PA) and 3 PAs will be studied at a low (L) level of intensity (80 wells per PA), for a total of 4 H PAs and 12 L PAs. Ideally, H PAs will be sampled over a two year period and L PAs will be sampled over a one year period. For operational purposes, some PAs might be grouped, and the number of wells in a given PA might be adjusted. The number of samples is based on an average sampling cost of \$11,000 (includes drilling costs for replacement wells in LUS networks). Implementation of a targeted analytical approach could allow for an increase in the number of samples. [R1-Region; PA-principal aquifer; L#-low intensity PA; H#-high intensity PA]

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
R1 H1	60	60	--	--	--	--	--	--	--	--
L8, L9, L11				--	80	--	80	--	80	--
R2 H2	60	60		--	--	--	--	--	--	--
L1, L4, L6	80	80	80		--	--	--	--	--	--
R3 H3			60	60	--	--	--	--	--	--
L2, L5, L7	80	80	80	--	--	--	--	--	--	--
R4 H4				60	60	--	--	--	--	--
L3, L10, L12	80			--	--	80	--	80	--	--
Number of wells	360	280	220	120	140	80	80	80	80	0
L PAs completed	3	2	2	0	1	1	1	1	1	0
H PAs completed	0	2	0	1	1	0	0	0	0	0

Table 3.5. Timing and number of FTEs associated with each of the four High Intensity Principal Aquifer modeling teams. Each team will be active for a period of six years (green-shaded cells). Multi-scale and multi-approach modeling investigations will be implemented in each of 4 Principal Aquifers identified as High Intensity. Sampling of Principal Aquifer Survey networks will be completed prior to the completion of the models so that the data collected by NAWQA can be used for developing the models [H PA-high intensity Principal Aquifer].

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
H PA #1	1.5	4	3	2	1.5	1	--	--	--	--
H PA #2	--	1.5	4	3	2	1.5	1	--	--	--
H PA #3	--	--	1.5	4	3	2	1.5	1	--	--
H PA #4	--	--	--	1.5	4	3	2	1.5	1	--
Total	1.5	5.5	8.5	10.5	10.5	7.5	4.5	2.5	1	

Table 3.6. Number of FTE associated with the Decision Support and Forecasting and Synthesis of Data and Models teams. The staffing for these teams will ramp up as the staffing for the PA modeling teams wind down.

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Decision Support and Forecasting	1	1	1	1	2	3	4	4	3	3
Synthesis of Data and Models	--	--	--	--	--	--	2	2	4	4

Products: Goal 1 and 2 Groundwater Studies

Products from NAWQA Groundwater studies will include web-based maps and tools, and written reports documenting assessments of groundwater quality (reports will be posted to the web). The National Status and Trends Team will conduct non-parametric statistical and time series analyses of data at PA and National scales. The National and PA Modeling Teams will construct predictive models at multiple scales (local, regional, PA, and National). The Decision Support and Forecasting Team will develop web-based tools that can be applied at multiple scales (local, regional, PA, and National). The Synthesis of Data and Models Team will operate during the last 4 years of the Cycle, and will provide assessments at PA and National scales. NAWQA products will focus on constituents that occur at concentrations of concern relative to human health or ecosystem condition.

National Maps of Groundwater Quality at the depth used for domestic supply and the depth used for public supply. These maps will be based on data collected by NAWQA and others, and on modeling conducted at PA and National scales. Maps will be provided for constituents that are present in groundwater at concentrations of significance to human health.

Principal Aquifer Assessments will provide an evaluation of the status of groundwater quality at the depth used for public supply, and will be based on data collected by NAWQA from 16 Principal Aquifer Surveys (PAS). Data collected from PAS networks, and PA-scale summaries of that data, will be reported to the web within 1 to 2 years of the completion of sampling in a PA (Table 3-4). The PA assessments will complement previous assessments based on MAS and LUS data. National-scale synthesis for selected groundwater constituents that limit water availability for human use, based on PAS data, will be provided on an ongoing basis, beginning in FY17.

Trend Assessments will provide an evaluation of changes in groundwater quality at PA and National scales, primarily at shallow (LUS networks) and intermediate depths (MAS networks). Trend Assessments will focus on constituents of significance to human health and ecosystem condition. National-scale maps, posted to the web, will be updated on an annual or biennial basis, as NAWQA networks will be re-sampled throughout Cycle 3. PA-scale trend assessments will be based on examination of NAWQA data at scales smaller than networks (sub-network analysis) and on data from the ETN networks.

Three Dimensional Assessments of Groundwater Quality will be based on data from NAWQA monitoring networks at multiple-depths (shallow LUS, intermediate depth MAS, and relatively deep PAS) and on models developed by NAWQA (SRG, FPT, and possibly other approaches). These assessments will be limited to selected high intensity PAs and to selected constituents (for example, TDS or nitrate).

Dynamic models that provide estimates of the contribution of contaminants from groundwater to streams and supply wells, with particular focus on the potential impacts of legacy contaminants (for example, nitrate). These models will be used to develop **web-based decision support systems** that allow users to **forecast** how groundwater quality might change in response to changes in driving forces such as land use, hydrologic alteration, or climate. These assessments will be limited to selected high intensity PAs.

Products from NAWQA Groundwater Studies 2013-2022 at the scale of Principal Aquifer

The general sequence of products to be produced by work at the PA scale is described below

- 2013 announce PA study design/location
- 2014 summarize data from first 3 L PAs
- 2015 summarize data from 2 additional L PAs and from the first 2 H PAs (R1 and R2)
- 2016 summarize data from 2 additional L PAs
- 2017 results from multi-scale modeling in the first H PA (R1)
results from ETN— first set of 12 wells with continuous monitoring and bimonthly sampling
- 2018 summarize data from 3 additional L PAs and the second 2 H PAs (R3 and R4)
additional results from multi-scale modeling in the first H PA (R1) includes summary circular
results from multi-scale modeling in the second H PA (R2)
results from regional modeling in support of IWS
- 2019 additional results from multi-scale modeling in the second H PA (R2) includes summary
circular, results from multi-scale modeling in the third H PA (R3), results from regional
modeling in support of IWS, results from regression modeling for 1 or 2 constituents at the
National scale (data only)
- 2020 summarize data from 2 additional L PAs
additional results from multi-scale modeling in the third H PA (R3) includes summary
circular, results from multi-scale modeling in the fourth H PAs (R4), results from regression
modeling for 1 or 2 additional constituents at the National scale (data only)
- 2021 additional results from multi-scale modeling in the 4th H PA (R4) includes summary circular,
results from multi-model approach for the Nation
- 2022 report out on enhanced trends networks (additional 12 wells)
report out on decadal trends

Status and Trends Assessment

Principal Aquifer Surveys and New Major Aquifer Surveys

A primary objective of Cycle 3 groundwater studies is the assessment of the quality of groundwater needed for domestic and public supply. Cycle 1 and 2 NAWQA networks primarily focused on shallow groundwater (Land Use Surveys) and on intermediate depth groundwater used for domestic supply (MAS networks). In Cycle 3, NAWQA will add a new network type – Principal Aquifer Surveys – to assess the quality of groundwater at the depth zone used for public supply. Although NAWQA did sample some public supply wells in Cycles 1 and 2, those wells were of limited spatial extent. The Cycle 3 PAS networks will be designed to provide a statistical assessment of groundwater quality over large spatial areas. NAWQA will implement 16 PAS networks in Cycle 3.

The primary criterion for selecting Principal Aquifers for assessment was rank based on the volume of pumping from public supply wells (Figure 3-2). Of the 68 PAs for which NAWQA has data (Appendix 3A), 6 PAs account for 50 percent of the pumping, 7 additional PAs account for an additional 25 percent (75 percent cumulative volume), and 12 additional PAs account for an additional 15 percent (90 percent cumulative volume). Additional criteria for selecting PAs were: rank for domestic use, lithology, and coordination with other NAWQA program elements and other USGS programs. In addition, some individual PAs were grouped on the basis of proximity. A total of 21 PAs have been identified for assessment within the overall framework of 16 PAS networks (Table 3-7). These 21 PAs account for 76 percent of the total volume of pumping for public supply in the United States, and also account for 85 percent of the total volume of pumping for domestic supply (Table 3-7). The California Coastal Basins PA is highly ranked for public supply pumping, but is not identified for a PAS because of previous coverage by the USGS California WSC GAMA Program.

Seven new Major Aquifer Surveys are planned for Cycle 3. These networks will primarily target domestic wells located within High Intensity Principal Aquifers. The new networks, in conjunction with the PAS networks, will allow for a three-dimensional assessment of groundwater quality and will be used to help calibrate models of groundwater flow and groundwater quality. The new MAS networks will be coordinated with the PAS networks and will be designed to provide coverage in those parts of the PAs where NAWQA does not currently have coverage.

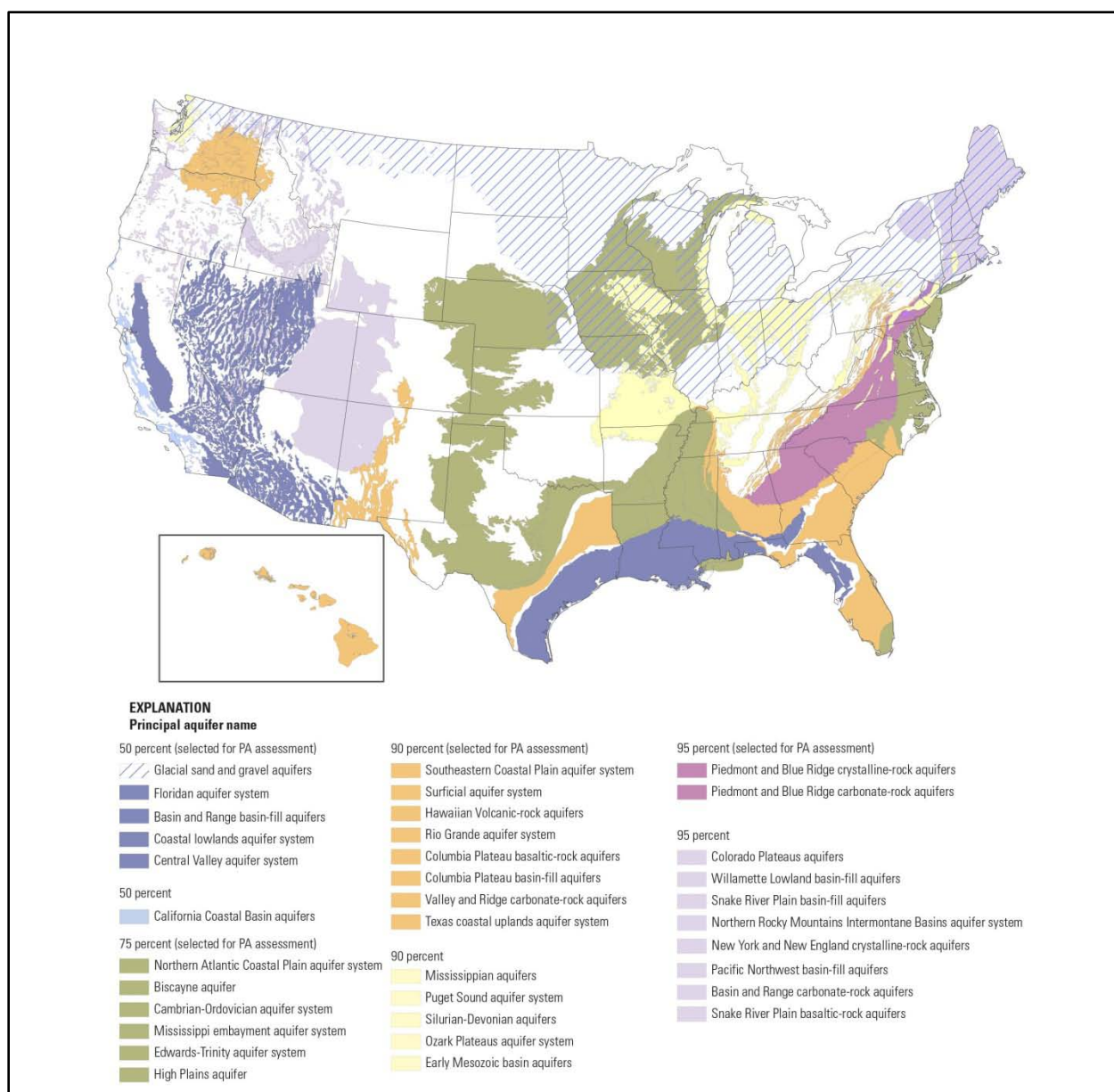


Figure 3.2. Principal Aquifers of the United States ranked by the volume of pumping for public supply (Appendix 3A). The top 6 PAs account for 50 percent of the total public supply pumping in the United States, the top 13 account for 75 percent (Stream Valley Aquifers not shown on map), and the top 25 account for 90 percent.

Table 3.7. Principal Aquifers identified for modeling and (or) Principal Aquifer Surveys during Cycle 3. Blue shaded cells are PAs combined for the purposes of modeling and sampling. Additional grouping of PAs for the purposes of sampling may also occur. The California Coastal Basins PA is ranked 3rd for public supply pumping (10 percent of US total) and 12th for domestic pumping (1.3 percent of US total), but is not identified as a PA selected for PA scale assessment in Cycle 3.

Principal Aquifer name	Public supply rank	Percent of Public supply pumping	Domestic rank	Percent of domestic pumping	High Intensity for modeling	High or low intensity sampling	Proposed FY for sampling
Glacial sand and gravel aquifers	1	12%	1	28%	yes	high	FY13and14
Coastal lowlands aquifer system	2	11%	3	12%	yes	high	FY13
Mississippi embayment aquifer system							FY14
Texas coastal uplands aquifer system							FY15
Floridan aquifer system	4	8.6%	4	8.0%	no	low	FY14
Northern Atlantic Coastal Plain aquifer system	5	7.0%	2	23%	yes	high	FY12and13
Valley and Ridge carbonate-rock aquifers							FY13
Piedmont and Blue Ridge crystalline-rock aquifers							FY14
Piedmont and Blue Ridge carbonates							FY15
Basin and Range basin-fill aquifers	6	6.5%	8	2.4%	no	low	FY13
Central Valley aquifer system	7	5.4%	5	5.1%	yes	none	--
Biscayne aquifer	8	4.5%	17	0.1%	no	low	FY15
Cambrian-Ordovician aquifer system	9	3.8%	11	1.6%	no	low	FY14
Edwards-Trinity aquifer system	10	2.7%	9	2.4%	no	low	FY18and19
Stream Valley Aquifers - non-glacial	11	2.6%	--	--	no	low	FY18,19,and20
High Plains aquifer	12	2.5%	--	--	no	low	FY16and17
Southeastern Coastal Plain aquifer system	13	2.2%	--	--	no	low	FY13
Surficial aquifer system	14	1.7%	--	--	no	low	FY16and17
Volcanic-rock aquifers (Hawaii)	15	1.6%	16	0.5%	no	low	FY20and21
Rio Grande aquifer system	16	1.6%	15	0.7%	no	low	FY15
Columbia Plateau basaltic-rock aquifers - AND Valley fill	17	1.4%	14	1.3%	no	low	FY16and17

Cycle 3 Trends Assessment

Evaluation of trends in groundwater quality remains an important goal for the NAWQA Program. At the end of Cycle 2, NAWQA had 93 “full-scale” MAS and LUS networks of 20 to 30 wells each (Table 3-8), and 54 reference networks of one to two wells each. Analysis of a subset of the National data has shown that groundwater quality is changing at the scale of networks (for example chloride, Figure 3-3) and sub-networks (for example, nitrate in the Delmarva Peninsula, Figure 3-4). Experience with these data also has shown that detection of trends at the network scale requires a sufficient number of paired samples (Figure 3-5), and that biennial sampling of 5 wells selected from a larger network tends to provide confirmation of results obtained from decadal sampling of the larger network. Consequently, NAWQA will continue with decadal resampling of full-scale networks and will eliminate biennial sampling of 5 well subsets. In addition, NAWQA will consolidate the 54 reference networks into a single National Reference Network, and will implement a new network type – Enhanced Trend Networks.

Table 3.8. Number of NAWQA MAS and LUS networks sampled in Cycle 2 and Cycle 3. Three of the 93 Cycle 2 networks were intended for re-sampling in the early part of Cycle 3.

Network type	Number of networks	
	Cycle 2	Cycle 3
Major aquifer survey (MAS)	31	31
Ag land use (Ag LUS)	32	27
Urban land use (Ur LUS)	30	20

Decadal resampling of MAS and LUS networks

Major Aquifer Survey (MAS) and Land Use Survey (LUS) networks have provided the bulk of groundwater data for the NAWQA program. Of the 93 MAS and LUS networks established by NAWQA: 68 were scheduled to have two full rounds of sampling by the end of Cycle 2 (end of FY 2012); 22 were new networks established in Cycle 2; and 3 were sampled in Cycle 1 and scheduled for resampling early in Cycle 3. As of the end of 2011, 56 networks had been evaluated statistically.

In Cycle 3, NAWQA will resample a total of 78 MAS and LUS networks (Table 3-8), and 7 new MAS networks for a total of 85. The criteria used to develop recommendations for which MAS and LUS networks should continue to be included in decadal-scale trends sampling are described in detail in Appendix 3B. Under the CFS, the total number of recommended trend networks is lower than the 90 MAS and LUS networks sampled in Cycle 2. Networks selected for re-sampling in Cycle 3 can be classified as “continued” or “reactivated”. Continued networks are those that were sampled in Cycle 2, and reactivated networks are those sampled in Cycle 1, but not in Cycle 2. Networks not selected for resampling in Cycle 3 can be classified as “postponed” (sampled in Cycle 2 but not planned for re-sampling in Cycle 3) and “inactive” (not sampled in Cycle 2 nor planned for sampling in Cycle 3). Figures 3-6 to 3-8 illustrate the distribution of MAS, agricultural LUS, and urban LUS networks, respectively. Tables 3-9 to 3-11 list the networks that are continued, postponed, and reactivated, respectively; the MAS and LUS networks are organized by Principal Aquifer (PA) because PAs are the primarily organizational unit for Cycle 3.

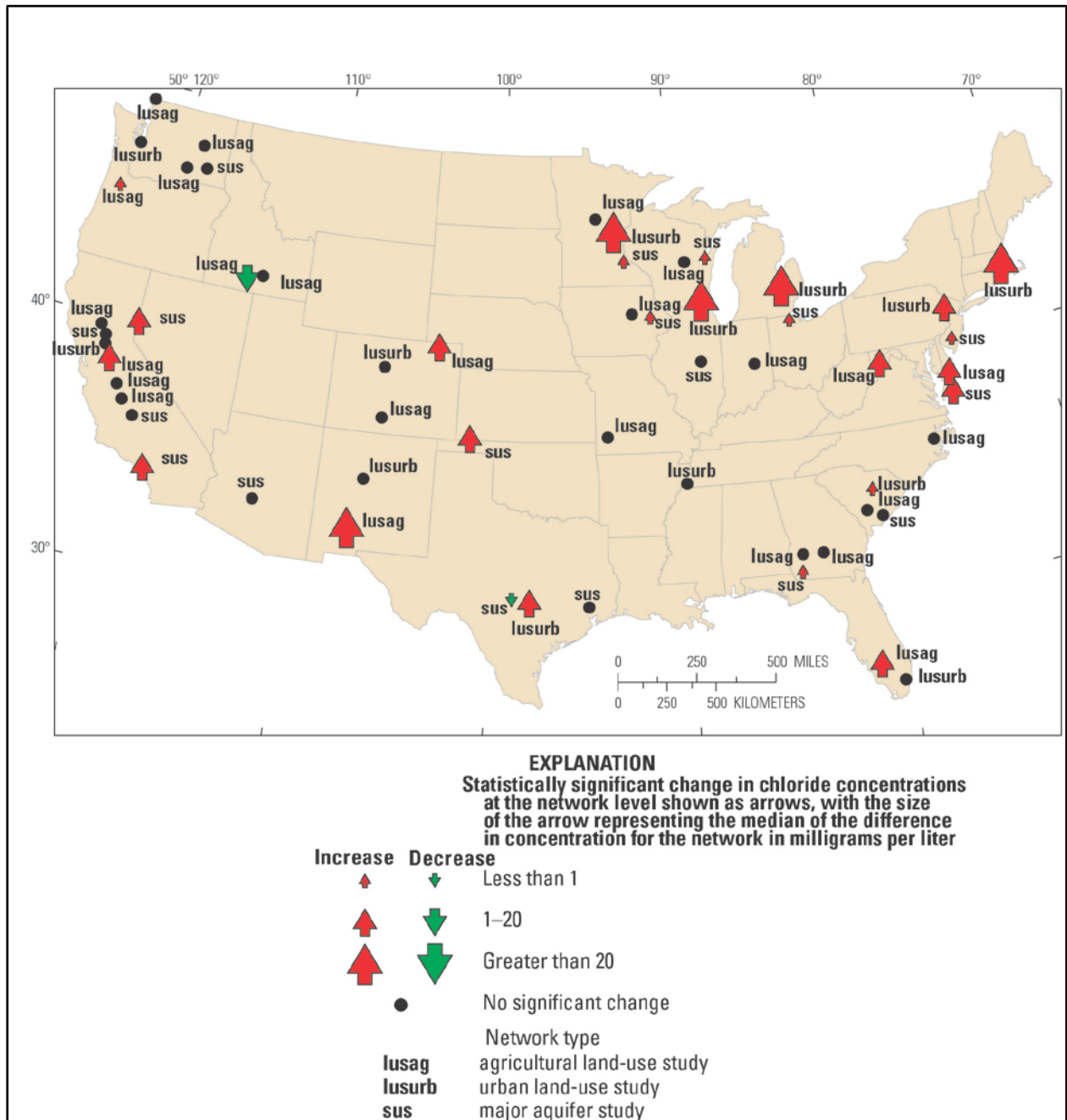


Figure 3.3. Map showing locations of well networks with and without statistically significant decadal-scale changes of chloride concentrations in groundwater in the United States 1988–2010. (from Lindsey and Rupert, in preparation)

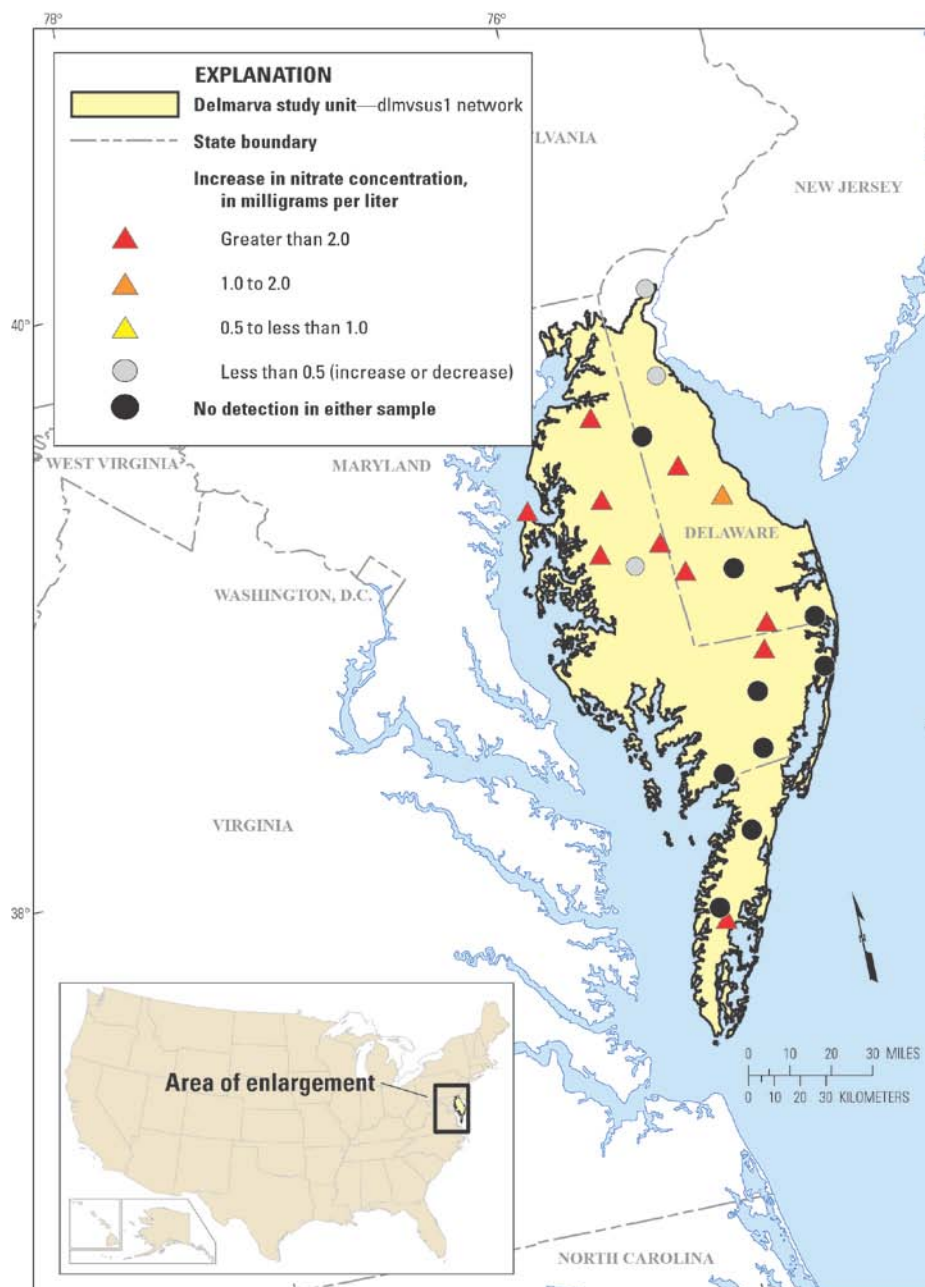


Figure 3.4. Map illustrating the uneven distribution of changes in concentration across a groundwater trends network (from Lindsey and Rupert, in preparation)

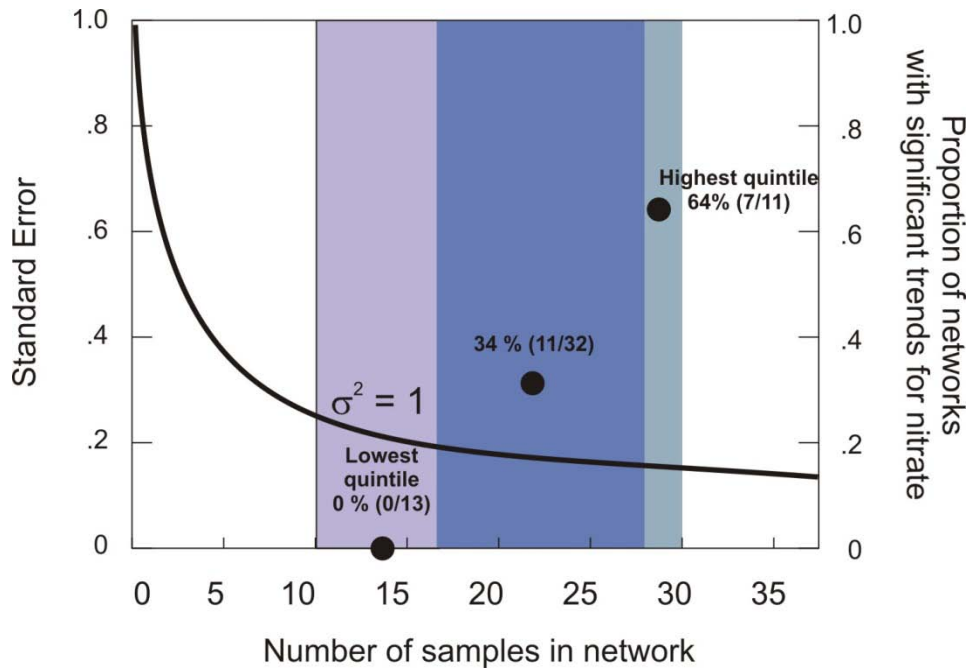


Figure 3.5. Graph illustrating the effect the number of sites in a network has on the ability to detect trends. For example, larger networks (28 to 30 wells) had significant changes in nitrate concentration in 64% of the networks (7 of 11 networks), whereas smaller networks (10 to 17 wells) had no networks with significant change in nitrate concentration (0 of 13 networks); intermediate-size networks (18 to 27 wells) showed an intermediate percent of networks with significant change (34 percent, 11 of 32 networks). Data from Lindsey and Rupert (in preparation).

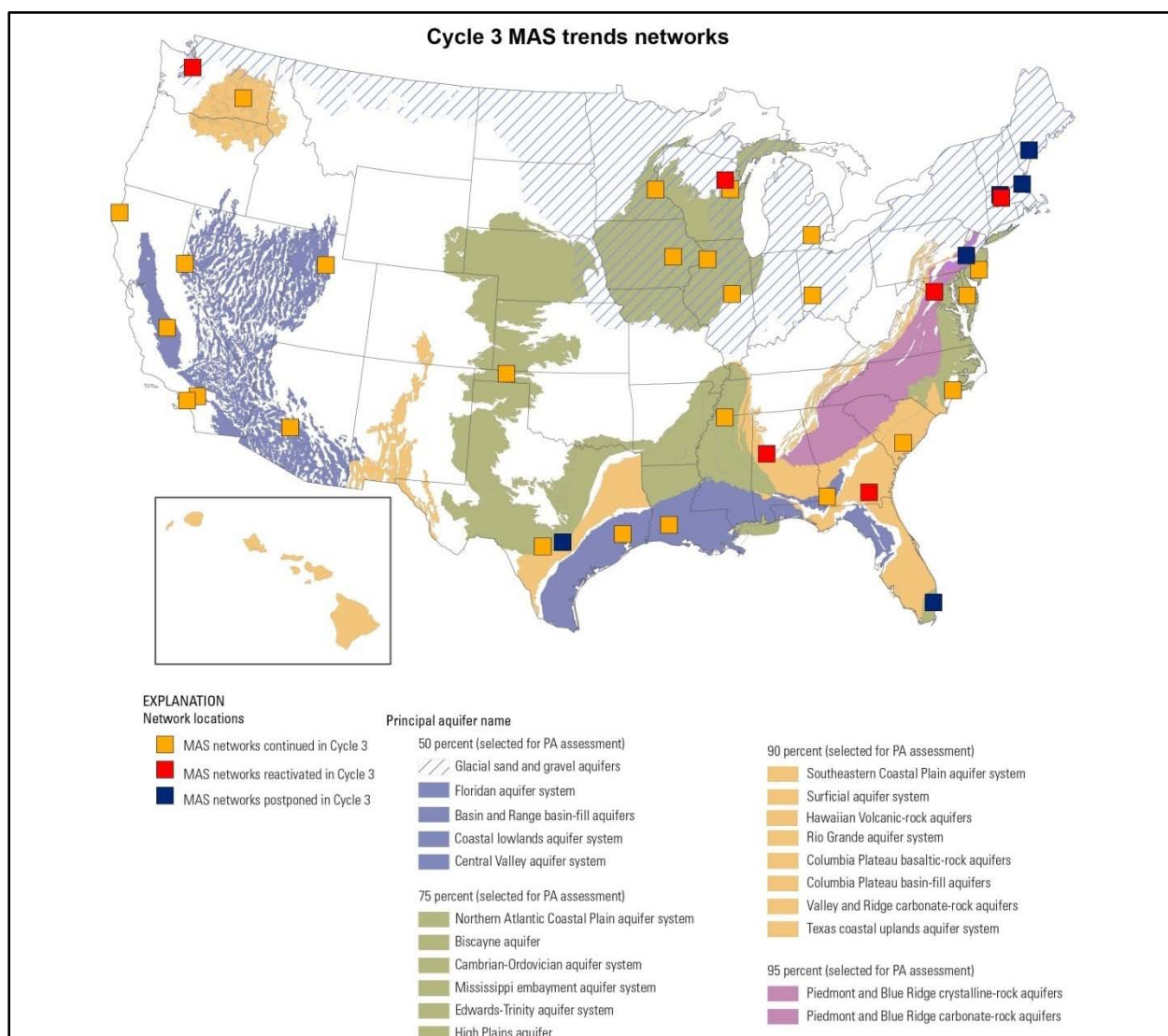


Figure 3.6. Major Aquifer Survey networks to be resampled in Cycle 3. Gold squares are continued networks (sampled in Cycles 2 and 3); red squares are reactivated networks (sampled in Cycle 1, not sampled in Cycle 2, and sampled in Cycle 3); blue squares are postponed networks (sampled in Cycle 2 but not in Cycle 3). Inactive networks (sampled in Cycle 1 but not in Cycle 2) are not shown. See Appendix 3B for a description of the criteria used to rank and select Cycle 3 trend networks.

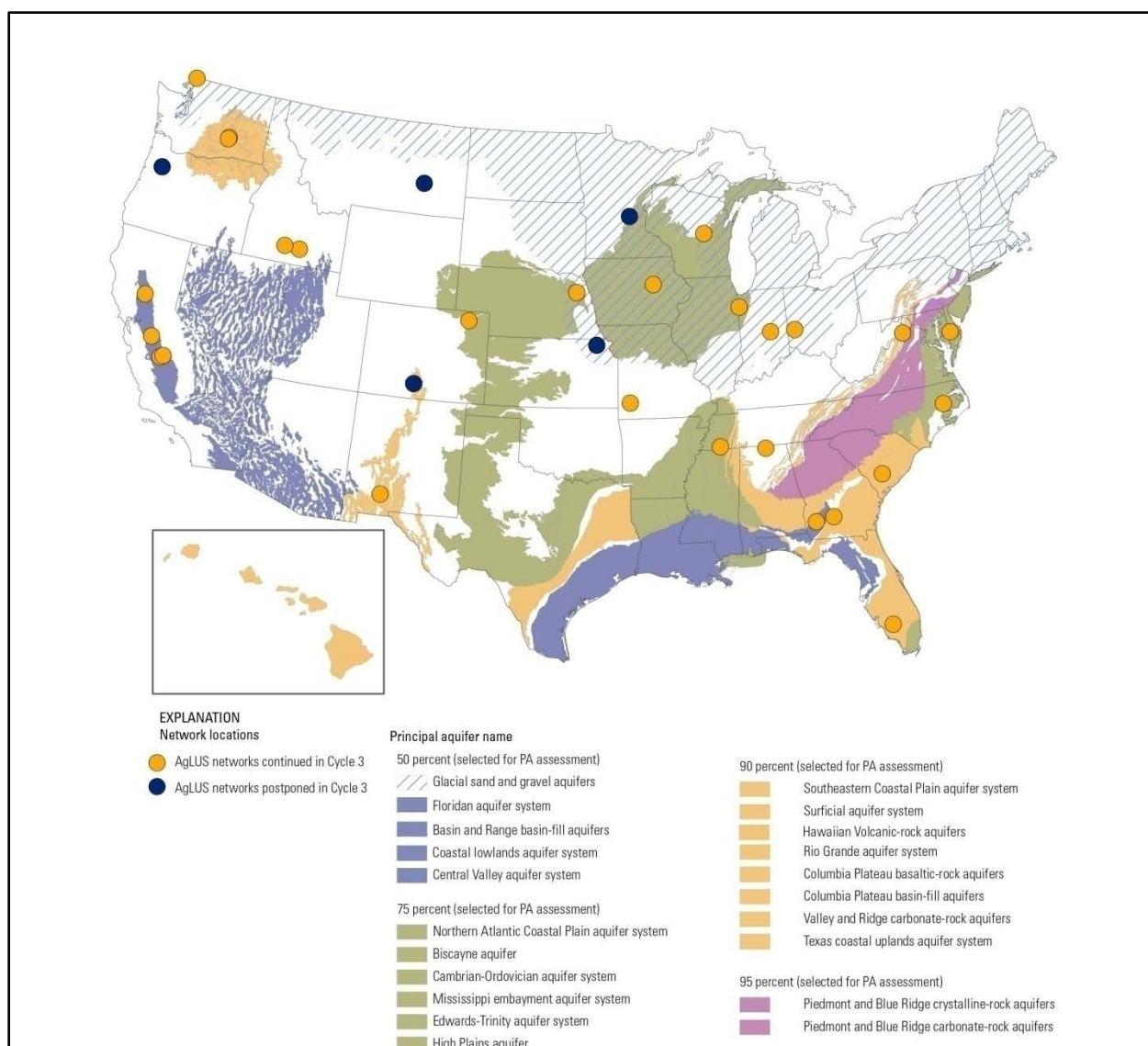


Figure 3.7. Agricultural Land-Use Study networks to be resampled in Cycle 3. Gold circles are continued networks (sampled in Cycles 2 and 3); blue circles are postponed networks (sampled in Cycle 2 but not in Cycle 3). Inactive networks (sampled in Cycle 1 but not in Cycle 2) are not shown. See Appendix 3B for a description of the criteria used to rank and select Cycle 3 trend networks.

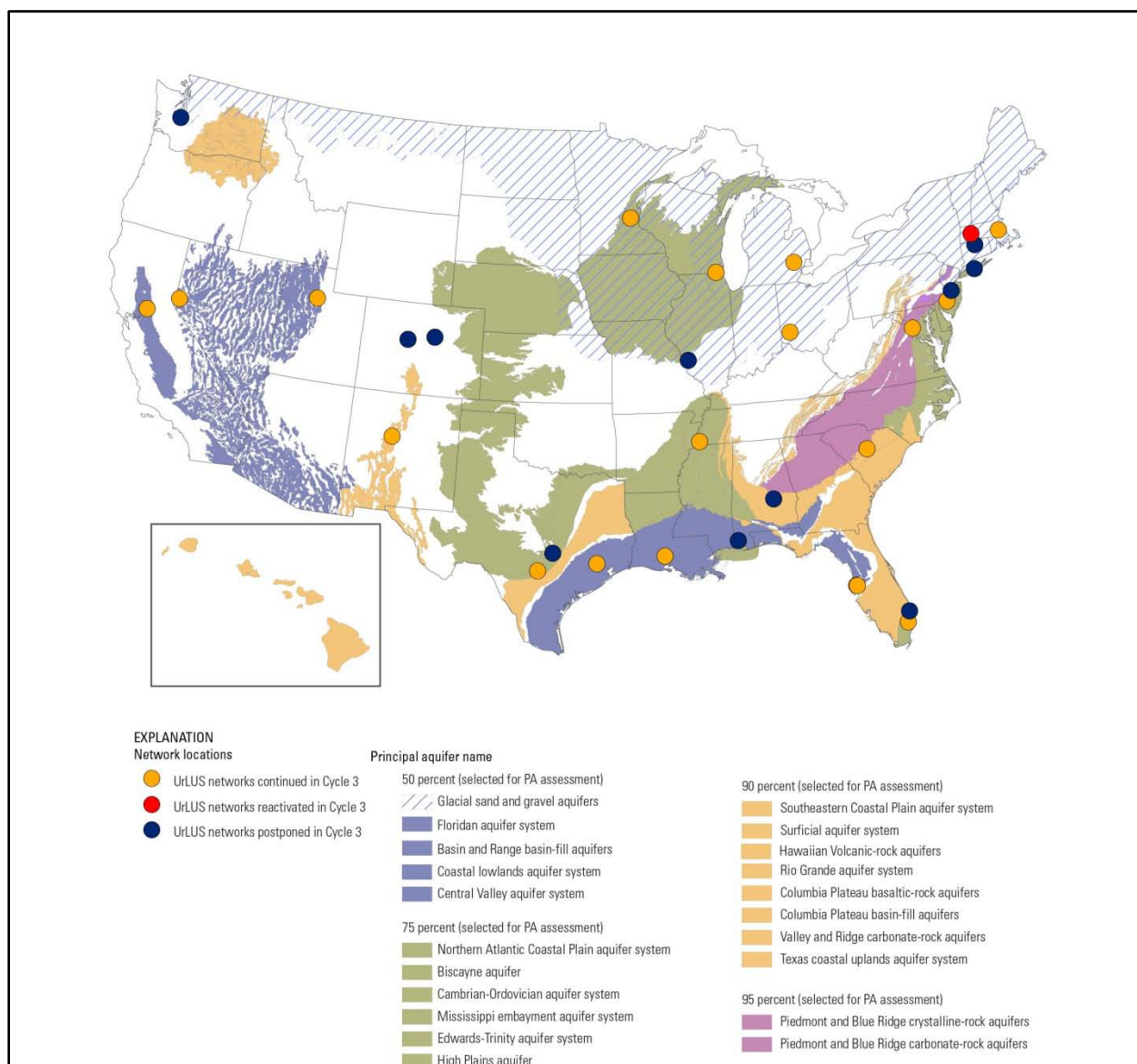


Figure 3.8. Urban Land-Use Study networks to be resampled in Cycle 3. Gold circles are continued networks (sampled in Cycles 2 and 3); red circles are reactivated networks (sampled in Cycle 1, not sampled in Cycle 2, and sampled in Cycle 3); blue circles are postponed networks (sampled in Cycle 2 but not in Cycle 3). Inactive networks (sampled in Cycle 1 but not in Cycle 2) are not shown. See Appendix 3B for a description of the criteria used to rank and select Cycle 3 trend networks.

Table 3-9. MAS and LUS networks to be continued in Cycle 3.

Principal Aquifer	Sucode	Fiscal Year Planned for Sampling
Continued MAS Trends Networks (n=25)		
Basin and Range aquifers	cazbsus1a	2018
Basin and Range aquifers	grslsus2	2020
Basin and Range aquifers	nvbrsus2	2016
California Coastal Basin aquifers	sacrsus4	2020
California Coastal basin aquifers	sanasus1	2022
California Coastal basin aquifers	sanasus2	2020
Cambrian-Ordovician aquifer system	uirbsus3	2019
Cambrian-Ordovician aquifer system	umissus3	2018
Cambrian-Ordovician aquifer system	wmicsus1	2015
Central Valley aquifer system	sanjsus1	2015
Coastal Lowlands aquifer system	acadsus1	2020
Coastal Lowlands aquifer system	trinsus3	2014
Columbia Plateau aquifer system	ccptsus1b	2015
Edwards-Trinity aquifer system	sctxsus1	2016
Floridan aquifer system	acfbus1	2015
Floridan aquifer system	santsus2	2018
Glacial-deposit aquifers	eiwasus2	2018
Glacial-deposit aquifers	lerisus1	2018
Glacial-deposit aquifers	lirbsus1	2018
Glacial-deposit aquifers	miamisus1	2019
High Plains aquifer	hpgwsus1a	2021
Miss. Embayment-TX Coastal Uplands aquifer system	misesus4	2019
Northern Atlantic Coastal Plain aquifer system	albesus7	2013
Northern Atlantic Coastal Plain aquifer system	dlmvsus1	2013
Northern Atlantic Coastal Plain aquifer system	linjsus2	2018
Continued Agricultural LUS Trends Networks (n=27)		
Alluvial aquifers	spltluscr1	2014
Alluvial aquifers	tennluscr2	2022
Central Valley aquifer system	sacrluscr1	2017
Central Valley aquifer system	sanjluscr1a	2015
Central Valley aquifer system	sanjlusor1a	2013
Central Valley aquifer system	sanjlusor2a	2014
Columbia Plateau aquifer system	ccptlusag2b	2014
Columbia Plateau aquifer system	ccptlusor1b	2015
Glacial-deposit aquifers	cnbrluscr1	2015
Glacial-deposit aquifers	eiwaluscr1	2019
Glacial-deposit aquifers	miamluscr1	2020

Glacial-deposit aquifers	pugtluscr1	2018
Glacial-deposit aquifers	uirbluscr1	2021
Glacial-deposit aquifers	whitluscr1	2014
Glacial-deposit aquifers	wmiclusag2	2014
Mississippian aquifers	ltenlusag1	2022
Northern Atlantic Coastal Plain aquifer system	albelusag1	2014
Northern Atlantic Coastal Plain aquifer system	dlnvluscr1	2013
Ozark Plateaus aquifer system	ozrklusag2a	2017
Rio Grande aquifer system	rioglusag1	2016
Snake River Plain aquifer system	usnkluscr2	2016
Snake River Plain aquifer system	usnkluscr3	2017
Southeastern Coastal Plain aquifer system	acfbcluscr3	2013
Surficial aquifer system	gaflluscr1	2015
Surficial aquifer system	santluscr1	2019
Surficial aquifer system	soflluscr1	2019
Valley and Ridge aquifers	potolusag1	2014
Continued Urban LUS Trends Networks (n=19)		
Basin and Range aquifers	grsllusrc1	2021
Basin and Range aquifers	nvbrlusrc1	2013
Biscayne aquifer	sofllusrc1a	2020
Central Valley aquifer system	sacrlusrc1	2017
Coastal Lowlands aquifer system	acadlusrc1	2022
Coastal Lowlands aquifer system	trinlusrc1	2015
Edwards-Trinity aquifer system	sctxlusrc1	2018
Floridan aquifer system	gafllusrc1b	2013
Glacial-deposit aquifers	lerilusrc1	2019
Glacial-deposit aquifers	miamlusrc1	2021
Glacial-deposit aquifers	necblusrc1	2021
Glacial-deposit aquifers	uirblusrc1	2021
Glacial-deposit aquifers	umislusrc1	2016
Miss. Embayment-TX Coastal Uplands aquifer system	miselusrc1	2017
Northern Atlantic Coastal Plain aquifer system	linjlusrc1	2016
Piedmont and Blue Ridge crystalline-rock aquifers	podllusrc1	2015
Rio Grande aquifer system	rioglusrc1	2016
Southeastern Coastal Plain aquifer system	santlusrc1	2016
Surficial aquifer system	gafllusrc1a	2013

Table 3-10. MAS and LUS networks postponed in Cycle 3.

Principal Aquifer	Sucode	Fiscal Year Planned for Sampling
Postponed MAS Trends Networks (n=6)		
Biscayne aquifer	soflsus1	--
Early Mesozoic Basin aquifers	delrsus1	--
Glacial-deposit aquifers	connsus2	--
Glacial-deposit aquifers	necbsus3	--
Miss. Embayment-TX Coastal Uplands aquifer system	sctxsus4	--
New York and New England crystalline-rock aquifers	necbsus1	--
Postponed Agricultural LUS Trends Networks (n=5)		
Alluvial aquifers	yelllusr1	--
Glacial-deposit aquifers	kanslusr1	--
Glacial-deposit aquifers	umislusr1	--
Rio Grande aquifer system	rioglusr1	--
Willamette Lowland aquifer system	willlusr3	--
Postponed Urban LUS Trends Networks (n=11)		
Alluvial aquifers	ucollusr1	--
Coastal Lowlands aquifer system	mobllusr2	--
Denver Basin Aquifer System	spltlusr2	--
Edwards-Trinity aquifer system	sctxlusr2	--
Glacial-deposit aquifers	connlusr1	--
Glacial-deposit aquifers	linjlusr2	--
Glacial-deposit aquifers	lirblusr1	--
Glacial-deposit aquifers	pugtlusr1	--
Northern Atlantic Coastal Plain aquifer system	delrlusr2	--
Southeastern Coastal Plain aquifer system	mobllusr1	--
Surficial aquifer system	soflusr2	--

Table 3-11. MAS and LUS networks to be reactivated in Cycle 3.

Principal Aquifer	Sucode	Fiscal Year Planned for Sampling
Reactivated MAS Trends Networks (n=6)		
Glacial-deposit aquifers	connsus1	2017
Glacial-deposit aquifers	pugtsus1	2016
Glacial-deposit aquifers	wmicsus2	2013
Piedmont and Blue Ridge crystalline-rock aquifers	potosus1	2014
Southeastern Coastal Plain aquifer system	moblsus1	2020
Surficial aquifer system	gaflsus1	2013
Reactivated Urban LUS Trends Networks (n=1)		
Glacial-deposit aquifers	connlusur1	2017

National Reference Network

The objective of the National Reference Network is to provide water-quality data that are minimally influenced by anthropogenic activity. These data, in turn, provide context for evaluating changes in groundwater quality collected at other NAWQA networks. Over the long-term, the National Reference Network may provide data that can be used to understand the effects of broad-scale drivers of change, such as atmospheric deposition of contaminants or climate change.

As of the end of Cycle 2, there were 102 reference wells in a total of 54 networks. These wells will be treated as a National Reference network, and will be resampled in Cycle 3 (Fig. 3.9). The resulting data-pairs (samples obtained in Cycles 2 and 3) will be evaluated at a National scale, and at Regional scales where data are sufficient. In turn, the results from the analysis will provide context for National and PA scale assessments of trends in groundwater quality in MAS and LUS networks.

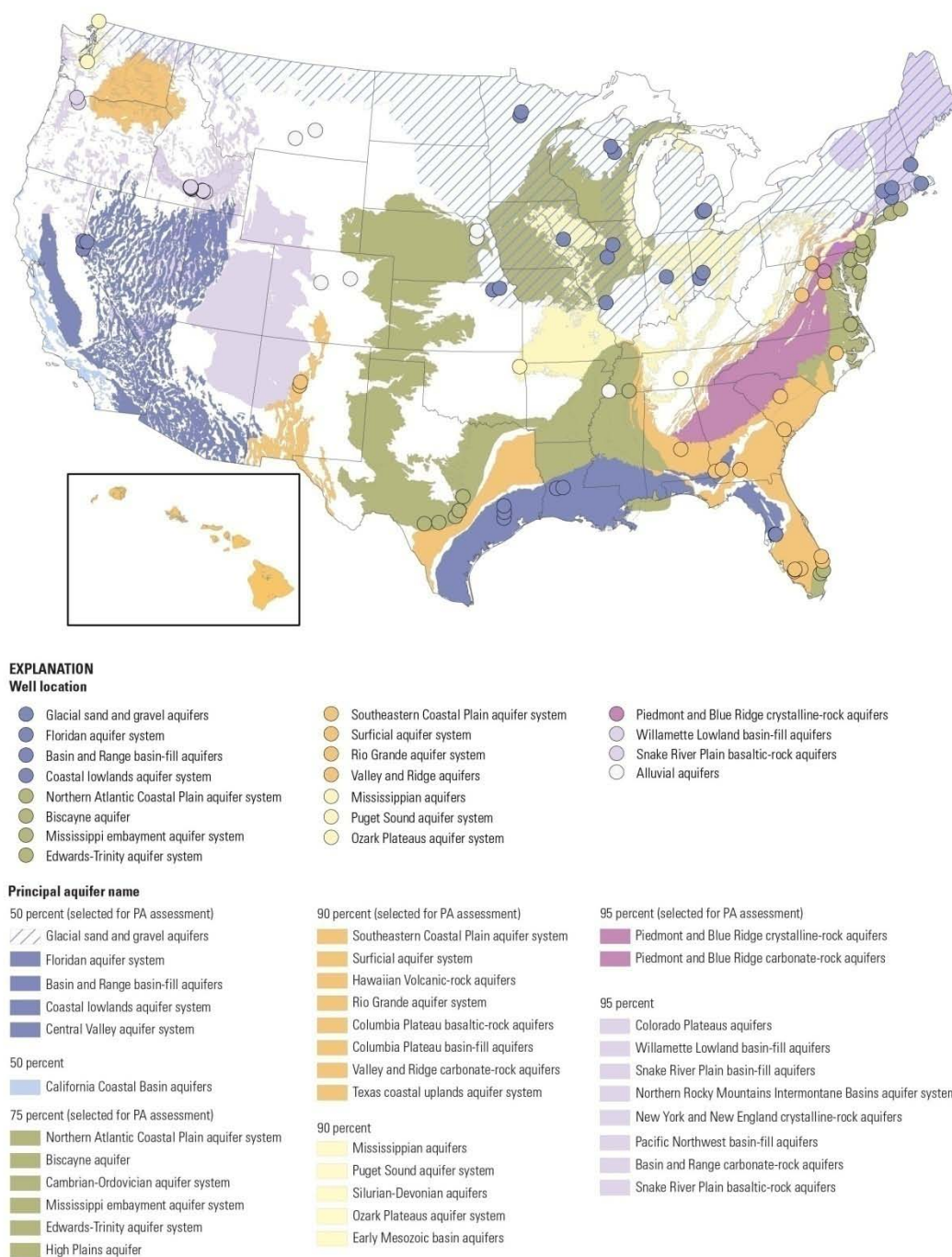


Figure 3-9. Cycle 3 National Reference Network.

Enhanced Trends Network

The Enhanced Trends Network (ETN) is designed to identify the time-scales over which groundwater quality changes. Results from ETN studies will provide context for understanding longer-term trends in concentrations of contaminants of concern. In Cycle 2, NAWQA resampled groundwater “trends” networks on a decadal basis, and a subset of wells in those networks on a biennial basis; these data

provided a basis for assessing long-term trends in groundwater quality. However, the relation between long-term changes and short-term variability in water quality are not well understood. Individual measurements of groundwater quality made on a biennial or decadal basis may be influenced by annual hydrologic conditions, seasonal patterns, and shorter-term fluctuations in water quality. The biennial and decadal sampling networks are always sampled at the same time of year to minimize the effects of this variability; however, this variability has not been quantified.

The NAWQA program has incorporated several data collection efforts to help to quantify the potential effects of short-term variability of groundwater quality. These efforts have included quarterly sampling of groundwater quality, biennial sampling, and quarterly water level measurements. To date, the temporal data collected has been insufficient to determine the magnitude and time-scale of variations in groundwater quality. And, more importantly, it is not known how short-term variations potentially affect the interpretation of long-term changes based on the decadal data set. In addition, a better understanding of the factors causing variability in water quality would help separate hydrologic-based changes in concentrations from changes due to an increase or decrease of the mass of a contaminant in the aquifer.

The approach to understanding the differences between short-term variability and long-term trends in groundwater quality in Cycle 3 will be to collect short-interval measurements at a small number of sites. It is believed that this approach will yield improved methods for distinguishing short-term hydrologic variability from long-term water-quality trends caused by changing climate or human-induced changes in contaminant loading to the aquifer. The ETN is proposed for Cycle 3 to address this issue and it will be comprised of a subset of wells from existing decadal trend networks in selected Principal Aquifers that will be continuously monitored for a selected set of parameters while also being sampled at a high frequency to address the issue of short-term variability in water quality. Selected ETN wells may be from the biennial network, as these wells have the most data and were selected to be representative of typical hydrogeologic and geochemical conditions in their respective networks. Continuous measurements will consist of water level, temperature, and specific conductance at a minimum; however other measurements may be added if technology and cost allow. High-frequency sampling will consist of bimonthly sampling for a period of 4 years (24 samples per well), followed by 6 years of biennial sampling (3 samples per well).

