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

Recommendations for Cycle II of National Water-Quality Assessment (NAWQA) Program

Open-File Report 99–470

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

USGS
science for a changing world

Recommendations for Cycle II of National Water-Quality Assessment (NAWQA) Program

by NAWQA Planning Team—

Gail E. Mallard
Jeffrey T. Armbruster
Robert E. Broshears
Eric J. Evenson
Samuel N. Luoma
Patrick J. Phillips
Keith R. Prince

Open-File Report 99–470

Reston, Virginia
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

Additional information can be obtained from:

Chief, National Water-Quality Assessment Program
413 National Center
Reston, VA 20192
water.usgs.gov/nawqa/nawqa_home.html

Copies of this report can be purchased from:

U.S. Geological Survey Information Services
Box 25286
Federal Center
Denver, CO 80225
e-mail: infoservices@usgs.gov

CONTENTS

TABLES

i. Acknowledgments

The NAWQA Planning Team acknowledges the excellent technical advice from the following individuals, all of whom have had considerable experience with the NAWQA Program:

Mark Ayers
Arthur Baehr
Kenneth Bencala
Gregory Clark
Charles Crawford
Lehn Franke
Ward Freeman
Robert Gilliom
Ivan James
Walton Low
Peter McMahon
Bruce Moring
David Mueller
Mark Munn
Thomas Reilly
David Rickert
Stewart Rounds
Timothy Spruill
Peter Van Metre
Brian Wagner
David Wolock
Michael Woodside
John Zogorski

Recommendations for Cycle II of National Water-Quality Assessment (NAWQA) Program

By NAWQA Planning Team—

Gail E. Mallard
Jeffrey T. Armbruster
Robert E. Broshears
Eric J. Evenson
Samuel N. Luoma
Patrick J. Phillips
Keith R. Prince

ii. Executive Summary

The Planning Team for the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program defines a successful NAWQA Program as one that makes a balanced contribution to study-unit issues, national issues, and to the pursuit of scientific knowledge. Using this criterion, NAWQA has been a success. The program has provided important new knowledge and understanding of scientific processes, and insights into the occurrence and distribution of contaminants that have been key to local and national policy decisions. Most of the basic design characteristics of NAWQA's first decade (1991–2000, hereafter called cycle I) remain appropriate as the program enters its second decade (cycle II) in 2001. In cycle II, the program has the opportunity to build on its successful base and to evolve to take advantage of the knowledge generated in cycle I. In addition to this expected evolution, NAWQA must also make some changes to compensate for the fact that program funding has not kept pace with inflation.

An important theme for the second cycle of NAWQA will be the integration of knowledge across scales and across disciplines. The question that drove the NAWQA design in the first cycle was "How is water quality related to land use?" Cycle II will build upon what was learned in cycle I and use land-use and water-quality gradients to identify and understand potential sources of various constituents and the processes affecting transport and fate of those constituents and their effects on receptors. The understanding we gain from applying this approach will be relevant to the interests of policymakers, regulatory agencies, and resource managers.

The table below summarizes some of the major recommendations of the Planning Team and illustrates the program's evolution. It is important to note that this summary table does not include the many aspects of NAWQA that will remain the same as it moves into cycle II. Instead, the table focuses on areas of major emphasis at the program, study-unit, and national synthesis scales.

Areas of major emphasis

Cycle	Overall NAWQA Program	Study units	National synthesis
I (1991–2000)	Occurrence and distribution of constituents	Data collection for land-use experiment	Constituent-specific compilation and analysis
II (2001–2010)	Understanding of processes and trends	Study-unit scale investigations of gradients and transport of constituents from source to receptor	Linkages among sources, watershed processes, and receptors

The Planning Team provides the following major conclusions and recommendations:

1. Goals: The primary goals of NAWQA during the first decade continue to be appropriate as the program enters cycle II. These goals are:

- Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources.
- Define long-term trends (or lack of trends) in water quality.
- Identify, describe, and explain, insofar as possible, the major factors that affect observed water-quality conditions and trends.

NAWQA should continue to make its data and information available to all who need it in a timely fashion and in a way that will be understood by the intended audience.

2. Emphasis: In cycle II, NAWQA should shift its emphasis from the occurrence and distribution of selected constituents to enhanced efforts toward understanding and explaining the processes controlling water quality. It is critical that the study-unit, regional, and national scales remain the primary scales of interest; a shift to explanation does not mean a shift to studies focused on understanding conditions only at very local scales. Places selected for data collection or explanatory study should represent a significant part of the study unit and should provide understanding applicable at regional and national scales. This shift in emphasis will require:

- Modifying network design to take better advantage of gradients in land use and other factors influencing water quality.
- Increasing efforts to understand changes in water quality as water moves through the hydrologic system.
- Developing a nested design for sampling efforts that allows information to be applied at several spatial scales in the same hydrologic unit.
- Conducting more synoptic and flowpath studies.
- Selecting basic fixed sites to provide temporal continuity at pivotal locations along gradients.
- Using more modeling applications within and across study units.
- Improving coordination of long-term goals with the National Research Program.

3. Trends: The emphasis placed on trends in the original design of NAWQA was appropriate, but not fully implemented in cycle I. Low-intensity sampling is critical for NAWQA to achieve its trends goal. The current design for low-intensity phase (LIP) sampling for surface water is minimal, but a reasonable way to start. The experimental network currently planned for ground-water LIP needs to be expanded to represent a broader range of land-use categories and chemical constituents. This expansion will provide a basis for design of an efficient, long-range ground-water LIP network for the broad range of hydrologic and land-use conditions that exist in the NAWQA study units. To avoid compromising the ability to detect trends in ground water, this expansion of the current plan should include all study units and should be started immediately, even if it requires diverting resources from other activities.

4. Number of study units: The original design of NAWQA called for a total of 60 study units, with 20 of them in high-intensity phase (HIP) at all times. This rotational design is still considered a sound one, but budget constraints have prevented its full implementation. The NAWQA Leadership Team (NLT) has been forced to make a series of decisions about delaying or consolidating study units without an overall context for those decisions. As the program enters its second decade, it needs a design that recognizes and adjusts for current funding realities. After careful study, the Planning Team has concluded that the most cost-effective modification is to consolidate some study units and eliminate others to bring the total number of study units to the equivalent of 45, with 15 in HIP at all times. The period of time in HIP and LIP for each study unit should be the same as cycle I. Continuation of the regional study of water quality in the High Plains is included in the recommendation for an equivalent of 45 study units.

This report provides guidelines for consolidation and elimination of study units while maintaining the goals of the program. Important criteria for selecting study units for continued study include population, water use, and maintaining the spatial distribution of study units. The full range of data-collection and interpretation activities should be maintained in each study unit, with the exception of the High Plains unit, where ground water is the primary focus. Funding levels for study units in cycle II will need to be comparable to those in cycle I. Cycle I activities allowed us to characterize watersheds within the study units. Bigger challenges and greater benefits will come in cycle II as we build on characterization and move toward improved understanding of watersheds. This cannot be accomplished with fewer resources. In addition to maintaining support for study units, the program should also increase the level of effort for ground water, for synoptic and flowpath studies, and for other explanatory studies. Budget projections indicate that the rotational design proposed in this report is realistic for the second decade of NAWQA with an important caveat: During most years, NAWQA must receive full compensation for uncontrollable cost increases to fulfill its potential.

5. Ground-water studies: The basic design for ground-water studies in NAWQA is sound but has not been adequately implemented. Ground water needs more emphasis during cycle II. The original design for the ground-water HIP should be implemented in each study unit to a greater extent than it has been. This will result in more wells sampled for water-quality/land-use relations and more reconnaissance surveys during cycle II than was typical in the study units begun in 1994 or 1997. In cycle II, ground-water flowpath studies should be the norm for each study unit during HIP; these studies should provide greater understanding of water-quality conditions and the causes of those conditions. The concept and application of flowpath work should be extended to larger spatial scales and should include public-supply wells as key receptors. Ground-water flow models can be used to a greater extent for network design and hypothesis testing. Special studies should be implemented that will focus on developing tools and methods that can be used to understand ground-water processes that occur on regional and national scales. As discussed in recommendation 3, the ground-water LIP must begin now.

6. National synthesis: In cycle II, the approach for national synthesis efforts should be shifted from a focus on groups of chemicals to an interdisciplinary approach that can better serve the explanatory goal of NAWQA. One of the major recommendations of the Planning Team is a shift in emphasis in cycle II to question-driven studies. National synthesis has a key role to play in bringing the new information and scientific understanding provided by each study unit into a national picture. Increased flexibility in moving from question to question can facilitate this approach. Synthesis Teams should be able to look at big questions in a flexible fashion and should be organized in a way that facilitates interdisciplinary syntheses. The best way to accomplish this is a redesign that brings all synthesis efforts under a single workplan and that facilitates movement of people among teams focusing on different questions and goals. Examples of questions of appropriate scale and significance for cycle II are provided in this report. These questions focus on integrating information to better understand sources of constituents, movement of constituents through the hydrologic cycle, and the effects of water quality on key receptors.

7. Biological studies: To better understand the sources of water-quality constituents, the processes controlling transport and transformation of constituents, and their effects on receptors, biology needs to be better integrated into NAWQA. Biological variables represent an important group of receptors. The best guide for biological activities in cycle II is the approach used by the many study units that were successful in fully integrating biology and biologists into their interdisciplinary teams. Biology should no longer be considered a separate subject in NAWQA discussions; instead, biology should be a necessary and integrated part of surface-water NAWQA and of every approach to every NAWQA question. Biological studies should be carried out at the same scale as the rest of the study-unit activities. This approach will result in collection of biological data at more sites throughout the study unit than was typical in cycle I, but with less effort expended at each site.

8. Flexibility: There can be more flexibility in network design and sampling schemes in cycle II, because study units are building on the knowledge gained in cycle I. In some cases, it may be appropriate to collect fewer samples or to test for fewer constituents in a sample. Rigorous criteria are suggested for deemphasizing locations or constituents. These or similar criteria are necessary to guide decisions at the study-unit level so that the decisions are systematic, nationally consistent, and compatible with the national design of the program and overall NAWQA goals.

9. Basic fixed site network: In cycle II, some reduction in the number of basic fixed sites may be possible. The basic fixed site network will remain an important framework for NAWQA, but each site should satisfy specific objectives, such as those outlined in this report. It is expected that the intensive fixed sites and the basic fixed sites that remain in the network will provide temporal context and continuity for more focused studies, such as synoptic surveys and flowpath studies, which should be conducted within watersheds containing basic fixed sites. Data collected systematically at basic fixed sites, augmented over time by special studies in the same watershed, will allow study units and National Synthesis Teams to build their understanding of hydrologic processes to meet the explanatory goal of NAWQA, which will have increased emphasis in cycle II.

10. Integration: The legacy and impact of NAWQA will be greater if it is better integrated into other water-resources programs of the USGS. For example, integration of NAWQA with other programs and projects conducted in Districts will bring many benefits. NAWQA provides Districts with new expertise, new ideas, new tools, new methods, and opportunities for spinoff studies funded through the Federal-State Cooperative Water Program. Strong linkages between NAWQA and the rest of the District program can best be accomplished if senior District managers are actively involved and supportive of the NAWQA effort. This includes participation in workplan development, conference calls, and meetings of liaison committees. Another example of needed improvement is the linkage between NAWQA and National Research Program (NRP) efforts. Stronger associations between study units and Synthesis Teams and the water-resources research community are expected in cycle II as the program increases emphasis on understanding of hydrologic processes. Specific examples of questions that can provide a basis for integrating research and NAWQA are provided in the "Research and cycle II of NAWQA" section of this report.

1. INTRODUCTION

This report presents recommendations for the design of the USGS NAWQA Program as it enters its second decade. The Planning Team has defined a successful NAWQA Program as one that makes a balanced contribution to study-unit issues, national issues, and scientific knowledge. After a careful review of program design and accomplishments, the authors of this report approach this task with the perspective that NAWQA is a successful program that has made many contributions to understanding the quality of the Nation's waters. A few examples: NAWQA data on fuel oxygenates in ground water (especially methyl *tert*-butyl ether, commonly known as MTBE) and nutrients in the Mississippi River system have been used by State and Federal agencies to identify sources and impacts of these chemicals. Additionally, NAWQA pesticide data resulting from analysis of about 5,000 surface- and ground-water samples have been used by Federal agencies and manufacturers to regulate chemical use and to improve application procedures. At the State level, NAWQA data are being used for regulatory decisions, to improve designs of statewide monitoring programs, and for public education.

NAWQA has been successful and does not need great change. Principles established during the first decade of the program continue to be valid and should guide NAWQA priorities during the second decade, including any design changes contemplated for the program. These principles are:

1. National and perennial: NAWQA is a national program and a perennial program. It is designed to answer water-quality questions that are broad in spatial and temporal scale. These characteristics of broad-scale and long-term commitment are two of the unique features of NAWQA and serve to differentiate it from other programs within the USGS or State and other Federal agencies.

2. Timely: NAWQA will continuously address important water-resource-management issues. As demonstrated in cycle I, it is not necessary to wait until all study-unit activities are completed or until a full decadal cycle is completed for the program to demonstrate and communicate its relevance. Although understanding of water quality on both the local and national scales will grow through time, NAWQA will continuously make important contributions to water-resource management. Other benefits from the program are that it provides field sites for development and testing of new methods and it produces data that will be invaluable for future analysis.

3. Focus: NAWQA cannot do everything. It cannot pursue every emerging issue or "hot topic." Nor does it need to. Other programs within the USGS, the Federal Government, and the wider water-resources community can address many emerging issues and local and short-term needs. NAWQA must keep its focus on issues that are appropriate for a program that is both national and perennial.

4. Creative tension: NAWQA uses state-of-the-science tools and methods applied consistently in many places simultaneously. This characteristic is necessary to provide regional and national descriptions of water quality and to identify trends over time. Because of the need for national consistency, there will always be a creative tension between national needs and the need to address local issues.

5. Multiple scales: NAWQA applies state-of-the-science tools at scales ranging from small watersheds or ground-water flowpaths to regional flowpaths, large watersheds, and study units. These data are then aggregated at the national scale to yield nationally consistent understanding of water quality and the processes affecting water quality, as well as the effect of water quality on receptors. It is this emphasis on working at different scales, and relating findings across scales, that characterizes the program's approach to water-quality assessment. This approach recognizes that there is no one ideal scale at which all investigations will take place. Rather, investigations take place at whatever scale is needed to ultimately provide understanding of water-quality conditions at study-unit and national scales.

Although the program is fundamentally sound, there are two primary reasons why it is prudent to make some modifications to the NAWQA Program as it enters its second decadal cycle. First, as a scientific program, it is natural that NAWQA will evolve as new knowledge is incorporated into the design of study-unit and national synthesis activities. Results from cycle I should guide the design of cycle II data collection and analysis to (1) build upon current understanding to give a more complete description of water quality and make progress toward achieving the three goals of NAWQA; and (2) adjust non-trend sampling activities to shift resources toward new, unstudied, geographic or topical areas of a study unit and (or) to conduct more interpretive investigations.

The second major reason why changes in program design are needed is that the program has not been fully implemented as it was designed. For several years during the first decadal cycle, the funds appropriated for the program did not keep pace with inflationary increases. Further, uncontrollable costs, such as salary increases, affected other USGS programs that were intended to provide data support and infrastructure for NAWQA and, thereby, help keep NAWQA costs down. Thus, the NLT has continuously made adjustments to the program to reduce costs. As a result, NAWQA has not been at the planned operational level of 20 study units in high-intensity phase at all times. At present, the NAWQA Program includes 20 study units that began in 1991; 16 that began in 1994; and 13 that began in 1997. In 1998, NAWQA initiated a special regional study focused on ground-water resources in all or parts of six additional study units located in the High Plains.

The design changes proposed in this report will address the impacts of previous inflationary shortfalls in a systematic way—primarily through consolidation and reduction in the number of study units. To some extent, the knowledge gained in cycle I provides the basis for operational efficiencies; however, these efficiencies can only be pushed so far. It is unrealistic to think that costs per study unit, for example, can be significantly reduced in cycle II. The baseline of water-quality conditions established during cycle I is an important point of departure. But the greatest challenges and the greatest opportunities will come as NAWQA shifts its emphasis toward greater understanding and explanation of water-quality conditions. It must be understood that this important shift cannot happen without resources. The program would be more robust and better serve the information needs of the Nation if it could be implemented as originally designed. With the cost savings proposed here, however, and with the assumption that future inflationary increases are matched by increased appropriations, NAWQA should be able to meet its major goals and provide an appropriate information return on the investment of public dollars.

2. SCOPE OF THIS REPORT

The authors of this report reviewed selected reports from the 1991 and 1994 study units, met with groups of advisors who were asked to comment on specific aspects of the program, spoke with many people who are familiar with NAWQA and its goals, and deliberated about the program's successes and ways to improve it in the future. Although the authors have solicited and received advice from many individuals, the conclusions and recommendations are the authors' own and are based on a consensus of all members of the NAWQA Planning Team.

When the NAWQA Planning Team was originally chartered (January 1997) by the NLT, 24 questions about the program were posed to the Team (see appendix 1). This report provides answers to most of those questions in the form of discussion and recommendations. The authors expect that these recommendations will be implemented as NAWQA plans the second period of high-intensity activity for the first group of study units, originally begun in 1991. This second period of high-intensity activity is referred to in this report as the beginning of cycle II. Cycle I, the first visit to the 1991, 1994, and 1997 study units, is still underway for some study units, and the Planning Team recommends that those activities proceed as currently planned.

It is assumed that readers of this report are familiar with the NAWQA Program as designed and as implemented. General information about current activities is provided as a point of reference. Readers who are unfamiliar with the program should refer to design documents referenced for a complete description of the program as it has been implemented in cycle I.

3. NAWQA GOALS

A fundamental and critical part of the NAWQA Program is to make data and information available to all who need it. NAWQA information has been and will continue to be valuable to a wide variety of users, from those making national environmental policy decisions to those simply interested in the environment and how their activities affect it.

The primary goals of NAWQA, as described by Hirsch and others (1988), in an early planning document for the program, continue to be appropriate as NAWQA begins cycle II. These goals are:

- "Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources.
- Define long-term trends (or lack of trends) in water quality.
- Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends."

To be successful, NAWQA must continue to focus on all of these goals. As the program moves into its second decade, however, there should be a shift in the relative emphasis and resources given to the three goals. Relative to the first cycle, the first goal, occurrence and distribution, should receive less emphasis in cycle II. The third goal, explanation, should receive greater emphasis. The relative emphasis given to trends should increase in cycle II because LIP sampling, a key component for trends analysis, was not fully implemented during cycle I.

A. Description of Current Water-Quality Conditions

The need to describe current water-quality conditions and to add to the body of knowledge of the occurrence and distribution of chemical constituents will continue in cycle II. Land uses will change; new chemicals will be used; and natural changes in the environment will affect water quality and physical habitat. Therefore, in cycle II, study-unit scientists will still need to do occurrence and distribution surveys. However, those surveys may have a different design than those conducted in cycle I. For example, occurrence and distribution synoptic surveys along gradients may be used to augment basic fixed site networks, as well as contributing to explanatory studies. Resources for synoptic studies may come from either having fewer fixed sites or from other efficiencies that can be realized during cycle II, as described later in this report. Also, the authors recommend adjustment of overall program priorities to provide support for synoptic studies and other explanatory work.

