CONCEPTUAL FRAMEWORKS FOR GROUND-WATER-QUALITY MONITORING

Ground-Water Focus Group,
Intergovernmental Task Force
on Monitoring Water Quality

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INTERGOVERNMENTAL TASK FORCE ON MONITORING WATER QUALITY

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Data Collection Methods	Herb Brass and Russell W. Sherer
Data Management and Information Sharing	Thomas H. Yorke
Environmental Indicators	Andrew Robertson
Framework	Bruce J. Baker
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By O.L. Franke and the Ground-Water Focus Group of the Intergovernmental Task Force on Monitoring Water Quality

Rodney S. DeHan	Florida Department of Environmental Protection
Emery T. Cleaves	Maryland Geological Survey
Charles A. Job	U.S. Environmental Protection Agency
A. Roger Anzzolin	U.S. Environmental Protection Agency
William G. Wilber	U.S. Geological Survey
Wayne W. Lapham	U.S. Geological Survey

Assisted by William D. Ward, The Cadmus Group

CONTENTS

Appendixes

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
	Flow	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8°C + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ADDITIONAL ABBREVIATIONS

mg/L milligrams per liter
ppb part per billion

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EXECUTIVE SUMMARY

Evaluation of past programs for the collection, compilation, and use of water-quality data has indicated that, despite vast expenditures on these efforts at Federal, State, and local levels, the resultant data were largely inadequate to guide regional water-resource management and related decisionmaking. In response, the Ground-Water Focus Group (GWFG) of the Intergovernmental Task Force on Monitoring Water Quality (ITFM) proposes a national approach for the design and implementation of ground-water-quality data-collection and monitoring activities, the general objectives of which are to characterize the quality of ground water, to encourage the greatest practical degree of inter-group collaboration in such activities, and to encourage the widest possible exchange of reliable water-quality data.

In the past, the shortcomings of and uncertainties in water-quality data, especially the data for ground water, have derived less from laboratory procedures than from field procedures; uncertainties about the hydrologic conditions relating to the samples; and analyte-selection decisions that focused on only one, sometimes limited, objective. Accordingly, the approach described in this report emphasizes ways to minimize the problems of the past and to improve the broad-scope usefulness of ground-water-quality data. Key elements in the suggested national approach are outlined under two headings in this summary: (1) Support functions and activities provided by organizations, such as ground-water programs conducted by a State, in support of monitoring programs and projects; and (2) steps in implementing a specific monitoring project and the activities and issues associated with these steps.

(1) Activities and functions provided by organizations, such as ground-water programs conducted by a State, in support of monitoring programs and projects.

Preparation and periodic review of a long-term monitoring strategy and plan. The purpose of a long-term plan is to address questions such as, "What will conditions be in the future, and what data need to be acquired now to meet future needs?" The plan consists of a prioritized list of broadly scoped monitoring projects in the most critical hydrogeologic units.

Assistance in coordination of project studies and collaboration with other agencies, organizations, and individuals. Increased collaboration is a major goal of the ITFM because of the many potential benefits to all parties, such as sharing of data, personnel, training costs, and project responsibilites.

Implementation of a quality-assurance and quality-control (QA/QC) plan and guidelines. The use of QA/QC ensures the integrity of data, a principal concern of the ITFM. A main concern in this report is how QA/QC relates to field collection of water-quality data, handling and analysis of water-quality data in the laboratory, and entry of the water-quality data into an appropriate electronic data base.

Maintenance of a data-management system. Data management refers to all activities related to data, affects all aspects of water-quality studies, and provides essential underpinning for other program and project support functions, such as the functions listed in this summary. A major goal of the ITFM is to promote data sharing among organizations, which involves, in part, technical issues of transferring data between different computer systems.

Provision of field and laboratory services and analytical support. Examples of services that an organization would provide for obtaining data in the field are installation of wells and piezometers and sampling. The organization also would provide the appropriate equipment, supplies, and trained field personnel to do the sampling. Once the samples are collected, the organization would ensure they are sent to a qualified laboratory for analysis. An integrated QA/QC plan and a data-management system would be needed to support these services.

Evaluation of the monitoring program. Periodic evaluation is the QC mechanism for the entire monitoring program and involves comparison of the products of all recent projects with the long-term strategy and plan of the program.

Description and quantification of the environmental setting. Sound interpretation of water-quality data depends on the availability and reliability of a large array of environmental information about the hydrogeologic and hydrologic setting, human activities and structures, and other resource information. Substantial resources may need to be allocated to assemble this information.

Evaluation of personnel and other project resources. Evaluation of resources needs to be ongoing in all programs and projects. The importance of trained personnel in all phases of a project and allocation of a principal project resource, personnel time, are emphasized in this report.

(2) Steps in implementing a specific monitoring project and the activities and issues associated with these steps.

Definition of initial objectives and scope of project. The impetus for a water-quality study may come from different sources, including the list of broadly formulated and prioritized projects that are part of the long-term monitoring strategy and plan. In general, ground-water-quality studies are defined by and reflect (1) the specific objectives of the study, (2) the environmental setting in which the study takes place, and (3) the resources available for the study. By logic and necessity, project objectives and project design are closely intertwined and have a two-way feedback.

Assembly of available data and review of literature, preliminary evaluation of existing data, and reformulation of objectives and development of a conceptual model to be tested. These three steps emphasize the importance of intensive review and evaluation of existing data from all possible sources because these steps may result in modifying project objectives and design and in redirecting resources. Furthermore, important issues may arise while evaluating the suitability and compatibility of data for analysis that are derived from different sources.

Development of design for sampling and data collection. The design for sampling and data collection is a focal point for virtually all project activities prior to the design process (for example, definition of project objectives and evaluation of existing information) and subsequent to the design process (for example, analysis and interpretation of data and presentation of project results). Principal tasks in design include: (1) Identifying the volume and characteristics of earth material targeted for sampling, (2) selecting target analytes, (3) defining the areal and temporal sampling strategy, and (4) selecting wells to be sampled. Selection of target analytes or indicators is a major focus of ITFM; therefore, this report (1) recommends a minimum list of analytes for all objectives related to ground-water monitoring and assessment (field measurements, major ions and dissolved solids, and selected nutrient species) and (2) suggests a process for selecting critical analytes, such as trace synthetic organic compounds and metals.

Implementation of design for sampling and data collection. In this step, logistical concerns that support field sampling take precedence. These concerns include: (1) Ordering of equipment and supplies, (2) training of field personnel in sampling protocols, (3) implementation of a QA/QC program for sampling, and (4) site visits to all wells.

Analysis and interpretation of data. The report briefly outlines this topic, which consists of: (1) The most common information elements in water-quality studies, and (2) the general approaches to the treatment of water-quality information. The importance of relating water-quality information to all aspects of the environmental setting is emphasized.

The final steps—Compilation and presentation of results and dissemination of products to constituencies of participating agencies. In these final steps of a project, the advantages of electronic files for all data and compilations, including a Geographic Information System (GIS) for maps, a data base capable of providing varied reports, and an implemented QA/QC plan for all project activities, are manifest. Furthermore, written reports benefit from early preparation of text and illustrations, particularly of those parts that do not depend on the final analysis of project data.

In presenting this suggested national approach for ground-water-quality monitoring, the report attempts to maintain the point of view of water-resource professionals who are engaged in and managing ground-water-quality studies and data-collection activities, while recognizing the special considerations of State and local agencies, including constant pressures to do more with less. Accordingly, the report emphasizes that less can actually be more. That is, a relatively few reliable ground-water analyses, which include a broad spectrum of analytes and which are carefully designed to meet short- and long-term needs, may be of greater benefit than a large number of reliable samples that have only a few targeted analytes, which are designed to meet only short-term needs.

Implementation of the national approach suggested in this report is voluntary, but the advantages for participants can be significant. In addition to opportunities for sharing training and other costs through collaboration and for building a more readily available base of reliable ground-water data, participation in the suggested national approach can provide a common direction to guide monitoring programs and dissemination of their resultant data into the future.

INTRODUCTION

In a perfect world, all the data that water-quality specialists work with would be totally appropriate and reliable. The data from in-house water analyses, as well as data from every other laboratory, would accurately reflect conditions in the stream or aquifer that was sampled and would be precisely the kinds of data that are needed. Moreover, the water-quality information in various archives would be just as reliable as the most recently collected data.

In actuality, all files of water-quality information may contain questionable data. For example, during an evaluation of water-quality programs and existing data for Colorado and Ohio, consisting of tens of thousands of analyzed ground-water samples, less than 2,000 met criteria selected to ensure the reliability of the results. One conclusion by the investigators was: "There probably are too few [reliable] ground-water analyses in the data base...to make a valid assessment of regional ground-water quality conditions" (Childress and others, 1987, p. 5; Hren and others, 1987). The two States selected for the evaluation (with cooperation of State officials) were not worst case selections, but were chosen partly because they were considered to be representative. Nationwide extrapolation of the uncertainties in the data bases for Colorado and Ohio imply that there could be risks in using contemporary water-quality-data files as a basis for management decisions— especially management decisions of far-reaching consequences. However, no strategy can ensure 100-percent reliability of the data, but with a concerted, cooperative effort, that reliability could be greatly improved. With analytical costs and demands for reliable water-quality data so high, can we afford to do otherwise?

Intergovernmental Task Force on Monitoring Water Quality

In response to the widespread problem concerning the reliability of water-quality data bases and other related water-quality issues, such as an inability to use the data to indicate long-term trends, the Intergovernmental Task Force on Monitoring Water Quality (ITFM) was formed in January 1992. At that time, the ITFM consisted of 16 representatives of Federal, State, and interstate government agencies and approximately 80 additional Federal and State members participating in four task groups. Leadership for the task force was provided by the U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS). The general mission of the ITFM was "...to develop and initiate...a strategic plan to achieve effective collection, interpretation, and presentation of water-quality data and to improve the availability of information for decisionmaking at all levels of government" (ITFM, 1992, p. 3). "The scope of the ITFM includes water-quality monitoring and the resulting collection, management, and use of water-quality information for the purposes of: assessing status and trends, identifying emerging problems, developing and implementing management and regulatory programs, and evaluating program effectiveness and compliance" (ITFM, 1992, p. A-1).

The objectives of the ITFM are (a) to develop an intergovernmental framework for water-quality monitoring and assessment that will improve information on the ground- and surface-water quality of the Nation; (b) to address the development and recommend application of environmental indicators and standard descriptors of aquatic conditions that agencies could use for different purposes; (c) to recommend linkages among information systems that would result in a nationwide water-information network that would provide access to and support the sharing of information holdings of Federal, State, local, and private organizations among primary and secondary users; and (d) to identify specific actions that Federal and State governments should implement, including the establishment of coordination mechanisms that are needed to carry out the recommendations (modified from ITFM, 1992, p. A-1 and A-2).

Ground-Water Focus Group within the Intergovernmental Task Force on Monitoring Water Quality

Because of the widely differing approaches to ground-water-quality monitoring as compared to surface-water-quality monitoring, which result largely from the different physical environments in which these waters occur, the ITFM recognized early in its deliberations that parallel, but separate, considerations of ground-water and surface-water monitoring were needed. Accordingly, the Ground-Water Focus Group (GWFG) was established within the broader framework of the ITFM. The general mission and objectives of the GWFG were the same as the objectives of the ITFM as discussed in the “Intergovernmental Task Force on Monitoring Water Quality” section, except the goals relate specifically to ground-water monitoring.

National Water Quality Monitoring Council

The mandated duration of the ITFM was 3 years (1992-94). The National Water Quality Monitoring Council (NWQMC) succeeds the ITFM as a Federal, State, and interstate organization with virtually the same mission, scope, and objectives as the ITFM. Its goal is to establish voluntary criteria, which will assist all parties—Federal, State, local government, and the private sector—in collecting, storing, retrieving, and sharing data that are reliable, comparable, and of known quality. It is expected that adherence to these voluntary criteria will lead to improved understanding of water-quality trends, higher levels of confidence in the data for policy and decision making in the public and private sectors, and reduced costs through data sharing. This report was started under the auspices of the GWFG of the ITFM.

Purpose and Scope

This report presents conceptual frameworks for ground-water-quality monitoring programs and projects and for facilitating collaboration between the groups and individuals involved in ground-water monitoring. These frameworks are intended to be relevant for all spatial scales and for any administrative level of government, as well as for any other interested organizations and constituencies. Furthermore, the combined conceptual frameworks outlined in this report comprise a proposed national approach to ground-water-quality monitoring. The report also encourages a long-term view of ground-water-quality monitoring and related activities in the water-resources community, especially for ongoing efforts to study, increase the understanding of, and better manage ground-water resources; however, fiscal, administrative, and legal constraints affect ground-water monitoring activities at all levels of government and could affect the implementation of the proposed approach. The proposed national approach aims to establish a general direction and to encourage progressive adjustments of monitoring activities, if appropriate, as constraints permit. Implementation of the proposed national approach and recommendations in this report is voluntary, but advantages for participants can be significant. For example:

(1) A well-planned, well-reviewed national approach could serve as a model for a State's approach to monitoring, thereby saving time and effort, but also would allow the State to customize its approach to meet the State's particular circumstances.

(2) The national approach would be a ready, reliable guide to use for training at State and local levels.

(3) The national approach would provide a guide for comparing existing State and local data and for finding gaps or deficiencies in those data.

(4) Adoption of and adherence to a sound national approach would make newly acquired State and local data equal in status with the most reliable data anywhere.

(5) Widespread adoption and adherence to a national approach would allow confident use of data from other agencies even when agencies are across jurisdictional boundaries (for example, participation in regional water-quality assessments).

(6) Adoption of and adherence to a national approach would ensure the highest level of confidence in meeting data-submission requirements for the USEPA national and regional water summaries (and so on), as well as State- or local-level data compilations.

(7) Adherence to the national approach would allow analysis of trends for similar environmental settings.

This report can be regarded as an initial overview report in a continuing series of reports that deal with issues related to ground-water-quality monitoring. It is not a how-to manual that provides all the relevant details that are needed to design and implement a ground-water-quality monitoring program. Other reports can provide relevant details in response to needs expressed by participating constituencies. In this report, however, the GWFG makes a conscious effort to list appropriate references that discuss in detail present (1997) views on many aspects of ground-water-quality monitoring. The content of this report is further limited because (1) it discusses only the quality of the ground-water resource and does not consider the quality of treated water or water at the tap and (2) it does not discuss the newly emerging field of biological monitoring of ground-water quality—that is, monitoring that uses potential biological indicators of water quality in addition to well-established tests and procedures that have long been used as indices of acceptable water quality.

CONCEPTUAL FRAMEWORKS FOR GROUND-WATER-QUALITY MONITORING PROGRAMS AND PROJECTS

Monitoring programs and projects intended to characterize the quality of ground water may be organized at three major levels: interagency group/public, monitoring program within an agency or organization, and project in a monitoring program (fig. 1). Within this hierarchical structure, there is a series of steps that progress through a ground-water monitoring program or project from conception to completion (fig. 1, Steps 1-12). To assist in implementing the monitoring projects, there are various support functions that need to be provided by the operating agency or by the lead agency in cooperative intergroup programs (fig. 1, Support Functions A-G). The conceptual frameworks embedded in figure 1 can apply to the design and implementation of any type of ground-water-quality monitoring program or individual monitoring project or study, whether it is site specific or regional in scale.

The relations between salient activities and elements in the design and implementation of ground-water-quality monitoring studies are shown in figure 1. The number of steps and support functions and their conceptual representation (by labels) is mostly arbitrary; some could be combined or others added. The design in figure 1 is intended to provide appropriate emphasis for major conceptual elements of a monitoring strategy and for the flow from one to another, while remaining simple enough for reader convenience.

A hierarchical structure with three major levels is shown in figure 1. The upper level, "Interagency Group/Public," is intended to represent all Federal, State and other organizations, and individuals who have interests in or might be affected by ITFM goals and recommendations for ground-water-quality programs. This level also represents only the broadest interests and concerns of all those parties. The upper level consists of the two ends of the progression (Steps 1 and 12)—the determination of the high-level objectives in the beginning and the feedback or final delivery of the resultant reports or data compilations at the end.

The middle level in figure 1, "Monitoring Program in an Agency or Organization," includes Steps 2 and 3 and Support Functions A through E. This level refers to the goals, strategy, and long-term plans for the monitoring program of an organization and to support services and activities that are not the responsibility of the individual project, but are provided by the operating agency or lead organization for all related monitoring projects.

The lower level in figure 1, designated "Project in a Monitoring Program," includes Steps 4 through 11 and Support Functions F and G. This level refers to activities that are related mainly to a specific project or study in the monitoring program of the operating organization.

The major steps in figure 1 generally progress sequentially in time, whereas the support functions usually are ongoing through the life of a project. Project steps for which these support functions are most critical are indicated by arrows that connect to the appropriate support functions. Readers need to note that the support functions listed in the second level in figure 1 also affect many of the steps in the third level.

For convenience of discussion, the steps and support functions in figure 1 are grouped as follows: (a) Steps 1-3—establishing long-term goals and needs for a monitoring program; (b) Support Functions A-G; (c) Steps 4-7—defining specific monitoring projects; (d) Steps 8-10—designing and implementing specific monitoring projects; and (e) Steps 11-12—presenting and disseminating project results. Just as each project element or activity depends to some extent on related earlier and future activities, frequent references to previous discussions and some repetition in the following sections are unavoidable. An outline for a ground-water-quality monitoring framework (ITFM, 1995, Technical Appendix L), which is similar in scope to and supports the discussion of the steps and support functions in figure 1, is provided in Appendix A for reference.

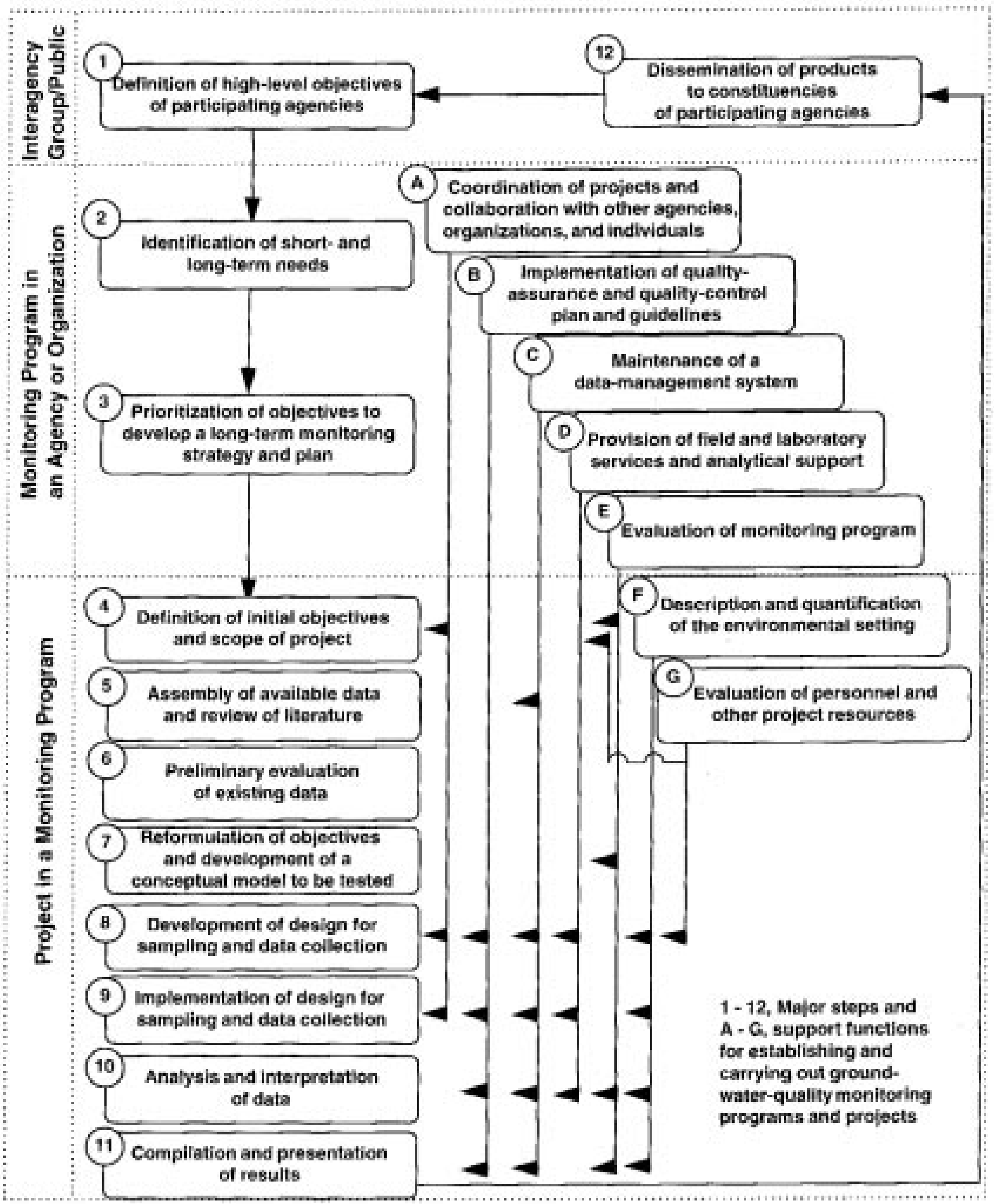

Figure 1. Flow chart showing major steps and support functions of coordinated monitoring programs and projects whose general objective is to characterize the quality of water.

