CONCEPTUAL DESIGN OF THE SURFACE WATER COMPONENT OF THE NATIONAL WATER QUALITY ASSESSMENT (NAWQA) PROGRAM

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ABSTRACT

The U.S. Geological Survey started, in a pilot phase, a program to provide nationally consistant information on the status and trends in the quality of the Nation's fresh water and to identify and describe the relationships between both the status and trends in water quality as they relate to natural factors and the history of land-use and land- and waste-management practices. The program is organized into hydrologically based study units and, for the study of surface water, involves a combination of fixed-station, synoptic and intensive study approaches.

INTRODUCTION

In 1986 the U.S. Geological Survey started a pilot National Water Quality Assessment (NAWQA) program to test, and modify as needed, an approach to assessing the quality of the Nation's freshwater resources. More specifically, the goals of the full scale program are to (1) Provide nationally consistent descriptions of the current status of water quality in a large, diverse, and geographically distributed portion of the Nation's water resources. (2) Where possible, define the trends in water quality which have occurred over recent decades and provide a baseline for evaluating future trends in water quality. (3) Identify and describe the relationships of both the status and the trends in water quality to the relevant natural factors and the history of land-use and land- and waste-management practices. This will provide information which is useful for examining the likely consequences of future changes in land-use or land- and waste-management practices.

The pilot phase is being undertaken in seven study units - four emphasizing surface water and three emphasizing ground water. The boundaries of these units are based on hydrologic units (drainage basins and aquifer systems). This paper will focus on the approaches for surface water only, although some of the principles suggested here will apply to ground water as well. The four pilot study units for surface water are the Yakima River basin in Washington, the Kansas and Blue River basins in Kansas and Nebraska, the Upper Illinois River basin in Wisconsin, Illinois and Indiana and the Kentucky River basin in Kentucky.

The approach of the NAWQA Program is to make maximum use of existing data to (1) provide, to the extent possible, a description of existing and past trends in water-quality conditions and (2) develop conceptual models which relate the observed conditions (concentrations and transport of substances, and biological conditions) to the sources and causes, both natural and human- controlled. New data will be collected to:

(1) verify the description of water-quality conditions obtained from the historical data,

(2) track long-term trends in water quality,

(3) reduce the uncertainty of the description of conditions by intensifying temporal or spatial sampling densities, and

(4) improve the understanding of the linkages between the causative factors and water quality, using statistical methods and analysis of physical, chemical, and biological processes.

GENERAL APPROACH

The problem of organizing an effort to acquire data, interpret them, and assess the Nation's water quality is formidable because of the very large area involved, the high cost of field work and laboratory analysis (especially for trace organics), the large number of water-quality variables of concern, and the high degree of spatial and temporal variability of water quality. To make the problem tractable, certain strategic choices have been made in designing the proposed

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National Water Quality Assessment Program. The following design concepts apply to a full-scale program as it is presently envisioned by the Geological Survey. No decision has been made to proceed beyond the present pilot phase to a full-scale program.

The first choice involves the extent of the water resource to be examined. A feasible and acceptable study design can be achieved by limiting the assessment to water resources which are perennial and of sufficient size to have been mapped (known aquifer boundaries for ground water, inclusion in the EPA River Reach File for surface water), and for which the natural water quality is adequate to support most uses typical of the area. Because of cost, the locations for sampling must be chosen in a way which serves a variety of purposes. These purposes include maximizing the statistical information content of the data as well as providing a causal understanding of processes and mass balances, including descriptions of the sources and sinks of contaminants. The study design chosen to accomplish this is the clustering of activity in study units, rather than distributing the effort evenly over the entire Nation.

For the program to be truly national in scope, the complete set of study units selected must account for a substantial majority of the Nation's water use and encompass a wide variety of the broad categories of water-resource environments of the Nation. For surface water, these study units would typically be the hydrologic subregions (watershed units defined by the USGS of which 222 comprise the entire Nation). The program would focus on about 90 of these units, selected to account in aggregate for more than 80 percent of the surface-water withdrawals in the Nation but only about 40 percent of the land area.