NAWQA will establish 8 ETN's of 3 wells each. Candidate areas for establishing an ETN will be those aquifers that have nested PAS, MAS and LUS networks, with priority given to LUS wells in High Intensity PAs. ETNs may also be located in Low Intensity PAs to provide geographic, climatic, and (or) lithologic coverage. ETN wells will be chosen from among the existing network wells. Criteria for well selection within a network should include: analysis of findings from previous monitoring efforts, hydrogeologic setting (position in flow system), and factors expected to affect temporal variability. Site selection will be done in conjunction with the Principal Aquifer Coordinators, Cycle 2 Principal Aquifer Lead Scientists, current or former study-unit staff, and the Water Science Center lead technicians. The selection of the aquifers, networks, and specific wells will be conducted in FY2012 or as early as possible in FY2013 in order to establish the networks during FY 2013.

Continuous monitoring will be implemented in FY2013 in all 8 networks. The high-frequency sampling will be implemented in 4 networks starting in FY2013 and in the other 4 networks starting in 2018. During years where networks are not undergoing high-frequency sampling, the network will be sampled biennially. The combination of high-frequency sampling and biennial sampling results in uneven expenditures across the 10-year cycle.

Analytical Strategy

The Cycle 3 analytical strategy for implementation of the current funding scenario supports the goals of assessing changes in groundwater quality in the most important drinking water resources in the nation, and scaling-up the occurrence and distribution surveys in selected principal aquifers. Consistent with this,

- The first priority is to collect data on constituents that have been shown to exceed human health benchmarks (HHB) by the occurrence and distribution assessments conducted during Cycle 1 and 2. Data for these groups will be collected in both the trends and PA assessments. The relative ranking of constituent groups based on available data is shown in Table 3-12.
- A second priority is to assess the occurrence and distribution of selected new analytes. Depending on the constituent, this will be done at either a spatially-distributed or targeted subset of networks.
- A third priority is to collect data on water-quality constituents and environmental tracers that can be used to understand which natural or human factors are controlling current conditions or observed changes.

Note that the current plan will visit a selected set of Principal Aquifers that in aggregate constitute almost 90 percent of the Nation's public drinking water resource. We will also try to assess the water quality in additional Principal Aquifers to the extent that other existing data can be obtained and funding allows, leveraging these data to attain the most comprehensive national assessment possible.

Trace elements, nutrients, major ions, and DOC: This suite of constituents will be analyzed in all wells because of the high frequency with which trace elements and nitrate exceed HHB, the change in the concentrations of time in nitrate and some trace elements, and the potential explanatory value of major ion and DOC data. Collection of trace element data in the ETNs will be evaluated after the first year of data collection.

Table 3.12. Frequency of exceedance (percent) of a human health benchmark by constituent class by predominant well type by study components (LUS, MAS, PAS) (Modified from Ayotte and Gronberg, 2011). [E. coli, *Escherichia coli*; VOCs, volatile organic compounds; Ag, agricultural; LUS, land-use study; MAS, major aquifer survey; SWA, source water assessment; PSW, public supply well].

Network Type	Trace Elements	Nitrate	Pathogens			Radiochemistry		VOCs	Pesticides
			Total coliform	E. coli	Enteric viruses	Gross alpha	Ra 226 & 228		
Ag LUS Monitoring wells	26	20	67	30				3	1
Urban LUS Monitoring wells	28	3	35	17				2	4
MAS Domestic wells	13	4	33	8				<1	<1
MAS Public Supply wells	13	2	16	3	24			2	2
MAS & SWA PSW	10+					5	19		
Mixed well types							4		

Environmental Tracers for age and origin: The insights that environmental tracers have contributed to the interpretation of contaminant distribution and changes in groundwater are profound. The Cycle 2 implementation plan called for age dating about 25 percent of all wells in the MAS and LUS networks; subsequent guidance recommended dating all wells in a network for two tracers. In addition about 36 of 93 Cycle 2 networks had 10 or more samples for multiple tracers (i.e. CFCs, SF₆, and/or tritium/helium), as reported in Hinkle and others (2010). For Cycle 3, the goal is to have as many samples as possible sampled for two tracers so the relative contribution of young water in a representative subset of wells in each network can be determined.

- **Principal Aquifer Surveys:** These wells are assumed to have the largest fraction of old water. All wells will be sampled for ¹⁴C and tritium, as well as stable isotopes (O and H); 25 percent of the systems will also have ³H/He dates collected, and this subset will target aquifers believed to have the shortest travel time from land surface to well screen.
- **MAS and LUS networks:** as about a half of all existing networks currently have 10 or more wells with data for multiple age tracers, additional data collection will be as follows:
 - Additional sample collection to attain at least two age dates—usually SF₆ and H/He—at 10 wells in all LUS and MAS networks, as well as tritium in all other wells.
 - Resample a 20 percent of networks that have existing data to evaluate change in tracer data over time (with priority given to areas where local and/or regional models are planned).
 - Sample all wells in areas where intensive modeling is planned.
- **FPS networks:** because these networks offer the best constrained flow systems, resample all wells to better understand change in tracers over time in context.

Pesticides: The number of samples analyzed for pesticides will be reduced during Cycle 3 due to the low frequency of pesticide concentrations approaching a HHB. Rather, the approach will be tiered to areas with known problems, supplemented by a spatially-distributed subset to assess the occurrence and distribution of new analytes recently added to the pesticide schedule.

- **Principal Aquifer Surveys:** Because these wells have not been sampled and are an unknown quantity, all PAS wells will be sampled for the new pesticide schedule (LC MS/MS).
- **MAS, Agricultural LUS outside of areas with known HHB exceedances – and all Urban LUS Networks:** Twenty percent of all wells will be sampled for the new pesticide schedule (LC MS/MS) to assess the occurrence and distribution of new analytes.
- **MAS and Agricultural LUS networks in problem areas:** In view of the high mobility of triazine herbicides, MAS and Agricultural LUS networks in high-ranked networks in the Glacial and North Atlantic Coastal Plain PAs where corn crop acreage exceeds 20 percent of the total will be sampled in their entirety. This includes 8 Agricultural LUSs (6 in the Glacial PA and 2 in the North Atlantic Coastal Plain), and 6 MASs (4 in the Glacial PA and 2 in the North Atlantic Coastal Plain). More extensive pesticide sampling will be considered on a case-by-case basis.
- **Urban LUS Networks:** As with the other non-target networks, 20 percent of all wells will be sampled for the new pesticide schedule (LC MS/MS) to assess the occurrence and distribution of new analytes.
- **FPS networks:** All FPS wells will be resampled for both pesticide schedules (new 2033, new 2050/2060).
- **ETN networks:** A subset for pesticides in a highly vulnerable setting—the Glacial and North Atlantic Coastal Plain PAs—will be sampled bimonthly for 3 years and biennially for the remaining of Cycle 3.

Table 3-13. Number of projected samples, analyses, and estimated costs by Cycle 3 network type. The number of wells for each study component represents a combination of comprehensive and targeted sampling approaches. Costs based on FY13 lab rates. [PAS, Principal Aquifer Survey; MAS, Major Aquifer Survey; Ag LUS, agricultural land-use study; Urb LUS, urban land-use study; ETN, extended trend network; Majors, major ions; Nuts, nutrients, TEs, trace elements; C, carbon; DOC, dissolved organic carbon; SF₆, sulfur hexafluoride; Sch, lab schedule; LC MS/MS, liquid chromatography mass spectrometry]

	PAS	MAS	Urban LUS	Ag LUS	Flow Path	ETN	ETN biennial	Reference
Well Count by Study Component	1440	1140	600	810	320	576	60	100
Majors, Nutrients, Trace elements, DOC	1440	1140	600	810	320	576	60	100
Pesticides								
Sch 2033					320			
Sch 2060					320			
New LC MS/MS (9030)	1440	372	120	354		144	12	100
Age-Dating								
Age Dating--Tritium (1 pCi/L)	1440	455	230	318				
Age Dating --SF ₆		305	170	223	320			
Age Dating--Dissolved Gases	360	305	170	223	320			100
Age Dating --Tritium/Helium	360	305	170	223	320			100
¹³ C and ¹⁴ C	1440							100
Oxygen and Deuterium isotopes	1440	305	170	223	320			100
Volatile Organic Compounds								
VOCs (with nontarget compounds)	1440	228	600		40			100
Gasoline oxygenate degradates	1440	228	600					100
Low-level EDB/DBCP				180	20			
Pharmaceuticals	360	285	150					100
Microbial Contaminants	833	465						100
Radionuclides	1440	540	330	270				100
Total Cost	\$ 6,739,016	\$ 2,553,953	\$ 1,417,269	\$ 1,327,790	\$ 890,388	\$ 411,523	\$ 40,215	\$ 549,249
Include 15% QA	\$ 7,749,868	\$ 2,937,045	\$ 1,629,859	\$ 1,526,959	\$ 1,023,946	\$ 473,252	\$ 46,247	\$ 631,636
Average Cost per Well	\$ 6,458	\$ 2,576	\$ 2,716	\$ 1,885	\$ 3,200	\$ 822	\$ 771	\$ 6,316

VOCs: Consistent with the pesticide sampling approach, the number of samples analyzed for VOCs will be reduced during Cycle 3 due to the low frequency of concentrations above a HHB.

- **Principal aquifers assessments:** Because these wells have not been sampled and are an unknown quantity, all PAA wells will be sampled for VOCs.
- **MAS networks:** Twenty-five percent of all wells will be sampled for VOCs.
- **Ag LUS networks:** Agricultural LUS networks in aquifers with a history of contamination by fumigants will have samples analyzed for low-level EDB and DBCP.
- **Urban LUS networks:** The VOC and gasoline oxygenate degradation products schedules will be analyzed for all urban LUS wells.
- **FPS networks:** VOCs will be collected for any resampled urban LUS.

Microbial Contaminants: Designing an informed approach to sampling for pathogens and other microbial contaminants is problematic because to date NAWQA coverage for one suite of analytes is moderate (1,244 wells, Embrey and others, 2006) but not comprehensive spatially, and new data for enteric viruses has not been collected. The case of enteric viruses is further complicated because data from a small study in southeast Michigan showed extremely inconsistent detection in replicate and time-series samples (i.e. samples with a positive result were usually negative upon resampling)(Francy and others, 2004). In addition, there are data which show that a variety of geochemical indicators (e.g. NO₃, Br/Cl ratios) are indicators of pathogen occurrence. In view of the uncertainties, guidance is to analyze for selected pathogens or related indicator organisms at all PAA and MAS networks in FY13 and 14 while the additional data collected during Cycle 2 is evaluated. During this time, the recommendations of the Microbial work group will be considered along with the preliminary data, and a targeted approach will then be developed and implemented in FY15. For budgeting purposes, it is assumed that data will be collected at 25 percent of wells after FY14, yielding data for 480 PA wells and 360 MAS wells.

Pharmaceuticals: Similar to pathogens, there is no extensive national data set for these constituents. There is, however, less expectation that these compounds will exceed a HHB. Therefore, guidance is to collect samples for pharmaceutical analyses in 25 percent of all drinking water wells, i.e., all PAAs and MASs, as well as 25 percent of urban LUSs.

Radionuclides: As with the trace elements, there are data that show radionuclide concentrations in some aquifers have been elevated by human influences on groundwater chemistry (Ayotte and other, 2011). In addition 4 percent (39/971) of NAWQA wells sampled showed an activity of (²²⁶Ra + ²²⁸Ra) greater than the MCL of 0.187 Bq (Szabo and others, in press), and most of these exceedances were confined to 7 of the 15 principal aquifers sampled. In view of the relatively high rate of MCL exceedance, possibility of mobilization by anthropogenic activities, the specific conditions that favor transport (low pH, low redox, and factors favoring desorption in general), and the sparse coverage in some of the aquifers that had some high concentrations (Glacial), radionuclides will be assessed in MAS and LUS networks in the following PAs: NACP, Floridan, Coastal Lowlands, Cambrian-Ordovician, and Mississippi Embayment-Texas Uplands. All of the new PAA networks will be sampled. Radionuclides and related radiochemical properties that will be considered for analysis include radon, radium (various isotopes), lead-210, polonium-210, gross alpha, and gross beta. Radiochemical constituents to be analyzed in each network vary depending on which constituents are known or believed to occur at concentrations approaching human health benchmarks and overall budget constraints.

- **Principal Aquifer Surveys:** All PAA wells will be sampled for radionuclides.
- **MAS networks:** A total of 18 MAS networks will be sampled or resampled.

- **Agricultural LUS networks:** Nine Agricultural LUS networks will be sampled or resampled.

Additional considerations: Additional analytes will be added as new methods and/or new analytes—such as pharmaceuticals and VOCs— become available for implementation, and after consideration of unique circumstances. Included in the first category will be schedules that are currently under development for high production volume chemicals. An example of the latter would be a targeted sampling designed to assess the occurrence and distribution of hexavalent chromium in highly oxic western principal aquifers.

Data management

Data management tasks are separated into two levels: tasks which will be done at the Water Science Center level and tasks which will be done at the Principal Aquifer coordinator level. For new status networks and trend networks, the Water Science Center liaison will be responsible for ensuring trained sampling crews are available, arranging for water-quality sampling, entering data into the NWIS database, and initial data checks of water-quality data. For networks with an ETN, the Water Science Center liaison will be responsible for the continuous data collection, maintenance of equipment, and the working, checking, and review of continuous data records for ADAPS.

The Principal Aquifer coordinator will have data management tasks as well. Generally the coordinator will oversee the Water Science center work, and ensure it is done in a timely manner. The coordinator will also be tasked with generating basic data reports that will be web-based products. For the ETN the coordinator will be tasked with initial analysis of the continuous data associations among the various measures of water quality and hydrology and meteorological data to evaluate if the networks are providing the information needed. Each Principal Aquifer coordinator will have responsibility for two ETN's.

Staffing of Groundwater Status and Trend team

The Groundwater Status and Trend Team will consist of 10 individuals with national-level responsibilities and tasks, and individuals with Principal Aquifer responsibilities and tasks. This team will also be integrated with the Groundwater Modeling Team to coordinate work, report products and sharing of data and findings. The team will also coordinate with the Integrated Watershed Studies projects and other NAWQA efforts at both the national and Principal Aquifer scales as needed.

The national-level effort will consist of a lead scientist, a hydrologist, a geochemist, and part-time GIS and database management support for a total of 3 FTE's throughout Cycle 3. The products of this team include national data products and national interpretive products for groundwater status and trends, but with more of a focus on trend products. The data products include maps illustrating trends in groundwater quality at the network level, and the necessary statistical analysis and reports needed to document and support these products. The interpretive products include national summaries of factors affecting groundwater trends,

The Principal Aquifer Coordinators will operate as a part of the Groundwater Status and Trends team. There will be 4 Principal Aquifer coordinators with each one responsible for operations in multiple principal aquifers in a geographic region. The coordinator will be the liaison between the NAWQA and the WSCs with respect to design and implementation of sampling plans for new status (PAS or MAS networks) and ongoing trends networks in their geographic region. The skill sets desired for the Principal Aquifer Coordinator include administration and operation of networks, ability to analyze status of the resource for new networks, interpretation of trends data at a network and sub-network level, and

interpretation of data from the ETN network. Other key skills include advanced knowledge in areas such as statistics, geochemistry, and groundwater-surface water interaction.

Table 3-14 -Proposed structure of the Groundwater Status and Trends Team

Position	Grade(s)	FTE	Duration	Position Description
Groundwater Status and Trends Team Lead Scientist	GS-13/14	1.0 FTE	FY13-FY22	Supervises Groundwater Status and Trends Team; provides technical guidance and oversees data collection, and product development activities carried out by the Status and trends team and the 4 Principal Aquifer coordinators. Coordinate flow of data into data products and statistical results Create national-level trend products bringing together results of 1) National statistical/data products, 2) GW Modeling effort, and 3) Findings from PA level. Coordinate with and support PA coordinators to ensure national needs are met by PA studies, and that PA specific knowledge flows up to national level products
Hydrologist/Geochemist	GS-13/14	1.0 FTE	FY13-FY22	Experienced geochemist Conducts analysis of factors affecting trends and writes reports.
Hydrologist/Statistician	GS-11/12/13	1.0 FTE	FY13-FY22	Hydrologist or statistician with background in statistical analysis and interpretation of GW chemistry and hydrologic data. Conducts trend analysis and writes reports.
GIS Lead support	GS-11/12/13	1.0 FTE	FY13-FY22	Hydrologist with experience manipulating large QW and hydrologic data sets who also has GIS skills. Provides analytical and writing support to lead authors of trends reports.
GIS support	GS-9/11	0.5 FTE	FY13-FY22	Hydrologist or other science discipline with GIS skills. Assists GIS lead support in providing data sets and conducting GIS analysis in support of GWSandT team.
Data/Database support	GS-11/12/13	1.0 FTE	FY13-FY22	A. Hydrologist with experience manipulating large QW and hydrologic data sets who also has database management skills. Provides analytical and writing support to lead authors of trends reports. Data QA/QC - Ensure Principal Aquifer network, Trend network, and ETN network data are thoroughly checked. Tabulation - Create basic tabulations of data. B. Coordinates sampling, networks, and budgeting tasks.
Principal Aquifer Coordinator(s)	GS-12/13/14	4.0 FTE	FY13-FY22	Provides technical guidance and oversees data collection and product development activities carried out by the Status and trends team in their respective Principal Aquifer. In conjunction with national GW team, work with Science Center liaisons to develop new networks and coordinate sampling of networks. Conducts network and sub-network level analysis of status and trend data. Develops reports plans for status and trends in Principal aquifer region. Oversee collection of data from ETN networks, interpret and report on findings of temporal variability of groundwater quality on the basis of ETN data.

Groundwater Status and Trend Outcomes and Products

The products are addressed with respect to new status, trends, and ETN findings.

The products for the new PAS and MAS sampling will include data-type summary reports which will indicate the proportion of the aquifers that are affected by various contaminants. Interpretive reports on factors affecting water quality will be produced as well. These products will be done on a Principal Aquifer, Regional, and National level.

Products from the decadal sampling of trend networks will include statistical reports and web-based products indicating trends, which will be updated annually. Other products will be produced which incorporate sampling from every type of study ranging from ETN and flow-path studies to LUS, MAS, and PAS networks and will focus on factors affecting trends in groundwater quality and critical drivers of change. These products will be used to help interpret the meaning of the statistical results shown in the national trend maps.

The products of the ETN effort will include both data reports and interpretive reports, both of which will be the responsibility of the Principal Aquifer Coordinator. Continuous monitoring data and discrete water-quality data will be summarized in data reports annually. These are anticipated to be highly automated and produced as web-only products. In addition, interpretive reports on the results of the continuous monitoring will be produced after the 4 year intensive data collection effort, summarizing variability in continuous parameters, water-quality measurements, relations between continuous and measured water quality parameters, and factors controlling variability in water-quality.

The interpretive reports will provide insight regarding the potential effect of short-term variability on our ability to assess long-term changes in concentrations. This work will help to indicate where variability in concentrations may be great enough to mask decadal trends. Conversely, this work should indicate when a statistically significant change in concentrations over a decadal time-scale can be attributed to a change in hydrologic conditions, climate, or some human-induced change in the system that occurred over the decade.

Coordination with the Groundwater Modeling team will provide important opportunities to produce reports that incorporate the findings from both teams. These efforts will range from sharing of data, for example obtaining residence time distribution curves from modelers to help interpret changes in water quality, to fully integrated technical and summary (circular) products that will bring together the results of both efforts.

Modeling and Mapping

Modeling is an important component of NAWQA Cycle 3. Models will be used to evaluate, extrapolate, and forecast water quality in drinking-water wells (domestic and public supply) and to inform NAWQA surface-water investigations with regard to groundwater discharging to streams. They will also provide insight into the relation between environmental drivers (land use, water use and management, climate), selected stressors (chemical and microbial contaminants) and various receptors (domestic wells, public-supply wells, streams). Models will be used to integrate findings at multiple scales (local, regional, principal aquifer, national) and to address spatial and depth gaps in groundwater-quality data. The multi-scale, multi-model type approach employed by NAWQA Cycle 3 enables groundwater quality data to be placed into a groundwater-flow system context, providing insight into how observed water quality is related to position and spatial location within an aquifer system. This plan identifies models that can be used to explain and forecast water quality in sampled wells, and variables that can be used to map vulnerability at a variety of scales and in areas and depth zones that have yet to be sampled.

Priority Locations for NAWQA Cycle 3 Groundwater Modeling

The following Principal Aquifers are of particular interest to the Program for Cycle 3 modeling tasks:

- Glacial aquifer system
- Northern Atlantic Coastal Plain aquifer system, and possibly Valley and Ridge, Piedmont and Blue Ridge crystalline, and Piedmont and Blue Ridge carbonate aquifer systems
- Central Valley aquifer system
- Mississippi Embayment aquifer system, and possibly Coastal Lowlands and Texas Coastal Uplands aquifer systems

These aquifers are recommended for High Intensity study modeling based on the following factors:

1. These aquifers rank at or near the top for public (primary) and domestic supply (secondary).
2. Available water-quality data indicate that one or more water-quality constituents that pose a risk to human health or stream ecosystems, such as nitrate, arsenic, uranium, or chloride, are a known concern to water resource managers.
3. PA-scale groundwater flow models that cover all or significant portions of the PA exist or will be produced early in Cycle 3 in collaboration with the Groundwater Resources Program, the Water Cooperative Program or other agencies.
4. The PA overlaps with the location of planned Integrated Watershed studies or other Cycle 3 design elements where model-generated estimates of flux of selected contaminants (e.g. nitrate) from groundwater to surface water are needed.
5. There is sufficient groundwater quality data from NAWQA, EPA, the States, or other sources to build high-quality statistical models of contaminant occurrence in the PA at the depth levels of interest.
6. National representation of a range of hydrogeologic and climatic conditions.

Modeling Products Overview

Expected products of the groundwater modeling effort include:

- Report(s) synthesizing collective findings from the modeling, forecasting and status and trends activities at the national scale. These reports will provide a national perspective on the relation between environmental drivers (land use, water use and management, climate), selected stressors (chemical and microbial contaminants) and various receptors (domestic wells, public-supply wells, streams), given the data and models available by the end of NAWQA Cycle 3.
- Concentration and vulnerability maps (maps showing the probability of exceeding a health-based threshold or fraction of a health-based threshold) for each of several contaminants at the depths of domestic wells and public-supply wells at the national scale.
- Concentration and vulnerability maps for each of several contaminants at the depths of domestic wells and public-supply wells for Principal Aquifers selected for high intensity study.
- Forecasts of concentration and (or) vulnerability for selected constituents at national, principal aquifer and (or) regional-scales under different scenarios of land use and climate change.
- Decision support system that makes scientific results accessible to a variety of stakeholders.
- Reports characterizing the relation between observed water quality, groundwater flow, and geochemical processes at various scales. These reports will focus on contaminants present at concentrations that are

high relative to health-based thresholds (human or aquatic). In addition, these reports will focus on the relevant receptors: domestic wells, public-supply wells and streams. Examples include contaminant input functions and modeled responses (concentrations and time lags), modeled estimates for depths of contaminant extinction within an aquifer, and insight into whether or not such depths are at or nearly at steady state.

- Reports describing case study relations between environmental drivers and water quality in selected areas investigated at the local scale.
- Reports documenting groundwater-flow and (or) transport models.

Plans for principal-aquifer-specific reports that include modeling results are collaboratively developed by the Principal Aquifer Chief and the National Groundwater-Modeling and Mapping Chief, taking into account existing models and related reports that have been previously published. All modeling reports generated by a Principal Aquifer Team will be in print by the end of the final year of modeling for that team (Table 3-5).

Rationale for Multi-Scale, Multi-Model Type Approach

In order to build two and three-dimensional depictions of the vulnerability of the Nation's groundwater and drinking-water wells, a multi-scale, multi-model type approach is required. Regardless of scale, the vulnerability of groundwater (GWV) to contamination is a function of contaminant input (CI); intrinsic susceptibility (IS), which is characterized by the physical factors affecting the flow of water to, and through, the saturated zone; and contaminant mobility and persistence in the groundwater (CMP). The vulnerability of a drinking-water well to contamination from chemicals and microorganisms in the groundwater is a function of the vulnerability of the groundwater ($GWV = f(CI, IS, CMP)$) and the location, design, operation, construction, and maintenance of the well. For example, the vulnerability of a public-supply well (PSWV) is a consequence of the vulnerability of the groundwater and the way in which the well interacts with the aquifer ($PSWV = f(GWV, WELL)$) (see below) (Eberts and others, in review at USGS). Likewise, the vulnerability of a stream to contaminants in the groundwater is a function of the vulnerability of the groundwater and the way in which the stream interacts with the aquifer. Surrogates for the different facets of vulnerability can be obtained through measurement or modeling and used to understand what contributes to observed water quality. The choice of vulnerability surrogates is scale dependent, as illustrated below, and affects the uncertainty in vulnerability estimates and water quality forecasts.

At the **individual-well scale**, when samples or simulations representing groundwater withdrawn from a well are used to obtain vulnerability surrogates for the well, the surrogates will integrate the effects of related processes throughout the contributing area of the well. For example, an estimate for the groundwater age mixture of the water that blends (or mixes) in a well will factor in the effects of recharge rates, aquifer hydraulic conductivities, porosities, hydraulic gradients, groundwater velocities, and travel times throughout the contributing area of the well. In other words, the groundwater age mixture for a well is an all encompassing measure of intrinsic susceptibility at the scale of an individual well. Well-scale surrogates for the other facets of vulnerability may include the sources of recharge that contribute water (and associated contaminants) to a well—a surrogate for contaminant input, and the geochemical conditions encountered by water withdrawn by a well—a surrogate for contaminant mobility and persistence (Figure 3-10A and 3-109B).

A number of different approaches can be taken to obtain well-scale vulnerability surrogates. For example, sources of recharge for an individual well can be estimated from measured concentrations (or ratios) of conservative constituents in water samples by using simple mixing models, if different parts of

the aquifer system have distinct concentrations (or ratios) of such constituents and the concentrations (or ratios) are known with some certainty. Sources of recharge for individual wells also can be estimated by using local-scale three-dimensional groundwater-flow and particle-tracking models or regional-scale groundwater-flow and particle-tracking models with a grid refinement approach (Paschke and others, 2007). The same modeling approach can be used to estimate the age mixture of water produced by a well. Where three-dimensional flow models are not available, lumped parameter mixing models (Eberts and others, 2012; Jurgens and others, in review at USGS) or groundwater stratigraphy models (Cook and Böhlke, 2000; Mendizabal and Stuyfzand, 2009) can be used to estimate the groundwater-age mixture for a well (ideally, models that will be used to estimate groundwater ages have also been calibrated to measured concentrations of environmental age tracers). Reactive solute-transport models (for example, SEAM3D, Waddill and Widdowson, 2000) can be used to simulate aquifer geochemical conditions and thus conditions encountered by water entering individual wells. If geochemical conditions within an aquifer system have been mapped in three dimensions, a more standard groundwater-flow and particle-tracking model can be used to estimate geochemical conditions encountered by water withdrawn from a well. In the absence of flow models, a redox framework (McMahon and Chapelle, 2007) that uses threshold concentrations of six water-quality constituents—dissolved oxygen, nitrate, manganese, iron, sulfate, and hydrogen sulfide—can be used to identify redox conditions for water from a well and can be readily implemented for a collection of wells by using a simple spreadsheet program (Jurgens and others, 2009).

When information on contaminant input in the area contributing recharge to a well, the age mixture of water withdrawn from the well, and contaminant degradation rates given the geochemical conditions in the aquifer surrounding the well is combined, the pathways and processes affecting contaminant transport to the well can be identified. A tool (TracerLPM) that enables such information to be combined at the scale of the individual well was developed during NAWQA Cycle 2 (Jurgens and others, in review at USGS) and can be used to generate water quality response curves for wells once an estimate of the groundwater age mixture for a well has been obtained.

In addition to providing insight into future water quality at a well, TracerLPM can be used to compare how different wells would respond to similar contaminant inputs. For example, water quality response curves for a representative public-supply well in each of four hydrologically distinct aquifers were found to differ when a common (hypothetical) contaminant input scenario was simulated using well-specific information on groundwater age mixtures, redox conditions and associated degradation rates (Figure 3-11). This type of information can be used to better understand observed water quality and water quality trends.

Although NAWQA Cycle 2 findings show that the vulnerability—and thus the water quality—of every well is unique, it is not necessary to sample and explain the water quality in every well to understand groundwater quality at a **principal-aquifer** or **national scale**. This is because spatial patterns in the factors affecting vulnerability exist, and thus systematic and predictable patterns in water quality also should exist. For example, Figure 3-12 depicts the aggregate proportion of water that is associated with different sources of recharge, geochemical conditions, and ages of groundwater from public-supply wells within Cycle 2 TANC study areas (Eberts and others, in review at USGS). Public-supply wells in several western study areas generally produce more oxic and older water than wells in two northeastern study areas. These differences in water characteristics mean that the vulnerability of the western study wells to contaminants such as benzene, toluene, and MTBE in recharge water is less than the vulnerability of the northeastern study wells to the same contaminants. Localized information such as this, however, is not sufficient for mapping groundwater and well vulnerability at the principal-aquifer

or national scales. Rather, vulnerability surrogates (model variables) for mapping at large-spatial scales must be widely available.

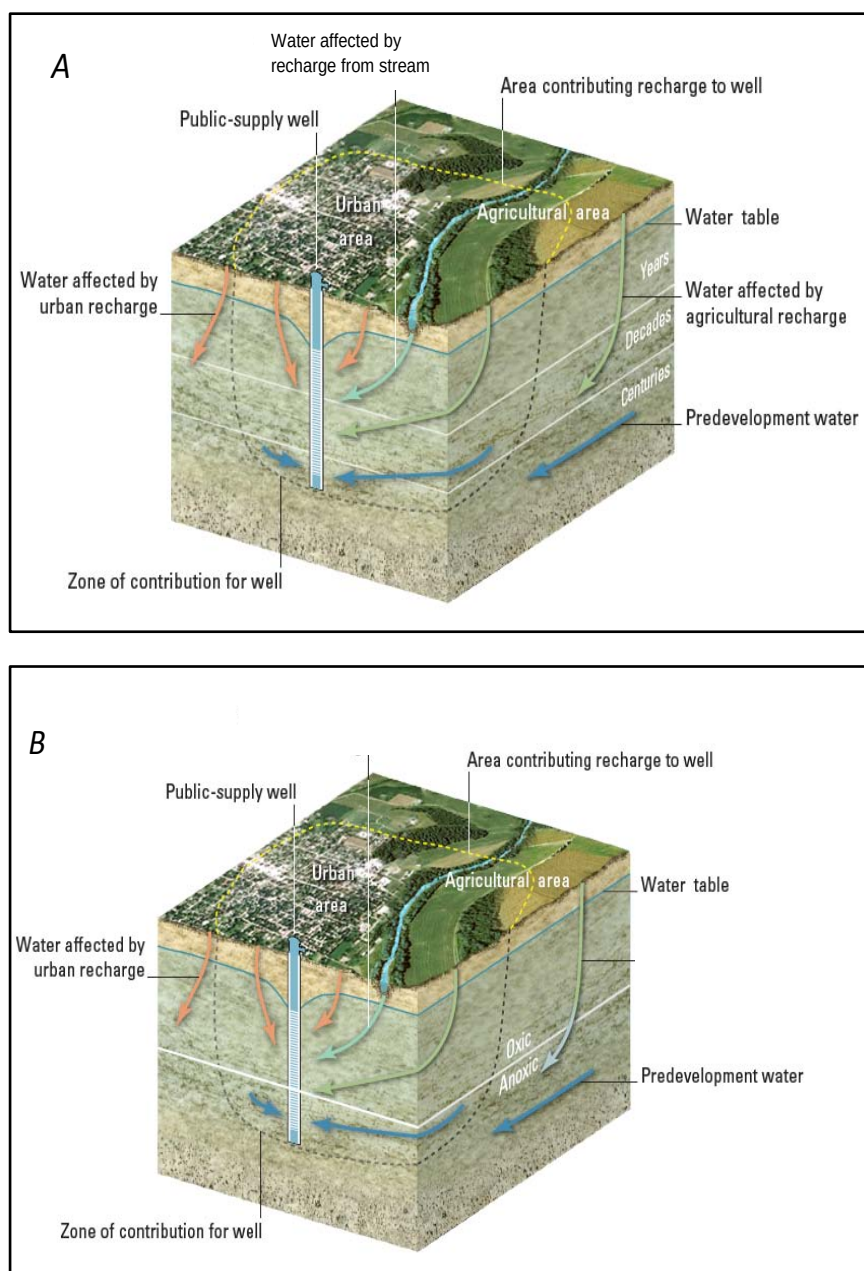


Figure 3.10. Conceptual models illustrating (A) the age mixture of water withdrawn from a well, and the sources of recharge that contribute water and associated contaminants to a well, and (B) the geochemical conditions encountered by water withdrawn by a well (Eberts and others, in review at USGS).

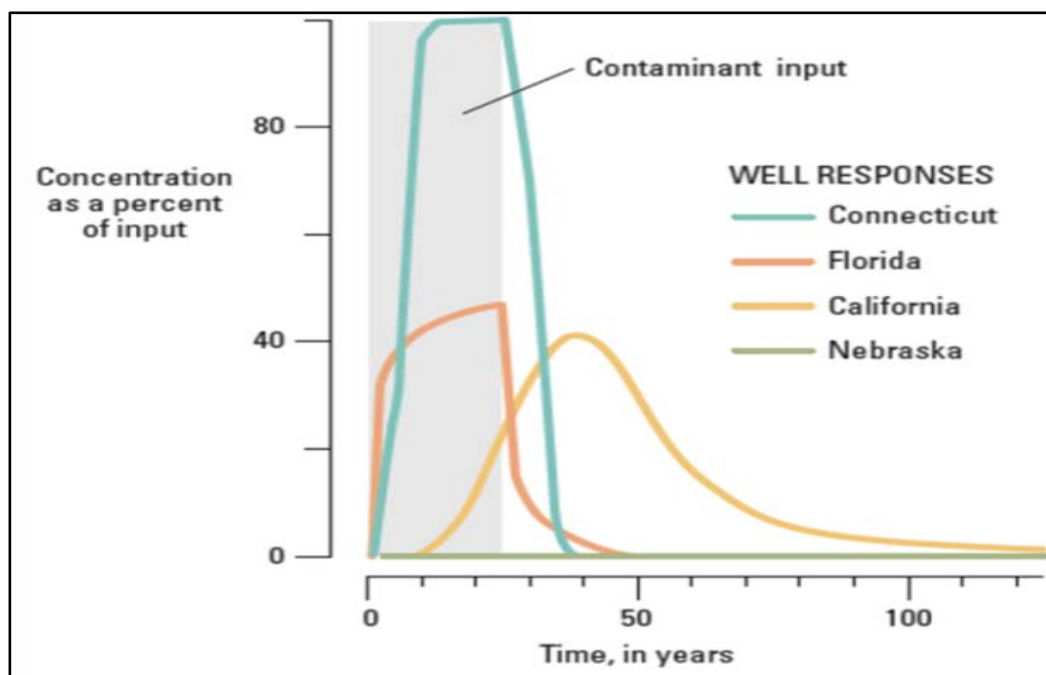


Figure 3.11. Forecasted water quality at four wells following 25 years of widespread contaminant input at the water table (McMahon and others, 2008).

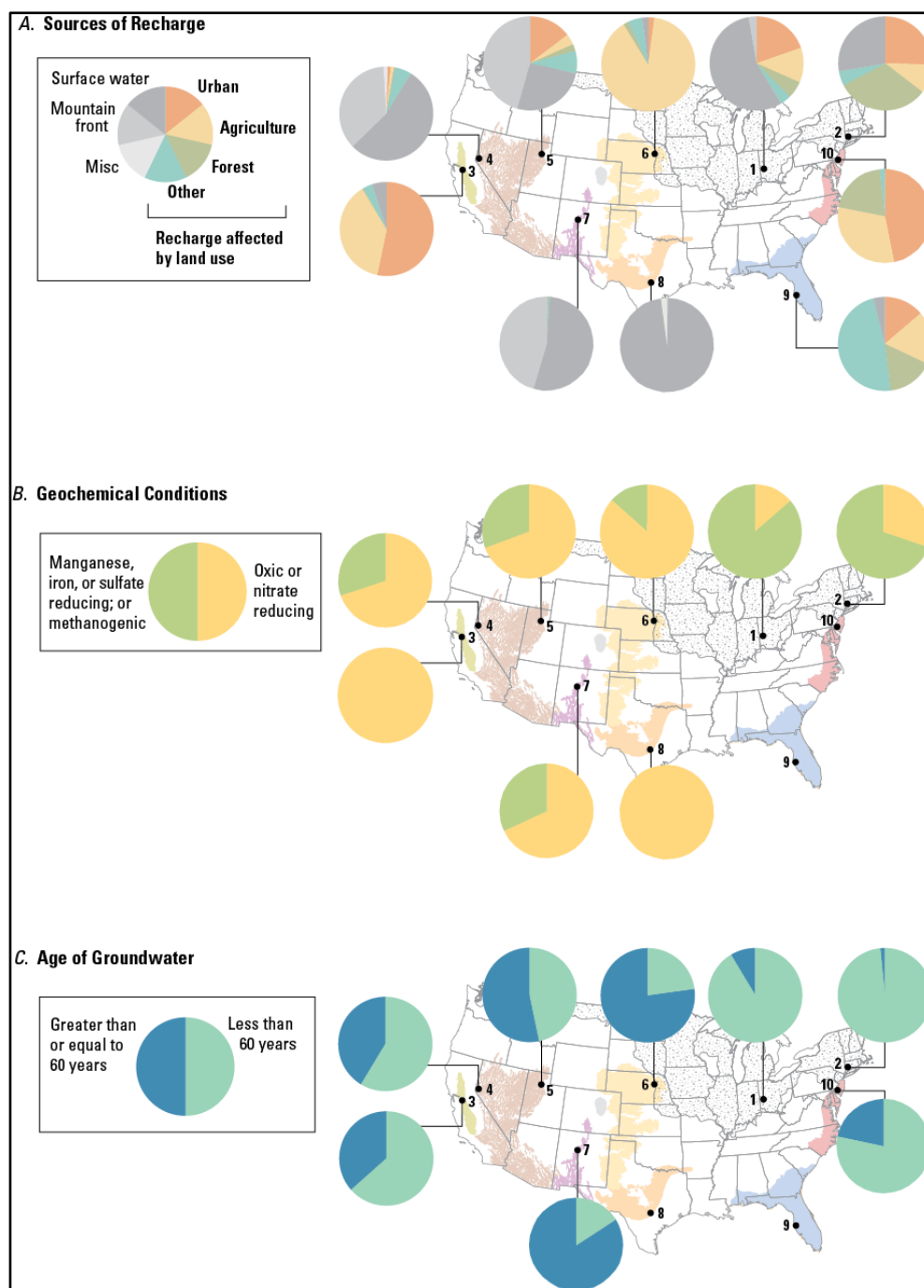


Figure 3.12. Maps depicting the aggregate proportion of water from public-supply wells in different study areas that was linked to various (A) sources of recharge, (B) geochemical conditions, and (C) groundwater ages by using groundwater-flow and particle-tracking models (Eberts and others, in review at USGS

The information used for mapping groundwater vulnerability and water quality “wall to wall” frequently takes the form of regional or national GIS coverages, such as land cover, population, and soils data. Consequently, the surrogate measures for the different facets of vulnerability that can be obtained at the principal aquifer or national scale describe fewer of the underlying processes affecting vulnerability and water quality than those obtained at the individual well scale. For example, percent of well-drained soils will not describe intrinsic susceptibility as completely as an estimate for the groundwater age mixture in a well, which accounts for the effects of recharge rates, aquifer hydraulic conductivities, porosities, hydraulic gradients, groundwater velocities, and travel times throughout the contributing area of the well (as noted above). However, trading well-scale vulnerability surrogates (independent variables) and local- to regional-scale mechanistic models for regional- to national-scale vulnerability surrogates (independent variables) and principal-aquifer- or national-scale statistical models enables perspectives on groundwater vulnerability and water quality to be obtained at the larger spatial scales. The amount of variability in observed water quality data (dependent variable) that can (cannot) be explained by using relatively simple surrogate measures of vulnerability (independent variables) is provided by the statistical models.

The types of information that typically has been used for developing national-scale groundwater vulnerability maps can be illustrated by referencing the national logistic regression model for the probability that nitrate exceeds 4 mg/L in shallow groundwater (Figure 3-13). Independent variables for the model were derived from Association of American Plant Food Control data, Landsat-derived National Land Cover Data (NLCD), 1990 Census population data, State Soil Geographic (STATSGO) data, and principal aquifer maps from the National Atlas of the United States. Variables in the final model included (A) N loading from inorganic fertilizer—an estimate for contaminant input, (B) NLCD percent cropland—pasture, natural log of human population density—surrogates for contaminant input; (C) percent well drained soils, presence or absence of unconsolidated sand and gravel aquifers—surrogates for intrinsic susceptibility; and (D) depth to seasonally high water table—a surrogate for reducing conditions conducive to denitrification, and thus, chemical mobility and persistence (Nolan and others, 2002).

Where more processes-based independent variables are desired for inclusion in principal-aquifer-scale statistical models, a meta model approach (hybrid mechanistic-statistical approach) can be taken. Several such models were developed during NAWQA Cycle 2 (for example, Nolan and others, 2011), and meta models will be used to an even greater degree during NAWQA Cycle 3.

In addition to being useful for explaining and forecasting water quality in aquifers and wells, groundwater-flow and solute-transport models can provide insight into groundwater and contaminant discharge to streams. For example, groundwater-flow models are useful for estimating the age distribution of groundwater discharging to streams and the lag time between widespread contamination at the water table and arrival of the contaminated water at different streams. Because the scale of a flow model affects which groundwater-flow systems (local; intermediate; regional) are simulated, model scale affects how much of the overall groundwater budget is simulated, and thus, the percentage of the groundwater discharge to streams within the modeled area that is simulated (Figures 3-14 and 3-15). Consequently, different scales of models are often constructed to simulate groundwater discharge to streams of different stream order.

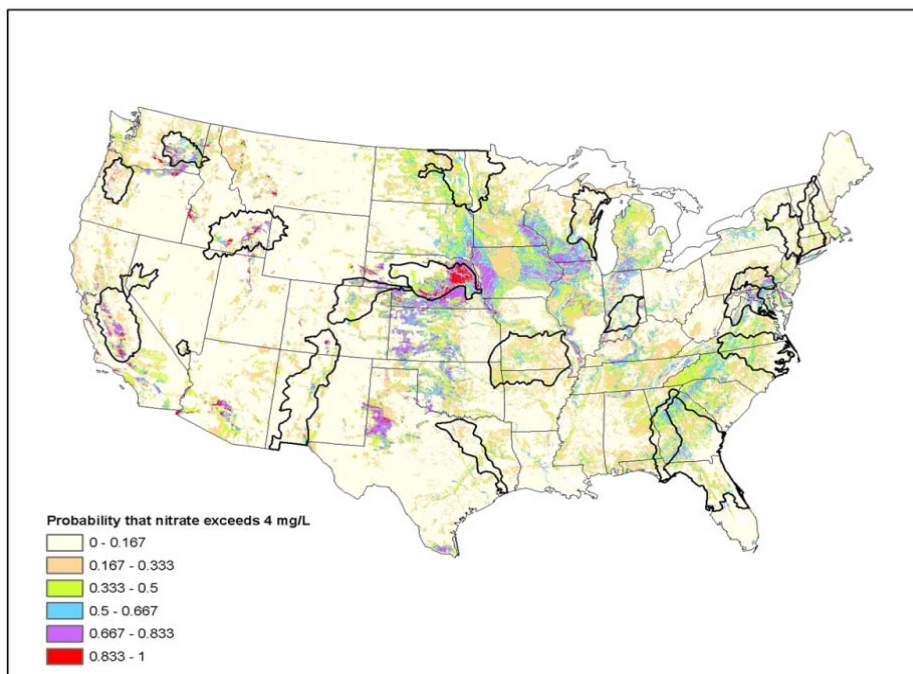


Figure 3.13. National model of groundwater vulnerability to nitrate contamination (Nolan and others, 2002). Outlines show Cycle 1 Study Units that supplied source data for the model.

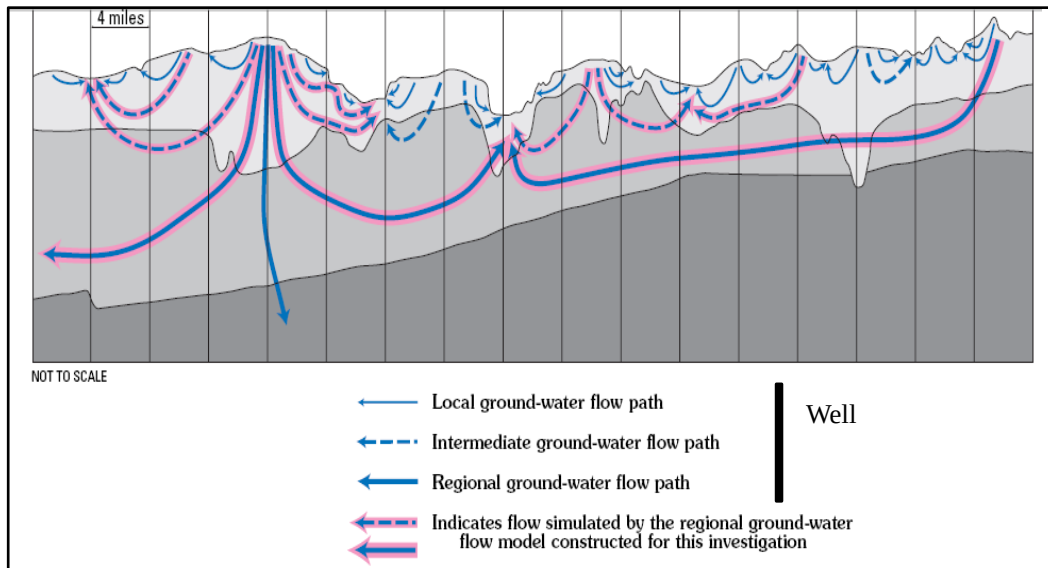


Figure 3.14. Schematic illustrating flow systems that may or may not be simulated by using a large-spatial scale groundwater-flow and particle-tracking model (Eberts and George, 2000).

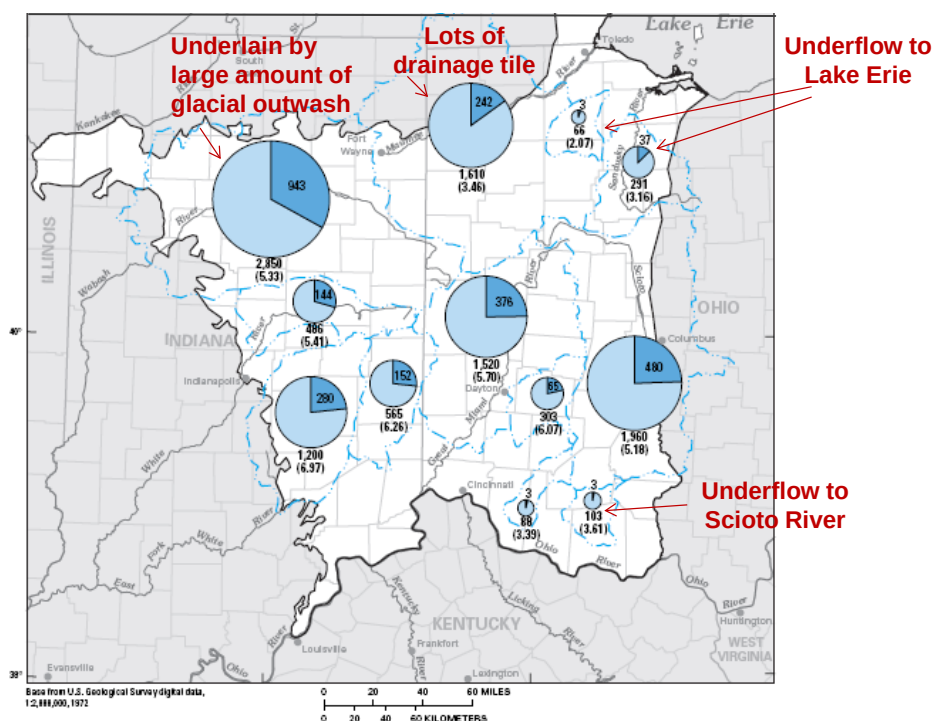


Figure 3.15. Map depicting differences in the percentage of baseflow in different watersheds within Ohio and Indiana from local-and regional-flow systems. Light blue areas within pie charts depict baseflow from local-flow systems that respond to short-term or seasonal variations in recharge; dark blue areas depict baseflow from groundwater-flow systems that remain relatively constant throughout the year and over long periods (Eberts and George, 2000).

Summary of Planned Groundwater Models for NAWQA Cycle 3

Table 3.15. Summary of the numbers, types, and scales of groundwater-related models that are recommended for Cycle 3 under the Current Funding Scenario.

Scale	Model Planned at given Intensity Level?		Total Number of Models for all 4 Regions			
	High	Low	Statistical Models ¹	Groundwater Flow and Particle-Tracking Models	Solute Transport Models; Flow and Reactive Chemistry Models	
National	yes	yes	6	4 ²	--	
Principal Aquifer	yes	--	24	8 ³ 4 (meta models) ⁴	--	
Regional	yes	--	--	--	--	
Local	yes	--	--	--	8 ⁵ 4 (meta models) ⁶	
Total number of planned models =			30	16	12	58

- ¹ For each constituent, statistical models will be done at two depth zones; the depth of domestic wells and depth of public-supply wells.
- ² One model per High-Intensity Principal Aquifer study.
- ³ There will be 2-3 models per High-Intensity Principal Aquifer.
- ⁴ Meta models are approximation models that will be used to upscale groundwater-flow model results to the principal aquifer scale. One per High-Intensity Principal Aquifer.
- ⁵ There will be 2-3 models per High-Intensity Principal Aquifer.
- ⁶ One meta model per High-Intensity Principal Aquifer. The meta models will be used to upscale unsaturated zone model results up to the regional or principal aquifer scale.

Statistical Models (Statistical Regression/Geospatial (SRG) Models) are constructed at national and principal aquifer scales (1,000s km²) to generate maps depicting groundwater or drinking-water well vulnerability to selected contaminants. For example, a vulnerability map might display spatially the probability that nitrate exceeds the USEPA Maximum Contaminant Level (MCL) at the depth zones representative of domestic wells or public-supply wells.

Groundwater-Flow and Particle-Tracking Models are constructed by Groundwater Resources Program personnel at the Principal Aquifer scale. NAWQA personnel will develop models at the regional scale. The groundwater-flow and particle tracking models will be used to provide a three-dimensional assessment of groundwater quality in important water-supply aquifers. Meta models (hybrid mechanistic-statistical models) are trained using flow and particle-tracking models; meta model output is then used to represent processes simulated by the flow and particle-tracking models in larger spatial-scale statistical models

Process and Process-Mimicking Models:

Solute Transport Models are constructed at the subregional scale to examine contaminant fluxes between the landscape and groundwater, and between groundwater and the relevant receptors (domestic wells, public supply wells, and streams). Solute transport will be linked to surface water/water quality models developed for NAWQA Integrated Watershed Studies (IWS), where possible. One-dimensional unsaturated zone mechanistic models are constructed to estimate vertical contaminant fluxes in selected areas. Meta models are trained using these unsaturated zone models; meta model output is then used as variables in principal-aquifer scale statistical models or as contaminant input functions for use with flow and particle-tracking model results

Flow and Reactive Chemistry Models are constructed to assess contaminant transport at the flow path scale. Model output will be used to estimate site-specific degradation rates, contaminant fluxes and future conditions

National-Scale Models and Planned Outcomes

National-scale statistical models (for example, logistic regression, nonlinear regression, or methods based on classification and regression trees, such as random forest) are built or updated. For example, existing national groundwater-vulnerability models (GWAVA models, Nolan and Hitt, 2006) for nitrate will be updated and refined to represent the deeper resource (i.e., public-supply wells), and to determine if better surrogate measures for the different aspects of vulnerability can be obtained in order to reduce model uncertainty.

Planned outcomes:

Maps of the vulnerability of groundwater (at depths used for domestic and public supply) to contamination from a number of different contaminants (for example, nitrate or arsenic) (see,

for example, Figure 3-13). Includes maps of both concentration and probability. Predictions of contaminant concentrations in drinking water are particularly useful to agencies such as the National Cancer Institute, who use USGS statistical modeling results to estimate exposures in epidemiological studies. The Groundwater-Modeling Decision Support and Forecasting Team will communicate with the epidemiological community and work to translate NAWQA GW modeling results into useful products for this (and other) stakeholder group(s).

Principal-Aquifer Scale Models and Planned Outcomes

Two types of investigations will be conducted at the principal-aquifer scale, those that are considered high intensity and those that are considered low intensity.

(A) High-Intensity Principal Aquifer Assessments

Existing *principal-aquifer scale groundwater-flow and particle-tracking models* will be used, where such models exist. (It may not be possible to obtain a single, all-encompassing groundwater-flow model of an aquifer system such as the glacial aquifer system.) Calibration data includes concentrations of environmental age tracers. Models will be used to determine the position of monitoring locations within an overall groundwater-flow system. For example, a model might be used to identify monitoring wells that are located in areas where hydraulic gradients are downward (wells potentially vulnerable to anthropogenic contaminants introduced at or near land surface) or upward (wells potentially less vulnerable to anthropogenic contaminants). This type of information will enable Principal Aquifer scientists (Modeling and Status and Trends team members) to determine whether flow-system position helps explain water quality, and whether a measure of flow-system position can serve as a useful surrogate for intrinsic susceptibility at the principal-aquifer scale. Principal-aquifer scale groundwater-flow and particle-tracking models will also be used to compute water budgets and travel times from recharge areas to wells or streams. Principal-aquifer scale flow models also are used to help define the conceptual model, framework, and pumping for new regional-scale flow models that are built. *Principal-aquifer scale statistical models* are built, or updated if they already exist. Independent variables for regression models may be derived, in part, from groundwater-flow and particle-tracking model results, RZWQM meta model outputs (N flux at the water table), or simple input functions (Liao and others, in press at Water Resources Research). Candidate approaches include logistic regression, nonlinear regression, random forest, and boosted regression trees.

Planned outcomes:

- Reports characterizing groundwater flow in the Principal Aquifers with emphasis on the relation between patterns of flow and observed water quality. Reports documenting updates to flow models.
- Maps of the vulnerability of groundwater (at one or more depth intervals) to contamination from a number of different contaminants (for example, nitrate, arsenic, or chloride).

(B) Low-Intensity Principal Aquifer Assessments

Principal-aquifer-scale groundwater-flow and particle-tracking model results are NOT available for the low intensity Principal Aquifers, however, data from the low intensity Principal Aquifers will be incorporated into national statistical models.