Establishing Long-Term Goals and Needs

Definition of High-Level Objectives of Participating Agencies (Step 1)

A logical first step in promoting the kind of collaboration and standardization envisioned by the ITFM is to identify the parallel and overlapping goals of agencies and other organizations involved in ground-water-quality monitoring programs. This step applies at regional and at local levels, as well as at the national and State levels. A clear statement of shared high-level objectives can be unifying and stabilizing for the agencies and other organizations that are collaborating in ground-water monitoring programs. The statements in the “Introduction” section about the mission and goals of the ITFM are a relevant example. In addition, the process of preparing a mission statement is a useful first step in building collaborative relationships between organizations because such a statement may indicate unrealized common ground. Even though mission statements usually seem far removed from the practicalities at program and project levels, a periodic review of broad, long-term goals also can be intrinsically useful to individual organizations as well as groups of organizations. Broadest agency or group objectives may be effectively related to and may shape specific programs and projects.

Identification of Short- and Long-Term Needs (Step 2)

The monitoring program in an organization, which supports specific monitoring projects, includes the following principal needs:

(1) Definition of long-term objectives of the monitoring program and preparation of a long-term plan that includes a prioritized grouping of broadly defined monitoring projects.

(2) Data-management system.

(3) Laboratory services.

(4) Well-drilling and piezometer-installation services and the associated protocols.

(5) Protocols for field sampling.

(6) Equipment and supplies for field sampling.

(7) Quality-assurance/quality-control (QA/QC) plans for field, laboratory, and office activities.

(8) Administrative-support structure.

(9) Computer resources to support all the activities listed above, data compilation and analysis, Geographic Information System (GIS) libraries and analyses, and so on.

(10) Appropriately educated and trained personnel.

(11) Long-term funding from internal and external sources.

Prioritization of Objectives to Develop a Long-Term Monitoring Strategy and Plan (Step 3)

The long-term objectives of the monitoring program for one organization may range from being similar to being considerably more specific than the mission statement of a group of collaborating organizations. The long-term monitoring strategy and plan of an organization, however, reflects the specific mission of the organization and relates explicitly to the land area and associated hydrogeologic units at various depths below the land surface in which the organization has some interest or for which it has some responsibility. The long-term aspect of the strategy needs to consider such questions as, "What will conditions be in the future, and what data should be acquired now to meet the future needs?"

Many organizations engaged in ground-water-quality monitoring do not have an explicit long-term monitoring plan because almost all of their time and resources are being used in mandated activities of various kinds and in responding to emergencies as they arise. Despite these realities, the GWFG believes that all monitoring organizations could benefit from the preparation and periodic review of a long-term monitoring plan. For example, if uncommitted resources from or opportunities for collaboration with other organizations, or both, become available, these resources and opportunities could be used efficiently and beneficially in programs where they are needed.

A useful procedure for developing a long-term monitoring plan includes the following:

(1) Defining the total volume of saturated earth material in which the organization has interest or for which it has responsibility. This total volume may consist of a large number of hydrogeologic units or groups of units, which need to be listed completely.

(2) Considering each hydrogeologic unit or group of units separately, and asking the questions: "What is already known, and what should an organization know about the water quality in the hydrogeologic unit that is not now known?" and associating the needs for water-quality information with the list of hydrogeologic units, subdividing some hydrogeologic units into smaller parts, as needed.

(3) Developing an explicit prioritization of the need for water-quality information in the individual hydrogeologic units on the list so that answers that are well thought out are always available for the questions: "What is being done with limited resources?" and "What should be done next with the limited resources?" The assumptions underlying this prioritization process are: the hydrogeologic unit is the basic building block of the subsurface environment, and monitoring projects and related activities need to be related explicitly to a particular hydrogeologic unit, a part of a hydrogeologic unit, or a logical combination of hydrogeologic units. Although the focus of this procedure should be on evaluating the need for water-quality information, the value of this evaluation can be greatly enhanced by also including an evaluation of the need for additional environmental information for each hydrogeologic unit (see discussion of Support Function F).

Examples of criteria that might be used, either singly or in combination, to prioritize water-quality studies by hydrogeologic units include:

(1) Total pumpage of ground water from a hydrogeologic unit; ground-water pumpage for public water supply; population obtaining water supply from a hydrogeologic unit; perceived vulnerability of wellhead-protection areas associated with public-supply wells in a hydrogeologic unit; ground-water pumpage from a hydrogeologic unit for purposes other than public water supply.

(2) Hydrogeologic unit for which a large increase in water use is projected.

(3) Known or hypothesized degradation of ground-water quality due to human activities or natural processes.

(4) Highly contaminated shallow hydrogeologic unit that is not a source of water for human activities, but is a major source of inflow to a deeper hydrogeologic unit that is heavily used for water supply.

(5) Parts of shallow hydrogeologic units having discharge to or recharge from surface-water bodies (for example, stream reaches or lake shorelines) where exchanges of water between ground water and surface water may greatly affect the quality of either water body.

(6) Importance of a hydrogeologic unit to maintenance of overlying wetlands.

(7) Hydrogeologic unit containing water that is pristine or almost pristine.

(8) Designation of a ground-water resource (parts or combinations of one or more hydrogeologic units) as a sole-source aquifer.

The results of the thinking and planning for this step and for Step 2 can be (a) a statement of long-term objectives for the ground-water-quality monitoring program of the organization, and (b) a prioritized grouping of broadly defined monitoring projects that, in total, constitutes an essential part of a long-term monitoring plan for the organization.

Support Functions and Activities for Ground-Water-Quality Monitoring Projects

Coordination of Projects and Collaboration with Other Agencies, Organizations, and Individuals (Support Function A)

One of the major goals of the ITFM is to increase meaningful collaboration among agencies at all levels of government, public and private organizations, and individuals who are directly involved or interested in water-quality studies and issues. Although this stated goal is eminently reasonable, defining and achieving meaningful collaboration are not always simple and easy and logically result in the question, "How can collaboration between government agencies, other public and private organizations, and individuals improve information on ground- and surface-water quality of the Nation?"

Beneficial collaboration among various constituencies can have different objectives and can occur at varying intensities. Brief generic examples of possible constructive collaboration among constituencies are discussed. In most States, domestic-well owners are required to send, or have the option of sending, a water sample to their State or county departments of health for analysis of a small number of health-related parameters, such as concentrations of nitrate and coliform bacteria. Usually, however, the location of the sampled well is known only approximately, sometimes only by county, and very little may be known about the construction of the sampled well. The value of the analytical results for describing the spatial distribution of these measured parameters, usually in surficial hydrogeologic units, would be greatly enhanced if arrangements could be made with other agencies to obtain more accurate location and more detailed well-construction information for at least a defined subset of all the wells that were sampled. The subset could be selected, for example, so as to maximize the spatial coverage of water-quality information or to target areas in which the shallow ground water is perceived to be most vulnerable to contamination. Analysis of the water samples from this subset of wells, or a still smaller subset, then could be done for a somewhat broader array of constituents.

Although this hypothetical example emphasizes how the value and applicability of data can be enhanced and extended by collaboration with other organizations, the data may be of some value as they are or after obtaining additional information. For example, an analysis of nitrate data from homeowners' wells was undertaken in Maryland in a suburban area underlain by crystalline rock. Although the project involved paper records and considerable effort in determining approximate locations of wells and minimal collaboration with other organizations, an overview of nitrate concentrations was obtained for the study area. At the time of the tests, owners of the few wells that had nitrate concentrations that exceeded the drinking-water standard (10 milligrams per liter as nitrate nitrogen) were notified. These homeowners undertook remedial measures, primarily related to well construction and, thereby, were able to lower the nitrate concentrations to less than the drinking-water standard.

Information about the locations of water wells may be from a variety of sources, such as land-ownership records, files of State agencies that administer ground-water rights, and agencies or universities that use well logs in geologic mapping. For example, many well locations in Maryland are included in an inventory developed by the USGS and the Maryland Geological Survey as part of their cooperative ground-water studies. Besides well location, the inventory documents well-construction features, water-quality data, and other information in Federal and State ground-water reports.

Less ambitious examples of collaboration often involve sharing of resources in various ways, such as:

(1) Sharing GIS specialized coverages. However, the establishment and operation of a GIS are based on intensive and specialized training. One agency might be designated to develop and maintain GIS coverages for the entire State or other area of responsibility that can be provided to collaborating agencies.

(2) Sharing expensive training costs. One technical area that is constantly evolving is field protocols for collecting samples that will be analyzed for trace constituents that occur at very low concentrations (parts per billion). If personnel from one agency are trained in the best available protocols, they could provide field mentoring or more formal training to personnel from other agencies, or both, if the agencies are collaborating.

(3) Sharing data-collection responsibilities. One agency engaged in a data-collection program could analyze water samples for analytes needed by another organization, while analyzing the samples for their own analytes of interest. An agency could arrange for the collection of additional sample bottles at each site by another agency and pay for additional suites of analytes and so on.

Implementing meaningful collaboration among organizations initially may be time-consuming and frustrating. A prerequisite for collaboration is that someone in the water-resources community needs to take the initiative to begin a dialogue with someone in another organization or people from several organizations and interest groups by identifying areas of common interest and concern. Developing collaborative relationships probably is best viewed as a long-term process in which tangible results may be modest in the beginning, but possibly large over time.

However it is achieved, collaboration among organizations in water-quality studies has the potential for enhancing the scope, content, and utility of these studies and for decreasing short- and long-term costs to individual organizations by various forms of resource sharing. One example of collaboration and cofunding is the long-standing USGS cooperative ground-water assessments conducted with other Federal, State, and local agencies.

Implementation of Quality-Assurance and Quality-Control Plan and Guidelines (Support Function B)

Quality assurance and quality control are essential and integral parts of a monitoring program (Kent and Payne, 1988; Mattraw and others, 1989; Koterba and others, 1995). Quality assurance is a management function that ensures that the quality of each component of a monitoring program, from planning to final report preparation, is known and meets quality standards with a stated level of confidence. Quality control includes those activities that define and measure quality and determine whether products and results meet specified and established quality standards. A main concern in this report is QA/QC as it relates to field collection of water-quality data, handling and analysis of water-quality samples in the laboratory, and entry of the water-quality data into an appropriate electronic data base.

Project-level QC is an aspect of QA that is intended to identify, measure, and decrease the systematic (bias; see Glossary) and random (variability; see Glossary) errors that are endemic to water-quality data-collection and data-analysis activities. To document the quality of the data, collection of QC samples needs to be done. Collection of QC samples by field personnel generally is to (1) demonstrate that the equipment and methods used can produce an uncontaminated sample, (2) determine the extent to which sample-matrix interference or analyte degradation affects the recovery of organic chemical constituents, and (3) assess the variability of the reported sample data. Furthermore, QC data can be used to assess whether differences in chemical concentrations among samples are environmentally significant or simply represent variations from sampling, processing, or analytical procedures.

Project-submitted QC samples generally fall into three categories according to their matrix and source: blank samples, environmental QC samples, and reference-material samples. The blank samples are laboratory produced and are a matrix of water (American Society for Testing and Materials Type 1) that meets strict specifications for low constituent concentrations. The matrix and source of an environmental QC sample is identical to the matrix and source of the ground water being sampled; the matrix for reference material is of known and meticulously measured constituent concentrations that are obtained from a laboratory or other organization that is certified to provide the matrix. In addition, there are QC samples that can have either a blank, environmental, or reference matrix, but are distinguished by treatment or use, such as spike samples and blind samples (see Glossary). Further explanation of the types and purposes of QC samples is provided in Appendix B.

Experience with the USGS's National Water-Quality Assessment (NAWQA) program underscores two factors. (1) Quality control needs to be implemented before full-scale field sampling; for example, pre-sampling QC could include (a) pumping blank water through the sampling system at the office to demonstrate that equipment initially is contaminant free, and (b) field testing of sampling protocols by sampling a moderately contaminated well, cleaning equipment, and then collecting a field-blank from that equipment. (2) Timely analysis of QC data during periods of sample and data collection is necessary to uncover problems that, if not immediately identified and corrected, could result in the total or partial loss of costly field data (fig. 2). For example, if the analysis of equipment blanks in figure 2 showed concentrations of MTBE greater than the method detection limit, the concentrations of MTBE in environmental samples that are greater than the method detection limit would be suspect; as a result, those data would be worthless.

In the USGS, the minimum number of QC samples needed for a project is 10 to 15 percent of the total number of environmental samples. This minimum number provides public accountability for producing QA data. The suggested number of project-submitted QC samples in the USGS is that number needed to demonstrate beyond a reasonable doubt that the data-quality objectives of the project are being met—that is, the data are of sufficient quality to achieve study objectives. This data-quality objective implies that QC samples compose 25 to 30 percent of the total number of samples collected per project. This proportion of QC samples usually is adequate to ensure that data-quality objectives of a QA/QC program will be satisfied. In general, the number of QC samples that are needed to meet data-quality objectives increases as the variability of constituent concentrations, particularly of targeted contaminants, increases.

Fully implemented QA/QC constitutes a substantial part of the cost of acquiring ground-water-quality data. However, QA/QC is just as essential to the soundness and reliability of the resultant data as is the detailed knowledge of the hydrogeologic source of the water sample and the construction details of the sampled well.

In conclusion, the following points regarding QA/QC are emphasized. (1) Consistent implementation of a sound QA/QC plan is essential for establishing (and documenting) the credibility of water-quality data, particularly for all aspects of data collection, laboratory procedures, and entry of data into a data base. (2) Complete documentation is needed not only for the general QA/QC plan, but also for the individual QC samples, in particular how they relate to the temporal sequence of environmental samples. (3) A staff person needs to be identified and trained as the QA/QC expert for the monitoring program, and this person needs to advise and assist in water-quality studies to ensure that the data-quality objectives or criteria are met in monitoring projects and, for the longer term, in the water-quality program.

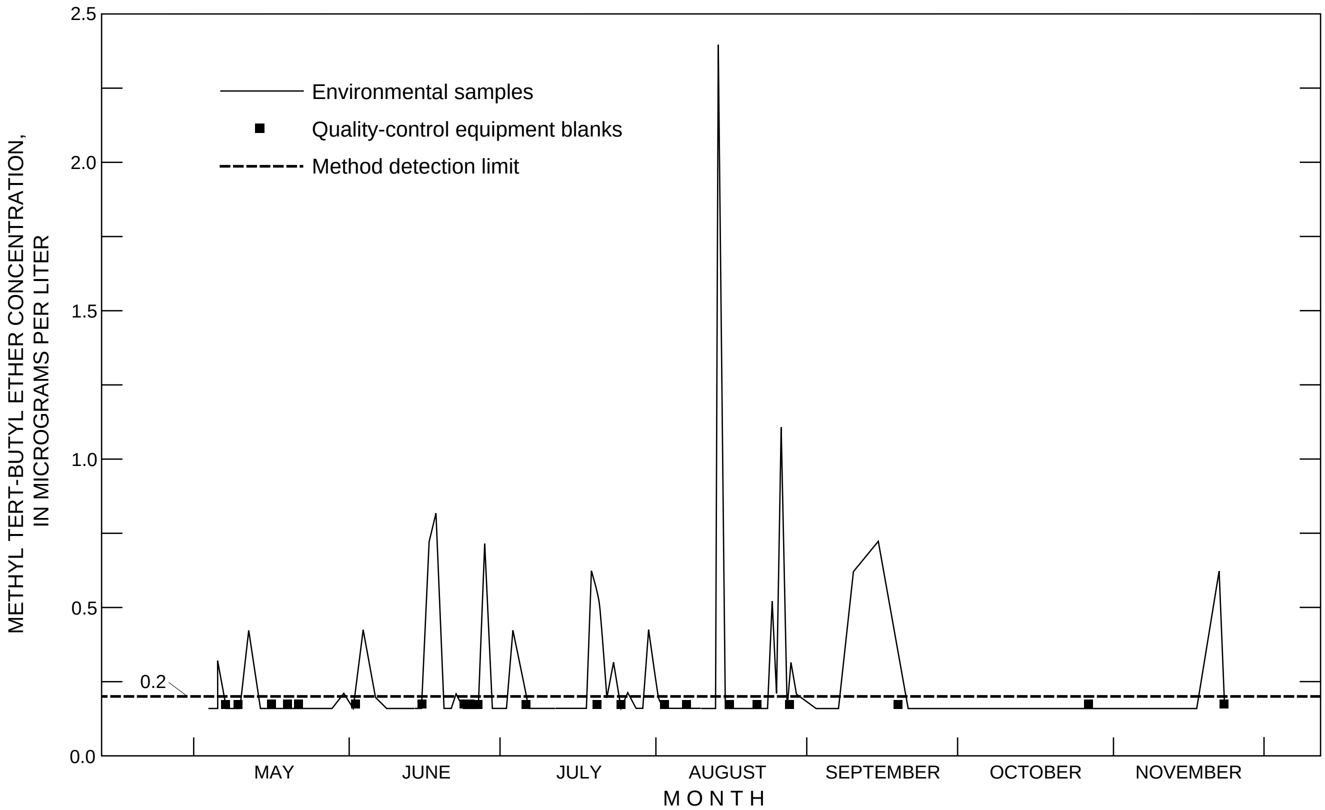

Figure 2. Temporal sequence of environmental and quality-control samples (equipment blanks) that were analyzed for methyl tert-butyl ether (MTBE) during a field-sampling season in the Connecticut River Basin National Water-Quality Assessment study. The concentrations of MTBE in QC samples were consistently at or lower than the method detection limit (0.2 microgram per liter), which indicates that equipment-decontamination procedures were effective. As a result, these QC samples, which are interspersed with environmental samples, increase confidence in the validity of MTBE concentrations in environmental samples. Also, the frequency of collection of QC samples during the early part of the sampling season is high. Concentrations of MTBE in environmental and QC samples that are less than the method detection limit are plotted arbitrarily in figure 2 slightly below the method-detection-limit line (Stephen Grady, USGS, written commun., 1996).

Maintenance of a Data-Management System (Support Function C)

In this discussion, data management refers to all activities related to data and includes (1) deciding which data elements to collect and planning where to collect them; (2) data collection and associated documentation; (3) data storage and retrieval; (4) data analysis and interpretation; (5) data publication; and (6) QA/QC for all these activities. Data management is a high-level program function that affects virtually all aspects of, and is essential to, the successful implementation and completion of present-day (1997) water-quality studies (fig. 1, Steps 4-12). Data management also provides essential underpinning for other program and project support functions, such as QA/QC activities (Support Function B); field and laboratory support (Support Function D); and description and quantification of the environmental setting (Support Function F) (fig. 1). The following paragraphs include some guiding principles in data management and a discussion of the efforts by ITFM to promote data sharing among organizations.