The implementation of the program would be at the USGS Water Resources Division District level. (USGS Districts are coincident with a single State or small cluster of States.) Teams of District scientists conducting the studies would interact during the planning, execution, and report-writing phases with officials of the relevant Federal, State, interstate, and local agencies concerned with the study unit. The purposes of these interactions would be to identify areas of mutual interest, find ways for the USGS study to serve the needs of those agencies, and find ways by which the existing data and studies of those agencies can be used in the USGS investigation. The role of the USGS Water Resources Division regional and headquarters staffs would be to coordinate the efforts in the study units, provide specialized technical expertise for the guidance and training of the field staff to assure the national uniformity of methods and results, and provide liaison between the program and the headquarters of other relevant Federal agencies.

For each study unit a liaison committee would be formed consisting of representatives of the Federal, State, interstate, and local agencies, which are involved in the management, protection, or study of the water resources of the study unit. The liaison committees would be forums for the USGS to (1) inform all interested parties of the goals, plans, data, and findings of the NAWQA Program, (2) seek advice and suggestions on areas of focus and concern in the study unit, (3) identify existing data and interpretive programs and reports, and (4) establish collaborative efforts and appropriate funding mechanisms to supplement and expand upon the core level NAWQA Program. These efforts could include: additional sampling, co-authorship of reports, use of other agencies' services, and selection of locations for and objectives of additional intensive study activities within the study units.

In the surface-and ground-water programs both target constituents and support variables will be measured. Target constituents are those that are of direct relevance to broad national water-quality issues, such as: 1) chemical contamination, 2) nutrient enrichment, 3) acidification, 4) sedimentation, and 5) acceptability of water for use. A set of national target constituents would be selected by a committee of scientists from the USGS and other State and Federal agencies and universities. The committee would consider a variety of factors in this selection process: (1) importance to the major water-quality issues, (2) extent of distribution, (3) persistence, (4) effects on humans and biota, and (5) laboratory capability to make reliable determinations at ranges of concentration that are important from a health or ecological perspective. These national target constituents would be measured in all study units. Other target constituents would be studied in some, but not all, study units because of their importance or occurrence in given regions of the country. Support variables aid in the interpretation of the target constituent data. Stream discharge is an example of a support variable. Support variables will also include descriptive information concerning the characteristics of the watershed such as climate, geology, soils, land cover and use, population, and known sources of contaminants.

The products of the program would be the basic data (available to all through the USGS WATSTORE system and the EPA STORET system), and interpretive reports at three scales: National, study unit, and smaller problem areas. The information in these reports would include both descriptive (including statistical) information, as well as explanations of the observed water-quality conditions. The descriptive information would include summaries of probability distributions of concentrations and estimates of transport of important substances for many individual sites or regions. Estimates of the relative impact of point versus nonpoint sources would be evaluated and trends over time will be assessed. In addition, statistical analyses would be carried out relating water-quality characteristics to the characteristics of the river basin or aquifer, such as geology, climate, land-use practices, waste disposal, and other factors thought to influence water quality. Such results would be used to extend results to areas not sampled and to formulate hypotheses about the causes of water-quality conditions. Finally, cause-and-effect investigations would be conducted on selected problem areas in each study unit. These investigations would involve the use of mathematical and conceptual models with an objective of evaluating the effect of various actions for remedying the specific problems.

NETWORK DESIGN CONFLICTS

The design of sampling networks for surface water quality presents a number of significant conflicting objectives. Several of these have been considered in the recent literature on surface water data collection: in particular Lettenmaier, 1979; Liebetrau, 1979; and VanBelle and Hughes, 1983.

In the spatial aspects of network design there are two major conflicts. The first is between desire to emphasize known major problems versus the desire to assess the whole resource. The former emphasis leads to very targeted sampling of problem reaches but does not allow for assessment of the total extent of problems and may leave many broader or more subtle problems unknown. The opposite approach is one of stratified random sampling of basin types, as was done in the National Fisheries Survey by the Environmental Protection Agency and the Fish and Wildlife Service (Glauz, 1984). This leads to major expenditures in areas which may be of limited practical interest. Clearly elements of both are needed. The other conflict is between the desire to enhance the interpretability of the network's data by sampling small and relatively homogeneous basins versus the desire to assess the flux of constituents (nutrients, toxics, sediments) to reservoirs or estuaries. The latter leads to sampling of larger more heterogeneous basins, such as the USGS National Stream Quality Accounting Network emphasizes (Smith and Alexander, 1985). The combined analysis of results from an ensemble of stations (as opposed to interpretation of single stations in isolation) is a relatively new type of activity (see Peters, N.E., 1984, and Smith and Alexander, in press, and Smith and others, in press) and this work demonstrates the importance of the smaller homogeneous basins. There is a potential approach which may minimize this apparent big basin - small basin conflict and that is to adopt a "incremental basin" approach. This approach would involve more of an examination of the differences in water quality or fluxes at downstream pairs of stations and attempt to relate these differences to the attributes of the intervening basin area. This is an approach which is relatively untested but has considerable potential.