Planned outcomes:

- National maps of the vulnerability of groundwater will reflect low intensity Principal Aquifer contributions. The national statistical models will simulate contamination of shallow (domestic) and deep (public supply) groundwater by different contaminants (for example, nitrate, arsenic, or chloride).

Regional-Scale Models and Planned Outcomes

Existing *regional scale groundwater-flow and particle-tracking models* are used, where such models exist. Otherwise, two (or three) new regional-scale groundwater flow models per high intensity Principal Aquifer will be built. Calibration data includes concentrations of environmental age tracers in order to help constrain simulated travel times. Regional-scale models will be used to estimate water budgets; groundwater age distributions throughout the model domains, and at wells and streams; and travel times from recharge to discharge areas, including lag times between contaminant input at the water table and contaminant discharge to surface water (Figures 3-16 and 3.17).

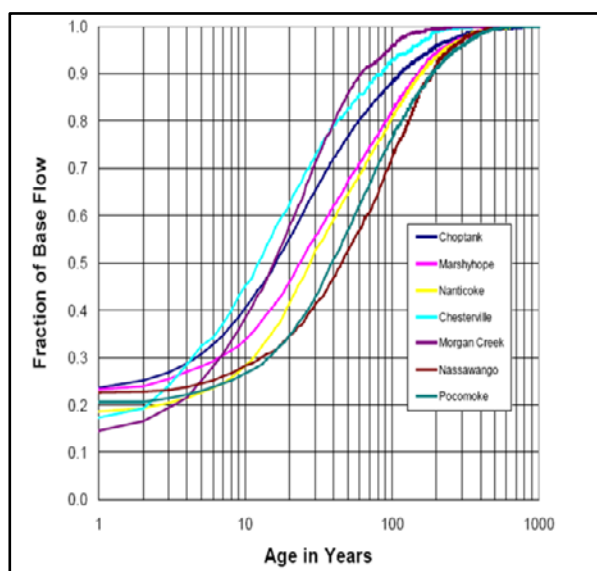


Figure 3.16. Example of differences in cumulative age distributions for groundwater discharging to different streams (W. Sanford, USGS, written commun., 2011).

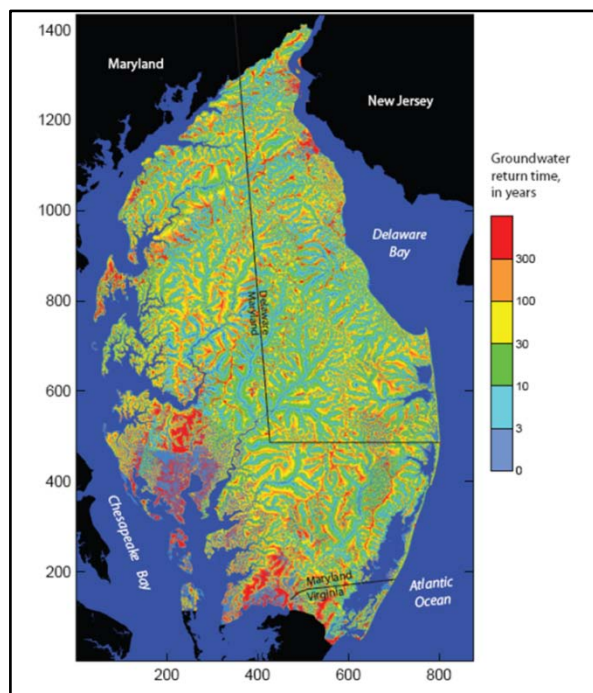


Figure 3.17. Example of lag times between input at the water table and discharge to surface water bodies (Chesapeake Bay) (W. Sanford, USGS, written commun., 2011).

Age distributions for a subset of wells within the groundwater-flow model domain may be compared to age distributions for the same wells computed using environmental age tracer data and *lumped-parameter mixing models* (Jurgens and others, in review at USGS) and (or) *groundwater stratigraphy models* (Vogel, 1967; Cook and Böhlke, 2000; and Mendizabal and Stuyfzand, 2009). For aquifers in which the different estimates are comparable (Figure 3-18), the simpler models may be used to estimate age mixtures in wells that fall outside the regional-scale model domains in order to help explain observed water quality.

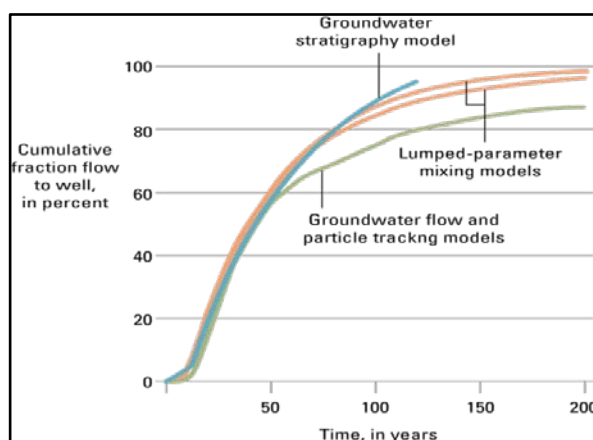


Figure 3.18. Comparison of groundwater age distributions for a well in Modesto, CA, computed using several models of varying complexity. Distributions compare favorably towards the young end (Eberts and others, in review at USGS).

One-dimensional flux models (for example, RZWQM; or simple input functions, Liao and others, in press at Water Resources Research) be developed, calibrated, and used to estimate vertical contaminant fluxes in shallow groundwater in recharge areas identified by using the three-dimensional groundwater-flow models. The resulting contaminant input functions are coupled with simulated groundwater-age distributions (from the 3-D models) at the depths of domestic wells and public-supply wells in order to reproduce observed trends (backcast) and forecast contaminant concentrations in different types of wells. Likewise, estimates will be generated for concentrations of contaminants in groundwater discharging to streams. (N-cycling processes such as crop uptake, mineralization, and fixation are key to leaching but are difficult to measure – therefore they will be estimated with RZWQM. In some regions, leaching is short-circuited by tile drains and most of the N applied at the land surface is conveyed directly to streams (e.g., tile drained areas of Corn Belt). In such cases, the unsaturated zone can have a large impact, but the receptor is surface water rather than deeper groundwater.)

Simulations of contaminant flux are used to estimate the steady-state depth of extinction (depth where the contaminant concentration goes to zero or concentrations approach background levels) for various contaminants in regional-scale study areas. Comparisons of observed and simulated extinction depths are used to identify aquifers in which selected contaminants are likely to occupy a greater thickness of aquifer in the future. See, for example, Figure 3-19.

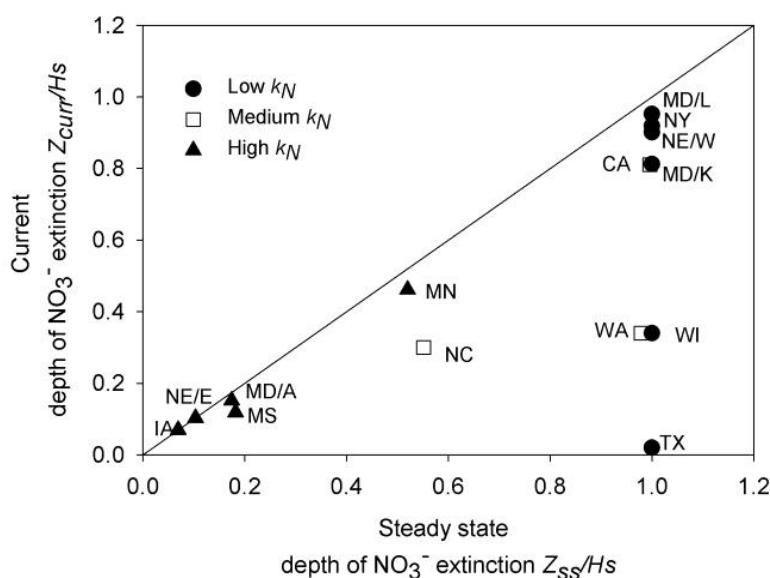


Figure 3.19. Comparison of current depth of NO_3^- extinction and depth of NO_3^- extinction at steady state in each of several study areas (Liao and others, 2012). Nitrate will likely occupy a greater thickness of aquifer at some future date in study areas that plot below the 1:1 line.

Planned outcomes:

- Reports characterizing groundwater flow in the regional-scale study areas with emphasis on the relation between patterns of flow and observed water quality. Reports documenting the groundwater-flow models. Models will help place water quality data from all well networks (PAS, MAS, LUS, ETN, FPS) into a flow system and watershed context. Reports will include a comparison of time lags and responses from contaminant input at the water table to contaminant discharge at different types of wells and at streams.
- Reports that characterize contaminant transport, storage, and transformations in the unsaturated zones of regional scale studies.

- Estimates of the proportion of the aquifers with constituent concentrations above a specified threshold. Insight into whether or not the estimated proportions and depths of contaminant extinction are at or nearly at steady state.
- Comparisons of water quality in the aquifers with water quality in streams within the Integrated Watershed Studies (IWS) (Spahr and others, 2010).

Local-Scale (Flow path-Scale) Models and Planned Outcomes

Solute transport, and flow and reactive chemistry models are constructed, as needed, to compute reactions rates and to better understand the evolution of water quality along flow paths (including the unsaturated zone). Some examples of models that might be used:

- RZWQM may be used in forecasting to evaluate the effects of changing land use and (or) climate on N transported through the unsaturated zone to the water table or to drains.
- PHREEQC may be used to understand rock-water interactions that affect the mobilization of naturally occurring trace elements.
- SEAM3D may be used in looking at how redox evolves in an aquifer depending on travel times and the availability of electron acceptors.

Planned outcomes:

- Reports describing case-study relations between environmental drivers and water quality.

Recommended Staff and Sequencing of Groundwater Modeling and Mapping Efforts

Teams required to perform the modeling activities described above include a National Groundwater Modeling and Mapping Team, a Groundwater Decision Support and Forecasting Team, and four High-Intensity Principal Aquifer Modeling Teams. (Figure 3-1).

National Groundwater-Modeling and Mapping Team

The National Groundwater-Modeling and Mapping Team is supported at approximately 5.5 FTE throughout Cycle 3 (see list of positions in Table 3-16 below). However, this level of support may vary somewhat over the course the 10-year Cycle. In general, the National Modeling and Mapping Team develops national-scale statistical models and vulnerability maps, ensures that PA Team modelers use current and consistent methods to address Program needs and to enable comparability of results. National Team members provide technical assistance to PA Team members. This includes development of pre- and post-processing programs for groundwater-flow and particle-tracking models, particularly for inclusion in statistical models. National GW-Modeling and Mapping Team members ensure that unsaturated zone models for estimating contaminant flux to the water table in selected settings are available for upscaling to the principal-aquifer scale. Meta modeling is the responsibility of the National Modeling Team. National GW-Modeling and Mapping Team members publish national-scale vulnerability maps and contribute to PA-scale publications, including results of unsaturated zone modeling, meta modeling, and flow-path modeling. The National GW-Modeling and Mapping Team provides input on the development of decision support systems, as well as decisions related to forecasting scenarios.

Table 3.16. List of positions recommended for the National Groundwater Modeling and Mapping Team.

Position	Grade(s)	FTE	Duration	Position Description
Chief, Groundwater Modeling and Mapping Team	GS 14	1.0 FTE	FY13-FY22	Manages National and PA Groundwater Modeling and Mapping teams and Groundwater Decision Support and Forecasting Team, coordinates with and explains modeling work to other programs within and outside USGS, develops modeling report prototypes, publishes summary of national-level assessments, interacts with stakeholders to help guide development of Decision-Support Systems (DSSs) and forecasting scenarios.
Senior Statistical Modeler	GS 13/14	1.0 FTE	FY13-FY22	Provides technical guidance to PA statistical modelers, oversees work of national team statistical/mechanistic modeler, builds national-scale statistical models and creates related vulnerability maps, publishes results, and provides input into the development of DSSs and forecasting scenarios.
Statistical/Mechanistic Modeler	GS 11/12/13	0.5 FTE	FY13-FY22	Assists Senior Statistical Modeler with national-scale models and maps, and with meta-model development for upscaling mechanistic model outputs.
Senior Groundwater-Flow Modeler	GS 13/14	0.5 FTE	FY13-FY22	Provides technical guidance to PA groundwater-flow modelers, develops model pre- and post-processing programs, publishes newly developed programs, and provides input into the development of DSSs and forecasting scenarios.
Senior Flow path Modeler	GS 13/14	1.0 FTE	FY13-FY22	Builds solute transport, and flow and reactive chemistry models at the flow path scale and publishes model results.
Senior GIS Specialist	GS 12/13	1.0 FTE	FY13-FY22	Provides "as needed" GIS support to all GW Modeling Team members.
Web Support Person	GS 11/12	0.5 FTE	FY13-FY22	Provides "as needed" Web support to all GW Modeling Team members.

High-Intensity Principal-Aquifer Modeling Teams

Four High-Intensity Principal-Aquifer Modeling teams will be active during NAWQA Cycle 3 (Table 3-17). Each team will operate for approximately 6 years—sequentially ramping up and back down over the course of the 6-year period. The total number of FTEs needed for PA-scale groundwater-modeling activities peaks at 10.5 FTE in years 4 and 5 (2016 and 2017) (Table 3-5). An organizational chart for a snapshot in time (year 5 or FY17) helps illustrate modeling activities at the PA- scale (Figure 3-20). In general, there is one PA Chief, a Senior PA GW-Modeler, a second PA GW-Modeler, and a PA Statistical Modeler per team. In addition, there is one Modeling Support Person for *each* PA or regional-scale groundwater-flow and particle-tracking model that is built. The PA Status and Trends Network Analyst will provide some of the modeling support. Additional senior scientists will be added, as needed, to help synthesize results at the PA scale.

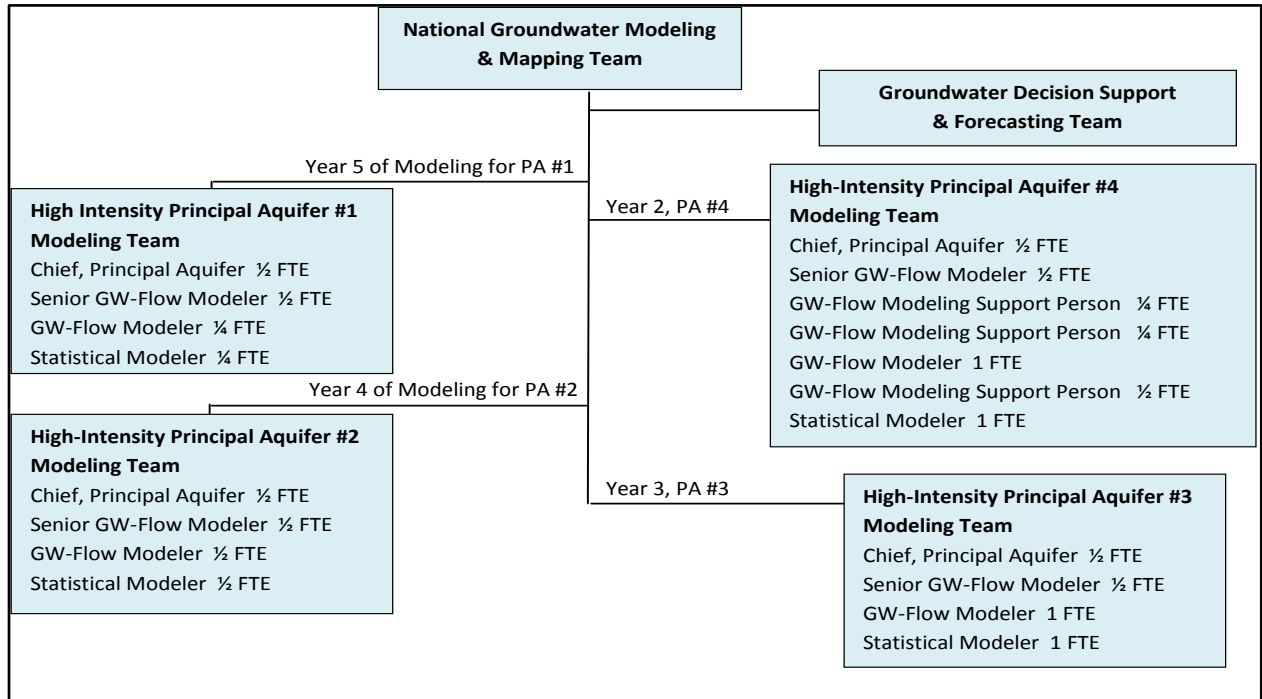


Figure 3.20. Chart showing staff distribution across High-Intensity Principle Aquifer modeling teams in year 5 (Fiscal Year 2017) of Cycle 3. The PA modeling team will be led by a full-time Chief; the Chief could be the Senior GW Flow Modeler, or a PA coordinator. The ½ FTE allocated in this chart reflects this flexibility.

Table 3.17. List of positions recommended for each High-Intensity Principal Aquifer Modeling Team. The PA modeling team will be led by a full-time Chief; the Chief could be the Senior GW Flow Modeler, or a PA coordinator. The ½ FTE allocated in this table reflects this flexibility.

Position	Grade(s)	FTE	Duration ¹	Position Description
Chief, Principal Aquifer	GS 13/14	0.5 FTE	FY13-FY18	Manages PA Team, prepares PA modeling reports plan (in concert with Groundwater Modeling and Mapping Team Chief), participates in PA investigations, publishes summary of PA work.
Senior Groundwater-Flow Modeler	GS 12/13/14	1.0 FTE ² OR 0.5 FTE	FY13-FY18	Builds or refines PA-scale and one regional-scale GW-flow and particle-tracking model, uses models to estimate water budgets, travel times, hydrologic position variables, and fluxes, and publishes results.
Groundwater-Flow Modeler	GS 11/12/13	1.0 FTE; 0.5 FTE; 0.25 FTE	FY14-FY15; FY16; FY17	Builds or refines one regional-scale GW-flow and particle tracking model, uses models to estimate water budgets, travel times, hydrologic position variables, and fluxes, and publishes results.
GW-Flow Modeling Support Person(s)	GS 9/11/12	0.5 FTE; 1.0 FTE	FY13; FY14	Collects data, helps build model framework and helps prepare model input files. (Various tasks may be done by different people.)
Statistical Modeler	GS 11/12/13	1.0 FTE; 0.5 FTE; 0.25 FTE	FY14-FY15; FY16; FY17	Builds or updates principal-aquifer scale statistical models, creates related PA-scale vulnerability maps, and publishes results.
Senior Scientist	GS 13/14/15	0.5 FTE	FY18	Helps synthesize findings at PA scale, and publishes results.

¹ Duration is for High-Intensity Principal Aquifer Team 1 beginning in FY13. High-Intensity Principal Aquifer Team 2 begins in FY14, Team 3 in FY15, and Team 4 in FY16 with Team 4 activities ending in FY21.

² This position is fulltime unless the selectee also serves as PA Chief, in which case an additional 0.5 FTE modeling support person is needed.

Description of a 6-year High Intensity Principal Aquifer Groundwater-Modeling cycle:

The sequence of data collection and modeling activities that each High-Intensity Principal Aquifer Modeling Team will be tasked with over the 6-year study are described below:

Year 1

- Senior PA GW-Flow Modeler brings the PA-scale groundwater-flow and particle-tracking model online. Model is a pre-existing model that may need to be updated (current pumping added; grid refinement; etc.) or a new model that is already nearing completion. Where possible, the model comes from the USGS Ground Water Resources Program. Regardless of the model's origins, the calibration will be refined using environmental-age tracer data, if available.
- Any new environmental age-tracer samples will be collected this first year so that results are back from the lab in time to be used for groundwater-flow model calibration.
- By end fiscal year, Senior PA GW-Flow Modeler decides which areas within the greater PA are to be modeled at the regional scale. In general, two regional-scale study areas are selected for flow and particle-tracking modeling; however, in the event that a PA-scale model is not available or practical, three regional-scale modeling investigations may be undertaken by the PA Modeling Team (for example, the

entire Glacial aquifer system would not be modeled as a single system). Groundwater use for drinking (domestic and public supply), groundwater/surface water interactions, activities of the NAWQA Cycle 3 Integrated Watershed Studies, ease of modeling (prior model; sufficient data for development of new model; etc.), water-quality issues and local cooperator interest are factored into decisions regarding locations for regional-scale flow models. Regional-scale groundwater-flow and particle-tracking models are generally nested within the PA-scale groundwater-flow model, but may extend beyond the PA boundaries. Regional-scale flow models may or may not be co-located with the PA Status and Trends high intensity sampling. One regional-scale model is co-located with the Integrated Watershed Study activities, if possible. Once the regional study areas are selected, the PA Chief together with the GW Modeling and Mapping Chief prepares a modeling reports plan for the Principal Aquifer Modeling Team.

- Modelers begin interacting with the Groundwater Modeling Decision Support and Forecasting Team to help identify data from the Hydrologic and Geographic Systems Analysis Team needed to support forecasting efforts to begin in Year 4.

Year 2

- A fulltime PA GW-Flow Modeler is hired at the beginning of the fiscal year and begins working on one of the regional-scale flow models.
- A fulltime PA Statistical Modeler is hired and begins working on the PA-scale statistical models.
- The Senior PA GW-Flow Modeler completes the PA-scale flow and particle-tracking model and documents the model in a USGS report. Results of the PA-scale flow model are shared with the PA Status and Trends Team and the Decision Support and Forecasting Team even before the modeling report is published.

Year 3

- Modelers no longer have access to modeling support personnel (see Figure 3-20 and Table 3-17).
- Regional-scale groundwater-flow and particle-tracking models are calibrated by the end of this year.
- Flow modelers, statistical modeler, network analyst, and IWS scientists work together to determine the types of flow and particle-tracking output that might best inform other program activities. For example, information on flow-system position (proximal; distal) and groundwater-age distributions (travel-time distributions) at monitoring wells are provided to the Status and Trends Team for discerning water-quality trends.
- Principal Aquifer-scale vulnerability maps are being developed.

Year 4

- Reports documenting regional-scale models and characterizing relations between groundwater flow and observed water quality at the regional scale are started.

Year 5

- Senior PA GW-Flow Modeler completes regional-scale modeling reports initiated during Year 4 and begins work on a final, comprehensive Principal Aquifer report, along with the PA Chief and Status and Trends team members.
- Work on all other modeling reports is completed.

Year 6

- Senior PA GW-Flow Modeler is potentially joined by other NAWQA program senior scientists to pursue synthesis topics.
- All principal-aquifer scale publications are completed this year, including a fact sheet summarizing salient points of the entire 6-year PA-scale effort—joint modeling and status and trends.

Groundwater Decision Support and Forecasting Team

The Groundwater Decision Support and Forecasting Team will assume the lead in designing Decision Support System(s) that will assist stakeholders in applying findings from NAWQA groundwater investigations to real-world management decisions. This team will also work with the Hydrologic Systems Team (HST; responsible for creating forecasting input files) to ensure that forecasting data developed for use with Cycle 3 groundwater statistical and mechanistic models are compatible with the models and can facilitate the desired forecasts. The team then uses the input data from the HST and the models from the Principal-Aquifer Modeling teams to generate forecasts. Relatively simple models, such as lumped-parameter mixing models or groundwater stratigraphy models, will be applied by the Team to extrapolate results from the high-intensity PAs to other less intensively studied areas. Team members will also contribute to a variety of publications. The level of support for the Groundwater Decision Support and Forecasting Team is variable—ramping up as statistical models and flow and particle-tracking models are completed by the Principal Aquifer Modeling teams—as depicted in Table 3-18.

Table 3.18. List of positions recommended for the Groundwater Decision Support and Forecasting Team.

Position	Grade(s)	FTE ¹	Duration	Position Description
Statistical / Mechanistic Modelers	GS 11/12/13	1.0 FTE; 2.0 FTE; 3.0 FTE; 4.0 FTE; 3.0 FTE	FY13-FY16; FY17; FY18; FY19-FY20; FY21-FY22	Develop Decision Support System(s) and uses spatial data from the Hydrologic and Geographic Systems Analysis Team, as well as models from the Principal Aquifer Modeling teams, to forecast water quality in principal aquifers and at selected receptors (domestic wells, public-supply wells, and streams). Use a variety of models / tools to extrapolate findings beyond high intensity PAs, where possible.

¹ Refers to the total FTE that will be employed during the time intervals indicated under the “Duration” column. For example, a total of 3.0 FTE would be employed during FY18. Note also that the FTE total may be split among multiple part-time staff, depending on the skill sets required.

Chapter 4-Recommendations for Integrated Watershed Studies

Introduction

Evaluating the impacts of human and natural factors, such as land use, water use and climate change, on surface and groundwater quality and quantity requires an understanding of processes occurring across a range of spatial and temporal scales. Water quantity and quality of large rivers that discharge to coastal environments are driven, in large part, by environmental processes occurring in small streams and their watersheds. For example, it has been shown that the most rapid transformation of ammonium to nitrate occurs in the smallest streams (Peterson *and others*, 2001). In turn, the downstream transport of nitrate from small streams to large rivers, and eventually to coastal environments is directly related to the magnitude and extent of anoxia in the Gulf of Mexico. An understanding of temporal changes in land use (e.g. seasonal variation in fertilizer application) and climatic (e.g. snowmelt) conditions that control the sources and transport of nitrogen, as well as phosphorous, carbon, and sediment, from the landscape to the stream is required to understand and predict trends in water quality.

Water quality studies generally have either a field (monitoring and/or experimental) or a modeling focus. Both these methodologies have their strengths and their weaknesses. In combination, they provide valuable insights that neither can provide alone. Combinations of monitoring and modeling studies have been conducted for years, but have generally been done at the small (catchment) scale. Water-quality studies also frequently focus either on the surface water or the ground water, and infrequently, at the groundwater-surface water interface. Seldom do studies target both groundwater and surface water in a holistic manner so that the larger hydrologic setting is well understood. In water quality monitoring studies, measurements of constituents are usually done using either discrete samples or using continuous probes. Only rarely are both done together to accommodate a range of constituents. Finally, when modeling is employed in water-quality studies, usually only one model is used. The combined use of two or more models that integrate individual different strengths and limitations can provide further valuable insights.

A substantial amount of data have been collected in large to very large (~50,000 to 500,000 km²) rivers and watersheds across the country to link changes in human and natural factors to water quality conditions. At the other end of the spectrum, similar extensive data sets are often limited in small watersheds that range from 5-1000 km². In contrast, extensive data sets in intermediate size streams/watersheds (~5,000 to 50,000 km²) are often lacking, and the subsequent lack of a process-based understanding of nutrient and sediment transport at these scales, including understanding the role of groundwater-surface water interactions, results in a disconnect between management activities, which often take place at the scale of the small stream/watershed, and observed water quality conditions in larger systems. Consequently, there is a lack of understanding of if, when, and how historical, current, and future climate, land use, and management practices will affect water quality.

Study Objectives

The general goal of the Integrated Watershed Studies (IWS) is to answer the question: “How do natural and anthropogenic factors influence the flux of nutrients and sediment in surface and groundwater at the watershed scale?”.

The objective of the Integrated Watershed Study (IWS) is to understand, quantify and model the human and natural factors that control nitrogen, phosphorous, carbon (together referred to as nutrients), and sediment fluxes across space (from small to intermediate watersheds) and time (from hourly to annual) by providing connections between field monitoring, process-based understanding, and modeling efforts.

This will be achieved by interpreting a combination of new and existing water-quality data at a range of spatial and temporal scales. The study areas will include a range of climatic and hydrologic settings, land uses, and management practices, to address the following objectives:

Determine nutrient, and suspended sediment delivery to streams as a function of land use and hydrologic position within the watershed. Specifically, across a gradient of land use and stream order, determine:

- Pathways and lag times of nutrient delivery to streams.
- The quantity, chemical quality, and sources of carbon.
- The quantity, sources, and sinks of sediment.
- In-stream nutrient processing rates.

Conceptually and mathematically connect environmental observations with environmental processes at the scale of small to intermediate sized watersheds across a range of temporal scales. Specifically, develop:

- Correlative models relating discrete and continuous data to rates of biogeochemical processes.
- Reach-scale process-based models that incorporate in-stream and biologic processing rates.
- Mixing models and mass-balance models that track and quantify nutrient and sediment fluxes across a range of watershed sizes.
- Dynamic water-quality models that explain time-varying changes in loads as a function of climate, hydrologic setting, management practices and biogeochemical processes that control nutrient, carbon, and sediment transport.

Provide policy makers with an understanding of how current and historic land use and management practices influence water quality conditions at the scale of small to intermediate sized watersheds. Specifically, develop:

- Improved decision-support systems that allow managers to better forecast water quality conditions in response to hypothetical land use, land management, and climate scenarios.
- Realistic expectations of how/when landscape changes may result in water-quality change.

Policy Objective: Give policymakers useful and meaningful answers to water-quality problems (nutrients, sediment) across the temporal and spatial scales at which water-quality policies and management practices are implemented.

These objectives will be addressed through a combined approach involving data analysis, monitoring, field experiments, and modeling. In addition, improved temporal resolution of water quality patterns will be achieved through the deployment of continuous monitors and dynamic models. Under the Current Funding Scenario these approaches will be applied initially in only three or four watersheds (target size range 6,000-60,000 km²) and smaller sub-basins within these watersheds. New field data collection will be largely conducted in only one of the IWS areas. Selection of the study areas, study design, modeling and field methods, staffing, timeline, products and budgets are described below.

Relevance to other Cycle 3 Components

The focus on understanding processes and the temporal component of the IWS are somewhat unique among NAWQA Cycle 3 goals and will inform, and be informed by, the findings of the other components of Cycle 3. In particular, the process-based understanding gained from the IWS will explain the observed patterns and trends in water-quality parameters observed in Goal 1 Status and Trend assessment and synthesis activities. Such understanding will also provide a foundation for managing resources to reduce

the negative impacts of nutrients and sediment on stream ecosystem condition identified through Goal 3 stressor effects studies.

The sources and movement of water, nitrogen, phosphorous, carbon, and sediment and other constituents are controlled by a combination of human activities, hydrologic setting, and the properties of the constituent. Their transport often spans many orders of magnitude in scale from the field and catchment scales to large regional rivers and aquifer systems. Since NAWQA is one of a few Federal programs that examines the water-quality of small- to intermediate-size streams and aquifer systems, it is able to connect field-scale research to broader environmental concerns. This IWS takes a national perspective and has identified study watersheds that span a range of hydrologic settings that are important in the national mosaic. The actual study basins will be selected to provide information on the hydrologic end-members of this national mosaic (groundwater-dominated areas, surface-runoff-dominated areas, artificial subsurface drainage-dominated areas). The decadal temporal cycle of NAWQA and the IWS will enable each study watershed to be investigated thoroughly using existing and current data and various modeling tools. This will allow for quantification of important year-to-year variability and enable future predictions of water quality.

The IWS builds off the successes from NAWQA Cycles 1 and 2. Surface- and groundwater quality and quantity data collected during those cycles will provide an important backbone to the existing data sets. Furthermore, an understanding of hydrologic flow paths, surface and subsurface flows and their exchanges for large watersheds (areas on the order of 30,000 square kilometers) has been gained through the past NAWQA investigations of study unit watersheds. The results of previous NAWQA studies have also identified critical information gaps with respect to land management and environmental policy. Specifically, results indicate that information is needed to develop: (1) local and regional management strategies for water quality contaminants that take into account land use patterns, chemical use, and natural factors, (2) environmental policies that consider the entire hydrologic system and its complexities, including surface water/groundwater interactions and atmospheric contributions, and (3) reliable predictive models to cost effectively estimate water-quality conditions that cannot be directly measured for a wide range of possible circumstances (U.S. Geological Survey, 1999). The objectives of the IWS are aimed at directly providing needed fundamental understanding and developing and integrating the modeling tools needed to address these three important goals.

In addition to the extensive environmental data collected in NAWQA Cycles 1 and 2, there was a focus on process understanding, particularly the biogeochemical processing of nitrogen and phosphorous and their effect on the aquatic ecosystem. One of the major lessons learned from NAWQA Cycle 2 topical studies is that the transport pathways, timing and magnitude of contaminants is closely tied to the movement of water. The corollary to this lesson is that an understanding of the water flow paths and travel-times is necessary to predict the occurrence and movement of contaminants. Cycle 2 also made advances in applications of modeling tools to watershed and groundwater studies. A range of different process-based, statistical-based and GIS-based models were used during Cycle 2 at many different spatial scales. These models include SPARROW, SWAT, TOPMODEL, MODFLOW/MODPATH, RZWQM, HYDRUS, LEACHM and WARP.

The NAWQA Cycle 3 Science Plan goal to evaluate how human activities and natural factors, such as land use, water use and climate change, are affecting the quality of surface waters and groundwater will be accomplished through both the Cycle 3 groundwater monitoring and modeling studies (largely focused on public drinking water supply) and the IWS. In the IWS design, as presented here, the Integrated Watershed Studies and the Intensive Studies have been merged (Figure 4.1).

The IWS is the portion of NAWQA Cycle 3 design that will integrate and advance the myriad environmental observations and modeling tools that have been developed by NAWQA and other researchers and agencies. This will be done in a limited number of prototype basins, to provide an evaluation for how this integration can be conducted and generalized for other areas of the Nation. One IWS area will be designated for the collection of new data. The other IWS areas will rely on existing data as well as on-going data collection during Cycle 3 by other components of NAWQA or other agencies.

The downstream boundary of each of the IWS basins is included in the NAWQA Cycle 3 National Fixed-Site Network (NFSN). The new-data-collection IWS will include two or more stream sites from the NFSN network. IWS will supplement data collection at the NFSN sites, such as the installation of continuous water-quality sensors. The data collected by NAWQA surface water trends in the previous two decades, as well as the hydrologic understanding of the basins, will be extremely important to the work of the IWS. The IWS will also benefit from one of the RSS being conducted by the Goal 1 Surface Water Assessment RSS Team. The first of the RSS will be done in the Midwestern Corn Belt region in collaboration with the EPA-NARS Wadeable Stream Assessment.

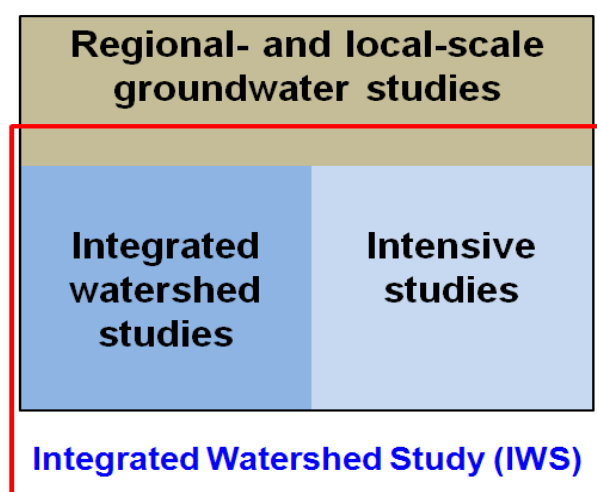


Figure 4.1. Schematic diagram illustrating relations among the Cycle 3 Science Plan's Goal 2 integrated watershed studies, Intensive studies (small-scale watersheds), and regional and local-scale groundwater studies (outlined by the black line). The current IWS design merges the Integrated Watershed and Intensive studies including the shallow portions of the groundwater system into one study as outlined by the red line. The regional- and local scale groundwater studies are coordinated and integrated with the Integrated Watershed studies in basins of mutual interest but are also conducted as independent studies in high-priority aquifer settings as part of the Goal 2 Groundwater Modeling and Mapping effort.

The IWS studies will also be connected to the Goal 1 Groundwater Assessment through data collection and modeling activities. The IWS will rely on groundwater data that have been collected in the first two Cycles of NAWQA, as well as data being collected as part of Cycle 3 regional- and local-scale flow path studies. Groundwater flow models will be developed in collaboration with the Goal 2 Groundwater Team. One or more models will be developed in each IWS area to assess surface-water/groundwater interactions and baseflow contributions of nitrate or other constituents to stream loads. Other groundwater models for the other IWS areas will come from a combination of existing models developed by the Groundwater Resources Program, Cooperative Water Program, or the National

Research Program. It is expected that the surface-water modeling, groundwater-quality and age-tracer data collected by the IWS will aid in the calibration of the Goal 2 groundwater-flow models.

The IWS will also participate in one the Regional Synoptic Studies being conducted by the Goal 1 RSS Team and the Goal 3 Effects of Stressors team. The first of these will be in the Upper Midwest Corn Belt region in conjunction with the Surface Water Status and Trends Assessments. In addition, the small-watershed field studies and continuous WQ monitoring components of the IWS will provide data and process understanding useful to the Goal 3 Ecological Effects team. The IWS monitoring sites can also provide a platform for which Goal 3 scientists can conduct specialized studies.

The forecasting components of the Cycle 3 Science Plan (Goal 4) are included as an integral part of the IWS. The IWS area will provide the best locations consistent with NAWQA Cycle 3 goals for detailed forecasting using a variety of different modeling tools. The models for the IWS basins will be developed, calibrated and verified, to the extent possible, with historical water quantity and quality data. The recommended IWS areas were largely chosen due to the richness of existing data. The models developed at these sites will ultimately provide some of the best opportunities in the Nation for developing backcasting models to quantify the uncertainty associated with models that will be used to forecast future conditions. In the first few years of Cycle 3, scientists working on the IWS will be focused on creating models, understanding the connections among the models and using them for spatial and temporal interpolation. In the second part of Cycle 3, IWS scientists will increase their focus on forecasting objectives including scenario development. The forecasting scenarios will be developed in close conjunction with the Hydrologic Systems Team. The HST will also assist the IWS to obtain the needed spatial and temporal datasets (Table 4.1).

Study Approach and Methods

Analysis of Environmental Settings – Selection of Study Areas

The IWS Goal 2-IWS Implementation Team conducted a systematic study area selection process. The endpoint of this process was to choose several basins where we could fulfill the IWS goals by use of existing data only and to choose one basin where new data would be collected to fulfill both the modeling and field study goals. Details regarding the site-selection process, which is described briefly below, can be found in Appendix 4.

Table 4.1. Examples of spatial and temporal datasets that will be needed for Integrated Watershed Studies models.

Spatial information (constant of time, more or less!)
Geo-referenced time series of aerial photography to define stream channel dynamics through time, improved digital elevation maps)
Data derived aerial LIDAR (including elevation and canopy features, floodplain width and bank height)
Watershed boundaries for any location on landscape
Soil information (permeability, chemistry, particle size, organic matter and sand/silt/clay content, etc.) Surface and subsurface geology (depth to groundwater, aquifer porosity, etc.) Subsurface redox conditions
Septic system locations Agricultural practices, permanent/semi-permanent (irrigation, drains, buffer strips, terraces, etc.)
Wastewater discharge locations, volumes and concentrations of nutrients and solids
Time-varying information (1980 to current)
Climate records (temperature, estimated ET, solar radiation, precipitation, hourly, daily, monthly, seasonally, annually
Runoff (streamflow) records hourly, daily, monthly, seasonally, annually
Stream network
Surface hydraulic properties (stream velocity and time of travel)
Surface water withdrawals (use types, volumes); reservoir/lake locations and geometry
Well water-level records
Ground water withdrawals (location, type, amount, purpose)
Land cover/use (type and density of vegetation, NPP, EVI, forest succession and management, mining activities, roads, impervious covers) ¹ .
Population distribution and density
Urban waste-water discharge (locations, volume, ...)
Point-source discharges
Crop information (type, nutrient content, harvesting, rotations), fertilizer use and type (crop applications, timing of applications)
Other agricultural amendments applied (recovered manure), agricultural practices, annually renewable (tillage, conservation practices, etc.)
Livestock (CAFOs, locations, number and type, discharge records)
Water-quality information
Surface water and groundwater water quality records, discrete and continuous; NWIS, STORET, other agency, other researchers.
Natural background nutrient concentrations (e.g., soil phosphorus)
Atmospheric deposition of nutrients and major ions

¹ NAWQA is collaborating with the USGS Eros Data Center and the USGS Geographic Analysis and Monitoring Program to produce spatially explicit, annual land-cover maps from the “present” time back to 1940, for the entire conterminous United States based on “backcasting” land cover models.

Candidate watersheds for IWS were determined *a priori* to range in size from about 6,000 to 60,000 square kilometers (~2,500 to 25,000 mi²) to best accommodate political, scientific, historical, and logistical concerns. This range of scale is important to water-quality managers and policymakers and is generally understudied. For example, this range of scale will bridge the gap between watershed models that are traditionally used at the regional scale (SPARROW) and those used at much smaller scales (SWAT). Extensive data sets exist for many basins at this scale due to previous studies by NAWQA and others. This is the scale of the original NAWQA Study Units, so the agency has experience conducting successful studies at this scale. These larger watersheds can be divided into sub-basins to examine more localized processes and test smaller scale modeling efforts. Also, information for the sub-basins can be aggregated into the larger areas to examine the uncertainty in scaling up modeling results and monitoring data.

Various criteria were used to identify candidate study areas. One important criterion was to include watersheds that represent a range of hydrologic settings, including areas with different water flow paths and residence times. Three hydrologic end members identified during Cycle 2 topical studies were considered: (1) runoff-dominated basins, (2) subsurface-flow dominated basins characterized by extensive artificial drainage such as ditches or subsurface drains, and (3) slow-flow groundwater dominated basins. The second criterion was based on land use. The IWS watersheds needed a relatively high percent of agricultural land use (>10%) and some developed (urbanized) areas to capture important water-quality stressors. Watersheds that had minimal disturbance caused by human activities were therefore excluded from the Cycle 3 IWS. A third important criterion was the existence of an extensive data set of discharge and water-quality measurements because the study will fundamentally rely on existing data. Under the CFS, only one IWS watershed will have new data collection (funded by IWS). Finally, it was important that the selected study areas have recent MODFLOW models, extensive geospatial data (including LIDAR), and good connections with other Cycle 3 studies and with other previous or on-going studies by USGS (e.g., National Research Program), other federal agencies [e.g., USDA Agricultural Research Service (ARS), USDA Natural Resources Conservation Service (NRCS), USDA Comprehensive Effects Assessment Program (CEAP)], or academic institutions.

The study area selection process started with a list of 269 watersheds, most of which were watersheds that had been part of the NAWQA, NASQAN, NMN, HBN and coastal rivers networks. Additional sites from the networks of NEON, ARS and other agencies were also evaluated. This group was decreased to 123 watersheds that met the criteria for watershed area. The number of candidate basins was further reduced by examining existing data on discharge, nitrogen, phosphorus, sediment and carbon — resulting in 43 remaining watersheds (see Appendix 4 for further details). This group was then evaluated in the final selection process for the IWS watersheds (Figure 4.2).

A variety of watershed characteristics were obtained for these basins, including land use, drainage area, existing gages (flow, water quality), soil type, dams and reservoirs, geologic setting and existing groundwater models. Figure 4.3 is an example of type of data that were examined (and mapped) in the selection process. In this case the map shows the distribution of land use in the White River (IN) watershed together with the existing stream gages. These results were used to evaluate the current infrastructure that could be employed by the IWS. A number of watersheds were eliminated from this group because of the lack of developed area (agricultural or urban) in the watershed or the prevalence of dams that would hinder the ability to test some of the watershed models and confound interpretations of field observations and calculate loads.

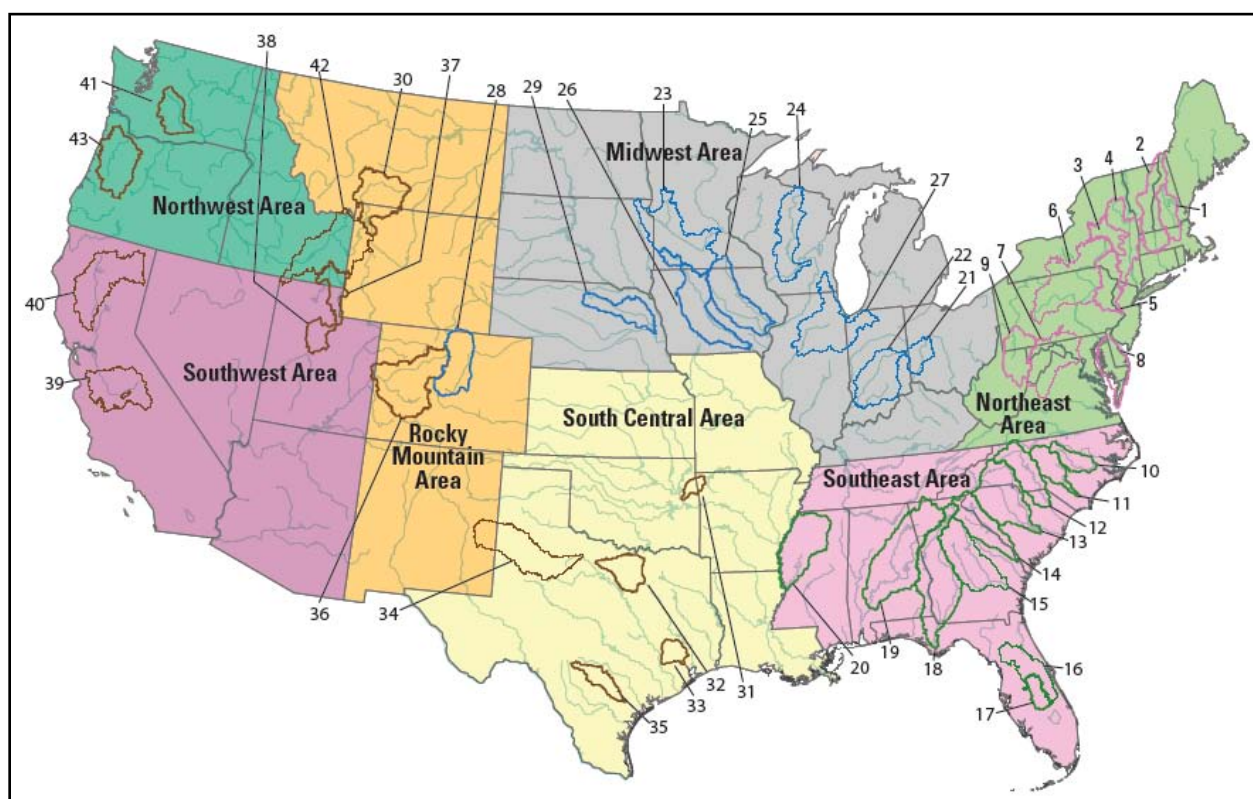


Figure 4.2. Location of 43 candidate Integrated Watershed study basins that meet the size and data selection criteria established by the Implementation Planning Team. Shaded colored areas are USGS Geographic Area boundaries. The names of the basins associated with the 43 numbered basins shown here are given Appendix 4.

Following the selection criteria outlined above, ten candidates with roughly equivalent viability for conducting the studies were identified (Figure 4.4). Based on projected funding constraints only three or four IWS were recommended as FY13 starts and only one will involve new data collection (the others will rely on existing data). Three proposed IWS were primarily selected because they are good examples of the three desired hydrologic settings (runoff, subsurface-drainage and slow-flow groundwater) and because all three are in the Mississippi River Basin where nutrient and sediment transport and their relation to hypoxia in the Gulf of Mexico is a major concern for the States, USDA, and EPA. The recommended basins are:

- Wisconsin River (Wisconsin), slow-flow groundwater basin,
- Yazoo River (Mississippi), surface runoff basin, and either the
- Iowa River (Iowa) OR White River (Indiana) sub-surface drainage basin.

Because this group of watersheds are all within the Mississippi River basin, findings from each can be easily compared and contrasted and having three hydrologically unique study basins within the Mississippi River basin may lead to a greater understanding of the larger basin as a whole and extrapolation of results to other parts of this nationally important region. The Mississippi River basin also has a number of on-going monitoring and modeling studies, some of which are being conducted by

the USGS but many others being done by the individual States or other Federal Agencies, and many with a larger focus on implications for hypoxia in the Gulf of Mexico. Our intention is to leverage the IWS with such activities to the extent possible.

Additionally, NAWQA will also collaborate with the Chesapeake Bay Program (CBP) in the Potomac River Basin to take advantage of long-term efforts by CBP personnel have been analyzing nutrient and sediment trends in surface water and groundwater and who have actively worked with NAWQA HST personnel to build a dynamic SPARROW model that will include forecasts of how changing land use, climate, and management practices might affect nutrient and sediment loading to Chesapeake Bay. The exact form of the collaboration will depend on future discussion involving IWS and CBP personnel but will likely focus on the Del Marva Peninsula and Potomac River Basin.

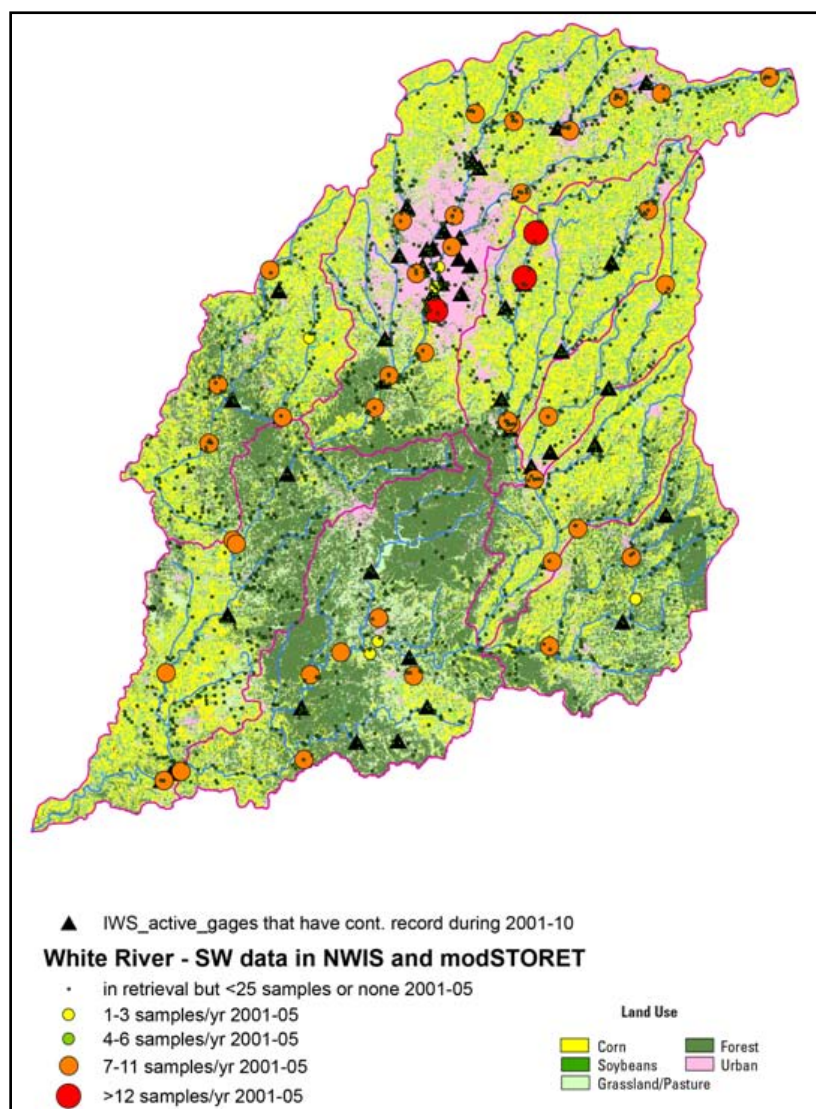


Figure 4.3. Example map showing the distribution of land use in the White River (IN) watersheds together with the existing gages (to evaluate the current infrastructure that could employed by the IWS) and the numbers of historic samples for nitrate that have been collected at various stream sites in the watershed. These types of data were used as part of the selection process (Chapter 4-Appendix).

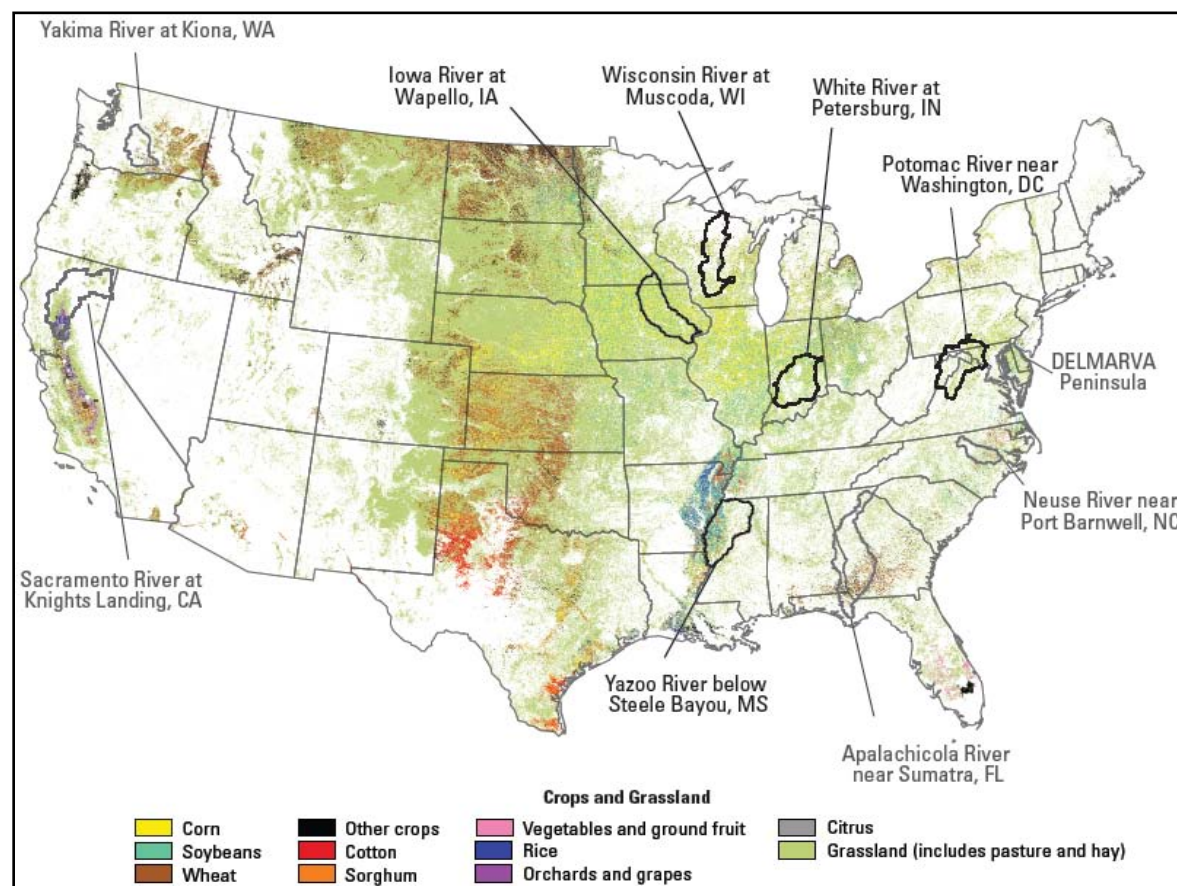


Figure 4.4. Location of the recommended watersheds for the IWS in relation to agricultural lands use. The watersheds outline in black recommended to start work in FY13: are either the Iowa or White River basins (for new data collection), and the Yazoo, Wisconsin and Potomac River Basins (for existing data analysis and modeling only). One or more of the other watersheds (outlined in gray) are recommended to begin in about Fiscal Year 2018 subject to available funding.