In many cases, cycle II will involve investigation of water quality in geographic areas that were not studied in cycle I. How should the sampling approach for occurrence and distribution be modified when the focus shifts to new areas of a study unit? On what basis would decisions be made about where and when to sample? In situations where there is a need to move to unstudied areas on the second visit to a study unit, insights gained during cycle I from similar areas can help to guide sampling design. For example, the Potomac study unit did very little sampling in the Coastal Plain during cycle I, but the Albemarle-Pamlico and Long Island-New Jersey study units did. Insights from those study units can help guide the design of cycle II in the Potomac. Changing the sampling approach will be easier for those study units that were able to cover all high-priority areas and water-quality issues in cycle I. For example, the second visit to the Apalachicola-Chattahoochee-Flint Basin (ACFB) will need to give significant emphasis to the Atlanta metropolitan area because of the effects of continuing population growth. The agricultural area of the basin was adequately covered in cycle I and great changes in agricultural practices are not expected; thus, this area could be deemphasized somewhat during cycle II.

B. Low-Intensity Phase of NAWQA and Analysis of Trends

The NAWQA Planning Team endorses most of the recommendations made by the ad hoc Trends Committee in 1994 (Luoma and others, 1994). The following quote from the Trends Committee report sums up the importance of trends detection and analysis for NAWQA: "The first cycle of data collection in NAWQA is the beginning of a large and long-term effort. These data are an investment in the future. Many long-term trends in water quality may not be detectable over time periods shorter than a decade because of complexities inherent in ground-water and surface-water systems. Thus, as time proceeds, the early investments in NAWQA data collection will become increasingly valuable. Trends will become more evident and the number of insights (some of them serendipitous) will grow. Only from such insights can the Nation begin to intelligently manage its priceless water resources."

The Trends Committee considered both HIP sampling alone, and HIP sampling augmented by LIP sampling. They were clear in their conclusions, which the Planning Team endorses:

- Comparisons of data collected during successive HIP's should be an important part of trend analysis in NAWQA. NAWQA should be aware, however, that this approach may be sensitive to only certain types of trends in certain types of circumstances.
- If the determination of trends is to be at an acceptable level of sensitivity, then the collection of data during the LIP is essential.

The concepts, objectives, and guidance for implementation of the trends component of NAWQA are embodied in many documents that have been generated over a long period of time. This makes it difficult for interested parties to read and determine the current objectives, goals, and design concepts for the trends component of NAWQA. NAWQA leadership has recognized this limitation and is planning to produce a publication that defines the latest program objectives, goals, and implementation plans for LIP. The Planning Team strongly endorses the publication of such a document and suggests that it be completed before the next cycle of NAWQA begins.

NAWQA's current surface-water LIP sampling plan includes a network of 47 sites in the 20 study units begun in 1991, with monthly sampling for chemical analyses, more intense sampling at some sites where pesticides are an issue, and bed sediment and tissue sampling two times per LIP. A ground-water LIP plan has been designed and implemented in fiscal year 1999. It is an experimental design aimed at gathering data needed to develop a blueprint for a long-term, full-scale, ground-water trends component of NAWQA. The pilot ground-water LIP network includes annual sampling at a total of 25 wells from 5 of the 20 study units begun in 1991.

The surface-water LIP, as presently implemented, is a minimal network; however, this may be the best way to start the effort. To some extent, LIP sampling is an experiment, and it is appropriate to start that experiment on a relatively small scale. It is important, however, that "minimal" not be defined as a network so small as to not be a legitimate experiment. For surface water, the Trends Committee suggested a network of at least four LIP stations per study unit. While some reduction in that number is probably feasible, any network that falls below an average of two or three stations per study unit (90–135 stations nationwide) will probably not be effective. Similar principles apply to ground water. An experiment with too few samples is no experiment at all.

Until recently, the absence of a ground-water LIP has been a significant deficiency in the implementation of NAWQA. The LIP sampling adds statistical power to our findings from the HIP phase, provides information on the annual variability of constituent concentrations, and provides a bridge to interpret, in a more meaningful way, the results from the more complete resampling during the next HIP. One major obstacle to implementing a ground-water LIP has been a lack of understanding about how to design an efficient, temporal sampling strategy that could identify meaningful trends in ground water across a broad range of time scales and hydrologic settings. The ground-water LIP design proposed for the 1991 study units, though small, will begin to collect data that can be used to address these important questions. While this initial experimental network will begin to gather important data, much more research is needed in the design of water-quality trends networks for ground water. If additional resources are not dedicated to the design and sampling of a ground-water LIP network, a meaningful ground-water-trends component of the program will be unlikely to materialize and the trends objective of the program will be compromised.

Recommendations

1. A combination of HIP and LIP sampling is essential for trends detection: HIP sampling expands spatial coverage beyond that available from LIP sampling, while LIP sampling adds continuous data collection at a few sites, thereby increasing the power to detect trends in shorter time periods and the ability to detect complex and diverse types of trends. Planning and sampling for trend analysis should be a key consideration for every study unit during both the HIP and LIP. HIP sampling sites should be selected with a clear vision of which sites will be used in the LIP sampling.

2. The basic implementation plan for surface-water LIP proposed by the Trends Committee has since been modified. The implementation plan for ground water is incomplete and needs to be expanded in several ways as the 1994 and 1997 study units move into the LIP phase. One of these ways is to implement a ground-water LIP for every study unit. Others are discussed in the subsequent recommendations. While these implementation plans for surface water and ground water may not be ideal, the Planning Team recognizes that it is not possible to create the ideal trend network a priori. The information needed to design the optimal network is in fact the information the network is being designed to collect. Therefore, it is fully expected that the trends network will evolve over time, as data are collected and scientific understanding of how to best sample for trends improves. The most important thing is to get started on this aspect of trends analysis and not become paralyzed over details of implementation. One caveat is that the initial trends design should not be such a limited investment that it provides no basis from which to evolve. LIP sampling on one or fewer surface-water sites per study unit, or as few as 25 ground-water sites per round, for example, is not likely to provide the basis from which NAWQA can learn and grow. At the other extreme, the design proposed by the Trends Committee may be ideal, but perhaps is more than is needed in the initial experimental stages of the LIP sampling.

3. As currently planned, ground-water LIP sampling in the 1991 study units will focus exclusively on shallow ground water beneath agricultural lands. Care must be taken to ensure that this does not become the de facto design for ground-water LIP. Future ground-water LIP efforts must also include sampling for a broad set of constituents beneath a variety of other land uses in a variety of hydrologic regimes. In this way, the necessary background information that will allow the development of a generalized long-range ground-water LIP plan for NAWQA can be gathered. An important reason for the Planning Team's recommendation of 45 study units (instead of a larger number) is the need to make sufficient funds available for full implementation of a ground-water LIP. No agency in the Nation is systematically following water-quality trends in ground water and no other program has the resources to do this. Because HIP sampling alone is unlikely to be adequate for detecting trends within several decades, carefully designed LIP sampling (for example, O.L. Franke, USGS, written commun., 1995) is essential. A ground-water LIP sampling component should be implemented as soon as possible and expanded to include all study units as cycle II begins in FY 2001, even if it requires reducing other program components.

4. The whole area of ground-water trends network sampling design is one in which very little information exists. Brian Wagner (USGS, written commun., 1997) began to shed light on this vexing subject through his study of trends in nitrate concentrations in ground water in Florida, but many questions remain

unresolved. Will other constituents behave the same way as nitrate? Will sampling strategies need to be modified for different hydrogeologic regimes? These are just a few of the questions that should be addressed through additional collaborative research between NRP and NAWQA, to define network design and sample frequencies needed to adequately detect meaningful trends in ground-water quality.

5. A major goal for NAWQA is to sample at sufficient frequency to acquire an adequate data base that will afford statistically valid trend analysis. For ground water, with a given level of resources, a small number of wells sampled at a high frequency is preferable to a larger number of wells sampled at a lower frequency. For example, it would be more desirable to sample 60 wells twice during the HIP than 120 wells once. Some of these wells should be sampled seasonally during the HIP to gather data regarding seasonal variability in ground-water constituents. A significant subset of these wells should be sampled during the LIP at a frequency consistent with optimum trend detection. The strategy for specific selection of sites suggested by the Trends Committee should be considered in both ground-water and surface-water LIP sampling. In the case of ground water, LIP needs to include wells from all three study components: study-unit surveys, land-use surveys, and flowpath studies. The national network should be developed with national-scale questions in mind, but it should also be possible to address specific questions of greatest interest to individual study units. The need to collect LIP samples from wells in the flowpath transects may be less obvious than in the other components of NAWQA, but it is important to be able to place the findings from the flowpath studies in a broader context. Sampling over time allows verification of hypotheses regarding evolution of water quality along flowpaths and the evaluation of the long-term effects of ground-water quality on receiving waters. To the extent possible, ground-water LIP sites should be selected within stream reaches sampled during LIP. LIP sampling sites should also include a few selected reference sites.

6. Selection of wells for LIP sampling must take into consideration the need for long-term accessibility. Resources should be reserved so that LIP wells can be redrilled if they are damaged or somehow become unavailable for sampling.

7. The concept of increasing emphasis on explanation during the second cycle of NAWQA should be integrated into the trends/LIP design. The gradient approach should be employed in the location of sites chosen for LIP sampling as well as HIP sampling. At least some ground-water LIP wells should be located within surface-water sampling areas to maximize understanding of the interconnections of ground water and surface water. Further understanding of such connection might eventually make it possible to monitor ground-water quality using (less expensive) base-flow water quality in selected streams.

8. Tools such as age dating of ground water or the analysis of sediment cores from surface-water bodies should be considered in implementing trend sampling.

9. NAWQA should carefully consider effects of natural variability, including changing climate, on trends. The Trends Committee suggested that collaborative studies with other programs investigating natural variability should be a part of cycle II activities, and the Planning Team further endorses this approach.

C. Increased Emphasis on Explanatory Science

At the beginning of the NAWQA Program, it was appropriate to emphasize nationally consistent descriptions of current water-quality conditions to establish a baseline. This was accomplished primarily through occurrence and distribution assessments. In cycle II, we should build upon the understanding gained from cycle I and shift emphasis toward more explanatory science. Study units will focus on providing answers, within their hydrologic settings, to questions of national importance. National synthesis will focus on integrating these answers at the national scale. An approach that can guide efforts at both the study-unit and national scales is to focus on improving understanding of potential sources of contaminants, processes affecting transport and fate of those contaminants, and their effects on receptors. Questions can be framed as follows:

> How does "A" affect the development of spatial and temporal profiles of "B" such that impairments occur in "C"?

Where:

"A" could be agriculture, urban and suburban development, mining, silviculture, hydrologic modification, automobile use, or natural variability;

"B" could be nutrients, pesticides, sediment, volatile organic compounds (VOC's), industrial organic compounds, or trace metals; and

"C" could be aquatic community structure, fishable and swimmable waters, or suitability of water for public or domestic supply.

Such a framing of questions would identify commonalities and differences among processes as they are influenced by broad-scale gradients in such factors as climate, soils, geology, and land-use patterns. On the basis of the current understanding of these relationships, as established in the first cycle of NAWQA, gradients should be defined as those that occur on watershed, study-unit, regional, and national scales. Central to this framework is an understanding of the evolution of water quality as it moves through the hydrologic system, including movement of water and chemicals between ground water and surface water.

The major regional or national issues and questions for cycle II should be developed by National Synthesis Teams in consultation with study-unit staffs. All study units may not be involved in all issues. The decision to include or exclude a study unit from a national issue will be based on both the local relevance of the issue and the need for a national perspective on that issue. In certain cases, the national need for an end member in a water-quality gradient may require participation by a study unit, even if local concern for that issue is minimal.

To illustrate the concept of using the source, transport, receptor model, and gradients in land use and water quality to guide efforts in cycle II, a few specific examples will be presented below. These examples focus on specific water-quality issues in specific study units and suggest an approach for cycle II that should yield an improved understanding of factors affecting water quality for the study unit. Aggregating these results across the country should provide regional and national insights.

What are the effects of mixed land use on water quality? During cycle I, the program developed an understanding of where urban, agricultural, and mining activities are creating problems at the study-unit scale. Although baselines of occurrence and distribution of various contaminants were established, it was usually not possible to investigate how these contaminants were transported through the basin. Cycle I studies also intentionally focused significant effort on sites that represented relatively homogeneous land-use and physiographic conditions rather than on mixed land uses, soils, or geology. The second HIP will provide an opportunity to further understand factors affecting water quality by including gradients in land-use or physiographic conditions and by investigating transport through a study unit.

For example, in cycle I, the Hudson River study unit documented the presence of diazinon, a pesticide associated with urban areas, in a part of the basin dominated by agricultural activities. With the primary focus on occurrence and distribution in cycle I, it was not possible to develop a full understanding of how a chemical associated with relatively minor land use contributes contaminants to the overall system. Another example is that cycle I data from the Clark Fork River in Montana and Idaho show that the river is affected by metals from past and current mining activities and by organic chemicals from pulp mills. During cycle II, we should improve our overall understanding of the separate and combined effects of these two sources of contamination on the suitability of the river for various purposes.

Possible steps toward an improved understanding and explanation of observed water-quality conditions include: (1) Identify major sources of specific constituents; (2) determine the distance downstream that these constituents can travel under various flow conditions and at different seasons; (3) measure the potential dilution from other tributaries or from ground-water inflow; (4) construct a conceptual or quantitative model of the system; and (5) "predict" downstream conditions. If predicted conditions are different from those observed, then continuing study would focus on developing a better understanding of additional hydrologic or human factors that must be considered.

If predicted conditions are observed, then understanding of the system is sufficient for resource managers to make decisions with some degree of confidence. In the case of the Hudson River, better understanding of how diazinon use affects downstream conditions might justify regulatory decisions on that pesticide. In the case of the Clark Fork River or other rivers with multiple sources of contamination, this approach could help decision makers quantify the probable overall effect if one source is changed but others remain the same. In either case, resource managers would have a better understanding of how reductions in sources could, over time, minimize the downstream area that is impacted.

What factors affect shallow ground-water quality? In many study units, cycle I provided insights into the relationships between land use and shallow ground-water quality. These insights can be improved upon in cycle II through a combination of flowpath studies and carefully designed surveys of recently recharged ground water. Questions that can guide data collection in cycle II include the following:

- How does a gradient in intensity of land use affect ground-water quality? In other words, how much agricultural or other land use is needed in a location before we start to see constituents associated with that land use in ground water?
- Do systems respond linearly to increasing proportions of a specific land-use type or level of exposure to specific chemicals? Or are there impact thresholds beyond which water-quality degradation is accelerated?
- Is there some mix of undeveloped land and urban and agricultural land-use patterns that is more or less protective of water quality?
- How are land-use effects propagated through or within a system of aquifers?

In addressing questions like these, it would be easy to focus on a relatively small part of the study unit because this is a scale that is very amenable to investigations of transport and to understanding processes. However, the focus must remain at the study-unit scale. Thus, broad gradients that cover a meaningful percentage of the study unit are needed. It will be easiest if gradients in land use or natural factors line up with ground-water-flow directions. Realistically, there may be few places where the flow system and the gradient line up exactly. However, a perfect match or a classic flow system may not be necessary to understand how water quality changes at the scale at which the work is being done. In humid environments, it can be assumed that water sampled at the water table comes from the land surface immediately above, while recognizing that three-dimensional flowpaths are affected by local and regional topography and variations in soil and aquifer properties. The relationship between land use and shallow ground-water quality may be more problematic in arid regions, where recharge may come from mountains some distance away from the sampled well.

Another complication that must be considered is the interaction of ground water and surface water. NAWQA investigations have shown that water quality may be altered substantially at the interface between ground water and surface water, where biological activity along steep gradients in oxidation-reduction conditions affects such processes as denitrification and metal solubility. During high-flow events, the reversal of normal hydraulic gradients between ground water and surface water can result in the transport of pesticides into temporary bank storage. Also, the quality of water from wells in alluvial aquifers could be highly influenced by the quality of water in the nearby stream. Clearly, a holistic appreciation for ground-water and surface-water interactions at a variety of spatial scales is necessary to understand the observed patterns of water quality along land-use gradients.

For both surface water and ground water, a sampling schedule targeted to specific seasonal or flow conditions may be necessary to improve understanding of variability in water quality. In addition to storm sampling, which was included in cycle I, sample collection may need to be targeted to other factors that contribute to water-quality variability. For example, we know that the water quality of streams affected by point sources and ground-water inflow are generally most acute during low-flow conditions. By contrast, water quality of streams affected by nonpoint surface runoff varies most during and after storm events. Pesticide and fertilizer use or road salting or lawn care occur seasonally in agricultural and urban areas. Sampling strategies may need to include the times of greatest use of these seasonally applied chemicals. The information derived from such a targeted sampling effort should be more policy relevant than just monthly and storm sampling and would provide resource managers with a better understanding of when and why water-quality problems are most acute. Resource managers could then use this knowledge as a basis for planning remedial strategies.

4. NATIONAL-SCALE UNDERSTANDING

A key aspect of NAWQA is its ability to provide data and understanding at the study-unit, regional, and national scales. Knowledge gained from NAWQA study units can be applied at the broader scales in two fundamental ways. First, NAWQA study units are selected to be representative of the Nation's water resources. Thus, characterization of water quality within NAWQA study-unit boundaries is a direct, representative measurement of the Nation's water quality. David Wolock (USGS, oral commun., 1999) compared fixed site basins for the 1991 and 1994 NAWQA study units with all stream basins in the conterminous United States. Basin attributes included land use and natural variables, such as soil, climate, and terrain. In general, NAWQA fixed site basins exhibited the same frequency distributions for these attributes as did basins in the Nation as a whole. The only significant difference was that NAWQA had greater representation of agricultural and urban land use in smaller basins.

A second way that NAWQA information can be applied at the broader scale is by using the relations between water quality and basin attributes developed by the program. This requires scientific judgment and application of statistical and other interpretive tools to draw inferences about water quality for specific basins or groups of basins beyond NAWQA study units. The emphasis being placed in cycle II on statistical and process-level explanation of water quality will increase the program's extrapolative power. Such extrapolations have been presented nationally for the risk of nitrate contamination in ground water (Nolan and others, 1997). Other nationally relevant efforts include Synthesis Team publications on pesticides in shallow ground water (Kolpin and others, 1998) and the impact of fuel oxygenates on water quality (Zogorski and others, 1996). Enhancing georeferenced tools, such as SPARROW, with the physically realistic terrain, soil, and climate features of TOPMODEL, and using NAWQA data to develop these tools, will further advance the program's ability to extrapolate beyond study-unit boundaries.

It has been suggested that NAWQA could sponsor regional synoptic studies of water quality to provide a snapshot of water-quality conditions at a broader scale than is possible from the aggregation of data from study units. The NAWQA Planning Team considered circumstances that would allow a regional synoptic study to make the largest contribution to understanding. Such studies can be beneficial and can help explain water-quality conditions if they are conducted in the context of study units that are in HIP or LIP. If regional synoptic studies are conducted primarily outside of study-unit boundaries, they should have a hydrologic and temporal context similar to that provided by NAWQA. This context can be provided by data collection or analysis supported by the USGS programs described later in this report or by non-USGS programs that produce data comparable to NAWQA data.

A. National Synthesis

A significant part of the success of the NAWQA Program will be judged by the program's ability to provide meaningful information that is useful to policymakers and water-resource managers at a national scale. The NAWQA national synthesis effort is designed to combine the results of study-unit investigations with existing information from other investigations and programs to produce a national assessment of water-quality conditions that is more meaningful and complete than the accumulation of the individual study-unit results. Synthesis is accomplished by explaining differences and commonalities in water-quality conditions among study units and by identifying the processes that affect water quality. For example, the current national understanding of the occurrence and distribution of methyl *tert*-butyl ether (MTBE) is the result of the ongoing National Synthesis Program working with information collected in geographically dispersed areas.