Some sound principles of data management are:

(1) Consistency in data-collection methods and in field-record forms for all aspects of data collection.

(2) Documentation of the data sources and methods used to collect and quality assure data.

(3) For data storage, (a) minimization of duplication of data in the same or closely related data bases; (b) use of consistent formats to store data; (c) early implementation of QA of data entered into a data base; (d) use of primary data rather than derived data whenever possible; (e) no storage of a mixture of primary data and derived data because such storage introduces ambiguities when the calculations based on the primary data do not agree with the derived data; and (f) inclusion of information about methods, sources, and limitations of derived data when the primary data are not stored.

In a special-case example of (1) and (2) in the previous paragraph, fullest achievement of project objectives could result in using modified or new methods of data collection. In this situation, particular care is needed in documenting the methods that are different from the usual methods.

One principal objective of the ITFM is to enhance the capabilities for data transfer between organizations. The roadblock to this objective is that each organization generally has its own data base that has different data structures and different computer software and hardware, which makes direct electronic communication between existing data bases virtually impossible. For those organizations that wish to participate, the ITFM Data Management and Information Sharing Task Group indicated three common elements for data management and transfer: (1) A common data-element glossary; (2) a minimum set of data elements that would serve as common vehicles for querying a data base; and (3) a set of standard reports (output from the data base of each organization in the form of graphs and tables with common format, and so on) that can be obtained from data bases of different organizations.

A common data-element glossary is essential to sharing, archiving, and interpreting data from different data bases. The glossary provides a logical arrangement of data elements, which is useful in developing a data model for a data base, and a list of names, definitions, data types, formats, and measurement units associated with the different data elements. Without a common data-element glossary, data in two data bases may have the same name, but may not be defined in exactly the same way; therefore, the data may not be strictly comparable and, as a result, may not be useable in the same data analysis.

A common data-element glossary, however, is not a mandate for participating organizations to store all the named data elements or to be limited on data elements that may be stored. Further, a common data-element glossary is not a data-base management system. A glossary only lists the data—this list cannot be queried or produce reports on the data. As a result, when data are received from another data base, the data need to be linked to computer software, such as a spreadsheet or statistical package, to organize and manipulate the data in a useful way. Another concern is that the data from another data base cannot be entered electronically into the inhouse data base, even with a common data-element glossary, without using a specially written software interface. The alternative is to enter the outside data manually.

Data elements that relate to all categories of data or specifically to ground water, surface water, or aquatic ecology were designated by the ITFM as the minimum number of data elements for facilitating the exchange of existing data (ITFM, 1995). These data elements are elements that requestors would most likely use to qualify a query for specific data from the data system of any organization. The collaborating organizations may need to modify their existing user interfaces or develop new interfaces to their data systems to incorporate the following elements, as defined by the ITFM (1995).

Data elements that relate to all categories of data, including ground water

Site name
Site number
Site type
Federal-Information-Processing-Standard (FIPS) county code
FIPS State code
Latitude and longitude [determined by Global Positioning System (GPS) or equivalent technology]
Collection start date
Collection end date
Collecting organization
Constituent
Reporting form
Sample depth
Water-body type

Data elements that relate to ground water

Aquifer name
Well depth

Data elements that relate primarily to surface water and aquatic ecology

Sample medium code
Ecoregion code
USEPA river-reach code
Hydrologic unit code
Water-body name
Habitat type
Taxonomic code

With these data elements, the data base from a participating organization could be queried to provide a report of all the water-quality data derived from wells that tap a designated aquifer and that were collected by the organization within a specified 5-year period. As the list indicates, additional data that include the latitude and longitude of the well, the depth of the well, and the county in which the well is located would accompany the specific analytical data.

The data elements that are designated by the ITFM as minimum data elements for facilitating the exchange of existing data are not intended to be adequate to support any ground-water study. Additional essential information about wells includes altitude of land surface, depth of screened interval, depth to nonpumping water level, and so on. Lists of essential and desirable information about wells are provided in the discussion of Support Function F.

Provision of Field and Laboratory Services and Analytical Support (Support Function D)

Field support and services can be divided into (1) well drilling and piezometer installation and (2) water-quality sampling. Much has been written on well drilling and piezometer installation for sampling purposes and, more particularly, about the possible effects, which may be substantial, of casing materials and the installation process on subsequent water-quality sampling (U.S. Environmental Protection Agency 1976, 1984, 1987a, 1991b; Barcelona and others, 1983; Gillham and others, 1983; Korte and Kearl, 1985; Aller and others, 1989; Hardy and others,1989; Dumouchelle and others, 1990; Parker and others, 1990; Nielsen, 1991; Hewitt, 1992; Lapham and others, 1995). Costs of constructing wells suitable for use as reliable sampling sites vary considerably in different parts of the country and depend largely on the rock materials that need to be penetrated (unconsolidated materials or bedrock) and well depth. At present (1997), preferred casing materials for wells that are installed for sampling a broad array of water-quality constituents are polyvinyl chloride (PVC) with threaded joints (not glued) and stainless steel. Furthermore, the process of well drilling and well development may introduce unwanted contaminants into the subsurface; for example, drilling fluids.

The process of water-quality sampling involves (1) purging the well, (2) drawing the sample, and (3) decontaminating equipment after sampling. Field sampling is based on appropriate sampling protocols with a built-in QA/QC plan (see discussion of Support Function B) (Radtke and others, in press; U.S. Geological Survey, 1977, 1980; Koterba and others, 1995). Also essential are appropriate equipment, supplies, and trained field personnel.

The sampling protocols mentioned in the preceding paragraph generally apply to wells. Springs, because of their wide range in physical settings and the different possible approaches to sampling them, do not lend themselves to one standard protocol. Protocols for springs need to be developed on an individual, detailed basis to ensure that sampling procedures are consistent over time and that temporal water-quality data from springs are comparable.

Meticulous documentation of not only all sampling protocols and QC plans, but also the implementation of these protocols and plans and any deviations from them, is an essential part of water-quality data management (see discussion of Support Function C).

Field equipment includes field vehicles and items such as pumps, hoses, tubing, pH meter, and dissolved-oxygen (DO) meter; and field supplies include items such as bottles, reagents, disposable gloves, and so on. In the USGS's NAWQA program, sampling crews use two vehicles—a dirty vehicle (to transport items such as pumps, fuel, some hoses and connections, and so on) and a clean laboratory vehicle (in which to process water samples). Sampling crews usually consist of two or three people, who generally sample two wells per day for a range of water-quality constituents. However, during an initial training or shakedown period and when QC samples are collected, only one well per day usually is sampled.

Immunoassay test kits are a valuable tool for analysis of some analytes, particularly when used with standard laboratory analyses, and are of particular interest because the kits can decrease laboratory analytical costs. A major drawback of these kits is their high detection limits for some analytes. A discussion of the potential application of these test kits in water-quality studies is provided in Appendix C.

To judge the adequacy of laboratory support and services, the qualities of a good laboratory are outlined by the USEPA (1992d, 1995b). These qualities include a comprehensive and consistently executed QA/QC plan for all activities in the laboratory that relate to sample handling, analytical procedures, and reporting of analytical results. Reporting-method detection limits of analytical procedures that are used by the laboratory are a particularly important consideration. The desirable qualities extend to the format for listing analytical results, which needs to be designed for easy transfer into the data base of an organization.

Analytical costs are a major expense in any water-quality study and can easily approach $2,000 (1994) per sample (table 1). However, these costs are somewhat under the control of project staff because the staff can increase or decrease the number of sample analytes and also the number of samples that are collected. In any case, getting the most reliable information possible from these expensive analyses is a common-sense objective. Often, the key to meeting that objective is not in the laboratory analytical steps, but in the field support and sampling steps, as well as in adequate knowledge of the hydrogeologic setting, thus ensuring that the wells sampled are entirely suitable to yield the samples desired. Furthermore, when strategies to reduce analytical costs are considered, it should be remembered that costs of proper sample collection may be similar to the high analytical costs.

Table 1. Mean costs of analyzing environmental ground-water samples by several representative laboratories, 1994[1]

Analyte group	Mean cost (dollars)[2]
General water quality (major ions and dissolved solids)	43
Nutrients	76
Nonmetals	85
Metals	260
Radionuclides	107
Acid and base/neutral hydrocarbons	313
Herbicides	357
Pesticides	381
Volatile organic compounds	380
Total	2,002

[1]Assumptions of cost analysis: (1) Samples are collected in glass jars that are sealed with a Teflon-coated septum. (2) Forms listing the date, time, and sampling location are completed when the sample is collected or shipped. (3) Samples are filtered in the laboratory.

[2]Rounded to nearest dollar.

The issue of the tradeoffs between number of samples and number of analytes is difficult to resolve during the design of a water-quality study (see discussion of Step 8 and fig. 1). Because the long-term value of water-quality samples for, possibly, multiple purposes generally is enhanced by a longer analyte list, the philosophy of doing less to do better may be appropriate in many situations. That is, minimum coverage of an area with proper samples that are analyzed for a broad array of analytes may be more beneficial in long-term data value than more samples in the area that are analyzed for fewer analytes.

Evaluation of Monitoring Program (Support Function E)

Evaluation of monitoring programs is a high-level function of an organization and, from a long-term perspective, should be ongoing. The evaluation may be considered in two parts: (1) Evaluation of individual projects, singly and collectively; and (2) evaluation of the monitoring program as a whole.

Periodic evaluation of a project during its formal term of operation (project review) is a normal and accepted process in all organizations. An ongoing QA/QC plan monitors many project activities, particularly activities related to sample collection, processing, analysis, and entry of information into a data base. A particularly important component of evaluation during each project review is to determine whether or not the forthcoming products of the project (written reports and water-quality data and associated environmental information) meet the project objectives (see discussions of Steps 4 and 7 and fig. 1). If those objectives are not being met, project planning, implementation, and management may need adjustments.

The review of individual projects provides the basic data with which to evaluate the monitoring program as a whole. This evaluation, which may be done yearly or less often, compares the products of all recent projects with the long-term monitoring strategy and plans of the organization (see discussion of Step 3). Continued evaluation and planning for the monitoring program and individual projects are essential to their optimization and success.

Description and Quantification of the Environmental Setting (Support Function F)

The environmental setting comprises the total environmental context in which water occurs and includes all physical, chemical, and biological factors and components that may affect water quality. Sound interpretation and understanding of water quality depends on the availability and reliability of such environmental information. The great importance of environmental information justifies the allocation of substantial resources to assemble this information, if needed, in any successful water-quality study. However, collaboration between organizations that have acquired, or are interested in acquiring, various parts of the information could greatly decrease the need for large resources and could enhance results.

An adequate description of the environmental setting needs information from different spatial scales. Therefore, the following discussion proceeds from a broad-scale consideration of the hydrogeologic framework to a local-scale description of a target well or spring and its immediate environment.

Features that describe the environmental setting, the natural setting and its human-related features, are listed in tables 2 and 3. Much of the information is often or best presented in map form. Many of the listed map coverages are most conveniently prepared, stored, updated, retrieved, and made available to others as GIS coverages.

Having the hydrogeologic framework well defined prior to any water-quality studies in a hydrogeologic unit or group of units is extremely important. Experience indicates that knowing the source of a water sample in terms of its parent hydrogeologic unit decreases potential misunderstanding, even conflict, from technical and management viewpoints. In some geologic settings, for example, structure-contour maps of the tops and bottoms of hydrogeologic units (table 2) may be the only firm basis for assigning hydrogeologic units to screened intervals of wells. Particularly difficult settings in which to work are thick sequences of unconsolidated deposits, such as those sequences beneath the Atlantic Coastal Plain and the thick basin-fill deposits in some parts of the Western United States. In such settings, subsurface stratigraphy and definition of the hydrogeologic framework by means of structure-contour maps may depend heavily on the availability and interpretation of borehole geophysical logs.

A feature in table 3 that relates to human activities is maps showing locations of known point sources of contamination. Often much water-quality and environmental information is collected in detailed studies of these contamination sites. Some of that information—for example, water-quality data for background wells associated with a contaminant plume study [item (5), table 4]—is of value from a regional perspective on water quality. The items marked by an asterisk in table 4 represent a short list that defines a minimum of essential items for a broad-scale assessment of ground-water quality. A small data base of this information, either the short list or the longer list (all of table 4), is a valuable accompaniment to the GIS coverage of the locations of contaminant point sources. Potential sources of ground-water-quality information associated with studies of point sources of contamination, including information from background wells, are the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, see Glossary), Resource Conservation and Recovery Act of 1976 (RCRA, see Glossary), and underground storage tank (UST) programs.

Table 2. Information needed to describe the geologic framework, hydrology, and natural environmental setting of a hydrogeologic unit

Feature	Comments
Information for Surficial or Confined Hydrogeologic Units, or Both	
Areal extent map	If a hydrogeologic unit has a surficial part (unconfined) and a confined part, the boundary between the two parts is delineated.

Table 2. Information needed to describe the geologic framework, hydrology, and natural environmental setting of a hydrogeologic unit--Continued

Feature	Comments
Information for Surficial or Confined Hydrogeologic Units, or Both--Continued	
Geologic map showing areal extent	A geologic map depicts structural features of the rocks and unconsolidated deposits, such as folds and faults, that may have a substantial effect on patterns and rates of ground-water flow.
Types or combinations of lithology	Lithologies include clastic and carbonate rocks, igneous and metamorphic basement rocks, granite and related rocks, basalt flows, and so on.
Types of sedimentary deposits	Sedimentary deposits include alluvial fans, flood-plain deposits, glacial outwash, till, loess, evaporites, and so on.
Detailed description of lithology	This description includes particle size and mineral composition of rocks and sedimentary particles; presence or absence of secondary minerals, such as pyrite, calcite or other carbonates, gypsum, quartz, and feldspar; presence of iron oxide or other types of mineral coatings on sedimentary grains or fracture surfaces; and organic-matter content in sedimentary deposits.
Structure-contour map of top of unit	This map may correspond, in part, to a topographic map of the land surface for surficial hydrogeologic units.
Structure-contour map of bottom of unit	The combination of this map and the structure-contour map of top of unit define the location of the hydrogeologic unit in three-dimensional space. With these maps and basic information on a well, the sampled interval in a well can be assigned to a specific hydrogeologic unit.
Isopach (thickness) map of unit	A thickness map defines the spatial geometry of the unit. Thickness of a unit at a point is one factor in the transmissivity (T) of the unit at that point (see next entry).
Transmissivity (T) map of unit	Transmissivity is a direct measure of the water-transmitting capability of the unit.
Location maps showing test borings and wells with interpretable lithologic logs and borehole geophysical logs	Data from these borings and wells define the hydrogeologic framework.
Potentiometric-surface map	Because horizontal ground-water flow generally is approximately perpendicular to contours of equal hydraulic head, general directions of ground-water flow can be inferred from these maps.
Selected vertical hydrogeologic sections	Hydrogeologic sections include not only the distribution of hydrogeologic units in a vertical section, but the distribution of hydraulic head. A combination of hydrogeologic sections can provide an initial appreciation for directions of three-dimensional flow in the hydrogeologic units.
Approximate water budget of unit	Water budgets of hydrogeologic units are most useful when they are associated with a map of areal extent or a schematic diagram, or both, showing locations and rates of recharge and discharge, approximate flow patterns, and so on. Ground-water flow models are a powerful extension of preliminary water budgets because they permit refinement of water budgets, definition of ground-water flow patterns in and between hydrogeologic units, and estimates of age of ground water by particle tracking, which can be compared with estimates of age by chemical means (see estimate of age entry).
Estimates of age of ground water at selected points in the ground-water flow system	Estimates of age can be obtained by analysis of selected radioactive isotopes, such as tritium, or ratios of isotopes and by analysis of some synthetic organic compounds, such as the chlorofluorocarbons. Age dating places a water sample in the historical time frame of human activity and establishes a time marker in the ground-water flow system. In addition, age dating is a valuable tool in calibrating ground-water flow models by permitting a comparison of ground-water ages determined by chemical means and by particle tracking (see water budget entry).

Table 2. Information needed to describe the geologic framework, hydrology, and natural environmental setting of a hydrogeologic unit--Continued

Feature	Comments
Information for Surficial or Confined Hydrogeologic Units, or Both--Continued	
Information for Surficial Hydrogeologic Units	
Map showing the water table and related surface-water bodies	General directions of shallow ground-water flow obtained from water-table maps permit approximate delineation of ground-water-contributing areas for surface-water bodies that receive ground-water discharge.
Estimates of ground-water contributions to streamflow	Estimates can be obtained by stream-hydrograph separation, by various types of modeling, and by applying methods that use environmental isotopes. A closely related issue is the effect of ground water on surface-water quality.
Map showing depth to the water table, and maps and logs depicting lithologic characteristics of the unsaturated zone	A map of depth to the water table represents the approximate thickness of the unsaturated zone, assuming that no perched ground water is present; however, the capillary fringe may extend the saturated part of the hydrogeologic unit above the water table. The thickness and lithologic character of the unsaturated zone may greatly affect the quantity and quality of recharge water percolating from the land surface that reaches the water table. Like the saturated zone, primary data on the unsaturated zone is obtained from borehole drilling logs, borehole samples and cores, and borehole geophysical logs. Relevant properties include rock type, mineralogy, and grain size of earth materials; vertical permeability; and organic-matter content.
Soils and soil-properties maps	Soils maps[1] have been compiled for much of the Nation at a scale of 1:250,000 and can be obtained in either map or digital format. County maps of soils generally are prepared at scales between 1:10,000 and 1:25,000. Compiled properties of soils, such as drainage characteristics, vertical permeability, and content of organic matter, may be of interest in a particular study.

[1]Obtained from U.S. Department of Agriculture National Resources Conservation Service (formerly the Soil Conservation Service).

Table 3. Features of a hydrogeologic unit that are related to human activities and often are useful in water-quality studies

Feature	Comments
Information for Surficial and Confined Hydrogeologic Units	
Map showing locations of wells screened in the hydrogeologic unit that can be sampled for water quality	Only wells that have sufficient information on construction and other features, such as location and length of well screen, are shown. Wells are further delineated by use (public supply, irrigation, domestic supply, observation, and so on) and by position of the screened interval in the unit (depth below the water table in a surficial unit or depth below the top in a confined unit) or position of the center of the screened interval compared to the thickness of the unit (a decimal fraction between 0.0 and 1.0).
Map showing distribution of pumpage in the hydrogeologic unit	Knowledge of the distribution of pumpage in a hydrogeologic unit may affect the design of a water-quality sampling program for that unit or the interpretation of the resultant data, or both.
Map(s) showing locations of injection wells in hydrogeologic units receiving injected fluids	Injected fluids may contain contaminants. Mixing waters of different chemical content may induce further chemical reactions.
Information for Surficial Hydrogeologic Units--Continued	
Map(s) showing land cover/land use	Depending on the objectives of a water-quality study, several levels of classification for urban and agricultural land may be needed. Geographic Information System coverages of these features and other features listed in this table are most useful.
Maps showing irrigated agricultural areas and associated structures	Irrigated areas are subdivided by source of water—surface water or ground water. If more than one aquifer supplies irrigation water, a further breakdown by aquifer may be useful.
Maps showing agricultural areas in which tile-drainage systems are operative	Tile-drainage systems tend to shift the movement of water from vertical drainage to the water table to lateral transport to surface drains and surface-water bodies.
Maps showing sewered areas	Some septic systems may remain active in sewered areas. Sewer networks that are located above the water table may be a substantial source of contamination to shallow ground water.
Maps showing locations of known point sources of contamination	Such point sources include Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites, military installations, industrial lagoons, State-identified sites, and so on.
Maps showing locations of selected facilities that often are sources of contamination	Such facilities may include tank farms for storage of petroleum products, underground storage tanks, chemical manufacturing plants, equipment-washing sheds, animal feedlots, landfills and other waste-disposal sites, airports, recharge wells, recharge ponds, and so on.
Map showing distribution of population	The presence of specific compounds and the overall degree of degradation of shallow ground water compared to population density has been investigated in some studies. In a sparsely populated area, a detailed study of the quality of shallow ground water may benefit from a map showing all human facilities—homes, barns, sheds, paved roads, commercial establishments, and so on.