In the second half of Cycle 3, IWS would add one or more additional watersheds to evaluate what has been learned from the first three. Information from these additional watersheds will be instrumental for testing modeling approaches developed with the initial IWS basins. This will also allow for additional assessment of the required to model and to support development of a National water-quality modeling framework. Candidate watersheds for the delayed start include, but are not limited to: Delmarva, Peninsula, Neuse River, Apalachicola River, Sacramento River and Yakima River

The new data collection portion of the IWS will be largely conducted in only one of the recommended FY13 starting basins. It is recommended by the Goal 2-IWS Implementation Team that the new data collection portion of the study should be conducted in the basin with substantial sub-surface drainage. This recommendation is based on the fact that sub-surface drainage can have a substantial impact on water-quality. It is one of key hydrologic features in the Mississippi River basin that mobilizes and delivers agricultural chemicals to streams and downstream coastal waters. In addition, the presence of subsurface flow allows for a more comprehensive assessment of groundwater and surface-water

interactions and their role in nutrient processing. Additionally, sample data acquired by IWS field studies will refine groundwater and surface water-interaction information and be useful for calibration and validation of the water-quality models built for this study area.

At this point in time, both the Iowa River Basin (Iowa) and White River Basin (Indiana) are primary candidates for the new data collection portion of the study. However, before a final decision is made, further evaluation of the two basins is needed including vetting of the Goal 2 Implementation Planning Team's recommendation by the NLT and NAWQA and Water, Science Center personnel. Such vetting will include exploration of leveraging opportunities with existing cooperators or other agencies and identifying candidate watersheds for the intensive small watershed needed for the new data collection portion of the study.

Multi-Component Design

The approach of the IWS will be to combine focused efforts in monitoring (both discrete and continuous) and modeling (both simple and complex) for both surface and groundwater and to quantify how each of these types of activities, across a range of spatial scales, will inform the understanding of the hydrology and water quality (Figure 4.5). The study will rely on existing data, but in one watershed new data will be collected to inform important process questions and to support modeling activities.

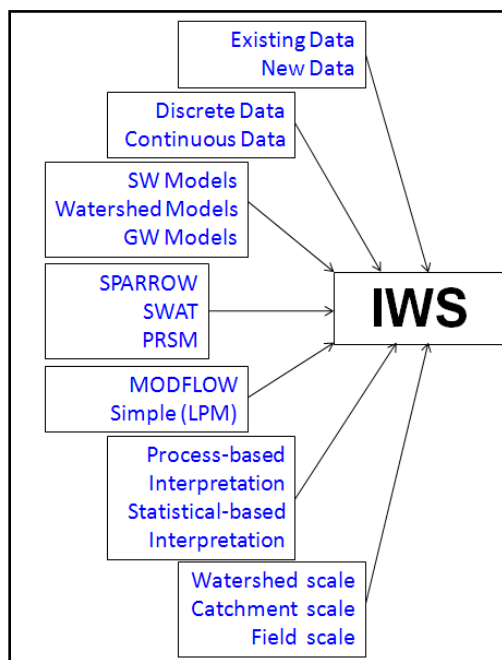


Figure 4.5. Diagram of the various design components that form the Integrated Watershed Study. The study will utilize both existing and new data. The new data that will be collected will both the traditional discrete water samples and a broad array of continuous sensors. Watershed, groundwater and in-stream models will be developed and their results compared. SPARROW, SWAT and PRMS will be the primary watershed models employed in the study. MODFLOW and a simple lumped parameter modeling approach (LPM) will be the primary groundwater models employed in the study. Field observations will employ be process- and statistical-based interpretation. Regression and mixing models will be used in conjunction with the field observations. Components of the IWS will be conducted at the watershed scale (6,000 to about 60,000 km²) catchment scale (10-100 km²) and at the field scale (< 1

km²). These components will be connected through modeling, interpretation of field observations and extrapolation of process understanding.

Modeling Methods

The modeling efforts will be focused on four general domains: watershed, groundwater, aggregated field-scale, and continuous sensor-based. Each will be briefly described below. The various models from here on are referred to as simple and complex models. Simple models are those that can be constructed and executed within a spreadsheet environment. Complex models are derived from coded algorithms which are either compiled to run as stand-alone programs (e.g. the WEPP model written in FORTRAN) or within a software environment like ArcGIS or SASS (SPARROW). The endpoints of the modeling activities include:

1. Acquire an understanding of the strengths and limitations of the individual models over a range of spatial and temporal scales and resolutions.
2. Identify the conceptual and practical connections of the inputs and outputs of the watershed, subsurface, and field-scale models.
3. Make direct comparisons of the outputs (predictions, extrapolations, and so forth) of models that provide similar outputs, and an improved understanding of the reasons for differences in outputs.
4. Develop models that can readily be used for forecasting needs in NAWQA Cycle 3.
5. Develop methods to practically generate field-scale modeling at the scale of intermediate sized watersheds (> 10,000 km²).
6. Incorporate field-scale model outputs into complex watershed model inputs.
7. Develop methods that utilize continuously-monitored water quality data in simple regression-type models and complex models.
8. Development of a prototype National water-quality modeling framework

The modeling efforts will target well-studied water-quality constituents that have large sets of existing data and are incorporated into some or all of the models. Not all models will be able to simulate all the targeted water quality parameters. The parameters, in increasing order of association with the particulate phase, include water (volume and velocity), specific conductance (SC), nitrate, organic carbon, total nitrogen, orthophosphate, total phosphorus, and suspended sediment. Nitrate and other dissolved ions (as measured by specific conductance), have little affinity for the particulate phase and will be largely transported by the water. This is in contrast with suspended sediment which is completely associated with the particle phase. The others parameters are distributed to varying degrees between the aqueous and particulate phases. This range of aqueous/particle distributions will provide information on the ability of the various models to simulate different types of transport processes. Also, this same set of parameters has a range of environmental lifetimes from essentially non-reactive (suspended sediment, SC) to very reactive (nitrate, orthophosphate), and will provide information on the ability of the various models to simulate different rates of transformation processes.

IWS basins recommended for study will possess extensive, existing data sets; these data will be used for model development and calibration. Some sub-sets of the existing data, as well as new data collected over Cycle 3, will be used as a component of the model calibration and verification process.

Watershed modeling

The quantity and quality of water in a stream is partially determined by its interactions with the landscape and partially by climate. Many different types of watershed models have been developed that focus on different processes or different endpoints. Each model was created to be used at a specific

spatial scale (or over a range of scales) and time step. As part of the IWS, a number of different watersheds models will be developed, utilized, and compared over a range of spatial scales from a few to several tens of thousands square kilometers. In this study the value and limitations of each of the modeling approaches at different spatial and time scales will be described. The models that will be used at the watershed scale include SPARROW, SWAT, PRMS and TOPMODEL.

SPARROW models will be applied in two modes in the IWS study areas. The first is an application of the existing steady-state version of SPARROW to estimate mean annual loads, sources, and transport for nutrients, carbon, and suspended sediment in the IWS study areas. Because SPARROW steady-state applications require a broad spatial gradient in the predictor conditions and large numbers of monitoring sites to support parameter estimation, the IWS models will be a nested sub-component within 1:100,000-scale SPARROW models developed for a broader area surrounding the IWS watershed. These broader areas could range in size from smaller areas that include the IWS and adjacent watersheds to larger areas that coincide with the regions (major river basins) being modeled as part of Goal 1 status assessment modeling studies. The IWS models will provide opportunities to evaluate watershed processes and geospatial data that are specific to the IWS study areas, with the potential to enhance the accuracy of the small-scale SPARROW predictions of mean-annual water-quality conditions in the IWS basins. Planned enhancements include the explicit linkage of groundwater properties (flow paths, residence times), as derived from coupling regional- and local-scale groundwater-flow models with the IWS SPARROW model applications. In addition, efforts will be made to include local datasets (e.g., conservation and management practices; USGS/USDA-ARS or NRCS research and monitoring) that extend the resolution and/or content of the available national and regional monitoring and geospatial ancillary data.

Secondly, a dynamic version of SPARROW that is currently being developed for the Potomac River Basin will be used to model seasonal loads and storage in IWS sub-basins and reaches. The source and transport features of the dynamic models will be informed by the initial steady state applications to the IWS for nutrients, carbon, and suspended sediment, including information gained from the coupled groundwater components about the subsurface movement of water and transport of dissolved nutrients and carbon. The explicit modeling of storage in the dynamic SPARROW models is anticipated to provide new insights into the potential lag times in contaminant transport in small to intermediate sized watersheds. The dynamic models will be used to explain historical trends in stressor loads and concentrations (N, P, C, sediment) in relation to changes in hydrology, contaminant sources, and management activities and improve our understanding of in-stream processing of the water-quality constituents. Additional monitoring data, not used in the development of the model, will be used to verify the model results. The new data that will be collected in the IWS, other parts of NAWQA and other USGS, state and local studies will be used for verification of the SPARROW models, as possible. The verified dynamic SPARROW models will be used to forecast future trends in stressor loads and concentrations resulting from different scenarios of future climate and land use changes.

The SWAT model simulates daily fluxes of water and concentration and loads of selected water quality constituents based on hydrologic source and transport equations for major components of the water, nutrient, carbon, and sediment cycles. SWAT models are frequently developed through limited calibration (manual or automated) for a restricted range of hydrologic and water-quality parameter values based on streamflow and watershed characteristics (e.g. peak runoff, recession lag, land use, soils, topography, management practices). SWAT is widely used to assess the impact of agriculture on the environment at a range of scales. The SWAT work within the IWS will be done in conjunction with the USDA/ARS to evaluate comparability between SWAT and SPARROW. The same set of watershed descriptors (GIS coverages) will be used for the SWAT and SPARROW models allowing for a direct

comparison of model outputs. SWAT models will be developed for each of the sub-basins (areas of 100s km²) in the IWS watersheds. The models will be applied in two modes: limited manual calibration (based on default parameters) and automated calibration using the available hydrologic and water-quality data. Figure 4.6 shows the HUC 12 sub-basins (mean area 60 km²) within the White River Basin as an example. The USGS currently operates gages at 47 sub-basins in the range of 1 to 750 km². These 47 sub-basins have the potential for a calibrated version of the SWAT model to be developed. Comparisons can be made for each of these sub-basins between SWAT models for different calibration modes and between the SWAT and SPARROW models. The effect of future climate and land use changes can also be examined with these SWAT models.

The hydrologic models PRMS, TOPMODEL, and SWAT will be applied in each of the IWS areas to provide better understanding of the flow systems; simulation results from each will be compared with the water budgets estimated by the calibrated and uncalibrated SWAT models. PRMS is a hydrologic model that provides an estimate of daily stream discharge based on precipitation and watershed landscape characteristics. TOPMODEL and SWAT provide two different flow generation constructs, with the former being saturation overland flow and the latter being Horton infiltration excess flow.

Groundwater Modeling

MODFLOW/MODPATH is a scalable model that quantifies groundwater flow (direction and velocity) and can also perform particle tracking to map groundwater-flow directions in three dimensions. In the IWS, regional MODFLOW models will be used to help understand large-scale, transient groundwater movement. These regional models will either be developed by the Goal 2 Groundwater Modeling and Mapping Team (Goals 1 and 2) or be existing models built by the USGS Groundwater Resources Program or by Water Science Centers through the Cooperative Water Program. The Groundwater Modeling and Mapping Team is coordinating with the IWS Team to develop new regional models that will be useful to both groups. The IWS will make use of the regional models in support of its needs for forecasting, comparison with the lumped parameter modeling tool (described below), to estimate groundwater-based inputs of nitrate or other dissolved contaminants to surface-water-quality models, generate estimates of water and contaminant transport times from recharge areas to discharge areas, and for process understanding.

Lumped parameter models (LPM), a simpler approach to estimating the distribution of ages of groundwater, will also be developed and tested over the range of hydrologic conditions included in the IWS. This simple approach uses only three parameters (porosity, saturated thickness and recharge rate) to simulate the probability curves of subsurface residence time (flow velocity) across a range of scales. The results of the LPM will be compared to environmental tracer concentrations and to the MODFLOW/ MODPATH results to evaluate the utility and limitations of this simpler approach for obtaining fluxes and loads to streams. For the range of conditions for which the method is viable, it will provide a fast and inexpensive approach to derive groundwater lag times. This will provide valuable input to the watershed models (lag time information that will vary in space), and aid in interpretation of water quality observations (such as nitrate) in streams as a function of land use, fertilizer use and implementation of best management practices (BMPs). This understanding of the groundwater lag time will help set realistic expectations on how quickly improved water-quality might be seen in response to the implementation of BMPs.

Another important component of the subsurface is the unsaturated zone. Water and chemicals must move through this environmental compartment from the land surface to top of the water table. Since water movement in the unsaturated zone is largely vertical, it is linked to specific locations on the

landscape. Therefore, the modeling techniques used for the unsaturated zone are included in the field-scale modeling activities described in the next section.

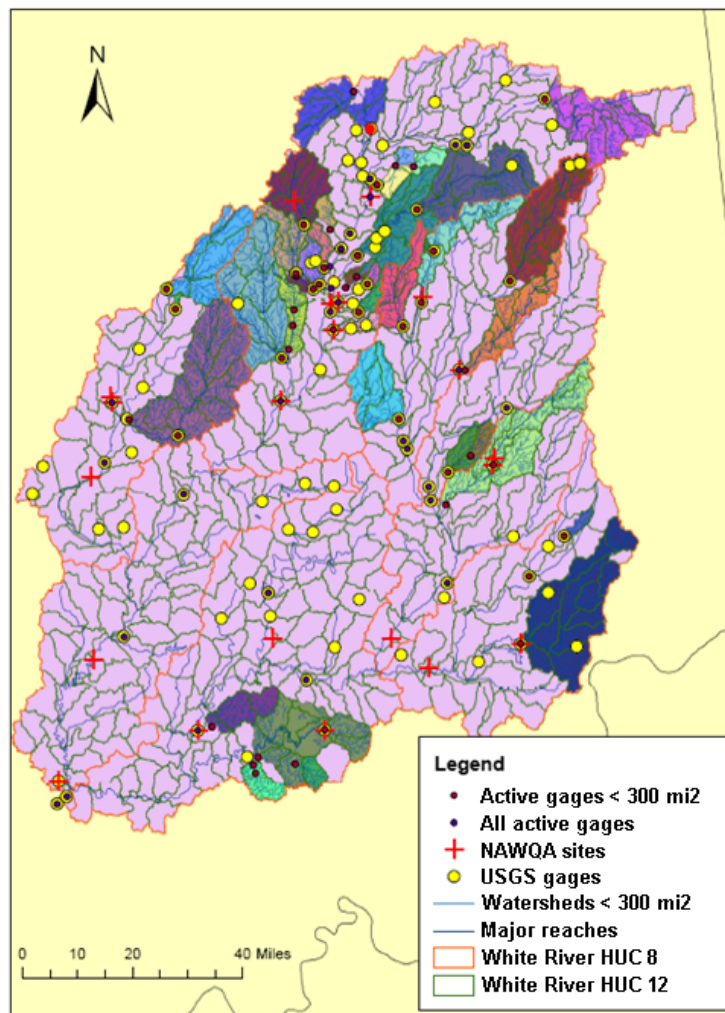


Figure 4.6. Map of White River Basin illustrating the location of gaged sub-basins less than 750 km² (~300 mi²), HUC8 basins (orange outlines), HUC12 basins (green outlines), active stream gages, USGS gages, and NAWQA water quality sites.

Aggregated Field-scale Modeling

WEPP, RUSLE, APEX and other models, many developed by the USDA, can be run at the field scale to develop a spatial understanding of the areas estimated to disproportionately contribute water, sediment and contaminants to a stream. The movement of water and chemicals from land surface to groundwater through the unsaturated zone will also be simulated and quantified at the field scale. Models such as LEACHM, RZWQM and others could be used. The interpretation of the output of the field-scale models will be useful on their own, but they may also be used as data layers in the more complex watersheds models like SPARROW, and perhaps, SWAT.

The availability of high resolution (30 m) geospatial data in recent years have opened up new possibilities for field-scale modeling. "Field scale" in this context refers to any parcel of land from which water flow paths can originate. In agriculture, this might be a cropped field or a pasture. In natural

settings, it might be a meadow or forested hill slope. In developed areas, it might be a small town or part of a larger urban area. Land use (NLCD), topography (LIDAR), satellite images, and (interpolated) soils data are available at this resolution. These data, combined with field-scale models, can be used to better understand the connection between specific areas of the landscape and the hydrologic system.

The information provided by the high-resolution land use data and satellite images can be used to identify field boundaries, location of permanent or semi-permanent management practices (buffer strips, lagoons, terraces, grassed waterways and irrigation) and determine water flow paths from each location to the specific part of the stream. This is information that is obtainable and desired, but currently not available.

The image data, together with the field-scale models, should be able to provide estimates of water flow paths (and their travel times) across the landscape. The direction and travel times of the subsurface flow paths from the subsurface models will supplement this information to provide a complete picture of where the water goes that falls on a part of the landscape. This type of information can be used to help identify the specific areas on the landscape that would most benefit from some type of hydrologic modification (BMP).

Continuous Sensor-based Modeling

Sensors that collect continuous measurements of pH, dissolved oxygen, specific conductance turbidity, and water temperature have been used to monitor water quality for years. New sensors that provide measurements of nitrate, chlorophyll *a*, dissolved organic carbon and other parameters have recently become available for routine use. These continuous sensors, together with measurements from discrete water samples will be used to provide an estimate of parameter uncertainty, and will provide powerful new tools to create dynamic regression-type models for the interpretation, extrapolation, and forecasting of water quality parameters and quantification of the time-varying sources of water to the stream (fast flow, slow flow).

Both existing and new continuous monitoring data sets will be used to develop regression-type models in the form such as:

$$[\text{parameter } X_t] = aQ_t + bSC_t + cDO_t - dTemp_t + e$$

Where parameter X_t is the concentration of the unknown parameter at time t ; Q is discharge; SC is specific conductance; DO is dissolved oxygen; $Temp$ is water temperature; and a , b , c , d and e are fitting parameters. Some of the regression models could be very simple with only one continuous parameter term; others could be more complex like the example above. Each of the regression-type models will probably be site specific, but in aggregation, can be interpreted for a better process understanding.

There has been some work done with the use of specific conductance as a surrogate parameter to help quantify the sources of water to the stream (Sanford and others, 2012). The ability to provide field-based, temporally-varying distributions of water sources to the stream can be used to verify and improve the estimates provided by MODPATH and the lumped parameter models. Finally, the discrete water quality samples, together with the continuous water quality and flow data can be used in end-member mixing analysis (EMMA)-type models to identify sources of various constituents to the streams. This will add insight to the environmental processes controlling the behavior and transport of the constituents that are being modeled by the complex watershed and sub-surface models

New Data Collection Field Studies

Under the Current Funding Scenario, new data collection activities will be primarily focused on a single watershed. New data will be collected to refine and improve models and conceptual understanding developed from existing data. Data collection and analysis will be conducted to track sources of nitrogen, phosphorous, dissolved solids, carbon and sediment, and their respective transport, at multiple spatial and temporal scales within the watershed ranging from small streams (first- to third-order) to large river sites. Additional watersheds or additional contaminants, such as pesticides, could be added to the new data collection activities, if additional funds become available. Figure 4.7 illustrates one possible scenario for the various IWS field components using the White River Basin as an example.

Most river network models simulate steady-state hydrologic conditions (Helton *and others*, 2011), limiting the simulation of most biogeochemical and hydrological processes that drive nutrient and carbon transport. The objectives of the new data collection of study are to:

1. Understand the effects of land use practices on watershed hydrology and water quality of streams, and
2. Determine the dynamic behavior of nutrient, carbon and sediment transport.

Specifically, the timing, delivery and attenuation of nutrients and carbon to small streams will be determined. Small streams will be emphasized in this study because

1. The water quality of small streams is more directly linked with land use practices in the watershed than is the water quality of streams in larger basins,
2. Most nutrients in large streams and rivers originated in small streams (e.g., first- to third-order; Alexander and others, 2007),
3. Denitrification and carbon processing rates are often higher in smaller streams (e.g., Böhlke and others, 2009; Alexander and others, 2009; Vannote and others, 1980) and
4. Small streams are often underrepresented by existing monitoring programs.

Long-term discrete and continuous monitoring is planned over a six-year period to capture the range of hydrologic conditions expected in the study area selected. This will allow for a robust assessment of the effects of hydrologic events on nutrient, carbon and sediment transport. Furthermore, the six-year sampling period will minimize the risk that uncharacteristic weather patterns (e.g., drought) will occur over the entire sampling period. The locations of sites will be determined in close collaboration with IWS team modelers to ensure that the data collected provide the maximum benefit to system understanding and uncertainty reduction. The data collection activities described below include:

1. **Intensive Small Stream Studies** focused on examining sources of nutrient, carbon and sediment and their transport from the land surface and/or aquifer to adjacent headwater streams,
2. **Large River Sampling** to link water quality changes and loads measured in small streams to those in downstream receiving waters and associated ecosystems,
3. **Spatial Synoptic Studies** designed to enhance spatial understanding of sources and transport of nutrients , carbon and sediment in small streams throughout the IWS watershed, and
4. **Longitudinal Synoptic Studies** designed to examine changes in nutrient, carbon and sediment sources and loads from headwater areas to the mouth of the watershed.

The spatial and longitudinal synoptic studies were not included in the draft Cycle 3 Science Plan but were added by the Goal 2-IWS Implementation Planning Team to address important data gaps.

The initial scope and approach for each study are described below, however, design specifics will be developed during the planning year of each study, and some aspects of scope and approach as outlined here could change.

Intensive Small Stream Studies

Six small watersheds will be selected within the larger IWS watershed for this study. Sites that meet the following criteria will be selected:

1. Wadeable first- to third-order streams,
2. Watershed land use within each small stream basin is representative of an important land use practice in the new data collection basin, and
3. As a group, the six sites should capture a gradient of land use practices, including reference conditions (or as close as possible) and hydrologic pathways.

The land use practice gradient may represent an activity (row crop, urban) and/or a technique (e.g., till/no till, type of irrigation) used to perform an activity; the gradient in hydrologic pathways may be represented by, for example, the relative contribution of groundwater to the surface water system.

Surface Water Sampling

Each site will be gaged and sampled monthly and during selected storm events; a total of 16 samples per year will be collected. Sampling will take place for six years. Analytes will include field parameters, major ions, nutrients, dissolved organic carbon (DOC) quantity and chemical quality (as determined by spectral measurements), suspended sediment and stable isotope analysis of water (Table 4.2). A tritium sample will be archived during each sampling event. Samples will be collected for age dating tracers (SF_6 , tritium-helium) during base flow once per year.

Continuous monitoring of DO, pH, specific conductance, temperature, chlorophyll *a*, turbidity, fluorescent dissolved organic matter (FDOM) and nitrate will be conducted at each site. DO and pH data will be used to determine whole stream production and respiration rates. Specific conductance data will be used for hydrograph separation and as an indicator of agricultural impacts. The continuous chlorophyll *a* data will provide a proxy for rates of primary productivity and will supplement the periphyton biomass sampling effort described below. Turbidity and FDOM will be the primary surrogates for suspended sediment concentration and DOC, respectively. FDOM data may also be employed as an indicator of riparian zone flow paths (Brown *and others*, 1999). A high-ranging optical-backscatter sensor will be used if maximum suspended-sediment concentrations exceed 2,000 mg/L in the watershed. The continuous FDOM data will be complemented with discrete sampling. Laboratory fluorescence analysis of discrete samples will be conducted by the Organic Carbon Research Group (USGS, Sacramento, CA) and will provide detailed information on how the source and chemical quality (e.g. redox state, availability of carbon for biologic processing) of the DOC changes as a function of changing hydrologic flow paths and/or land use. Additionally, this sampling effort will establish a diverse library of organic carbon quality data that can be used to identify potential carbon sources to streams.

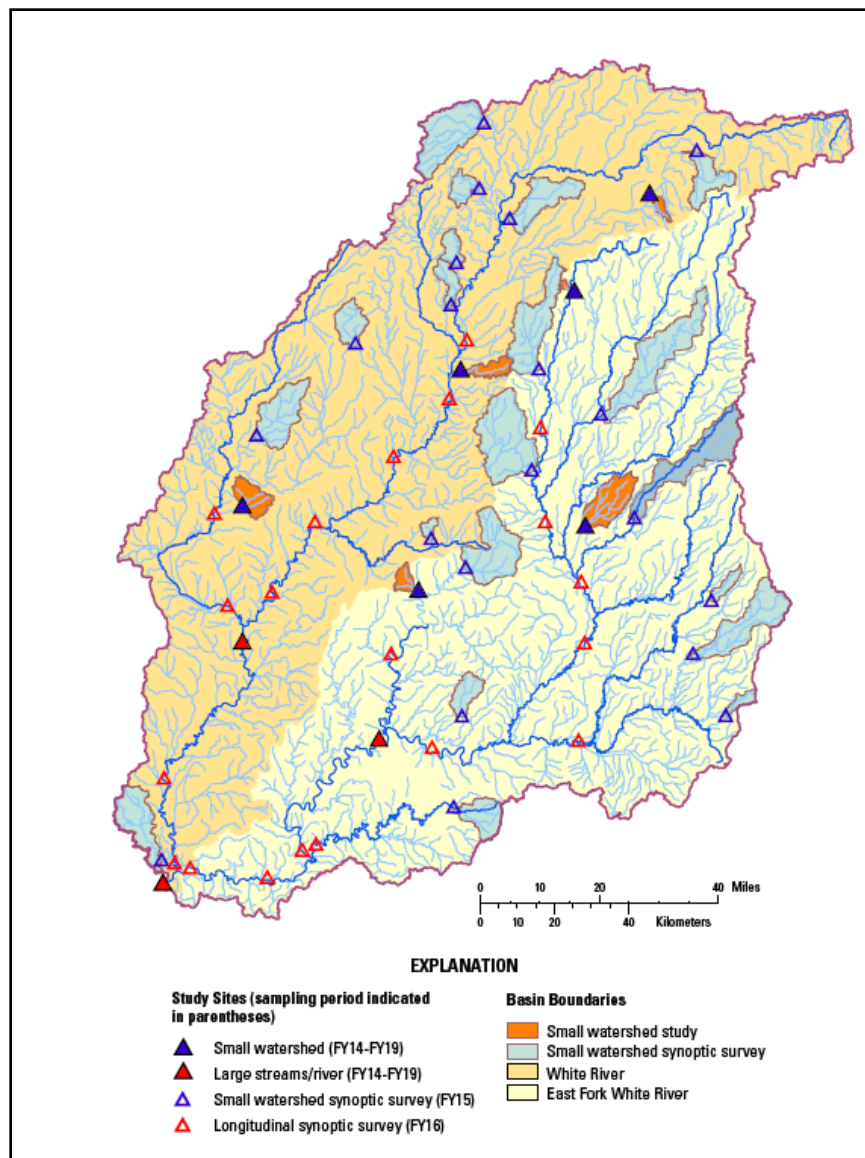


Figure 4.7 Map of one possible scenario for the various IWS field components using the White River watershed as an example. Within the larger White river watershed, six small watersheds (colored orange) will be studied over six years for process understanding and as validated areas for the models. Each of these stream sites will have a gage (filled blue triangles). In addition, a few the larger stream sites will also have new water quality data collection and a gage (solid red triangles). There will be also short term (one year) synoptic studies in a larger number of small watersheds (colored blue) and another short-term synoptic study between small watershed and large river sites (open orange triangles). There will not always be a gage at the synoptic sites although stage variations will be monitored using pressure transducers.

Table 4.2. Surface-water sampling and analysis plan for each study.

Study Component	Sites	Duration	Discharge Measurement	Continuous Monitoring	Sampling Frequency ¹
Small Watershed Study	6	6 years	Gaged	Nitrate, DO, pH, SC, Temp, FDOM, Turbidity	16 per year
Spatial and Longitudinal Synoptics	40 (20 per study)	1 year	Transducer	SC, Temp, Turbidity	4 in one year
Larger Streams/Rivers	3	6 years	Gaged	Nitrate, DO, pH, SC, Temp, FDOM, Turbidity, Chlorophyll <i>a</i>	16 per year

¹ Analytes: nutrients (Schedule 2711), major ions (Schedule 2701), suspended sediment, DOC, age tracers (Schedule 1173) and source tracers

Streambed Sampling

Six dedicated (permanent) streambed piezometers will be installed at each surface water site using a drive point system (AMS, 2012) to help quantify nutrient and carbon inputs from groundwater and to assess hyporheic exchange. Streambed samples will be collected from each drive point once per year during base flow. Samples will be analyzed for field parameters, major ions, nutrients and DOC every year; SF₆ and tritium-helium samples will be collected the first year only. A passive diffusion sampler (Gardner and Solomon, 2009) will be deployed adjacent to each drive point and will be used to collect samples for noble gases and dissolved excess nitrogen and argon. These samples will be analyzed at the USGS Noble Gas Laboratory in Denver.

Well Installation and Groundwater Sampling

Monitoring well clusters (three wells per cluster screened at different depths) will be installed in the recharge and discharge areas of three of the watersheds selected for a small stream study. A total of 18 wells will be installed. Wells will be sampled once per year for field parameters, major ions, nutrients and DOC. Samples will be collected and analyzed for SF₆ and tritium-helium samples only during the first year. Continuous monitors (head, conductance, temperature, dissolved oxygen and FDOM) will be installed in the shallow monitoring well in the discharge area of each of the three sites where monitoring wells are installed.

Sediment Surveys

Sediment surveys will be conducted in combination with sediment fingerprinting work to characterize the primary sources and sinks of fine-grained (<.063 mm) sediment in the headwaters of the new data collection watersheds to better understand the degree and time-scales at which management or landscape activities may affect downstream suspended sediment concentrations and loads. Sediment surveys will be comprised of many single-point measurements of erosional and depositional processes on streambeds, stream banks, floodplains, and upland areas. In each small watershed, data will be

collected over a period of time to derive rates of erosion and deposition. Cross sections to record channel morphologic changes (bed and bank) will be surveyed at the beginning of the study and in response to high-flow conditions (such as a bankfull flood). Irrespective of flows, surveys will be conducted a minimum of every other year. Approximately 10 cross sections will be surveyed per small watershed. Bank pin measurements to record stream bank erosion will be made at the surveyed cross sections and 10 other reaches. Measurements will be made twice a year but can be made more frequently in response to large storm events. Clay pads which quantify floodplain deposition will be located at the surveyed cross sections and read at the same time as the bank pins.

Sediment fingerprinting

Sediment fingerprinting work will be done in combination with surveying work to establish converging lines of evidence regarding the primary sources and sinks of suspended-sediment in headwater basins. The general steps include quantifying surface erosion rates, identification of geochemical tracers that distinguish varied sources of sediment, collection of these tracers in suspended-sediment samples, and then statistical analysis to quantify the contribution of sediment sources.

In FY13 and FY14, a library of sediment sources will be developed and upland erosion/ deposition rates will be quantified across the gradient of land use/land management. Beginning in FY14 suspended material will be analyzed for various source types. The current plan is to collect suspended material from passive sediment samplers, streambeds, and floodplains from all 6 headwater basins, with some possible data collection at downstream points in the watershed. Approximately 10 samples per site will be collected during the study period (collected depending upon flow condition) with a total of at least 50 samples collected to establish a source library. The number of storm events sampled for source analysis may vary from year to year. Five in-channel sediment storage sites will also be sampled 4 times per year per watershed. The sediments will be analyzed for Cesium-137, Lead-210, and possibly other radionuclides, and likely trace elements and metals. Analyte selection will be refined during the planning stage (FY13). These data are then extrapolated by land use type and Strahler Order to estimate the sediment budget of each respective headwater basin. While most of this activity will be undertaken at headwater basins, some will be done downstream in the watershed to help characterize processes estimated using existing data analysis.

Periphyton Biomass

The spatial and temporal variability in total algal accrual, rate of accrual, and degradation will be determined to provide insight into how gross properties of algal communities respond to environmental stresses associated with nutrient enrichment and sediment movement. Periphyton samplers will be placed at each study site twice per year to coincide with contrasting hydrologic conditions associated with natural or anthropogenic events — and to account for seasonal variations in riparian vegetative cover. During each sampling event it is anticipated that ten periphyton samplers will be placed at each study site. Two samplers will be distributed at each of 5 different locations within the study reach based on study area dimensions, spatial characteristics of local groundwater-surface water exchange, coincidence of sediment monitoring, and adjacent land-use/land-cover characteristics. Each sampler contains 16-20 glass slides. Samplers will be left in place for approximately 2.5 weeks (Biggs and Kilroy 2000). To assess rates of algal accrual, a subset of slides (4-5/sampler) will be removed every 4 days and prepared for analysis of algal pigments using local or NWQL facilities (Eaton *and others*, 1995; Moulton *and others*, 2002;). Comparisons of total algal accrual will be based on chlorophyll *a* concentrations at the end of the colonization period. Ratios of chlorophyll *a* and pheophytin *a* determined at the end of the colonization period will provide an estimate of relative disturbance (Peterson *and others*, 1990).

To meaningfully identify environmental conditions that influence any observed correlations between gross properties of algal communities and nutrient/carbon transport it is necessary to quantify habitat characteristics that are likely to influence the abundance and distribution of algal communities. The amount of incident solar radiation will be determined once at each sampling location during initial placement of samplers using a solar pathfinder. These measurements will provide estimates of riparian vegetative cover, amount of shading and incident solar radiation on a daily, monthly, and annual basis. In addition, a systematic assessment of macroalgae and macrophyte cover throughout the study reach will be conducted prior to periphyton sampling (Biggs and Kilroy 2000). Assessments of stream channel morphology, habitat-specific flow velocity, and substrate characteristics will be performed as necessary (modifications to Fitzpatrick and others 1998) to provide information on key physical determinants of nutrient and sediment transport and retention, as well as primary production.

Denitrification and Nitrification Rate Determinations

Denitrification and nitrification rates will be determined using benthic chambers (e.g., Smith and others, 2009). Bromide (as a conservative tracer) and $^{15}\text{NO}_3^-$ (or $^{15}\text{NH}_4^+$) will be added to plastic cylindrical or dome shaped chambers that are positioned in the stream bed. Stream water and sediment samples will then be collected for ^{15}N content before and after a 24 h incubation period. NO_3^- loss rates will be determined by calculating the dilution-corrected loss of ^{15}N labeled NO_3^- or NH_4^+ over time. Denitrification rates will be determined in $^{15}\text{NO}_3^-$ addition experiments by measuring the accumulation of $^{15}\text{N}_2$, while nitrification rates will be determined in $^{15}\text{NH}_4^+$ addition experiments by measuring increases in $^{15}\text{N}_2$ and $^{15}\text{NO}_3^-$. Samples will be shipped to either the USGS Isotope Tracers Project laboratory in Menlo Park, CA or the USGS Reston Stable Isotope Laboratory. Six chambers will be installed at each of the six small watershed studies in both the spring and summer for a total of 72 total installations.

Assimilatory N demand will also be calculated from diel nitrate variation (if present) based on the integrated difference between an estimated nitrate baseline (e.g., from pre-dawn peak values) and diel variations (Heffernan and Cohen, 2010). Denitrification rates may also be determined from the diel nitrate data provided estimates of heterotrophic N assimilation from metabolism measurements and nitrate inputs can be made.

Carbon serves as an electron donor for the process of denitrification. Therefore, rates of sediment denitrification are dependent on the amount and chemical quality (redox state and/or lability) of organic carbon (Baker and Vervier, 2004; Barnes *and others*, 2012). Stream water samples and sediment extracts will be analyzed for carbon quantity and quality to explore the relation between carbon quality and quantity and denitrification rates.

Reach Scale Mass Balance and Reactive Transport

A reach scale mass balance and reactive transport study will be conducted during the seasonal low-flow period at two of the small watershed study sites: a groundwater-dominated stream and a quick-flow dominated stream. A 72-hour injection will be conducted at each site to facilitate mass balance calculations and to estimate the size of the transient storage zone. The injectate will consist of sodium bromide (Br^-) mixed with ~600 L of stream water (final concentration $160\text{--}310 \text{ g Br}^- \text{ L}^{-1}$) and will be pumped into the stream at $\sim 0.1 \text{ L min}^{-1}$ using a rotary-drive, positive-displacement piston pump controlled by a data logger. Bromide will be sampled at the base of a mixing reach and at 2-3 downstream locations (e.g., 100-400 m apart). Ground-water discharge will be calculated by tracer dilution between upstream and downstream stations. A reach-scale NO_3^- and organic carbon quantity and quality mass balance will be determined at each stream during the 72-h tracer injection under

background nutrient conditions. The gross NO_3^- and carbon flux from ground water ($Q_{\text{gw}} * C_{\text{gw}}$) will be calculated as ground-water discharge times the median ground-water NO_3^- and carbon concentrations. The median ground-water NO_3^- and carbon concentrations will be estimated from small-diameter drive points deployed throughout the reach extending 0.1-1.0 m below the bed (10–30 samples) and from near-stream well data. Within reach net NO_3^- and carbon flux ($(Q_2 * C_2) - (Q_1 * C_1)$) will be estimated from the upstream-downstream change in NO_3^- and carbon mass. Nitrate and carbon retention in ground-water discharge will be estimated by determining the difference between gross ground-water NO_3^- and carbon input and the net NO_3^- and carbon flux from the bed to the water.

Characterization and modeling of the hydrologic conditions using Br^- data will allow for prediction of anticipated downstream NO_3^- and carbon concentrations in the absence of degradation and/or production of these constituents (i.e. conservative transport). Differences between expected concentrations and measured concentrations of NO_3^- or carbon can be attributed to production/degradation processes occurring within the reach. Such differences can then be used to develop reach scale reactive transport models that include terms for the production and degradation of NO_3^- and carbon quantity and quality. Such terms may include rates of nitrification/denitrification (described above) and estimates of primary production from in situ chlorophyll *a* sensors and periphyton samples.

Large Stream or River Sampling

Larger streams and rivers will also be studied to examine how nutrient loads and processes change as a function of hydrologic position within the watershed. Understanding how changing water quality conditions in small streams are linked to water quality conditions at downstream large river sites is important for identifying the spatial extent of impacts driven by land use, climate and in-stream processes. Such an understanding provides a link between management activities in small basins and water quality conditions at downstream sites. Three large streams or rivers in the watershed (including the outlet) will be sampled 16 times per year for a period of six years (Table 4.2, Figure 4.7). At least two of these sites will be part of the NAWQA National Fixed-Site Network. Samples will be analyzed for the same constituents as the small stream studies (Table 4.2). Similarly, continuous monitoring at the large river sites (DO, pH, specific conductance, temperature, chlorophyll *a*, turbidity, FDOM, and nitrate) will be the same as the small stream sites. Nutrient, carbon and sediment transport pathways and processes will be explored using the monitoring data collected at these sites (e.g., stream metabolism, hydrograph separation) and in conjunction with the modeling activities. Inclusion of the large stream and river sites will allow for comparison of changes measured in the small watersheds with any changes detected at the watershed outlet and will provide data to support the longitudinal synoptic studies described below. It is anticipated that a regional groundwater flow path study (funded by Goal 2 GW) will be co-located with one of the watersheds associated with large stream or river sites.

Spatial Synoptic Study

The small watershed studies will provide detailed temporal information on the pathways and processes affecting nutrient, carbon and sediment transport in agricultural basins. The objective of the spatial synoptic study is to determine the variability of nutrient, carbon and sediment concentrations, pathways and processes across the landscape. The spatial synoptic study will extend the findings from the small fixed watershed studies by utilizing relations between constituents and surrogates developed in the small watershed studies (Soulsby *and others*, 2004). These data will aid in understanding the spatial variability amongst various land uses, soil properties, and other spatial characteristics. They will provide a spatially distributed dataset to aid in model verification.

Surface water samples will be collected from each site four times during the study year to coincide with critical time periods (e.g., base flow, storm events, timing of fertilizer applications, Figure 4.7). Analytes will be the same as described above for the small watershed studies (Table 4.2). Continuous monitoring will be limited to temperature, conductance, turbidity and hydraulic head (from pressure transducer). One streambed groundwater sample will be collected at each site (Table 4.3). Sites selected for this study will be similar in size as the small watershed study sites and will cover a representative range of land use practices. One spatial synoptic study will be conducted in FY15.

Table 4.3. Groundwater sampling and analysis plan for each study.

Study Component	Upland and Riparian	Streambed Sampling	Duration	Continuous Monitors	Sampling Frequency ¹
Small Watershed Study	18 total, two well nests in each of three watersheds; three wells per nest.	36 total; Six sites in each of six watersheds	6 years	Level, SC, Temp, FDOM (three shallow riparian sites)	Once per year
Spatial and Longitudinal Synoptics	None	40 (20 per study)	1 year	None	Once per year
Larger Streams/Rivers	Flow System Study from Goal 2 GW	None	Determined by NAWQA Goal 2 GW	Determined by NAWQA Goal 2 GW	Determined by NAWQA Goal 2 GW

¹ Analytes: Every sampling - nutrients, major ions, DOC. First year only: age dating and source tracers.

Longitudinal Synoptic Study

The objective of the longitudinal study is to connect the findings at the small watershed scale with those observed at the large stream and river sites. Specifically, this study will address how inputs, pathways and processes change as a function of position within the watershed. Processes that are expected to vary as a function of longitudinal position will be examined at longitudinal study sites. For example, it has been suggested that riparian buffers in higher order streams are more effective at removing nitrate than lower-order streams (Montreuil *and others*, 2010). Similarly, nitrogen loss from streams may vary markedly as a function of longitudinal position in the watershed as a result of changes in nitrate concentration and/or stream depth (Mulholland *and others*, 2008; Böhlke *and others*, 2009). These data will aid in understanding the spatial variability along the river as a function of increasing flow. They will provide a longitudinally-distributed dataset to aid in model verification to help capture the variability due to source and sink processes within the stream network.

One longitudinal synoptic study will be conducted in FY16. Sites selected for this study will be spread longitudinally from a small watershed study site to the large river site (Figure 4.7). Sample analytes, frequency and continuous monitoring will be the same as the spatial synoptic study (Table 4.2). The following describes a 1-year synoptic study that could be used to assess the flux and sources of sediment, carbon and nutrients longitudinally through the watershed. Under the assumption that there

are multiple gaged sites staged throughout the study basin, continuous monitors would be installed at existing gaged sites along a longitudinal gradient to monitor sediment (and likely other parameters) transport in the watershed. Because existing sites in the watershed will already have developed relations between turbidity and suspended-sediment concentrations, one would require minimal discrete sampling to get accurate estimates of sediment flux at other gaged-locations within the watershed. Turbidity sensors could be deployed at existing stream gage locations for a 10-month period (approx. February to November) to quantify how sediment and other constituents move from headwater to downstream basins during different storm events. Additionally, total nitrogen and phosphorus in sediment, as well as previously identified indicators of sediment sources will be sampled from floodplains and streambeds using passive samplers to characterize sediment-bound nutrient transport and sediment sources from headwater to downstream sites.

Recommended IWS Staff

The recommended staff for the IWS consist of both National and local WSC components. There are diverse skills needed amongst the member of the IWS — specific requirements include expertise in field sampling, data organization, GIS expertise, data analysis, interpretation, and modeling. The proposed staffing plan for the IWS Team is presented in Table 4.4. The recommended staffing plan creates a National team of scientists that will be together for the duration of Cycle 3 with participation of scientists and technicians from local Water Science Centers who will assist with new data collection, organization of existing data, data interpretation and who will also be asked to provide the National IWS Team with insights into how hydrologic processes work locally in the selected IWS. Each IWS will require the combined efforts of the National IWS Team and local WSC staff. Each IWS will have a WSC member (0.5 FTE for 2 years) to help compile and organize existing water and water quality data. In addition, the National IWS will have a team member located in the local WSC. This person will serve two roles. He or she will be the liaison between the National IWS team and the WSC and local stakeholders and will be responsible for making sure the IWS is producing information relevant to local issues to the extent possible. This person will also be expected to serve a scientific role on the National IWS team, generally as an expert in modeling or another needed skill set. The exact scientific contributions will be determined after the locations of the IWSs are chosen and the skill sets of the WSC staff in those locations are evaluated.

The long-term field and modeling resources, developed by the IWS, will provide a platform for other scientists to conduct investigations. Interactions with scientists from other components of NAWQA, NWQL, NRP, WSC and other USGS programs will be encouraged. Many researchers have already expressed interest in working with the IWS and more will be identified and encouraged to participate. Specialty studies with other Federal agencies, especially the USDA-ARS, will be developed. One specific area that has been identified for collaboration between USGS and USDA-ARS scientists is comparison of the model outputs between SWAT and SPARROW models at different scales. Collaboration in the field studies is planned with other components of NAWQA, the local Water Science Center, and the USGS Upper Mississippi Environmental Sciences Center. Additional collaboration will be sought from universities, Federal, State and local agencies as determined by IWS scientists working with local WSC scientists and managers.

Table 4.4. List of recommended staff for National and Local Water Science Center teams for the Integrated Watershed Studies.

Position	Grade(s)	FTE	Duration	Position Description	Team Type
Chief, National Integrated Watershed Study Team	GS-14	1.0 FTE	FY13-FY22	Supervises Surface Water Assessment Teams; provides technical guidance and oversees data collection, modeling, and product development activities carried out by the team.	National Team
IWS Surface Water Team					
Chemist/Hydrologist	GS-13/14	0.25 FTE	FY13-FY22	Chemist/hydrologist with experience in planning, conducting and interpreting field studies of surface-water quality. Provides guidance to other chemists and modelers on Team. Conducts data analysis and writes reports.	National Team
Modeler (SPARROW)	GS-13/14	1.0 FTE	FY13-FY22	Hydrologists or statistician with experience with SPARROW modeling. Provides guidance to other modelers on Team. Conducts research on and evaluates modeling tool, develops models and writes reports.	National Team
Modeler (SWAT-)	GS-12/13/14	1.0 FTE	FY13-FY22	Hydrologists or statistician with experience with SWAT and/or PRMS modeling. Provides guidance to other modelers on Team. Conducts research on and evaluates modeling tool, develops models and writes reports.	National Team
Ecologist/Chemist/Hydrologist	GS-12/13	1.0 FTE	FY13-FY22	Chemist/hydrologist with experience in conducting and interpreting field studies of nutrient cycling and transport. Conducts data analysis and writes reports.	National Team
Hydrologist-Sediment Transport	GS-11/12/13	1.0 FTE	FY13-FY22	Chemist/hydrologist with experience in conducting and interpreting field studies of sediment sources and transport. Conducts data analysis and writes reports.	National Team
Modeler (SPARROW)	GS-11/12/13	0.5 FTE	FY13-FY14	Hydrologists or statistician with experience with SPARROW modeling. Provides analytical and writing support to lead authors of reports.	National Team
IWS Groundwater Studies Team					
Chemist/Hydrologist	GS-13/14	1.0 FTE	FY13-FY22	Chemist/hydrologist with experience in planning, conducting and interpreting field studies of groundwater quality. Provides guidance to other chemists and modelers on Team. Conducts data analysis and writes reports.	National Team
Modeler (MODFLOW)	GS-12/13/14	1.0 FTE	FY17-FY22	Hydrologists or statistician with experience with MODFLOW/MODPATH modeling. Provides guidance to other modelers on Team. Conducts research on and evaluates modeling tool, develops models and writes reports.	National Team
GIS or Modeler IWS/WSC Liaison (Existing data IWS)	GS-11/12/13	0.66 FTE	FY13-FY22	Hydrologist with experience with GIS or MODFLOW modeling. Acts as liaison between IWS and WCS/local cooperators. Provides analytical and writing support to others on Team.	Local WSC
GIS or Modeler IWS/WSC Liaison (Existing data IWS)	GS-11/12/13	0.66 FTE	FY13-FY22	Hydrologist with experience with GIS or MODFLOW modeling. Acts as liaison between IWS and WCS/local cooperators. Provides analytical and writing support to others on Team.	Local WSC
IWS GIS and Ancillary Data Team					
GIS Analyst/Hydrologist (Lead)	GS-13/14	1.0 FTE	FY13-FY22	GIS analyst with extensive experience in developing and interpreting spatial datasets. Provides guidance to other GIS analyst on Team. Conducts data analysis and writes reports.	National Team

GIS Analyst/Hydrologist (New data IWS)	GS-11/12/13	1.0 FTE	FY13-FY22	Hydrologist with experience with GIS or modeling. Acts as liaison between IWS and WCS/local cooperators. Provides analytical and writing support to others on Team.	Local WSC
Modeler (Field-scale)	GS-11/12	1.0 FTE	FY13-FY22	Hydrologist with experience with field-scale modeling, manipulating large QW and hydrologic data sets and GIS skills. Conducts data analysis and writes reports.	National Team
Hydrologist (data and analysis support): IWS A	GS-9/11/12	0.5 FTE	FY13-FY14	Hydrologist with experience manipulating large QW and hydrologic data sets who also has GIS skills.	Local WSC
Hydrologist (data and analysis support): IWS B	GS-11/12	0.5 FTE	FY13-FY14	Hydrologist with experience manipulating large QW and hydrologic data sets who also has GIS skills.	Local WSC
Hydrologist (data and analysis support): IWS C	GS-11/12	0.5 FTE	FY13-FY14	Hydrologist with experience manipulating large QW and hydrologic data sets who also has GIS skills.	Local WSC

Schedule of IWS Activities

The timeline of activities for the IWS is summarized in the Table 4-5. The activities in FY13 include organization of existing environmental data, organization of existing GIS data, initial model development, production of initial interpretations of existing data, and installation of gaging and monitoring equipment at new field sites. In FY14, data collection will begin at the new field sites as well as tests on how the various models can be used in conjunction with each other. By FY15, the models will be mature enough to begin to develop spatial interpolations and direct comparisons of the model outputs. By FY18, forecasting, using scenarios developed in conjunction with the HST, will be included. In FY19, collection of new water-quality data at the small stream sites will end. Throughout the duration of Cycle 3, data will be interpreted and reports written to improve our understanding of critical hydrologic and environmental processes and to improve hydrologic and water-quality models. The tools and understanding developed as part of this effort will be used, in conjunction with the Center for Integrated Data Analytics (CIDA), to build a prototype of a National decision-support tool that will incorporate the advances made by the IWS.

Table 4-5 Timeline of activities for the Integrated Watershed Study

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
New data collection watershed										
Organize existing data										
Interpretation of existing data										
Create SW models										
Create MODFLOW model										
Create field-scale models										
Modeling scenarios: process										
Modeling scenarios: predictive										
Small watershed study	P	DC	DC	DC	DC	DC	DC			
Process studies		P	DC	DC						
Spatial and longitudinal syn.		P	DC	DC						
Large stream and rivers	P	DC	DC	DC	DC	DC	DC			
Groundwater sampling	P	I	DC	DC						
Age-dating synoptic	PDC		DC							
Existing data only										
Organize existing data										
Interpretation of existing data										
Create SW models										
Create MODFLOW model										
Create field-scale models										
Modeling scenarios :process										
Modeling scenarios: predictive										
Begin delayed start IWS(s)										

Color Code for Cells		
	High intensity year	
	Lower intensity year	
P	Planning	
I	Installation of equipment	
DC	Data collection	

Products

The Goal 2-IWS Implementation Team has identified a number of potential product-types that could come from this study, which are briefly described below. A few examples for each type are presented below and more examples are given on the Excel file tab J-1 Products.

- 1. Process Understanding Studies** will yield journal articles for USGS reports that focus on advances in our understanding of a specific topic:

Environmental processes:

- Denitrification and carbon production/degradation rates as a function of biologic activity in small watersheds across a land use gradient
- Estimating water and nutrient lag times using multiple lines of evidence: Age-dating, particle tracking and lumped parameter models.
- Identification of land use and biologic controls on trends in concentrations and loads of nutrients and organic carbon in small watersheds

Model advancements

- Use of EMMA and continuous data to enhance process understanding (i.e. flow sources, primary productivity, nutrient processing, source area identification)
- Comparison model findings between dynamic SPARROW and SWAT/PRMS
- Improved understanding, incorporated into the dynamic SPARROW models and the regional SPARROW models, of how water-quality conditions (N, P, C, and SS) respond to changes in land use, chemical use, management, and climate

Monitoring advancements

- Load estimation methods for sediment derived from continuous turbidity measurements
- New techniques that utilize continuous SC data collected for hydrologic and biogeochemical processes
- Use of sediment fingerprinting and sediment budget emphasizing natural (i.e. climate change) versus anthropogenic factors.

2. Databases will be in the form of water-quality data, GIS coverages and chemical libraries.

- Data reports of new data that are collected, as well as organized existing data that will be used in the development, calibration and verification of the models.
- A library database of spectral characteristics of DOC from various sources and surface waters would be developed.
- GIS coverages based on field-scale models (RUSLE, WEPP such as water budgets and soil erosion) will be developed to be used for mapping and as spatial layers for other modeling tools.

3. Synthesis/Policy Reports will be in the form of Circulars and other USGS series reports.

- Hydrologic processes and land use conditions influencing water quality in tributaries of the Mississippi River
- Assessing stream vulnerability to legacy nutrients using watershed characteristics.
- Lessons learned from the IWS toward a National watershed-based water-quality framework

4. Decision-Support Systems are web-based tools and products that help visual the data and modeling results for managers and the public. These will be built on the foundation that has been established during NAWQA Cycle 2. The IWS focuses on a few demonstration watersheds where model-based tools will be developed, looking forward to a National WQ modeling framework that will be put into place in NAWQA Cycle 4. This framework would incorporate models that scale from field-scale to the Nation and will encompass the landscape, streams, ground water and their connections. Such a framework would serve as the basis for local-decision making and aid decisions to be made at question appropriate scales. It will help set realistic expectations of when implementation of management practices may result in water-quality improvements and be used to forecast how water-quality conditions will respond in

response to hypothetical changes in land use, water use, or climate. This framework could be used to both inform WQ managers and the general public (at the field to catchment to watershed scales).