Current approach

The national synthesis effort is organized into five Synthesis Teams that report to a central National Synthesis Coordinator. Four of the Synthesis Teams (pesticides, nutrients, VOC's, and trace metals) have been formed around major compounds or a class of compounds of national interest. The fifth team is the aquatic ecology team, which is based on the scientific discipline. The teams themselves are geographically dispersed across the country, as are some of the members of the individual Synthesis Teams; not all members of a given team reside in the same location. Team leaders are responsible for technical direction of their portion of the program, as well as supervisory control of the members of the respective teams. The disciplinary makeup of each team is determined by the needs associated with the primary topic of interest for that team.

Strengths and limitations

Each National Synthesis Team is a collection of recognized experts within their respective fields. As such, the national synthesis effort provides expertise to the study units in the collection, analysis, and interpretation of water-quality constituents that are within the purview of each team. This ensures that nationally consistent information is being collected throughout the NAWQA Program. The teams also provide USGS external liaison with other agencies for questions regarding the respective synthesis topics. The geographically dispersed nature of the Synthesis Teams facilitates recruitment of the best possible talent and enables close interaction with colleagues working in related fields who are not members of the NAWQA Program. The current design of the synthesis effort was useful during the initial phases of the program and through the first cycle, particularly in establishing data collection and quality assurance procedures and in advancing development of laboratory analytical methods. National Synthesis Teams also made significant contributions to NAWQA through developing and maintaining critically important national data bases and by producing many interpretive products that have allowed NAWQA to make definitive statements about water quality at regional and national scales.

In spite of the many contributions of National Synthesis Teams, there are ways to modify the organization of NAWQA's national synthesis effort to allow even greater contributions in cycle II. Because each Synthesis Team focuses on a different group of constituents, each team has a somewhat different set of priorities for location of sampling points and timing of data collection and analysis. Thus, it is sometimes difficult for study units to interact with and provide data and information to the various Synthesis Teams. Staff from many study units expressed concern that their activities were dominated by mandates to supply raw data (e.g., concentrations and discharges) to disparate National Synthesis Teams. This constraint on resources reduced the ability of many study units to pursue well-developed, broad-scale watershed studies addressing key issues of local concern.

Another concern about the current structure is that it is inflexible with respect to changing national priorities and needs. It is difficult to address new water-quality concerns as they emerge because most Synthesis Teams are organized around selected compounds or a class of compounds. Under the current structure, addressing a new issue such as pathogens, uncontaminated sediment, or pharmaceuticals would require formation of a new National Synthesis Team. Yet adding an additional team would be a heavy burden both on resources for national synthesis and on study units responding to the new team's mandates. Once a synthesis topic has been established, it is unlikely that all scientific questions related to that topic will be answered and that the Synthesis Team will be disbanded. Nor is it likely that water-quality issues associated with the current constituent groups will decline in importance. In an early model for national synthesis, teams based on constituent groups were to cycle between periods of high and low activity, perhaps on a decadal frequency. Such cycling is problematic. Lack of technical support during periods when synthesis topics are in low activity would be detrimental to study units then involved in issues related to that constituent group. Post facto analysis by national synthesis of study-unit work completed during the low-intensity phase for that synthesis topic could be expected to be more difficult. Also, the ability to respond to major shifts in public interest in certain synthesis topics would be diminished. Although NAWQA cannot and should not respond to the inevitable variability in public concern about water-quality issues, some flexibility in this regard is important at the national level in the program.

Alternative organizational structures for national synthesis were considered by the Planning Team. Two National Synthesis Teams—one focused on agricultural impacts on water quality and the second on urban impacts—would provide a more integrated approach to problems associated with these land uses. But such a structure would not address other human activities, such as mining, and might not accommodate effects of mixed land use. Another potential model for national synthesis would be to define teams focusing on impacts to ecological health and to human health. This structure would provide incentives for integrated scientific work and might enhance dialogue with regulatory agencies with responsibilities for either human health or aquatic systems. However, the aquatic versus human-health structure would suffer from redundancies in source and transport issues and might limit the scale of some watershed studies.

Recommendations

In order to optimize national synthesis, the following principles and goals should be addressed:

- Provide a multidisciplinary perspective to water-quality issues.
- Facilitate the analysis and understanding of multistressor and synergistic effects of chemicals.
- Determine the effect of constituents on receptors.
- Interact with study units effectively.
- Maximize the ability to incorporate important new topics.
- Contribute to USGS science needs, including external liaison.
- Avoid redundancy in staff and products.

National synthesis should help NAWQA move beyond occurrence and distribution questions. Understanding the implications for water resources of various water-quality conditions requires knowledge of uses of the water resources, sources of contamination, transport processes, and the ultimate fate of compounds and classes of compounds. Further, the program needs to be able to address the synergistic effects of nutrients, pesticides, VOC's, and trace metals, and how they relate to aquatic life, human health, and other uses of water resources.

The ideal structure for national synthesis would allow for a more interdisciplinary approach than that currently in place. It also would allow national synthesis to examine issues across groups of compounds and facilitate studies focused on the interaction of these compounds with aquatic biota. The goals for NAWQA in cycle II will be better achieved by a well-integrated but spatially distributed group collaborating under a single workplan. The unified workplan will define multidisciplinary approaches to understand the Nation's most important water-quality issues. These issues will be articulated at the onset of each decadal cycle, and they will be reviewed as each group of study units enters its HIP. The plan should include specific objectives, tasks, and outputs, and identify the data expected from study units. Issues will be framed at the watershed scale and it will be clear to each study unit how it fits into the overall picture. The objectives for study units and for the national synthesis will be better harmonized in cycle II by this approach. Both organizational levels will be guided by the multidisciplinary, watershed-scale, source-transport-receptor paradigm. National synthesis will develop general principles for network design and interpretation of data; study-unit staff will have the common goal of designing the most effective network and interpretive approach for their study unit. Interpretive findings from study units, in addition to raw data, will be the major products forwarded to national synthesis.

The Planning Team's deliberations on national synthesis have focused primarily on how best to address national water-quality issues and to interact with study units. Management structure and, more specifically, supervisory chain of command, was of secondary importance. Problems with the current organization delineated by constituent groups have been described. The Planning Team considered but cannot recommend an organizational structure that cycles through constituent groups or that is based exclusively on land use or on ecological and human health. Further, in the section of this report on biology in NAWQA, the Planning Team is adamant that biology should not be isolated in concept, in organizational structure, or in field implementation.

The primary recommendation for national synthesis is that the program should operate under a unified workplan addressing multidisciplinary watershed-scale issues of national importance. This recommendation clearly requires a change in the organizational structure of NAWQA national synthesis. To a considerable extent, national synthesis must operate as a single team. A National Synthesis Coordinator will have overall responsibility for the design of a multidisciplinary, issue-driven, policy-relevant synthesis of scientific understanding at the national scale. The National Synthesis Coordinator will be responsible for the development and publication of a comprehensive national synthesis workplan that will articulate the major questions that the program will address in 3- to 10-year cycles.

Members of the National Synthesis Team can then be assigned to work in smaller groups to address one or more of these major questions in an interdisciplinary way. National Synthesis group leaders will ensure that issues relevant to the various disciplines are addressed in the national synthesis plan and in the execution of related work in each of the study units. Group members will be key contacts for their respective areas of expertise, both for the study units and for external liaison. Products from national synthesis will include technical reports aimed at other scientists, as well as topical publications (Circulars, Water-Resources Investigations Reports, and Fact Sheets) for policymakers and the lay audience.

B. Periodic National Summaries

In addition to national synthesis efforts, another way that NAWQA can formally provide insights about the entire country is through periodic national summaries. The intended audiences for these reports are senior water-resource managers, Congress and congressional staff, and policy and elected officials at many levels of government and nongovernmental positions. A national summary report will be produced every 3 years at the conclusion of each HIP to document the findings of groups of study units. The report needs to be produced in a timely fashion, immediately following the completion of each set of study-unit summary reports, to ensure that the synthesis of results is fresh and relevant. A comprehensive communication plan should be developed for each report that ensures proactive distribution to a broad spectrum of customers. Periodic national summary reports should be cumulative and include data from previous reports. The last report in each decadal cycle should be longer and more comprehensive to allow for a summary of the full range of information generated during that cycle of NAWQA.

Periodic national summary reports should be brief (approximately 20 to 25 pages). They should supplement the study-unit summary reports and include:

- A brief discussion of principal results from each group of concurrently operated study units, including national comparison data displayed on national maps.
- A synopsis of particularly important findings from each study unit.
- Observations on co-occurrence of constituents.
- Comparisons among similar environmental settings.
- A discussion that will provide some context for how the study units covered in the report compare with basins in the rest of the country in terms of size, population, land use, and other important variables.
- A companion Fact Sheet that provides for a snapshot overview of the topic and a quick grasp of policy implications for briefing purposes.

5. RECOMMENDED NUMBER OF STUDY UNITS AND THEIR ROTATION

The NAWQA Program, as originally conceived, was to be implemented in a phased approach, with 3 groups of 20 study units beginning in 1991, 1994, and 1997. It was intended that the study units were to be revisited on approximately a decadal cycle. For example, the 1991 study units are scheduled to begin their second period of high activity in FY 2002. A fundamental reason for this approach was one of resources. The cost of data collection (including the laboratory cost of analyses) during the intensive phase of the program dictated that a manageable number of study units should be in HIP at any given time.

Between 1991 and present, the NLT has been forced to combine study units or indefinitely defer work on study units in response to funding constraints. At present, funding is not sufficient to accomplish the program's three major goals in the full complement of study units. In 1997, for example, two study units in eastern New England were combined into one, thereby reducing the number of study units from 60 to 59. Fifty-one of these 59 have had or will have one HIP followed by an LIP. All or parts of another five study units have been combined with the Central Nebraska Basin (a 1991 start) into the High Plains study, with a focus on ground water. Work in the remaining three study units has been postponed. It will be difficult to maintain the rotation originally planned in cycle II because it is clear that funds are insufficient to reinitiate all 20 of the 1991 study units in FY 2002. In the absence of substantial funding increases, some adjustment in the rotation scheme or number of study units will be required.

The Planning Team considered a variety of options for adjusting the number of study units and their rotational scheme. These included (1) varying the level of activities among active study units, (2) lengthening the rotational period, and (3) changing the number of study units. The Planning Team did not consider eliminating LIP sampling because LIP is essential to achieving the trends goal of NAWQA. Budgetary implications were calculated for each option through the year 2007, assuming there are either no inflationary increases or increases that would compensate for inflation. It was clear that without compensation for inflation during the next 10 years, NAWQA will not survive in a recognizable form. The discussion below assumes that there will almost always be compensation for inflation.

Changes in the level of activity, period of rotation, or number of study units will have implications beyond the budget. For each option, the Planning Team evaluated implications for NAWQA's three major goals, as well as implications for a variety of other factors. These other factors include (1) coverage of the Nation's water use, land surface, and population; (2) impacts on national synthesis; (3) local spinoff projects; (4) staffing issues; (5) ground-water and surface-water assessments; (6) ecological studies; (7) regional studies; (8) LIP sampling; and (9) reports. The major characteristics and implications of the options are summarized in table 1. The recommended option is described in the text. Additional information about the other options is presented in appendix 2. Note that some options have no implications for some of the factors listed above. Only those factors that are significantly affected are discussed.

Recommended option

The recommended option operates 43 study units at or near full activity on the rotational scheme presently in place. In addition, the Planning Team endorses and recommends continuing the regional ground-water study, which includes all or part of six study units. Because the High Plains study will be in HIP for 6 years instead of 3, it will be the financial equivalent of 2 regular study units. Thus, the combination of 43 study units and the High Plains study is the equivalent of 45 study units. To reduce the number of study units from 59 (the current number) to 45, the Planning Team recommends elimination of some study units and consolidation of others to maintain spatial coverage. Major benefits of this option are that it provides a structured procedure for reducing the number of study units and it takes advantage of work completed in cycle I. For example, it was advantageous to include a number of relatively small study units in cycle I because of the need for detailed characterization; however, NAWQA now has a sufficient baseline about some of these smaller study units so that consolidation is feasible.

Budget implications

The 45 study-unit option is one of the least costly options considered. If inflation is fully compensated for, a budget analysis shows that through 2007, all study-unit costs can be covered, plus up to $3 million per year would be available for other high-priority activities, such as more explanatory studies, more gradient studies, additional ground-water activity, and full implementation of LIP activities. If inflationary compensation never occurs, large deficits will result in the need to further reduce the number of study units, jeopardizing NAWQA's ability to represent water-quality conditions in the Nation. The advantage of this option is that NAWQA would be able to make measured decisions to cut back and achieve stability in the number of study units, rather than being forced to make ad hoc decisions every year.

Effects on achieving NAWQA's goals

This option would sustain a high level of diverse activities in a sizable number of study units (but fewer study units than originally designed). Unlike other options, it does not inherently result in large shifts of resources between ground water and surface water or among occurrence and distribution, trends, and explanation. As in cycle I, NAWQA will have an established plan to rotate through study units. This should reduce its susceptibility to being affected by short-term needs. Effects on specific goals are as follows:

- Occurrence and distribution: This option would use a structured procedure to decide how to reduce activities and will build on the results from cycle I to help guide activities in cycle II. For example, in those cases where contiguous study units are consolidated, knowledge gained from cycle I studies can be used to judiciously sample the new larger study units. This option may increase information about the occurrence

Table 1. Major characteristics of design options for cycle II

	Original design	Current approach	Recommended option	Extended rotation option	Hybrid options
Number of study units (su's)	60	• 51 su's will be active in cycle I (includes 2 of original 60 combined) • All or parts of 6 are included in High Plains • 3 postponed	43 su's + High Plains Equivalent of 45 su's (including High Plains)	52 su's	Several combinations possible
Grouping	3 groups of 20 su's	3 groups of su's (20+16+15)	3 groups of 15	4 groups of 13	3 groups
Years in HIP	3	3	3 for most su's 6 for High Plains	3	3
Years in LIP	6	6	6 for most su's 3 for High Plains	9	6
Effect on goals	Able to achieve all goals	• Funds insufficient to achieve original design characteristics • Fewer explanatory studies in later groups of su's • LIP delayed and reduced level of effort	• Provides full activity in su's • Funds available for explanatory studies • Funds available for more ground-water effort • Funds available for LIP (trends)	• Negative impact on explanation • Loss of spatially intense data in HIP impacts trends	• Give up explanation in data only
Budget implications	Past inflationary shortfalls made this unrealistic	• Shortfalls in some areas expected to continue • No funds for ground-water explanatory studies	Feasible	• Significant deficits • High cost of extended LIP	• Unacceptable deficits projected • Reducing level of activity in su's does not save as much as reducing number of su's
Other considerations		• Will need to adjust period of rotation for original 20 because insufficient funds to conduct 20 su's simultaneously • Need for ad hoc design	• Consolidation of su's possible to maintain coverage • Structured approach	• Fewer spinoff studies • Less focus on local issues • More data collection than explanation	• Su's have extreme differences in level of activity—surface water (SW) only, or data only • Causes unacceptable separation in study of SW and GW

and distribution of constituents in ground water because it frees some funds to do more comprehensive ground-water studies.

- Trends: This option provides resources for better implementation of the trend component of NAWQA.
- Explanation: Funds are available for more explanatory studies as compared to cycle I. Larger, consolidated study units can provide some advantages for studying gradients and for considering the basic source-transport-receptor paradigm. For example, the Upper and Lower Illinois Basins are candidates for consolidation (see below). They include Chicago and the Corn Belt. Thus, one consolidated study unit will provide a gradient for ecological integration and other explanatory studies. It will also provide the opportunity to give more emphasis to either agricultural or urban effects in different cycles of NAWQA.

Effects on other program characteristics

- Distribution of study units: Depending on which study units are chosen for consolidation and elimination, it will be possible to keep the same mixture of urban, agricultural, mining, and other land uses as was available in cycle I. Because all land-use types are still available with a minimum loss of coverage, NAWQA will continue to have the flexibility to respond to future demands.
- Level of activity in study units: A wide range of activity occurs in all study units under this option. All study units would receive funding for the full complement of sampling efforts conducted in cycle I, plus funds for more explanatory studies. In reality, there may be some loss of spatial intensity in the consolidated study units. However, the consolidation of study units as proposed in this report would result in newly formed study units that are smaller than some of the largest study units from cycle I.
- Percentage of water use, land coverage, and population: Through careful selection of study units to be consolidated or eliminated, this option minimizes the impact on coverage. Even though the impacts on extent of national coverage can be minimized while allowing NAWQA to continue to achieve its goals, fewer study units may not be a popular choice with some stakeholders. This is likely to be a particular issue in those study units that are eliminated or consolidated.
- National synthesis: There may be some loss of opportunities for national synthesis. For example, studies of surface-water pesticides in the High Plains may be difficult; however, there will be benefits to other aspects of synthesis. For example, synthesis of VOC's may benefit from the relative increase in emphasis on urban areas that will result from the consolidated High Plains study. Furthermore, there may be opportunities for better understanding of many synthesis topics from the larger gradients available in consolidated study units or from regional synoptic studies that may include several study units.
- Staffing issues and spinoff projects: This option could create disparities among WRD Regions with regard to NAWQA budgets by consolidating and eliminating some study units. However, an advantage is that this option will reduce the annual uncertainties associated with ad hoc decisions about number and funding level of study units, which are presently necessitated by budget uncertainties. More explanatory studies will mean more local opportunities for spinoff projects. Districts and study-unit teams may feel a greater sense of control if funding problems are stabilized.
- Ground-water and surface-water assessments: This option will allow continued expansion into poorly understood areas of study units. NAWQA will lose surface-water information in the High Plains as compared to the original plan, except where surface water interacts with ground water. Some occurrence and distribution sites might also be lost in consolidated study units. Also, areas that are perceived to be less interesting may be lost, especially in consolidated study units.

- LIP: This option will allow about the same LIP as now planned, with some losses as described in the changes of activities.
- Reports: This option creates the opportunity and the mechanism for more explanatory reports, more gradient studies, and a shift away from emphasis on occurrence and distribution.

Transition from 59 to 45 study units

The number of study units can be reduced from 59 to 45 using a combination of consolidation and elimination of study units. Two or more study units may be consolidated when the following criteria are met:

1. The study units are adjacent or near each other.
2. The surface-water outflow of one study unit is the inflow to the second study unit.
3. The study units share similar land use, land cover, physiography, or other characteristics, so that the study units would have used a similar stratification scheme and network design.
4. The combined study units can be managed by one office or staff.
5. One or both study units have a small population compared with most other study units.
6. The water-quality issues in the study units are similar enough so that data collected by the study units if they remained separate would be redundant.

Criteria for elimination of study units include numbers 3, 5, and 6 above. An additional criterion for determining which study units can be eliminated is that the water-quality issues in a study unit are minor compared with those in other study units. Water-quality issues can be considered minor if they are not of national concern or scope or if concentrations of water-quality constituents of interest are generally low.

Deciding which particular study units should be combined or eliminated requires a judgment based on weighing the above factors for each candidate study unit. It is likely that some or all candidates for elimination will meet some, but not all, of these criteria. Such comparisons and judgments are beyond the scope of this report. However, the Planning Team has developed an example, in order to illustrate that it is possible to decrease the number of study units from 59 to 45 without greatly decreasing the total population, water use, and areal coverage of the NAWQA Program. The proposed consolidations and elimination of study units given below should not be considered the recommended choices. Rather, this analysis represents only one of many potential ways to reduce the number of study units to a number that can be sustained over the next cycle.