Table 4. Information about point sources of contamination that is useful for a broad-scale perspective on water quality

[Asterisks indicate the most important items of information about a point-source contaminant plume for broad-scale assessments of water quality.]

Item	Description
(1)	Geographical Information System coverage of source area and location of contaminant plume at a scale of 1:24,000.
(2)	Criteria for establishing approximate boundaries of plume in map view (text).
*(3)	Latitude and longitude at or near the center of the source area.
(4)	Chemical analyses of source fluids.
*(5)	Well and water-quality data for background well(s) sampled in connection with plume study.
(6)	Well and water-quality data for the well or wells from which the samples have highest concentrations of specified contaminants.
*(7)	Does present location or inferred future movement of the plume endanger the water quality of public supply or homeowners' wells? (Yes, No)
*(8)	Does contaminant plume discharge into a local surface-water body? (Yes, No)
*(9)	List of contaminants that may endanger public-supply or homeowners' wells or may discharge into a surface-water body with the contaminant-plume water.
*(10)	Name of receiving surface-water body (generally, name of pond/lake, creek/stream/river, or wetland)
(11)	Latitude and longitude of center of contaminant plume in map view at shore of surface-water body.
*(12)	U.S. Environmental Protection Agency river mile for latitude and longitude in item (11), if appropriate.
(13)	Well and water-quality data for a representative nearby well, the water quality of which may reflect the quality of water discharging into the surface-water body from the contaminant plume.
(14)	Estimates of loads of selected water-quality constituents entering the surface-water body. [Load estimates may be based on estimated rates of plume discharge into the surface-water body or (for streams) on measured streamflow and concentrations in the stream water.]

One of the most common shortcomings in evaluating previous ground-water-quality data is the use of samples from wells that were not evaluated for their suitability for providing the desired water-quality information (for example, suitable construction features and use of well and knowledge of the specific hydrogeologic source of the water). Two lists of essential information on wells that needs to be available for all wells in a data base, particularly for those wells that are sampled for water quality, are in tables 5 and 6. The first list (table 5) is the USEPA's minimum set of data elements for ground-water quality and consists of 21 data elements. The second, considerably longer list (table 6) is used by the USGS's NAWQA program as a guide. The USEPA's minimum set of data elements may be regarded as a bare minimum; an additional data element that is essential for most water-quality projects is the hydrogeologic unit from which the water sample is derived (see previous discussion in this section). Experience has indicated that many otherwise suitable wells are rejected as sites for water-quality sampling because essential information (tables 5 and 6) about these wells is lacking.

Table 5. Minimum set of data elements (MSDE) for a well that is sampled for ground-water quality (modified from U.S. Environmental Protection Agency, 1992a)

Minimum Set of Data Elements for Ground-Water Quality

The MSDE is comprised of 21 data elements that are divided into the following four categories or descriptors: the general descriptor—describes where the well information is maintained; the geographic descriptors—describe a well or spring in relation to the Earth's surface; the well descriptors—describe various features of a well or spring; and the sample descriptors—describe different aspects of collecting, analyzing, and recording the results from a ground-water sample.

General Descriptor

1. Data Sources—The names of the organizations to direct questions regarding the following data: (1) latitude and longitude coordinates, (2) altitude, (3) well log information, (4) sample collection, and (5) laboratory sample analyses.

Geographic Descriptors

2. Latitude—A coordinate representation that indicates a location on the surface of the Earth using the Earth's equator as the latitude origin, reported in degrees (D), minutes (M), seconds (S), and fractions of a second in decimal format (if fractions of a second are available).

3. Longitude—A coordinate representation that indicates a location on the surface of the Earth using the prime meridian (Greenwich, England) as the longitude origin, reported in degrees (D), minutes (M), seconds (S), and fractions of a second in decimal format (if fractions of a second are available).

4. Method Used to Determine Latitude and Longitude—The procedure used to determine the latitude and longitude coordinates (Technology of Method Used), the standard used for three-dimensional and horizontal positioning (Reference Datum), the method used for map interpolation (Scale of Map), and the date on which the coordinates were determined (Date). Latitude always precedes longitude.

5. Description of Entity—A textual description of the entity to which the latitude and longitude coordinate refers.

6. Accuracy of Latitude and Longitude Measurement—The quantitative measurement of the amount of deviation from true value present in a measurement (estimate of error). It describes the correctness of a measurement.

7. Altitude—The vertical distance from the National Reference Datum for Altitude to the land surface or other measuring point, in feet or meters. If the measuring point is above the National Reference Datum for Altitude, a "+" (plus) sign shall precede the reported altitude value. If the measuring point is below the National Reference Datum for Altitude, a "-" (minus) sign shall precede the reported altitude value.

8. Method Used to Determine Altitude—The method used to determine the altitude value (Altitude Method), the National Reference Datum on which the altitude measurement is based (National Reference Datum for Altitude), and the date the measurement was taken (Altitude Date).

9. State FIPS Code—A Federal Information Processing Standard (FIPS) alphabetic or numeric code to indicate the location of the State (or its equivalent, such as territory or province) in which the well is located.

10. County FIPS Code—A Federal Information Processing Standard (FIPS) numeric code to indicate the location of the county (or county equivalent) in which the well is located.

Well Descriptors

11. Well Identifier—A unique well identifier assigned by the responsible organization.

12. Well Use—The principal current use of the well, or if the well is not currently in use, then the original or principal purpose for its construction.

Table 5. Minimum set of data elements (MSDE) for a well that is sampled for ground-water quality (modified from U.S. Environmental Protection Agency, 1992a)--Continued

Minimum Set of Data Elements for Ground-Water Quality--Continued
13. Type of Log—The type of record-keeping log(s) available for a well.
14. Depth of Well at Completion—The depth of the completed well below the land surface or other measuring point, in feet or meters.
15. Screened/Open Interval—The depth below the measuring point to the top and bottom of the open section in a well reported as an interval in feet or meters. The open section may be a well screen, perforated casing, or open hole.
<u>Sample Descriptors</u>
16. Sample Identifier—A unique number for each water-quality sample collected at a well (Sample Control Number), which references the date (Sample Date); the depth at which each sample is taken, reported in feet or meters (Sample Depth); and the time the sample is taken (Sample Time).
17. Depth to Water—The vertical distance between the measuring point and the water-surface level at a well, corrected to land surface, where the measuring point is not the land surface. This distance should be reported in feet or meters (Measurement Depth), along with the date and time the measurement was taken (Measurement Date and Measurement Time).
18. Constituent or Parameter Measured—Measurement of a physical, chemical, or biological component. The physical, chemical, or biological components are referred to as constituents or parameters.
19. Concentration/Value—The analytical results value, the units of measure used (Analytical Concentration/Value), and the analytical method applied (Analytical Method) to the samples collected.
20. Analytical Results Qualifier—Qualifying information that will assist in the interpretation of the concentration/value, such as whether the value is below the detectable limit or if the constituents (parameters) of interest are present, but cannot be quantified.
21. Quality-Assurance Indicator—The quality assurance of the field protocol plan and laboratory quality-assurance/quality-control (QA/QC) procedures.

A preliminary and informal list of basic information about springs, which is analogous to the lists related to wells in tables 5 and 6, is provided in table 7. Some of the data elements in table 7 are similar to the data elements for wells, particularly elements identifying location. A key data element for springs, which is not pertinent to most wells, is the discharge of the spring at the time of sampling.

dditional information on the spring site and its environment that may be useful or even critical in water-quality studies includes: (1) Further description of the spring [for example, number and type(s) of spring openings, pool area and maximum depth, spring improvements (man-made structures), and extent and type of vegetation in and surrounding the spring pool]; (2) land-cover and land-use information for the neighborhood of the spring [the field form used for wells (fig. 3) that describes nearby land use also can be used for springs]; (3) further information about the spring, such as: type of spring, water-bearing hydrogeologic unit, rock structure associated with the spring, magnitude of spring discharge, variability of spring discharge; and (4) information on QC for existing data.

Table 6. Site characteristics recorded in the Ground-Water Site-Inventory File to extent possible in all sampled wells (from Hardy and others, 1989, table 1)

Code	Site characteristic
C1	Site Identification (station number)
C2	Type of site
C3	Data reliability
C4	Agency code
C5	Project number
C6	District code
C7	State code
C8	County code
C9	Latitude
C10	Longitude
C11	Latitude-longitude accuracy code
C12	Local well number
C16	Altitude of land surface, in feet
C17	Method used to determine altitude
C18	Accuracy of altitude
C19	Topographic setting
C23	Primary use of site
C24	Primary use of water
C28	Depth of well, in feet
C29	Source of depth data
C43	Type of lift
C60	Date of well construction
C65	Method of construction
C66	Type of finish
C67	Type of surface seal
C80	Casing material
C83	Depth to top of open interval, in feet (for each open interval)
C84	Depth to bottom of open interval, in feet (for each open interval)
C91	Depth to top of geohydrologic unit, in feet (for each unit)
C92	Depth to bottom of geohydrologic unit, in feet (for each unit)
C93	Lithologic unit identifier (for each unit)
C161	Well owner
C235	Date water level measured
C237	Water level, in feet below land surface
C238	Status of well at time of water-level measurement
C239	Method used to measure water level
C268	Rated capacity of pump, in gallons per minute
C276	Accuracy of water-level measurement
C321	Begin date for use of water-level measuring point
C322	End date for use of water-level measuring point
C323	Height of water-level measuring point
C324	Description of water-level measuring point
C713	Aquifer-type code
C714	Primary aquifer

Table 7. Information about springs that is necessary to use water-quality data for the springs in a broad-scale assessment of water quality

[USEPA, U.S. Environmental Protection Agency; additional information may be useful or essential in some studies. Asterisks indicate elements that are essential for maximum utility of water-quality information from springs.]

Descriptor classification	Descriptor
Geographic	Station identification number*
	Agency collecting data*
	State FIPS code*
	County FIPS code*
	Latitude and longitude of site*
	Station name
	Altitude of site*
	Hydrologic-unit code*
	USEPA river mile (useful if a spring has a large flow and discharges within a short distance into a surface-water body)
Site	Topographic setting (text)
	Description of site (text)*
	Primary use of site
	Primary use of water
	Spring owner and contact information
	Hydrogeologic unit from which spring discharges*
	Lithologic description of hydrogeologic unit*
	Contributing drainage area of spring* (estimated area, if there is any basis for making an estimate, and comments on how the estimate is made; generally, firm estimates of contributing areas of springs are difficult to obtain)
Sample	Detailed description of where and how the spring is sampled*(text)
	Spring discharge at time of sampling*
	Date of sampling and discharge measurement*
	Time of sampling and discharge measurement*

An essential question about spring-water data, especially existing data, is: "Is the spring or seep sampled as surface water or as ground water?" Probably most large-discharge springs are sampled as surface water. Smaller springs and seeps, however, may be sampled as ground water—for example, by means of a piezometer or a shallow well. The approach to sampling a spring might affect the pH and concentrations of some analytes.

A scale of environmental description that is between the broad scale of the hydrogeologic framework and the point scale of the sampling site is the local-scale environmental setting in the vicinity of the sampling site. An example of the form used to describe the land cover and land use in the neighborhood of the sampling site, which is filled out by field personnel at the time of sampling, is in figure 3. In general, this form is used only for wells that are screened in surficial aquifers or for springs. The form is particularly relevant in studies that attempt to relate water quality of shallow ground water, or of springs, to overlying or nearby land cover/land use. Some studies may use aerial photographs in addition to a field form to specify more precisely land cover and land use near the sampling site. When aerial photographs are used, field checking of observed structures and features is a needed part of the descriptive process.

LAND-USE/LAND-COVER FIELD SHEET - GROUND-WATER COMPONENT OF NAWQA STUDIES - Page 1 (04/93)

1. NAWQA Study-Unit name using 4-letter abbreviation: ____________
Field-check date ___/___/___ Person conducting field inspection: ____________________
Well station-id: ____________________ Latitude: ______________ Longitude: ______________

2. LAND USE AND LAND COVER CLASSIFICATION - (modified from Anderson and others, 1976, p.8). Check all land uses that occur within each approximate distance range from the sampled well. Identify the predominant land use within each distance range and estimate its percentage of the total area within a 1/4-mile radius of the well.

Land use and land cover	Within 100 ft	100 ft-1/4 mi	Comments
I. URBAN LAND			
--Residential			
--Commercial			
--Industrial			
--Other (Specify)________			
II. AGRICULTURAL LAND			
--Nonirrigated cropland			
--Irrigated cropland			
--Pasture			
--Orchard, grove, vineyard, or nursery			
--Confined feeding			
--Other (Specify)________			
III. RANGELAND			
IV. FOREST LAND			
V. WATER			
VI. WETLAND			
VII. BARREN LAND			
Predominant land use			
Approximate percentage of area covered by predominant land use			

3. AGRICULTURAL PRACTICES within 1/4 mile of the sampled well.

a. Extent of irrigation - Indicate those that apply.
Nonirrigated ____ Supplemental irrigation in dry years only ____ Irrigated ____

b. Method of irrigation - Indicate those that apply.
Spray ___ Flood ___ Furrow ___ Drip ___ Chemigation ___ Other ___ (Specify) ____________

c. Source of irrigation water - Indicate those that apply.
Ground water ____ Surface water ____ Spring ____
Sewage effluent ____ (treatment): Primary ____ Secondary ____ Tertiary ____

d. Pesticide and fertilizer application - Provide information about present and past pesticides and fertilizers used, application rates, and application methods ____________________

e. Crop and animal types - Provide information about present and past crop and animal types, and crop rotation practices ____________________

Entered by ________________ Date ___/___/___ Checked by ________________ Date ___/___/___

Figure 3. Field sheet for summarizing observed land use and land cover in the vicinity of monitoring wells that is used by the U.S. Geological Survey's National Water-Quality Assessment program (from Koterba and others, 1995).

LAND-USE/LAND-COVER FIELD SHEET - GROUND-WATER COMPONENT OF NAWQA STUDIES-Page 2 (04/93)

Well station-id: ______________________________ Field-check date: ___/___/___

4. LOCAL FEATURES - Indicate all local features that may affect ground-water quality which occur within each approximate distance range from the sampled well.

Feature	within 100 ft	100 ft - 1/4 mi	Comments
Gas station			
Dry cleaner			
Chemical plant or storage facility			
Airport			
Military base			
Road			
Pipeline or fuel storage facility			
Septic field			
Waste disposal pond			
Landfill			
Golf course			
Stream, river, or creek Perennial __ Ephemeral __			
Irrigation canal Lined __ Unlined __			
Drainage ditch Lined __ Unlined __			
Lake Natural __ Manmade __			
Reservoir Lined __ Unlined __			
Bay or estuary			
Spring Geothermal (> 25 C)__ Nongeothermal__			
Salt flat or playa Dry __ Wet __			
Mine, quarry, or pit Active __Abandoned__			
Oil well			
Major withdrawal well			
Waste injection well			
Recharge injection well			
Other ______________			

Figure 3. Field sheet for summarizing observed land use and land cover in the vicinity of monitoring wells that is used by the U.S. Geological Survey's National Water-Quality Assessment program (from Koterba and others, 1995)—Continued.

LAND-USE/LAND-COVER FIELD SHEET - GROUND-WATER COMPONENT OF NAWQA STUDIES -Page 3 (04/93)

Well station-id: ______________________ Field-check date: ___/___/___

5. LAND-USE CHANGES - Have there been major changes in the last 10 years in land use within 1/4 mile of the sampled well? Yes __, Probably __, Probably not __, No __ If yes, describe major changes.

6. ADDITIONAL COMMENTS - Emphasize factors that might influence local ground-water quality.

Remarks

Figure 3. Field sheet for summarizing observed land use and land cover in the vicinity of monitoring wells that is used by the U.S. Geological Survey's National Water-Quality Assessment program (from Koterba and others, 1995)—Continued.

The importance of developing the environmental-setting information before or concurrently with the full-scale sampling cannot be overemphasized. In the past, considerable effort has been spent on trying to resurrect incomplete or questionable ground-water-quality data by relating those data to modern knowledge of the environmental setting. Usually such working backward is not very fruitful.

The lists of necessary environmental and sampling-site information (tables 2-7) are formidable. However, the information they represent is essential for meeting the objectives of the ITFM. Most of the data in the lists are just as essential to sound, broad-scope understanding of the ground-water quality as human medical histories and life-style information are to planning medical tests and treatment. One of the major advantages of the kind of intergroup collaboration promoted by the ITFM is the possibility of obtaining much of the needed background information from among the collaborating agencies or other reliable sources.

Evaluation of Personnel and Other Project Resources (Support Function G)

Evaluation of personnel and other resources is done more or less continuously in ground-water-quality monitoring programs. In addition to meeting the more general needs of personnel and other resources at the program level (see discussion of Step 2 and Support Functions B and D), a more specific matching of resources to the various tasks of a project is needed at the implementation of a project or study. The following discussion assumes that an adequate budget and basic support functions (Support Functions A-F) are in place for a project, although shortcomings in these essential supports can occur and frustrate the best conceived plans.

For most projects, a specific evaluation of personnel and other resources generally is done during the initial planning for the project (see discussion of Step 4 and fig. 1) and while developing the design for sampling and data collection (see discussion of Step 8 and fig. 1) before field sampling begins. During or between these periods, the equipment, facilities, and personnel services are acquired or arranged for to meet the specific project needs. The more collaboration on the project, the more opportunities are available to meet these specific needs through borrowing of the needed resources and specialists from among participating agencies, universities, and private organizations. Another advantage of collaborative projects may be an enhanced opportunity for training of project personnel on established standards consistent with the national approach, which is one of the main objectives of the ITFM.

The budgeting associated with specific project planning generally is driven by personnel costs. Salaries plus benefit costs for all personnel participating in a ground-water-quality monitoring project usually account for more than one-half of total project costs and commonly exceed 80 percent of the total costs.

Despite its obvious importance, personnel time often is the least well managed of the project resources. Personnel time for field activities, such as well inventories, site visits, well sampling, well drilling, and so on, usually can be estimated fairly well. Time for essential activities in the office, however, such as time to plan a project, to gather and organize environmental information, and to present results (for example, write reports and transfer/share data) often is seriously underestimated. Viewed in another way, discussion of steps in a water-quality project (Steps 4-12, fig. 1) is divided in the Table of Contents and subsequently in this report into three parts: defining specific monitoring projects (Steps 4-7); designing and implementing specific monitoring projects (Steps 8-10); and presenting and disseminating project results (Steps 11-12). As a first cut in allocating personnel time, even with the substantial differences in objectives and scopes of water-quality projects, each of the three groups of project steps may be allocated about one-third of total personnel time. This allocation of time emphasizes the importance of initial planning and careful review of existing data (see discussion of Steps 4-7) and preparation of reports (the principal activity associated with Steps 11 and 12). The substantial time costs of other project tasks that may be overlooked or underestimated include preparation of contracts and procurement; training of personnel; preparation for and attendance at meetings of various kinds; and activities at the end of the project, such as closing contracts, disposing of equipment, and archiving files and data.

During the evaluation of resources, decisions are made about doing all the work in-house, sharing work with collaborating organizations, or contracting out, or all three. Contracts commonly are needed for well drilling and placement of special piezometers for sampling; in addition, contracting out may be needed for highly specialized tasks that are outside the expertise of the lead agency and collaborating groups (or simply because of established policies).

As necessary as they may be, outside contracts can present unforeseen pitfalls just as disastrous to project schedules and budgets as the underestimation of report-writing time. The best results from any contract is ensured by detailed monitoring of contractor activities; the time of a knowledgeable person (often one of the most experienced on the project staff) likely needs to be diverted from other key project tasks to monitor the contract. The ever-present risk of the contractor not performing the contract satisfactorily, coupled with the need to divert key personnel to monitor the contract, often makes contracting out the choice of last resort. Again, collaboration with other organizations that have a vested interest in the monitoring project may offer opportunities to spread the effort as well as the risks.