The entryway for this tool would be a standard internet mapping tool that is currently available (for example, Google maps). The user would use this mapping tool to define an area of interest such as a field. The models and databases behind the framework tool could then provide information on:

- soil type, water budget, land cover, slope, existing BMPs, climate, watershed name,
- time for surface water movement from the field to the local stream, major river and coast,
- time for groundwater movement from the field to the local stream, major river and coast,
- estimated loads of N, P, C, and sediment coming from the field under various land uses, particularly environmentally-vulnerable area within the field (i.e., erosion),
- summary of observed water quality data (if any),
- estimated water quantity and water quality data in run-off or recharge,
- photographs,
- presence or irrigation or drainage networks.

The DSS could also ask the user if the presented data is correct or if information on subsurface drainage or other landscape changes is available and should be added to the simulations. Ideally any model or observation that can be simulated at the appropriate scale (field, catchment, or watershed), could be included in the DSS.

The DSS would also allow users to simulate past, present and future water-quality conditions based on watershed characteristics, selected climate or landscape change scenarios, and available water-quality data. The IWS, in collaboration with other Cycle 3 components, will help develop and test the modeling techniques, ancillary data, and information technology requirements needed to support the overall DSS, explore its limitations, and contribute tools that will support the completed DSS as the technology of modeling and remote-sensing improves over the upcoming decade.

Budget

The proposed multi-year budget for the IWS is summarized in the Table 4-6 and given in more detail on the Excel file tab-1. This budget is presented by year with the new data collection portion separated out from the rest. The budget that is presented almost conforms to the multi-year constraints given by the current funding scenario targets for the IWS.

Table 4.6. Summary of proposed budget for Integrated Watershed Study (in millions of dollars).

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Target	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	40.00
Target with inflation	4.00	3.84	3.69	3.54	3.40	3.26	3.13	3.01	2.89	2.77	33.53
Field Costs	0.50	0.86	1.41	1.36	1.31	0.76	0.76	0.29	0.29	0.29	7.82
Staff Costs	3.23	3.23	2.79	2.74	2.96	2.96	2.85	2.85	2.85	2.85	29.31
Total Costs	3.73	4.09	4.20	4.10	4.27	3.72	3.61	3.14	3.14	3.14	37.13
Annual over/under	-0.28	0.25	0.51	0.56	0.87	0.46	0.48	0.13	0.25	0.37	3.60
Field (% of budget)	12.4	22.4	38.2	38.4	38.5	23.3	24.2	9.7	10.1	10.5	
Staff (% of budget)	87.6	77.6	61.8	61.6	61.5	76.7	75.8	90.3	89.9	89.5	

Chapter 5-Recommendations for Effects of Stressors on Stream Ecosystems Studies

Introduction

During Cycle I, stream ecology studies were focused primarily on study-unit level assessments and trends. In Cycle II, new stream ecology studies were the focus of two topical studies. The Effects of Urbanization on Stream Ecosystems study examined the response of streams to urban land use gradients (Brown and others 2009, Cuffney and Falcone 2009, Cuffney and others 2010). The Effects of Nutrients on Agricultural Stream Ecosystems study examined the influence of nutrient gradients on agricultural streams (Duff and others 2008, Frankforter and others 2009, Munn and others 2010). Along with these efforts, there was substantial progress nationally in addressing ecological issues on biological condition (Carlisle and Meador 2007), streamflow alteration (Konrad and others 2008, Kennen and others 2009, Carlisle and others 2010), pesticide effects on stream biota (Yuan and others 2009), watershed predictive models and stream invertebrates (Waite and others 2010), and ecological trends (Miller and others 2011, Kennen and others 2012).

One of the early activities of the C3PT was to survey NAWQA stakeholders with regard to water quality issues they felt were most pressing for their programs in the next decade. Results from this survey indicated that the effects of stressors on aquatic ecosystems was one of the top three issues, with emerging contaminants and climate the other two (Rowe and others, 2010). This increased interest in the influence of stressors on stream systems is driven by a number of factors. First, the Clean Water Act identifies biological integrity as a key part of water quality; consequently, regulatory agencies and resource managers are incorporating biological endpoints into their water quality programs for assessing present condition and for tracking changes due to management practices. Second, biological processes are important determinants of water-quality conditions in that they influence both the chemical and physical properties of surface waters. Last, agencies are under increasing pressure to show that policy and management practices are achieving their desired goals. This is becoming increasingly important given the growing number of competing resource issues relative to available funds.

While there are numerous natural and anthropogenic stressors, the stressors most often identified as concerns to resource managers include nutrients, streamflow alteration, sediment, and contaminants. Hence these stressors were selected for special emphasis in assessment activities and interpretative studies included in the Science Plan. Sediment, streamflow variation, and nutrients are essential parts of a natural, healthy stream ecosystem; however, deviation from their natural condition can degrade stream ecosystems. Contaminants differ from the other stressors in that although there are some natural contaminants (e.g. trace elements), most are derived from human activities, and through toxic or endocrine-disrupting effects have the potential to directly affect aquatic life. In addition, interactions between and among stressors are complex and often difficult to discern. Nevertheless, effective management of water resources requires information about how an individual stressor or combinations of stressors influence stream ecosystems.

Study Goal and Objectives

Assess the effects and interactions of sediment, streamflow alteration, nutrients and contaminants on stream ecosystems within selected environmental settings and implications for management.

- Determine the specific effects and interactions of key stressors on stream ecosystems.
- Develop and test indicators of specific ecological responses to key stressors.
- Develop models that can be used to support ecosystem based management.

Expected Partners and Collaborators

Expected partners and collaborators will consist of a combination of national programs both within and outside of the USGS, along with a variety of groups that will be part of regional studies.

USGS

CERC: Scientists at the CERC facility have been collaborating with NAWQA studies throughout Cycles I and II and participated in Cycle III planning. This relationship will continue as the ecological effects of contaminants are explored for Goal 3. The CERC will participate in both synoptic and intensive studies. The NAWQA Cycle 3 activities that would involve collaboration with CERC include providing technical advice on toxicological issues, designing and performing laboratory toxicity tests, including ones that assess both water and sediments with endpoints of percent mortality, growth, and possibly reproduction. CERC would also be involved in fish health studies addressing the influence of various physiological and biochemical effects of specific contaminants.

FORT: The USGS FORT Center supports several natural resource economists and public policy scientists. Collaboration with these experts will bring an important socio-economic dimension to regional assessments of the ecological effects of stressors. For example, incremental losses in socioeconomic values associated with reduced ecological condition can be evaluated in some regions. Preliminary dialogue with this group has begun, but more detailed discussions will occur as the Cycle 3 plans become more firm.

WaterSMART: NAWQA has already begun collaboration with WaterSMART and expects to continue throughout Cycle 3. Starting in FY10, NAWQA and WaterSMART began a jointly funded project to develop a nationwide hydrologic classification of streams. This work continues. In addition, the placement of regional streamflow studies conducted by NAWQA will be influenced by the WaterSMART focus areas, which include the Delaware River, Colorado River, and Apalachicola-Chattahoochee-Flint River basins. For example, the first streamflow alteration study will be done in the Western Mountains which includes the Colorado River WaterSMART study area. Co-locations of at least some NAWQA and WaterSMART activities will prove to be mutually beneficial.

USEPA

National Aquatic Resource Surveys (NARS): NAWQA has collaborated with USEPA since the beginning of the national surveys (2004), and will continue to do so. As is detailed elsewhere, Cycle 3 Goals 1 and 3 will collaborate with NARS survey in 2013 in the upper Midwest, an area where the stressors of interest are contaminants and nutrients.

Office of Research and Development (ORD): Cycle 3 Goal 3 anticipates continued collaboration with scientists at ORD. Collaborations have already begun that focus on developing predictive models for streambed sediment and other habitat features through the efforts of combining EPA and NAWQA datasets. Additional collaboration will focus on refining regional models of biological condition (e.g.,

O/E and IBIs) for aquatic communities. Refined models would benefit EPA and NAWQA, as well as researchers and other bioassessment practitioners.

Office of Science and Technology (OST): NAWQA NEET and ENS have been collaborating with EPA scientists in the OST, specifically with respect to nutrient criteria and streamflow standards. This collaboration will continue, particularly during the Goal 3 study design phase in order to maximize the relevance of Goal 3 activities to the needs of OST.

Bureau of Reclamation (BOR):

NAWQA ENS has been collaborating with BOR researchers since 2009. From this collaboration, a jointly funded study of the ecological effects of streamflow alteration was conducted in 2010. Funding for an additional study in FY 12 has also been obtained. It is expected that this collaboration will continue, which will elevate NAWQA's studies of streamflow alteration within the Bureau.

Regional Partners

There are numerous regional activities that will likely be interest in and cooperate with each individual RSS. The Nature Conservancy has a large effort addressing streamflow in various river systems in the United States. They have expressed interest in working with us in the regions selected for Hydrologic Alteration studies. Other potential regional partners include States, Tribes, Regional USFWS centers, and non-governmental organizations.

Connections with other Cycle 3 Goals

When appropriate, the four goals in Cycle 3 will coordinate their activities in order to reduce potential duplicative efforts and increase the interpretive capacity of Cycle 3 studies. The Effects of Stressors on Stream Ecosystems effort (hereafter "Stressor-Effects" studies) has a number of potential collaborative opportunities presented below.

Goal 1 Surface Water Assessment-This component provides the NFSN for assessing the status and trends of water quality and therefore has several strong connections with the Goal 3 Stressor-Effects Study. First, the status portion of Goal 1 includes a number of regional-based synoptic studies that focus on chemical stressors, including nutrients and contaminants, across various land uses. This work includes assessing the occurrence and time-integrated concentrations of contaminants and nutrients, developing models for predicting nutrient and contaminant concentrations at un-sampled locations, and assessing the toxicity of water and sediment borne contaminants. Synergy between this activity and the efforts of the Stressor-Effects Goal will be important because contaminants are a major stressor being addressed in Goal 3. Linking the effects of complex contaminants to ecological effects is challenging and requires a thorough understanding of contaminant exposure over time and potential toxicological effects of some key contaminants. The toxicity assessment objective in Goal 1 will address 'when and where' toxicity occurs while Goal 3 will address why and how toxicity occurs and attempts to identify the mechanisms that produce toxicity. This effort will be a collaborative effort with CERC. Therefore, the RSS in Goal 3 will partly depend on the intensive contaminant sampling activities in Goal 1 to better understand contaminant effects in stream ecosystems. Goal 1 and 3 may at times also work together at intensive sites within each region (see details below under design).

Goal 1 Ecological Trends analysis and Goal 3 Stressor-Effects studies have a strong natural fit in that both are interested in understanding the influence of stressors on stream ecosystems. Therefore, these two efforts will work together to integrate, where possible, the temporal and spatial components of both studies. Ecological Trends will provide an important temporal context for the Goal 3 RSS and Goal 3 RSS will provide a strong spatial context for Ecological Trends. Along with these efforts, Goal 3 is planning on

incorporating some Intensive Studies that will include sites where detailed studies on stressor-effects can be carried out over short time periods, seasons, or even potentially several years. The Intensive Study sites therefore could provide Ecological Trends with information on processes influencing biota and seasonal changes in stressors and biological condition.

Goal 1 Groundwater Assessment-Collaboration with the GW component of Goal 1 could take on a large range of possibilities, depending on the degree to which study sites or regions are co-located. In a fully co-located scenario, the groundwater studies and modeling will allow for an estimation of percent GW contribution for flow, nutrients, and numerous contaminants. This comparison between predicted GW contribution and observed SW condition may range from simple comparisons to new data input and re-calibration of models based on observed differences attributable to saturated zone transformations.

Goal 2 Integrated Watershed Studies-The objective of Goal 2 is to determine how watershed processes influence nutrients and sediment transport from headwaters downstream. This goal is focused on two of the four primary stressors of concern in Cycle 3 and will provide important fine-scale understanding of the factors that influence the transport and transformations of nutrients and sediment at the watershed scale, including the role of surface and groundwater interactions. While Goal 2 and 3 are primarily at very different scales, Goal 3 is interested in including the Goal 2 IWS within Goal 3 activities. This could be done in two ways. First, information gained in Goal 2 may help to explain some of the stressors identified as ecologically important in Goal 3 effect studies. Second, the IWS scale could provide Goal 3 with an ideal location for some of the Intensive Studies outlined below.

Goal 4 Forecasting-One of the objectives in Goal 3 is to “Develop models that can be used to support ecosystem based management”. These efforts include both testing various management scenarios along with forecasting future conditions. Goal 3 will be working closely with members of HST in the development and testing of these models and decision support systems. Goal 3 will provide stressor effect models (regression models, hierarchical models, and network models) that can be used in Goal 4 to forecast effects of climate change and management decisions.

Study Design

The Stressor-Effects Goal will be accomplished through two types of studies, RSS that collects data at numerous sites over a short period, and Intensive Site Studies (ISS) that occur at few sites with greater levels of intensity over time (1-3 years). Both studies will focus on perennial wadeable streams. The RSS studies will assess the influence of key stressors or combinations of stressors on ecological response, identify important indicators of both stressors and effects, and develop regional-scale predictive models for resource management. The purpose of the Intensive Site Studies will be to examine specific aspects of the stressor-response relationship, including stressor-response interactions in a temporal context, experimental studies, or how these interactions are influenced by management practices.

Regional Synoptic Studies (RSS)

Regional Synoptic Studies will be used to examine how key stressors influence stream ecosystems and how various management practices influence these relationships. The EPA Level II Ecoregions (n=19, Fig 5.1) were the starting place for ranking regions for inclusion in a RSS. Ecoregions reduce natural variation in biological and some environmental conditions thereby making it easier to isolate the effects of major environmental drivers (urban development, agricultural practices, and water use) and related stressors. Each RSS will consist of about 100 sites where data on current ecological condition and stressors will be determined. Addressing the relationships between specific stressors and biological response at the regional scale will require that “stressor gradients” be used in the study design. This implies selecting sites that span a wide range of a particular or group of stressors. Because it is not

feasible to capture all stressors across a single gradient, each regional study will design along a streamflow alteration or contaminant gradient as the primary design approach, with other stressors (e.g., nutrients and sediment) collected at the same sites.

The contaminant-based RSS will be coordinated with the Goal 1 RSS, with the streamflow-based RSS done independently. Lessons from Cycles 1 and 2 of the NAWQA program indicate that different contaminant groups are associated with urban and agricultural land uses. Therefore, in order to better isolate the effects of certain contaminant groups, the contaminant-based RSS will focus on either urban or agricultural lands. Streamflow alteration RSS will be done in regions where there is little influence from urban or agricultural activities, thereby permitting a clearer understanding of how streamflow alteration influences stream ecosystems; however, streamflow will be measured in all the RSS regardless of the design emphasis

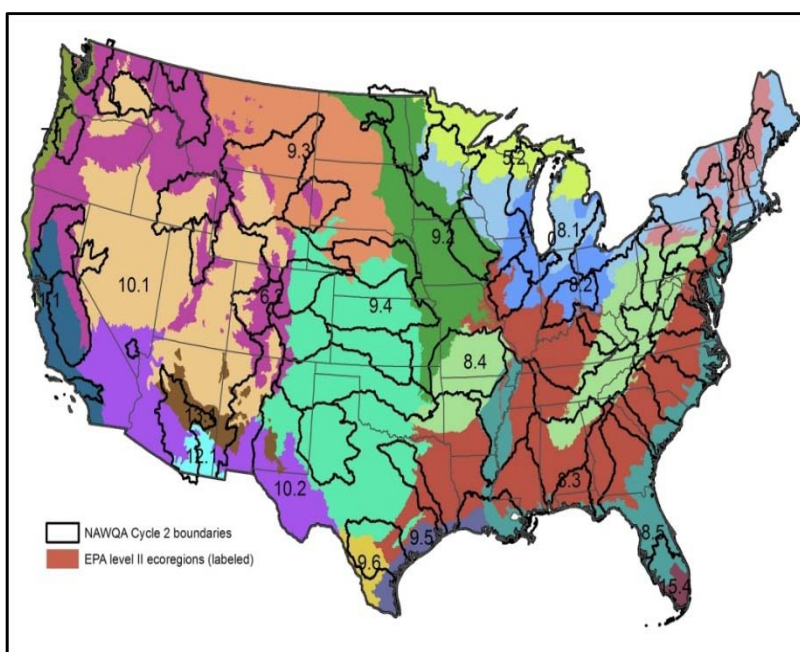


Figure 5.1. Level II ecoregions and NAWQA study units.

Criteria for ranking regions for assessing key stressors

The criteria for ranking Level II ecoregions for Goal 3 RSS are based upon a combination of several factors. While the regions used in the ranking procedure include the 19 EPA Level II Ecoregions, it is likely that actual study boundaries may include only a portion of a region, or a combination of two areas in adjacent regions. However, the use of the Level II ecoregions provides a starting point by which to rank regions.

The following criteria and procedures were used in the regional ranking process:

1. Ecological Reference Sites: Because Goal 3 will address the influence of stressors on biological response, regions must contain a sufficient number of ecological reference sites to compare with non-reference sites. Therefore regions were ranked on the number of potential reference sites (NAWQA and EMAP) with a score of 1 for poor, 2 for moderate, and 3 for good reference site potential (details on the quantitative approach used to establish reference sites and scoring are shown below).
2. Stressors: Streamflow alteration and contaminants were the primary stressors used to rank regions. Because agricultural and urban contaminants tend to differ, regions were scored separately on their

suitability to provide gradients for both urban (URB) and agricultural (AG) stressors (i.e., groups of contaminants associated with urban and agricultural land uses). For streamflow alteration and contaminants, regions were ranked from 1 (lack of sufficient gradient) to 3 (strong stressor gradient). Details on assessing specific stressor gradients presented below.

3. **Ranking Process:** Regions were scored as candidates for RSS if they had acceptable scores (defined below) for both the Ecological Reference and one or more stressors (streamflow alteration or contaminants (agriculture and urban scored separately)), so as to capture stressor gradients and specific management settings within the region. Rankings were based on:

- Streamflow alteration: Region selected if Ecological Reference = 3 and Streamflow Alteration = 3.
- Agricultural land contaminants: Regional selected if Ecological Reference = 2 or 3 and Agricultural contaminants = 3.
- Urban land contaminants: Region selected if Ecological Reference = 2 or 3 and Urban contaminants = 3.

Ecological Reference Site Assessment

The presence of sufficient ecological reference sites within a region was assessed by examining existing NAWQA and EMAP reference sites in each Level II ecoregion (see Fig. 5.2 for example). Benthic invertebrate data were analyzed for a series of metrics at each reference site within an ecoregion. The invertebrate metrics included intolerant taxa richness, tolerant taxa richness, abundance percentage of intolerant taxa, abundance of tolerant taxa, and richness of tolerant taxa. The rankings indicate the relative magnitude of biological change that might be expected over a stressor gradient. Ecoregions with higher ranks can change more over the gradient which should make detecting changes easier. Ecoregions were then given a 1 (poor), 2 (moderate) or 3 (best) rating as to having sites that will permit a strong comparison of reference to non-reference ecological conditions. Once each invertebrate metric was ranked from 1 to 3, scores for each ecoregion were averaged to obtain a final ranking.

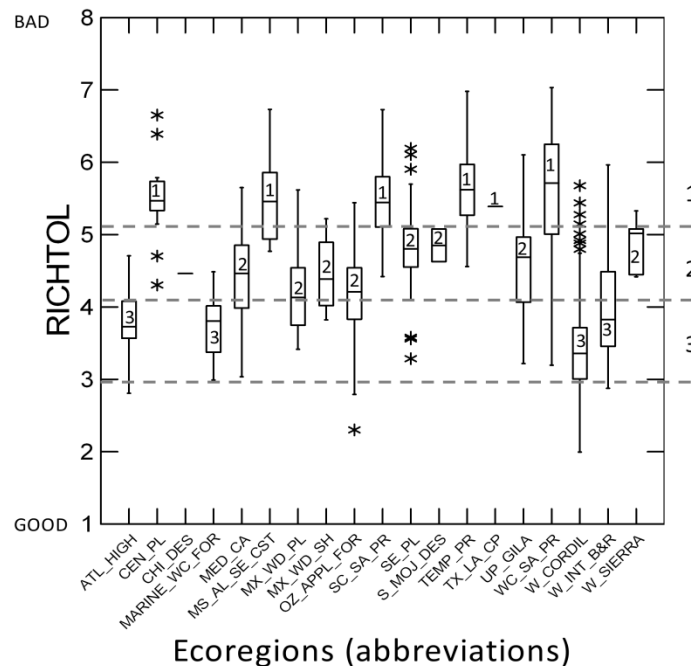


Figure 5.2 Example of the distribution of one of the benthic invertebrate metrics at reference sites.

Streamflow Alteration

Streamflow alteration was assessed in terms of number of gages in a region listed in the GAGES database (Fig. 5.3, Falcone and others 2009) rather than HUC10s because streamflow alteration RSS requires a substantial number of sites close to existing streamflow gages. Regional investigations of the effects of streamflow alteration will require gages at hydrologic reference sites (sites that have low level of human impacts on streamflow patterns), at sites that span a gradient of streamflow alteration that is likely to correspond to ecological effect gradients, and sites that represent ecological reference conditions. Three types of human impacts to streamflow were evaluated: dam storage circa 2006, annual withdrawals, and road density. Hydrologic reference sites had <1 cm dam storage, <1 cm annual withdrawals, and <2 km/km² road density. Intermediate sites had 1-10 cm dam storage, 1-10 cm annual withdrawals, and 2-6 km/km² road density. All other sites were assumed to have substantial ecological effects due to streamflow alteration and were not used for screening regions. Regions were scored 3 if they had at least 20 gages at hydrologic reference sites and 100 gages across a streamflow gradient. Regions were scored 2 if they had at least 20 gages at hydrologic reference sites and 50 gages across a streamflow gradient. Regions were scored 1 if they had less than 20 gages at hydrologic reference sites or less than 50 gages across a streamflow gradient.

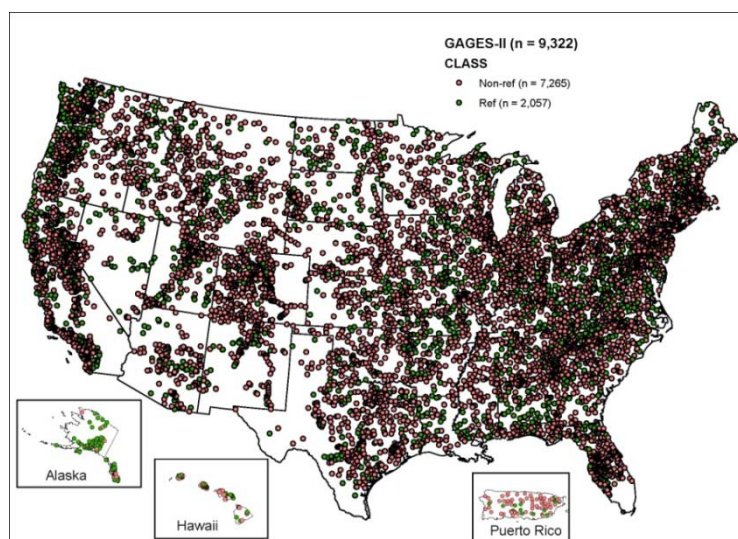


Figure 5.3 Sites included in the GAGES database (Falcone and others 2009).

Contaminants

Assessing the ecological effects of contaminants poses the most complicated challenge due to the complex mixture of multiple contaminants and the variation in concentrations over space and time. Results of Cycle 1 and 2 studies indicate that different contaminant groups are associated with urban and agricultural land uses. Therefore each region was scored for contaminant gradients in both its urban and agricultural settings. Scoring was based on the number of HUC10 streams along a complete agricultural or urban gradient and the assumption that these HUC10 streams will approximate the distribution of basin characteristics in the regions. In addition, the probability of finding suitable sites was assumed to be higher in regions with larger numbers of HUC 10 sites.

Agricultural Settings

In agricultural settings, two metrics were evaluated to give an indication of, or prediction of, the contaminant stressor likely to be present, i.e. the target gradient. The primary metric used was the Toxicity Weighted Use for benthic invertebrates (TWU_{bi}), which was scored quantitatively and used to assign an initial ranking to Level II ecoregions (Fig. 5.4). The goal of this ranking is to indicate whether the region contains sufficient streams at the HUC10 level to support a contaminant focused RSS on agricultural pesticides. Subsequently, data on crop type was evaluated from the USDA Farm Resource Region (FRR) national crop inventory. This inventory lists the crops in production annually for major orchard and row crops nationally. The amount (on an areal basis) of a given crop and the diversity of crops common in a region was evaluated as an indication of consistency in cropping pattern, and therefore expected future pesticide use. These crop type data were used to adjust the initial regional rankings based on TWU_{bi} , or to more finely prioritize top-ranked regions.

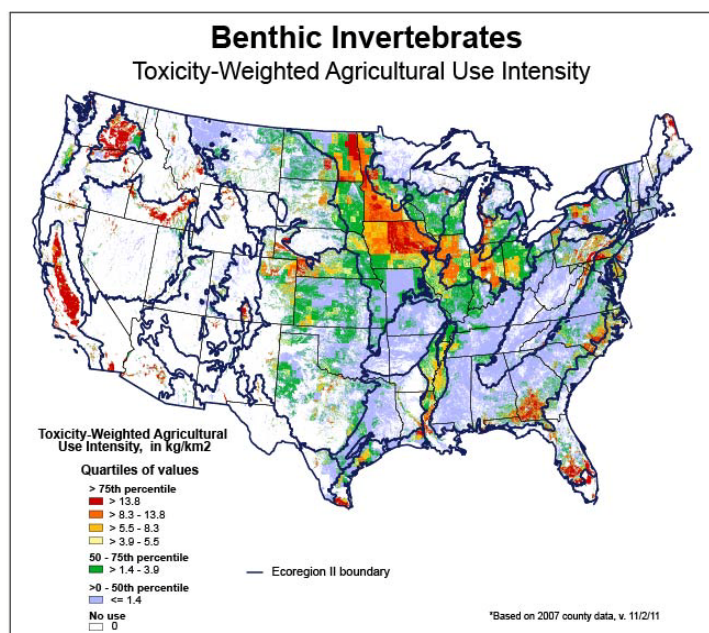


Figure 5.4. Toxicity-weighted use for agricultural pesticides relative to benthic invertebrates.

The initial ranking on the basis of TWU_{bi} was done as follows: (1) Pesticide use estimates, consisting of 356 documented pesticides on a county level, were re-gridded and mapped for individual HUC10 watersheds. For all pesticides with estimated use within a given HUC10 stream basin, PTI scores were calculated by dividing the use estimates by their respective Pesticide Toxicity Index (Munn and others 2006) scores for benthic invertebrates (PTI_{bi}). These PTI_{bi} scores are available for 118 of the more commonly used pesticides. The result was a TWU_{bi} score for each HUC10 stream. (2) Percentiles of the TWU_{bi} values for all HUC10 streams were calculated and used as the basis for gradient categories, such as <10th percentile, 10-20th percentile, etc., up to >95th percentile. These categories were used as the basis for ascertaining whether a sufficient agricultural pesticide gradient existed in that HUC10. (3) Level II ecoregions (ER2) were then divided into subregions using USDA FRR boundaries, which designate different types of agricultural commodities and chemical use. This was done to avoid ranking a region low because it has large areas of undeveloped land, even though there may be sufficient HUC10 streams for an agricultural study within a particular subregion. (4) HUC10 streams with more than 5 percent urban land were dropped from HUC10 counts per subregion, so that urban contaminants would not interfere with measuring a contaminant response along the agricultural gradient. (5) Each FRR-ER2

subregions were then scored, 1(poor) to 3 (best), as to whether they had sufficient streams throughout the TWU_{bi} gradient, from. (6) Finally, each Level II ecoregion received the rank corresponding to the highest rated of its subregions, on the premise that if at least one subregion contained sufficient HUC10 streams along the gradient, it should be possible to do an agricultural study in that ecoregion. Figure 5.5 shows the distribution of a low ranked region (1) compared to a high ranked region (3).

Information on crop patterns expected in regions that receive scores of 2 or 3 will be considered, and may result in changes to some preliminary ranking. Collectively, the two metrics (TWU_{bi} and crop pattern) will be considered as a measure of the 'likelihood of a stressor gradient' for an agricultural contaminant gradient study in a particular regional setting. This score will be evaluated along with the suitability of other stressors types (flow, nutrients, sediment, temperature) as well as the 'likelihood of biological response', discussed further below, in selecting a given regional setting.

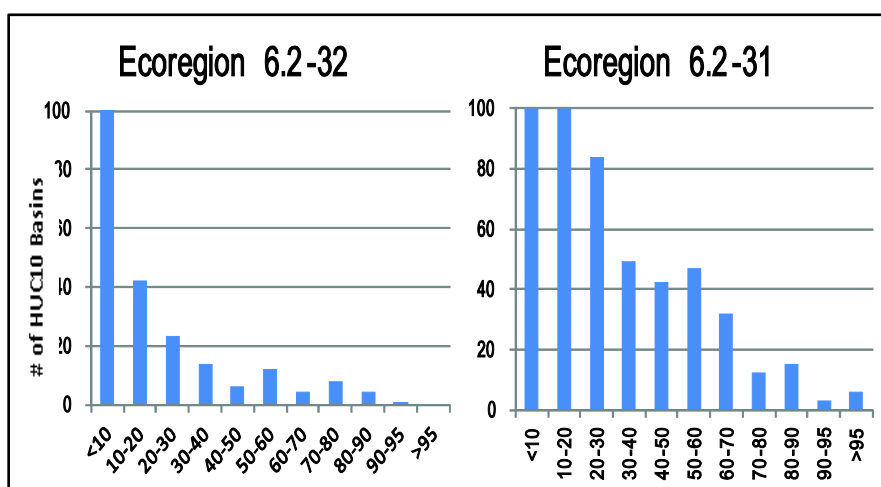


Figure 5.5. Comparison of two regional distributions of TWU_{bi} (benthic invertebrate PTI). Left graph shows a poor contaminant gradient due to low numbers of sites with high toxicity (rank 1) with right showing strong gradient of potential toxicological effects (rank 3).

Urban Settings

The sources of pollutants in urban streams are diverse and in general, less predictable than in agricultural settings. From the recent Urban Bed Sediment Study (Moran and others 2011), it appears that there is a weak, but significant, positive relationship between the frequency of detection of urban bed sediment pollutants and urbanization. However, there were significant differences in the relationships between contaminant concentrations and degree of urbanization in the seven metropolitan areas studied. Because source-specific information for contaminants in urban settings is lacking, a surrogate measure of contaminant intensity, such as urban land cover, population density or impervious surface, will be utilized, in conjunction with available stream contaminant data (from both within the NAWQA program and outside), to define an urban contaminant gradient.

Given the complexity of ranking regions by urban contaminants, we used urban land cover as a surrogate for contaminants in our ranking of Level II ecoregions. This approach assumes: (1) urban stressor gradients can be approximated from urban land cover gradients (i.e., there are more stressors at higher concentrations as urban intensity increases), (2) urban gradients should include sites that span the majority of the possible range of urban intensities (toxicity is more likely at moderate to high levels) and (3) the presence of agriculture (%) was minimized (i.e., low urban sites should have < 50 % ag) to maximize urban signal.

The process of ranking ecoregions for urban stressors involved determining how well the urban gradient was represented in each ecoregion. This was accomplished by dividing sites with relatively low agriculture ($\leq 15\%$) into 20 categories of urban intensity (0-5, 5-10, ... to 95-100% urban). Sites with $< 70\%$ of the urban categories represented were ranked low (1), $>70-94\%$ were ranked moderate (2) and $\geq 95\%$ were ranked high (3) (Figure 5.6). The number of sites at the low (≤ 10) and high (≥ 70) ends of the urban gradient were also considered. Ecoregions with high numbers of sites (≥ 100 sites for low urban, ≥ 50 for high urban) got high rankings (3) and ecoregions with low numbers of sites (≤ 20 sites for low urban, ≤ 10 sites for high urban) got low rankings (1). Median values of the three urban stressor rankings (rounded to the nearest whole number) were combined with median rankings of the biological condition of reference sites to produce the final ecoregion ranking (Figure 5.6).

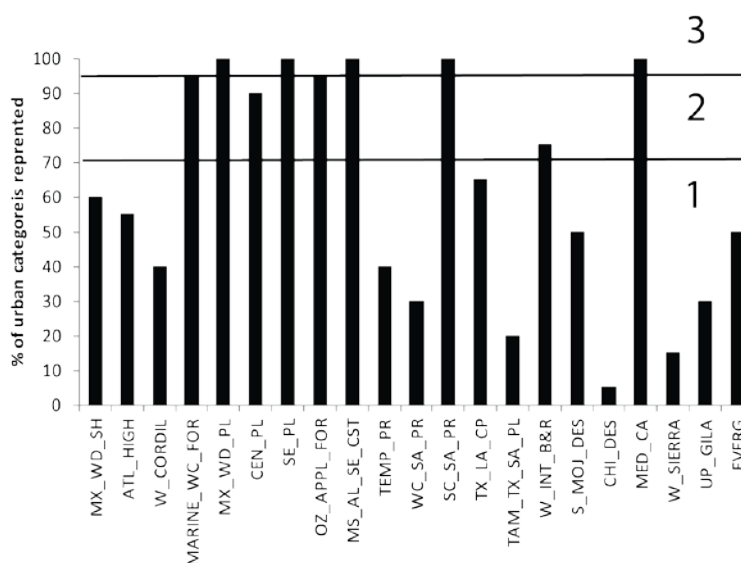


Figure 5.6. Plot showing the number of urban intensity categories with number of sites by ecoregion. Strong urban gradients are found when all urban categories contain sites, therefore high values represent strong candidate regions (score of 3).

Nutrients

While nutrients are not one of the two key stressors used for ranking regions, they were scored to determine which regions are most suited for assessing nutrients along a gradient. A key requirement for assessing the influence of nutrients on stream ecosystems is capturing a range of sites that span a gradient of nutrient concentrations. The range must include sites that are below the initial growth thresholds of 0.5 mg/L TN and 0.03 mg/L TP and continue up past the threshold levels. Since concentrations are highly ephemeral in nature, loading of TN and TP to a watershed were used as a surrogate for potential nutrient ranges. TN and TP input to watersheds were modeled using a combination of percent agriculture, fertilizer sales, atmospheric deposition, and animal population (Ruddy and others, 2006). The input of both TN and TP was then calculated by HUC 10 and summarized by Ecoregion Level II. In order for a region to be considered a candidate it had to have a high percentage of sites within the target range of nutrient inputs. Regions classified as a 1 included those that either had very low concentrations, including many mountain systems, and regions that contained primarily high levels of nutrients, like some of the Midwest agricultural regions. Regions classified as 2 included those that had some potential for use in a nutrient study, but need further information prior to confirming.

Regions classified as a 3 included those that contained the majority of data in the appropriate range of nutrient input, including sites with very low input to sites with high loading of nutrients.

Results of regional ranking process

The regional ranking process resulted in eight Level II ecoregions (Table 5.1) that satisfied the selection criteria above, with three regions satisfying multiple categories (results of rankings for all candidate Level II ecoregions considered are given in Appendix 5). The Central Plains/Temperate Prairies did not meet the selection criteria, but is included because Goal 1 Surface Water is doing a contaminant-focused RSS as part of a cooperative study between NAWQA and USEPA NARS. While nutrients and sediment were not used in the regional selection process, they will be included in the RSS since they are important stressors. There are insufficient funds under the Current Funding Scenario to initiate all candidate RSS in Table 5.1, therefore a subset of regions were selected to cover streamflow alteration and contaminants in both urban and agricultural lands (Table 5.1 bolded, Figure 5.7). The ordering of the regional studies below is based upon a combination of existing information, geographic distribution, and the number of basins with varying levels of land use or stressors. However, it is important to note that all regions in Table 5.1 are strong candidates for assessing the influence of stressors on stream ecosystems.

Table 5.1. Summary of candidate regional studies by dominant stressor category and ordered in priority. **Bolded regions** have priority under the Current Funding Scenario; non-bolded would be added under Science Plan Scenario.

Streamflow Alteration Design	Contaminant Design	
	Urban	Agricultural
1. Western Cordillera (MTNS)	1. Southeastern Plains (Atlanta to Raleigh)	1. Central Plains/Temperate Prairies (upper Midwest- NARS)
2. Atlantic Highlands	2. Mediterranean California (SF to San Diego)	2. Cold Desert (Irrig west, CCYK to USNK)
3. Ozark/Appalachian Forest	3. Marine West Coast Forest (Seattle to Portland)	3. Mixed Wood Plains
4. Marine West Coast Forest (PNW)	4. Mixed Wood Plains (Minneapolis to Detroit)	4. Mediterranean California (coastal CA, not Central Valley)
	5. Ozark/Appalachian Forest	

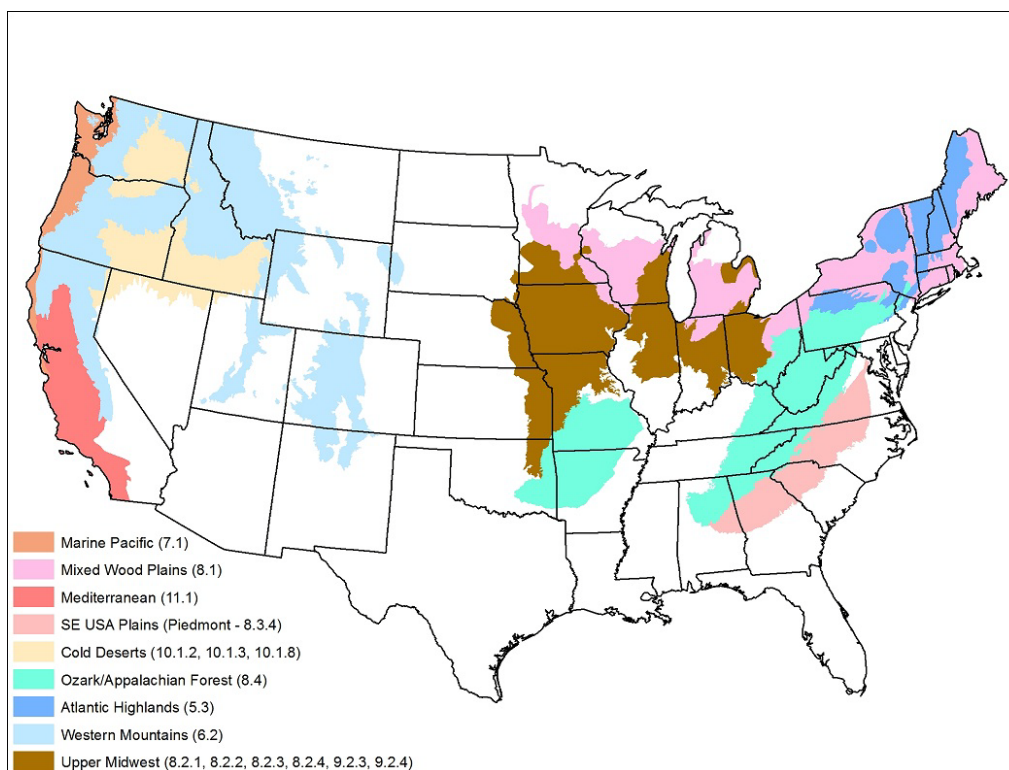


Figure 5.7. Map showing distribution of proposed regional studies. In many cases the actual study will occur in a subarea within a region to better isolate and control for various stressor conditions.

Background on Regions selected:

All the regions presented below have a number of important land use and/or water use issues, and all include a variety of important biological resource issues that are related to water use. Briefly, the seven regions proposed for RSS, their relative timing, and the rationale for their selection are:

1. **Upper Midwest (NAWQA/NARS)(FY13)**– primarily agricultural focus, but also including mixed land-use sites typical of the region. Collaborative study by NAWQA and the USEPA National Aquatic Resource Survey Program. Goal 3 activities in this study will include technical advice on design and analysis of ecological data. This study was selected because it is one of the largest and most economically important agricultural regions of the country, has high levels of pesticide and nutrient use and occurrence in streams, and is important for contaminant loading to the Mississippi River and Gulf of Mexico. See Chapter 2 section on Goal 1 Regional Synoptic Studies for more detail.
2. **Western Cordillera (mountains) (FY13)** – this study is designed primarily as a streamflow alteration RSS, but will address other important stressors as in nutrients and sediment. This regional synoptic study will include approximately 100 sites selected along a gradient of streamflow alteration conditions and will attempt to minimize sites influenced by urban or agricultural activities. However, water use activities will be incorporated into the design. The study will be done in coordination with scientists within the WaterSMART program and potentially other programs in the region. This region was selected due to its high number of gages, quality of reference sites, wide range in streamflow alteration, and sites without substantial urban or agricultural land use. This region also includes parts of the Colorado River Basin under study by the WaterSMART Program.

3. **Atlantic Highlands (FY14)** – this study is the second of the streamflow alteration studies and therefore satisfies many of the same selection criteria presented above. One reason this region ranked high was the fact that it contains the upper reaches of the Delaware River, which is an area of focus for the USGS WaterSMART program.
4. **Southeastern Plains/Piedmont subregion (FY14/15)**- This study will focus on urban lands in a subregion of the southeastern plains called the Piedmont (Level 8.3.4), which includes Atlanta to DC. Urban contaminants are the primary stressor that will be used in the design of this study, although the other key stressors (sediment, streamflow alteration and nutrients) will be assessed. The rationale for this region being the first urban focused regional study is the fact that NAWQA has a long history in this region, particularly due to the work done the EUSE studies in Raleigh and Atlanta. One of the most challenging aspects of assessing multiple stressors in an urban setting is the diverse number of contaminants that can occur. Therefore, it is optimal for the first urban regional study to start with a strong understanding of issues, land use activities, and knowledge of how stressors affect biological endpoints. Starting in this region will also permit a more complete assessment of how management practices are influencing stream quality. This region also contains the Apalachicola-Chattahoochee-Flint River basins, which is of interest to the WaterSMART program.
5. **Cold Desert (Irrigated west) (FY15-16)**- This is the second agriculturally focused regional study and includes an important agricultural region with a wide diversity of crops, chemical use, and irrigation practices. Like the Southeastern Plains, this region contains two NAWQA study units with extensive data on water quality and biological condition (Central Columbia Plateau, Upper Snake River Basin), both of which were included in the NAWQA cycle 2 Nutrient Effects Topical Study (NEET). This study will also utilize contaminants as the primary design feature for site selection, but will address other important stressor issues including sediment, streamflow alteration, and nutrients. The Mediterranean California region is also a strong candidate for assessing the effects of stressors in heavily irrigated agricultural stream ecosystems.
6. **Mediterranean California (SF to SD) (FY17-18)**- This study will focus on urban lands from the Russian River north of San Francisco to San Diego, with the Central Valley likely excluded due to lack of appropriate reference sites. This region has both extensive urban centers with high populations and extensive agricultural activity, but also contains large areas of lands with limited land use activity. Contaminants will be the primary design stressor, but will include sediment, nutrients and streamflow alteration. This region differs from others in that NAWQA has not done any extensive urban studies as part of EUSE, but did include some urban sites during Cycle 1. It is important to note that the Mediterranean California region is also a strong candidate for assessing the effects of stressors on agricultural stream ecosystems.
7. **Ozark/Appalachian Forest (FY19)**- This region is the third of the streamflow alteration studies and is important due to its freshwater biological diversity. The southern Appalachian Mountains are an ancient, topographically diverse mountain range, which have resulted in array of habitats for both flora and fauna, and have contributed to the high levels of diversity and endemism that is unparalleled in the temperate zone. Freshwater mussels, freshwater fishes and salamanders are all diverse within this region. For instance, nearly 10 percent of global salamander diversity and 10 percent of freshwater mussel diversity occur in this region. Therefore, this region provides a unique opportunity to address the influence of streamflow and other stressors of concern on aquatic biota. Note that this region is also a candidate for an urban regional study, but is not considered as strong a candidate as the other urban regional studies.

8. **Marine West Coast Forest (PNW)** – This region includes the coasts of Washington, Oregon, and northern California, and also includes two NAWQA study units (Puget Sound and Willamette River Basin). This region has important water resources issues related to both freshwater and coastal resources, particularly around the issues of salmon. The Marine West Coast region satisfied the criteria for both a streamflow alteration and an urban regional study. Existing data and strong regional interest makes this region a good candidate for either type of regional study.
9. **Mixed Wood Plains (Minneapolis to Detroit)**– This region was also selected as a strong candidate for two regional studies, the urban and agricultural RSS. This area covers a wide range of conditions from Minnesota to Maine, including multiple NAWQA study units. Due to this large area and issues, any regional study in this region would have to be focused to a smaller portion of the region and topic. For example, if an urban regional study was done in this area it would be optimal to focus the effort in the area from Minneapolis to Detroit, although other urban areas could be considered.

Data collection

Due to the objectives of this study, the stressors addressed will primarily be sediment, streamflow alteration, nutrients, and contaminants; however, other stressors can be included, such as temperature, chloride, DO, etc. In regards to biological response, the primary approach will be to rely on algal and invertebrate communities, with fish collected when appropriate and feasible. There are two levels of data collection in Goal 3. First, data representing a set of core variables (Table 5.2) will be collected at all sites within all regions. The second level of data collection will depend on the specific region and stressors in that region. For example, if a RSS is examining contaminants in urban areas then additional needs could include water and sediment chemistry, fish health indicators, laboratory toxicity tests, field toxicity tests, etc. The number of samples per site will depend on the contaminants of interest. For example, if sediment contaminants like PAHs are sampled in an urban setting, then a single composite sediment sample would be sufficient to address exposure to aquatic life; however if the water-column contaminants are sampled then it may be necessary to collect a time-series of samples in order to capture the conditions over the period of interest. For example, in the first RSS in the upper Midwest (NARS + NAWQA) there will be extensive time-series data collected to address pesticides in the water column which is needed to both develop predictive models and to relate to biological data collected by the NARS program. Other contaminant sampling methods will also be considered, as in passive sampling devices that integrate waterborne contaminants over time (e.g., SPMD, POCIS).

Table 5.2. List of core variables required to be collected at all sites within all regions for Goal 3.

Field Parameters	Surface Chemistry	Biology
Continuous water temperature	Major ions	RTH Invertebrates (LC2172)
pH	Sulfate (LC1572)	RTH Algae
Specific conductance	Chloride (LC1571)	Benthic chlorophyll (SH1632)
Alkalinity	Nutrients (SH2711/2120)	Fish (if possible)
Dissolved Oxygen	Carbon (SH2631)	
Aquatic plant cover	Suspended sediments (conc.)	
Habitat		

Intensive Site Studies

Intensive Site Studies will occur as needed within each of the RSS or within an area under study by other NAWQA Goals, like the Integrated Watershed Study. Each ISS will have a somewhat unique design in order to address specific questions. The ISS could consist of anywhere from 1 to 5 sites with studies ranging from short-term (months) experimental studies to longer-term (several years). Examples of questions that could be addressed by and benefits that could be accrued through ISS are listed below.

- Develop and test new methods for use in Stressor-Effects Studies, or other components of NAWQA. For example, this could include new field-based toxicity methods or methods for assessing the influence of suspended and bed sediments on biological condition.
- Determine seasonal or annual variability in stressor-effects. This could be a joint study between Goal 3 and the Ecological Trends portion of Goal 1.
- Refine understanding of how specific stressors influence biological response; this may include conducting both in-situ and laboratory-based exposure studies to differentiate the effects of chemical contaminants from those of other stressors (e.g., sediment, nutrients), assess the cumulative effects of contaminant mixtures, and interpret the effects of chemicals for which toxicity data are lacking.
- Generating benthic invertebrate tolerance scores (both from the literature and from toxicity testing) to specific contaminants or family of contaminants for use in interpreting bioassessment data. (Such a metric would be of great interest to many state and federal programs in addition to NAWQA.)
- Test hypothesis about the interaction of two specific stressors in a more controlled setting. For example, conduct stream experiments to determine the interactions of two or more stressors such as suspended sediment and pesticides or sediment, nutrients, and DO on biotic response.
- Provide collaborative opportunities with other programs within the USGS or with other agencies and universities.
- Provide opportunity for process-based ecological studies that cannot be done at a larger scale due to cost.
- Assess endpoints that cannot be addressed in short-term RSS.

Developing Ecological Models that Integrate Stressors, Effects, and Management Practices

Models will play an important role in Goal 3 for study design (prioritizing regions and identifying stressor gradients), analysis (identification of important stressors; defining relations among stressors, response, and land use; refining conceptual models), for assessing the implications of specific management strategies, and communicating results to water-quality managers and the public.

In regards to scenario development for forecasting purposes, it is useful to distinguish between what humans can control (i.e., management decisions) and what they can't control (i.e., environmental variability, ecological process uncertainty). In Goal 3, the objective is to develop models that can predict stream ecosystem response under different kinds of management scenarios such as storm water mitigation or implementation of land use restrictions. The models should also improve understanding of what would happen under different kinds of environmental variability (climate change) scenarios (e.g., water temperature increase, erratic weather patterns, etc.). Ultimately, these two kinds of future system changes interact, and the role of decision analysis modeling is to appropriately integrate these two different problem elements and yield the most optimal decisions and preferred outcomes in the context of existing or future variability/uncertainty.

A. Use of models in the selection of study regions and identification of stressor gradients:

1. SPARROW models: identify broad-scale patterns in nutrients and sediment
2. WARP models: identify patterns in pesticides, particularly in agricultural areas
3. Regression models: identify relations between stressors and GIS-indicators of urban and agricultural intensity as well as relations with contaminants to facilitate establishing stressor gradients.

B. Use of models in the analysis of stressor-response gradients and comparisons among regions

1. Regression models (single and multiple, linear, nonlinear) will be used to evaluate relations among stressors, stressors and land use, and stressors and response (physical, chemical, and biological). The form and relative rates of response will be important in comparing responses among regions, subregions, or between stressors (e.g., pesticides versus hydrologic alteration). Regression models will also be used to develop biological indicators of stressors (e.g., sensitive taxa or metrics) based on probability of occurrence or extirpation derived from logistic regression models.
2. Regression tree analysis will be used to identify stressor and environmental variables that are most important in shaping responses and in devising models that predict group membership. This type of analysis can be used to determine if the predefined stressor gradient is the most important variable in determining responses or if other variables are more important. These variables can then be incorporated into simpler regression models or incorporated into network models. Regression trees can also be used to understand and predict responses to stressors or combinations of stressors. These analyses are also useful for drawing comparisons of variables that are important in determining response among regions or subregions.
3. Network models [Structural Equation (SEM) or Bayesian Network models] will be used to develop and refine the conceptual models that represent our understanding of how stressor gradients affect responses and how they are affected by other natural and anthropogenic factors (e.g., land use), thus improving our overall and specific understanding of these factors and processes. Network models can be used to establish linkages between stressors (natural and anthropogenic) and responses and to define the strength (importance) of linkages. These models are particularly useful for testing the effects of management scenarios and addressing the effects of BMPs by incorporating nodes that address the effects of BMPs such as reductions in sedimentation, hydrologic variability, and contaminant loads and concentrations.
4. Multilevel models are useful for explaining large-scale patterns in physical, chemical, and biological responses. Multilevel hierarchical regression models will be used to develop models that account for response parameters observed at regional spatial scales (e.g., slopes and intercepts in regional responses to a stressor) based on national-scale predictors (e.g., regional climate, soils, or geology). The ability to develop these models will depend upon the number of regions that are studied and that contribute to the development of a national-scale model.
5. Decision Support Systems will be used to provide simplified versions of the network models that can be used by managers and the public to assess the possible consequences of management decisions. Decision support systems will be developed in cooperation with other parts of the program for use in web-based applications that would be readily available to the general public. The decision support systems must accurately reflect the relations between stressors and responses uncovered using the modeling techniques outlined in sections B1-4.

Budget, Staffing and Timing

The CFS incorporates a decrease in funding over Cycle 3, with the Science Plan Scenario staying constant throughout the cycle (Table 5.3). This Implementation Plan presents detail information on the major components of the budget and the staffing plan under the Current Funding Scenario; however, only general information will be included under the Full Science Plan Scenario.

Table 5.3. Proposed targets for Goal 3 Stressor-Effect Current Funding and Science Plan Scenarios. Amounts are millions of dollars, adjusted for inflation.

Funding Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Current Funding	\$4.00	\$3.84	\$3.69	\$3.54	\$3.40	\$3.26	\$3.13	\$3.01	\$2.89	\$2.77
Science Plan	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0	\$13.0

Current Funding Scenario

Under the Current Funding Scenario the plan is to complete the seven regional studies identified through the RSS selection process; the remaining regions would be completed only under the Science Plan Scenario. Under the CFS, funding starts at \$4 million and decreases to \$2.77 million by FY22 (Table 5.3). In order to complete the studies during Cycle 3, the budget was divided into two parts: studies and interpretive work. Studies include labor for managing regional studies along with both labor and laboratory funds for collecting data. Interpretive funds support scientists who participate on the National Stressor Effects Team and scientists from Water Science Centers. Figure 5.8 shows the distribution of funding between the collection of data (labor and laboratory analyses) and the interpretive efforts. Figure 5.9 shows the funds being distributed to the Stressor-Effects Team relative to staff in the Water Science Centers. Note that the majority of National Stressor Effects Team will be distributed throughout Water Science Centers, not USGS Regional Centers or Headquarters.

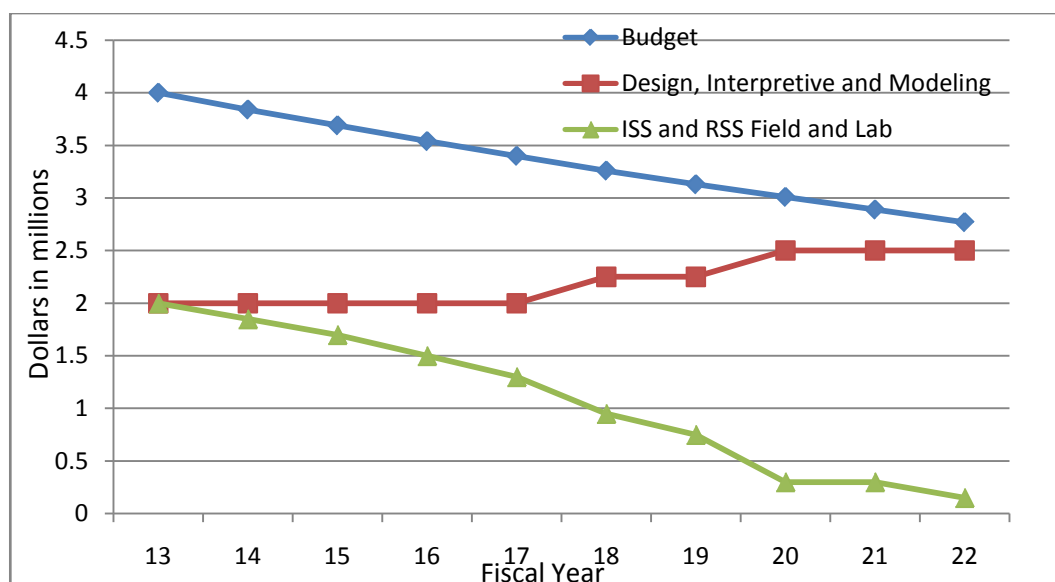


Figure 5.8. Comparison of funds allocated to the design, interpretative, and modeling efforts compared to funds allocated for Intensive Site Studies and Regional Synoptic Study data collection and laboratory analyses at the National Water-Quality Laboratory. In order to offset the projected decrease in Goal 3 funding during Cycle 3, the majority of the Intensive Site Studies and Regional Synoptic Study studies are conducted in the first 5-6 years of the cycle, with the funds allocated for interpretive work increasing due to increased work load to complete products.