Much of the reduction in the number of study units can come as a result of combining one or more study units into a larger study unit. The largest consolidation will come in the High Plains, where the program has already begun a study that includes all or parts of six study units (Canadian-Cimarron, Central Nebraska, Kansas, Middle Arkansas, Southern High Plains, and North Platte). The High Plains study unit will be unique in comparison with other NAWQA study units because the primary focus will be on investigating ground-water quality. This is reasonable because nearly all of the water use in these study units is from ground water. This study unit is the only exception to the general rule that a full range of water-quality data collection (ground water, surface water, and ecology) should occur in each study unit. The six study units in the High Plains meet many of the criteria for consolidation, as all are located near one another and have similar land-use and water-use patterns. Most of the six study units consolidated to form the High Plains study unit have small populations, with the average population less than 1,000,000 per study unit. In addition, these study units are also sparsely populated, with population densities ranging from 7 to 31 people per square mile. By comparison, population densities for the other study units are from 4 to 2,100 per square mile with a median of 88 people per square mile. Because the High Plains study unit encompasses such a large area and because a 6-year HIP is planned, it was treated in the budget analysis as the equivalent of 2.4 study units.

Consolidation of eight study units into four newly combined study units is an option for further reducing the number of study units while maintaining areal coverage. The units explored for consolidation are (1) Upper and Lower Illinois, (2) Upper and Lower Tennessee, (3) Allegheny-Monongahela and Kanawha-New River Basins, and (4) Central Columbia Plateau and Yakima River Basin. Each of these pairs of study units are located next to one another, share major water-quality issues, and so can be considered candidates for consolidation or, possibly, elimination.

A total of six more study units must be dropped in order to reduce the number of study units (including High Plains) to the equivalent of 45 total. If the six study units with some of the lowest populations (Delmarva Peninsula, Kentucky River Basin, Cheyenne-Belle Fourche Basins, Red River of the North, Upper Colorado Basin, and Cook Inlet Basin) were dropped, the total population in all NAWQA study units would decrease by 1.7 percent, or 2.6 million people. The water use in NAWQA study units would decrease by 2.3 percent, or 4.9 million gallons per day. If these six study units were dropped, the total area of NAWQA study units would drop by 8.8 percent, or 130,000 square miles. Overall, the effect of dropping these six study units would slightly decrease the number of people and water use in NAWQA study units, with a more substantial decrease in the total area covered by NAWQA.

6. GROUND-WATER STUDY DESIGN

The core objective of the ground-water studies in the NAWQA Program will continue to be assessment of the water-quality conditions of major aquifers in each study unit with emphasis on the quality of recently recharged ground water (Gilliom and others, 1995). Because ground-water quality tends to vary more spatially than temporally, the focus of the ground-water assessment has been primarily on spatial characterization. For the purpose of defining trends, however, there still remains a need to define temporal variability in ground-water quality. The original network design as outlined in Gilliom and others (1995) was well suited to the task of defining spatial variability, and will continue to form the basis for the occurrence and distribution part of the data-collection network in cycle II. Some effort should also be given to defining temporal variability through (1) sampling some wells more than once per HIP to detect seasonal or other short-term trends, and (2) sampling some wells during LIP to detect longer term trends. The three major components of ground-water investigation recommended for cycle II are briefly described in table 2.

Table 2. Components and attributes of the NAWQA ground-water sampling design (modified from Gilliom and others, 1995)

Feature	Study component		
	Reconnaissance Surveys	Studies of Recently Recharged Ground Water	Flowpath Studies
General objective	Provide a broad overview of the quality of the most important current and future ground-water resources	Examine natural and human factors that affect the quality of shallow ground water through: (1) occurrence and distribution in less-explored areas; (2) explanation of gradients within or across explored land use	Examine spatial and temporal distribution of water quality in relation to ground-water flowpaths and interactions of ground water and surface water
Spatial domain	Ground-water resources throughout study unit, including: (1) newly sampled areas; (2) repeat sampling in old areas (~10%)	Across large parts of study unit, including: (1) recently recharged water; (2) linkages between ground-water quality and land use (or other gradients)	Local areas of interest in specific settings
Depth of interest	Shallow and deep aquifers	Shallow aquifers	Typically shallow flow systems but may include deeper flow systems discharging to known terminal receptors
Number of wells	30–35 per subunit	30 per land-use setting	As needed for flowpath definition, typically 10–15
Well-selection strategy	Spatially distributed "random" sampling Primarily existing wells	Spatially distributed "random" sampling Primarily new wells	Wells distributed at multiple depths along flowpath New wells to extent possible
Temporal sampling strategy	Each well sampled at least once per HIP cycle	Each well sampled at least once per HIP cycle	Variable; multiple samples from most wells

In cycle II, special ground-water studies will be aimed at developing a broad understanding of factors that influence water-quality conditions and the effects of the observed water-quality conditions on a range of terminal receptors. These studies will be conducted locally but will define processes that control water quality at scales of regional and national significance. Emphasis will be placed on sampling along gradients to try to understand their influence on water quality. Special investigations will be conducted as part of Reconnaissance Surveys and Studies of Recently Recharged Ground Water, but the primary instrument for these studies will be the ground-water flowpath networks. Implementation of these special studies will require coordinating ground-water activities, including flowpaths, with surface-water activities, including intensive fixed sites both within and across multiple study units.

The special studies will consist of a series of related studies from multiple study units that will build on current knowledge and test hypotheses that have been formed either in cycle I or during the early stages of cycle II. For example, in cycle I, NAWQA has developed new insights into the processes that control denitrification as ground water moves from recharge areas and discharges to streams. As part of the flowpath investigation in the South Platte study unit, it was found that denitrification was occurring in the floodplain and riverbed sediments, substantially reducing nitrate concentrations between recharge areas and discharge areas (McMahon and Bohlke, 1996). Similar work has been done in the Red River of the North (Stoner and others, 1997) and the Puget Sound study units (Tesoriero and Voss, 1997), as well as several other NAWQA study units. This body of knowledge and understanding constitutes the type of broad regional and national understanding of the fate and transport of nitrate in the ground-water system that is the goal of this new program of special studies.

While data collection for these studies will necessarily be done at local and subregional scales, the findings from these studies will have to be scaled up to the regional and national levels. As in the previous example, new insights and understanding will be developed by synthesizing the information gathered in several different study units. This scaling up of results represents one of the greater challenges to the NAWQA Program, and NAWQA should invest resources into learning and refining how this scaling can best be accomplished.

The Planning Team places such a high priority on conducting this research on scaling and these special studies that this was a major consideration in determining the overall program design recommended for cycle II.

With the shift in emphasis in NAWQA toward the explanation of observed water-quality conditions and their implications for water supply, it becomes more important to understand observed water quality in the context of the ground-water-flow system, from sources of contamination to their influence on terminal receptors. Prior to any network design and data collection, it is incumbent upon the study-unit team to develop a conceptual model of the flow system, including water and chemical budgets. This conceptual model should form the basis for designing the sampling network. When significant questions about the conceptual model of the flow system exist and these uncertainties affect the design of the data-collection network, NAWQA should provide resources to test the conceptual model. Possible approaches might include preliminary sampling of a few representative wells or the use of numerical models of ground-water flow and transport.

In conjunction with water-quality and ground-water age data, ground-water-flow and transport models can be used to test and refine conceptual models of the flow system and help explain the water-quality conditions that are observed. For example, using an areal flow model and particle-tracking routine, Modica and others (1998) and Modica (1999) were able to identify water discharging to the Cohansey River, New Jersey, that was affected by agricultural practices. They were also able to demonstrate that nitrate concentration was inversely related to ground-water age as determined by chlorofluorocarbon concentrations. They could explain the observed pattern of nitrate concentration with respect to agricultural land use at ground-water source areas. These relations could not have been understood without a sound knowledge of the ground-water-flow system.

In order to continue to make progress on the original NAWQA goals and to accommodate the new emphasis on processes and explanation, a two-part approach is recommended. The first part will be to conduct the basic occurrence and distribution studies in a more efficient manner. The second part will be to bring new resources to the ground-water component for expanded studies devoted to process understanding, explanation, and regionalizing concepts. Modification of priorities and resource allocation within the NAWQA Program will be required to accommodate these changing goals and to compensate for past erosion of resources in the ground-water program. Details of the modified strategy are outlined in the next sections of this report.

A. Reconnaissance Surveys

Current approach

The primary objective of the original study-unit survey (hereafter referred to as the Reconnaissance Survey) is to provide a broad spatial assessment of the water-quality conditions of the most important present and future ground-water resources of each study unit (Gilliom and others, 1995). In the initial design, each study unit was to be divided into several subunits (generally three to five) that were expected to be homogeneous in water-quality characteristics compared to the study unit as a whole. This subdivision was done on the basis of major hydrogeologic settings and was to include both deep and shallow ground water. Shallow aquifer systems were further subdivided on the basis of physiographic characteristics. Several subunits would be sampled during each HIP and from this, an overview of the water-quality conditions of the study unit could be developed.

Limitations

1. The ability to successfully carry out the original occurrence and distribution objectives has been hampered by the erosion of resources available for the NAWQA Program. Limitations in the availability of NAWQA resources has forced the NLT to make adjustments and changes in the original program design for NAWQA to remain a viable perennial water-quality assessment program. On a study-unit basis, the proportion of NAWQA funds dedicated to ground water decreased when comparing the 1991 and 1994 study units. In contrast, the proportion of funds dedicated to surface water and ecology increased slightly. Reconnaissance Surveys have not been implemented to the extent envisioned in the original design. Therefore, completion of the Reconnaissance Surveys will be delayed and will necessarily take place over multiple NAWQA cycles.

2. Reconnaissance Survey sampling priorities have focused mostly on the currently used resource, to the exclusion of sampling possible future ground-water resources. These unsampled parts of the study unit represent an important potential resource that may be developed in the future. This resource needs to be characterized to provide information upon which future management decisions might be based.

3. In cycle I, emphasis was placed on the land-use experiment and anthropogenic influences on ground-water quality. In an attempt to conserve resources, some of the land-use study wells were used in the Reconnaissance Surveys. In some cases this resulted in a bias in sample network design toward recently recharged shallow ground water and ground water in shallow, circulating flow systems. Because of this emphasis and of difficulties associated with sampling deep ground water (few wells, sparse coverage, large depth to water), only 5–10 percent of the sampling was targeted to deep ground-water quality. Depending on the relative importance of deep ground water, this sampling plan may not provide an adequate representation.

Recommendations

1. Reconnaissance sampling in cycle II will be aimed at filling in knowledge gaps that remain after cycle I sampling. Selection of subunits and well-sampling strategy in cycle II should be guided by all of the information available to study units. Information to be considered should include data collected within the study unit during previous cycles, as well as data collected in similar settings in adjoining study units. The study-unit team should also use water-quality information collected by other agencies and other USGS programs to help guide network design and sampling strategy. These data will form the basis for the development of a set of working hypotheses that describe the occurrence and distribution of water-quality constituents in the study unit. These hypotheses should be used as the basis upon which areas for additional sampling will be selected; then, constituents for inclusion in the laboratory analysis schedule will be selected.

2. To help guide the design of the data-collection network and to aid in the interpretation of water-quality information, the study-unit team should develop a conceptual model of the basin or watershed. Essential components of the conceptual model are water and chemical budgets, as well as an understanding of the geohydrology of the study unit. This includes probable sources, directions and rates of ground-water flow, dis-

charge areas and terminal receptors, land-use patterns, and areas of probable future development in the study unit. This is generally done in an informal manner by the study-unit team in the course of planning and conducting the HIP. It is essential, however, that these conceptual models be documented in a more formal way through published reports, in order to provide a context and basis for the explanatory work and as background for future studies in the basin or watershed.

3. Completion of the Reconnaissance Surveys will be delayed, taking place over multiple NAWQA cycles because of the limited number of subunits that are being sampled in each study unit. This is not inconsistent with the original ground-water study design; however, the long-range goal of characterizing water-quality conditions throughout the study unit must be preserved as the program evolves over multiple NAWQA cycles. The eventual characterization of the entire study-unit resource can be accomplished only through the use of the technique of iterative search. With this technique, some of the study unit's resources are allocated to sampling previously unsampled parts of the study unit until a complete characterization of the unit has taken place. In addition to sampling different parts of the study unit through time, periodic resampling of areas covered in earlier NAWQA cycles is also necessary, especially in those areas where water-quality changes may have taken place. This will ensure that the study-unit characterization based on data collected in earlier cycles is still valid. No additional resources are likely to become available for Reconnaissance Surveys, so careful planning of future sampling is necessary to ensure that new areas can be sampled while monitoring continues in areas previously sampled.

4. Well selection in each subunit should continue to rely on the grid-based random-sampling approach used in cycle I (Scott, 1990; Alley, 1993). However, it is important that the water-quality information collected is suitable to meet the explanatory goals of NAWQA. Therefore, it is recommended that to the extent possible, Reconnaissance Survey sampling be done only where the following conditions are met:

- The study-unit team has developed a set of hypotheses that will be tested.
- There is at least a rudimentary conceptual model of the hydrologic system.
- Recharge areas are delineated and flowpaths are generally known.
- Land use/land cover of recharge areas is known.

5. Reconnaissance Survey sampling is exploratory in nature. Therefore, some sampling should take place in areas that are not as yet fully developed but that may be developed in the future. To the extent that deep ground water is, or has the potential to become, a significant source of supply in a study unit, sampling of this part of the resource must be included in the reconnaissance sampling network. The goal of deep ground-water sampling is to broadly characterize the quality of water that may become drinking water. This includes water flowing in deeper aquifer systems that may potentially be tapped in the future. An additional ancillary goal of deep ground-water monitoring is to provide outpost monitoring, or early warning, of potential contamination of the deep ground-water system. Therefore, sampling should also include water that is likely to be intercepted by municipal-supply wells that currently tap deep aquifers. It is expected that 10 percent of the wells sampled for Reconnaissance Surveys would be dedicated to sampling public-supply wells and deep ground water that may be tapped in the future. A greater percentage may be advisable in systems where deep ground water is the primary source of drinking water or where water-quality problems are suspected. In characterizing deep ground water for the Reconnaissance Surveys, data collected by other agencies for the EPA Source Water Assessment Program should not be overlooked.

6. Age dating should be included in Reconnaissance Survey sampling where possible, especially when sampling deep ground water. Age dating is a useful tool for verifying the conceptual flow model, testing linkages between shallow and deep ground water, and validating hypotheses.

7. The occurrence and distribution part of ground-water studies should be modified to account for existing information within the study unit or in nearby study units, or in similar land-use or hydrogeologic settings. For example, if a subunit is in a region or setting where previous data have indicated little to no contamination of ground water by a constituent, the frequency of sampling for that constituent can be decreased to a level as low as 10 percent of the samples collected in cycle I. If

initial sampling indicates unexpected results, however, then additional sampling would be warranted.

8. For areas sampled in cycle I, a subset of previously sampled wells should be resampled in future NAWQA cycles to verify that water-quality conditions have not significantly changed. In these areas, it may only be necessary to resample as few as 10 percent of the wells. If the results from the initial 10 percent are not consistent with previous rounds of sampling, then additional sampling in the area would be necessary to identify and quantify the changes that have occurred since the last round of samples were collected. If the results are consistent with previous rounds of sampling, then the sampling can be considered adequate.

9. Selection of wells to be included in future Reconnaissance Surveys must also take into consideration NAWQA's objective to determine long-term trends in water quality. In order to accomplish this objective, a subset of wells must be sampled repeatedly to develop a data base for statistical analysis of trends. In selecting wells to be sampled for the Reconnaissance Survey in cycle II, a conscious effort should be made to identify a subset of wells sampled in cycle I. This includes all wells sampled during the LIP in cycle I. Consideration should also be given to continued sampling of any reference well sites.

B. Studies of Recently Recharged Ground Water

Current approach

The primary objective of Studies of Recently Recharged Ground Water (previously called Land-Use Studies) is to assess the concentration and distribution of water-quality constituents in ground water associated with the most significant, current land uses and hydrologic conditions in each study unit. A closely related second objective is to understand the human and natural factors in each setting that affect ground-water quality.

Limitations

The focus on recently recharged shallow ground water in priority land-use settings enables direct assessment of relations between land-use activities and ground-water quality. There needs to be further investigation into the strength of these linkages. Possible questions include: (1) Is there a threshold effect, beneath which a certain land use or activity has no discernible effect on ground-water quality? (2) Are these linkages consistent across different hydrologic, geologic, and physiographic regimes? In order to answer these questions, sampling in the Studies of Recently Recharged Ground Water must also be designed to examine gradients.

Recommendations

The network design for the Studies of Recently Recharged Ground Water will remain largely unchanged from cycle I. The primary difference lies in the shift in emphasis toward the explanation of observed water quality and the need to be as efficient as possible in the use of resources. In order to develop insights into the factors influencing observed water-quality conditions, NAWQA cycle II study units should design these studies to sample along hydrologic, geologic, physiographic, and land-use gradients. By sampling along these gradients, the relations between water quality and human activity and natural characteristics will be more readily apparent.

C. Flowpath Studies

Current approach

The primary objectives of the Flowpath Studies are to (1) characterize the spatial and temporal distribution of water quality in relation to ground-water flow for particular settings of interest, (2) evaluate the natural processes and human influences that affect the evolution of ground-water quality along flowpaths through the saturated zone, and (3) evaluate the extent and significance for water quality of interaction between ground water and surface water.

Limitations

The Flowpath Study component of many study units was dropped completely because of a lack of background information and financial resources. In some study units there was little or no historical water-quality data available upon which to formulate hypotheses and objectives for the Flowpath Studies. Also, in some cases, the understanding of the ground-water-flow system was inadequate to design a Flowpath Study sampling network. This was unfortunate because the Flowpath Studies are the primary instrument for investigation of processes and for explanation of observed conditions.

Flowpath Studies that have been conducted to date have emphasized relatively shallow and short flowpaths terminating in discharge to streams, where the primary receptor is the aquatic community. Limiting the Flowpath Studies to relatively shallow systems does not allow for a full range of investigation. There are significant benefits in understanding the effects of shallow ground water on deep ground-water quality and potential terminal receptors, such as municipal-supply wells.

Recommendations

1. In cycle II, program emphasis should be shifted toward the explanation of why water-quality constituents are or are not found in a ground-water system and how ground-water quality evolves as it moves through a system, including movement to deep ground water and receiving waters. The best approach to answering these questions is through Flowpath Studies. Therefore, a high-priority activity for every study unit will be the identification of an appropriate location for a well-designed and executed Flowpath Study. This activity is of such importance to the NAWQA Program that resources should be reprogrammed both within study units and nationally to enable each study unit to conduct at least one Flowpath Study. Some ways in which the ground-water Reconnaissance Surveys and Studies of Recently Recharged Ground Water could be conducted more efficiently are discussed later in this report. In addition, the Planning Team has endorsed an overall NAWQA Program design that makes substantial resources available for Flowpath Studies.

2. Ideally, the Flowpath Study sites will be selected to provide a perspective on the potential significance or influence of poor-quality shallow ground water on deep regional ground water and receiving waters at discharge points and municipal-supply well fields. Furthermore, where possible, these Flowpath Studies should provide information that can be used to explain observed water quality and to develop insights and understanding into processes at a regional and national level.

3. In some cases, it may not be possible to identify a working hypothesis for testing, or to locate a flowpath along which a study could logically be conducted. In these few instances, Flowpath Studies may be excluded. Such a decision should not be made, however, without exhausting all possibilities to develop new insights about the factors that control the evolution of water quality in the ground-water-flow system, including the influence of shallow ground water on deep ground-water and receiving-water quality.

4. Flowpath Studies should consider sources, transport, and effects of constituents of concern in ground-water systems. The concept and application of flowpath work should be extended to larger spatial scales and should include public-supply wells as key receptors. This may require conducting Flowpath Studies in relatively deep-circulating flow systems.

5. Greater emphasis should be placed on nested studies. The ability to develop new concepts, insights, and understanding, and to extrapolate these concepts and understanding to other areas is best facilitated by designing the network so that various ground-water and surface-water components are nested within one another. Therefore, the original guidelines are strengthened regarding the relation of the transect to indicator basins and LIP data-collection sites. One of the major strengths of the NAWQA Program lies in its multidisciplinary approach to assessing water quality; thus, in cycle II, Flowpath Study sites should be selected to be coincident with an indicator basin basic fixed site (or intensive fixed site). This will ensure that the entire pathway is being monitored from the source to the receiving waters. Also, wherever possible, the transect should include LIP ground-water sampling sites. Coupling the transect with LIP sites provides data that, over time, can be used to evaluate changing conditions along the transect.