Defining Specific Monitoring Projects

Definition of Initial Objectives and Scope of Project (Step 4)

The impetus for a water-quality study may come from different sources, including the list of broadly formulated and prioritized projects that are part of the long-term monitoring strategy and plan (see discussion of Step 3). In general, ground-water-quality studies are defined by and reflect (1) the specific objectives, (2) the environmental setting in which the study takes place, and (3) the resources available for the study. By logic and necessity, project objectives and project design are closely intertwined and have a two-way feedback. Design elements that are essential to project objectives include the scale of the study (broad scale or local scale), the hydrogeologic unit(s) or part of a unit that is targeted for sampling, strategy for selecting wells to be sampled (newly constructed project or existing wells and the types of existing wells), and selection of analytes (see discussion of Step 8). Specific examples of different types of monitoring studies, including their differing objectives, are discussed briefly in the “Applying Conceptual Frameworks to Ground-Water-Quality Monitoring Studies That Have Different Objectives” section.

A simple mechanism for formulating and sharpening project objectives is expressing these objectives in the form of questions to be answered. For example, a project objective might be expressed as follows: to carry out a broad-scale survey of the occurrence and distribution of human-related contaminants in ground water in a particular hydrogeologic unit. An alternative and more focused expression might be: Are particular classes of compounds present in the water in a hydrogeologic unit; if so, where are they and what are their concentrations? Such questions and their answers can guide more specific aspects of the study.

Assembly of Available Data and Review of Literature (Step 5)

Assembling and analyzing existing water-quality data and related information for a project is a necessary, demanding, and time-consuming task. National electronic data bases that may contain useful information, even for local-scale studies, include the USEPA's Storage and Retrieval System (STORET) and the USGS's National Water Information System (NWIS). A starting list of data bases for large-basin studies in the USGS's NAWQA program is in table 8. Another potential source of data for broad-scale water-quality assessments is upgradient monitoring wells associated with RCRA and CERCLA sites, where the water quality reflects ambient conditions in the vicinity of the site. Besides the broad-scale data bases, State and local data bases need to be identified and evaluated. For example, potential local sources of valuable water-quality data are some public water-supply purveyors that derive their water from wells. Because public water-supply purveyors are required to test only treated water as it leaves the supply facility, only some (usually large) purveyors may analyze untreated ground water (raw water) to guide their water-treatment process, which makes these purveyors a source of useful data.

Table 8. Data bases containing ancillary data to be used in the National Water-Quality Assessment program (from Hirsch and others, 1988, table 5)

Data base	Description	Reference
Acid Deposition System	Information on the chemistry of wet atmospheric deposition collected at about 400 sites in North America.	Olsen and Slavich, 1986
National Uranium Resource Evaluation	Information on the concentrations of a broad array of trace elements for nearly one million samples in water and sediments from the 48 conterminous States and Alaska, identified by $1° \times 2°$ quadrangles.	Averett, 1984
Natural Resources Inventory	Estimates of sheet and rill erosion for about 800,000 sample plots, aggregated by county and identified according to land use, including cropland, pastureland, rangeland, and forest land.	U.S. Department of Commerce, 1984a
Resources for the Future, Environmental Data Inventory	Estimates of biochemical-oxygen demand, nutrient, and metal loads discharged to United States streams and lakes from about 32,000 industrial and municipal waste-treatment facilities and from runoff from major land uses, including urban, cropland, pastureland, rangeland, and forest land.	Gianessi and Peskin, 1984; Gianessi and others, 1986
Resources for the Future, Pesticide Usage Inventory	Inventory of 184 pesticides used in the United States, identified by crop type and by county.	Gianessi and Puffer, 1986
U.S. Census of Agriculture	Census of farm operators, including county-based estimates of crop, forest, pasture, and range acreage; agricultural chemical and fertilizer use; and inventories and sales of livestock and poultry.	U.S. Department of Commerce, 1984b
U.S. Census of Population	Population in the United States summarized for about 400,000 block groups and enumeration districts; identified by latitude and longitude	U.S. Census Bureau, 1983
U.S. Coal Production	Surface and underground coal production by county.	Mining Informational Services, 1983
U.S. Environmental Protection Agency Industrial Facility Discharge File	Estimated discharge from about 54,000 industrial and municipal facilities having U.S. Environmental Protection Agency permits; identified by permit number in the National Pollution Discharge Elimination System (NPDES) and by river-reach number.	Philip Taylor, U.S. Environmental Protection Agency, verbal commun., 1988.
U.S. Environmental Protection Agency Needs Survey	Estimates of flow and concentrations of biochemical-oxygen demand in the effluent discharged from about 30,000 publicly owned sewage-treatment plants identified by NPDES permit number and river-reach number.	U.S. Environmental Protection Agency, 1982b
U.S. Environmental Protection Agency River-Reach File.	Numeric listing of about 67,000 stream reaches arranged systematically to provide hydrologic linkages among major United States rivers.	Dewald and others, 1987

Table 8. Data bases containing ancillary data to be used in the National Water-Quality Assessment program (from Hirsch and others, 1988, table 5)--Continued

Data base	Description	Reference
U.S. Environmental Protection Agency STOrage and RETrieval System (STORET)	Contains geographic and other descriptive data for water-quality data-collection sites; data related to the physical characteristics and chemical constituents of water, fish tissue, and sediment; information on municipal waste sources and disposal systems; data on pollution-caused fish kills; and daily streamflow data.	U.S. Environmental Protection Agency, 1982a
U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program	Formerly referred to as the National Pesticide Monitoring Program. Monitors temporal and geographic trends in organochlorine chemical and elemental contaminants in the Nation’s freshwater fish.	May and McKinney, 1981; Lowe and others, 1985
U.S. Geological Survey National Digital Cartographic Data Base	Base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analysis. The categories include the Public Land Survey System, boundary, hydrography, transportation, and altitude data at 1:24,000 scale; hydrography and transportation data at 1:100,000 scale; boundary, Census tract, hydrologic unit, Federal land ownership, land use and land cover, and altitude data at 1:250,000 scale; and boundary, transportation, and hydrography data at 1:300,000 scale.	McEwen and others, 1983
U.S. Geological Survey Rock Analysis Storage System	Chemical analyses for more than 500,000 samples of sediments, surficial materials, plants, and rocks from the United States; identified by State, county, and latitude and longitude.	U.S. Geological Survey, 1983
U.S. Geological Survey National Water Information System (NWIS)	Provides for the processing, storage, and retrieval of water data pertaining to surface water, ground water, and water quality.	Edwards and others, 1986
U.S. Geological Survey National Water-Use Information Program	Information compiled for 12 categories of water use for 47 States. Each State has an automated data system that contains site-specific information about the water use in each category. The National Water-Use Data System contains information for the 12 categories summarized by counties and river basins within each State.	Mann and others, 1982

The usefulness of data and information and its accessibility in State and local data sources may differ widely. For example, some ground-water-quality data may include a sound QA/QC plan and some may not, or potentially valuable water-quality data may exist only in paper files and, as a result, are time consuming to use. Before scanning electronic data bases or inspecting paper data files, the data being sought needs to specified and the most efficient means of screening out unwanted or unsuitable data needs to be developed. For example, suitable water-quality data could be unuseable if there is a lack of essential information about the wells.

The experience of the USGS's NAWQA program concerning the availability of existing water-quality data is that considerable data of varying quality are available for standard field parameters, common inorganic ions, and nutrients. From a national perspective, the availability of data on radionuclides, trace metals, and synthetic organic compounds is generally poor, although such data are available in selected areas, particularly for agricultural chemicals.

A literature review for the project provides an overview of work that has been done in the area of concern and includes not only reports from governmental agencies, such as State geological surveys, water boards, water-management districts, irrigation districts, other State agencies, counties, and cities, but also may include university theses or ongoing graduate student research. Environmental impact statements for proposed land or water developments and other engineering-consultant reports should not be overlooked as potential sources of useful information. Even the diaries of early explorers have yielded information about springs (setting, flow, temperature, and so forth). In fact, such historical documents can be invaluable as sources of information about natural (pre-development) conditions. In addition, the literature review may not only identify organizations and individuals that may already have information of interest, which eliminates duplication of effort, but also these same organizations and individuals may be potential candidates for further mutually beneficial collaboration.

Preliminary Evaluation of Existing Data (Step 6)

The following discussion focuses on the evaluation of existing ground-water-quality data that already have undergone a preliminary screening process to determine their possible suitability for inclusion in a project. This preliminary screening process asks two questions and accepts or rejects the water-quality data accordingly—(1) Is critical information available about the well where a sample is taken that is needed to fulfill project objectives? [Examples of such information are location of well, hydrogeologic unit in which the well is screened, and so on (see discussions of Support Function F and Step 5)]; and (2) Are the analytes for a water sample appropriate for study in the project?

As discussed for Support Function B, the next step in evaluating the suitability of water-quality data from an untested data base involves critical evaluation of the QA/QC plan and procedures (that is, collection, analysis, and storage) that produced the existing data. Even if the QA/QC plan is deemed adequate, additional issues routinely arise concerning the evaluation of the data, particularly in the combining of data from different sources into one coherent assessment of water quality. Hamilton and others (1991) and Rupert (1994) are noteworthy for the care with which the different data sources, data issues, and resolution of the issues are described.

One common technique that can be used when data from several different sources are assembled to assess the water quality of a particular hydrogeologic unit is an analysis for errors in the electroneutrality of ionic constituents (ion balance) in a group of water samples. This type of analysis can identify possible analytical errors. In general, potable water that is most susceptible to analytical errors and, therefore, to significant errors in calculations of electroneutrality, is a very dilute water. A statistical analysis of such errors identifies outliers in the distribution of errors and whether that distribution is centered near zero or whether that distribution is centered above zero, in which case a key analyte may be missing from the chemical analysis. A reasonable approach in this evaluation of errors is not to select a pre-determined and arbitrary cutoff error at which a chemical analysis is rejected from the water-quality assessment, but to make decisions on the suitability of data based on the complete distribution of errors (Koterba and others, 1991).

Issues related to single data sets and to combining data sets from different sources include:

(1) Selection of a representative value of an analyte for a well that has multiple samples; commonly used alternatives include the average or median of all concentrations, the highest concentration, and the most recently measured concentration.

(2) Combination of data from filtered (dissolved analyte) and unfiltered (total analyte) samples. In some environments and for some analytes, concentration data from filtered and unfiltered samples are almost identical and may be combined; for other analytes, such as iron, near identity between the two concentrations cannot be expected.

(3) Introduction of a geographical bias into a combined data set, if the component data sets have different geographical coverages. For example, if a large county data set covering part of a hydrogeologic

unit and a smaller State data set covering all of the same hydrogeologic unit are both suitable for inclusion in a study, and if the analyst wishes to use all the data in both data sets, then the two data sets need to be analyzed and reported on separately to prevent introduction of a geographical bias.

(4) Combination of data for an analyte from the same or different data sets for which different detection limits are valid. In general, the highest detection limit is used for the combined data.

(5) Combination of analyses for individual constituents that represent different laboratory analytical methods. Based on a knowledge of the different methods and of the general chemistry of the water being analyzed, combining such data may be reasonable.

In summary, the data analyst needs to (1) be familiar with the data and use good judgment in the evaluation and (2) carefully document the source of the data and how the data are treated. Approaches to analyzing existing or newly collected water-quality data for a project are included in the discussion of Step 10.

Reformulation of Objectives and Development of a Conceptual Model to be Tested (Step 7)

The activities associated with Steps 3, 4, and 7 (fig. 1) all relate to formulating objectives and related plans, but at different levels of planning and with different scopes. In this closely related temporal sequence of activities, the trend is toward refinement and increased specificity in the objectives and plans that are developed. The refinement of objectives in Step 7 is done in response to what has been learned from the assembly and analysis of existing information for the subject water-quality project.

Evaluation of existing information may considerably affect the objectives/design of a project. For example, existing information may indicate the presence of a hitherto unsuspected and critical compound in the targeted hydrogeologic unit. This discovery would result in a lengthened analyte list and the question: "What is the occurrence and distribution of this compound?" If this compound is discovered in the recharge area of the hydrogeologic unit, then the spatial coverage of the study may focus on this recharge area instead of on the entire hydrogeologic unit.

Designing and Implementing Specific Monitoring Projects

Development of Design for Sampling and Data Collection (Step 8)

The design for sampling and data collection is a focal point for virtually all activities in a ground-water-quality monitoring project as indicated in figure 1 by the many arrows pointing to Step 8. Support functions (fig. 1) that have major effects on sampling design include the QA/QC plan and guidelines, the data-management system, the field and laboratory support, the description and quantification of the environmental setting, and the project resources (see discussions of Support Functions A-G). Furthermore, this design step of a monitoring project may be an ideal time to arrange collaborative efforts with other organizations (see discussion of Support Function A) because field sampling and laboratory analysis are expensive, and sharing these costs, as well as personnel and equipment, can benefit all parties.

The special importance of feedback and crossfeed between selected project components is shown in figure 4. Four of these components are shown in the upper large rectangle: objectives of project, environmental setting, existing information, and project resources. As indicated by the arrows, these four project components interrelate closely with one another, in ways not possible to show in figure 1. The resulting total interaction feeds into the design for data-collection component.

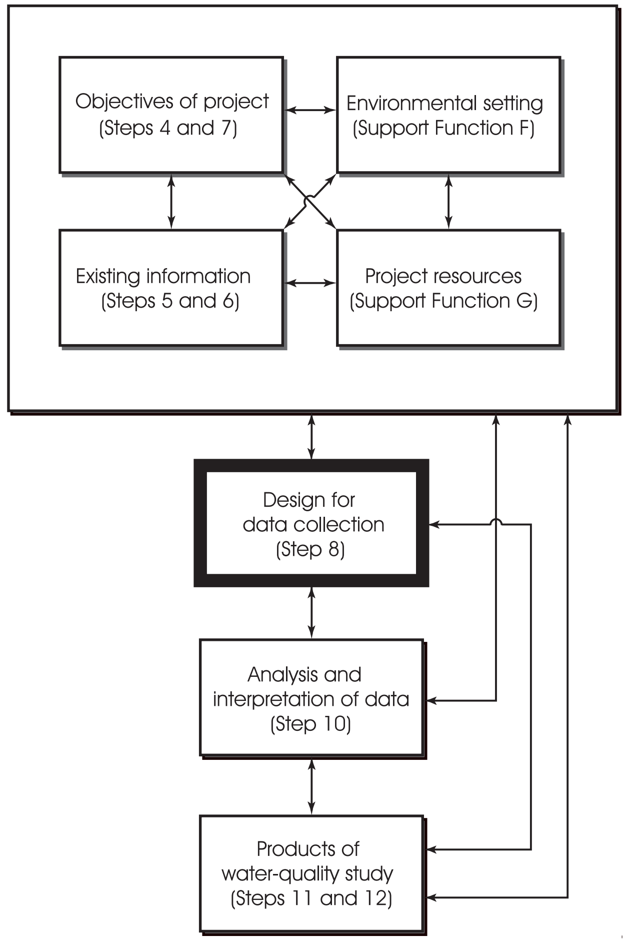

Figure 4. Flow chart showing selected steps and support functions in coordinated ground-water-quality monitoring projects that emphasizes feedback and crossfeed between the selected components, particularly as the components relate to project design for data collection. (Designations from fig. 1 are shown in parentheses.)

Feedback needs to continue beyond the design for data-collection component to include the analysis and interpretation of data and the products of water-quality study components (fig. 4). For example, the initial formulation of project objectives and the design for data collection may be strongly affected by the available methods for analysis and interpretation of data. Therefore, how the project data will be analyzed to best meet project objectives needs to be planned long before the data are collected. Moreover, the products of a water-quality study, the project design for data collection, and the project objectives need to be mutually consistent. Finally, the importance of feedback and crossfeed between the project components depicted in figure 4 (and other components as well) throughout a water-quality monitoring project cannot be overemphasized.

Knowledge of the environmental setting (Support Function F) is needed in project design for data collection (upper part of fig. 4) because not only is general information describing the environmental setting of value, but also specific features of the environmental setting are needed—for example, depth to the water table, bedrock versus unconsolidated hydrogeologic units, and so on—because these features may affect project costs and efficiency.

Step 8 (fig. 1) can be divided into four main tasks: (1) identifying the volume and characteristics of earth material targeted for sampling; (2) selecting the target field parameters and analytes; (3) defining the areal and temporal sampling strategy; and (4) selecting wells to be sampled. These principal tasks are best accomplished in a sequence of work elements and decisions (table 9).

Table 9. Principal tasks in design of sampling and data collection in a ground-water-quality monitoring project

Task	Description
1.	Identifying the volume and characteristics of earth material targeted for sampling
2.	Selecting the target field parameters and analytes (a) Recommended short list of field parameters and analytes for all ground-water samples (table 10) (b) Selection of additional critical analytes
3.	Defining the areal and temporal sampling strategy (a) Number of wells to be sampled to meet project objectives (b) Schedule of repetitive sampling of selected wells
4.	Selecting wells to be sampled (a) Development of criteria for selecting existing wells suitable for sampling (b) Identification of existing wells suitable for sampling (c) Selection of wells to be sampled from target population of suitable existing wells (d) Installation of new wells, if needed, to complete a data-collection network

Identifying the volume and characteristics of earth material targeted for sampling

The first task in designing a well-sampling program is to define explicitly, in three-dimensional space, the volume of earth material that is targeted for sampling. The basic building blocks of the hydrogeologic framework are the locally and regionally defined hydrogeologic units—the three-dimensional bodies of earth material that have been differentiated and defined primarily on the basis of lithology (see discussion of Support Function F). Thus, it is convenient to identify the volume of earth material that is targeted for sampling by the hydrogeologic units or, for surficial units, by the saturated part of these hydrogeologic units. In most water-quality studies, the targeted volume of earth material would be (1) a single hydrogeologic unit, (2) a part of a single hydrogeologic unit, or (3) a combination of two or more hydrogeologic units that are similar in lithology and hydrogeologic setting, but may not be contiguous.

An example of (2) in the preceding paragraph might derive from a need to sample a thick and areally extensive surficial aquifer underlying an intensively farmed area. For this example, existing data indicate that concentrations of agricultural contaminants, such as nutrients and pesticides that are derived from the land surface, decrease rapidly with depth below the water table. To conserve resources, a decision is made to sample this hydrogeologic unit only in the earth material that extends from the average position of the shallow water table down to 50 feet below that average position. This approach concentrates the sampling in the potentially most contaminated part of the aquifer.

An example of (3) in the first paragraph in this section might derive from a need to sample a group of alluvial deposits in a particular drainage basin. These deposits might be roughly similar in lithology and environmental setting, but might not be present as a single, spatially continuous hydrogeologic unit. Nevertheless, all these deposits together may represent a logical target for a focused ground-water-sampling project.

Selecting the target field parameters and analytes

One of the key elements in the design of a water-quality monitoring project, whether the project is focused on background conditions, effects of land use on shallow ground-water quality, or compliance monitoring, is the selection of the properties, elements, and compounds to be measured. The selection of the analyte list is particularly difficult because of the high cost of collecting and analyzing water samples for some of the most critical analytes and analyte groups. The selection of the analyte list, which always involves a detailed evaluation of available project resources (see discussion of Support Function G), including personnel capabilities, is divided into two sub-tasks (table 9): (a) A short list of field parameters and analytes for all ground-water samples and (b) the selection of additional critical analytes.

To be a candidate for monitoring, an analyte generally needs to fulfill any or all of the following criteria:

It is potentially toxic to human health and the environment, livestock, and beneficial plants; for example, pesticides, volatile organic compounds, trace elements, sodium, and nitrogen species.

It impairs the suitability of the water for general use; for example, hardness, iron, manganese, taste, odor, and color.

It is a contaminant in surface water and may be transported from ground- to surface-water systems; for example, nitrogen species and pesticides.

It is an important support variable for interpreting the results of physical and chemical measurements; for example, temperature, specific conductance, major ion balance, and selected isotopes.

Furthermore, one of the principal goals of the ITFM is to encourage collection of water-quality data that (1) are affordable, (2) use well-established analytical methods with minimum detection and reporting levels that are appropriate for achieving the objectives of the study, (3) are comparable between individual studies and between agencies, and (4) are suitable for more than one purpose.