Temporal sampling conflicts arise because of the desire to provide unbiased estimates of conditions over time but also to obtain the greatest amount of information about the times of expected maximum concentration or maximum transport. If one focuses data collection on these critical times and then attempts to use regression or stratified estimators to estimate the long term distribution of conditions, the resulting estimates can not be assured to be unbiased. In addition, the more flexible approaches which are focused on critical times can be very costly and difficult to administer. Much of the sampling work load can occur in a small fraction of the year and in many cases the appropriate time windows for sampling are so short that a great deal of night and weekend work is required. Because flexible sampling rules are difficult to specify precisely, they may gradually change with time as personnel changes. These changes can easily lead to spurious time trends in the data set.

The obvious alternative to flexible sampling is time uniform sampling. This is easiest to administer, assures unbiased estimates and prevents spurious trends as a result of sampling rules. However, it may be inefficient in terms of transport estimation or estimation of frequencies of extreme conditions. One compromise is to use volume-uniform sampling, where a sample is taken each time a specified volume of water passes the station, rather than after a specified time. This may be particularly efficient for transport estimation and it is objective. It does, however, require a data transmission scheme which allows the hydrologist to know the discharge at all times. Furthermore, the work can not be scheduled in advance. Other options are to use time uniform sampling with supplementary targeted sampling which is flagged as such in the data base. Also, the use of automatic sampling approaches (pump samplers and monitors) which are of lower accuracy than manually collected samples may provide enough information between fixed-interval samplings to mitigate the disadvantage of the fixed interval approach.

PROGRAM DESIGN

As a result of consideration of the overall NAWQA program objectives, and consideration of these and many other conflicts and alternatives, a conceptual design for the surface-water NAWQA program has been developed within the USGS. The surface-water program would be conducted on a rotational basis with about one-third of the designated study units undergoing intense data acquisition and study at any one time. For any given study unit, there would be a 3-year period of concentrated data acquisition and interpretation. At the conclusion of the 3-year period reports would be written and published which assess the quality of the water resource. These reports would describe frequency distributions of concentrations over space and time, provide estimates of mass balances or fluxes of constituents, give locations and descriptions of the large problem areas and large areas of high-quality water, and quantify cause-and-effect relationships where possible. Following this, the activity in the study unit would be maintained at a lower level for 6 years, to document the occurrence of gross changes in water quality which may occur. While 60 study units operate at lower levels of activity, the major efforts would be centered in the other 30 study units, and the level of effort nationally would remain constant. In any given year the array of active study units would be widely dispersed around the Nation. After each 3-year active phase, the new data would be compared to those from previous active phases to identify and explain changes occurring in the study unit.

Acquisition of 3 years of data is considered necessary because water quality can be subtantially affected by hydrologic conditions, such as dry or wet periods, which may persist for 1 or more years. A cyclic system in which the intensive sampling lasts for only 1 or 2 years in each cycle runs a greater risk of having difficulty in making cycle-to-cycle comparisons of water quality because of differences in the underlying hydrologic conditions. Also, sufficient time is needed to carry out exploratory sampling, develop and test hypotheses, and document and publish findings. Through a series of 3-year studies, knowledge of a study unit would grow in detail and in interpretational quality, such that after several complete cycles a thorough picture of water quality, from a national perspective, could be attained from the combined results of the unit studies. During these 3-year studies, three major types of activities would be undertaken in surface-water assessments: fixed station sampling, synoptic sampling, and intensive-reach studies.