6. In identifying candidate transects and designing data-collection networks, it is of utmost importance to have a clear conceptual model of the flow system and chemistry. Ground-water-flow models can be used very effectively to develop and refine conceptual models of the flow system. These models can be used to evaluate multiple hypotheses about probable flow directions and rates of ground-water movement, location and extent of recharge areas and discharge areas, and depth to which the system circulates. Knowledge about all of these aspects of the flow system is required before the Flowpath Study can be designed. Models can also be used to evaluate the uncertainty in a given conceptual model

and to design a data-collection network that would reduce this uncertainty. For example, it is not uncommon for some uncertainty to exist about the depth to which shallow flow systems circulate. Models can be used to identify the most effective locations and depths for the installation of observation wells. Therefore, study units should strongly consider the use of areal and (or) cross-sectional ground-water-flow models to identify and evaluate candidate transects and to design the data-collection network for selected transects.

Further benefit can then be accrued from these models in the interpretive stage of the study. The models can be used in conjunction with the water-quality and age data collected along the transect to evaluate and refine concepts and hypotheses regarding the transport and fate of constituents found in the ground-water-flow system. Rates of movement, retardation, chemical degradation, dispersion, and the eventual effect on the terminal receptor or receiving water can also be evaluated in the context of the flow system.

7. SURFACE-WATER STUDY DESIGN

A. Basic Fixed Sites

Current approach

The original intent of basic fixed site sampling was to provide an integrated assessment of the spatial and temporal distribution of general water-quality conditions in relation to hydrologic conditions and major sources of chemical constituents (Gilliom and others, 1995). Thus, the basic fixed site data were designed to be an important part of building temporal understanding of water quality (emphasizing occurrence and distribution) in the first round of NAWQA. Ideally, it was also hoped that the basic fixed site network would provide information about the movement of chemical constituents through the hydrologic system and, eventually, aid in understanding the processes responsible for observed conditions. In the original design, another implicit goal of the basic fixed site network was to compute loads of constituents and to relate these loads to sources. The successes in achieving these goals differed widely among study units and, in many cases, were limited.

The basic fixed site network was thus originally designed to be the cornerstone for much of the surface-water-data collection activities in the NAWQA Program. It was well recognized that basic hydrologic data provide the necessary underpinning for interpreting nearly all water-quality data in streams. It was also recognized that interpretation of many types of water-quality data requires frequent collection throughout the year because of high temporal variability in hydrologic data and in constituents such as nutrients, sediment, many modern pesticides, and some of the major ions. Although many of these data vary on different time scales, they all benefit from use of the fixed station approach. In cycle I of NAWQA, most basic fixed sites were sampled 12–15 times per year. Pesticide data were collected at intensive fixed sites, which were basic fixed sites with additional sampling during the period of pesticide use in the basin.

Limitations

Many study units recognized the basic fixed site network as the cornerstone of NAWQA's water-quality network. In other study units, however, the value of the basic fixed site network relative to its cost was questioned. Overall, this was one of the more controversial aspects of the program among study-unit personnel. The basic fixed site network undoubtedly laid the groundwork for the overall sense of water-quality and water-resource characteristics in the study units. However, these characteristics were incorporated as supporting data in interpretive reports or expressed only in data reports. The basic fixed site data alone may not have contributed as much as other approaches did to the number of interpretive reports or to novel insights about occurrence and distribution of water-quality constituents. This could be one source of controversy about the network.

The number of basic fixed sites in each study unit was smaller than originally planned (when the goals for the network were established) and has continued to decline through the first cycle of NAWQA. This has been an important limitation to the usefulness of the network data and has contributed to the frustration with the basic fixed site approach. Although data from the basic fixed site network is unquestionably essential, both directly and indirectly (as ancillary support to other data), the cost of collecting these data is high. Cost is the primary factor that has limited the number of sites in a study unit. Because of the small number of sites, basic fixed site data do not always fully depict water-quality conditions across the study unit; this is particularly true in some coastal and other study units that do not have a single unified drainage network. Rarely, if ever, in cycle I were there enough sites to compute a complete mass balance or load calculations on the scale of the larger watersheds. Restriction to 12 samples per year, collected at regular intervals, was seen by many NAWQA personnel as insufficient to characterize flow-dependent variables, or even to develop credible relationships between constituent concentrations and flow.

In the first cycle, the design of the basic fixed site network might be described as somewhat ad hoc with determination of the number of basic fixed sites per study unit achieved by balancing study-unit needs with budget constraints. With no change in NAWQA design, the number of fixed sites could continue to decrease over time at the cost of achieving important NAWQA objectives. Fewer basic fixed sites are likely if NAWQA chooses to incorporate a more complete assessment of water-quality conditions and ecology at each fixed site. Alternatively, the number of basic fixed sites could be sustained and other approaches (for example, synoptic sampling) curtailed. Balancing NAWQA's goals by using such tradeoffs is not necessarily simple. If the number of analytes increases, or the sampling frequency of existing analytes must increase to allow for accurate determination of loads, the cost of each basic fixed site could increase greatly. This could result in fewer fixed sites. However, fewer fixed sites may make it difficult to assess how representative the network is of conditions across the study unit. It will be necessary to increasingly augment the basic fixed site network with data from synoptic surveys across the study unit so that the representativeness of the data from the basic fixed site network can be assessed.

Recommendations

There will continue to be a great need for data from basic fixed sites as the NAWQA Program moves from an emphasis on the occurrence and distribution of chemical constituents to a greater focus on developing an understanding of source, transport, and receptor, or the reasons for observed conditions. The balance among needs and costs might be best obtained by carefully building upon the successes of the existing basic fixed site network.

The strategy for the temporal distribution of 15 annual samples at each basic fixed site has been dominantly calendar based. Typically, samples have been collected monthly with the remaining three samples per year taken during critical conditions, such as high discharge. This strategy will continue to define the sampling schedule at many sites. However, at many other sites, data and conceptual understanding have demonstrated that water quality is predictable on the basis of seasonal variation in discharge and human activity. At such sites, sampling frequency may be reduced to a quarterly schedule during periods of low variability. The resources thus conserved can be invested in more frequent sampling under conditions of higher variability and (or) greater concern about water-quality conditions.

Basic fixed site data have many uses that must be sustained in the second cycle of NAWQA. Because water-quality data are collected at the basic fixed sites over a relatively long period of time and over a variety of flow conditions, these are the sites where links can be made most clearly among water-quality, seasonal, and hydrologic conditions. In addition, because data are collected at indicator and integrator sites, these data can be compared to assess the effect of different land-use patterns on water quality, as well as to compare differences among different scales. On a national level, these data have been used to determine median and mean concentrations for constituents at these sites and so have served as a means for national comparisons of water-quality conditions. In many cases, it is not possible to perform these types of analyses on data collected less frequently. On the study-unit scale, integration of the basic fixed site network with other data-collection activities was frequently beneficial. For example, in instances where ground-water, surface-water, and biological data were collected within a basic fixed site watershed, more powerful interpretations about the causes and ultimate effects of observed water-quality conditions could be made.

With the above uses in mind, it is recommended that a basic fixed site should be continued or established only if it meets specific goals consistent with the overall objectives of the second cycle of NAWQA. It is recognized that all basic fixed sites cannot meet all goals; a flexible approach to the network is recommended to best optimize each site in the nationwide network. The purposes of modifying the network are to (1) sustain collection of data that can only be obtained by frequent sampling, (2) optimize the utility of the basic fixed site

Table 3. Components of the surface-water design

Goal (1)	Number of sites per study unit (su)	Assignment of sites to goal (2)	Frequency of sample collection	Constituents	Strategy
Center of excellence	2–3	A+B+(C)	12–15/year	All	Statistical sample
Mean and median	*	A–H	< or = 12/year	Flow sensitive	Pick up from all sites
Load/transport	2–3	D+E+(F) or others above	>15 (some years) (not all su's)	Selected (transportation of constituent of interest)	Focus on question
Indicators of representative flow	2	G+H	< or = 12/year	Selected (flow sensitive)	Watershed not covered above
Pesticide occurrence	*	A+(B)+(C)	>15/year	Selected pesticides	
Reference sites	1–2	I+(J) (could be others)	< or = 12?/year	Issue specific	Issue specific Reference
LIP	*	A+B+(C)	12–15/year	All	Statistical
Total	7–10				

(1) Basic fixed sites are intended to be an integrator of gradient studies and any studies that involve source/transport/receptor studies.

(2) Each letter represents one of the 10 possible sites in a study unit. Parentheses indicate uncertainty about the number of sites.

* No sites dedicated to this goal.

data, and (3) replace at least some of the cost of the basic fixed site network with synoptic sampling. Therefore, in the second cycle, the overall basic fixed site network may include fewer stations than during the first cycle, but it should remain as effective, or more effective, because of the sharp focus on objectives. The goals of basic fixed site sampling are summarized in table 3 and are described in more detail below.

1. Centers of excellence: Basic fixed sites should be chosen (or continued) at locations that show potential for developing, over time, into centers for watershed understanding in the study unit or for national synthesis. This means that basic fixed sites should have priority if they:

- Aid analysis of gradients in water-quality characteristics.
- Are suitable sites for ecological integration.
- Aid understanding of processes that affect water quality on the study-unit scale.
- Aid understanding of effects of ground water on surface water at the study-unit scale.
- Appear to be good locations for trend analysis (LIP sampling).

A subset of the basic fixed site network in each study unit should be chosen specifically to address the goal of having centers of excellence. The standard 15 samples per year with the full suite of water-quality constituents should be continued at each basic fixed site chosen to meet this goal, with sampling intervals at LIP sites optimized for determination of long-term trends. However, supplemental sampling might be considered so that goals for specific special studies or for development of process understanding can be accomplished.

2. Mean and median concentration: NAWQA should continue to use basic fixed sites to identify mean and

median concentrations of water-quality constituents in the most important streams and rivers in the watershed. This goal should emphasize constituents and locations for which frequent sampling is crucial to determine an accurate mean condition. The standard 15 samples per year at all basic fixed sites in a study unit could accomplish this goal, but all basic fixed sites could be used to determine mean and median concentrations. Only on rare occasions should basic fixed sites be selected specifically to meet this single goal.

3. Loads: Study units should use hypotheses developed from the first round of study to choose individual basic fixed sites that will characterize loads of key constituents from major (or interesting) sources in watersheds, study units, regions, and the Nation. NAWQA cannot afford a basic fixed site network designed solely to calculate loads transported through all study units. Determination of loads and characterization of sources can be relevant for some constituents and for some individual basic fixed sites; it also will not be relevant or reasonable for some other constituents. In cycle I, sampling frequency was typically limited to 15 samples per year for 1 to 3 years. This limitation constrained load determinations and development of rating curves, at least at some basic fixed sites. Thus, for cycle II, a higher sampling frequency is recommended (30 samples per year) for basic fixed sites used for this purpose. Exceptions are large river basins, where 15 samples per year can be adequate for development of rating curves; or LIP sites where the aggregation of data collected over long periods of time might be a feasible way to develop rating curves.

4. Indicators of representative flow: Basic fixed sites should be selected that are optimally located to characterize what happens to constituents over changing flow conditions, across seasons, and from year to year. Only basic fixed sites can provide a temporal context for synoptic observations of key water-quality variables in the basin. It is important to retain basic fixed sites that help to accomplish this goal. Basic fixed sites selected for this role should have flow conditions representative of large geographic areas in the study unit or region. A sampling frequency of 15 times per year is adequate to meet this goal.

5. Spatial comparability: Basic fixed sites should be selected explicitly to characterize, compare, and thereby, extrapolate temporal variability among indicator (homogeneous) sites, integrator sites, and basins of intermediate complexity. It may be possible to expand spatial knowledge of the temporal variability of constituents by selecting basic fixed sites so that a comparative basin approach is possible. This goal is consistent with goal number 4 (indicators of representative flow), and sites should be selected and sampled using the same criteria.

6. Transport and mass balance: In selected watersheds, rather than in the network as a whole, basic fixed sites may be nested in key locations to aid understanding of constituent movement, total mass loading from a complex array of sources, or processes affecting movement of constituents through a watershed. NAWQA's niche in the greater scientific enterprise is to conduct such studies at the larger watershed scale and to provide an example to others of the optimal approaches to characterizing inputs and transport. Therefore, the nested basic fixed sites should characterize a larger, but manageable, watershed of intense interest in a region. Not every study unit will use basic fixed site sampling to accomplish this goal. A sampling frequency of greater than 15 times per year may be necessary in the nested basic fixed sites. This is the type of goal that might be facilitated by obtaining funding from cooperators.

The recommended changes in the program will bring new challenges to the basic fixed site network that will require careful analysis and difficult choices. Although data from the basic fixed site network are very valuable, the costs of collecting these data are high; therefore, such data can only be collected from a limited number of sites in a study unit. A scaled-down basic fixed site network should only be considered if the overall network can meet the above goals at the study-unit, regional, and (or) national scale. If the goals of each basic fixed site are clarified, then it may be possible to reduce and sharpen the value of the network. Flexibility in the purposes of basic fixed sites and in the sampling that accompanies basic fixed sites should be the guideline. Study-unit teams will decide the resources available, the number of sites, sampling intensity, sampling strategy, and analytical needs at basic fixed sites on a site-by-site basis based on previously collected data, as well as on local hydrologic understanding. At sites where constituents of interest change quite rapidly with changing flow conditions, it may be possible to install automatic sampling equipment. In some instances, where concentrations of water-quality constituents change more slowly, sample collection may be limited to a monthly basis, with additional high-flow or low-flow samples collected to supplement these data. The number of samples at a given basic fixed site may range from 15 to 30 per year, based on local conditions and data needs. Data collected at each basic fixed site should be sufficient so that the aims of the network can be met and adequate data collected to compute concentrations, trends, loads, and variability for key constituents in a study unit and (or) a region.

B. Intensive Fixed Sites

Many of the points made for the basic fixed site network are also applicable to the intensive fixed site network because the intensive fixed sites are a subset of the basic fixed sites. In many instances, study-unit and National Synthesis Team members believed that the intensive fixed sites were among the most useful of the basic fixed sites because of the additional pesticide data collected at these sites. Many of these sites represented a unique data set in the study unit. Other analytes besides pesticides were also collected more intensively at these sites, which enabled the information collected at intensive fixed sites to be used for determination of loads for these constituents.

Many of the intensive fixed sites have become LIP sites and, therefore, represent a long-term investment in understanding the trends in water quality for particular settings in the study unit. Intensive fixed sites that are also LIP sites should probably be maintained so that a trends network is established and maintained by the program. Because many of these sites also had other data collected within the drainage basin, including ground-water and biological data, these sites are also the sites where observable trends in constituent concentrations or effects may be able to be related to explanatory variables, such as hydrology, land-use changes, or other factors. The program should strive, wherever possible, to maintain the strategy of nesting indicator fixed sites within integrator fixed sites, as well as nesting ground-water and biological networks within indicator intensive fixed sites. Such a strategy will likely be crucial to meeting the goal of increasing the explanatory emphasis of the program.

During cycle I, data from many of the intensive fixed sites were used to provide a basis for understanding variations in pesticides with regard to seasons and hydrologic conditions. As with the basic fixed sites, there may be a need to adjust the analytical range for samples collected at the intensive fixed sites (increase the number of analytes at some sites; reduce constituent coverage at others) on the basis of results of cycle I and goals for cycle II. Over time, then, the distinction between some basic fixed sites and some intensive fixed sites may be blurred, as various combinations of sampling frequency and suites of chemical constituents are tailored to the particular hydrologic, land-use, and water-quality questions in specific sampling locations and study units.

C. Reference Sites

As the program shifts to increasing emphasis on analyzing water-quality variability along gradients, the importance of having sampling sites and study areas in watersheds that are relatively unimpacted by the constituents of interest will be as important, if not more important, than in the first cycle. Research on study design consistently shows that multiple references are essential to convincingly demonstrate the more complicated effects of human activities. Each reference site will have to be considered on a constituent-specific basis. In some instances, reference sites do not have to be small, forested pristine watersheds with no or minimal human activities; rather, they will have to represent reference conditions for a particular constituent or issue. For example, while an agricultural watershed could not be a reference site for nutrients or pesticides, it may be an adequate reference site for investigating the distribution of polychlorinated biphenyls (PCB's) or VOC's. The key will be local and goal-specific flexibility in selecting such sites, rather than the generic reference site approach. Synthesis of knowledge gained from these local and goal-specific studies, rather than a simple synthesis of generic data, will be essential to developing national-scale perspectives.

8. BIOLOGICAL STUDY DESIGN

Current approach

Biological studies were added to NAWQA after the initial program design had been completed. The ad hoc committee (also known as the Rubin Committee) that provided the basic design for NAWQA (1985) did not discuss biology in NAWQA in any detail and did not consider a substantial biological component in their budget estimates. The 1988 Concepts document (Hirsch and others, 1988) described the objectives that determined the biological agenda for the first cycle of NAWQA. These included (1) determining the occurrence and distribution of potentially toxic substances ("tissue analysis"), and (2) assessing relationships between the physical and chemical characteristics of streams and the functional or structural aspects of biological communities. These two objectives constituted the biological program of NAWQA in its first cycle.

The tissue-analyses objectives were more easily integrated into the original NAWQA design than were ecological studies. There were several reasons why this was possible. First, tissue analyses were integrated with synoptic studies of contaminants in sediments early in the program, thereby coordinating chemical and biological field efforts. Second, a protocol for tissue analysis was available early in the program (Crawford and Luoma, 1992). Third, analytical techniques were rapidly and effectively developed by the National Water Quality Laboratory, so data were available to study units and Synthesis Teams in a manner comparable with other aspects of the program. Fourth, tissue analysis is amenable to chemical-monitoring design principles. Finally, relatively straightforward occurrence and distribution interpretations are also possible. Thus, USGS personnel were familiar with many of the principles necessary for rapid and effective use of tissue-analysis data. Integration with other interpretations was readily accomplished and some useful publications have arisen out of the tissue-analysis data.

Ecological analyses were more difficult to implement, partly because of the challenge of balancing local variability and a regional- and (or) national-scale interpretation. The original design called for Fixed Site Reach Assessments, which are intensive study of habitat, as well as of benthos, algae, and fish communities at suitable basic fixed sites, and Ecological Synoptic Studies, which are less intensive sampling over broader scales in the watershed (Gilliom and others, 1995). The Fixed Site Reach Assessments were conducted in every study unit, and Ecological Synoptic Studies were less frequently accomplished.

Limitations and strengths

Tissue: The tissue analyses presented some challenges to the study-unit teams. Field collection of sufficient numbers of individuals and (or) of comparable species was challenging for many study-unit teams. This aspect of the program has evolved toward more emphasis on fish collections and less on invertebrates than was originally envisioned in the protocol. Interpretation of the multiple-species data, on regional and national scales, remains a challenge, although not an insurmountable one. Sampling a sufficient number of sites with comparable data is another challenge for most study units. In general, however, the tissue-analysis protocol was successfully followed in most study units and has become a useful component of the overall NAWQA design. Data from tissue analysis have proven to be a useful complement to sediment data, as originally envisioned, and they have presented opportunities to bring biological relevance to the chemical data in a number of study units.