Based on these criteria, the following groups of parameters and analytes are routinely considered for ground-water-quality monitoring projects: (1) Field parameters (temperature, specific conductance, pH, dissolved oxygen, and alkalinity); (2) major inorganic ions and dissolved solids; (3) nutrients; (4) dissolved organic carbon; (5) pesticides; (6) volatile organic compounds; (7) metals and trace elements; (8) radionuclides; and (9) bacteria.

Recommended short list of field parameters and analytes for all ground-water samples

The response of the ITFM GWFG to the goals and lists in the preceding section is to recommend a short list of field parameters and analytes (table 10) as a minimum for all ground-water-quality samples that are collected, irrespective of the objectives of the water-quality study. A primary goal of using this short list is to increase the long-term value of water-quality samples.

The water-quality field parameters and analytes in table 10 correspond to groups (1), (2), and (3) in the preceding section: common field parameters, major ions and dissolved solids, and nutrients. These measures of water quality are chosen largely because they provide a broad characterization of the quality of the water sample that can answer many important questions on the suitability of the water for various uses (table 10). Also, considerable data on these parameters and analytes are already available in existing data bases; therefore, these parameters are potentially useful in identifying trends in water quality. For example, a trend in one (or more) of these analytes, such as nitrate, might be a flag that triggers further sampling, perhaps with a broader array of target analytes, to try to determine the cause of the trend. In addition, these recommended minimum water-quality parameters and analytes were chosen because they are (1) easy to collect in the field compared to other analyte groups (such as synthetic organic compounds) and (2) relatively inexpensive to analyze in the laboratory compared to other analyte groups. The major ions and nutrients can all be analyzed for about $125 (l994) by most laboratories (see discussion of Support Function D and table 1).

Table 10. Recommended short list of field parameters and analytes for all studies related to ground-water monitoring and assessment

Field parameters and analytes	Comments
	Field parameters
Specific conductance pH Temperature Dissolved oxygen Alkalinity	The combination of field parameters and major ions provides the basic characterization of water chemistry in a hydrogeologic setting.
	Major ions and dissolved solids
Calcium Magnesium Sodium Potassium Dissolved solids Chloride Sulfate Total hardness	The major ions determine the general suitability of the water for various uses. In addition, the ions define, in part, the basic geochemistry of the water and permit a calculation of the ion balance.
	Nutrients
Nitrite plus nitrate (combined) Ammonium Orthophosphate	The nitrogen species are potential contaminants at high concentrations compared to usual background concentrations and are a potential indicator of human effects on water quality in many environmental settings.

Many water-quality programs and projects may choose to monitor additional analytes routinely, such as (1) iron (Fe) and manganese (Mn) (water suitability and oxidation-reduction state in water sample), (2) aluminum (Al) (measure of leaching of metals from soils), and (3) a measure of coliform bacteria (possible indicator of human waste). Studies that seek to distinguish between sources of water (for example, ground water and surface water) often use the stable isotopes, oxygen 18 and deuterium, and sometimes use dissolved organic carbon (DOC).

Selection of additional critical analytes

Critical analytes in a monitoring project are the important groups of analytes (5) through (9) listed in the "Selecting the Target Field Parameters and Analytes" section, which include pesticides, volatile organic compounds, metals and trace elements, radionuclides, and bacteria. A suggested general process (fig. 5) for selecting water-quality analytes from these groups is outlined in the following paragraphs (paraphrased from ITFM, 1995, Technical Appendix L).

Stage 1 (fig. 5) in the process is to determine whether there is a recently documented occurrence of the analyte(s) by using existing information. Over the years, ambient water-quality data have been collected by many organizations to address a range of objectives. Much of these data can be obtained from the USEPA's Storage and Retrieval System (STORET) and the USGS's National Water Data Storage and Retrieval (WATSTORE) data bases. Many of these data may be useful for selecting analytes, provided that appropriate care is taken to ascertain how the data were collected and analyzed and the individual environmental settings they represent. For example, information used to establish the occurrence of pesticides and other trace organic contaminants in the environment needs to be based on appropriately sensitive analytical procedures.

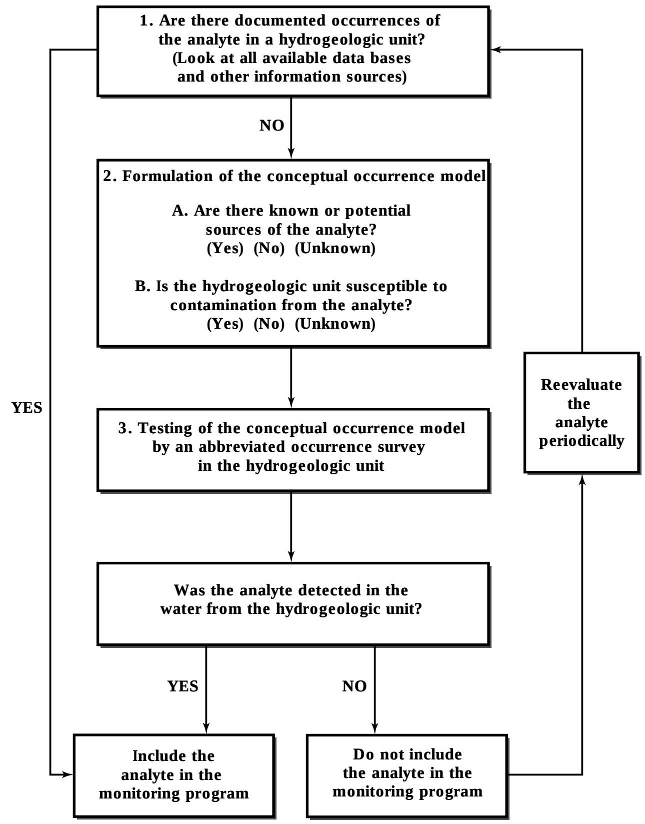

Figure 5. Flow chart showing process for selecting critical analytes to be monitored in water from a hydrogeologic unit (modified from ITFM, 1995, Technical Appendix L).

Additional data, some of which may not be in computer files, may be obtained through contacts with other agencies and organizations or through literature reviews. Municipalities, utilities, and the private sector collect a large amount of water-quality data, often at considerable expense, to comply with statutory and regulatory mandates or for their own use. For example, some (usually large) public water-supply systems may collect ambient water-quality data for use in the operation of their water-treatment systems. These data are not routinely included in national computerized data bases, but may be available from State agencies or individual water utilities and facilities.

Similarly, under the RCRA, hazardous waste facilities are required to monitor ground water upgradient and downgradient from waste-disposal units for contaminants that could be in the waste stream(s) managed by the facility (table 4, items 5 and 6). Many of these data may be useful for providing information on locally important analytes and the occurrence of different analytes in relation to different types of facilities and sources.

In stage 2 (fig. 5), the likelihood that specific analytes, which have not been documented and have not been detected in samples collected from the targeted hydrogeologic unit(s), will be present is assessed. This assessment addresses the question: Is it likely that this potential analyte is present in this (these) hydrogeologic unit(s)? Formulation of a response to this question accounts for what is known about the potential sources of the analyte(s), the physical and chemical properties of the analyte(s) that govern transport through the unsaturated zone and in the saturated ground-water system, and knowledge of the local hydrogeology and susceptibility of the hydrogeologic unit(s) to contamination.

Stage 3 (fig. 5) in the process for selecting critical analytes is especially important because of the limited knowledge and understanding of the occurrence of different critical analytes in ground water. In this stage, the hypothesis that a critical analyte is likely or unlikely to occur in the targeted hydrogeologic unit(s) is tested by an abbreviated occurrence survey. An occurrence survey consists of sampling selected wells in the targeted hydrogeologic unit(s) (see the “Broad-Scale Assessment of the Water Quality of Hydrogeologic Units” section). The number of wells to be sampled is determined on the basis of the size of the study region and the complexity of the hydrogeologic setting. In most instances, the minimum number of sampled wells in the abbreviated occurrence survey probably is between 10 and 25. The lower number (10 wells) might be appropriate for some confined hydrogeologic units in which the expected local-scale (spatial) variability is low, and the higher number (25 wells) might be appropriate for contaminated surficial hydrogeologic units.

On the basis of the results of this survey, the investigator determines whether or not the analyte needs to be included in subsequent sampling. As knowledge of the occurrence of different analytes in different environmental settings improves, the uncertainty associated with understanding of that occurrence, as well as the need for extensive verification, should decrease.

This process is repeated at an appropriate interval (for example, 10 years for ambient or land-use-impact monitoring) or as deemed necessary, given changes in land and water-management activities, chemical-use patterns, or analytical methods.

This approach for selecting water-quality analytes is being implemented by several of the States. For example, Florida has selected the set of monitored analytes in their ambient program on the basis of their understanding of local water-quality patterns and contaminant sources. In regions of intense agricultural land use, Florida uses nitrate and chloride levels in ground water to assess trends in water quality. Similarly, Florida uses certain trace metals (for example, arsenic, barium, cadmium, chromium, copper, mercury, nickel, silver, and zinc) to assess trends in regions of industrial land use.

In conclusion, the suggested process for selecting critical analytes for a monitoring program is conservative in that it is based on carefully collected and analyzed field data. Even if there is only a slight likelihood of finding a particular analyte of interest in ground water (stage 2, fig. 5), this hypothesis is tested by means of data collected in the field (stage 3). Furthermore, the hypothesis of nonoccurrence of a given analyte should be retested periodically.

Information about the presence of pesticides and their transformation products, which are of great concern in current (1997) environmental awareness, is contained in two studies by the USEPA (1990b, 1992c) and in an extensive literature review of monitoring studies for pesticides by Barbash and Resek (1996). This information may assist in selecting target analytes for this important group of synthetic organic compounds.

<u>Defining the areal and temporal sampling strategy</u>

At this point in the project design, the sampling strategy (table 9) involves two issues: (1) The number of wells to be sampled to meet project objectives, and (2) the schedule of repetitive sampling of selected wells. These issues are discussed in the next two sections.

Number of wells to be sampled to meet project objectives

The number of wells sampled depends on the project objectives and the anticipated method of data analysis. For example, the objective of a broad-scale water-quality assessment of a particular hydrogeologic unit is to sample a sufficient number of wells to define the statistical distribution of various water-quality parameters. The most important factor in selecting the number of wells to be sampled is the known or anticipated spatial variability in ground-water quality because if spatial variability is great, a greater number of wells is needed for sampling. In the USGS's NAWQA program, samples from 30 wells are the minimum number that are chosen to meet the goal of this kind of survey. The statistical justification for this number is discussed by Alley (1993, p. 65).

In general, more samples probably are needed for those hydrogeologic units that may have a high degree of spatial variability in water quality. Examples of such units are surficial hydrogeologic units that are overlain by areally extensive, varied, and concentrated human activities. Also, more samples are needed to assess those hydrogeologic units of large areal extent (thousands to tens of thousands of square miles), such as the High Plains Aquifer that underlies the western plains. On the other hand, however, fewer samples may be sufficient to assess broad-scale water-quality conditions in confined hydrogeologic units, in contrast to heavily impacted surficial hydrogeologic units, because often the spatial variability in water-quality conditions is less in the confined units.

Schedule of repetitive sampling of selected wells

Among the large population of water wells in the United States, many probably have not been sampled for water quality even once, and relatively few wells have been sampled more than once. Categories of wells that are sampled on a fixed schedule include (1) some specifically designated monitoring wells associated with known sources of contamination, which may be sampled periodically for extended periods of time; (2) wells to monitor the possible movement of saltwater/freshwater interfaces; and (3) other wells that are sampled specifically to identify possible trends in water quality for any purpose. (The three categories of wells are not mutually exclusive.) The periodic sampling of wells in these three categories indicates changes in water quality that are related to the transport of contaminants in ground water.

Although a one-time sampling of a network of wells often is sufficient to meet project objectives, annual, seasonal, and even monthly sampling sometimes is needed, either for a specified period, longer term, or both. For example, in a farming region where pesticides are intensively applied during 1 or 2 months of the year, the monitoring objective might be to detect maximum concentrations of pesticides in the shallow ground water near the water table. A study approach might consist of seasonal sampling of specially constructed wells that are screened near the water table for a period of 1 or more years and longer term sampling for one season thereafter.

For most other project objectives related to changes in water quality, annual sampling probably is more than sufficient. Even for annual sampling, however, sampling at the same time of the annual hydrologic cycle, particularly for wells that tap surficial aquifers, is wise, to avoid possible complications of seasonal variations in water quality. In general, seasonal variability in water quality in samples from confined aquifers probably is less than from surficial aquifers.

Selecting wells to be sampled

The selection of wells to be sampled is a four-part process (table 9). The emphasis in this discussion is the sampling of existing wells, if such sampling meets project objectives. If a decision is made at the start to sample only newly constructed project wells, parts (a), (c), and (d) (table 9) would indirectly provide appropriate information, even though the discussion does emphasize the sampling of existing wells.

Development of criteria for selecting existing wells suitable for sampling

Criteria for wells that are suitable for sampling may vary for different projects. Therefore, the first step in defining suitable wells is to list (and subsequently document in the monitoring-program data base) an explicit set of criteria that are needed, and information about the well that has to be available for the well to be acceptable for sampling. These criteria also are a starting point in developing specifications for constructing project wells.

The most fundamental criterion is that a well yields water from, and only from, the particular volume of earth material (hydrogeologic unit or units) that is targeted for sampling. A second criterion, the well type (primary purpose for which the well was constructed), relates to existing wells and is a key consideration in judging their suitability for sampling in order to meet project objectives. Well types may be subdivided into two major categories: large-capacity wells and small-capacity wells. Relevant information on these two categories of wells for water-quality sampling is listed in table 11 (Lapham and others, 1995). Sometimes the type of well to be sampled is an explicit part of the project objectives—for example, a water-quality survey of domestic wells or of public-supply wells tapping a particular hydrogeologic unit.

A third criterion involves the construction features of the well (USEPA, 1976, 1984, 1987a, 1991b; Barcelona and others, 1983; Gillham and others, 1983; Driscoll, 1986; Aller and others, 1989; Dumouchelle and others, 1990; Parker and others, 1990; Nielsen, 1991; Hewitt, 1992). Key considerations include:

(1) Length of the access interval—project objectives may not be served by very long well screens (or long open-hole intervals in bedrock wells) because long well screens or open-hole intervals create uncertainties in the actual water source.

(2) Type of casing material—results of sampling for metals may be compromised by metal casing (except stainless steel) and for some volatile organic compounds (VOC's) may be compromised by polyvinyl chloride (PVC) casing, particularly if glued joints are used.

(3) Methods of drilling and developing the well—could introduce contaminants into the strata or change the chemical environment in the vicinity of the wellbore.

In addition to these criteria for selecting existing wells that are suitable for sampling is the availability of detailed information about these wells (see discussion of Support Function F and fig. 1). The process of evaluating the suitability of existing wells for sampling is part of assembling and evaluating existing water-quality information in the different hydrogeologic units (see discussions of Steps 5 and 6 and fig. 1). As indicated in those steps, an important prerequisite for screening existing water-quality data is the existence, preferably in an electronic data base, of basic information on well location, well-construction features, and at least one water level when the well was not being pumped. Two basic lists of essential information about a well are provided in tables 5 and 6. Large numbers of otherwise suitable wells may be eliminated as candidates for sampling because essential information about the wells is lacking.

Identification of existing wells suitable for sampling

Identification of existing wells that are suitable for sampling can be divided into three stages:

(1) Identifying all the wells in existing data bases that are screened only in the volume of earth material (hydrogeologic unit or units) that is targeted for sampling.

(2) Applying a screening process to the wells identified in (1) to determine the subset of wells that meet the explicitly defined suitability criteria for sampling.

Table 11. Advantages and disadvantages of large-capacity[1] and small-capacity[2] wells for sampling ground-water quality

Advantages	Disadvantages
Large-Capacity Wells	
Water samples may provide a large vertical integration of water from an aquifer or aquifer system because of long well screen or long open-hole interval in bedrock and, thus, may provide a more integrated measure of regional ground-water quality.	The usual goal is producing maximum water yield; therefore, long vertical gravel packs or open intervals may span more than one aquifer or aquifer system. The source(s) of water in a long vertical interval often is (are) unknown.
Much of the water produced for public supply and irrigation is from large-capacity wells that allow a direct sampling of the used resource.	Local ground-water flow patterns may be atypical of regional ground-water movement as a result of enhanced vertical flow or compaction of earth materials.
Wells usually are well developed and fully purged because of high pumping rates.	Public-supply wells that produce water not meeting quality standards are often abandoned, making the well population biased toward wells and parts of aquifers that have acceptable water quality.
Long-term access to the well for sampling may be possible, particularly for public-supply wells.	Control of the flow rate may be lacking. Downhole chlorination may be present in public-supply wells. Pump oil can cause local downhole contamination.
Long-term water-quality data may be available, particularly for public-supply wells.	Irrigation wells generally are pumped only seasonally, which can result in seasonal variations in water quality that are an artifact of the pumping regime.
Documentation of well construction for public water-supply and industrial/commercial wells is generally good.	Documentation of well construction for irrigation wells is highly variable.
Small-Capacity Wells	
Well screens or open intervals are generally short, permitting sampling at a point in the hydrogeologic unit. Domestic wells may provide good to excellent spatial coverage in some areas, particularly for near-surface units.	Domestic wells may not be available in urban and suburban areas.
Domestic wells are a major source of supply for the rural population.	Well construction, pressure tanks, and pumps may limit access for sampling or may bias concentrations of some constituents, such as volatile organic compounds. Wells generally are located near houses, septic systems, and other structures, resulting in a tendency for shallow ground water to be affected by local sources of contamination.
Documentation of well construction for monitoring and observation wells is generally good, and data from multiple samples for water quality may be available.	Monitoring and observation wells often are installed for a specific purpose. This purpose may not be compatible with the objectives of a particular water-quality study.

[1]Large-capacity wells include public water-supply, industrial/commercial, and irrigation wells generally yielding ground water at rates of hundreds of gallons or more per minute.

[2]Small-capacity wells include mainly domestic wells and monitoring/observation wells generally yielding ground water at rates of tens of gallons or less per minute.

(3) Evaluating the spatial distribution of wells that are suitable for sampling, not only in map view, but also according to the depths of the screened intervals of these wells in the hydrogeologic unit. This latter evaluation may be enhanced by map plots of depth of screened interval below the water table or depth of screened interval compared to total thickness of the hydrogeologic unit, or both (see discussion of Step 10).

Selection of wells to be sampled from target population of suitable existing wells

To achieve the maximum reliable information about water quality, an investigator has options for selecting suitable existing wells to be sampled or, alternatively, for selecting map locations at or near which project wells are to be constructed. For some projects, the purpose may be to reduce sampling bias by using a predetermined procedure that generally involves a random site selection. (For further discussion of procedures for site selection, see Alley, 1993, chap. 3.) Such procedures usually are applied to broad-scale assessments and surveys of land-use effects on water quality.

An example of a random well-selection procedure for broad-scale water-quality assessment (occurrence) surveys that is used in the USGS's NAWQA program is shown in figure 6. A large ground-water basin (the rectangle in figure 6) is subdivided into its principal surficial hydrogeologic units A, B, and C. Hydrogeologic unit A is targeted for sampling. The area of unit A is subdivided into N approximately equal subareas (only four subareas are shown in fig. 6) by a computer program developed by Scott (1990), where N equals the total number of samples to be collected. The computer program then randomly selects a location in each of the N subareas. A well from a previously developed list of wells suitable for sampling in this hydrogeologic unit that is closest to the randomly selected location in each subarea is designated for sampling. The second closest well to the randomly selected location in each subarea also is selected should the first well not be sampled for some reason, known or unknown.