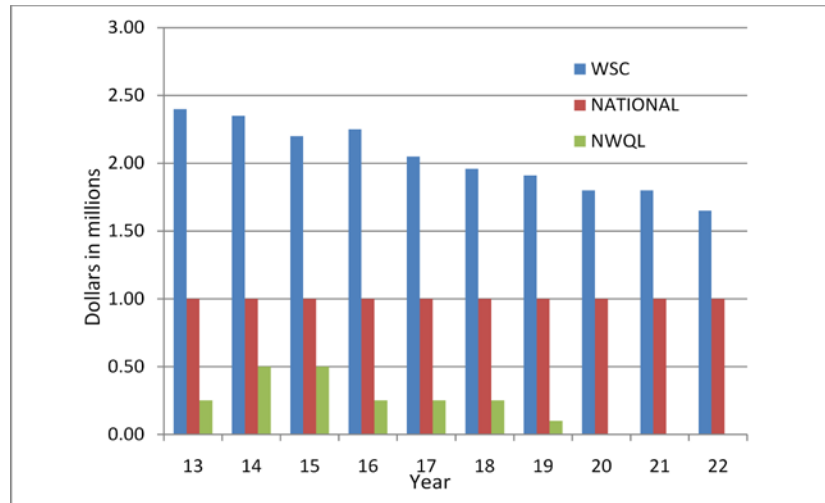


Figure 5.9. Comparison of the total funds allocated to Science Centers, scientists on distributed NAWQA teams, and the National Water Quality Laboratory.

Staffing

Staffing for Goal 3 consists of a Stressor-Effects Lead Scientist who leads a distributed national team of scientists and support staff (Fig. 5.10). The national team will include WSC scientists. This team and additional staff drawn from local WSCs will form regional study teams responsible for the design and execution of the RSS. The distributed national Stressor-Effects Team will stay relatively consistent throughout Cycle 3, with the regional teams working during the individual RSS. List of staffing needs is shown in Table 4.

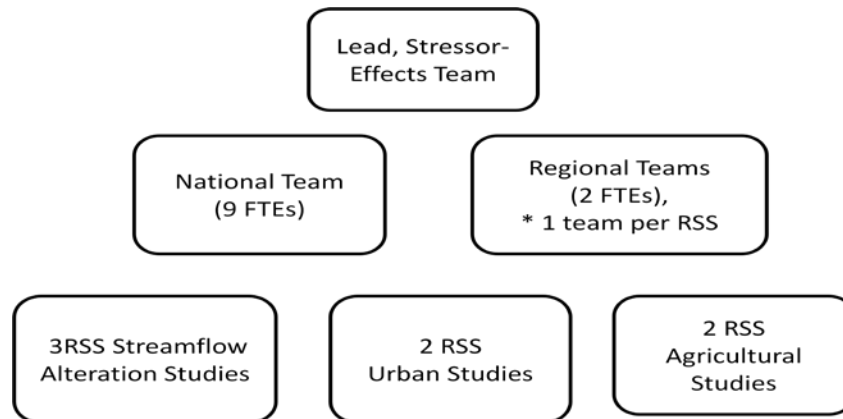


Figure 5.10. Organizational structure of Stressor Effects Team and related studies.

Table 5.4. Proposed staffing for Stream Ecology studies under Current Funding Scenario. This includes an interpretive team consisting of National NAWQA scientists and Water Science Center scientists, along with staffing for RSS teams

Position	Grade(s)	FTE	Duration	Position Description
Lead, Stressor-Effects Team	GS-14	1.0	FY13-22	Supervises Stressor-Effects Team; provides technical guidance and oversees data collection, modeling, and product development activities.
Regional Coordinators	GS-12/13	1.0	Region dependent	Supervises regional stressor-effects studies in coordination with Team Leader and National Scientists working on study. Coordinator is responsible for assisting in site selection, preparing and collecting field data, supervising regional field technicians, and entering all data into appropriate databases. When appropriate, coordinators will be involved in interpretive portions of goal 3.
Ecologist, Streamflow	GS-13/14	1.0	FY13-22	Provides technical guidance and interpretation on effects of streamflow alteration on stream ecosystems.
Ecologist, Nutrients	GS-13/14	1.0	FY13-22	Provides technical guidance and interpretation on effects of nutrients on stream ecosystems.
Ecologist, Contaminants	GS-13/14	1.0	FY13-22	Provides technical guidance and interpretation on effects of contaminants on stream ecosystems. Includes bioaccumulation, toxicity and community response.
Ecologist, Fish Ecology	GS-13/14	1.0	FY13-22	Provides technical guidance and interpretation on effects of various stressors on fish health and communities.
Ecological Modeler	GS-13/14	1.5	FY13-22	Provides technical guidance on study design and interpretation in regards to modeling. Develops ecologically based management models that can be used by water resource managers. Will coordinate with HST.
Hydrologist, streamflow specialist	GS-13/14	1.0	FY13-22	Provides technical guidance and interpretation on effects of streamflow alteration on stream ecosystems. Must have strong hydrology background working with streamflow alteration.
Toxicologist	GS-12/13	0.5	FY13-22	Provides technical guidance and interpretation on toxicological effects of contaminant on aquatic biota. This includes laboratory and field methods. Will work closely with Goal 1 and CERC.
Statistician	GS-12/13/14	0.5	FY13-FY22	Provides statistical guidance on the design of studies, interpretation of results, and the development of management models. Will work closely with HST.
GIS specialist	GS-12/13	0.5	FY13-FY22	Serves as a Geographic Information Systems (GIS) analyst for the national NAWQA Stressor-Effects Team.
DB specialist	GS-12/13	0.5	FY13-FY22	Serves as database analyst for the national NAWQA Stressor-Effects Team.

Science Plan Funding

The Full Science Plan Scenario is \$13M a year and therefore involves a substantial increase in both staffing and studies. The following elements would be added under this scenario.

1. Addition of the four regions in Table 5.1, which would greatly increase geographic coverage.
2. Additional sites would be added to each RSS.
3. A subset of sites within each RSS would be sampled seasonally for three years to assess temporal variability in stressor-response.
4. Addition of extensive work at intensive sites (which could include some of the long-term sites). This work would include stream experimental work on stressors, as well as laboratory experiments to help partition stressor effects.
5. Addition of detailed work assessing the influence of specific management practices such as BMPs in agricultural or urban lands.
6. Additional work on climatic and extreme events, including flood events or drought.

Timelines

Seven major studies are recommended under the Current Funding Scenarios. These studies are sequenced in order to accommodate issues surrounding planning, field work, and time for interpretation, analysis, modeling, and report preparation.

Table 5.5. Timeline for completing the six studies outlined under the Current Funding Scenario [AG, Agricultural RSS; SA, Streamflow Alteration RSS; URB, Urban RSS]

	Fiscal Year	Type	12	13	14	15	16	17	18	19	20	21	22
1	Upper Midwest (NARS)	AG	Plan	Field	Lab	Report							
2	Western Cordillera (Mt)	SA	Plan	Field	Lab	Report							
3	Atlantic Highlands	SA		Plan	Field	Lab	Report						
4	Southeastern	URB	Plan	Plan	Field		Lab	Report					
5	West Cold Desert	AG			Plan	Field		Lab	Report				
6	Mediterranean CA	URB					Plan	Field		Lab	Report		
7	Ozarks/Appalachian Forest	SA							Plan	Field	Lab	Report	

Products

Fact sheets and mini-circulars

These products will be disseminated largely to the general public and non-technical audiences and will be focused on either a specific region or topic. For example, a fact sheet will be produced that highlights NAWQA findings on the ecological effects of streamflow alteration within each region where it is assessed. In addition, one or more mini-circulars (i.e., <25 pages) will be produced periodically during Cycle 3 that summarize streamflow alteration findings across all study regions—from a national perspective.

Web-based information

These products will be intended largely for the general public and non-technical audiences. A central web site will be developed that summarizes the objectives, study areas, and expected products from Goal 3. As findings from specific studies become available, maps showing the study area, sampling sites and summaries of findings will be made available as a link to the main web page. For example, press releases of major findings for each study will include a link to the web site as well as the link where the interested public can explore, on a map-driven interface, locations and results from each sampling site. A user interface similar to WaterWatch will be adopted.

Web-based tools

These products are intended for assessment practitioners and other technical oriented people. A link to the main web page will lead to an array of web-based tools. These tools will include a wide range of complexity. For example, simple regression models showing ecological responses to streamflow alteration across a region will be displayed and described. At the other extreme, Bayesian network models that allow users to interact with the model and generate predictions will also be included.

Technical reports and publications

These products will serve as the foundation of the aforementioned products and are intended for the technical audience. Emphasis will be placed on publishing in scientific journals that are widely read and highly cited. Examples of some publications could include:

- Understanding the influence of streamflow alteration on stream communities and processes: a comparison of major land use settings.
- Comparison of major stressor gradients in contrasting urbanizing systems.
- The influence of urban and agricultural stressors on stream communities of the Mediterranean California ecoregion.
- Identification of metrics and species traits that best characterize responses to specific stressors in urban and agricultural lands.
- Implication of management practices on the physical, chemical, and biological condition of agricultural systems in the Mediterranean California ecoregion.

Chapter 6-Recommendations for Forecasting and Model Development

Model development and technical support in Cycle 3 will be provided by the Hydrologic Systems Team (HST). The HST will continue to improve spatial extrapolation tools, such as the steady-state SPARROW model, and the team also will develop modeling approaches to forecast the effects of changes in climate and land use on water-quality and ecosystem conditions over time. To accomplish these goals, the HST will work closely with the other Cycle 3 science teams.

This chapter of the implementation plan includes four sections related to forecasting and model development: (1) an approach for developing and applying forecasting tools, (2) funding levels and staffing for forecasting and the Hydrologic Systems Team, (3) recommendations for SPARROW model development, and (4) priority tasks and timeline.

Section 1-An approach for developing and applying forecasting tools

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

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

In Cycle 3, NAWQA will develop tools for scientists, water-resource managers, and policy makers to predict the effects of changes in land use, water use, and climate on water quality and the suitability of water for human and aquatic ecosystem needs. These tools will be based on models and decision-support systems that already have 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—the effects of human activities, climate change, and management strategies on water quality and ecosystem conditions. In addition to developing modeling tools, NAWQA will assess and report on the effects of human activities, climate change, and management strategies on water quality and ecosystem conditions on a national level and at selected study areas. The planned outcome is:

“Improved understanding of how human activities, climate change, and management strategies might affect future water quality (both physical and chemical aspects) and ecosystem conditions.”

Products:

- Models that predict how the use and management of land and water, along with climate change, are likely to affect future water quality (both physical and chemical aspects) and ecosystem conditions.
- Model-based decision-support system (DSS) tools for scientists, 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.
- Reports describing studies that assess the potential effects of climate and land-use change, together with management strategies, on water quality and ecosystem conditions.

Objectives:

Objective 1: Develop water-quality models for predicting the effects of changes in climate and land use on water quality and ecosystem conditions.

Objective 2: 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.

Objective 3: Predict the physical and chemical water-quality and ecosystem conditions expected to result from changes in climate and land use for selected watersheds and at a national scale.

Overall approach and organization of teams:

Cycle 3 forecasting objectives will be accomplished by a combined effort of the Surface Water Assessment (abbreviated as SW in this plan), Groundwater Assessment (GW), Integrated Watershed Study (IWS), Stressor Effects Studies (Ecology), and Hydrologic Systems teams (HST) and the Center for Integrated Data Analytics ([CIDA](#)). The leader of the HST will be responsible for coordinating the Cycle 3 forecasting efforts.

1. Modelers on the SW, GW, IWS, and Ecology teams will work with the HST to evaluate the suitability of existing NAWQA models for forecasting and make required modifications.
2. The HST will coordinate the development of required ancillary datasets, including historical climate data, climate-change forecast scenarios, reconstruction of historical land cover based on land-change models, and land-change forecast scenarios. Assembling the ancillary datasets will require assistance from the national group of NAWQA GIS specialists as well as Climate and Land Use (CLU) Mission Area geographers.
3. The HST and CIDA will coordinate the development of decision-support system (DSS) tools.
4. Modelers on the SW, GW, IWS, and Ecology teams, with technical support from the HST and CIDA, will conduct and document studies that evaluate the effects of climate and land-use change at a national level and for selected watersheds and regions.

It is important to note that the HST will provide technical support for all NAWQA efforts in Cycle 3, not just the forecasting objectives.

Forecasting tasks:

Task 1-Evaluate the suitability of existing models for forecasting and make required modifications

A variety of water-quality and ecosystem models was developed by NAWQA during Cycles 1 and 2 (Table 6.1) and will be considered as forecasting tools. The preference for evaluating NAWQA models reflects the advantages of using models for which the USGS already has significant expertise. This expertise provides knowledge regarding appropriate model applications and ability to modify models as necessary. These models will be evaluated in terms of their suitability for predicting the effects of changes in climate and land use on water-quality and ecosystem conditions. Some of these models may be useful “as is” for addressing forecasting objectives, and others will be enhanced to improve their utility for forecasting.

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

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

Other models, including the USGS Precipitation-Runoff Modeling System (PRMS) and the USDA Soil and Water Assessment Tool (SWAT) may be used in forecasting studies. PRMS simulates flow and sediment fluxes in streams, whereas SWAT simulates a variety of water-quality constituents. In addition, simplified versions of complex models (meta-models; for example, Nolan and others, 2012) and combinations of models (multi-models; for example, Wiley and others, 2010) also will be considered.

Ecological models have been developed for NAWQA in a variety of geographic and land use settings and can serve as a basis upon which to build upon for future models for bioassessment and forecasting. Complex hierarchical models have been developed to describe the interaction of natural factors with urban land use to describe their effects on biological communities in nine diverse environmental settings across the U.S (Qian and others, 2010). Bayesian models have been developed for the northeastern U.S. that provide a strong foundation for decision-support tools related to human disturbance and biological condition in streams (Kashuba and others, 2012). Structural equation models were developed for eight areas across a gradient of agricultural intensity that highlight some of the

important direct and indirect factors affecting biological condition (Riseng and others, 2011). Lastly, watershed disturbance predictive models have been developed for select watersheds in the western and eastern U.S. that relate the effects of landscape human disturbance (for example, population density, urban and agricultural land use, road density, and manmade channels) to macroinvertebrate indicator metrics (Waite and others, 2010). Together these models can serve as a strong foundation upon which to build more detailed models that can be used to do scenario testing and forecast modeling in Cycle 3.

Many of the existing NAWQA models (Table 6.1) estimate steady-state water-quality conditions. SPARROW, for example, predicts mean-annual fluxes of nutrients and sediment throughout a river network as a function of sources applied to the land surface, land-to-stream delivery factors, and in-stream attenuation factors. In the SPARROW model for nitrogen, mean-annual nitrogen flux is a function of sources (including land use, fertilizer, atmospheric deposition, and wastewater discharge), land-to-water delivery factors (precipitation, temperature, soil permeability, and extent of tile drainage), and attenuation factors (instream decay). Regression coefficients that represent the strength of the delivery and attenuation factors are determined through calibration of model-estimated fluxes to measured fluxes at or near streamgages. After the model has been calibrated, some scenarios of changes in land use or management practices can be evaluated by increasing or decreasing specific sources. Similarly, climate-change scenarios, which would be expected to alter the fraction of sources delivered to streams, can be evaluated by adjusting land-to-stream delivery factors. Results from these types of model application indicate the long-term steady-state effect of a specified land use or management change. These types of scenario applications, however, do not provide any information about the lag time between a change in land-use management and its subsequent effect on water quality.

SPARROW has been used in a number of analyses involving forecasted responses of water quality to changes in causative factors. The model has been used to evaluate the effects of a U.S. Environmental Protection Agency (USEPA) regulation for the suspended sediment content of runoff from construction sites (Schwarz, 2008), and the regional nutrient SPARROW models for New England and the Chesapeake Bay have been used to evaluate changes in source loadings associated with proposed water-quality regulation (Moore and others, 2004; Preston and Brakebill, 1999; Brakebill and others, 2010). Preliminary SPARROW analyses have investigated the effects of expanding the prevalence of confined animal feeding operations (CAFOs) on nutrients and pathogens, and the national SPARROW model has been used to design cost-efficient control strategies for reducing nitrogen delivery to estuaries. Additionally, SPARROW has been used to provide a preliminary evaluation of the effects of expanded bio-fuel production, primarily through increased production of corn, on nutrient loads.

Each of the SPARROW studies, listed above, forecasts changes in water quality by altering the source inputs to the model; the transport coefficients of the model were unaltered in the analyses. The main limitation to the application of SPARROW in these types of analyses, as compared to other deterministic models such as SWAT, concerns SPARROW's lack of controls; SPARROW has a coarse, empirically-based representation of the delivery process that does not articulate all the possible factors affecting contaminant transport. This limitation can be overcome by coupling SPARROW with a deterministic model that can simulate the delivery of contaminants to the edge of a field, allowing SPARROW processes to evaluate the remaining delivery to stream channels. Such an approach was utilized in the analysis of the USEPA construction rule (Schwarz, 2008). Further research evaluating this approach will be conducted in Cycle 3.

Steady-state statistical models—which comprise most of the models listed in Table 6.1—are developed through calibration 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 pattern, of the monitoring data and the explanatory variables. Using such a model to represent changes over time is possible, but only if variations over time have the same effect as differences across space. This “space for time” substitution assumes that, for example, differences in fertilizer application rates over space have comparable effects on water quality as changes in fertilizer application rates over time. The validity of this assumption will be tested for each potential forecasting model through backcasting, in which the steady-state model that has been calibrated to current conditions is used to estimate historical water-quality conditions based on historical explanatory data. If the estimated backcasted water-quality conditions reasonably match monitored data, then the “space for time” substitution can be considered valid.

Lag time information is critical to understanding relations between changes in environmental drivers and subsequent effects on water quality. The lack of lag-time estimates in most steady-state models does not apply to a dynamic model, which simulates transient conditions; therefore, one of the model-enhancement objectives 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” constituents (such as nutrients or sediment) and also specifying input time series such as monthly or seasonal values for fluxes of water and chemicals. Like steady-state models, dynamic models need to be evaluated using backcasting.

A transient model is not necessarily required to evaluate the lag time between changes over time in land use and/or climate and changes in water quality. For example, the steady-state version of MODFLOW predicts spatial patterns of flow paths and statistical distributions of travel times; these variables can be used to evaluate time lags required for a change at the land surface (such as fertilizer application) to propagate through the system (Kauffman and others, 2001). In addition, one of the HST goals for Cycle 3 is to develop geospatial maps of lag times based on simple models that can be applied across the conterminous U.S. (See the ancillary data section.)

The criteria that will be used to evaluate the suitability of NAWQA models for forecasting and identify potential necessary modifications are:

- Applicability at watershed, regional and/or national scale
- Explanatory or input variables that represent environmental drivers or stressors expected to change in the future
- Dependent variables that represent stressors or receptors relevant to stakeholders
- Acceptable levels of uncertainty as determined through backcasting

Task 2-Develop ancillary datasets

A variety of ancillary datasets are required to support forecasting objectives in Cycle 3. Most of these datasets also will be used to accomplish other SW, GW, IWS, and Ecology objectives. Some of the most critical datasets for forecasting are listed below. Development of these datasets will be done by the national GIS team and the HST.

Streamflow information:

The fate and transport of water-quality constituents, as well as aquatic ecosystem conditions, are highly dependent on the fluxes of water through streams and rivers. Estimates of runoff and streamflow—for both historical periods and future conditions—are needed to backcast and forecast water-quality and ecosystem conditions. Given that NAWQA models often are used to estimate conditions at ungaged sites, methods are needed to predict streamflow information for all streams and rivers in the commonly

used digital networks, namely USEPA's River Reach File 1 ([RF1](#)) and National Hydrography Dataset ([NHDPlus](#)).

Two general approaches have been used by the USGS to estimate streamflow information at ungaged sites. One approach is to use statistical methods to interpolate flow measured at streamgages to ungaged locations (Brakebill and others, 2011). The other approach is to use simulation models based on physical concepts to predict streamflow time series. The time step of these simulation models varies from daily (for PRMS) to monthly or annual (for water-balance models) (McCabe and Wolock, 2011). Simulation models are particularly useful for forecasting applications because climate-change scenarios can be processed by such models in a straightforward manner to predict future streamflow conditions. Both statistical and simulation approaches will be used in Cycle 3 to produce the required streamflow information.

Climate:

Climate data—primarily precipitation and temperature—are key to the accomplishing the forecasting objectives. Climate data are needed as input to models for quantifying hydrologic conditions, and climate variables also directly affect water-quality and ecosystem conditions. Examples of direct climate effects are the influence of precipitation intensity on overland flow and the effect of air temperature on stream temperature.

Historical climate data are widely available at a variety of spatial and temporal resolutions. The PRISM ([Parameter-elevation Regressions on Independent Slopes Model](#)) Climate Group provides precipitation and temperature data for the conterminous U.S. at monthly time steps for the period 1895 to present at a spatial resolution of 150 arc-seconds (about 4 km). In addition, mean-monthly and mean-annual climate data for the time period 1971-2000 can be obtained at 30 arc-seconds (about 0.8 km) resolution.

Historical meteorological data collected at National Weather Service stations are available from the National Climatic Data Center ([NCDC](#)). Most of the sites (11,000) are in the Cooperative Observer Program (COOP) network and report daily precipitation along with daily minimum and maximum temperature values. Also, the North American Land Data Assimilation System ([NLDAS-2](#)) provides a variety of meteorological variables at hourly temporal resolution on 450 arc-second (about 12 km) resolution for North America.

Future climate scenarios are based on output from global climate models (GCMs). Typically, GCM data are downscaled (the spatial resolution of the climate predictions is enhanced) using various approaches. The National Research Program's Modeling of Watershed Systems ([MOWS](#)) project has expertise in acquiring and using downscaled GCM data. NAWQA will use tools developed by MOWS and CIDA to obtain climate change scenarios and link them to hydrologic and water-quality models.

Land use and related datasets:

Modeling water-quality and ecosystem conditions requires accurate land-use data. High quality land-use data are needed both for evaluating models with backcasting and constructing the best possible forecasts. Land-use data typically are generated by combining interpreted satellite images with urban and agricultural census information. Land-change models, calibrated to land-use data, then can be used to backcast historical land use and forecast future land use.

The USGS has made significant progress in backcasting and forecasting land-use changes. The FORE-SCE (FOREcasting SCenarios of land use change) model (Sohl and others, 2012) has been used to generate scenarios of future land use for the conterminous U.S. on a 250-m resolution grid out to the year 2050. The same model has been adapted for backcasting and will be applied back to 1950. These land use

estimates for historical and future conditions will be used in Cycle 3 for model testing and for forecasting future water-quality conditions at the national scale.

Land-use data must be combined with other information to provide the necessary inputs to water-quality models, such as the amount of pesticide or fertilizer applied to the land surface. The required estimates of chemical sources such as fertilizers and pesticides have been developed by combining annual state-level sales data with 5-year interval county-level census information and geospatial land use data. Other sources, such as manure, are derived from 5-year interval census data. Reasonable estimates of nutrient sources back to 1950 are available, whereas pesticide use information prior to 1990 will be highly uncertain. In addition, pesticide monitoring data prior to 1990 are sparse. Linking spatially generalized chemical use information with land-use data will be a high priority ancillary data need for Cycle 3.

Land-use change models and other input datasets most likely will need to be customized to address NAWQA's regional and watershed-scale forecasting studies, such as those planned for Integrated Watershed Study (IWS) areas. For examining future land-use effects on streamflow, for example, information on water storage and domestic, industrial, and agricultural water use would be critical. Different crop types and environmental settings have different irrigation requirements, so land-use models might need to simulate changes in specific crops rather than generalized changes in "agriculture" or "cropland". Moreover, investigating the water-quality impacts of future population growth will likely require forecasts of future populations on sewer versus septic waste-water systems and assumptions regarding treatment technologies.

National land-change scenarios, such as those developed to support the USGS Land Carbon project (Sohl and others, 2012), probably are suitable for a national SPARROW-based forecast but will either have to be significantly modified or completely redone to achieve relevance for local stakeholders in specific basins. For example, in the Chesapeake Bay watershed, county planners were involved in crafting future scenarios so that the scenarios could inform county-level planning decisions. Generic land-change models (Claggett and others, 2004) were customized in order to simulate the effects of housing infill/redevelopment, land conservation, zoning and other policies that could be implemented by local governments. If NAWQA wants to inform local decisions, then the groups whose decisions might be informed by future scenarios need to be involved in their development in order for the scenarios to be relevant. Development of such customized, regional-scale scenarios will be a significant effort; the Water and CLU Mission Areas can, potentially, jointly plan and support the development of locally meaningful land-change scenarios.

Another important component of land-use information is data that describe how agricultural and urban lands are managed. Agricultural management data are available from a variety of sources such as the USDA National Resources Inventory (NRI) but, in general, the data are aggregated to 8-digit hydrologic unit or county levels resulting in a coarse resolution. One of the challenges for NAWQA is to obtain agricultural practices and management data at a finer resolution. An approach that has potential is to combine remotely sensed data with other information to infer spatial patterns of management practices. For example, satellite-based crop data ([Cropland Data Layer](#)) have been combined with a digital soils map (such as [STATSGO](#)) to infer locations where artificial drainage practices were most likely implemented (Baker and Capel, 2011). Another approach to improving the spatial detail of management practice data involves obtaining special permission to access NRI farm-level data and producing an information product that does not reveal specific location and ownership information. This approach recently has been piloted for the conterminous U.S. and will be pursued further in Cycle 3.

Hydrologic process variables:

Estimates of lag time are critical to predicting the length of time between a change at the land surface and a subsequent effect at some location in a groundwater system or a stream. In groundwater, lag time is defined as the time it takes for water (and associated solutes) to move from the point of recharge to the point of discharge. For a stream, the lag time through groundwater can help explain why concentrations of chemical constituents in streams might not decrease (and could even increase) immediately after a solute source is reduced or eliminated. Similarly, contaminant concentrations might increase in concentration over a long time period after the source of the contaminant is reduced or eliminated in recharge.

Lag times can be computed with models of varying complexity. In some cases, fairly simple equations—often referred to as lumped-parameter models—can be used to estimate a lag time or lag time distributions (Abrams, in review; Haitjema, 1995; Luther and Haitjema, 1998; Vitvar and others, 2002). In other more complicated cases, such as an aquifer with significant pumping or varying recharge, a more complex numerical model might be required. In Cycle 3, both types of analysis will be done.

Another hydrologic variable related to forecasting the effects of climate and land change on water quality is identification of the dominant flow paths of water delivered to streams. Estimating the relative importance of overland flow, tile-drain flow, and groundwater discharge in streamflow is necessary to predict how water quality in streams responds to changes in climate and land use. Some progress was made in Cycle 2 to quantify flow-path components (for example, Wolock, 2003), but additional work is needed. New approaches will be pursued in Cycle 3 to estimate the various flow-path components in streamflow for ungaged streams and rivers. One example of a new method is base-flow separation (estimation of the percentage of groundwater in streamflow) using chemical tracers instead of traditional hydrograph analysis (Sanford and others, 2012).

Task 3-Develop decision-support tools

One of the primary forecasting products is model-based decision-support tools for scientists, managers, and policy makers. Useful tools range from comprehensive multi-purpose decision-support systems to simple focused tools.

An example of a comprehensive system is the web-based decision support infrastructure that already has been developed to provide access to NAWQA models of stream water-quality conditions (Booth and others, 2011). This system offers sophisticated scenario testing capabilities for research and water-quality planning via a graphical user interface. This DSS is provided through a web browser, 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 modeled scenarios of future conditions, and generate maps illustrating model predictions at various scales.

Currently, NAWQA's DSS includes steady-state SPARROW nutrient and sediment models. The most important enhancements to the DSS for Cycle 3, which will be completed by CIDA, are (1) support more models in addition to SPARROW, (2) explicit depiction of predictive reliability, (3) seamless access to land-use and climate change scenarios that are used to estimate the effects of various change scenarios on water quality, and (4) enhanced functionality for scenario testing. A few details regarding these enhancements are described below.

Support additional models:

- Models previously developed by NAWQA—such as WARP, MODFLOW, and structural equation models—with enhancements for prediction and forecasting

- New SPARROW models for carbon, temperature, dissolved oxygen, pesticides and salinity
- Models developed and supported outside of NAWQA, such as [PRMS](#) and [SWAT](#), that provide functionality (such as daily time-step simulations) unavailable in widely used NAWQA models

Predictive reliability:

Quantification of model reliability is crucial for meaningful model predictions. Placing model predictions within a reliability/uncertainty context is essential to avoid over confidence or misinterpretation by the DSS user.

Seamless access to climate and land-use change scenarios:

Two USGS projects—the [Center for Integrated Data Analysis](#) and the [Modeling of Watershed Systems Project](#)—are collaborating to develop seamless access to a variety of climate and land-use change scenarios. The term “seamless” indicates that a user accessing the DSS web site through the internet would be able to choose, in an intuitive and straightforward way, both a change scenario and model to evaluate the effects of climate and land-use change on water quality and aquatic ecosystem condition. Climate and land-use change scenarios are constantly evolving, and several sources of scenarios that could be used to drive transient water-quality or ecological models will be evaluated.

Enhanced functionality for scenario testing:

- Perform simulations using a user-supplied source scenario file
- Capability to perform economic analysis would take cost and effectiveness information for various user-defined control measures to design control strategies meeting designated water-quality standards or pollution reduction goals at minimum cost
- Allow for the adjustment of transport processes, providing the necessary functionality for application of the DSS to evaluate climate-induced changes in water quality

Another type of DSS will be developed based on statistical models. If models are constructed such that explanatory variables include the factors describing a change of interest (such as climate or land use), then an interface can be developed to help a user visualize graphically how changes in the explanatory variables might affect a target constituent (for example, a map of concentrations). Bayesian network models (Kashuba and others, 2012) are an example of a type of statistical model that can be the basis of a DSS. A network analysis shows how different variables are related to each other and allows a user to see how a change in one variable propagates to changes in other dependent variables.

Conceptual decision-support systems also can be developed. Such a system could be based on actual models but packaged to demonstrate generally applicable concepts rather than processes specific to a certain location. An example might be an application where a travel time distribution is generated given a few basic parameters of a groundwater well, and different scenarios of land use and (or) climate change could be chosen by the user resulting in a forecast of how concentration might change over time based on the selected scenario.

The specific choices for decision-support systems that will be implemented in Cycle 3 will be determined over time based on available resources and, importantly, feedback from interested groups who would be likely to use such tools.

Task 4-Conduct studies to evaluate the effects of climate and land-use change at a national level and for selected watersheds and regions

In addition to providing models (Objective 1) and an associated decision-support system (Objective 2), NAWQA will complete selected studies of the potential effects of climate, land use, and water use changes on water quality and ecosystems. The geographic scope of some of these studies will include the entire conterminous U.S. Other forecasting efforts will be conducted in selected regions and groundwater flow systems. The specific location of these studies has not yet been determined.

Personnel from the SW, GW, IWS, and Ecology teams will lead the forecasting studies; that is, scientists from the SW, GW, IWS, and Ecology teams will assume responsibility for all aspects of the forecasting studies, including report writing. In addition, most of the costs for these studies will be covered by the SW, GW, IWS, and Ecology team budgets. Technical support for all of the studies will be provided by HST personnel funded under the HST budget.

Surface water assessment: Status and trends assessment is the highest priority for surface water assessment. It is likely, however, that there will be opportunities in the latter half of the decade to examine, at the national scale, the potential effects of changes in land use and management, along with climate change, on water quality using SPARROW and WARP.

Groundwater assessment: Groundwater flow and particle-tracking models developed in Cycle 3 will be used to estimate groundwater age distributions and lag times for contaminants transported from sources to wells or discharged to streams. The age and lag time estimates will be combined with chemical degradation rates and redox conditions to predict the fate of contaminants. Climate and land-change scenarios will be used with the hydrologic information derived from groundwater models to backcast and forecast conditions at drinking-water supply wells and groundwater discharging to streams. A vadose zone model also may be used to evaluate the effects of climate changes on groundwater recharge and the transport of chemicals to the water table.

Integrated watershed study: The integrated watershed study areas will be a primary focus for developing and testing models that can be used for forecasting. The IWS candidate areas were specifically chosen because of the richness of available historical water-quality monitoring data. These data, together with historical climate and land-use geospatial information, will provide the opportunity to test NAWQA models through backcasting. Backcasting is the most informative test of whether a model can realistically predict changes in water quality over time due to changes in climate, land use, and land management. If a model can be shown to accurately show the effects of changes in environmental drivers during the past, then the model can be applied forward in time to predict future water-quality conditions.

After forecasting approaches have been tested, they will be applied in the IWS areas to evaluate the effects of climate and land-change scenarios on water quality. The results of these studies will be presented in reports and journal articles.

Stressor effects studies: Ecological models will be developed for two types of forecasting/prediction objectives: (1) assessing the implications of specific management strategies on ecosystem conditions, and (2) evaluating the impacts of environmental variability, such as changes in climate, on aquatic ecosystems. Decision analysis methods will be used to integrate information from these modeling studies to determine the decisions that optimize current or future ecosystem conditions. It is anticipated that network models, such as structural equation and Bayesian network models, will be used to build decision-support tools.

Section 2-Funding Levels and Staff for Forecasting and the Hydrologic Systems Team (HST):

The Cycle 3 funding targets for the HST are shown in Table 6.2. The first year budget target value (\$2M) was determined by the Cycle 3 Planning Team (C3PT) and the NAWQA National Leadership Team (NLT). The budget target after the first year (FY13) is discounted by 4% for each successive year.

Table 6.2. Cycle 3 budget targets for forecasting. The budget target is \$2M in FY13 and is discounted by 4% for each successive following year.

Forecasting: Current Funding Scenario budget targets (millions of dollars per year)									
FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
\$2.00	\$1.92	\$1.84	\$1.77	\$1.70	\$1.63	\$1.57	\$1.50	\$1.44	\$1.39

The HST will provide technical support for all NAWQA goals, but about half of the total HST effort will focus on coordinating and supporting the forecasting objectives. The HST will include a lead scientist (1 FTE/year for 10 years), a GIS specialist (1 FTE/year for 10 years), modelers (4 FTE/year for 10 years), and a GIS coordinator (0.5 FTE for 10 years) (Table 6.3). Note that the cost for the GW modeling position is funded half by the HST (indicated in Table 6.3) and half by the groundwater study team. Similarly, the aquatic ecosystem modeling position is funded half by the HST and half by the ecosystem effects team.

Table 6.3. Hydrologic Systems Team composition in Cycle 3

Position	Grade	FTE	Duration	Position description
Hydrologist-HST coordinator	GS-14/15	1	FY13-FY22	Oversees the HST; coordinates forecasting tasks; coordinates with program managers in NAWQA, technical offices, National Research Program (NRP), and other agencies
Geographer-GIS coordinator	GS-13/14	0.5	FY13-FY22	Coordinates development of an integrated ancillary data and analysis system; coordinates NAWQA's geographically distributed national group of GIS specialists
Geographer-GIS specialist	GS-12/13	1	FY13-FY22	Provides GIS support to the HST and NAWQA study teams; develops improved geospatial analysis methods; works with GIS specialists in other USGS projects to enhance modeling tools
Ecologist-Model developer	GS-13/14	0.5	FY13-FY22	Develops improved models; supports modeling and data analysis in NAWQA study teams; coordinates model development with the NRP, technical offices, and other agencies
Hydrologist-Groundwater model developer	GS-13/14	0.5	FY13-FY22	Develops improved models; supports modeling and data analysis in NAWQA study teams; coordinates model development with the NRP, technical offices, and other agencies
Hydrologist-SPARROW model developer	GS-13/14	1	FY13-FY22	Develops improved models; supports modeling and data analysis in NAWQA study teams; coordinates model development with the NRP, technical offices, and other agencies
Hydrologist-SPARROW model developer	GS-14/15	1	FY13-FY22	Develops improved models; supports modeling and data analysis in NAWQA study teams; coordinates model development with the NRP, technical offices, and other agencies
Economist-SPARROW model developer	GS-13/14	1	FY13-FY22	Develops improved models; supports modeling and data analysis in NAWQA study teams; coordinates model development with the NRP, technical offices, and other agencies

Specific tasks of the HST will evolve as Cycle 3 progresses, but the primary focus of the HST will be on providing technical support of the forecasting objectives. These tasks will entail (1) model development, (2) development of high priority ancillary data, (3) piloting new modeling approaches, such as meta-models and multi-models, and (4) working with CIDA to improve decision-support tools. These tasks are described in prior sections of the forecasting implementation plan. A discussion of SPARROW development tasks for Cycle 3 is in the section that follows.

The estimated budget for all of the HST positions (6.5 FTE) in Table 6.3 is \$1.5M/year. The difference between the HST personnel costs and the budget target values is shown in Table 6.4. This difference initially is \$0.5M in FY13 and decreases to zero in FY20. This funding will be used by CIDA to enhance existing decision-support system tools to include functionality required for forecasting, such as access to climate and land-use change scenarios. The funding also may be used to support the development of high priority ancillary datasets, such as land-change scenarios.

Table 6.4. Budget targets, HST costs, and CIDA funding support

Budget targets, HST costs, and CIDA funding support in millions of dollars per year										
	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Budget targets	2.00	1.92	1.84	1.77	1.70	1.63	1.57	1.50	1.44	1.39
HST	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Support for CIDA and ancillary data development	0.50	0.42	0.34	0.27	0.20	0.13	0.07	0.00	0.06	0.11

The SW, GW, IWS, and Ecology components as well as the HST will fund FTEs focused on the forecasting objectives. (The level of effort throughout Cycle 3 is shown in Table 6.5.) The three FTEs shown for the HST represent about half of the total 6.5 FTEs in the HST.

Table 6.5. FTEs focused on forecasting. The numbers indicate the FTEs funded by each study component for forecasting model development and application. The abbreviations in the table are SW (Surface Water Assessment), GW (Groundwater Assessment), IWS (Integrated Watershed Studies), Ecology (Stressor Effects Studies), and Hydrologic Systems Team (HST).

Forecasting effort (FTEs) funded by the SW, GW, IWS, and Ecology teams and the HST										
	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
SW	1	1	1	1	1	1	1	1	1	1
GW	1	1	1	1	2	3	4	4	3	3
IWS	0	0	0	0	0	2	2	2	2	2
Ecology	0	0	0	0	0	1	1	1	1	1
HST	3	3	3	3	3	3	3	3	3	3
Total	5	5	5	5	6	10	11	11	10	10

Section 3-SPARROW model development

SPARROW model development under Cycle 3 will proceed on two fronts: enhancements in the methodology used for model estimation and prediction, and expanding the suite of contaminants for which models are developed. The following describes a list of specific SPARROW enhancements for SPARROW considered for Cycle 3. These enhancements include those designed to address the

combined scope of all Cycle 3 SPARROW applications, including status assessment, integrated watershed studies, and forecasting. The ordering of the new developments in the following narrative is indicative of their overall prioritization for Cycle 3, although changing needs or a better appreciation for the difficulty of implementation could cause a change in this ranking. Generally, these modifications are independent of the ability to achieve success for the SPARROW products anticipated for Cycle 3; however, the highest priority is given to those enhancements that are prerequisites to key products.

SPARROW Model Methodology

The current SPARROW model has a number of limitations, making it unsuited for certain water-quality applications. The development plan for SPARROW in Cycle 3 calls for a number of methodological improvements that address these limitations. Each model development is expected to lead to a journal publication, with additional effort required to update the SPARROW documentation.

Dynamic SPARROW (Primary application to Integrated Watershed Studies)

Perhaps the most limiting feature of SPARROW concerns its exclusive modeling of the steady state water-quality condition. As explained in Schwarz and others (2006), the emphasis on the steady state is central to the imposition of mass balance. Unfortunately, restricting the model in this way makes it incapable of describing or explaining the range of contaminant concentrations and loads for a given location, particularly as these conditions relate to specific hydrologic events. Moreover, the exclusive focus on the steady state prohibits gaining an understanding of the adjustment of water-quality conditions to changes in the underlying causal variables. As described in recent literature (see, for example, Lindsey and others, 2003), water-quality conditions can be slow to respond to changes in causal factors.

To address this issue, a temporal dimension will be introduced to make SPARROW a dynamic model. The Integrated Watershed Studies planned for Cycle 3 require dynamic SPARROW models, so the realization of this capability receives the highest priority. The dynamic version of SPARROW will operate on a monthly or seasonal time step and include storage of contaminants as an integral feature of the model. Efforts are currently underway in Cycle 2 to achieve this capability and it is expected that a dynamic version of SPARROW will be demonstrated prior to the initiation of Cycle 3.

The dynamic SPARROW model is a simple extension of the existing steady-state models, whereby load leaving a reach in the current period is a linear function of load leaving the reach in the previous period. Functionally, this capability is achieved by simply stacking the watershed data required to estimate a SPARROW model period by period, producing an effective “watershed” consisting of “reach-periods.” This modification is straightforward, the only complication being the computational burden of modeling large regions having a large number of periods. This limitation can be met by restricting the analysis to smaller watersheds, using multiple observations of load over time to compensate for a smaller number of stations. The remaining principal complication introduced by the dynamic element concerns the determination of initial values for the previous period’s load, which must be evaluated for every individual reach in the study area. There are a number of approaches to solving this problem currently under evaluation.

Seasonal SPARROW/Multi-contaminant Model (Primary application to Surface Water Assessment)

A related approach to introducing a temporal element into SPARROW is to extend the steady-state analysis beyond the modeling of mean annual conditions to include the estimation of mean seasonal loads. This approach to dynamic modeling is conceptually simpler to implement than the dynamic model described above in that the model does not require initial values for the individual reach loads; rather,

implementation is by modeling multiple contaminants simultaneously, the multiple contaminants being the different seasonal values of the subject contaminant. As with the dynamic models, the seasonal models account for storage of contaminants across seasons.

The Cycle 3 plan for Surface Water Assessment calls for the modeling of mean seasonal conditions in addition to the standard mean annual conditions. Consequently, the modification of SPARROW to include multiple contaminants has a high priority. A capability to model multiple contaminants simultaneously has a number of applications besides the modeling of seasonal conditions (see the description of proposed exploratory SPARROW models for Cycle 3, below), so this feature should become an important component of the SPARROW model. For example, a multiple contaminant model could describe the transformation of nitrogen across its various forms, to model the size distribution of sediment, and to evaluate the common factors affecting the transport of a suite of pesticides.

A conceptual plan currently exists for introducing multiple contaminants into SPARROW, and significant progress on this feature is expected in Cycle 3. A primary feature of the multi-contaminant model is that it retains mass balance, a restriction that implies the multiple contaminants relate to each other using a linear functional form. The problem of partial data, whereby measurement of only some of the water-quality variables occurs at a given site, represents a technical challenge to the specification of the model.

Enhanced Error Structure (Applies to all SPARROW applications)

The existing SPARROW model is simplistic in the way it incorporates model error. Model error is additive in form, meaning that it cannot be ascribed to individual processes, and it is applied only at monitoring stations, implying it is not localized to specific spatial features of the model (i.e., to individual reaches; see Schwarz and others, 2006). This limitation makes it difficult to determine the error of model predictions, including the error of load estimates for a group of reaches, how error propagates downstream, and the error associated with the apportionment of load to specific contaminant sources.

A major effort in Cycle 3 will enhance the error structure of the SPARROW model by introducing multiple errors into the analysis. Errors will be associated with specific sources and processes of the model, and have a spatial referencing that affects their correlation across reaches. The enhanced error structure will better characterize the correlation of error across reaches, allow for the apportionment of unexplained load to individual contaminant sources, improve the assessment of error in that apportionment, and account for error in the monitored load estimates.

The proposed method is essentially a hierarchical design, and provides an alternative approach to regionalization than the fixed-effects method employed in a recent paper by Schwarz and others (2011). The introduction of multiple sources of error produces estimation problems in a SPARROW model because the error components enter the model nonlinearly, implying the model must be estimated using maximum likelihood methods. One approach to estimation is to use simulated maximum likelihood methods to integrate out the multiple error terms, but this approach may be computationally infeasible for large-scale models. A more feasible approach may be to form a linear approximation of the model in which the multiple error terms become additive. This approach results in a standard error-components model that is much easier to estimate. Unfortunately, this approach implies predictions from the model are also approximate and may require further correction to adhere to mass balance constraints.

Conditional Prediction (Applies to all SPARROW applications)

The current SPARROW model has the capability to condition predictions only on upstream monitored loads; it does not allow for the interpolation of load between monitoring stations. This implies that load

predictions conditioned on monitored values may exhibit abrupt changes at monitored reaches, an obvious inconsistency with actual loading conditions. The method also assumes no error in monitored load, an assumption that is inconsistent with the methodology used to estimate load. The enhanced error structure described above provides a statistical framework for optimally interpolating error between stations and for applying this information to improve the load predictions.

Conditional prediction represents the most efficient use of monitoring data. Under the current SPARROW methodology, without conditional prediction, the information from a monitored load is used in conjunction with all other monitored loads to collectively fit the model parameters. In this role, a monitored load has a relatively small marginal impact on model predictions. Conditional prediction provides each monitored value a much greater impact on model predictions, and affords each monitoring station its greatest informational marginal value. Quantifying this value, which is possible by comparing prediction accuracy with and without a given station's load estimate, provides a direct measure of a station's information value, and provides to network managers a better indication of the importance of individual stations.

The computational complexities described above for the enhanced error structure are pertinent to the discussion of conditional prediction. The method of specifying an approximate linear form for the components of error may facilitate the computational feasibility of this new prediction capability. Monte Carlo studies and sequestered data provide a means of validating the effectiveness of the methodology.

Frequency Distribution of Contaminant Concentrations (Applies to all SPARROW applications)

Many water-quality standards are expressed as limits on the frequency of occurrence of a given contaminant concentration. In order to evaluate these standards using a model, it is necessary for the model to describe the distribution of contaminant concentrations experienced at a given location. Many water-quality models address this need by dynamically modeling the hydrologic system using short time steps. However, the computational complexity of such a temporally high-resolution approach limits the spatial scale of the analysis.

Existing SPARROW models only address the mean water-quality condition, and even the proposed dynamic models will be too coarse temporally to provide an adequate evaluation of frequency of occurrence relative to existing water-quality standards. An alternative approach, one that retains the capability of large-scale modeling while providing information on the frequency of occurrence, is to extend the SPARROW model to explain the distribution of water-quality conditions. A simple way to proceed is to assume concentrations follow an approximate log-normal distribution. Such an assumption implies only two parameters characterize the distribution: the mean and variance. Existing SPARROW models effectively model the mean load condition, and coupled with an estimate of mean flow and the covariance between concentration and flow, it is possible to estimate a time-weighted average concentration (see Schwarz and others, 2006). The proposed approach, calls for extending SPARROW to directly model the variance of load and flow, thereby providing the information necessary (with an estimate of the covariance between concentration and flow) to estimate the variance of concentration.

The proposed approach has a number of advantages. Because the model has no time domain, it is possible to apply the model to large spatial scales, providing a cost-effective approach to the national evaluation of proposed water-quality standards. The model of the variance of load can retain the concept of mass balance, an important concept for the specification of a SPARROW model of mean conditions and for interpretation of model results. Perhaps most importantly, the approach provides the ability to provide a spatial and source accounting for the determinants of the variance of load. This information may be particularly useful to the design of management practices to achieve water-quality

standards in cases where violation is due to high variability in concentration rather than an excessive mean condition. It would be very useful to compare the approach to other standard approaches, such as the time-domain methods and WARP-type empirical models, which do not provide direct information on the causes of temporal variance in concentration.

Bayesian Analysis (Applies to all SPARROW applications)

Bayesian analysis represents an alternative approach to model estimation and evaluation. Unlike the existing SPARROW model, which uses weighted nonlinear least squares to determine the distribution of model parameter sample estimates, Bayesian estimates treat the model parameters as random variables and use the sample data to determine their inherent distribution. Under a Bayesian approach, model estimation is by simulation of the model for randomly selected values of the model parameters and residuals. The simulation approach is quite flexible and allows model specification to be structurally complex, although greater complexity generally implies the need for more simulations to achieve an adequate description of the parameter distributions. The method of simulated maximum likelihood, proposed for the estimation of SPARROW models with an enhanced error structure (see above), also requires simulation to obtain sample estimates of the parameters. However, in the case of simulated maximum likelihood, simulations pertain strictly to the iterative evaluation of the likelihood function, implying the fitting process ultimately discards many of the simulations. Bayesian analysis is more efficient in that, after an initial “warm-up” process, the evaluation of the final parameter distributions uses all simulations.

A Bayesian approach has other advantages. A SPARROW model is nonlinear in its parameters, and model predictions require correction for the bias induced by the nonlinear evaluation of the uncertain parameter estimates, a correction achieved using bootstrap analysis. Although the SPARROW model maintains mass balance, the imposition of the bootstrap correction slightly breaks this restriction (mass balance remains in the limit of model estimation, as sample sizes become large). Conversely, under Bayesian estimation, each simulation imposes mass balance, causing balanced mass in the final distribution of the model predictions. Consequently, no further correction of the distributions is required.

A Bayesian approach may provide a way to link SPARROW models across spatial scales. For example, due to computational complexity, the dynamic SPARROW models proposed for Cycle 3 must be limited to smaller watersheds. The size of these regions limits the variation of some of the contaminant sources and transport processes included in the study, making it difficult to obtain precise empirical estimates of their importance. A Bayesian approach allows for the transfer of information from one model to another model through the specification of the prior distribution for model coefficients. Thus, coefficients that are more accurately estimated using large-scale, steady-state models may be transferred to the smaller-scale dynamic models. The validity of this connection requires that a given coefficient in the steady-state model has the same interpretation in the dynamic model; if the two coefficients mediate inherently different relations the transfer of information across models is invalid. Additional analysis will be required to explore this potential.

The primary limitation to a Bayesian approach is the large number of simulations required to obtain a reasonable description of the parameter and prediction distributions. For example, the Bayesian SPARROW model developed for the Albemarle-Pamlico Sound watershed (Qian and others, 2005) required over a million iterations, implying over a million accumulation passes through the reach network. For comparison, a typical national SPARROW model estimated using nonlinear least squares requires less than a thousand accumulations of the network. The development of a Bayesian SPARROW

model will require a better understanding of implications of this computational limitation for model complexity and scale of the analysis.

Expanded List of Contaminants Modeled Using SPARROW

An important aspect of SPARROW model development concerns the range of contaminants included in model applications. New models for additional contaminants invariably lead to a new understanding of transport processes and innovative insights into the statistical properties of existing models. The models are also useful for germinating new interest in SPARROW from the academic and regulatory community.

Published SPARROW models currently exist for total nitrogen, total phosphorus, suspended sediment, dissolved solids and organic carbon. Additionally, there are exploratory SPARROW models for fecal coliform, streamflow, atrazine, temperature, and fish diversity. Development of many of these exploratory models will continue during Cycle 3, with particular emphasis on streamflow and pesticide models. Additional contaminants that should receive high priority for Cycle 3 model development are mercury, emerging contaminants, and chloride.

Although these models and existing models have some common factors affecting contaminant transport, each model is unique in terms of principal sources of contamination. Thus, the implementation of these models will require the development of new spatial data sets. Where feasible, model development will proceed with shared resources from other interested partners, with the expectation that outside interest factors prominently in model completion. Interest in additional models may also arise internally from NAWQA ecological studies, as a means of extrapolating stressors to evaluate ecological conditions in unmonitored streams.

The planned upgrade of SPARROW to allow for the simultaneous analysis of multiple contaminants should lead to a number of new contaminant models. One application would be to model the conversion of nitrogen between its alternate forms of nitrate, nitrite and Kjeldahl nitrogen to determine empirically the prominent factors affecting this conversion and to better identify the specific sources of each primary contaminant. Another application would be the modeling of the size distribution of sediment for an improved understanding of the determinants of fine grain material and the differential effects of factors affecting mobility and storage.

The level of dissolved oxygen in water is an important measure of a stream's ecological health and a key water-quality standard. A complete assessment of the nation's water quality requires a census of the stream miles having depleted oxygen. Due to high monitoring costs, a comprehensive assessment must partly rely on model estimates. A model of dissolved oxygen requires the simultaneous modeling of number of constituents and water properties, including the level of dissolved oxygen, temperature, salinity, and biochemical oxygen demand (and, possibly, carbonaceous biochemical oxygen demand to distinguish the importance of ammonia oxidation). The multiple contaminant version of SPARROW should provide the capability to adequately model dissolved oxygen. To characterize the level of dissolved oxygen under limiting conditions, at a minimum the model should describe summertime conditions, although a four-season model may be desirable.

The existence of a large number of contaminants, many having little monitoring data to form a viable statistical model, complicates the modeling of pesticides. One approach to this problem is to pool all pesticide data together and assume contaminant transport is a function of observable chemical properties, thereby restricting the number of free parameters estimated in the model. One analytical approach is to stack each contaminant in SPARROW, forming a pooled model that is analogous to the dynamic SPARROW model. Alternatively, a multiple contaminant model may be used.

A multiple contaminant approach is also appropriate for modeling the distribution of contaminant concentrations, such as the set of percentile concentrations currently modeled independently in WARP. The independent approach has the potential problem of generating predictions of individual percentile concentrations that “cross” each other; that is, without restrictions on the model coefficients, it is possible that the 20th percentile concentration is predicted to be greater than the 40th percentile. A multiple contaminant model would allow for restrictions on the coefficients to insure this situation never occurs.