Ecological analyses: There are several reasons why the limitations and strengths of the ecological analyses are more difficult to interpret:

1. In many instances, Ecological Synoptic Studies were successfully employed to complement explanations of aspects of study-unit water quality (for example, Fend and Carter, 1995; Tate and Heiny, 1995; Carter and others, 1996; Cuffney and others, 1997; Wall and others, 1998). In all these examples, sampling involved more than 20 locations (the range was 21–77 among studies). Usually, individual study units employed substantial initiative to obtain taxonomic analysis. These cases strongly illustrate the powerful potential of the biological component of NAWQA to contribute to overall understanding of water quality and to add relevance to the NAWQA Program.

2. The original goals of the ecological analysis were probably at least somewhat inappropriate. The primary goal of routine fixed site ecological analysis (relations between environment and communities at regional scales) is explanatory. Other components of NAWQA began with an occurrence and distribution emphasis. For the benthic communities and algae, the intensive approach to sampling may be incompatible with the occurrence and distribution goal. There may be too few sampling sites to determine whether observed occurrence and distributions of benthos were representative of the study unit or the region (Hayden and others,

1997). To date, a successful aspect of the ecological analysis program has been the fish collections. It is interesting that this aspect of NAWQA has contributed useful occurrence and distribution data (e.g., Goldstein, 1995), partly because of the ability to collect novel data (nongame fish abundance) and partly because the collections are inherently less intensive and more extensive (in terms of both taxonomy and sampling) than benthic sampling.

3. Most of the benthic and algal data are not yet available. Resolution of bottlenecks that prevented taxonomic analyses of benthic and algal samples will allow better evaluation of these components.

4. At the national level, NAWQA biology could be better integrated with other components of NAWQA. At the study-unit level, the integration of biology with other disciplines was as successful as any integration between disciplines.

5. The ecological analysis has been something of a moving target throughout much of its development, perhaps, in part, because of the early focus of the program on developing methods and analytical techniques or capabilities for the ecological component of the program. Although protocols existed, many aspects of the effort were overly ambitious, did not clearly define choices that were necessary, and set unrealistic goals and expectations. The future success of ecology in the NAWQA Program will require making difficult choices among controversial options and identifying achievable, practical objectives.

Recommendations for cycle II

1. It is essential that NAWQA retain a biological component for all the reasons so frequently cited in the various protocol documents (e.g., Gurtz, 1994). However, some patience with the development of this component of NAWQA is essential. Ecological monitoring is a subject of substantial scientific discussion and uncertainty. Full consensus has not been reached in the scientific community on fundamental aspects of how to do this. That is, the technology of ecological monitoring is less developed than the technologies of hydrologic and chemical monitoring.

2. Goals and methodology must be complementary in future ecological analyses. Hayden and others (1997) summarized some important design principles for ecological monitoring in their report on the results of an Ecological Society of America workshop on Ecological Resource Monitoring. The following quotes from that summary are relevant to NAWQA: "An environmental monitoring framework must recognize the different roles of intensive sites, networks of sites, surveys, and complete coverage in assessing trends in ecological resources." "Intensive sites collect more information per site than monitoring networks, which collect more information per site than surveys." "Intensive sites may not be representative of subsets of populations, and should not be treated like statistical samples from a region." "Intensive measurements at a few sites may provide detailed mechanistic information for those sites, but this information may not be generally applicable to the region." The most appropriate networks for the ecology work in NAWQA are those that include as large a number of sites as possible. In choosing between maximizing the number of sites sampled and minimizing the effort for ecology sampling, versus minimizing the number of sites sampled and maximizing the sampling effort at the sites, the number of sites should be maximized. In the zero-sum game of effort per site versus number of sites, NAWQA should err on the side of the latter.

3. Biology needs to be fully integrated with the other disciplines in the surface-water NAWQA design. The biological aspects of NAWQA must be closely tied to all other aspects. Biologists working side by side with hydrologists and chemists in the study-unit teams is the appropriate model.

4. The biological themes of cycle II of NAWQA should complement and be integrated into the overall themes of NAWQA. Gradients, explanatory processes, and ground-water/surface-water interactions will drive the NAWQA design in cycle II. Sources, transport, and receptors will be important considerations in that design. In this respect, ecological analysis and tissue analysis can provide powerful tools to explain implications of water-quality observations and provide the needed receptor term in those explanations. Ecological studies must be designed in coordination with all other NAWQA studies. Sample collection and interpretation should be related to the surface-water and ground-water aspects of study-unit investigations.

5. Interpretations of effects of contaminants (especially pesticides), within the larger context of watershed hydrology, should be one of the explanatory focuses of ecological analysis. To quote Hayden and

others (1997) again: "The usefulness of information on changes and trends in the condition of an ecological resource increases when accompanied by information on changes and trends in one or more stressors." NAWQA has unique multiscale data on potentially important contaminant stressors, in addition to hydrology, nutrients, etc. The program's ecological analyses should fully integrate contaminant data into its analysis of ecological conditions. This is especially important given the NAWQA Program's strong emphasis on pesticide occurrence, distributions, and trends.

6. The established, relevant scale for biological studies in NAWQA is the study unit. Although the challenges are great, study-unit-scale studies can (a) be different from the work of other institutions, and (b) be consistent with how all the rest of NAWQA works. There are ways to do biological studies at a scale consistent with the rest of NAWQA; incorporating that scale into our biological studies needs to be a primary goal.

7. NAWQA must pioneer new approaches to understanding biological community responses to gradients of multiple stressors, on study-unit and multistudy-unit scales. The design of gradient studies will be a particular challenge for all of NAWQA. Examples of sophisticated approaches to this difficult problem exist (Guegan and others, 1998). NAWQA should be an important contributor to the development of this literature in the future. One example is to take advantage in cycle II of large-scale natural gradients identified in cycle I NAWQA, recognizing that land-use designations are accurate only in the broadest sense and, as NAWQA has already done, using modern statistical tools to identify relationships.

8. National synthesis of ecological studies is important, but it should be a long-term goal. The most important use of ecological analysis in the second cycle of NAWQA may lie in explanatory studies at the study-unit scale. It is important to first establish a "proof of principles" that ecological analysis at the watershed and study-unit scale has important applications in NAWQA. Such demonstrations may be an essential first step from which to best learn how to conduct a sophisticated national synthesis. Thus, planning a national synthesis experiment should not take precedence over local uses of ecological analysis in the second cycle. Because the development of an ecological synthesis will depend on understanding generated at the study-unit level, it will be necessary to be patient with the development of the ecological synthesis effort.

9. Both broad-scale, statistically developed hypotheses, and selected small-scale explanatory studies can occur in the second cycle of NAWQA. But the small-scale studies should be limited in number and limited in scope to testing hypotheses developed from larger scale, broader studies. NAWQA must emphasize the development of ecological analysis at the large watershed and study-unit scale.

9. ADJUSTMENTS TO SAMPLING STRATEGIES FOR NON-TREND ACTIVITIES

In cycle I, NAWQA required that samples be analyzed for a standard set of constituents throughout all study units, even in areas where one would not expect to find these constituents. The reasons for this requirement were that (1) often what we do not find is as interesting as what we do find; and (2) NAWQA wanted to maximize the possibility of unexpected results, and there were many such cases. For example, in the past 4 years, in the Delta region of the Mississippi Embayment study unit, crop distribution has shifted from nearly 100 percent cotton to about 20 percent cotton and 80 percent corn and soybeans. During that same time period, the reverse shift happened in the ACFB. Had NAWQA looked only for cotton pesticides or for corn-soybean herbicides in either study unit, an important piece of the pesticide occurrence story might not have been told.

In cycle II, it may not be necessary to sample as intensively as in cycle I. Because there was a heavy emphasis on occurrence and distribution in cycle I, cycle II will not need to have as many "nondetects" to be reasonably certain that relationships between water quality and land use are understood. However, NAWQA should retain all constituents from cycle I unless they can be eliminated by a suite of formal criteria that can be applied consistently. Study-unit chiefs for two study units in different parts of the country or two chiefs for the same study unit in different cycles should come to similar conclusions about which constituents are important, given similar circumstances. Adjustments cannot be made ad hoc by a study unit; instead, a structured thought process must occur.

The Planning Team recommends four criteria that can be used to guide sampling strategies. Core requirements for water-quality constituents and sampling strategies may be changed during cycle II when one or more of the following conditions are clearly supported both by data and by conceptual understanding:

1. If a class of constituents has not been found near a level of interest to either national synthesis or local interests, and this absence is consistent with known sources and current understanding of constituent behavior, then sampling may be reduced significantly during cycle II, perhaps to as low as 10 percent of the original intensity. Levels of interest for the USGS may (and very likely will) include concentrations well below regulatory concern. The intent of the repeat sampling is to verify that conditions observed in cycle I are continuing and that the constituents are not present at levels of interest. Therefore, it is appropriate to give priority in the cycle II sampling to locations where the occurrence of the constituent is most likely (early-warning system). Low concentrations may be of interest to national synthesis or local interests if, for example, study teams are attempting to understand water-quality variation along gradients.

Some examples will help illustrate the impact of the changes in emphasis between cycles I and II. In the Upper Snake River Basin, during cycle I, 200 ground-water samples were collected and analyzed for 87 VOC's. Only one compound was detected in one sample. The results of this sampling effort were not unexpected because few sources of VOC's exist in the study area. So long as no new sources of VOC's are introduced into the study area, it is appropriate to significantly reduce the level of effort for VOC's in cycle II. The exact level of sampling should be established during development of the workplan for the second cycle.

During cycle I of the Upper Colorado study unit's work, 95 samples were collected from wells and analyzed for pesticides or pesticide-degradation products and for 87 VOC's. There were three detections of two pesticides. These three detections were only marginally above the reporting limits. There were 24 detections of 7 VOC's, all only marginally above the reporting limit. While some could argue that the USGS is interested in these very low levels of constituents, there are water-quality issues of greater importance in the basin that require an increased level of effort. Therefore, the study-unit team can plan to direct significantly less effort toward pesticides and VOC's during cycle II. Justification for reduced sampling should be fully explained in the workplan for cycle II.

In a different situation, pesticides were observed in lower concentrations in shallow ground water in the ACFB than were anticipated in light of the level of pesticides used in the basin. These findings have not yet been sufficiently explained; therefore, even though only minor amounts of pesticides were detected during cycle I, reducing sampling to 10 percent of the previously sampled wells would not be appropriate. While reduced sampling is justified in this example, explaining the findings from the occurrence and distribution surveys in cycle I would require resampling more than 10 percent of those wells sampled in cycle I.

2. As few as 10 percent of the wells that were sampled in cycle I for random characterization of the resource, such as in ground-water study-unit surveys, might be resampled if that resource is either not used, not likely to be used, or does not influence a used resource. While this criterion was used, to some extent, in setting priorities for sample collection in cycle I, it will likely be used more often in cycle II. For example, during cycle I, the Long Island-New Jersey study unit could have studied ground water under the city of Newark, but chose not to sample that system because no one uses that water and the aquifer there is not hydraulically connected to aquifers that are used as drinking-water sources.

3. If sampling in cycle I indicates that analysis of a constituent in a given setting is redundant with other settings within the study unit or among other study units, sampling may be reduced to a frequency sufficient to prove that water quality has not changed between cycles I and II. For example, if VOC's were found infrequently in the Upper Snake River Basin in cycle I, the hypothesis could be tested that VOC's will probably be found infrequently in the Yellowstone. In cycle II, the experience with resampling for VOC's from the Upper Snake should guide the number and locations of sampling sites in the Yellowstone.

Many of the fixed sites sampled in cycle I in the coastal plain of New Jersey coincided with present and historical sites maintained through the Federal-State Cooperative Water Program. If there is a similarity in nutrient and major ion data between the two sampling programs, this insight should be used in designing cycle II sampling. Similar analytical results might permit the inclusion of data from the Federal-State Cooperative Water Program network into the NAWQA network and allow reduction in sample frequency and spatial distribution.

In several cases, data collected by a study unit in cycle I were consistent with and gave similar insights into water-quality conditions as did pre-NAWQA data. For example, the Hudson River study unit collected PCB data. Historically, the USGS and State agencies have sampled extensively for PCB's in the Hudson River using sampling and analytical protocols that may not have been identical to NAWQA protocols. Yet the data present the same picture of the extent of contaminated sediment in those parts of the basin where coverages overlap. In such cases, all available quality-assured data should be used in designing cycle II.

Finally, as we gain insight and understanding, that knowledge can help influence decisions for cycle II. Nearly all of the first group of study units in cycle I had an agricultural indicator basin for corn. The second group of study units in cycle I had fewer such indicator basins because of what was learned from the first group. Thus, indicator basins for other land-use types were possible.

4. For constituents that were shown to be highly correlated with stream discharge or another water-quality characteristic in cycle I, sampling frequency can be decreased in cycle II. A clear example of this issue can be seen in the high degree of correlation between major ions and flow at some of the basic fixed sites in the Upper Snake River Basin. Unless there are significant changes in atmospheric deposition or new point sources or changes in land use, a lower sampling frequency is justified in cycle II, compared with cycle I. However, sampling should always be sufficient to establish a statistically reliable relation between the variables and should continue at a frequency adequate to maintain confidence that the relation has not changed.

10. MODELING

A model is defined most simply as a representation of a real system or process. This representation can take the form of a conceptual model, a physical model, or a mathematical model. A conceptual model is a hypothesis for how a system or process operates (Konikow and Reilly, 1999). A physical model simulates a system or process directly but at a more manageable scale. A mathematical model simulates a system or process in mathematical terms that can be solved statistically, directly through analytical solutions, or numerically using computer programs. A conceptual model is necessary before physical or mathematical models can be constructed or applied.

Models can be used to predict the outcome of some stress or perturbation on the system, or they can be used to test hypotheses about the system and interplay between the various controlling processes within the system. Here the Planning Team considers a model as a conceptual and quantitative framework for understanding relations among environmental variables. Models vary in form, but all express linkages between dependent variables and independent variables. In water-quality models, these linkages are between the occurrence and distribution of water-quality constituents and other physical measures of the world in which these constituents have their source, transport, and fate.

Monitoring and modeling are two essential components in the iterative process that is the scientific method. Monitoring and modeling are synergistic; each enhances but cannot replace the other, nor can one stand alone without the other. High-quality monitoring data are essential for developing models and for using them as descriptive or predictive tools. Models in turn help refine the conceptual basis underlying the design of efficient data-collection networks. This last point is often overlooked when considering the use and benefit of models.

Current approach

Modeling within NAWQA is being pursued at different scales and to varying levels of complexity. On the national scale, statistical modeling is being explored to evaluate local processes and to extrapolate these processes across regional and national scales. Promising tools currently under development include the SPARROW and TOPMODEL models. These models employ a mix of statistical and physically based approaches. Both provide linkages among large national data sets for water-quality and basin attributes, which can be analyzed within a platform housing geographic information system tools. SPARROW performs regressions that relate instream loads to spatially referenced descriptors of pollutant sources and characteristics of land surfaces and stream channels (Smith and others, 1997). It has been used to examine phosphorus and nitrogen transport at national and regional scales. TOPMODEL is a physically based watershed model (Wolock, 1993; Beven, 1997). It performs a hydrologic mass balance function, tracking water that enters a watershed as precipitation and eventually leaves as streamflow. A recent application of TOPMODEL at the national scale (David Wolock, USGS, written commun., 1999) characterized atrazine concentration in surface water as a function of pesticide application rate and the fraction of overland flow in total streamflow.

On a local scale, surface-water and ground-water-flow models are not routinely being used by study units, but they do have some applicability. MODFLOW (McDonald and Harbaugh, 1988) and MODPATH (Pollock, 1989, 1994) are being used by the Long Island-New Jersey study unit in a three-dimensional regional flowpath study to assess water quality on a spatial scale relevant to water supply (A.L. Baehr, USGS, oral commun., 1999; P.G. Stackelberg and others, USGS, written commun., 1999). But the potential exists for a much greater use of models to help design data-collection networks and to explain observed water quality on a study-unit scale.

Limitations and strengths

The main question is to what extent should modeling be a part of NAWQA? All too often models are viewed as a product rather than a tool. The value of models is not limited to their ability to make projections or predictions. At a more basic level, modeling can be used to help design data networks within study units and to improve interpretation of observed conditions. Proper network design requires a knowledge of the flow system that is to be sampled. Source terms must be identified and quantified, and flowpaths and transport processes must be understood before an ideal monitoring network can be designed. Similarly, understanding and explaining observed water-quality conditions and trends requires that data be placed in the context of the physical flow system. Models can be very useful in understanding the location of the sampling point relative to the water-quality distribution and how it relates to land use.

There is great potential for the use of models in NAWQA to achieve the goals of explaining observed water-quality conditions, of process understanding, and of extrapolation. In this context, the role of modeling in NAWQA is threefold, reflecting three overlapping purposes, approaches, and spatial scales. First, at the national scale, modeling can define broad relations among environmental variables. Modeling at this scale is largely statistical in nature. Second, at the local or study-unit scale, models can provide the framework for understanding the interplay of physical, chemical, and biological processes that collectively determine water quality. Modeling at this scale typically is physically based, using numerical solutions for differential equations depicting current understanding of the actual processes of interest. Third, perhaps the most promising opportunities for modeling in NAWQA occur at scales that are neither fully national nor merely local. By coordinating modeling activities across groups of NAWQA study units, the program can address conceptual and parameter-estimation barriers that currently constrain the usefulness of models in water-resource management.

Recommendations

1. Throughout the NAWQA Program, there exists tremendous opportunity for expanded use of models of all kinds. From national synthesis through individual study units, NAWQA has the opportunity to use its national design to advance the science of water-quality modeling, which will enhance the utility of various modeling approaches for understanding water quality and predicting the consequences of resource-management strategies. By coordinating parallel modeling projects in multiple study units, conceptual formulation and parameter estimation can be contrasted across gradients in climate, geology, land use, and other natural and anthropogenic factors. Examples of questions that might be addressed in these parallel modeling projects include:

   - What key processes occurring in riparian buffers and in hyporheic zones control pollutant loading and instream transport and fate? Can management practices affect these processes to improve water quality?
   - How can water-quality algorithms best be incorporated into watershed models that more realistically capture the physical and spatial relations between surface and subsurface water

during storm events? What data-collection networks are necessary to support such models?

- What factors best explain variability in the mobility and persistence of pesticides and other organic compounds in ground water? Can knowledge of these factors be exploited to minimize water-quality degradation?

- What sampling design elements are most successful in characterizing nonpoint source loading of sediments, nutrients, and other pollutants? Can this characterization help to design better management practices to reduce such loading?

2. National synthesis efforts will continue to address relations between the occurrence and distribution of nutrients, metals, and organic compounds and such explanatory variables as land use, soil type, and other measures of the hydrologic setting. In cycle II of the program, regression models explaining occurrence and distribution, as well as temporal trends, will continue to evolve. Improvements in the relational capacity of the USGS data-base structure should render these forms of statistical modeling less arduous than with the current system. NAWQA will work with other agencies to better define and improve the quality of ancillary data bases. As models and data bases improve, the ability to extrapolate water-quality assessments beyond study-unit boundaries will be increased. While such statistical approaches demonstrate important relations, they do not in themselves explain water-quality processes. They do, however, help generate better hypotheses concerning cause and effect.

3. Individual study units will use both statistical and physically based models to help understand the occurrence and distribution of water-quality constituents at local scales. In addition to the tools described above, a growing suite of water-quality models is available to study-unit teams. It is expected that a greater use will be made of the MODFLOW/MODPATH modeling system in flowpath studies to better understand conservative transport of dissolved constituents in ground water and their effects on receiving waters. These tools could also be used to better delineate areas contributing water to wells, thus improving the linkage between ground-water quality and land use in recharge zones. BIOMOC and MOC–3D have potential for use in developing better understanding of the transport and fate of reactive constituents in ground water. Some study units might use TOPMODEL to better characterize variable areas contributing overland and subsurface flow during the storm events that can dominate nonpoint source pollutant loading. In such cases, opportunities may exist for incorporating variable-source, water-quality algorithms into TOPMODEL.