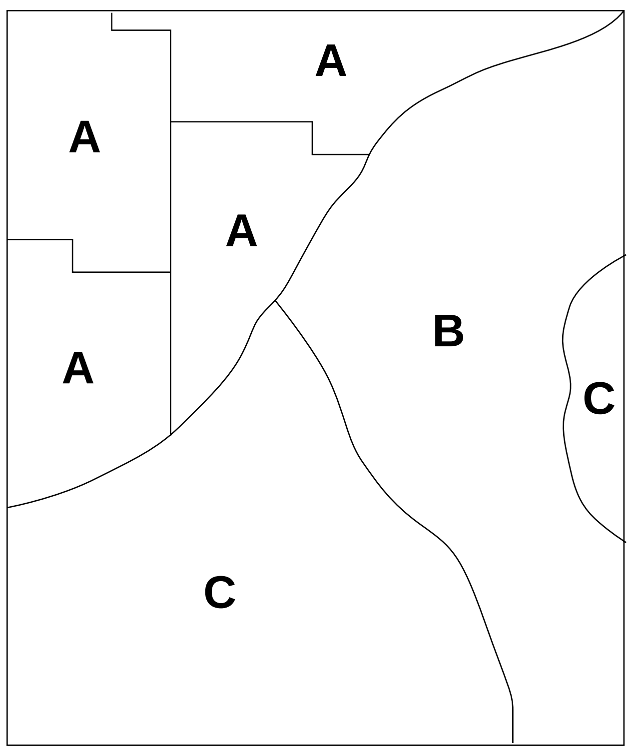

Figure 6. Hypothetical map showing a rectangular study area that is underlain by three surficial hydrogeologic units—A, B, and C. Unit A is subdivided into N approximately equal subdivisions (N = 4) where N equals the number of samples to be collected in an ambient ground-water-quality survey. The equal-area delineation was by means of a computer program developed by Scott (1990).

For other types of projects, well location and design may be based strictly on local hydrogeologic conditions. Guidelines for such situations are discussed in the "Local-Scale Assessments and Research Studies of Ground-Water Quality” section.

Installation of new wells, if needed, to complete a data-collection network

After the determination of the number and spatial distribution of existing wells that are suitable for sampling and the number of wells to be sampled, the next determination is whether a subset of the existing suitable wells can be selected that will meet project objectives. If not, new project wells are needed, either for all samples in the study or to fill in the gaps. Then the question is: "Are resources available to construct new wells?" If resources are not available, reevaluation of project objectives and modification of the design for sampling may be necessary, unless enough resources can be made available through collaboration with other organizations involved in ground-water monitoring.

The obvious advantages of drilling project wells include: selection of the well location and access to the well for sampling and other purposes; designation of the screened interval of the well in the hydrogeologic unit; control over other specific construction features of the well; and possible assurance of long-term availability of the well for sampling. The principal disadvantages of drilling project wells are the potentially large additional cost and difficulties in obtaining permission and legal easements to drill wells at desired locations.

The decision to drill project wells generally is based on lack of availability of appropriate existing wells to meet project objectives, the perceived value of the data to be obtained, and the cost of the drilling compared to existing funds. There are several common examples of situations in which wells may not exist or be appropriate to meet project objectives or may not be suitable for water-quality sampling. One example involves studies that attempt to relate the quality of shallow ground water to overlying land use (land-use monitoring) (see the “Broad-Scale Assessment of the Effect of Land Use on the Quality of Ground Water near the Water Table” section). The most contaminated ground water may be present within a few tens of feet below the water table, whereas most existing wells are screened at depths sufficient to avoid detecting this contamination. Thus, new project wells may be necessary to sample this contaminated zone. A second example may involve bedrock wells that are unlined (open) holes for tens to hundreds of feet. A water sample from such a well probably would represent a mixture of waters from different horizons having possibly marked differences in natural water quality (also, different water ages) and possibly different levels of contamination. This situation would virtually prevent determination of changes in ground-water quality with depth, which is usually a goal of many water-quality studies. Other studies that commonly need the drilling of new wells to meet project objectives are local-scale ground-water-quality studies, such as monitoring near industrial facilities.

One type of monitoring well that often justifies special design and construction is a well that will be used for long-term monitoring—that is, a trends well. Because of the large costs to collect and analyze the samples from such a well over many years, reliability of the data is imperative. The quality of these data may depend on a specific location of the well and its screened interval and on a nonstandard design and construction of the well.

Implementation of Design for Sampling and Data Collection (Step 9)

In this step, logistical concerns that support the field sampling take precedence. Activities involved in preparing for sampling are extensive and may involve months of personnel time. These activities include (1) ordering of equipment and supplies for sampling; (2) training of field personnel in sampling protocols; (3) implementation of the QA/QC program with the training of field personnel (item 2), including analysis of equipment blanks and possibly other types of QC samples and laboratory analysis of preliminary QC samples (needs to be available before the environmental sampling program begins); and (4) visits to all wells to confirm permission to sample, location of well, and accessibility of sampling ports to obtain an appropriate water sample and also to anticipate logistical problems in obtaining a water sample. One common problem is disposal of the water that is pumped during purging of a well prior to sampling, particularly when sampling a domestic well. During the field sampling, QC samples need to be analyzed quickly and the resulting data evaluated as soon as they are available.

Activities in Step 9 also include entering field information related to sampling and laboratory analyses of samples, after appropriate evaluation, into a data base. Furthermore, a comprehensive project plan may indicate continuing efforts to describe the environmental setting associated with the project at all scales and planning and writing sections of project reports during the same time period.

Analysis and Interpretation of Data (Step 10)

The analysis and interpretation of data are guided closely by project objectives and design because the analyzed and interpreted data are the principal results of the project that will be communicated to the constituencies of an organization. Some of the most common information elements in water-quality reports are listed in table 12. These information elements are found in published water-quality studies as table headings, labels in graphs, designations of points and contours on maps, and parameters in multivariate analyses. Many of these information elements can be, and routinely are, related directly to individual water-quality samples or to water-quality data sets. Detailed discussion of analysis and interpretation of data is beyond the scope of this report and is only outlined.

Table 12. Information elements that are useful in water-quality studies

Description of information element	Comments
Water-Quality Parameters	
Constituent concentration	
Property of water	Examples include specific conductance, pH, temperature, and so on.
Presence or absence of a constituent	Reported as detect versus nondetect
Method detection limit of a constituent	Relates to laboratory analytical procedure and is particularly important for trace inorganic and organic constituents.
Ratios of constituent concentrations	
Sums of constituent concentrations	
Availability of Water-Quality Data	
Number of sampled sites	Types of sites include wells, springs and seeps, and ground-water collection galleries; water-quality information is compiled separately for each type of site.
Number of samples	Number of samples at individual sites and total number of samples.
Number of samples in which a particular analyte is present	
Number of samples in which a particular analyte is analyzed for, but is not detected	
Number of samples associated with a particular hydrogeologic unit	
Number of samples that can be associated with a particular land use overlying a surficial hydrogeologic unit	Water-quality data from sampled wells are available for a surficial hydrogeologic unit; a possible criterion for selecting wells that can be associated with a particular overlying land use is the selection of an acceptable sampled interval between the water table and some depth below the water table; for example, the interval between the water table and 25 feet below the water table.

Table 12. Information elements that are useful in water-quality studies--Continued

Description of information element	Comments
Time of water-quality data collection	Water-quality data often are compiled and evaluated for a specified time period.
Location of Sampling Point in Space	
Location in conventional two-dimensional space	Latitude and longitude are standard coordinates.
Location in conventional three-dimensional space	Add depth of sampled interval below land surface or altitude of sampled interval to latitude and longitude.
Location compared to land surface	
(1) Depth to center or top of screened or open interval of well below land surface[1]	This depth notation is suitable for confined aquifers. However, for surficial aquifers with a water table, the subdivision of this single depth into two parts, as shown in item 2, is highly preferable.
(2) For surficial aquifers only, item 1 is divided into two parts: (a) depth to water table (approximate thickness of unsaturated zone) and (b) depth below the water table to center or top of screened or open interval of well (fig. 7).	The time of travel of recharge water through the unsaturated zone, which is directly related to the thickness of the unsaturated zone, may have a substantial effect on the quality of shallowest ground water at the water table compared to recharge water at the land surface. Furthermore, in most hydrogeologic settings, the point of entry of recharge water into the saturated zone at the water table that is sampled at a well becomes more distant upgradient from the well, and the age of the ground water increases, as depth of the sampled interval below the water table increases. As a hypothetical example, the age and chemical history of two water samples that were obtained from 50 feet below land surface in the same hydrogeologic unit—the first sample from 10 feet below the water table and 40 feet of unsaturated zone and the second sample from 40 feet below the water table and 10 feet of unsaturated zone—may be highly dissimilar.
Location compared to total thickness of hydrogeologic unit—expressed as the ratio of the depth of center or top of screened or open interval below the top of the hydrogeologic unit to total thickness of the unit (fig. 8).[2]	Designation of sampling point ranges from 0.0 to 1.0; total thickness of hydrogeologic unit is the saturated thickness of a surficial unit at the sampling location or the total thickness of a confined unit defined by the difference in altitude between the top and bottom of the unit. This detail of sample location helps to determine and describe the depth distribution of sampling points in a particular hydrogeologic unit.
Distance along an assumed ground-water flow path from a specified starting point	Describing and analyzing changes in water chemistry along a ground-water flow path is a highly favored approach to interpreting observed changes in water chemistry in different parts of a ground-water flow system.
Representation of Water-Quality information in Time	
Age of a ground-water sample	Ages of ground-water samples are particularly useful in studies of human-related contamination. Also, the age of ground-water samples, source locations of which are known precisely, are useful in calibration of models that simulate the ground-water flow system.
Traveltime along a ground-water flow path between specified points	Approximate traveltimes between two points on a ground-water flow path can be obtained by (1) difference between sample age dates at the two points, (2) calculations based on Darcy's law, and (3) model simulation of the ground-water system accompanied by particle tracking. Use of all three approaches in concert is beneficial.

Table 12. Information elements that are useful in water-quality studies--Continued

Description of information element	Comments
Conventional time designations	For example, minute, hour, day, month, calendar year, and so on, of sample collection.
Lithology of Hydrogeologic Unit(s) Under Study	
Formal or accepted name of hydrogeologic unit	Found in geologic and hydrogeologic reports; descriptions of lithology can be associated with hydrogeologic units that are under study.
Types or combinations of lithology	Clastic and carbonate rocks, igneous and metamorphic basement rocks, granite and related rocks, basalt flows, and so on.
Types of sedimentary deposits	Alluvial fans, flood-plain deposits, glacial outwash, till, evaporites, and so on.
Detailed description of lithology	Particle size and mineral composition of rocks and sedimentary particles; presence or absence of secondary minerals, such as pyrite, calcite or other carbonates, gypsum, quartz, and feldspar; and presence of iron oxide or other types of mineral coatings on sedimentary grains or fracture surfaces; organic-matter content of sedimentary deposits.
Environmental Setting Associated with Surficial Hydrogeologic Units and Outcrop Areas of Confined Hydrogeologic Units	
Land cover/land use overlying surficial hydrogeologic units	Relating the quality of ground water near the water table to overlying land use is a potentially productive means of evaluating the broad-scale water quality in surficial hydrogeologic units. Agricultural and urban land may have several levels of classification for best correlations.
Differentiation between irrigated and nonirrigated agricultural land	
Differentiation between sewered and unsewered urban land	
Application rates of chemicals and fluids at the land surface	Manure, other fertilizers, pesticides and herbicides, recharge from irrigation water, and so on.
Selected properties of soils	Drainage characteristics (well-drained or poorly drained soils) and organic-matter content.
Selected properties of the unsaturated zone	Thickness, grain-size distribution, moisture content, and organic-matter content.
Average annual recharge rate from precipitation to the water table	Usually expressed in inches per year; recharge rate largely defines the degree of hydraulic linkage between the land surface and the water table. Generally, downward percolation of areal recharge water, which is derived from precipitation, through the unsaturated zone is the principal mechanism of contaminant transport from the land surface to the water table.

Table 12. Information elements that are useful in water-quality studies--Continued

Description of information element	Comments
Population density	Some studies indicate that increasing population density results in increasing contamination of shallow ground water.

[1]The phrase "center or top of screened or open interval of well" is used several times in the table. The difference in depth between the top and center of the well interval that is open to the surrounding hydrogeologic unit is not important in water-quality studies for short open intervals—that is, where the length of this interval is small compared to the total thickness of the hydrogeologic unit. Water-quality data from wells that have long open intervals, however, can be difficult to interpret because the source depth or distribution of source depths (horizons yielding the sampled water) cannot be discerned. For example, a sampled well has a long open interval that extends downward from the water table in an area where the concentration of some water-quality constituents may decrease rapidly with depth. How is the depth below the land surface or below the water table of the sample designated? There is no clear answer to this question. The best approach is to avoid sampling wells that have long open intervals in most types of water-quality studies. In some terrains, however, wells that have short open intervals are few or nonexistent.

[2]Particularly for hydrogeologic units that are areally extensive and thick, the altitudes and the depths compared to land surface of the tops and bottoms of these units can vary widely. As a result, when interpreting a water-quality data set from such hydrogeologic units, the analyst may not know whether any given sample was obtained from the upper, middle, or lower part of the unit and whether the data set adequately represents the hydrogeologic unit for the depth range of the unit. This information element, location (of open interval of well) compared to total thickness of hydrogeologic unit (fig. 8), can help the data analyst decide whether the available water-quality data provide a depth-biased view of the quality of water in the hydrogeologic unit.

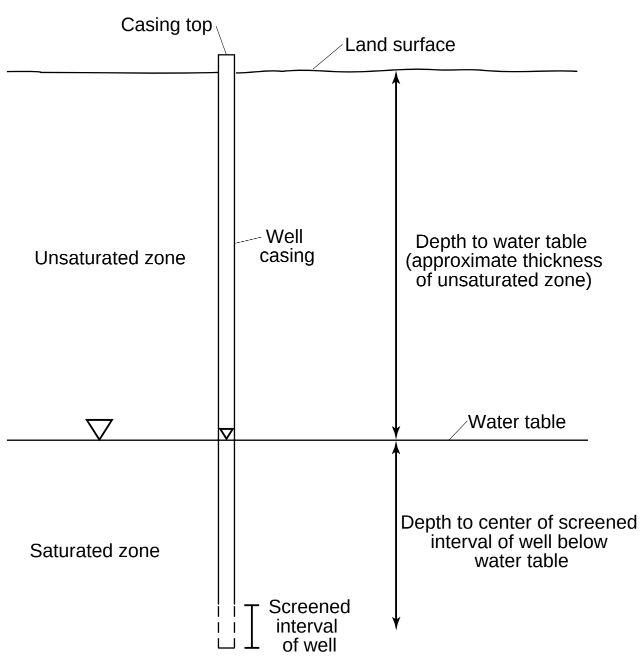

Figure 7. Hypothetical section showing the location of the screened or open interval of a well that taps a surficial hydrogeologic unit, expressed in two parts—depth to water table and depth to center of screened or open interval of well below the water table (table 12).

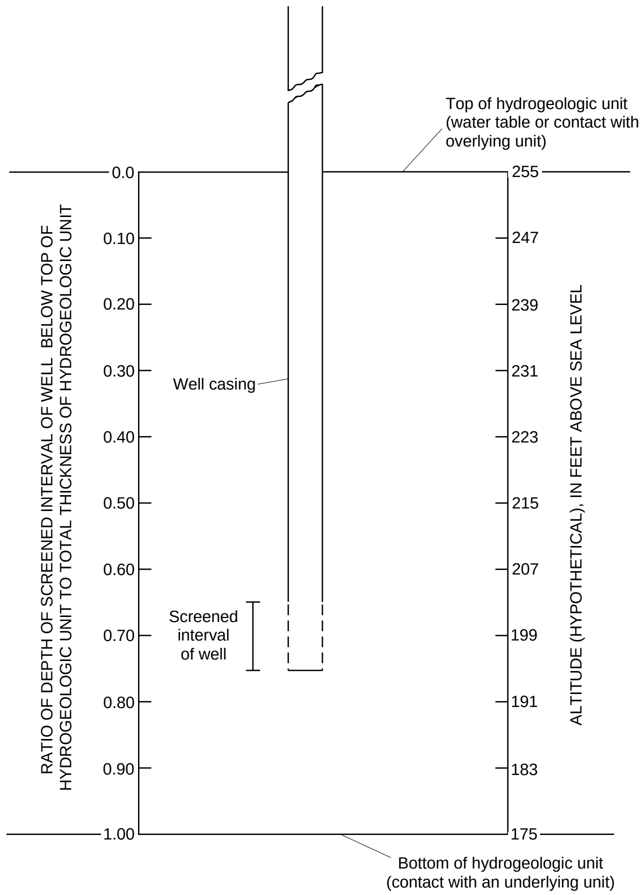

Figure 8. Hypothetical section showing the location of the screened or open interval of a well compared to the total thickness of the tapped hydrogeologic unit (table 12). In this example, the altitude of the screened interval is 195 to 203 feet above sea level, and the relative depth of the screened interval in the hydrogeologic unit is 0.65 to 0.75. This relative depth of the screened interval can be calculated using depth below the land surface or altitude, whichever is convenient.

General approaches to the treatment of water-quality information (table 13) include: descriptive statistics; statistical comparison of data sets; multivariate statistical analyses and related statistical approaches; plots of information on maps; graphical plots; use of information on the environmental setting in various ways; suggested chemical mechanisms (for example, specific chemical reactions) to explain observed water chemistry; formal use of chemical models; and application of unsaturated-flow models, ground-water flow models, and ground-water transport models. Some water-quality studies use mainly one general approach, and other studies may combine elements from several approaches. The necessary data and information in a water-quality study (tables 2, 3, 4, 5, 6, 7, and 12; fig. 3) vary, depending on study objectives and type of analysis and interpretation planned (table 13).

Table 13. General approaches to description, analysis, and interpretation of water-quality data and related information in water-quality studies

Approaches	Comments
(1) Description of water-quality data	Tables and computer files of water-quality constituents and related sampling-site data, and maps showing locations of sampling sites, as in a water-quality data report; minimal or no interpretation of the data is provided.
(2) Description of and comparison between carefully defined water-quality data sets	Data sets may be described and compared for different hydrogeologic units or for parts of the same unit (for example, different horizons of a hydrogeologic unit or from near the water table underlying different types of land use). Boxplots are a powerful graphical tool for describing the distribution of constituent concentrations in a data set and for comparing constituent-concentration distributions between data sets.
(3) Empirical (statistical) modeling	Examples include multivariate, regression, cluster, and factor analysis (Helsel and Hirsch, 1992). One primary purpose of empirical modeling is to determine which factors are most important in explaining water-quality relations.
(4) Geochemical modeling as an analytical and interpretive tool	These tools are particularly powerful for modeling changes in water chemistry along a ground-water flow path. As the previous sentence implies, plots of chemical constituents compared to the ground-water flow system (for example, superposed on a potentiometric-surface map of a hydrogeologic unit) often are an integral part of these studies. Water/rock interactions are a fundamental part of geochemical modeling. Modeling may consist of pencil and paper analyses or application of sophisticated computer codes, or both (Truesdell and Jones, 1974; Plummer and others, 1976, 1983, 1988, 1991; Parkhurst and others, 1980; Ball and Nordstrom, 1991)
(5) Studies of transport and fate of selected chemical constituents and prediction of future water-quality conditions	Tools for these studies include geochemical modeling as in item 4 above and models of unsaturated flow, ground-water flow, and solute transport. Historically, these types of studies have been mainly at the local scale. Broader scale studies using these same or modified tools might be useful (Konikow and Bredehoeft, 1978; McDonald and Harbaugh, 1988; Pollock, 1989, 1990; Hill, 1992; Zheng, 1992)

The general approaches and tools for obtaining, analyzing, and interpreting water-quality information (table 13) can be placed in two broad categories: (1) statistical and (2) physically based or deterministic. Both of these categories are widely applicable. Statistical tools are useful for describing and comparing data sets and for developing hypotheses as to which variables seem to affect water quality most. Thus, the statistical viewpoint may be a central element in study design. The physically based approaches and tools basically develop and test hypotheses that indicate which specific physical/chemical mechanisms are functioning to produce the observed water quality; thereby, these approaches and tools increase the understanding of cause and effect on water quality.