At least 12 fixed-location river-sampling stations would be operated in each study unit. These could include existing National Stream Quality Accounting Network (NASQAN), Hydrologic Benchmark Network stations, and stations operated under the USGS Federal/State Cooperative Program or operated by the USGS on behalf of other Federal agencies. Reactivation of stations from the EPA National Water Quality Surveillance System (NWQSS) network may also be desirable. Special consideration would be given to sampling at or near major drinking-water intakes; above and below reservoirs, urban areas, and industrial complexes; and in various small, sub-basins where the land use is relatively homogeneous. Information on point and nonpoint source discharges and on atmospheric deposition, mostly collected by existing sampling programs, would be utilized to interpret the surface-water quality.

River stations would be sampled for most variables at least once a month during the 3-year high-activity period. In addition to regularly scheduled sampling, additional high-flow samples would be taken. The need for repetitive sampling arises from the considerable temporal variability of surface-water quality. This variability mainly is a result of variations in river discharge, waste inputs, and temperature. Data from these stations would be interpreted and summarized in terms of frequency distributions of concentrations and mass balances of constituents between stations. Hypotheses aimed at relating these conditions to causative factors would be developed and tested. They would enable one to draw inferences about water quality on a regional scale and to point out some of the policy implications of the observations. The relevant results obtained would also be considered in national analyses to examine the relationships between the water quality and various causative factors. In each 3-year high-activity period, the newly collected data would be compared with any appropriate past data (from before the program began or from earlier cycles of the program) to detect and describe trends in water quality.

For the remaining 6 years of the 9-year cycle the NAWQA activity in the study unit would consist of a low-intensity data-acquisition effort. However, if funds are available from the USGS Federal-State Cooperative Program or from other Federal agencies, then activities during the interim 6-year period might involve more intense sampling or the extension of interpretive studies. The additional data collected and analyses performed could provide a signal of major changes in water quality and assist in placing the 3-year active-cycle data in perspective. Specifically, the data-acquisition in this 6-year period would help to demonstrate the extent to which the 3-year periods are typical of long term conditions. This knowledge may be vital for assessing the long term movement and storage of sediment and the contaminants associated with sediment because their movement can be highly episodic, associated with large flood events.

The purpose of synoptic sampling is to provide a "snapshot" of the occurrence of certain kinds of water-quality conditions over a broad geographical area by making single measurements at many sites at one point in time. The synoptic studies would be tailored to a specific type of known or suspected problem. Water, suspended sediments, bed material, and biota would be sampled to provide information on conditions and certain problems which do not lend themselves to assessment through a fixed-station approach -- for example, dissolved oxygen. The synoptic studies would also test the sensitivity of the fixed station network for detecting potential problems, thereby leading to possible adjustments in station location. Such adjustments would occur in cases where the synoptic surveys reveal important water-quality problems which are not apparent from the fixed-station data. By sampling at intervals of about 25 river miles, the synoptic sampling should make it possible to identify reaches of 50 miles or more with chronic water-quality problems.

On the basis of prior knowledge of the study unit and the knowledge gained through synoptic studies, a limited number of areas will be chosen for intensive study. Involvement of other agencies with specific management responsibility would be a key factor in selecting and designing these intensive studies. Special sampling and mathematical simulations (modeling) will be used in these areas to better define the water-quality conditions and gain an understanding of their causes. The studies would involve 2 or 3 years of data collection. If the results show that the cause-and-effect relationships are well understood then mathematical models may be used to project the outcomes of alternative management strategies for dealing with the specific water-quality issues. These intensive study areas would be revisited in later study cycles (9 years) to study the changes and determine if they correspond to prior understanding of the processes at work.

In addition to the efforts occuring within individual study units, there would be a national team of scientists with the task of assembling the results from all of the studies and from other national data sets with the purpose of summarizing and reporting results at a nationally aggregated level. These results would include statements about the prevalence of certain kinds of water-quality conditions and trends and the relationship of these conditions and trends to factors associated with the Nation's rivers and drainage basins. These factors would include geology, climate, soils, demography, land use, municipal and industrial waste disposal, agricultural, forestry, grazing or mining practices, and atmospheric deposition. Knowledge of these relationships would be important to the development of Federal, State and local laws, regulations, and plans to improve or protect surface-water quality.

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