4. The initial focus of a study unit as it enters into a new high-intensity phase should be the identification of problems or class of problems that will be addressed by that study unit. The selection of specific models would follow naturally from the problem class identification. Therefore, it is beyond the scope of this committee to make specific recommendations of models to be used in NAWQA.

11. COMMUNICATING NAWQA FINDINGS

A fundamental and critical part of the NAWQA Program is to make data and information available to all who need it. NAWQA information has been and will continue to be valuable to a wide variety of users, from those making national environmental policy decisions to those simply interested in the environment and how their activities affect it. For example, the U.S. Department of Agriculture has benefited from NAWQA information on pesticides and nutrients. The U.S. Environmental Protection Agency has made extensive use of all information collected in the program. State and local agencies are also faced with implementing statutes or regulations, often without adequate information. The NAWQA data base has provided great benefit to these agencies as well. Still another category of users that has been keenly interested in NAWQA data is the chemical manufacturing industry that produces many of the compounds, including VOC's and pesticides, analyzed for in all study units. Obviously, information about the behavior of these compounds in the environment, produced at a national scale, is useful to them.

The involved public has found the data and interpretations beneficial in setting a benchmark for the status of the Nation's waters and in measuring the effectiveness of regulatory and management programs. NAWQA has planned an entire series of publications targeted for the involved public. Providing the information in a format that the nontechnical reader can easily assimilate and put to use is a priority of the program.

The NAWQA Program has done an exceptional job in communicating its data and interpretations to its users in a rapid fashion through highly effective reports, fact sheets, and other communication outlets. Because no single product or category of products is suitable to meet the needs of the diverse suite of users, NAWQA must produce a variety of high-quality outputs, designed to meet the needs of a wide audience. Report planning is a critical part of delivering information to those that need it, in a form they will understand, and in a timeframe that is appropriate. Even high-quality information may be of little value if not available in time for a critical decision. NAWQA products should include a wide variety of report types, including detailed journal articles, formal and informal series USGS reports, fact sheets, and posters. NAWQA data-collection and analysis protocols are also in demand, so keeping them up to date and documented is essential. In addition, there is a rapidly increasing demand for products delivered through the Internet and for other digital products such as CD-ROM's of archived data sets.

This wide variety of products and audiences presents an interesting challenge for the program. As scientists, NAWQA investigators are accustomed to writing reports for other scientists, so highly technical reports such as journal articles are routine. Yet if the intended audience for a particular product is nontechnical, describing the implications of analyses is often problematic. Investigators comfortably describe (often in detail) not only what they have done, but also the results of their analyses. The challenge for many, however, is to describe, in understandable terms, what the results mean in the context of the audience's interest. Many of the study units have done an excellent job of conveying complex information in clear, understandable ways. As we continue to learn better ways of conveying our data and findings, additional uses for that information are expected. Communication must also be viewed in its broadest sense. It is not just the written products, but also the fostering of effective relationships with these audiences through meetings, briefings, workshops, presence at public venues, and an electronic presence as well.

A special type of collaboration with other agencies that started with the pilot program of NAWQA and that has continued to the present—the liaison committee process—must be continued. The local study-unit liaison committees, composed of a broad cross section of individuals and agencies concerned about water resources, have provided extremely valuable input, insight, and review of NAWQA activities at the study-unit level. Contributions by liaison committees have included recommendations for sampling design, details of local water-quality concerns, workplan and report review, and in many cases, dissemination of study-unit products. The local connections that are provided by liaison committee members are critically important to the success of study-unit activities. At the national level, the program receives valuable advice from a national advisory council. The advisory council could provide other valuable contributions, and NAWQA should diligently pursue options for greater involvement and input to the program from the national group.

The Planning Team's recommendations for increasing future audiences in the subsequent cycles of the NAWQA Program are integrated directly into the technical recommendations for the design of the program, both for study units and national synthesis. As NAWQA's technical design generates more information on trends and cause-and-effect relationships, and the effective mechanisms for communication of this information that are already developed are applied, NAWQA will reach broader audiences. Information on cause and effects will generate intense interest from State and local water-management agencies, as well as from the research community. NAWQA should continue to have a dialogue with all audiences to understand their pressing environmental concerns and apply it to the extent allowable in the NAWQA design.

As other agencies become aware of the NAWQA findings, there will be interest in relating findings from the NAWQA Program to other State and Federal water-quality programs. Water-quality monitoring programs are generally designed to address specific questions and so have their own particular approaches, and, by necessity, assumptions. Thus, it may not always be possible to directly merge data collected by NAWQA with other water-quality monitoring programs. To the extent possible, however, NAWQA should try to coordinate the types of questions it is asking with questions that are being addressed by other water-quality monitoring programs. Coordinating approaches and questions, whenever possible, will allow both NAWQA and outside programs to cover a larger area than either would individually and will further demonstrate the usefulness of the NAWQA Program. Even in situations when it is inappropriate for NAWQA and other large monitoring efforts to directly exchange data or approaches, NAWQA's overall design will address important questions. Thus, the general NAWQA findings, if not the specific data, will be useful to outside monitoring programs and should be communicated with that broadest potential impact in mind.

12. RELATION OF NAWQA TO OTHER USGS WATER-RESOURCES PROGRAMS

A. District/NAWQA Interactions

When the NAWQA Program began full implementation of the first 20 study units, it had a profound effect on the Districts that it was operating in, as well as other water-resource programs within USGS. It brought a variety of new experiences and challenges to the Districts. Having a NAWQA study unit operating in a District or multiple Districts provided the opportunity for a 5-year project, completely focused on water quality. It also brought the opportunity for new outside contacts with agencies, new tools, new personnel, and new managerial challenges. These interactions have now been experienced in the majority of Districts.

While there are many benefits of having a NAWQA study unit operating in the District, there are also some distinct challenges, particularly for District management. The first challenge is coping with the budget cycle of the NAWQA Program. Typically, a NAWQA study unit receives $1 million for the planning year, approximately $1.6 million per year during the HIP, $1 million for the report-writing year, and $0.3 million per year during the LIP. The transition from the high-funding years to the low-funding years poses a challenge to a District because it must develop a program to support the NAWQA staff during the LIP years when budgets are low. This is most challenging in Districts with only one NAWQA project and a historically small program. In Districts with larger programs and (or) NAWQA study units in complementary cycles, the effects are dampened. The funding for study units in the NAWQA Program does fluctuate, but it is predictable. As a result, District management should be able to plan and accommodate these changes in their program. Some alternatives for managing the large changes in personnel budgets include the use of time-limited appointments or contract employees for some NAWQA positions. Development of spinoff projects for NAWQA staff during the years with low budgets can also reduce funding impacts.

The second and related challenge is how to maintain the experienced and knowledgeable NAWQA study-unit staff between HIP phases so that they will be available for the next cycle. Loss of NAWQA study-unit staff that has been trained in NAWQA study methods and approaches after the completion of the HIP phase will pose a disadvantage to both the program and the District in the next HIP phase. It is obviously desirable to keep the same technical staff in place from one cycle to the next so as to minimize retraining personnel in the study unit. Maintaining the staff will require Districts to develop funded projects for their technical staff, yet once staff have become invested in a new project or series of projects, it may become difficult for personnel to leave those projects and return to the NAWQA study-unit activities. Districts must carefully plan for these times of transition as project budgets and activities increase or decrease.

Recommendations

There is a shared responsibility between the District management and the NAWQA Program to bring about the successful implementation of the program. Clearly, there are many benefits that can accrue to Districts from having a study unit operating in the District. There are also challenges that come with the implementation of a NAWQA study unit. The Planning Team believes that several considerations would increase the ability to meet the challenges. First, familiarity with the NAWQA Program objectives and national design will benefit District managers in helping the study units. It is recommended that the NLT periodically hold a workshop for District managers to explain the current and future design of the program and what is expected of the study units within the context of national/regional synthesis. This could greatly raise the awareness of District managers to NAWQA issues and help them in decision making for study-unit designs. An opportune time to hold these workshops would be at the beginning of each HIP period.

Success of the NAWQA Program is a management issue and must remain a joint effort of both District and NAWQA management. The District responsibility is to be actively involved in the management of the study. In this regard, District management should treat the NAWQA study unit in the same fashion that it would any other large study within the District. Management should also treat the NLT like it would any other large cooperator. This means being involved in the negotiations of project workplan and design, familiarity with the environmental issues involved, and responsiveness to requests for assistance. In particular, it is suggested that senior District managers participate when possible in the workplan conference calls to help set the priorities for the year's work. District management should actively plan for future projects through a concerted effort of program development. Spinoffs are not the sole responsibility of the study-unit staff. Finally, Districts must proactively plan for the low-funded period of the NAWQA study unit. Planning for placement of study-unit staff during the LIP must take place during the HIP.

B. Research and Cycle II of NAWQA

A successful NAWQA must include a research component that continually develops knowledge and methods useful to the program. Direct linkages with internal water-resources research, primarily conducted by the NRP, has had advantages for NAWQA. Out of this long-term research program came the concept of NAWQA itself; protocols, such as the protocol for determining contaminants in tissues; specific, widely used modern methodologies, such as novel methods for the age dating of ground water and new uses of isotopes; minor modifications of methods, such as sieving sediments for metal analysis; and, more recently, research data used to overcome obstacles hindering the development of the central biological laboratory.

The research and development needs of NAWQA include immediate needs and longer term needs for tools, methods, and knowledge of how to approach some of the most complex problems in hydrology. An example of an immediate need of NAWQA is methods for field extraction of organic chemicals. Immediate needs can change from year to year, as new, immediate problems arise and the old ones are forgotten (although not necessarily solved). In cycle I, the narrow and immediate development needs of NAWQA were met with ad hoc designation of funding. These funds are also important to NAWQA and other water-resources programs in sustaining a long-term attack on the more recalcitrant problems in hydrology, especially as they relate to water-quality assessment. The difficulty of achieving real solutions to water-quality assessment problems is often underappreciated. Many solutions must evolve from broad, careful, systematic, and sometimes long-term research efforts. Solutions also can come unpredictably from unexpected directions, so interaction with a broad hydrologic research program is an asset. The need to understand how or if base flow in streams is an integrating measure for ground-water quality is an example of a long-term research need. Immediate needs and long-term needs also can be interrelated. In fact, NAWQA's immediate needs for tools and knowledge are many, and some are not even overtly recognized until the crucial advance is made. Thus, any of a wide variety of advances in scientific understanding that result from conducting long-term research can result in a better NAWQA. In cycle I, 10 percent of program funds were designated to the NRP to work on long-term research for NAWQA. It is expected that the partnership and the 10-percent investment in long-term research will continue through the second cycle of NAWQA.

The need for research and interaction with researchers will be even more important in cycle II than it was in cycle I, as NAWQA becomes more explanatory. The evolution of NAWQA toward understanding-based studies will better match the approach of researchers, so some types of direct interaction with researchers may develop more easily than in the past. In cycle II, however, it is important that NAWQA be better tied to research and research be better tied to NAWQA. This does not mean that research should focus solely on NAWQA's immediate or transient needs. There is also a need to sustain the valuable and unexpected findings that come from long-term, investigator-driven research.

With the goal of optimizing the relationship between NAWQA and researchers, the Planning Team suggests the following strategies for improving collaboration between researchers and NAWQA. These strategies emphasize the need for each program to see the other as a valuable resource:

1. A set of relevant questions is needed to bring research capabilities to NAWQA's long-term needs. Such questions might allow researchers to optimally identify where their work fits into NAWQA needs and to direct their expertise appropriately. It is proposed

that USGS water-resources research community develop a small set of broad questions that researchers feel would be relevant to NAWQA and that would fit within the capabilities of internal research. Development of questions and hypotheses by NAWQA personnel, via NAWQA leadership, is also encouraged. Specifically, the Planning Team suggests that a future Research Committee meeting could develop 10 (or some limited number of) broad, long-term areas of study that researchers feel would be of value to NAWQA over the next 2 decades. Examples of relevant questions and areas of study at the scale appropriate to both NAWQA and researchers include:

- Are human activities gradually contaminating progressively older ground water?
- Where and how does ground water influence surface-water quality? Where and when can surface-water base-flow information be useful in resolving the complicated problem of assessing trends in ground-water quality? Study of geochemical, physical, biogeochemical, and biological interactions in the hyporheic zone is an example of an area of need.
- Can changes in water quality and its receptors along land-use gradients be used to explain water-quality observations and to understand or predict trends? A better understanding of such gradients at the study-unit and larger scales is needed. Approaches to define them and to experiment with them at these scales must be developed.
- What tools and approaches are needed to describe and understand ground-water processes at the watershed scale?
- Developments that continue to improve the user friendliness of advanced surface-water and ground-water models will be of great importance to NAWQA because it is expected that models will find a growing number of uses in NAWQA in the second cycle.
- The fate and effects of contaminants in surface waters can best be understood at large scales by interdisciplinary studies that link knowledge of sources, hydrobiogeochemical processes, and receptors. Knowledge of such linkages or how to develop understanding of those linkages is needed.
- In general, researchers are encouraged to develop agendas that focus on issues of scale in watershed processes. Quantification of watershed properties and processes at large scales is challenging. Understanding appropriate spatial and temporal scales for averaging watershed attributes and techniques for linking and interpreting these averaged values remain elusive. By applying such tools as SPARROW and TOPMODEL (perhaps within the Modular Modeling System) at nested scales in space and time, partnerships between researchers and NAWQA may advance fundamental watershed science, as well as the goals of the NAWQA Program.

2. An ongoing communication link is needed between NAWQA study units and researchers. Regularly scheduled workshops (analogous to the mercury or nitrogen cycling workshops held in the past) can be convened to bring together NAWQA projects and the internal research community into a discussion over a well-defined question relevant to NAWQA. These workshops could be centered on one or more of the NAWQA-relevant questions stated above or on proposals for new research questions relevant to NAWQA. It would be optimal if individual workshops were not overly large, but enough smaller workshops were held with sufficient frequency to result in participation by a large proportion of interested personnel over several years. Incentives should be developed to encourage proposals for, and organization of, workshops from the bottom up. Lectureships are also proposed to spread information from researchers to NAWQA and from NAWQA to researchers. Within the management organization, research advisors and discipline specialists might be asked to develop linkages with NAWQA synthesis for the purposes of recognizing possibilities for interaction.

3. Traditional process-oriented research at smaller spatial scales could be performed by researchers within NAWQA study units, perhaps at or near intensive fixed sites. NAWQA would benefit by better understanding local processes affecting water quality, and NRP researchers would profit by being able to place their observations within a larger hydrologic context. Direct collaborative efforts between researchers and NAWQA

personnel were uncommon in the field and in report collaboration in cycle I. In developing a protocol to increase such interaction, NAWQA might study the relationship between researchers and the Toxic Substances Hydrology (Toxics) Program. Two ingredients of that program have been especially successful. First, from the program's inception, District and NRP researchers have made efforts to work together at study sites, sharing field and interpretive activities and coauthoring reports. Special studies in NAWQA study units might employ this strategy. Secondly, Toxics projects have a sustained level of funding, which may last for many years. Sustained interaction between researchers and NAWQA LIP activities might be the best way to facilitate continuing interactions.

4. More formal relationships among NRP research advisors and National Synthesis Teams should be explored. The former could help articulate the major questions that will dominate national synthesis and study-unit network design in each decadal cycle. Incentives should also be established that encourage researchers to periodically work on specific reviews or syntheses within their areas of expertise as an alternative to hiring permanent synthesis personnel.

5. An increased emphasis on explanatory components and emerging issues in large-scale watershed processes provides ample opportunities for research-oriented work within NAWQA. This trend may provide increased incentive for NAWQA personnel to become more involved in the Research Grade Evaluation (RGE) program. More RGE personnel on NAWQA study-unit staffs should increase technical exchanges with NRP.

6. The Planning Team recognizes that these are not revolutionary ideas and that technology transfer is a long-standing challenge. Two common hurdles to technology transfer are knowing what to do (i.e., communication at project chief level or lower) and providing the funding to do it. Both problems, but especially the first, might be improved if research for NAWQA is viewed with the same long-term, persistent perspective as the assessment program itself. Researchers and NAWQA need to identify some big, recalcitrant challenges for water-quality assessment and find ways to talk about those challenges. Discussions of how those challenges can be translated into studies and programs at the level of the scientists hold the ultimate promise for this interaction.

C. Streamgaging

From the outset of planning for the NAWQA Program, in the mid 1980's, NAWQA was never intended to be a stand-alone program separated from other major programs. Instead, the early architects of NAWQA designed the program to take full advantage of existing USGS activities, such as the streamgaging program. Rather than NAWQA fully funding the collection of streamflow data at the basic fixed site sampling network, whenever and wherever possible, those sites were to be colocated with existing gaging stations. During the first cycle, as many basic fixed sites as possible were located at existing gaging stations. In some study units, most or all of the basic fixed sites were at existing gages, while in other study units, many to most sampling sites required the construction plus operation and maintenance of gaging stations. On average, about half the basic fixed sites are at existing gages, while the other half are necessarily supported by NAWQA. The program should continue to use existing infrastructure as much as possible to ensure that NAWQA resources are used as effectively as possible.

D. National Stream Quality Accounting Network

The National Stream Quality Accounting Network (NASQAN) complements NAWQA by adding consistent measurements of concentrations and transport of a broad range of constituents (similar to those measured by NAWQA) on the main stem of large rivers downstream from NAWQA study units. These data will be used to verify regional inferences about water quality developed from NAWQA studies. For example, relations between chemical flux and land use developed from NAWQA investigations will be used to estimate fluxes in large rivers where direct measurements will be made by NASQAN. The degree of agreement between estimates (NAWQA) and observations (NASQAN) in the large rivers will be an important indication of how confidently NAWQA study-unit findings can be extended to regional water-quality issues. NAWQA will complement NASQAN by providing a cause-and-effect basis for interpreting water-quality conditions and trends in the largest rivers. Within the very large NASQAN basins, NAWQA study units will serve as intensively studied examples of cause-and-effect relations in key regional settings. At the

NASQAN scale, NAWQA study units will serve as "indicator sites."

E. Ground-Water Resources

The Ground-Water Resources Program (GWRP) conducts issue-based regional ground-water assessments. Current topics include saltwater intrusion along the Atlantic coast and the interaction of surface water and ground water in the Southwestern United States. The GWRP and NAWQA should coordinate their efforts to take maximum advantage of each other's resources. The choice of focal issues for the GWRP should reflect the potential availability of information from the NAWQA Program. The GWRP should participate in the development of ground-water aspects of the unified plan for NAWQA national synthesis. NAWQA, in turn, should view GWRP as a resource for the regional synthesis of information on processes affecting key aspects of ground-water quality.

F. National Trends Network

Several study units have made use of data from the National Trends Network (NTN), which is part of the National Atmospheric Deposition Program, and rely heavily on those data for computing atmospheric loadings of a variety of chemical constituents. An early study-unit activity should be an attempt to develop a nutrient budget for the study unit to help better understand some of the major factors that affect nutrient concentrations, loads, and transport. Often, one of the largest single inputs of nutrients to a study unit is from atmospheric deposition. Thus, the connection to the NTN is and will remain an important one for NAWQA. A small but growing subset of the NTN, currently about 30 sites nationwide, is being sampled for mercury. Data from this suite of sampling stations should provide useful information to study units as they analyze water-column and bottom-sediment concentrations of mercury. Atmospheric sources of mercury could be a significant input to study units.