The development of a multiple contaminant SPARROW model in Cycle 3 would make it desirable to port the WARP model into the SPARROW estimation framework. Such a transfer is technically feasible, even though WARP is a watershed model and SPARROW is a mass balance model. The only complication concerns the possible censoring of the dependent variable, which is common in WARP analyses. To accommodate censored data, SPARROW will use maximum likelihood as the estimation objective rather than least squares, a modification that should be straightforward.

The SPARROW development team will have the primary responsibility for creating new contaminant models in Cycle 3. Although most new SPARROW models will ultimately appear in journal publications, some models, depending on interest, will be documented through USGS publications. A primary objective with new model development is to expand the horizons of SPARROW to discover interesting new processes or applications, and to guide the development of additional models. The payoff from these models, therefore, will come equally from model implementation and dissemination.

Economic Analyses (Applies to all SPARROW applications)

The existing SPARROW modeling framework permits the development of least cost strategies for reducing contaminant loads to meet specified instream concentration and estuary discharge standards. Under Cycle 2, application of this framework led to the development of cost effective strategies for controlling total nitrogen. For Cycle 3, the methodology will be extended to other contaminants, including total phosphorus, suspended sediment, and dissolved solids. The definition of control options represents the greatest obstacle to implementing the method, a process that requires extensive literature search. Given a list of specified control options, expressed in terms of percent effectiveness (i.e., percent reduction) and cost per unit reduction, an automated algorithm readily provides the minimum cost solution.

The existing economic analysis framework can perform cost minimization for only a single contaminant at a time. In Cycle 3, the enhanced framework will identify minimum cost strategies for multiple contaminants simultaneously. A multiple contaminant capability is not a trivial extension of the single contaminant framework. The single contaminant method needs just one pass through the reach network to identify a minimum cost strategy; a multiple contaminant capability requires an iterative method, such as the heuristic simulated annealing algorithm. This additional level of complexity may limit the capabilities of the multiple-contaminant algorithm. For example, it may be necessary to identify water-quality targets for only a few reaches rather than all reaches, or the analysis may require a coarser spatial resolution.

The economic analyses proposed above produce a number of useful byproducts. The economic cost of pollution reduction provides a practical metric for evaluating network design. Reduction cost may serve as a common metric across multiple contaminants for the evaluation of an index of water quality. One approach along these lines is to compute the aggregate costs required for a group of contaminants to meet all water-quality standards. Such a metric, tracked over time, could determine if water-quality conditions are improving or declining.

Connections between SPARROW and WARP

The existing WARP model requires basin-level data, aggregated from the E2RF1 catchment data, for its estimation and prediction. In Cycle 3, WARP will use the NHDPlus reach network, the same data infrastructure as SPARROW. New algorithms will aggregate the NHDPlus information to provide basin attributes for WARP model estimation and prediction.

The Cycle 3 plan anticipates a number of SPARROW enhancements, many of these potentially useful for WARP modeling. For example, a multi-contaminant model would allow for the simultaneous estimation of the suite of concentration percentiles currently estimated independently with WARP. Simultaneous estimation of the percentile distribution is preferred to independent estimation as it allows for greater efficiency in the estimation process, can insure that predictions of percentiles are consistent (the 90th percentile is always greater than the 80th percentile), and can impose appropriate restrictions on the model functional form and parameter estimates. A multi-contaminant model also would be useful for determining the efficiency of contaminant transport according to common chemical and physical properties of the pesticides. The ability to interpolate predictions between monitoring stations on the reach network represents another SPARROW improvement that could lead to greater accuracy in WARP model predictions and simulations.

The realization of these SPARROW enhancements in Cycle 3 may make it desirable to port the WARP estimation and prediction capability directly into the SPARROW modeling system. Such a capability would require modifications to SPARROW to account for censored values of the dependent variable, implying a change in the SPARROW estimation methodology from least squares to maximum likelihood. This should be a relatively straightforward modification of SPARROW.

Section 4-Priority tasks and timeline

Some of the model development and forecasting tasks can be started immediately: assembly of ancillary data, evaluation and modification of models, and enhancement of decision-support tools. Most of effort in applying the models to evaluate the effects of climate and land-use change on water quality and aquatic ecosystems will take place in the latter half of the Cycle 3 decade. Table 6.6 shows lists of tasks, an expected timeline, the primary team responsible for the task, and the task priority.

Table 6.6. Task list, timeline, team with primary responsibility (listed in column labeled “Who”), and priority for model development and forecasting tasks in Cycle 3. FTEs focused on forecasting. The abbreviations in the table are SW (Surface Water Assessment team), GW (Groundwater Assessment team), IWS (Integrated Watershed Studies team), ECO (Stressor Effects Studies team), and Hydrologic Systems Team (HST).

Task	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Who	Priority
1. Model enhancements for forecasting												
Test steady-state SPARROW with backcasting				x	x	x					SW	High
Develop dynamic SPARROW	x	x	x	x	x	x					HST	High
Test dynamic SPARROW with backcasting				x	x	x	x	x			IWS	High
Test MODFLOW/MODPATH with backcasting				x	x	x	x	x			GW	High
Test WARP with backcasting				x	x	x	x	x			SW	High
Assess multi-model and meta-model approaches	x	x	x	x	x	x					HST	Low
Develop and test ecological models	x	x	x	x	x	x					HST	High
2. Develop ancillary datasets for forecasting												
Historical streamflow information	x	x	x	x	x						HST	High
Future streamflow scenarios	x	x	x	x	x						HST	High
Historical land and chemical use	x	x	x	x	x						HST	High
Future land and chemical use scenarios	x	x	x	x	x						HST	High
Historical land use linked to chemical use	x	x	x	x	x						HST	High
Agricultural management data	x	x	x	x	x						HST	High
Urban management data	x	x	x	x	x						HST	High
Lag time for streams and groundwater	x	x	x	x	x						HST	High
Dominant flow path information	x	x	x	x	x						HST	High
3. Decision-support systems (DSS)												
Improve MODFLOW pre-processor	x	x	x	x	x						HST	High
Improve MODFLOW post-processor	x	x	x	x	x						HST	High
Develop WARP DSS	x	x	x	x	x						CIDA	High
Develop MODFLOW DSS	x	x	x	x	x	x	x	x			HST	High
Develop DSS for stream ecology						x	x	x	x	x	CIDA	High
Develop DSS for PRMS						x	x	x	x	x	CIDA	Low
Develop DSS for SWAT						x	x	x	x	x	CIDA	Low
Incorporate economic analyses				x	x	x	x	x			CIDA	High
Incorporate model uncertainty	x	x	x	x	x	x					CIDA	High
Seamless access to climate scenarios	x	x	x	x	x						CIDA	High
Seamless access to land change scenarios	x	x	x	x	x						CIDA	High
Enhanced functionality for scenario testing	x	x	x	x	x	x	x	x	x	x	CIDA	High

Table 6.6 continued.

Task	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Who	Priority
4. SPARROW model development												
Seasonal models	x	x	x	x	x						HST	High
Multi-contaminant models	x	x	x	x	x						HST	High
Enhanced error structure	x	x	x	x	x						HST	High
Conditional prediction	x	x	x	x	x						HST	High
Frequency distribution of concentrations			x	x	x	x	x	x			HST	Medium
Bayesian analysis			x	x	x	x	x	x			HST	Medium
Fecal coliform model						x	x	x	x	x	HST	Low
Streamflow model	x	x	x	x	x						HST	Medium
Atrazine model						x	x	x	x	x	HST	Low
Dissolved oxygen model		x	x	x	x	x					HST	Medium
Temperature model	x	x	x	x	x						HST	Medium
Fish diversity model						x	x	x	x	x	HST	Low
Mercury model						x	x	x	x	x	HST	Low
Emerging contaminants model						x	x	x	x	x	HST	Low
Chloride model						x	x	x	x	x	HST	Medium
Economic analyses	x	x	x	x	x						HST	High
Integration of WARP into SPARROW framework	x	x	x	x	x						HST	Medium
5. Conduct forecasting studies												
Forecasts with dynamic SPARROW				x	x	x	x	x	x	x	IWS	High
Forecasts with steady-state SPARROW			x	x	x	x	x	x	x	x	SW	High
Forecasts with WARP						x	x	x	x	x	SW	High
Forecasts with MODFLOW						x	x	x	x	x	GW	High
Management effects on ecosystems						x	x	x	x	x	ECO	High
Environmental variability effects on ecosystems						x	x	x	x	x	ECO	High

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Appendix 1-Cycle 3 Implementation Planning Team Memo from Bill Wilber, July 25, 2011

From: William G. Willber
To: Distribution
Cc: gs-w nawqa nlt, gs-w nawqa c3pt
Date: 07/25/2011 07:44 AM
Subject: Request for your participation in developing the NAWQA Cycle 3 Implementation Plan

The purpose of this email is to request your help and participation in developing the implementation plans for the third decade (Cycle 3) of the National Water-Quality Assessment (NAWQA) Program. Many of you have already helped with development and advice that led to the completion of a science strategy for Cycle 3 that describes an updated 10-year strategy for national assessment of the quality of the Nation's freshwater streams and aquifers during 2013-2023. The science strategy for Cycle 3 is based on an evaluation of assessment progress by NAWQA and its partners during Cycles 1 and 2 (1991-2012) and an updated review of stakeholder priorities. The Cycle 3 plan maintains key characteristics essential to the Program's long-term success—such as national-scale relevance, method consistency, and partnerships—but also adjusts some of the approaches needed to face challenges driven by population growth, increasing demands for water, changing land use, and changing climate. A copy of the science plan is at the link provided here. The National Research Council has completed a review of the plan and provided a strong letter of support to the Director last winter. We expect their final report later this summer.

Now that the science strategy is completed, we're ready to move ahead on the implementation plan, which will include identification of specific products and outcomes associated with Cycle 3 goals and objectives, along with a more detailed discussion of the approach, resource requirements, budgets and timelines necessary to achieve those outcomes. The implementation planning will be organized by Cycle 3 goals and objectives. Each group will be led by one of the Cycle 3 Planning Team members. Each of you is being asked to participate in a specific team. The leaders of each team will begin organizing conference calls within the next few weeks to review the science strategy and the vision for the specific topics of focus for the team, and then to proceed with developing the first draft of the implementation plan.

We envision a 3-day meeting of the entire Implementation Planning Team and the NAWQA Leadership Team towards the end of September in Denver. The purpose of the meeting in Denver will be to check the status of current planning of the individual teams; make adjustments where necessary; but most importantly, to provide an initial opportunity to work on developing the connections and coordination between teams that are addressing objectives and activities that need to be linked together. Planning within and among teams will continue after the meeting in Denver. Our goal is to complete the implementation plan by the end of February 2012 so that key aspects of the plan can be included in the fiscal year 2013 work plan guidance.

We are envisioning that your involvement with the implementation planning process will require several weeks spread out over the next six months. Salary and travel expenses will be paid for by the NAWQA Program. You will be contacted shortly by the leader of the team you are being asked to work with to discuss this invitation; address any questions or issues you may have; and begin to schedule the initial discussions mentioned above. For those of you who are already working on NAWQA activities and are concerned that accepting this request will impact your ability to meet existing timelines for other high priority work (e.g. Cycle 2 reports), we share this concern. However, as a program, we have decided that the development of the implementation plan needs to take priority, because completing the plan

affects many people both within and outside of the program and over a long period of time. If you believe that your situation is unusual and would like to discuss it, please feel free to give me a call at (703) 648-6878.

The success of the NAWQA Program over the years is due in large measure to two factors--first and foremost the involvement of people like yourself that have strong technical backgrounds and have dedicated themselves to achieving the mission and goals of the program; and second, the substantial investment by the program in planning for the future. We hope that you will favorably consider our request and look forward to your continued contributions to the NAWQA Program.

Regards,

Bill

Appendix 2A-Contaminant Toxicity and Properties Team

Introduction

The Contaminant Toxicity and Properties Team will be a resource for and collaborator with all Surface Water and Groundwater Status and Trends Assessment Teams, but will be managed as part of the National Monitoring and Status Assessment Team for Surface Water. As part of many NAWQA water-quality studies, the potential significance of water-quality findings to human health and aquatic organisms is assessed. These screening-level assessments help to address the needs of the public, agency partners, and other stakeholders and are a first step toward understanding the potential significance of contaminant occurrence to human health and aquatic organisms. The Contaminant Toxicity and Properties Team will be a resource for NAWQA teams planning and conducting screening-level assessments and it will conduct its own assessments on priority human-health and aquatic-life topics.

In human-health screening-level assessments, contaminant concentrations in surface water and groundwater samples collected prior to treatment or blending are compared to human-health benchmarks. These benchmarks include U.S. Environmental Protection Agency (USEPA) drinking-water standards and guidelines, and Health-Based Screening Levels (HBSLs) developed by USGS in collaboration with the USEPA and others. A screening-level perspective on the potential significance of contaminants to aquatic life and fish-eating wildlife is obtained by comparing contaminant concentrations measured in surface water, bed sediment, and whole fish with benchmarks from USEPA and others for the appropriate environmental media.

In order to conduct these screening-level assessments, it is critical to have up-to-date information about the toxicity and physical-chemical properties of the contaminants analyzed by NAWQA. In addition, information on physical-chemical properties is necessary for developing water quality models and for assessing the likely environmental behavior and mobility of contaminants in surface and groundwater. The Contaminant Toxicity and Properties Team will be the primary source for these data for NAWQA assessments.

The primary responsibilities of the Contaminant Toxicity and Properties Team are in three main categories:

1. Benchmark and Database Maintenance—maintain and update human-health and aquatic-life benchmarks and physical-chemical property and related databases,
2. Emerging Topical Studies—conduct assessments on priority topics related to potential effects of contaminants, including the development of new benchmarks for emerging contaminants and the characterization and significance of chemical mixtures to humans and aquatic life as required for Cycle 3 studies, and
3. Status Assessments—participate in surface water and groundwater status assessments as project team members or leaders, with a particular focus on human health or aquatic ecosystem significance.

As detailed later, the Contaminant Toxicity and Properties Team is a two person team (2 FTE/yr) planned for approximately 30-40 percent time on Benchmark and Database Management, 20-30 percent on Emerging Topical Studies, and 30-50 percent on participation in Status Assessments for surface water and groundwater. The following sections describe plans for work on Benchmark and Database Management and on Emerging Topical Studies. Plans for Status Assessments are described separately as part of the overall plan for surface and groundwater status assessments.

Benchmark and Database Maintenance

Contaminant toxicity data for human health and aquatic life are needed for many Cycle 3 studies, along with the physical and chemical properties of contaminants. Such data will be centrally located, enabling easy access to the data and increased efficiency.

Human-Health Benchmarks and Databases

To evaluate the potential significance of contaminant occurrence to human health, contaminant concentrations have been compared to regulatory Maximum Contaminant Levels (MCLs) or non-regulatory HBSLs. Regulated contaminants are those contaminants for which the USEPA has established drinking-water standards (MCLs) under the Safe Drinking Water Act (SDWA), and unregulated contaminants are those that are not regulated in drinking water under the SDWA.

HBSL Database and Website

Background: HBSLs are non-enforceable benchmark concentrations of contaminants in water that were developed by the USGS in collaboration with the USEPA and others using: (1) USEPA Office of Water methodologies for establishing drinking-water guidelines, and (2) the most recent, USEPA peer-reviewed, publicly available human-health toxicity information. As a result, HBSL values are consistent with existing USEPA drinking-water guideline values, such as Lifetime Health Advisory values and Cancer Risk Concentration values (when they exist), except for unregulated contaminants for which more recent toxicity information has become available (Toccalino, 2007).

Procedures are in place for regularly updating and maintaining the HBSL database and website (<http://water.usgs.gov/nawqa/HBSL>). USEPA periodically publishes new information (monthly to about every two years, depending on the data source). Keeping up with new toxicity information is time consuming. The last major updates to the HBSL database and website were completed in January 2012.

Strategy:

- Regularly update and maintain the HBSL database.
- Search for updated USEPA toxicity information for NAWQA analytes at least once per year. Less frequent updates result in substantial expenditures of time per update. Sources of toxicity information include the USEPA Office of Water (OW), Integrated Risk Information System (IRIS) database, and Office of Pesticide Programs (OPP) documents.
- Follow established quality-control procedures for updates to the HBSL database. These procedures include methods for verifying the toxicity information collected from USEPA and verifying the computation of HBSL values and the methodology used to compute them.
- Update HBSL values, as needed, when toxicity information change.
- Consult with USEPA OW in cases where the computation of an HBSL is not straightforward, as described by Toccalino (2007).
- Update the HBSL website (<http://water.usgs.gov/nawqa/HBSL>) at least once per year when new toxicity data become available. These updates are currently completed by staff from the USGS Center for Integrated Data Analytics (CIDA).
- The HBSL database is backed up on two individual PC and the shared drive maintained by the CA WSC. A scaled-down version of the HBSL database that contains the publicly available information is maintained by CIDA. All previous versions of the database are retained for historical purposes.

Products:

- The most current HBSLs are publicly available on the HBSL website (<http://water.usgs.gov/nawqa/HBSL>).
- The most current HBSLs also are included on the internal NAWQA Data Warehouse website (<http://internal.mdc.usgs.gov/apex/f?p=142:39:3934595007178325::NO::>) under “Internal Benchmark Queries”. The query results include links to the HBSL website for more information and guidance on the use of HBSLs.

Maximum Contaminant Levels

Background: MCLs are legally enforceable USEPA drinking-water standards that set the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are set as close as feasible to the maximum level of a contaminant at which no known or anticipated adverse effects on human health would occur over a lifetime, taking into account the best available analytical and treatment technologies, cost considerations, expert judgment, and public comments (U.S. Environmental Protection Agency, 2011a). As a result, not all MCLs are based on health-effects data alone.

The SDWA directs USEPA to regulate contaminants in drinking water that present the greatest public-health concern. As part of determining whether drinking-water regulations are needed, the SDWA requires USEPA to publish a list of unregulated contaminants called the Contaminant Candidate List (CCL) every 5 years. The CCL includes contaminants that currently are not subject to any proposed or promulgated national primary drinking water regulations, which are known or anticipated to occur in public water systems, and which may require regulation under the SDWA in the future. Following the publication of each CCL, USEPA decides whether to regulate at least five contaminants from the CCL in drinking water (called regulatory determinations) on the basis of the contaminant’s potential for adverse human-health effects and occurrence in public water systems, and a meaningful opportunity to protect public health (U.S. Environmental Protection Agency, 2011b). The USEPA uses USGS data on the occurrence of unregulated contaminants in water resources as part of both the CCL and regulatory determination processes.

Strategy:

- MCLs are established by the USEPA and infrequently change. However, all updates to USEPA OW benchmarks, including MCLs, are captured in the HBSL database. These updates occur about every two years.
- Share USGS water-quality data with the USEPA OW as part of their CCL and regulatory determination processes.

Products:

- The most current USEPA MCLs are included on the internal NAWQA Data Warehouse website (<http://internal.mdc.usgs.gov/apex/f?p=142:39:3934595007178325::NO::>) under “Internal Benchmark Queries”. The query results include links to USEPA websites for more information and links that provide guidance on the use of MCLs and HBSLs.
- MCLs are captured in the HBSL database, but are not posted on the HBSL website.

Aquatic-Life Benchmarks and Toxicity Data

To evaluate the potential significance of contaminant occurrence to aquatic life, contaminant concentrations can be compared to several types of aquatic-life benchmarks for water, including acute and chronic values for different taxonomic groups (fish, invertebrates, aquatic plants), or for sediment.

Historically in the NAWQA Program, benchmarks for assessing the potential for pesticides in stream water to adversely affect aquatic life were of two general types: (1) ambient water-quality criteria for the protection of aquatic life, which were developed by USEPA OW (U.S. Environmental Protection Agency, 2002), and (2) benchmarks derived from toxicity values obtained from registration and risk-assessment documents developed by USEPA OPP

(<http://www.epa.gov/oppsrrd1/reregistration/status.htm>). Toxicity data from OPP documents were used to supplement OW criteria to expand the coverage of pesticides and to incorporate the most recent toxicity information used by USEPA. OPP has since assumed responsibility for this benchmark effort and now publishes OPP aquatic-life benchmarks (U.S. Environmental Protection Agency, 2011c). USGS has worked with OPP on evaluating published benchmarks and requesting development of benchmarks for specific pesticide compounds.

NAWQA has used two types of USEPA sediment benchmarks to assess the potential for pesticide compounds to affect aquatic life: (1) threshold effect concentrations (TEC) from consensus-based sediment-quality guidelines developed for sediment-dwelling aquatic organisms (MacDonald and others, 2000), and (2) USEPA's equilibrium partitioning sediment benchmarks (ESB) (U.S. Environmental Protection Agency, 2004).

Aquatic-Life Benchmarks

Background: The Pesticide Characteristics Database contains aquatic-life benchmarks for pesticides and some other contaminants. Compounds in the Pesticide Characteristics Database include pesticides and some VOCs (e.g. fumigants and adjuvants) on NAWQA analytical schedules, plus pesticides for which recent (2007) agricultural use data were available. Benchmark sources include USEPA OW and OPP, and also Environment Canada (Canadian Council of Ministers of the Environment, 2007).

For pesticides, seven types of aquatic toxicity values were compiled from OPP's registration and risk-assessment documents. The OPP toxicity values are for specific types of organisms. Acute and chronic values were compiled for fish and invertebrates, and acute values for vascular and nonvascular plants. A value for aquatic-community effects was available only for atrazine. The types and amounts of toxicity data available for different pesticides were highly variable. USEPA estimates the toxicity or hazard of a pesticide by selecting the most sensitive endpoints from multiple acute and chronic laboratory and field studies. NAWQA derived benchmarks from OPP toxicity values, generally following OPP procedures (U.S. Environmental Protection Agency, 2005), until OPP assumed responsibility for this effort. However, the aquatic-life toxicity data compiled from OPP extend beyond those compounds for which OPP has developed benchmarks, and additional benchmarks may be developed by OPP in the future.

Strategy:

- Create separate aquatic-life database (all data currently housed in the Pesticide Characteristics Database) to contain benchmarks and other aquatic-life data.
- Periodically update aquatic-life benchmarks in the database as they become available or when they are updated.

- Establish and follow quality-control procedures for updates to the aquatic-life database. These procedures should include methods for verifying the toxicity information collected, and, if developing benchmarks, verifying their calculations.
- Expand the list of pesticide compounds in the database to include pesticides in the more recent (2009) agricultural use database. Compile benchmarks and/or toxicity data for these additional compounds.
- Expand the aquatic-life database to other contaminant classes as needed or create separate database for those classes (see section on developing new benchmarks).
- Ensure compatibility of all databases (e.g. aquatic-life, HBSL, and chemical properties databases) for linkage and queries between.
- Establish and follow procedures for a more secure and reliable database backup. Currently data are backed up locally on an external hard drive, and remotely on the Pesticide National Synthesis network drive maintained by the CA WSC.
- Continue existing collaborations with USEPA OPP with respect to development of aquatic-life benchmarks.

Products:

- Database of aquatic-life benchmarks for comparison with water-quality data.
- Website or other means for making the aquatic-life database accessible for NAWQA assessments.

Pesticide Toxicity Index (PTI) Values

Background: To expand the assessment of potential effects of pesticides in stream water on aquatic life, NAWQA developed a Pesticide Toxicity Index (Munn and Gilliom, 2001). The Pesticide Toxicity Index (PTI) accounts for multiple pesticides in a sample, including pesticides without established benchmarks for aquatic life. The PTI combines information on exposure of aquatic biota to pesticides (measured concentrations of pesticides in stream water) with toxicity estimates (results from laboratory toxicity studies) to produce a relative index value for a sample or stream. The PTI value is computed for each sample of stream water by summing the toxicity quotients for all pesticides detected in the sample. The toxicity quotient is the measured concentration of a pesticide divided by its toxicity concentration from bioassays (such as an LC50 or EC50). The PTI provides a means to rank different stream sites compared with each other and is a tool for investigating relationships between pesticide levels and the quality of aquatic ecosystems.

Aquatic-life toxicity data for pesticides and some VOC compounds (fumigants or adjuvants) were compiled from USEPA's ECOTOX database in 2007 (U.S. Environmental Protection Agency, 2007). The list of pesticides for which data were compiled was the same as those compounds in the Pesticide Characteristics Database (see Aquatic-Life Benchmarks section above). ECOTOX data were aggregated to determine minimum, median, and maximum acute toxicity values for three taxonomic groups—fish, cladocerans, and benthic invertebrates—for each pesticide compound for which data were available. The minimum and median PTI toxicity values are contained in the Pesticide Characteristics Database.

Strategy:

- Establish and follow quality-control procedures for updates to the PTI data. These procedures should include methods for verifying the aggregation of toxicity values and calculation of min/max/median values.
- Expand the list of pesticide compounds to include pesticides in the more recent (2009) agricultural use database.
- Update PTI toxicity values (re-query ECOTOX for aquatic-life toxicity data and recalculate values).

- Incorporate updated PTI toxicity values and underlying toxicity data into aquatic-life database.

Products:

- Updated PTI toxicity values for an expanded list of analytes.
- Updated PTI report – 3rd edition

Sediment Benchmarks

Background: The Pesticide Characteristics Database contains some sediment benchmarks for aquatic-life, including USEPA's equilibrium partitioning sediment benchmarks (ESB), Environment Canada's interim sediment quality guidelines and probable effect concentrations (Canadian Council of Ministers of the Environment, 2002). Additional benchmarks—TECs from MacDonald and others (2000) and sediment-quality screening values from Lopes and Furlong (2001)—have been compiled, but are not part of the Pesticide Characteristics Database. Compared to aquatic-life benchmarks for water, there are few sediment benchmarks available for pesticides. There are also sediment benchmarks from these sources available for other contaminant groups; these values have been compiled, but are not included in the database.

Historically for pesticides, aquatic-life benchmarks for sediment, both TECs and ESBs, were compared with pesticide concentrations measured by NAWQA in composite bed-sediment samples collected from depositional areas in streams (one sample per site).

Strategy:

- Incorporate all sediment benchmarks listed above into aquatic-life database.
- Maintain and update existing sediment benchmark values when needed.
- Determine which contaminants from other contaminant classes will be analyzed in sediment and whether benchmarks are needed.
- Add sediment benchmarks for other contaminant classes to aquatic-life database or a separate database for non-pesticide compounds.
- Pursue development of additional sediment benchmarks for aquatic life, if needed.
- Establish and follow quality-control procedures as described for aquatic-life benchmarks.
- Establish and follow procedures for database backup as described for aquatic-life benchmarks.

Products:

- Database of sediment benchmarks for comparison with sediment data.
- Website or other means for making the sediment database accessible for NAWQA assessments.
- Publish methodology for development of sediment benchmarks for aquatic life, if needed.

Chemical Properties Database

Physical-chemical properties of contaminants have been used in several ways by the NAWQA Program, including predicting the transport and fate of contaminants in the environment, explaining environmental occurrence patterns of pesticides, and prioritizing contaminants for inclusion in analytical methods, especially for sediment, for Cycle 3.

Background: Physical-chemical property data currently in the Pesticide Characteristics Database were compiled from literature sources by the NAWQA program and include: Kow, Koc, water solubility, KH, aerobic soil half-life (lab), field dissipation half-life in soil, and water half-life. Additional physical-chemical property data for pesticides were obtained from the publicly available Pesticide Properties DataBase (PPDB) from the University of Hertfordshire (UH) in the UK (<http://sitem.herts.ac.uk/aeru/footprint/en/>). An MS Access version of the PPDB was purchased by the NAWQA Program by agreement with UH for quarterly updates for two years ending in January 2011 (Pesticide Properties Database, 2009). The Pesticide Characteristics Database was set up to link to the PPDB in order to extract physical-chemical property values for desired compounds.

USEPA's EPI Suite program (U.S. Environmental Protection Agency, 2009) has also been used to compile both estimated physical-chemical property values using the various property estimation programs within EPI Suite and, when available, experimental values contained in its database. These values are not contained in the Pesticide Characteristics Database but values compiled from EPI Suite were linked to the Pesticide Characteristics Database in a similar manner as the PPDB. Vapor pressure values, which are not included in the Pesticide Characteristics Database, have been compiled from both the PPDB and EPI Suite.

Strategy:

- Toxicity data currently in the Pesticide Characteristics Database will be moved to a separate aquatic-life database, leaving physical-chemical property and other data in a database, which can be called the chemical properties database (CPD).
- Establish and follow quality-control procedures for updates to the CPD. These procedures should include methods for verifying the data collected.
- Improve linkage between databases depending on future purchase agreement for an updated PPDB.
- Compile estimated and experimental property values from EPI Suite for an expanded list of analytes (pesticides and possibly non-pesticides) and incorporate data into CPD.
- Establish and follow procedures for database backup as for aquatic-life database.
- Explore the possibility of providing physical-chemical data in a way that would indicate which environmental compartment(s) is mostly likely to contain a given contaminant.

Products:

- Database of physical-chemical property data.
- Website or other means for making the physical-chemical property database accessible for NAWQA assessments. Note, however that, by terms of the PPDB license with UH, we cannot reproduce PPDB data in other databases. Public access to the PPDB is available online for a single compound at a time.
- Indication of "preferred" property values for contaminants in the database.

Other Benchmarks

If needed for Cycle 3 assessments, the Contaminant Toxicity and Properties Team will compile additional benchmarks. Additional benchmarks include those related to fish tissue (human consumption of edible fish, wildlife consumption of whole fish, and fish health) and recreational benchmarks designed to protect swimmers from illnesses due to exposure to pathogens in recreational waters.

Emerging Topical Studies

Several priority topics have emerged from analysis of results for NAWQA Cycles 1 and 2, progress in the broad field of contaminant assessments (both internal and external to NAWQA), needs of other agencies and interest groups, and new data on contaminants produced from NAWQA Cycle 2 studies. The priority topics are:

1. New benchmarks for emerging contaminants
2. Characterization and significance of chemical mixtures

Successfully addressing these topics will depend on collaboration with a variety of NAWQA teams and studies. These topics affect broad national water-quality issues that extend to many contaminant groups and water-quality factors. Below, a strategy is outlined for addressing each of these topics. In Implementation of Cycle 3, however, the approaches to these topics will largely be incrementally integrated into broader status assessments.

New Benchmarks for Emerging Contaminants

Background: The proposed addition of new or emerging contaminants to Cycle 3 monitoring is based on recommendations from the NAWQA Target Analyte Strategy (NTAS) work group. A high priority for many stakeholders is for NAWQA to assess new or previously unrecognized contaminants that are currently unregulated and yet pose a potential 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 such as pathogens.

New HBSLs need to be developed, where possible, for unregulated contaminants added to NAWQA analytical schedules. This is critical for assessing which contaminants are of greatest potential concern to human health and will be done in collaboration with the USEPA OW. Unfortunately, HBSLs cannot currently be developed for many of the new or emerging contaminants because of a lack of acceptable toxicity information, so alternative strategies need to be explored. Acceptable toxicity information for developing HBSLs is the most recent, peer reviewed, publicly available human-health toxicity information published by USEPA (Toccalino, 2007).

As of **January 2012**, HBSLs are not available for 202 of the 434 unregulated contaminants in the HBSL database (<http://water.usgs.gov/nawqa/HBSL>) because of a lack of toxicity information.

For aquatic-life, it needs to be determined whether benchmarks beyond those that exist from USEPA and Canada are needed for contaminant classes other than pesticides in order to assess which contaminants are of potential concern for aquatic life. If other classes of contaminants require benchmarks, available toxicity data will need to be identified and collected and a methodology for developing those benchmarks will need to be developed. Further, either a new database to contain these data for non-pesticide compounds will be needed, or the aquatic-life database, which will contain data primarily for pesticide compounds, will need to be expanded to other contaminant groups.

Strategy:

- Expand HBSLs to include all new and emerging contaminants recommended by NTAS for which acceptable USEPA toxicity information is available.
- For contaminants for which acceptable USEPA human-health toxicity information is not available, develop new human-health benchmarks using a modification of the existing HBSL methodology to allow for the use of toxicity data from sources beyond those currently deemed acceptable. These new benchmarks

should have a different name than HBSLs in order to not confuse them with HBSLs developed using standard USEPA OW methodologies.

- Identify additional sources of toxicity data, particularly those sources have the desired characteristics (peer reviewed, publicly available data, etc.). Examples of such data from the United States include regional EPA data (primarily Regions 3 and 9), USEPA ORD Provisional Peer-Reviewed Toxicity Values (PPRTVs), and Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs). The ACToR database is another potential source.
- Conduct a literature review to identify any water-quality benchmarks developed for emerging contaminants such as pharmaceuticals. Toxicity data for some pharmaceutical products may be available in the peer-reviewed literature, and possibly through FDA's Center for Drug Evaluation Research.
- For pharmaceuticals, consider using efficacy information, where available, instead of toxicity information to develop new human-health benchmarks.
- Explore indirect methods for estimating toxicity information such as Quantitative Structure Activity Relationships (QSARs) for compounds for which no toxicity information is available.
- Utilize expertise from the Mixtures Technical Advisory Committee to explore methods for obtaining surrogate toxicity values. In a 1/20/2011 conference call, Committee members suggested exploring computational tools such as the Threshold of Toxicological Concern (TTC), the Cramer classification system, and SARs for obtaining surrogate toxicity values. Toxtree (http://ihcp.jrc.ec.europa.eu/our_labs/computational_toxicology/qsar_tools/toxtree) is a user-friendly open source application that places chemicals into categories and predicts various kinds of toxic effects by applying decision tree approaches, including the Cramer rules.
- Consult with the USGS Toxic Substances Hydrology Program to determine the extent to which they have explored benchmark development for emerging contaminants.
- Consult with USEPA OW for the development of new human-health benchmarks.
- Determine which additional NAWQA contaminant classes require aquatic-life benchmarks.
- Develop methodology for computing aquatic-life benchmarks for non-pesticide contaminants.
- Compile aquatic-life toxicity data for non-pesticide contaminants and apply new methodology to compute benchmarks.

Products:

- Publish an expanded HBSL database on the HBSL website that includes HBSLs for new or emerging contaminants.
- Create a new database for new human-health benchmarks developed using alternative toxicity data and/or methodologies.
- Publish an SIR describing the methodology and data sources used in the development of the new human-health benchmarks.
- Publish an SIR describing the methodology and data sources used in the development of non-pesticide aquatic-life benchmarks.
- Enhance existing database containing aquatic-life benchmarks and toxicity data to include non-pesticide compounds or create new database.

Characterization and Significance of Chemical Mixtures

Background: NAWQA assessments show that contaminants almost always occur as mixtures, rather than individually, in surface water and groundwater. Because humans and aquatic organisms are exposed to mixtures of inorganic and organic contaminant across multiple contaminant groups, understanding their occurrence, composition, patterns in relation to land uses, and potential effects is critical to effective water-quality management. The extent and nature of mixture issues varies greatly among streams (most complex) and groundwater, and each has different aspects to address.

The nature and potential significance of mixtures of pesticides in stream water and stream bed sediment have been analyzed at a basic level. The frequency of occurrence has been evaluated by land use, the most common mixtures for each land use have been identified, and the PTI was developed for evaluating potential toxicity to aquatic life by the additive toxicity model (Gilliom and others, 2006). The number of anthropogenic organic compounds detected in source-water samples from streams has also been evaluated (Kingsbury and others, 2008). More work is needed to evaluate the patterns of occurrence, composition, and potential toxicity to aquatic life and humans across multiple contaminant groups and in relation to land uses, crop settings, and seasons.

The occurrence, composition, and potential human toxicity of chemical mixtures in groundwater has been characterized in source waters from public-supply wells (Toccalino and others, 2010; Toccalino and others, 2012), and to a somewhat lesser extent, in samples from domestic wells (DeSimone, 2009). The potential toxicity of mixtures was characterized by addition of benchmark-normalized component concentrations. These analyses were conducted across multiple contaminant groups, including pesticides, VOCs, trace elements, nutrients (nitrate), and radionuclides (radon). Additional analyses are warranted on the occurrence of chemical mixtures with respect to a variety of ancillary data, including principal aquifer, land use, and aquifer type.

Strategy:

- In surface water, assess the occurrence, composition, and geographical distribution of chemical mixtures across all NAWQA analytes as a function of land use, crop settings, and seasons.
- In groundwater, assess the occurrence, composition, and geographical distribution of chemical mixtures across all NAWQA analytes as a function of aquifer type, land use, well type, well depth, and principal aquifer.
- Identify those mixtures in surface waters that have the greatest potential for toxicity to humans and aquatic organisms.
- Identify those mixtures in groundwater that have the greatest potential for toxicity to humans.
- For potential human-health effects, assess mixtures by whether mixture components are carcinogens or noncarcinogens and by groups of chemicals known to have common mechanism of toxicity (for example, organophosphate pesticides).
- Continue to consult with external experts on evaluating the occurrence of chemical mixtures in the context of human health. An external Mixtures Technical Advisory Committee was established in late 2010, and includes four committee members are from USEPA Office of Research and Development, the Centers for Disease Control (CDC) Agency for Toxic Substances and Disease Registry (ATSDR), and Emory University.
- Consider developing benchmarks for mixtures, if needed.

Products:

- At least 1 journal article, maybe 2, on the assessment of chemical mixtures in surface water and groundwater and potential for human-health effects.
- At least 1 journal article, maybe 2, on the assessment of chemical mixtures in surface water and potential for aquatic-life effects.
- Potentially develop some sort of generic tool (perhaps analogous to PTI) to assess the potential significance of chemical mixtures to human health.
- Potentially develop a product to hand off to ATSDR, CDC, EPA, and/or NIH that could suggest future research directions for toxicity assessments of chemical mixtures in water resources.

Team Composition

The Contaminant Toxicity and Properties Team will consist of a lead scientist to coordinate activities, conduct analyses, and write reports and an assistant lead scientist and data analyst to compile and maintain data and databases, conduct data analyses, and write reports. As described earlier, the Contaminant Toxicity and Properties Team is a two person team (2 FTE/yr) planned for approximately 30-40 percent time on Benchmark and Database Management, 20-30 percent on Emerging Topical Studies, and 30-50 percent on participation in Status Assessments for surface water and groundwater.

In order to carry out the tasks in this implementation plan, the Contaminant Toxicity and Properties Team will require some support from other personnel in the following areas: hydrologists/chemists (GS-13/14) with expertise in physical-chemical properties, aquatic-life, sediment, and fish tissue benchmarks, and mixtures data analysis; a statistician (GS-12/13) to provide statistical support and conduct limited analyses; a geographer (GS-12/13) to provide ancillary data support and map production; and an IT specialist (GS-9) to update and develop online data resources.

Lead Scientist GS-13/14 (1 FTE)

Hydrologist or chemist with experience in interpreting water-quality data in the context of human health and aquatic life, project management, and written and oral communication. Provides national-level technical leadership, management, and coordination of the Contaminant Toxicity and Properties Team. Monitors the progress of activities and reviews completed work. Participates in analysis and interpretation of data and technical information and prepares reports and articles describing the same. Coordinates with task leaders of other components of NAWQA Cycle 3. Interfaces with external agencies and organizations as needed on the development of benchmarks, providing status updates, and seeking technical guidance on new science directions.

Assistant Lead Scientist and Data Analyst GS-12/13 (1 FTE)

Hydrologist or chemist who assists the Lead Scientist in providing technical leadership, management, and coordination of the Contaminant Toxicity and Properties Team. Has background in compiling and manipulating large data sets, analysis and interpretation of water-quality data in the context of human health and aquatic life, and technical report writing. Evaluates and critically reviews existing data sources on contaminant toxicity and related information in order to develop and maintain databases of water-quality benchmarks and contaminant properties. Provides toxicity and physical-chemical property data to members of the status and trends team. Provides analytical and writing support to authors of status and trends reports and prepares reports and articles for the Contaminant Toxicity and Properties Team.

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Appendix 2B-Data Infrastructure in Support of Cycle 3 Modeling and Status Assessment

Status assessment under Cycle 3 will require an efficient, comprehensive and flexible data infrastructure for organizing and storing water-quality and ancillary information. At present, NAWQA employs numerous databases to store information, including the NAWQA [data warehouse](#) (U.S. Geological Survey, 2011a), the National Stream Quality Accounting Network (NASQAN) data portal (U.S. Geological Survey, 2009) and National Water Information System (NWIS) databases (U.S. Geological Survey, 2011b). Non-USGS data used in SPARROW modeling and MRB trend assessment currently are not made directly available through the USGS, although a USGS-sponsored web service is under development to query the USEPA STORET database (U.S. Geological Survey, 2008).

There currently exists no single data infrastructure for ancillary data used in NAWQA modeling or assessment studies. SPARROW model ancillary data are generally model specific and stored according to reaches defined by the Enhanced River Reach File 2 (Nolan and others, 2002), a network consisting of over 65,000 reaches and a recent enhancement to delineate catchments based on 100 meter resolution digital elevation data (Brakebill and Terziotti, 2011), and NHDPlus (U.S. Environmental Protection Agency and U.S. Geological Survey, 2010), a network based on the 1:100,000 scale National Hydrologic Database (NHD) consisting of over 2.5 million directed flow reach segments with catchments derived from the 30-meter digital elevation model. Both levels of spatial data are currently served using the online Decision Support System tool (U.S. Geological Survey, 2011c). WARP model data are derived from the E2RF1 reach network and stored in a separate database. A dedicated online mapping tool for WARP (U.S. Geological Survey, 2011d) is also based on the E2RF1 reach network.

The Cycle 3 plan proposes to unify the water-quality and ancillary data infrastructure used in Cycle 3 assessments. As part of this unification, it is proposed that the NHDPlus reach network will serve as the spatial infrastructure for all water-quality modeling efforts included under Cycle 3 status and trend assessment.

Enhancement of the NHDPlus Reach Network

NHDPlus has become a standard reach network in support of USEPA modeling (see the description of the Hydrologic and Water Quality System [HAWQS]; U.S. Department of Agriculture, Agriculture Research Service, 2011) and other State and regional water-assessment efforts. Although NHDPlus does not have the highest resolution available (NHD high-res has over 10 million reaches), it is currently the highest resolution network with validated flow direction, navigational enhancements, and catchment delineation. The medium resolution of NHDPlus represents a significant improvement in resolution compared to the Enhanced Reach File 1 network (Nolan and others, 2004) used in previous SPARROW and WARP models, and should be adequate for NAWQA modeling considering the large scale of these models and the limited resolution of ancillary data to be used in the analyses.

The ancillary data compiled in support of status and trend assessment is expected to have applications to other surface-water components of the NAWQA Cycle 3 plan, including modeling efforts undertaken as part of the integrated watershed analysis, ecological investigations, and regional synoptic studies. The reach network offers a potentially useful information structure for extrapolating findings from these studies to regions beyond the confines of the original study. Groundwater studies also may benefit from a reach-oriented organization of the ancillary data, most likely for analyses related to ground and surface water interaction; however, it is not yet known whether a reach-oriented data structure is necessary or useful for exclusive groundwater modeling.

NAWQA effort under Cycle 3, directed largely through the SPARROW development team, will continue to improve the NHDPlus network. Specific features of the existing network to be addressed include the determinations of channel slope, mean streamflow and velocity, the characteristics of reservoirs, and the designations of segments having intermittent flow. Improvements in channel slope estimation will require the investigation of alternative smoothing algorithms to better account for local errors in the digital elevation data. Streamflow estimates will be refined using statistical methods to interpolate streamflow between monitored reaches, and to provide estimates of mean streamflow for specific periods and seasons. Improved velocity estimates will be developed using a more comprehensive set of tracer-based time-of-travel measurements, and the estimation method will permit the determination of velocity for arbitrary streamflow conditions. Over 55,000 dams from the National Inventory of Dams (NID; U.S. Army Corps of Engineers, 2010), consisting of over 79,000 dams, have recently been indexed to the high-resolution NHD, and the NHDPlus development team has plans to transfer this information to NHDPlus. NAWQA effort will be required to identify cases where multiple dams in the NID pertain to a common reservoir. Finally, NAWQA, in coordination with the NHDPlus development team and other partners, will investigate and implement methods for improving the designation of stream segments having intermittent flow.

One limitation imposed by NHDPlus concerns the fact that the network is currently not defined for Alaska and Hawaii. Consideration will be given in Cycle 3 to provide NAWQA support to extend NHDPlus to these States and other territories of the U.S.

Thinning of the NHDPlus Network

The imposition of mass balance in SPARROW requires the calculations used to relate water quality to causative factors operate on individual reach segments. This feature may represent a limitation on the application of SPARROW to large regions due to the magnitude of the computations required to accommodate a large number of reaches, particularly for the operation of model estimation, which needs a large number of iterative evaluations to fit the model. One way to circumvent this limitation is to “thin” the network by aggregating spatial information to a smaller set of reaches. The thinning process can be achieved using automated tools that modify the navigational information to be consistent with a smaller set of reaches, and perform the basic aggregation operations of spatial data accumulation and averaging. It is proposed that the SPARROW model development team create such tools for use in Cycle 3 modeling. The model development team will also investigate the potential for using “thinned” estimated models to predict and simulate results for the entire, un-thinned network.

Because WARP models are applied to only complete drainage basins associated with included monitoring stations and prediction sites, and not the individual reaches within those basins, the issue of thinning is not a direct concern. However, the generation of basin-level information for estimating a WARP model is essentially the operation of thinning the network to the level of the contributing basins, implying the thinning (or reach aggregation) algorithms will also be useful for these models.

Water-Quality Data

NAWQA Cycle 3 WARP modeling, trend analysis, and regional synoptic studies will be based on water-quality data collected for the specific purposes of those studies and on other data available from the NAWQA fixed-site network. However, these data will be insufficient for NAWQA SPARROW modeling and other NAWQA data-driven status assessment efforts. To ensure an adequate base of water-quality information, the regional components of the SPARROW modeling team will use methods developed by Saad and others (2011) to identify water-quality data in NWIS, the USEPA Storage and Retrieval system (STORET) and other State databases having sufficient quality and proximity with USGS streamgages to

permit inclusion in SPARROW regional and national models. Consideration will be given to using this water-quality information in support of the data-driven NAWQA status assessments. Additional methods beyond those described in Saad and others (2011) will be developed to improve the determination of daily streamflow for water-quality stations that are not co-located with a USGS streamgage. This effort may be supplemented by other efforts funded as part of the USGS streamgaging program to provide daily flow estimates for ungaged locations (Kiang, written communication). All data from non-USGS approved sources, and the load estimates derived from them, will be served to the public in some form if they are used in USGS reports.

Load Estimation

Load estimation is a critical component of SPARROW modeling and improvements with the methods could lead to significant improvements in the accuracy of these models. Currently, all load estimates for SPARROW models are based on the ESTIMATOR method developed by Cohn (2005), with modifications implemented through FLUXMASTER to obtain detrended estimates (Schwarz and others, 2006).

New methods are becoming available that could improve the estimation of load, including a Kalman filter method (currently available in FLUXMASTER), and the Weighted Regression on Time, Discharge, and Season (WRTDS; Hirsch and others, 2010). Recent concern has been raised regarding the accuracy of the standard 7-parameter ESTIMATOR method as applied to certain contaminants. Some of this concern may require modifications to the load estimation methodology implemented by ESTIMATOR/FLUXMASTER, including the consideration of other predictors and new estimation methods that account for heteroscedastic errors in the water-quality model. WRTDS appears to be robust to these problems and may represent a viable alternative load estimation method; however, more needs to be known about WRTDS data requirements, which many stations currently used in SPARROW cannot meet, and additional development of the methodology is required to produce an estimate of error in the load estimates. Recent analysis using WRTDS shows the utility of various graphical depictions of the data for the identification of potential problems in the load estimation methodology (Hirsch, written communication). Much of the effort to improve load estimation will be undertaken collaboratively by the National Research Program and the SPARROW model development team. Regardless of the algorithm implemented for standard load estimation, WRTDS or a modified Fluxmaster, it will be necessary to provide published documentation describing the operation of the program and the limitations on its use.

The Cycle 3 plan envisions making the load estimates for all national and regional SPARROW models publicly accessible via an online database, with links to the underlying water-quality and streamflow measurements used to make the estimates (see the description of water-quality data above).

Ancillary Data

An essential element of status and trend assessment concerns the determination of causal factors affecting water quality conditions. Such assessment requires a broad range of ancillary data to be used to explain patterns observed in the water-quality data. Ancillary data to be used for explaining water quality consists of spatial information describing features of the landscape and characteristics of stream channels. It is expected that all ancillary data in support of Cycle 3 status and trend assessment activities, including SPARROW and WARP modeling, will be linked to NHDPlus reaches and catchments.

The NHDPlus development team maintains a suite of tools developed to facilitate revisions to the network. Such tools insure the navigation and ancillary data supported in NHDPlus remain consistent with periodic revisions to the line work, topological connections and catchment delineations provided by

users of the network (see NHDPlus documentation). In order for NAWQA to remain current with different versions of NHDPlus, it is imperative to endow all NAWQA ancillary data linked to NHDPlus with similar tools (including documentation) that automate to the greatest extent possible the linking of base data sets to the network. Operationally, it is anticipated that each spatial coverage supported by NAWQA in Cycle 3 will have a dedicated person responsible for developing these tools and for ensuring their respective data are current with NHDPlus. Having dedicated personnel assigned to specific coverages will have the additional benefit of ensuring NAWQA maintains a knowledge base for advising users as to the valid use of these data.

NHDPlus consists of two spatial data sets: a vector coverage depicting the stream channels derived from the 1:100,000 scale maps, and associated catchments derived from 30 meter digital elevation data. Ancillary data linked to NHDPlus can be classified into data sets that are indexed to the stream channels, with NHDPlus serving as an address system, and variables that are allocated to the NHDPlus catchments, effectively providing a runoff-based organization to spatial data.

Ancillary data indexed to streams

Considerable progress has recently been made in indexing a number of data sets to NHDPlus, including most USGS streamgages and water-quality monitoring stations, and major point source dischargers and drinking water intakes. This indexation effort will continue under Cycle 3, probably in partnership with USEPA. Additionally, the USGS SPARROW GIS and data management team will work to improve information on diversions associated with the NHDPlus network, including an improved census of the locations of major irrigation diversions and return flows, and a determination of the fraction of streamflow diverted or returned at each junction. The team will also develop methods to assign diversion fractions for a prioritized list of over 50,000 natural diversions currently identified in NHDPlus.

The Cycle 2 SPARROW regional models benefited from a large national effort to improve the estimation of point source contaminant discharge to NHDPlus. Load estimates for nutrient contaminants were estimated using information from the National Permit Compliance System (PCS), with missing information estimated using typical pollutant concentrations (TPC). A continuation of this effort is planned for Cycle 3 to produce updated versions of the existing information. Additionally, new methods will be developed to improve the estimates of loadings, possibly by sampling dischargers' permit application forms (the C4 form, which contains information on concentrations for non-regulated contaminants) to better estimate typical pollutant concentrations.

Ancillary data allocated to catchments

One of the most important ancillary spatial data sets is land cover. Land cover is a foundational data set essential to water-quality modeling, not just as a surrogate variable for contaminant sources, but also as a support data set for improving the resolution of spatially coarse data sets. An example of the latter would be the allocation of county estimates of fertilizer or pesticide use to individual reach catchments on the basis of the share of county agricultural land contained in the catchment.

The principal land cover data set is the National Land Cover Dataset (NLCD). Current versions of these data are for 1992, 2001, and 2006, and the release of these data effectively marks major revisions in SPARROW models. One difficulty in the timely implementation of these data into water-quality models concerns inherent inconsistencies between the land cover-based estimates of aggregate land use, and county-level estimates of agriculture, and county-based information from more definitive sources, such as the Census of Agriculture. In Cycle 3, the methods development team will investigate statistical methods that use the error matrices produced in conjunction with the NLCD to adjust the pixel

estimates to be consistent with Census information. The use of statistical methods should be a relatively inexpensive and efficient approach to data adjustment, as compared to more resource intensive methods such as reinterpretation of aerial and satellite photography.

Data on contaminant sources are essential for nutrient and pesticide modeling, and useful information on fertilizer and pesticide application are available. Unfortunately, these data are reported only at State or county levels, making them a poor fit for modeling with medium and high-resolution reach networks, particularly for the generation of predictions at the headwater reach scale. To correct this, the State and county-level information must be allocated to individual reach catchments on the basis of ancillary information, principally land cover information.

Current approaches use NLCD information to allocate contaminant source data (Thelin and Stone, 2010; Wieczorek and LaMotte, 2010a). These approaches do not recognize the inherent error in the allocation, nor in the source information itself. In Cycle 3, the methods development team will work to improve the allocation of contaminant source information by developing statistical methods, akin to Kalman filtering, that have the ability to improve the accuracy of the allocation and provide an assessment of the allocation error.

The population of animals associated with concentrated animal feeding operations (CAFOs) is used as a source variable in nutrient and pathogen models. At present, this information is provided by the U.S. Department of Agriculture (USDA; Kellogg and others, 2000) at the county level, which, like the other sources described above, is too coarse for accurate prediction of water quality in headwater reaches. The allocation of this county information is more challenging than the allocation of fertilizer and pesticide application because the CAFOs are not necessarily closely aligned with a particular land cover area (Alexander and others, 2008). Efforts will be made in Cycle 3, possibly in coordination with the USDA, to improve the spatial disaggregation of the county information.

The atmospheric deposition is an important source variable for SPARROW models of total nitrogen. Current versions of the national and regional models use measurements from the National Atmospheric Deposition Program (NADP) to derive spatial coverages of inorganic, nitrate, and ammonium wet deposition (Alexander and others, 2008). Efforts will be made in Cycle 3 to improve the spatial resolution of these estimates, to provide estimates by season, and to develop models that permit an extension of the estimates to include dry deposition.

Other landscape variables are required to describe the transport of contaminants from the land surface to the receiving reach channels. Important examples are topography, soils, climate, and runoff data. For NHDPlus, topography can be derived from the same 30-meter digital elevation data used to delineate catchments. Soils data for Cycle 3 will be from Soil Survey Geographic database (SSURGO; U.S. Department of Agriculture, Natural Resources Conservation Program, 2011b), a higher resolution version of the currently used State Soils Geographic data set (STATSGO; U.S. Department of Agriculture, Natural Resources Conservation Program, 2011c). SSURGO data are nearly complete for the entire conterminous U.S.; however, some fill-in with STATSGO data will be required in some counties lacking SSURGO information (see the SSURGO status map, U.S. Department of Agriculture, Natural Resources Conservation Service, 2011a). The SPARROW models planned for Cycle 3 will require mean seasonal climate conditions in addition to mean annual conditions, Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly and others, 2011) being a viable data source for both. Existing methods for generating estimates of runoff for the E2RF1 network will be used to compute mean annual and seasonal runoff for NHDPlus catchments (Wieczorek and LaMotte, 2010b).