G. Toxic Substances Hydrology Program

The Toxic Substances Hydrology (Toxics) Program conducts research and methods development focused on understanding processes controlling transport and transformation of various contaminants in surface- and ground-water systems. The Toxics Program typically conducts studies at a much smaller spatial scale than NAWQA. Unlike NAWQA, these investigations can continue in a high-intensity mode for several years. But when they are concluded, there is no expectation of a return visit. The Toxics Program has developed sampling methods and process understanding that are used by NAWQA and other USGS programs. Findings from the Toxics Program will be particularly important for cycle II of NAWQA as it increases emphasis on explaining water-quality conditions. In turn, NAWQA can identify pervasive water-quality problems that need additional understanding at the scale appropriate for the Toxics Program. The Planning Team recommends that program managers for NAWQA and Toxics continue to work together to identify productive interactions between the two programs.

13. MANAGEMENT STRUCTURE

The present senior-level management structure for NAWQA is the NLT. The NLT has six members: the Assistant Chief Hydrologist for NAWQA, the National Synthesis Coordinator, and an Assistant Regional Hydrologist for NAWQA (ARH/N) in each of the WRD regional offices. The Assistant Chief Hydrologist for NAWQA is responsible for directing the entire program, including study-unit operations and regional and national synthesis. The Assistant Chief Hydrologist for NAWQA is supported directly by a staff of about 10. The National Synthesis Coordinator is responsible for the direction of the national synthesis activities, is supported by National Synthesis Teams, and coordinates interaction among study units and the national synthesis efforts. The ARH/N's are responsible for directing the NAWQA study units within their respective Region and for coordinating those study-unit efforts with the national office, the National Synthesis Teams, and other study units.

The present management structure of the program is simple, understandable, and modest, considering the size of the program. Representatives of the NAWQA Program at all levels were interviewed by the Planning Team. They indicated that the management structure works effectively. The NLT deals with all major management issues of the program and has dealt with a large number of operational and policy issues in the nearly 8-year history of the operational part of the program. Many of these decisions involved significantly "rescoping" the program in response to shrinking budgets and lack of inflationary adjustments during that period. The NLT has managed the program effectively through these difficulties.

As discussed earlier, as the NAWQA Program shifts its focus toward explanation of causative factors affecting water quality, the national synthesis design and organization of the National Synthesis Teams should change to meet the new demands and evolving focus of the program. Such an evolution is a natural and expected change in the program. Other than this, the Planning Team found no reason to suggest a change in the program's overall management structure. The current structure works well, is managing the program effectively, and is guiding the program to achieve its goals.

14. REFERENCES

Ad Hoc Committee, 1985, Final report of the Ad Hoc Committee on principles of water-quality data acquisition and utilization: U.S. Geological Survey Report of the Committee, July 19, 1985.

Alley, W.M., 1993, Ground-water-quality surveys, *in* Alley, W.M., ed., Regional ground-water quality: New York, NY, Van Nostrand Reinhold, p. 63–85.

Bevin, K.J., 1997, TOPMODEL—a critique: Hydrologic Processes, v. 32, p. 1069–1086.

Carter, J.L., Fend, S.V., and Kennelly, S.S., 1996, The relationship among three habitat scales and stream benthic invertebrate community structure: Freshwater Biology, v. 35, p. 109–124.

Crawford, J.K., and Luoma, S.N., 1992, Guidelines for studies of contaminants in biological tissues for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 92–492, 69 p.

Cuffney, T.F., Meador, M.R., Porter, S.D., and Gurtz, M.E., 1997, Distribution of fish, benthic invertebrate, and algal communities in relation to physical and chemical conditions, Yakima River Basin, Washington, 1990: U.S. Geological Survey Water-Resources Investigations Report 96–4280, 94 p.

Fend, S.V., and Carter, J.L., 1995, The relationship of habitat characteristics to the distribution of Chironomidae (Diptera) as measured by pupal exuviae collections in a large river system: Journal Freshwater Ecology, v. 10, p. 343–359.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Goldstein, R.M., 1995, Aquatic communities and contaminants in fish from streams of the Red River of the North Basin, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 95–4047, 34 p.

Guegan, J.F., Lek, S., and Oberdorff, T., 1998, Energy availability and habitat heterogeneity predict global riverine fish diversity: Nature, v. 391, p. 382–384.

Gurtz, M.E., 1994, Design of biological components of National Water-Quality Assessment (NAWQA) Program, *in* Loeb, S.L., and Spacie, A., eds., Biological monitoring of freshwater ecosystems: Boca Raton, Fla., Lewis Publishers, p. 323–354.

Hayden, B.P., Ellison, A.M., Oehlert, G.W., and Esterby, S.R., 1997, Ecological resources monitoring: Change and Trend Detection Workshop Report, Bulletin of the Ecological Society of America, January 1997, p. 11–14.

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Kolpin, D.W., Barbash, J.E., and Gilliom, R.J., 1998, Occurrence of pesticides in shallow groundwater of the United States—Initial results from the National Water-Quality Assessment Program: Environmental Science and Technology, v. 32, p. 558–566.

Konikow, L.F., and Reilly, T.E., 1999, Groundwater modeling, *in* Delleur, J.W., The Handbook of Groundwater Engineering, chap. 20: Boca Raton, Fla., CRC Press, p. 20–21.

Luoma, S.N., Hsieh, P.A., Betancourt, J.L., Cayan, Daniel, Hill, M.C., Robertson, D.M., Vecchia, A.V., Wagner, B.J., and Helsel, D.R., 1994, Guidelines for determination of water quality trends in the National Water-Quality Assessment Program, unpub. report.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

McMahon, P.B., and Bohlke, J.K., 1996, Denitrification and mixing in stream-aquifer system—Effects on nitrate loading to surface water: Journal of Hydrology, v. 186, p. 105–128.

Modica, E., Buxton, H.T., and Plummer, L.N., 1998, Evaluating the source area and residence times of ground-water seepage to streams, New Jersey Coastal Plain, Water Resources Research, v. 34, p. 2797–2810.

Modica, Edward, 1999, Sources and age of ground-water seepage to streams: U.S. Geological Survey Fact Sheet FS–063–99, 4 p.

Nolan, B.T., Ruddy, B.C., Hitt, K.J., and Helsel, D.R., 1997, Risk of nitrate in the groundwaters of the United States—A national perspective: Environmental Science and Technology, v. 31, p. 2229–2236.

Pollock, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 89–381, 188 p.

——— 1994, User's guide for MODPATH/MODPATH-PLOT, version 3—A particle tracking postprocessing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 94–464.

Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of ground-water-quality sampling network: U.S. Geological Survey Water-Resources Investigations Report 90–4101, 109 p.

Smith, R.A., Schwarz, G.E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data: Water Resources Research, v. 33, p. 2781–2798.

Stoner, J.D., Cowdery, T.K., and Puckett, L.J., 1997, Ground water age dating and other tools to assess land-use effects on water quality: U.S. Geological Survey Water-Resources Investigations Report 97–4150, 6 p.

Tate, C.M., and Heiny, J.S., 1995, The ordination of benthic invertebrate communities in the South Platte River Basin in relation to environmental factors: Freshwater Biology, v. 33, p. 439–454.

Tesoriero, A.J., and Voss, F.D., 1997, Predicting the probability of elevated nitrate concentrations in the Puget Sound Basin—Implications for aquifer susceptibility and vulnerability: Ground Water, v. 35, no. 6, p. 1129–1139.

Wall, G.R., Phillips, P.J., and Riva-Murray, K., 1998, Seasonal and spatial patterns of nitrate and silica concentrations in Canajoharie Creek: New York, Journal of Environmental Quality, v. 27, p. 381–389.

Wolock, D.M., 1993, Simulating the variable-source-area concept of streamflow generation with the watershed model TOPMODEL: U.S. Geological Survey Water-Resources Investigations Report 93–4124, 33 p.

Zogorski, J.S., Morduchowitz, A.M., Baehr, A.L., Bauman, B.J., Conrad, D.L., Drew, R.T., Korte, N.E., Lapham, W.W., Pankow, J.F., and Washington, E.R., 1996, Fuel oxygenates and water quality—Current understanding of sources, occurrence in natural waters, environmental behavior, fate, and significance—Final report: Office of Science and Technology Policy, Executive Office of the President, 37 p. with attachments.

Appendix 1. Charter of NAWQA Planning Committee

A. Establishment

It is the goal of the USGS to provide long-term, nationally consistent data and information on water quality through the National Water-Quality Assessment (NAWQA) Program. In support of this goal, this document establishes a NAWQA Program Planning Committee (henceforth called the Planning Committee) and sets forth the purpose, scope, process, composition, and tenure for this committee.

B. Introduction

The NAWQA Program began as a pilot program in 1986, and transitioned to full implementation from 1991 to 1996. NAWQA is now starting its second decade of operation. An operational plan was developed in 1990 (Circular 1021) and has been followed rather closely until 1995, when a shortfall in program funding increases required NAWQA to be scaled back from the 20 study units begun in 1994 to 15 study units. Given that major change in implementation of the operational plan, some additional minor changes, and the need for NAWQA to evolve and remain relevant, there presently is a need for program planning and review.

C. Purpose

The Planning Committee will be responsible for review of the NAWQA Program for determining accomplishments to date toward NAWQA goals and for strategic planning so that the program can meet future national water-quality information needs. After about 10 years of experience, now is an ideal time to review NAWQA accomplishments and to make any necessary adjustments for the next 5 to 10 years.

D. Scope

The Planning Committee will be responsible for reviewing NAWQA Program execution and planning for adjustments to NAWQA. In this case, program planning should be strategic and address three major areas: (1) Review and evaluate how well the program has met stated goals and has effectively implemented and balanced program elements; (2) recommend near-term (1–3 year) adjustments to program elements that will maximize the amount and relevance of water-quality knowledge produced by NAWQA; and (3) strategize longer term (5–10 year) development and directional adjustments to NAWQA that will position the program well to meet future water-quality information needs. Addressing all three areas requires a substantial effort, but without the evaluation and planning effort, NAWQA risks becoming less effective and relevant over the next decade.

Topics of interest to the NAWQA Program for the Planning Committee to consider cover a broad range of issues. Arranged in priority order they are:

1. Plan for downward budget scenarios, or level funding with inflation.
2. Address overall program goals to achieve balance among: occurrence and distribution, trends, and explanation elements of the program.
3. Identify appropriate number, distribution, and selection criteria for study units.
4. Address ancillary data and data-base management needs.
5. Review rotational scheme for study units.
6. Balance study-unit components, fixed sites and synoptic sites, ground water and surface water, etc.
7. Determine relationship of NAWQA to other WRD programs: Fed/State Coop, critical aquifers, NASQAN-II, and Toxics.
8. Evaluate report products to determine whether there is an adequate scientific foundation for planned reports.
9. Determine what policy issues NAWQA can or should influence.
10. Determine how NAWQA should extrapolate results from study units to the rest of the United States.
11. Determine whether all study units should be studied equally, with the same level of resources.
12. Determine balance between physical hydrology, chemistry, and biology; identify what information should be supplied on ecology,
13. Identify options for low-intensity phase sampling.

14. Identify the content of periodic national summaries.
15. Determine how a rotation through synthesis topics should be done.
16. Identify the research that should support NAWQA.
17. Determine whether there are additional analytical needs for NAWQA.
18. Evaluate regional synoptic surveys—how, when, and what.
19. Review the NAWQA management structure.
20. Address outreach needs and approaches used by NAWQA.
21. Determine the role of modeling in NAWQA.
22. Address staffing issues for high-intensity phase, low-intensity phase, grouping of study units, and cycling of units.
23. Determine whether the program must include lakes, reservoirs, and estuaries.
24. Determine appropriate partnerships with other agencies, nongovernmental organizations, and industry.

E. Planning Process

In addition to the three areas addressed by the Planning Committee, there are four elements to the planning process: (1) structure of the planning process with various committees or work groups guided by the Planning Committee, (2) timing for the review and planning, (3) authority of the Planning Committee and its relation to the NAWQA Leadership Team (NLT), and (4) products from the planning process.

Structure: To accomplish the evaluation and planning process, this charter establishes the Planning Committee, which will have about eight members from outside the NAWQA Program. Members are therefore not encumbered or biased by ongoing management or historical operational decisions. For connection to NAWQA management, the Planning Committee will have an ex officio member from the NLT. Because the responsibility for strategic planning covers a wide scope for NAWQA, the Planning Committee will oversee review/evaluation/planning activities of various work groups that the Planning Committee establishes to accomplish tasks with appropriate expertise. The ex officio member will work with the Planning Committee to ensure that planning activities can be accommodated within the NAWQA budget.

Timing: Beginning in fiscal year (FY) 1997, the Planning Committee will convene to initiate the planning process at the call of the Committee Chair and the Chief of NAWQA. Because of the scope of work, it is anticipated the planning process will require about 2 years. Thus, although adjustments (implementations of recommendations) may occur over the 2 years of planning, most major adjustments to NAWQA that may be needed will probably occur in the beginning of FY 1999, thus, about one decade after full implementation of NAWQA began.

Authority: This strategic-planning process is crucial to the continuing and future success of NAWQA. As a result, the Planning Committee has authority to review and change the NAWQA Program to ensure that NAWQA remains at the forefront of objective water-quality assessment in the Nation. There are two additional aspects of authority and responsibility to consider. First, it is the responsibility of both the Planning Committee and the NLT to develop an implementation plan for NAWQA Program changes. Second, the NLT has responsibility for NAWQA management and is thus charged with implementation of any planned program changes or adjustments.

Products: The Planning Committee will produce various products including committee minutes and agenda. Primarily, however, the principal product of the Planning Committee will be one or more peer-reviewed reports that document the results of their reviews and recommendations. Publication of official documents is intended to update the literature that identifies goals and implementation of the NAWQA Program, e.g., Circular 1021. Such documents will serve as a basis for future program management.

F. Composition

The Planning Committee shall be about six to eight members who represent the major disciplines and organizational units of the WRD. Members may be selected from the following representations: (1) National Research Program, ecologist; (2) Headquarters Hydrologist, generalist; (3) Other Federal Agency, NAWQA product user; (4) Regional Office, chemist or modeler; (5) 1991 Study-Unit Chief, Surface-Water Specialist; (6) District Chief, State program management;

(7) Ground-Water Specialist; and (8) an ex officio member from the NLT, Surface-Water Specialist. The Planning Committee will be chaired by the Headquarters generalist, who also is responsible for Division program planning as a member of the Bureau Program Council.

G. Tenure

The Planning Committee is established and the members serve at the discretion of the NAWQA Chief. The tenure of the committee is expected to be about 2 years unless modified by the NAWQA Chief.

Appendix 2. Analysis of Options Considered and Rejected for the Number of Study Units and Their Rotation

1. CURRENT APPROACH

- Maintain 59 study units or equivalent spatial coverage.
- 3-year HIP.
- 1 year of ramp up and 2 years of report writing.
- 6-year LIP.

On the basis of national coverage and sound scientific design, this would be the preferred option. However, earlier budget shortfalls have cut into the program; NAWQA will be unable to make up most of the effects of those shortfalls. As described elsewhere in this report, it is unlikely that the program will be able to revisit all 20 of the 1991 study units; there are 3 study units where activity has been postponed indefinitely; and 6 study units have already been consolidated into the High Plains regional aquifer study. For every year that inflation is not compensated, another study unit is lost. Maintaining the status quo in the number of study units and rotation period makes a shift toward more explanatory studies unlikely because of budget constraints. NAWQA could become a program with descriptive evaluations of study units, a few special studies, important local stories, and compilations of data for national synthesis. NAWQA could eventually have trouble maintaining a national program of significance under this option if there are years when budget increases do not fully compensate for inflation. The result will be increasingly difficult ad hoc decision making and breakdown of the structure that has guided the NLT in past years.

2. INCREASE ROTATION PERIOD

- 52 study units.
- 4 groups of 13 study units.
- 3-year HIP.
- 1 year of ramp up and 2 years of report writing.
- 9-year LIP.
- First repeat is complicated.

This option improves the budgetary challenges faced by NAWQA, but this still means NAWQA must eliminate seven study units. It was rejected primarily because the budget projections showed that the savings obtained via changing rotation alone are limited. Because of the cost of retaining an extended LIP, this option does not achieve as much budgetary flexibility as the recommended option. There are also important tradeoffs in analysis of trends and in the "presence" NAWQA brings to a study unit during HIP. Under this option, NAWQA sustains spatial coverage in the central part of the country at a cost of less temporal coverage and less frequent local presence nationwide.

Limitations and strengths

Advantages of this option are that it sustains a maximum level of activity in study units and that it sustains maximum coverage.

In addition to the inadequate budgetary flexibility, the primary limitations of this option are:

- There would be a loss of statistical power to detect trends in spatially intense data collected during HIP because of the reduced frequency of HIP sampling on each individual study unit.
- Relating causes to observed trends will also be more difficult because the program will return to intensive cycles less frequently.
- This option would slow the rate at which synthesis accumulates data, although ultimately, more data would be available than under greater consolidation scenarios. This would mean that there will be less opportunity for cycling synthesis projects.
- An important disadvantage is a possible loss of impact on local issues. NAWQA will less frequently have the right people in the right place at the right time, because fewer study units are in HIP at any given time. Local spinoff projects will be harder to develop because a given study unit only spends one-quarter of its time in high mode of discovery instead of one-third of its time.

- Similarly, this option could result in fewer reports per unit time and it will be less likely that experts will stay around in study units. It will be more common that new investigators will have to reinitiate a study unit in a new cycle. This will inhibit the buildup of local expertise that was an important subliminal goal of NAWQA.

- NAWQA will become more of an LIP-dependent assessment program.

- This option could result in perception of need for more regional synoptics to help bridge time gaps. However, the Planning Committee does not believe that regional synoptics without the continued temporal and spatial coverage of LIP and HIP will provide the explanatory information of the original design or of the recommended option.

3. **HYBRID OPTIONS** (surface-water only, ground-water only, and data-only study units)
   - 60 study units (3 groups of 20 study units with 4 categories of effort).
   - 8 study units with full activity.
   - 4 study units, surface water only.
   - 4 study units, ground water only.
   - 4 study units, data only (data collection to support national synthesis and LIP).

For each cohort of 20 study units, this option has 8 that would maintain full activities (similar to cycle I); 4 that study only surface-water problems; 4 that study only ground-water problems; and 4 that are relegated to basic data collection only. It was assumed that the LIP is maintained as planned in all study units. This option was rejected because budget analysis showed that reducing activities in study units does not save nearly as much money as reducing the number of study units. The budgetary savings from this option were inadequate. NAWQA cannot cut activities alone and reach its goals. This option also institutionalizes a separation of surface water and ground water that is not desirable in modern hydrology.

Limitations and strengths

- This option does not result in as much savings as other strategies.

- A strong trend design is retained, but trend value gained from successive HIP-to-HIP is lost to some degree in the data-only study units.

- This design shifts resources in relative terms to trends and LIP.

- Overall, NAWQA could become more of a data-collection, trend-related program, with pockets of greater explanation.

- This option will sacrifice expanded understanding of unused resource and unsampled areas.

- This option will shift overall resources in relative terms to ground-water resources from surface-water resources. Ecological integration will be restricted to less than the full complement of study units.

- This option can claim credit for greater than five-sixths of the coverage originally proposed; however, in reality, there will be some loss of activity in greater than 20 percent of the area, and explanatory opportunities will be lost in greater than 20 percent of the total area.

- A full set of synthesis data will be achieved in this option, but Synthesis Teams will get less feedback and knowledge from some project teams. This option aids traditional data analysis but could reduce synthesis of principles.

- It could be difficult to find 24 data study units in which less-than-complete studies are appropriate. It is easier to eliminate some study units and to consolidate others while retaining full activities, compared with cutting activities in a larger number of study units to data only (12) and focused activities (12).

- Qualified staff could be lost to Districts that house data-only and focused study units. This option could also result in loss of local connections and spinoff opportunities in the data-only study units.

NAWQA Planning Team / Recommendations for Cycle II of National Water-Quality Assessment (NAWQA) Program / Open-File Report 99–470

150
U.S. Department of the Interior
1849•1999

Printed on recycled paper