In recent years, the NRCS has granted USGS limited access to proprietary National Resources Inventory (NRI) data to produce high-resolution estimates of irrigated land. The USGS intends to continue this

effort under Cycle 3, using statistical methods to improve the estimates and to apply these methods to produce maps of other NRI variables, such as tile drainage, erosion, and management practices. If possible, these methods will also be applied to proprietary data from the USDA's Conservation Effects Assessment Program (CEAP) program to produce estimates for a number of management actions not currently described in the NRI data.

Cycle 3 SPARROW models will be used to improve understanding of the interaction between groundwater and surface water. In support of this effort, groundwater models developed by NAWQA for Cycle 3 will be used to make reach-level seasonal estimates of the groundwater component of streamflow. Other geologic variables will be developed to aid this effort, including NHDPlus catchment-delineated maps of surficial and sub-surficial geology, for the description of various aquifer characteristics, such as recharge rate and transmissivity. Existing spatial data sets of natural phosphorus will be further improved to provide coverage for most of the conterminous U.S.

Ancillary Data for Dynamic and Seasonal Models

The integrated watershed modeling plan for Cycle 3 calls for the development of dynamic SPARROW models, and the Cycle 3 plan for status assessment requires models to have a seasonal component. In support of these efforts it will be necessary to develop temporally varying values for a number of key SPARROW model input data, primarily the contaminant source and climate variables. Temporal and seasonal values of the climate variables are readily available from the PRISM data set described above, and their development presents no special challenges. Seasonal and temporal values for source variables will be generated from existing sources, perhaps with the simplifying assumption that the annual application of contaminant sources such as fertilizer and pesticides takes place exclusively during a fixed period of the year, that period being determined using other ancillary information such as spatial patterns in the typical planting dates for predominant crops.

Appendix 3A-Principal Aquifer Rankings

Aquifer name	Irrigation	Public-supply	Self-supplied industrial	Total	Rank Public Supply	Rank Total Use	running sum public	Cum_percent
Glacial sand and gravel aquifers	977	1,868	558.4354	3,410	1	7	1,868	12%
California Coastal Basin aquifers	1,760	1,580	106	3,440	2	6	3,448	22%
Floridan aquifer system	1,930	1,330	385	3,640	3	5	4,778	31%
Basin and Range basin-fill aquifers	4,550	1,010	63.3	5,620	4	4	5,788	38%
Coastal lowlands aquifer system	933	1,010	425	2,370	4	9	6,798	44%
Central Valley aquifer system	8,910	839	58.9	9,810	6	2	7,637	50%
Northern Atlantic Coastal Plain aquifer system	70.2	793	172	1,040	7	13	8,430	55%
Biscayne aquifer	114	698	0	812	8	19	9,128	59%
Cambrian-Ordovician aquifer system	92.4	590	251	932	9	16	9,718	63%
Mississippi embayment aquifer system	195	576	175	946	10	14	10,294	67%
Edwards-Trinity aquifer system	282	411	47.2	740	11	20	10,705	69%
Stream Valley Aquifers	984	400	177	1561	12	10	11,105	72%
High Plains aquifer	17,000	389	99.2	17,500	13	1	11,494	75%
Southeastern Coastal Plain aquifer system	382	340	138	860	15	18	11,834	77%
Surficial aquifer system	364	263	23.1	650	16	21	12,097	78%
Volcanic-rock aquifers (Hawaii)	171	243	14.5	428	17	25	12,340	80%
Rio Grande aquifer system	867	240	12.2	1,120	18	11	12,580	82%
Columbia Plateau basaltic-rock aquifers	674	223	35.7	933	19	15	12,803	83%
Mississippian aquifers	6.31	211	67.9	286	20	32	13,014	84%
Puget Sound aquifer system	44.9	192	23.4	260	21	34	13,206	86%
Valley and Ridge carbonate-rock aquifers	5.65	177	83.9	267	22	33	13,383	87%
Silurian-Devonian aquifers	27.4	164	54.7	246	23	35	13,547	88%
Texas coastal uplands aquifer system	188	148	45	381	24	28	13,695	89%
Ozark Plateaus aquifer system	20.5	131	14	165	26	38	13,826	90%
Early Mesozoic basin aquifers	6.42	108	17.1	131	27	41	13,934	90%
Colorado Plateaus aquifers	81.9	102	13.9	198	28	36	14,036	91%
Willamette Lowland basin-fill aquifers	245	98.7	75.5	419	29	26	14,135	92%
Piedmont and Blue Ridge crystalline-rock aquifers	29.9	92.1	23.6	146	30	39	14,227	92%
Snake River Plain basin-fill aquifers	379	81.4	10.2	471	31	24	14,308	93%
Northern Rocky Mountains Intermontane Basins aquifer system	264	78.4	35.1	378	32	29	14,386	93%
New England crystalline-rock aquifers	11.1	73.6	11.6	96.3	33	45	14,460	94%
Pacific Northwest basin-fill aquifers	784	71.8	9.28	865	34	17	14,532	94%

Basin and Range carbonate-rock aquifers	0.5	71.2	1.92	73.6	35	47	14,603	95%
Snake River Plain basaltic-rock aquifers	2,520	70	14.4	2,610	36	8	14,673	95%
Mississippi River Valley alluvial aquifer	9,125	69.61291	70.21131	9,265	37	3	14,743	96%
Intermediate aquifer system (Florida)	292	61.2	0.74	354	38	30	14,804	96%
Pennsylvanian aquifers	4.462977	61.15932	38.80508	103.9	39	43	14,865	96%
Lower Cretaceous aquifers	259	52.9	4.89	317	40	31	14,918	97%
Valley and Ridge aquifers	0.61	48.9	45.5	95	41	46	14,967	97%
Pacific Northwest basaltic-rock aquifers	422	48.8	4.21	475	42	23	15,016	97%
North Coast Limestone aquifer system (Puerto Rico)	5.71	46.8	6.41	58.9	43	48	15,062	98%
New York and New England carbonate-rock aquifers	1.98	35.8	8.64	46.4	44	52	15,098	98%
Marshall aquifer	13.3	35.2	4.66	53.2	45	51	15,133	98%
New York sandstone aquifers	0.87	34.3	20.8	55.9	46	50	15,168	98%
Northern Great Plains aquifer system	66.6	33	1.62	101	47	44	15,201	99%
Unconsolidated-deposit aquifers (Alaska)	0.99	27.8	4.13	33	48	57	15,229	99%
Central Oklahoma aquifer	5.25	25.6	0.82	31.7	49	58	15,254	99%
South Coast aquifer (Puerto Rico)	15.6	25.5	2.15	43.3	50	54	15,280	99%
Castle Hayne aquifer	7.64	23.4	2.07	33.1	51	56	15,303	99%
Roswell Basin aquifer system	364	21.1	1.17	386	52	27	15,324	99%
Lower Tertiary aquifers					52		15,324	99%
Upper Cretaceous aquifers					52		15,324	99%
Piedmont and Blue Ridge carbonate-rock aquifers	0.35	17.8	11.8	29.9	53	59	15,342	99%
Denver Basin aquifer system	11.9	16.9	7.44	36.3	54	55	15,359	100%
Paleozoic aquifers	3.55	13.2	1.32	18.1	55	60	15,372	100%
Pecos River Basin alluvial aquifer	109	12	2.46	124	56	42	15,384	100%
Upper carbonate aquifer	0.35	7.52	1.68	9.55	57	61	15,392	100%
Seymour aquifer	162	7.4	0.6	170	58	37	15,399	100%
Rush Springs aquifer	49.7	6.2	0.37	56.2	59	49	15,405	100%
Ordovician aquifers	0.56	4.85	0.38	5.79	60	62	15,410	100%
Ada-Vamoosa aquifer	0.06	3.99	0.02	4.07	61	64	15,414	100%
Jacobsville aquifer	0.06	2.81	0.14	3.01	62	65	15,417	100%
Arbuckle-Simpson aquifer	1.19	2.38	0.61	4.18	63	63	15,419	100%
Upper Tertiary aquifers	0.6	0.92	0.09	1.61	64	66	15,420	100%
Kingshill aquifer (Virgin Islands)	0	0.52	0.22	0.74	65	67	15,421	100%
Blaine aquifer	43.2	0.3	0.69	44.2	66	53	15,421	100%
Columbia Plateau basin-fill aquifers	136	0	7.5	143	67	40	15,421	100%
Southern Nevada volcanic-rock aquifers	0	0	0	0	67	68	15,421	100%

Appendix 3B: Criteria Used to Rank and Select existing MAS and LUS Networks for Decadal Trends Sampling for Cycle 3

Background: Cycle 2 selection criteria

Significant planning went into the design of the trends network at the beginning of Cycle 2, and the overall objectives for monitoring of trends remains the same. Therefore, the existing groundwater trends networks were used as the basis for the design of the Cycle 3 networks. Cycle 1 networks that were not part of the trends networks were not considered for Cycle 3 sampling, except in a few cases where MAS networks were selected to improve physical nesting with highly-ranked Ag or Urban LUS networks. MAS trends networks in Cycle 2 were selected from principal aquifers that had the following characteristics:

- The aquifer is an important current or potential source of drinking water and is part of one of 16 principal aquifer systems of the U.S. selected by NAWQA.
- The aquifer represents one of the 6 major lithologies of aquifer systems (unconsolidated sand and gravel, semiconsolidated sand, sandstone, carbonate rock, crystalline rock, and basaltic / volcanic rock).
- The aquifers collectively cover a reasonable spatial distribution of hydrologic landscapes across the U.S.
- Many selected MASs contain within their boundaries one or more agricultural or urban LUSs.
- The MAS is located in a NAWQA study unit that will be sampled during Cycle 2.

Given the above characteristics, the number of MAS networks allocated to a principal aquifer in Cycle 2 was determined by ranks of domestic and public supply water use and the areal extent of the aquifer system.

AgLUS trends networks in Cycle 2 were selected on the basis of specific crop groups that served as surrogates for agricultural practices and pesticide and fertilizer use, in combination with a systematic assessment of intrinsic vulnerability of shallow aquifers based on Hydrologic Landscape concepts. By combining the highest use areas with the most susceptible areas, it was anticipated that networks prioritized for trends sampling would be most likely to change in a 10 year timeframe. Urban LUS networks in Cycle 2 were selected from the 16 principal aquifer systems of the U.S. selected by NAWQA and on the basis of population growth and the number of people using groundwater for drinking water.

Cycle 3 Selection Criteria

Additional factors (or combinations) were considered in the design of the national groundwater trends network for Cycle 3:

- networks with two rounds of decadal sampling
- domestic and public water use of principal aquifer
- reduce duplication of land-use type within a principal aquifer (to include specific crop type)
- maintain or improve nesting of land-use study within a major aquifer study or FPS within a LUS
- reasonable geographic distribution
- presence of significant change if sampled twice
- maintaining a minimum number of sites that can be sampled on a decadal basis

The initial target for the number of networks previously sampled in Cycles 2 and (or) 1 and resampled in Cycle 3 was about 80. Because of the Cycle 3 emphasis on aquifers used for drinking water supply, the number of MAS networks was planned to remain constant or increase from 31 to a range of 30-35 (31 under proposed plan). The initial target for the number of Ag LUS networks sampled in Cycle 2 and resampled in Cycle 3 required a reduction from 32 to a range of 25-30 networks (27 under proposed plan). Given the amount of urban land use (5 to 25 year old residential or commercial) relative to agricultural land use, the number of Urban LUS networks was targeted for a reduction from 30 to 20 networks.

Networks were ranked primarily according to water use and nesting with other NAWQA networks (Table 3B1). For MAS networks, the overall ranking was a sum of the ranks for water use for public and domestic supply, and the nesting ranks. For the Ag LUS networks, the overall ranking was a sum of the ranks for water use for public supply, the nesting ranks, and the agricultural crop group rank (table 3B2). Recognizing that selection of Cycle 2 Ag LUS networks was based on a combination of major crop groups, pesticide and fertilizer use, and aquifer susceptibility, it was desirable to maintain the selected crop groups yet avoid redundancy where possible; therefore, a lower rank was given to crops that were represented with multiple networks. For Urban LUS networks, the overall ranking was a sum of the ranks for water use for public supply and the nesting ranks. Additionally, in areas where TANC small-scale studies were done in Cycle 2, urban LUS networks nested with TANC studies were maintained or substituted for existing urban LUS trends networks in the same study unit because of the detailed models and associated monitoring data, which would allow for better understanding of trends in these areas.

Because of the increased emphasis in Cycle 3 on drinking water used for public supply, a weight of 1.5 times the rank was applied to the public supply rank. An exception to this weighting is in the Ag LUS networks since the locations of those networks are less related to public supply water use, and because of significant effort was undertaken during Cycle 2 design to determine the appropriate crop groups for inclusion in trends analysis; therefore, it was desirable to preserve the crop distributions as much as possible and not overly weight the ranking to the highest public supply water use.

Physically-nested networks are those in which a LUS or FPS is nested within a larger LUS or MAS network; these networks are co-located in the same hydrogeologic subarea of the larger principal aquifer. Conceptually-nested networks are other networks located in the same principal aquifer (or hydrologically-linked principal aquifers), but not co-located in the same hydrogeologic subarea. Because of the emphasis on groundwater modeling at the principal aquifer and regional scale in Cycle 2, it is anticipated that interpreting trends in conceptually-nested networks can be done with the aid of these additional tools, without physical co-location.

Table 3B-1. Numerical values given to network ranking criteria used in selection of Cycle 3 groundwater trends networks.

Network Ranking Criteria		
Water use for Public Supply	4	Principal Aquifer in top 50% of supply
	3	50-75%
	2	75-90%
	1	>90%
Water use for Domestic Supply	3	Principal Aquifer rank 1 thru 8
	2	9 thru 16
	1	> 16th
Physically-nested networks	3	all three network types nested (MAS, LUS, FPS)
	2	one other nested network (MAS, LUS or LUS, FPS)
	1	only that network (no nesting)
Conceptually-nested networks	0.75	both LUS and MAS conceptually related within SU
	0.67	other network of different type (MAS or LUS)
	0.5	other network of same type (MAS or LUS)

Currently active trends networks were evaluated within the constraints of the targeted number of networks of each network type, resulting in a proposed list of groundwater trends networks to be continued in Cycle 3 (table 3-9). Similarly, to meet target network numbers, selected networks were slated for postponement due to low ranking or other criteria (table 3-10). "Postponed" networks are those that are not planned for sampling during Cycle 3. Postponed networks may be considered for sampling if additional funding becomes available during Cycle 3; therefore, no existing trends networks are considered "dropped." Additionally, all trends networks may be considered for sampling in Cycle 4. In some cases, networks with lower ranks were kept for sampling in Cycle 3 over networks with higher ranks (especially in Urban LUS networks because of the large reduction in the number of networks). This was done to preserve representation of principal aquifer or crop groups by reducing redundancy where possible. The Glacial Aquifer makes up the largest proportion of networks in all three network types and was targeted for some reduction in the number of networks; however, this aquifer has a large areal extent and high domestic and public supply water use so a large number of networks is to be expected. Additional notes and actual ranks of the networks are included in the appendix in table Appendix GXX.

In a few cases, additional MAS or LUS networks sampled during Cycle 1 were added to the trends networks planned for sampling in Cycle 3 (Table 3-11). These "reactivated" networks were selected to improve nesting with other high-ranked networks in the study area, and generally ranked higher than

Table 3B-2. Ranks of different Ag-LUS crop settings used to prioritize Cycle 3 Ag LUS studies

Crop Name	Rank	Number of networks Cycle 2
Berries	3	1
Field grass>50'	3	1
Potatoes and Corn*	3	1
Rice > 50	3	1
Corn (non-soybean) groups:		
Corn > 20 Alfalfa > 20	2	1
Corn > 20 Wheat and other grains > 20	2	1
Corn > 50	2	1
Cotton groups:		
Cotton > 50	2	1
Cotton > 50, peanuts>10	2	1
Cotton, corn, soybeans	2	1
Wheat groups:		
Wheat and other grains > 20 Alfalfa > 20	2	1
Wheat and other grains > 50	2	1
Wheat>20 Alfalfa>20	2	1
Orchard/Vineyard	2	4
Corn and Soybean groups: Corn>20	1	1
Soybeans>20 Wheat and other grains>20		
Corn > 20 Soybeans > 20	1	10

* This crop name corresponds to study unit network description (appears to be misclassified as Wheat and other grains).

any of the networks slated for postponement. Because some of the analysis of the trends network data will be done separate from the groundwater modeling analysis, improvement in physical nesting of networks was desirable to facilitate interpretation in important study areas without compromising coherency of the entire decadal trends analysis. Additional notes of explanation and ranks of the reactivated networks are included in the appendix in table Appendix GXX.

The number of MAS networks allocated to Principal Aquifers in Cycle 3 is summarized in table 3B3. The top 15 aquifers used for public supply are represented, with the exception of the Biscayne (ranked 8) and Stream Valley aquifers (ranked 12). Trends wells sampled in the Biscayne were public-supply wells and because of the high ranking for public supply water use in this aquifer, these wells will already be sampled as part of the PA assessment. No MAS trends networks were present in the Stream Valley aquifers. MAS networks were also postponed in the Early Mesozoic Basin and New York and New England crystalline-rock aquifers; these PAs ranked 25th and 31st for public supply (9th and 12th for domestic supply).

Table 3B-3. Number of groundwater trends networks by Principal Aquifers in Cycle 3

Cycle 3 MAS Trends Networks (n=31)		
Principal Aquifer	Public Supply Rank	Number of networks
Glacial-deposit aquifers	1	7
California Coastal Basin aquifers	2	3
Floridan aquifer system	3	2
Basin and Range aquifers	4	3
Coastal Lowlands aquifer system	4	2
Central Valley aquifer system	6	1
Northern Atlantic Coastal Plain aquifer system	7	3
Cambrian-Ordovician aquifer system	9	3
Miss. Embayment-TX Coastal Uplands aquifer system	10	1
Edwards-Trinity aquifer system	11	1
High Plains aquifer	13	1
Southeastern Coastal Plain aquifer system	14	1
Surficial aquifer system	15	1
Columbia Plateau aquifer system	18	1
Piedmont and Blue Ridge crystalline-rock aquifers	28*	1

* important source of domestic supply (ranked 2nd)

The spatial distribution of groundwater trends networks is shown in Figures 3-6 to 3-8, including those that are currently active and will be resampled in Cycle 3, those that are slated for postponement, and those that are reactivated from Cycle 1. The network ranking approach resulted in a generally good geographic distribution for the MAS networks within areas of greatest groundwater use for drinking water. Similarly, the LUS networks have a generally good geographic distribution within areas of greatest groundwater use for drinking water combined with dominantly agricultural or urban land use settings.

Table 3B-4. Currently active trends networks that are proposed to be continued or postponed in Cycle 3

Purple shaded cells are MAS networks slated for postponement or substitution, green shaded cells are Ag LUS networks that are slated for postponement or substitution, blue shaded cells are Urban LUS networks slated for postponement or substitution, and brown shaded cells are networks needing verification for nesting with TANC studies. See notes column for more detailed explanation on postponement or substitution decisions.

Currently active MAS Trends Networks			
Principal Aquifer	Sucode	RANK	Notes
Glacial-deposit aquifers	eiwasus2	12.8	
Glacial-deposit aquifers	connsus2	12.5	Since ur1 sub'd for rc1, sub with nested connsus1
Glacial-deposit aquifers	lerisus1	12.0	
Central Valley aquifer system	sanjsus1	12.0	

Glacial-deposit aquifers	lirbsus1	11.8	
Floridan aquifer system	acfbSus1	11.7	
Glacial-deposit aquifers	miamSus1	11.7	
Coastal Lowlands aquifer system	acadsus1	11.5	
Basin and Range aquifers	grslsus2	11.5	
California Coastal basin aquifers	sanasus2	11.5	
Coastal Lowlands aquifer system	trinsus3	11.5	
Northern Atlantic Coastal Plain aquifer system	linjsus2	11.2	
Northern Atlantic Coastal Plain aquifer system	dImvsus1	11.0	
Glacial-deposit aquifers	necbsus3	11.0	Lowest ranked of Glacial Aquifer; sub for pugtsus1 (nested w/pugtluscr1)
Basin and Range aquifers	nvbrsus2	10.8	
Basin and Range aquifers	cazbsus1a	10.5	
California Coastal basin aquifers	sanasus1	10.5	
Edwards-Trinity aquifer system	sctxsus1	10.3	
Miss. Embayment-TX Coastal Uplands aquifer system	misesus4	10.0	
Floridan aquifer system	santsus2	10.0	
California Coastal Basin aquifers	sacrsus4	9.5	
High Plains aquifer	hpgwsus1a	9.3	
Northern Atlantic Coastal Plain aquifer system	albesus7	9.0	
Cambrian-Ordovician aquifer system	uirbsus3	8.3	
Cambrian-Ordovician aquifer system	wmicSus1	8.3	
Cambrian-Ordovician aquifer system	umissus3	8.0	
Columbia Plateau aquifer system	ccptsus1b	7.5	Kept (over sctx) due to only remaining in Col Plateau Aq
Miss. Embayment-TX Coastal Uplands aquifer system	sctxsus4	7.5	Postponed due to low ranking and other studies avail in PA
Biscayne aquifer	soflsus1	7.3	Will be sampled as part of PA assessment
Early Mesozoic Basin aquifers	delrsus1	6.0	Postponed due to low ranking
New York and New England crystalline-rock aquifers	necbsus1	5.0	Picked up piedmont network potosus1 as bedrock aquifer

Currently active Ag LUS Trends Networks

Principal Aquifer	Sucode	rank	Notes
Glacial-deposit aquifers	pugtluscr1	10.5	
Glacial-deposit aquifers	wmiclusag2	9.8	
Central Valley aquifer system	sanjlusor1a	9.0	
Central Valley aquifer system	sanjlusor2a	9.0	
Glacial-deposit aquifers	cnbrluscr1	8.8	
Glacial-deposit aquifers	eiwaluscr1	8.8	
Central Valley aquifer system	sacrluscr1	8.8	
Central Valley aquifer system	sanjluscr1a	8.5	
Glacial-deposit aquifers	uirbluscr1	7.8	

Northern Atlantic Coastal Plain aquifer system	albelusag1	7.7	
Northern Atlantic Coastal Plain aquifer system	dImvluscr1	7.7	
Glacial-deposit aquifers	miamluscr1	7.5	
Glacial-deposit aquifers	whitluscr1	7.5	
Ozark Plateaus aquifer system	ozrkclusag2a	6.8	
Surficial aquifer system	santluscr1	6.8	
Glacial-deposit aquifers	umisluscr1	6.8	2nd lowest ranked Glacial Aquifer w/Corn, Soybeans
Surficial aquifer system	gaflluscr1	6.7	
Alluvial aquifers	spltluscr1	6.7	
Southeastern Coastal Plain aquifer system	acfbcluscr3	6.5	
Valley and Ridge aquifers	potolusag1	6.5	
Rio Grande aquifer system	rioglusag1	6.5	
Glacial-deposit aquifers	kansluscr1	6.0	Lowest ranked Glacial Aquifer w/Corn, Soybeans
Mississippian aquifers	ltenlusag1	6.0	
Columbia Plateau aquifer system	ccptlusag2b	5.8	
Columbia Plateau aquifer system	ccptlusor1b	5.8	
Surficial aquifer system	sofllusor1	5.8	
Snake River Plain aquifer system	usnkluscr2	5.8	
Snake River Plain aquifer system	usnkluscr3	5.8	
Alluvial aquifers	tennluscr2	5.7	
Rio Grande aquifer system	riogluscr1	5.5	Postponed due to low ranking
Willamette Lowland aquifer system	willlusag3	5.5	Postponed due to low ranking
Alluvial aquifers	yellluscr1	5.0	Postponed due to low ranking

Currently active Ur LUS Trends Networks

Principal Aquifer	Sucode	rank	Notes
Glacial-deposit aquifers	connluscr1	7.75	Replace with TANC-nested network: connlusur1
Basin and Range aquifers	grsllusrc1	7.67	
Glacial-deposit aquifers	lerilusrc1	7	
Basin and Range aquifers	nvbrlusrc1	6.75	
Coastal Lowlands aquifer system	acadlusrc1	6.75	
Glacial-deposit aquifers	uirblusrc1	6.75	
Glacial-deposit aquifers	umislusrc1	6.75	
Coastal Lowlands aquifer system	trinlusrc1	6.67	
Edwards-Trinity aquifer system	sctxlusrc1	6.67	
Floridan aquifer system	gafllusrc1b	6.67	Ensure correct TANC-nested network in UFA; otherwise substitute
Central Valley aquifer system	sacrlusrc1	6.5	
Glacial-deposit aquifers	miamlusrc1	6.5	
Glacial-deposit aquifers	pugtlusrs1	6.5	No commercial / not consistent with other UrLUS
Northern Atlantic Coastal Plain aquifer system	linjlusrc1	6.5	

Coastal Lowlands aquifer system	mobllusrc2	6	Higher ranked than Biscayne, but other Coastal Lowlands networks avail
Glacial-deposit aquifers	necblusrc1	6	
Biscayne aquifer	sofllusrc1a	5.75	Kept due to only remaining Biscayne
Glacial-deposit aquifers	lirblusrc1	5.75	2nd lowest ranked Glacial Aquifer
Glacial-deposit aquifers	linjlusrc2	5	Lowest ranked Glacial Aquifer
Edwards-Trinity aquifer system	sctxlusrc2	4.75	Postponed due to low ranking
Surficial aquifer system	sofllusrc2	4.75	Postponed due to low ranking
Miss. Embayment-TX Coastal Uplands aquifer system	miselusrc1	4.67	Kept due to only remaining Miss Embay
Surficial aquifer system	gafllusrc1a	4.67	Ensure correct TANC-nested network in surficial; otherwise substitute
Rio Grande aquifer system	rioglusrc1	4.5	Kept due to TANC study area
Southeastern Coastal Plain aquifer system	santlusrc1	4.5	Kept due to only remaining SE Coastal Plain
Northern Atlantic Coastal Plain aquifer system	delrlusrc2	4	Postponed due to low ranking
Denver Basin Aquifer System	spltlusrc2	3.75	Postponed due to low ranking
Southeastern Coastal Plain aquifer system	mobllusrc1	3.75	Postponed due to low ranking
Alluvial aquifers	ucollusrc1	3.67	Postponed due to low ranking
Piedmont and Blue Ridge crystalline-rock aquifers	podllusrc1	3	Kept due to coordination with Chesapeake Bay Program work

Table 3B5. Groundwater networks reactivated in Cycle 3

See notes column for reasoning on reactivation of networks

Reactivated MAS trends networks: (n=6)

Principal Aquifer	Sucode	RANK	Notes
Glacial-deposit aquifers	connsus1	12.7	Added for nesting w/TANC-related connlusur1
Glacial-deposit aquifers	pugtsus1	12.8	Added for nesting w/pugtlusrs1 and FSS
Glacial-deposit aquifers	wmicus2	12.8	Added for nesting w/wmiclusag2, FSS, and underlying C/O
Piedmont and Blue Ridge crystalline-rock aquifers	potosus1	6.7	Added due to coord with Chesapeake Bay Program work, nesting w/podllusrc1
Southeastern Coastal Plain aquifer system	moblsus1	6.7	Added because no MAS in Southeastern Coastal Plain
Surficial aquifer system	gaflsus1	5.5	Added because surficial contributes to underlying Floridan, an important source of drinking water; also nests with gaflluscr1

Reactivated Urban LUS trends networks (n=1)

Principal Aquifer	Sucode	RANK	Notes
Glacial-deposit aquifers	connlusur1	7.75	Added for nesting w/TANC study

Aquifer name	Irrigation	Public-supply	Self-supplied industrial	Total	rank public	rank total	running sum public	Cum_percent
Glacial sand and gravel aquifers	977	1,868	558.4354	3,410	1	7	1,868	12%
California Coastal Basin aquifers	1,760	1,580	106	3,440	2	6	3,448	22%
Floridan aquifer system	1,930	1,330	385	3,640	3	5	4,778	31%
Basin and Range basin-fill aquifers	4,550	1,010	63.3	5,620	4	4	5,788	38%
Coastal lowlands aquifer system	933	1,010	425	2,370	4	9	6,798	44%
Central Valley aquifer system	8,910	839	58.9	9,810	6	2	7,637	50%
Northern Atlantic Coastal Plain aquifer system	70.2	793	172	1,040	7	13	8,430	55%
Biscayne aquifer	114	698	0	812	8	19	9,128	59%
Cambrian-Ordovician aquifer system	92.4	590	251	932	9	16	9,718	63%
Mississippi embayment aquifer system	195	576	175	946	10	14	10,294	67%
Edwards-Trinity aquifer system	282	411	47.2	740	11	20	10,705	69%
Stream Valley Aquifers	984	400	177	1561	12	10	11,105	72%

High Plains aquifer	17,000	389	99.2	17,500	13	1	11,494	75%
Southeastern Coastal Plain aquifer system	382	340	138	860	15	18	11,834	77%
Surficial aquifer system	364	263	23.1	650	16	21	12,097	78%
Volcanic-rock aquifers (Hawaii)	171	243	14.5	428	17	25	12,340	80%
Rio Grande aquifer system	867	240	12.2	1,120	18	11	12,580	82%
Columbia Plateau basaltic-rock aquifers	674	223	35.7	933	19	15	12,803	83%
Mississippian aquifers	6.31	211	67.9	286	20	32	13,014	84%
Puget Sound aquifer system	44.9	192	23.4	260	21	34	13,206	86%
Valley and Ridge carbonate-rock aquifers	5.65	177	83.9	267	22	33	13,383	87%
Silurian-Devonian aquifers	27.4	164	54.7	246	23	35	13,547	88%
Texas coastal uplands aquifer system	188	148	45	381	24	28	13,695	89%
Ozark Plateaus aquifer system	20.5	131	14	165	26	38	13,826	90%
Early Mesozoic basin aquifers	6.42	108	17.1	131	27	41	13,934	90%
Colorado Plateaus aquifers	81.9	102	13.9	198	28	36	14,036	91%
Willamette Lowland basin-fill aquifers	245	98.7	75.5	419	29	26	14,135	92%
Piedmont and Blue Ridge crystalline-rock aquifers	29.9	92.1	23.6	146	30	39	14,227	92%
Snake River Plain basin-fill aquifers	379	81.4	10.2	471	31	24	14,308	93%
Northern Rocky Mountains Intermontane Basins aquifer system	264	78.4	35.1	378	32	29	14,386	93%
New England crystalline-rock aquifers	11.1	73.6	11.6	96.3	33	45	14,460	94%
Pacific Northwest basin-fill aquifers	784	71.8	9.28	865	34	17	14,532	94%
Basin and Range carbonate-rock aquifers	0.5	71.2	1.92	73.6	35	47	14,603	95%
Snake River Plain basaltic-rock aquifers	2,520	70	14.4	2,610	36	8	14,673	95%
Mississippi River Valley alluvial aquifer	9,125	69.61291	70.21131	9,265	37	3	14,743	96%
Intermediate aquifer system (Florida)	292	61.2	0.74	354	38	30	14,804	96%
Pennsylvanian aquifers	4.462977	61.15932	38.80508	103.9	39	43	14,865	96%
Lower Cretaceous aquifers	259	52.9	4.89	317	40	31	14,918	97%
Valley and Ridge aquifers	0.61	48.9	45.5	95	41	46	14,967	97%
Pacific Northwest basaltic-rock aquifers	422	48.8	4.21	475	42	23	15,016	97%
North Coast Limestone aquifer system (Puerto Rico)	5.71	46.8	6.41	58.9	43	48	15,062	98%
New York and New England carbonate-rock aquifers	1.98	35.8	8.64	46.4	44	52	15,098	98%
Marshall aquifer	13.3	35.2	4.66	53.2	45	51	15,133	98%
New York sandstone aquifers	0.87	34.3	20.8	55.9	46	50	15,168	98%
Northern Great Plains aquifer system	66.6	33	1.62	101	47	44	15,201	99%
Unconsolidated-deposit aquifers (Alaska)	0.99	27.8	4.13	33	48	57	15,229	99%

Central Oklahoma aquifer	5.25	25.6	0.82	31.7	49	58	15,254	99%
South Coast aquifer (Puerto Rico)	15.6	25.5	2.15	43.3	50	54	15,280	99%
Castle Hayne aquifer	7.64	23.4	2.07	33.1	51	56	15,303	99%
Roswell Basin aquifer system	364	21.1	1.17	386	52	27	15,324	99%
Lower Tertiary aquifers					52		15,324	99%
Upper Cretaceous aquifers					52		15,324	99%
Piedmont and Blue Ridge carbonate-rock aquifers	0.35	17.8	11.8	29.9	53	59	15,342	99%
Denver Basin aquifer system	11.9	16.9	7.44	36.3	54	55	15,359	100%
Paleozoic aquifers	3.55	13.2	1.32	18.1	55	60	15,372	100%
Pecos River Basin alluvial aquifer	109	12	2.46	124	56	42	15,384	100%
Upper carbonate aquifer	0.35	7.52	1.68	9.55	57	61	15,392	100%
Seymour aquifer	162	7.4	0.6	170	58	37	15,399	100%
Rush Springs aquifer	49.7	6.2	0.37	56.2	59	49	15,405	100%
Ordovician aquifers	0.56	4.85	0.38	5.79	60	62	15,410	100%
Ada-Vamoosa aquifer	0.06	3.99	0.02	4.07	61	64	15,414	100%
Jacobsville aquifer	0.06	2.81	0.14	3.01	62	65	15,417	100%
Arbuckle-Simpson aquifer	1.19	2.38	0.61	4.18	63	63	15,419	100%
Upper Tertiary aquifers	0.6	0.92	0.09	1.61	64	66	15,420	100%
Kingshill aquifer (Virgin Islands)	0	0.52	0.22	0.74	65	67	15,421	100%
Blaine aquifer	43.2	0.3	0.69	44.2	66	53	15,421	100%
Columbia Plateau basin-fill aquifers	136	0	7.5	143	67	40	15,421	100%
Southern Nevada volcanic-rock aquifers	0	0	0	0	67	68	15,421	100%

Appendix 4-Criteria and Process used in the Selection of Recommended Integrated Watershed Study Basins

Selection approach

A candidate list of more than 250 basins was narrowed to a final list of 10 basins during a 5-step selection process, summarized below.

Step 1-Used as the starting candidate list the set of 269 basins/monitoring sites proposed for the 'Science Needs' FSN for Cycle 3. Narrowed this set to 58 candidate basins within the size range 1,000 to 100,000 square kilometers. (Rationale: We started with the proposed 'Science Needs' FSN 269 sites because an IWS basin needs to be anchored at its outlet by a long-term monitoring site and this set of 269 sites is a comprehensive list of long-term water-quality monitoring sites from NAWQA, NASQAN, NMN, and other agencies. The prescribed size range for the IWS basins is actually 5,000-50,000 square kilometers: however, for this initial screening we used min/max range of 1,000 and 100,000 square kilometer to capture all possible basins.)

Step 2-Added 65 'special interest' basins to the list of 58, for various reasons:

1. to make sure that all special research and experimental watersheds (NEON/ARS/MRBI) are contained the set of candidate basins: identified which of these special watersheds were not 'captured' as nested upstream of any of the starting set of 58 candidate basins and delineated a new candidate basin by defining as the basin outlet a long-term gage site somewhere downstream of the NEON/ARS/MRBI and with a drainage area in the 1,000-100,000 square kilometer size range.
2. to take advantage of the ground-water flow path modeling work and estimated ground-water lag times in the Delmarva, delineated a candidate 'basin' that corresponds to the Delmarva peninsula.

The set of 123 basins developed in Steps 1 and 2 is shown in Figure in Chapter 4A-1.

Step 3. Narrowed the list of 123 candidates to 43 basins (Appendix Table) based on a quantitative ranking of availability of surface-water water-quality data (ranking method described in a later section) in the NWIS/ModernSTORET inventory produced December 2011 (Denise Argue, written commun.)

Step 4. Narrowed list of 43 candidates to ten finalists, based on qualitative evaluation of several factors:

- land use (is agricultural land use > 10%),
- regional distribution (retain at least two finalists from each region),
- agricultural water management practices (e.g. finalist basins for the Western region should represent irrigated agriculture, finalist basins for the Midwest region should represent artificial tile drainage),
- physical characteristics, including soils, hydrologic pathway (finalists should have a mix of fast to slow ground water lag times), etc. (maps provided by Nancy Baker and Jennifer Lanning-Rush)
- information on historic and current gages
- overlap with the regional synoptic studies (RSS) and ARS/NEON/MRBI activities
- number and locations (relative to monitoring sites) of dams
- availability of existing (or high priority for the GW team for developing) ground-water flow and flow path models for the surficial aquifer
- inclusion of outlet site in the flat-funding FSN for Cycle 3,
- ground-water water-quality data availability (However, we discarded the results from evaluating this criteria because of concern that the ground-water monitoring data from state agencies is, for most

states, not included in STORET, and therefore the relative rankings between sites may be substantially biased.)

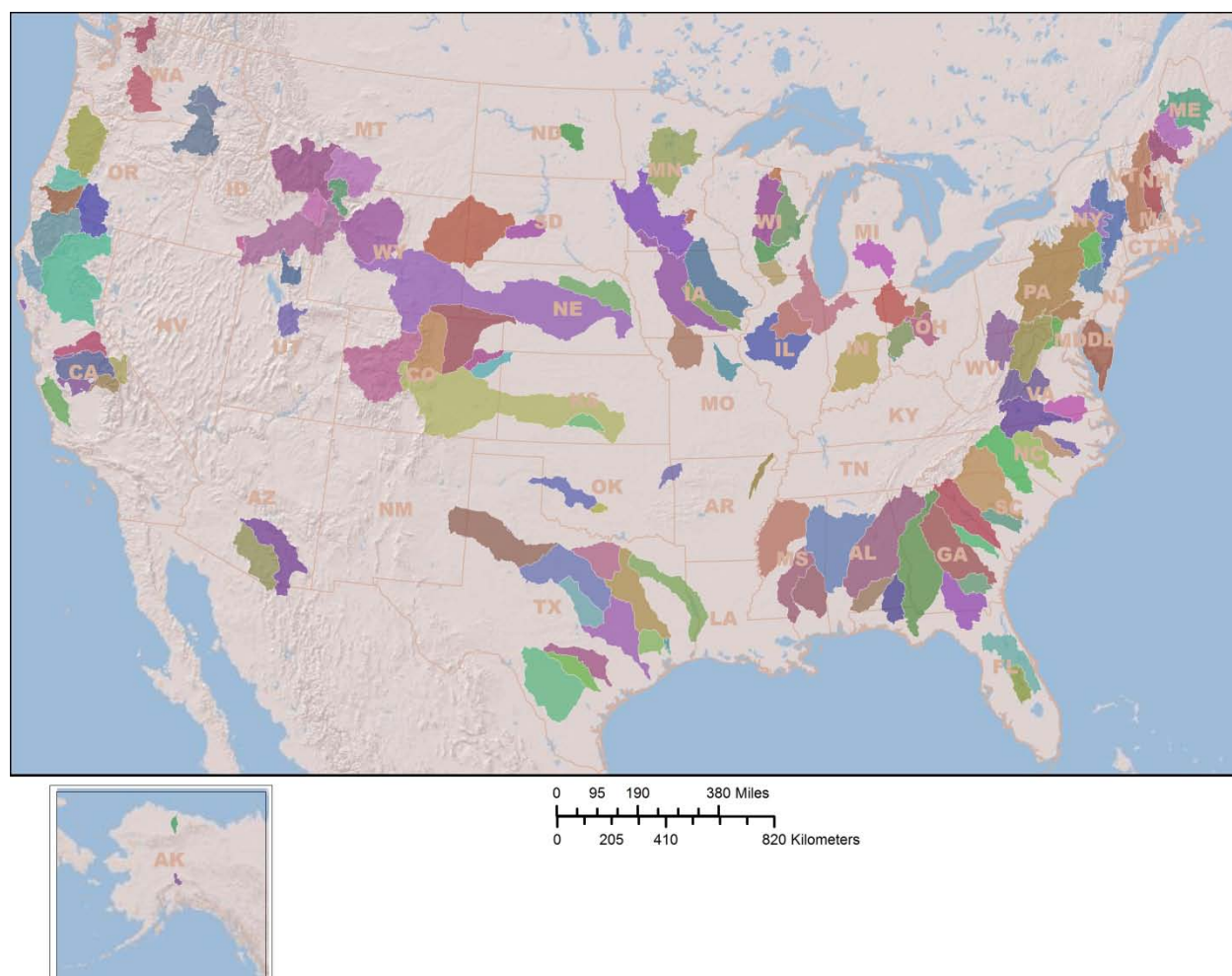


Figure 4.1-Locations of 123 river basins evaluated as candidates for a NAWQA Cycle 3 Integrated Watershed Study Basin, and locations of potential collaborative water-quality studies

Table 4.1. Attributes of 43 basins selected on the basis of availability of surface-water-quality data.
 [Shading represents the four large geographic groupings: Northeast, Southeast, Midwest, and West]

Map number	Station identifier (monitoring station)	Station name	Rating for Surface Water Quality Data Availability (SWDataAvail)	Drainage area, square kilometers	Watershed percent "planted/ cultivated" (agriculture), 2006 era	Watershed percent "developed" (urban)	Population density, persons per sq km	Dam density pre1990; number per 100 sq km	Outlet site included in the draft flat funding FSN?
1	01100000	Merrimack River BI Concord River At Lowell, Ma	0	11,983	5	13	117	4.5	No
2	01184000	Connecticut River At Thompsonville, Ct.	77	25,049	6	7	45	3.2	Yes
3	01357500	Mohawk River At Cohoes Ny	78	8,935					No
4	01372058	Hudson River Below Poughkeepsie Ny	91	30,782	16	8	59	1.8	Yes
5	01463500	Delaware River At Trenton Nj	106	17,580	15	10	76	3.5	Yes
6	01578310	Susquehanna River At Sunbury, PA	104	47,364	22	6	39	1.1	Yes
7	01646580	Potomac River Near Wash, Dc Little Falls Pump St	111	29,952	30	10	66	1.2	Yes
8	01491000	Delmarva Peninsula	86	14,130					NA
9	03085000	Monongahela River At Braddock, PA	78	19,002					No
10	02091814	Neuse River Near Fort Barnwell, Nc	83	10,220	32	15	113	3.6	Yes
11	02105769	Cape Fear R At Lock #1 Nr Kelly, Nc	0	13,660	20	14	103	4.4	No
12	02131000	Pee Dee River At Peedee, Sc	87	22,841	24	11	67	3.1	No
13	02171500	Santee River Near Pineville, Sc	111	37,732	16	14	86	3.6	No
14	02198500	Savannah River Near Clio, Ga	105	25,531	15	8	38	2.7	No
15	02226160	Altamaha River At Doctortown, Ga	113	35,273	16	11	65	3.7	Yes
16	02244450	St. Johns R At Buffalo Bluff Near Satsuma, Fl	107	17,513	18	15	103	0.1	No
17	02272500	Kissimmee River Near Basinger, Fl	108	7,016					No
18	02359170	Apalachicola River Nr Sumatra, Fla.	109	49,802	21	10	66	2.8	Yes
19	02429500	Alabama River At Claiborne Al	107	56,892					No
20	07288955	Yazoo River BI Steele Bayou Nr Long Lake, Ms	92	34,856	49	6	16	1.9	Yes
21	03274000	Great Miami River At Hamilton OH	0	9,404	70	17	124	0.9	No
22	03374000	White River At Petersburg, In	92	28,809	55	12	79	1.7	Yes
23	05330920	Minnesota River At Fort Snelling State Park, Mn	94	43,960	78	7	20	0.3	No
24	05407000	Wisconsin River At Muscoda, Wi	0	27,401	33	6	19	1.0	No
25	05465500	Iowa River At Wapello, IA	98	32,365	79	9	25	0.5	Yes
26	05490500	Des Moines River At Keosauqua,	107		79	7	22	1.3	Yes

		IA		36,286					
27	05568500	Illinois River At Kingston Mines, Il	116	40,963	66	20	226	0.7	Yes
28	06754000	South Platte River Near Kersey, Co.	107	25,016	13	10	112	2.1	Yes
29	06800500	Elkhorn River At Waterloo, Ne	0	17,989	57	4	7	0.3	Yes
30	06214500	Yellowstone River At Billings MT	83	29,549	5	1	4	0.2	No
31	07198000	Illinois River Near Gore, OK	106	56,892					No
32	08057410	Trinity Rv Bl Dallas, TX	0	16,227	14	22	219	3.8	Yes
33	08072050	San Jacinto Rv Nr Sheldon, TX	73	7,456					No
34	08096500	Brazos Rv At Seymour, TX	0	40,353	43	5	10	0.3	No
35	08188500	San Antonio Rv At Goliad, TX	0	10,120	25	16	147	1.5	No
36	09163500	Colorado River Near Colorado-Utah State Line	110	46,274	4	1	7	1.0	Yes
37	10092700	Bear River At Idaho-Utah State Line	79	12,649					No
38	10171000	Jordan River @ 1700 South @ Salt Lake City, Ut	97	8,244					Yes
39	11303500	San Joaquin R Nr Crows Landing Ca	77	30,040	30	5	37	0.2	Yes
40	11447650	Sacramento R A Knights Landing Ca	83	39,993	13	3	10	0.3	Yes
41	12510500	Yakima River At Kiona, Wa	0	14,536	15	5	18	0.2	Yes
42	13094000	Snake R Nr Minidoka Id (At Howells Ferry)	82	48,830	16	2	6	0.1	No
43	14211720	Willamette River At Portland, Or	103	28,937	20	7	67	0.8	Yes

Step 5. Assessed the number of sites in each of the 10 finalist basins that could be used to calibrate a dynamic (seasonal) SPARROW model for the period of interest. To do this we identified and mapped the locations of the frequently-sampled water-quality monitoring sites (identified using method described in a later section) and compared these locations with the spatial distribution of recent streamflow gages to estimate the number of sites that could be used to reliably estimate seasonally and annually varying load for the period of interest for the IWS.

The remainder of this appendix provides detailed descriptions of the methods used to generate the results for Steps 3 and 5.

Method for quantitatively ranking the availability of surface-water-quality data, used in Step 3. to narrow list the list of 123 candidate basins to 43 basins (and caution about possible biases)

The following steps were used to identify the basins that are 'better than the average' for availability of surface- water-quality data availability in NWIS and modernized STORET (ModSTORET). The retrieval of surface-water-quality monitoring data used in this evaluation was made by Jessica Thompson in November 2011.

1. Determine the number of upstream surface water sites (upstream from the basin outlet) with >20 nutrient (N,P) samples. This was computed as the average of a. number of upstream surface water sites

with >20 samples of P (no_swsites_gt20samps_P from the inventory) and b. number of upstream surface water sites with >20 samples of nitrate (maximum of no_swsites_gt20samps_no3 and no_swsites_gt20samps_no3no2)

2. Determine the number of upstream surface water sites with >20 carbon samples (any fraction, used no_swsites_gt20samps_carbon result from the inventory)
3. Determine the number of upstream surface water sites with >20 suspended sediment samples (compute as the maximum of the value for no_swsites_gt20samps_SSC and no_swsites_gt20samps_TSS)
4. Determine the number of upstream gages with greater than 5 years record (no_ge5yrs_upstrm_gages).
5. For each of a. b., c. and d. determine (yes/no) if the value is greater than the median value for the set of 122 sites. If all four answers are yes AND if all of the values in a.b.c.d. are greater than zero (no gaps for any of the stressors) then rate SW availability for site as "1", otherwise as "0".
6. For sites rated as 1, calculate a numeric score as the average of the ranks for each of a., b., c., and d.; then subtract the value from 123 so that the scoring increases with higher rank.
7. (added when processing version 2 of the retrieval): Repeat steps a. through f. after normalizing the numbers (a. – d.) by the drainage area of the basin. Sites rated as 1 using the normalized results were added to the list of sites that had been rated as 1 without normalizing.

Thirty-four basins were rated as "1" when these steps were applied to version 1 of the NWIS/ ModSTORET data retrieval and inventory (Denise Argue, written commun., November 10, 2011). Five of the 34 basins were immediately dropped: two (Arkansas and Platte) because drainage area was too large (>50,000 sq km), three (Delaware, Potomac, Snake) because they were nested upstream or downstream of another candidate basin. To this set of 29 sites we added back five sites in the Midwest that we suspected had been given "0" ratings because of missing data from the November retrieval, and added Delmarva. Also note that Trinity below Dallas was retained rather than Trinity at Wallisville, presuming that the former's 0 rating was due to an error in upstream site assignment.

The resulting set of 35 basins is listed on the Excel file "Appendix A_Candidate basins." Using version 2 of the retrieval (Denise Argue, written commun., December 16, 2011), an additional eight sites were rated as "1" and added to the set of candidates, for a total of 43 basins.

Caution about possible biases in the ranking results.

The rankings are based on monitoring data retrieved from NWIS and Modernized STORET (December 2011) and are therefore possibly biased to favor basins in areas/states where monitoring data have been fully transferred to STORET without time gaps. (Most State monitoring agencies are now uploading current data to STORET but gaps remain -- for example, Mississippi state monitoring data prior to 2005 are not stored in modern STORET) Some State monitoring data entered via the Water-Quality Exchange (WQX) are not fully uploading into STORET and are therefore not available for download (owing to a data glitch recently discovered by EPA's STORET team). A full accounting of how these data transfer issues may have affected the ranking results for the candidate basins is outside the scope of this analysis; however the tab of the Excel file Appendix A_ModernSTORET, which summarizes

all data records in Modern STORET state, agency, and year (Denise Argue, written commun., January 2012) can be used to examine the issue on a state by state basis.

Method for identifying monitoring sites that can be used to calibrate a dynamic (seasonal) SPARROW model for the period of interest used in Step 5

We want to know if water-quality sampling at a potential calibration site is of sufficient frequency during a core period of interest to accurately estimate not only mean annual load from the monitoring data, but also to accurately represent the seasonal and annual time series of loads (4 time steps per year) during that period. Accurate estimation of the seasonal series of loads from monitoring data requires multiple samples during each season of each year during the calibration period. We considered as the minimum level of sufficiency of sampling frequency = 8/year for at least 2 or 3 years during the core period of interest for calibration. In addition we set 25 as the minimum acceptable number of samples collected during the period of interest (this corresponds to the minimum number of samples required to reliably calibrate a 5-parameter load regression model).

Assume that the core period of interest for calibration, and thus for monitoring data, is the most recent decade, 2001-2010. In other words, assume that we want to be able to calibrate conditions and explain trends at least during that period (earlier periods are also of interest, but the most recent decade is essential).

Our approach was therefore to calculate the average number of samples during the core period for each stressor and compare that to the minimum threshold: if average number ≥ 8 samples/year during 2001-10 then the monitoring is of sufficient frequency to accurately estimate seasonal time series of load and to calibrate the SPARROW model. (We later considered that as few as 4-5 samples/year might also be sufficient, since this might represent 6 or more samples during one or two of the years, with fewer samples during other years). We decided to focus on the subperiod 2001-05 rather than 2001-10 (we were concerned that data during 2006-2010 might not be complete because of delays in uploading from state data bases to STORET).

For each IWS basin we mapped the sampling frequency results for each stressor, and compared the distribution with the locations of streamflow gages with daily streamflow record during 2001-2010 (illustrated for nitrate in the White River Basin in Figure 4.3). We counted a site as a potential calibration site for a stressor model if the site had ≥ 4 samples/yr on average during 2001-05 and was reasonably near a contemporaneous streamflow gage on the same flowline. Judgment of 'reasonably near' was subjective (eyeball) and as roughly within 25% of drainage area and either upstream of or downstream from the monitoring site.

The resulting counts should be considered as rough estimates, useful for comparing between the 10 finalist basins. Several qualifying notes should be made about these counts: a. the rough relative comparisons between basins break down for the basins in states where the State monitoring agencies have not transferred information to Modern STORET (California, possibly other States as well), and they also fail to account for the monitoring data from the experimental watersheds studies run by ARS, USFS, etc.; b. count accuracy breaks down where sites are clustered together in a basin. c. the counts may appear to be inflated by "1" in some cases – this is because the downstream basin outlet monitoring site is not included in these maps but it is a NAWQA fixed site in almost all cases and was added to the count because it should have sufficient data for nitrate, TKN, phosphorus, and suspended sediment.

Appendix 5-Summary of Level II Ecoregion Rankings

Summary of RSS rankings of candidate Level II ecoregions based upon ecological reference sites combined with key stressors including streamflow alteration (SA) and contaminants for both agricultural and urban dominated areas. EcoRef refers to the presence of ecological reference sites within the region for use in the study. Regions with a score of 1 are those where Eco Ref, streamflow alteration, or contaminants had poor ability to address gradient study, 2 indicates some potential, and a score of 3 indicates the region is a strong candidate for assessing specific stressors and ecological condition. While not used as a primary design feature, nutrients are also presented. Regions flagged with an X under Management Setting are those regions that are the candidate regions for Goal 3.

		Eco Ref	Stressors				Management Setting		
			SA	Contaminants		Nutrients	Water Use	Agriculture	Urban
Code	Ecoregion II NA_L2NAME			Agriculture	Urban				
5.3	ATLANTIC HIGHLANDS	3	3	1	1	1	X		
7.1	MARINE WEST COAST FOREST	3	3	1	3	1	X		X
8.4	OZARK/APPALACHIAN FORESTS	3	3	1	3	3	X		X
6.2	WESTERN CORDILLERA (MTNS)	3	3	2	1	1	X		
10.1	COLD DESERTS (Xeric west)	2	3	3	1	3		X	
11.1	MEDITERRANEAN CALIFORNIA	2	1	3	3	2		X	X
8.1	MIXED WOOD PLAINS	2	2	3	3	3		X	X
5.2	MIXED WOOD SHIELD	2	2	1	1	1			
8.3	SOUTHEASTERN USA PLAINS	2	3	1	3	3			X
9.6	TAMAULIPAS-TEXAS PLAIN	2	1	1	1	1			
13.1	UPPER GILA MOUNTAINS	2	1	1	1	1			
12.1	WESTERN SIERRA PIEDMONT	2	1	1	1	1			
8.2	CENTRAL USA PLAINS	1	2	1	1	1			
8.5	MISSISSIPPI AND SE COASTAL	1	1	3	3	1			
9.4	SOUTH CENTRAL SEMIARID PRAIRIES	1	2	3	3	2			
9.2	TEMPERATE PRAIRIES	1	2	1	1	1			
9.5	TEXAS-LOUISIANA COASTAL PLAIN	1	1	1	1	1			
10.2	WARM DESERTS	1	1	1	1	1			
9.3	WEST-CENTRAL SEMIARID PRAIRIES	1	1	3	1	2			