Fundamental controls on the quality of ground water, which has not been affected by human activities, are (1) the lithology and mineralogy of the sediments and rocks in which the ground water occurs, and (2) the length of time during which the ground water and earth materials can interact. In general, as a parcel of ground water moves along its flow path, there is a tendency for dissolved solids to increase.

Furthermore, in large regional systems, the chemical character of the ground water may change markedly along long flow paths. For example, in the shallow part of regional ground-water systems that are well flushed with fresh ground water, the predominant anion is generally bicarbonate (HCO_3); at intermediate depths having slow-moving ground water, sulfate (SO_4) may become predominant; and at still greater depths, where little or no flushing has occurred and the ground water is almost stagnant, chloride (Cl) is the predominant anion. These observations indicate that insight into differences in ground-water quality may be obtained by relating the observed water quality to the local and regional flow patterns in the surrounding ground-water flow system. Furthermore, additional insights can be obtained by mineralogic and chemical analysis of the matrix materials in which the ground water occurs. The relation of water quality to the ground-water flow system can be represented in many physically based computer models (table 13). However, insight into this relation can be obtained without the use of these sophisticated tools—for example, by plotting water-quality data on maps that also show the potentiometric surface (and, by inference, the general directions and lengths of ground-water flow paths) for the hydrogeologic unit under study.

Presenting and Disseminating Project Results

Compilation and Presentation of Results (Step 11) and Dissemination of Products to Constituencies of Participating Agencies (Step 12)

The discussion in this section assumes that at least preliminary analysis and interpretation of project data have been done during Step 10. Furthermore, because presentation of results and preparation of report products were not discussed earlier in this report, some remarks and suggestions on these topics will refer to previous steps and times in the development of the project. The results of a typical ground-water-quality study include: (1) Water analyses and other basic data; (2) maps of the study area and, usually, more detailed maps of specific parts of the study area; (3) tables, graphs, and other illustrations that depict and support the analysis and interpretive aspects of the study; and (4) written descriptions that convey information about all of the preceding items.

During the compilation of the project information, the advantages of electronic files become apparent. The entry of the basic data into standard computer files and the spatial information into GIS allows the digital data to be retrieved and portrayed in a variety of ways by the use of various computer software programs.

The compiled information may be used directly or may, at least, be the basis for preparation of the final information products for the project. In the sequence shown in figure 1, the products expected from the project are specified in the early planning and coordinating steps. For efficient progression into that final step, the various compilations need to fit the formats and other design requirements of the final information products. All too often delays are incurred, compilation work needs to be redone and, thereby, chances of errors are increased because graphs (hydrographs especially), maps, or tables are compiled in nonpublishable or otherwise unusable formats. Also, the compilations that are unlikely to change in the latter stages of the project need to be made as soon as is practical.

Presenting the results of a water-quality study in various ways and delivering the tangible products to appropriate constituencies represent the final steps and culmination of intense effort by the project staff. Examples of useful and accepted methods for information transfer include: (1) Verbal presentations by project staff at meetings of various kinds; (2) news reports and television interviews; (3) community outreach programs; (4) sharing/transfer of data sets, preferably in electronic form, between organizations; (5) published data reports; (6) letter reports to participating organizations and to constituencies; and (7) published interpretative reports. To provide maximum accessibility and use of study data, analyses, and results, all information products need to be planned from the start for availability and dissemination in electronic form. Access via Internet Home Pages may be a preferred mechanism for product dissemination in the future.

Published reports can be targeted to different audiences—for example, students at various levels, the general public, water managers, legislators and their staffs, and the technical community. Often, technical project personnel have particular difficulty in communicating their findings to audiences other than their technical colleagues. Various measures may be needed to improve the communication skills of the technical staff, such as special training in writing different types of reports and availability of highly trained publications staffs to assist in preparation of text and visual displays of all kinds.

The time needed to implement the various methods of information transfer, particularly for published interpretive reports, is routinely underestimated, resulting in cost overruns and diminished quality or delayed delivery of promised products, or both. This shortcoming underscores the need to begin the interpretation of data and preparation of the information products as early as possible during other project steps. For example, clear statements of the objectives and scope of the project need to be available from the planning and coordinating steps for the project (Steps 1-4) to keep the later project steps on track. These objective-and-scope statements can be combined with descriptions of the hydrogeologic setting, culture, and so forth, to create introductions to a variety of information products and to decrease the later tasks of product preparation. Early preparation of maps, data tables, and other information elements that are not likely to change during the project can greatly facilitate the completion of Step 12.

Some technical report specialists suggest writing a draft of an entire report, including descriptions of the investigational steps and expected results. Other report specialists argue that forecasting the results tends to create bias in the interpretations. In any case, whichever method is used, usually, more than one-half of the final report could be written before the project data are fully analyzed. Early preparation of the information products facilitates the quality and timeliness of the promised products, which are the tangible results by which the success of the project is judged. Generally, a small number of tightly focused reports can be prepared more efficiently than one long report. Furthermore, the short reports often receive a more favorable response from the constituencies of an organization.

If report-writing capability in the project is a problem, contracting out the preparation of the information products might be a choice. However, the same cautions previously discussed in Support Function G for general contract work apply, especially to the information products of a project. Satisfactory preparation of these report products by a contractor needs intense collaboration and follow-up by the most knowledgeable member(s) of the project staff.

APPLYING CONCEPTUAL FRAMEWORKS TO GROUND-WATER-QUALITY MONITORING STUDIES WITH DIFFERENT OBJECTIVES

The previous chapter presents conceptual frameworks for the design and implementation of ground-water-quality monitoring programs and projects. This chapter presents selected examples of water-quality monitoring projects that have different objectives and emphasizes salient features of project design. These examples continue the consideration of various features of project support, design, and implementation that were emphasized in the previous chapter, namely that:

(1) Collaboration between organizations in water-quality studies has the potential for decreasing costs and enhancing these studies by shaping the objectives and design of water-quality projects to meet the needs of a larger number of constituencies (Support Function A, fig. 1).

(2) Consistent implementation of a sound QA/QC plan for collection, analysis, and archiving of water-quality data is essential to support the integrity of these data (Support Function B, fig. 1).

(3) Increased ease and reliability of data transfer between data bases of organizations is a boon to all participants (Support Function C, fig. 1).

(4) Extensive and organized information about the environmental setting for water-quality studies is the basis for sound interpretation and understanding of water-quality data (Support Function F, fig. 1).

(5) Water-quality data are collected that can be used for more than one purpose (Step 8, fig. 1; table 10).

(6) Reliable, focused, and unambiguous project products (reports or data compilations, or both), delivered in timely fashion, are essential for meeting the objectives of the monitoring project and program (Steps 11 and 12, fig. 1).

Broad-Scale Assessment of the Water Quality of Hydrogeologic Units

Broad-scale assessments, or occurrence and distribution surveys (which are essentially equivalent to ambient water-quality surveys), of hydrogeologic units are characterized by (1) a wide spatial coverage and (2) a broad array of analytes. The principal purposes of these broad surveys are to provide evidence for naturally occurring constituents including contaminants and contaminants related to human activities that are present in water samples derived from a hydrogeologic unit and to provide an indication of their concentrations and geographic location. Salient features in the design of these surveys are presented in table 14.

Table 14. Attributes of a broad-scale assessment of the water quality of a hydrogeologic unit or group of units (occurrence and distribution survey)

Attribute	Explanation
General objective	To supplement existing data by providing a broad overview of ground-water quality in a targeted hydrogeologic unit or group of units—an occurrence survey and the beginning of a study of spatial distribution of water-quality constituents in the hydrogeologic unit(s).
Volume of earth material that is targeted for sampling	Generally, an entire hydrogeologic unit or group of units; in thick hydrogeologic units in which significant changes in water quality with depth are known or anticipated, dividing the hydrogeologic unit into two or more parts based on lithology or depth, or both, may be advisable; then these parts would be sampled as separate entities.
Existing wells or new wells	Generally, existing wells are sampled exclusively.
Number of wells to be sampled	A minimum of 30 wells; number depends, in part, on the quality and breadth of analyte coverage of existing water-quality data and on the known or anticipated spatial variability in water quality; for example, in some surficial hydrogeologic units, a considerably larger number of wells may be needed for a reasonable occurrence survey compared to some deeper confined hydrogeologic units.
Well-selection strategy	A random component in well selection is highly desirable; sampling as few different types of wells as possible is advisable as long as the desired spatial coverage is achieved.[1]
Temporal sampling strategy	Most wells are sampled once unless (1) the entire assessment survey is repeated at some later (generally 10 years or more) time or (2) a well(s) is (are) selected to be part of a long-term monitoring (trends) network that is sampled at a fixed time interval.
Selection of analytes	Broadest array of analytes, including recommended minimum analyte list (table 10), all of which are analyzed at a method detection limit (MDL) that is low enough to meet project and monitoring-program objectives.

[1]Water-quality samples from each type of well may have a particular, but unknown, bias (Step 8). The advantage of sampling a single type of well is that all samples in a survey have a similar bias in contrast to a mixture of biases if several well types are sampled.

Because resources are frequently limited, a recurring issue in the design of any ground-water-quality survey, the objective of which is to provide an overview of water quality for a particular study area, is the trade-off between the number of wells sampled versus the number of analytes for each sample. That is, the question is whether to sample fewer wells using a longer list of analytes or to sample more wells using a shorter list of analytes. Undoubtedly, both approaches could be applied in different situations. Selection of the best approach in a given situation probably depends, in large part, on the quantity and suitability of existing water-quality data for the particular study area to meet project objectives. If, as is often the case, very few data exist in a study area for critical contaminants, such as pesticides and VOC's, an initial survey using fewer wells and a longer list of analytes may be appropriate. The survey outlined in this section uses this preceding approach. Based on the results of the initial survey, a subsequent survey may involve a larger number of wells and a more focused analyte list. If, however, existing data are already sufficient to define a more targeted analyte list, then an areal water-quality survey may consist of more wells and the shorter, more targeted list of analytes.

In a long-term monitoring program by an organization, the occurrence surveys outlined in this section provide a firm basis for planning and implementing (or deferring) additional more focused water-quality studies in the targeted hydrogeologic unit. Ideally, these surveys are repeated periodically in the most used and vulnerable hydrogeologic units (see discussion of Step 8).

Water-quality data from these surveys usually are reported in detection and non-detection summaries and as concentration distributions of selected chemical constituents. Interpretation of the occurrence and distribution of selected chemical constituents may be enhanced greatly by relating the water-quality information from each sampling site to the local ground-water flow system and to pertinent information on the environmental setting.

Broad-Scale Assessment of the Effect of Land Use on the Ground-Water Quality near the Water Table

The primary goal of published land-use monitoring studies has been to characterize the effect of human activities at and near the land surface on the quality of the most shallow ground water (water-table aquifer), which could, however, be as deep as several hundred feet below the land surface in some parts of the Nation. Particular features of land-use surveys are (1) a restricted volume of earth material, sometimes only a small part of thick surficial hydrogeologic units, that is targeted for sampling; and (2) a broad array of analytes. Comments on salient features in the design of land-use surveys are provided in table 15.

Table 15. Attributes of a broad-scale assessment of the effects of land use on the ground-water quality near the water table (land-use monitoring)

Attribute	Explanation
General objectives	To examine natural and human factors that affect the quality of ground water at or near the water table underlying different types of land use.[1]
Volume of earth material that is targeted for sampling	At the time of sampling, the open interval (screened interval) of the sampled wells is between the water table and a specified depth below the water table—for example, 25 to 30 feet below the water table—and the well is overlain by the targeted land use.
Existing wells or new wells	New wells are an option to be considered; the decision depends on the presence or absence of existing wells that have appropriate screened intervals and the cost of new wells, which, in turn, depends on depth to the water table and lithologic type(s) of earth materials to be drilled (primarily unconsolidated versus consolidated earth materials).[2]
Number of wells to be sampled	Minimum of 30 wells (Step 8) for one combination of a particular land use and a particular surficial hydrogeologic unit.
Well-selection strategy	A random component in the procedure for selecting existing wells or locations for new wells is highly desirable.
Temporal sampling strategy	Most wells are sampled once unless (1) the entire assessment survey is repeated at some later date (generally 10 years or more) or (2) a well(s) is (are) selected to be part of a long-term monitoring (trends) network that is sampled at a fixed time interval.
Selection of analytes	Broadest array of analytes, including recommended minimum analyte list (table 10), all of which are analyzed at a method detection limit (MDL) that is low enough to meet project and monitoring-program objectives.

[1]This type of survey generally targets the effects of nonpoint sources on shallow ground-water quality, as in agricultural settings, or the effects of nonpoint sources and of many point sources, as in urban/suburban settings. Contamination resulting from strong point sources generally is not targeted, but may be sampled inadvertently.

[2]These comments indicate that serious consideration of newly drilled project wells in land-use surveys is needed. A potential difficulty in data interpretation may arise if a single land-use study collects water-quality data from existing wells and from project wells. In addition to possible differences in well construction that may affect water quality, the placement of the well screen compared to the water table may differ markedly between existing wells and project wells. Project wells presumably would have short screens that are located a few feet below the lowest expected altitude of the water table. Screened intervals in existing wells may be routinely located at a greater depth below the water table. If concentrations of key constituents decrease rapidly with depth, the water from the two types of wells may have consistent differences in concentrations.

Specific ground-water-quality indicators (see Glossary) that may be appropriate for monitoring in areas having different types of land use and sources of contaminants are listed in tables 16 and 17. The indicators listed in table 16 are associated with municipal, domestic, commercial, and agricultural land use, and the indicators in table 17 are associated with manufacturing and industrial land use. These listings provide a starting point for selecting the types of analytes and analyte groups in ground-water monitoring programs to be used to assess the effects of land use on shallow ground-water quality. These two tables were developed by the GWFG and are contained in the final report of the ITFM (1995, Technical Appendix L).

Table 16. Ground-water-quality indicators likely to be associated with different land uses and contaminant sources (from ITFM, 1995, Technical Appendix L)

Parameters	Land use[1]											
	Municipal			Domestic			Commercial			Agricultural		
	Landfill	Sewer/ pipeline	Other uses[2]	Sanitation	Storage[3]	General use[4]	Irrigation	Sanitation	Commercial property[5]	Irrigation	Animal feedlots	Cultivation
Physical												
Color	X	X	X	X	X	X	X	X	X	X	X	X
Odor	X	X	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X	X	X
Specific conductance	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X
Total dissolved solids	X	X	X	X	X	X	X	X	X	X	X	X
Common ions	X	X	X	X	X	X	X	X	X	X	X	X
Volatile organic compounds	X[6]		X[6]		X[6]		X[6]					
Perchloroethylene	X											
Trichloroethylene	X						X					
Trichloroacetic acid	X						X					
1,1 Dichloroethylene	X						X					
Methylene chloride	X						X					
Vinyl chloride	X						X					
Semivolatile organic compounds	X[7]		X[7]		X[7]							
Pentachlorophenol	X											
Polycyclic aromatic hydrocarbons	X											
Dioxins	X											
Polychlorinated biphenyls	X											
Petroleum hydrocarbons	X		X		X	X			X			
Benzene, toluene, ethylene, xylene	X	X	X		X				X			
Pesticides			X			X	X		X	X	X	X
Trace metals	X	X										
Arsenic	X	X										
Cadmium	X	X										
Chromium		X										
Lead	X	X										
Nickel		X										
Zinc		X										
Nitrate		X	X	X		X	X	X	X	X	X	X
Biological		X	X	X		X		X				
Pathogens		X	X	X		X		X			X	

[1]This is a subset of possible land use and source terms. They are intended as examples for indicator use.
[2]Municipal activities might include vehicle maintenance areas and salt storage piles.
[3]Domestic storage includes such things as underground oil and gas storage tanks.
[4]General domestic activities include domestic lawn fertilization and home and garden pesticide use.
[5]Commercial property includes retail stores and office buildings.
[6]As appropriate to suspected contaminants; for example, trichloroethylene might be useful indicator around maintenance areas where degreasing operations are untertaken.
[7]As appropriate to suspected contaminants; for example, pentachlorophenol might be a useful indicator around lumber storage areas.

Table 17. Ground-water-quality indicators likely to be associated with manufacturing or industrial activities (from ITFM, 1995, Technical Appendix L)

[This is a subset of possible land use and source terms. They are intended as examples for indicator use.]

Parameters	Chemical			Electrical	Landfills/waste sites					Mining		Lumber	Pesticides	Petroleum	
	Battery recycling	Solvents	Munitions	Plating	Poly-chlori-nated biphenyls sites	Dioxins and furans sites	Landfills	Organics sites	Metals/ organics sites	Mining waste	Asbestos	Wood treatment	Manufacture/ storage/load-ing	Refining storage	Gas stations
Physical															
Color	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Odor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Specific conductance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total dissolved solids	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Common ions [1]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Volatile organic compounds															
Perchloroethylene		X	X	X	X		X	X	X					X	
Tetrachloroethylene		X	X	X	X			X	X				X		
Trichloroethylene		X	X	X	X		X	X	X		X	X	X	X	
Trichloroacetic acid		X		X	X		X	X	X						
1,1 Dichloroethylene		X		X	X		X	X	X				X		
Methylene chloride		X	X	X	X		X	X	X						
Vinyl chloride		X			X		X	X	X				X	X	
Semivolatile organic compounds [2]		X		X	X	X	X		X			X	X		
Pentachlorophenol												X		X	
Polycyclic aromatic hydrocarbons [3]		X								X		X	X		
Dioxins and furans						X									
Polychlorinated biphenyls				X	X				X			X		X	X
Petroleum hydrocarbons			X										X	X	X
Benzene, toluene, ethylene, xylene		X	X	X	X		X	X	X		X	X	X		
Pesticides [4]													X	X	
Trace metals	X	X	X	X	X		X	X	X		X	X	X		
Arsenic	X	X	X	X	X		X	X	X	X		X	X		
Cadmium	X	X	X	X	X		X	X	X	X	X		X		
Chromium		X	X	X	X		X	X	X	X		X	X	X	
Lead	X	X	X	X			X	X	X	X		X	X		
Nickel		X	X	X	X		X	X	X	X	X	X	X		
Zinc		X	X	X	X			X	X	X		X	X		
Radionuclides			X							X					

[1]Chloride and sodium ions may serve as indicators of salinity. An ionic balance may provide a fingerprint for comparison of ground-water quality in different areas.
[2]Semivolatile organic compounds are the second most frequently detected class of organic priority pollutants and also may be suitable for some types of leak detection.
[3]Polycyclic aromatic hydrocarbons are prevalent in petroleum, coal, and wood-treatment products and are pervasive in commercial and industrial processes and wastes.
[4]Pesticides that are appropriate for use as ground-water indicators will vary regionally according to crops and agricultural practices.

The entries in table 16 associated with irrigation and cultivation (under agriculture) and those entries under commercial and domestic (urban settings) best fit the broad-scale nature of the survey that is outlined in this section. Most other entries in table 16 and the entries in table 17 generally relate to point sources and may be appropriately referenced to local-scale studies of ground-water quality, as discussed in the "Local-Scale Assessments and Research Studies of Ground-Water Quality" section.

Based on existing studies (for example, Eckhardt and Stackelberg, 1995), shallow ground water beneath urban and agricultural land is more contaminated by various constituents from different human-related sources at the land surface than ground water underlying other types of land use. The exception is ground water beneath some point sources of contamination. Major questions to be answered are: whether the contaminated ground water near the water table would remain in and affect water supplies only in the surficial hydrogeologic unit; whether the contaminants would move to deeper hydrogeologic units that are used for water supply; or whether the contaminants would discharge into surface-water bodies and degrade their water quality. These questions can only be addressed through detailed knowledge, usually obtained, in part, from model simulation, of the associated ground-water flow system.

Monitoring of ground-water quality in areas of land use other than urban and agricultural, such as forest and rangeland, generally indicates lower levels of contamination and different constituent groups. Analysis of water-quality data related to land use has consisted mostly of comparisons of the distributions of concentrations of selected constituents between different types of land use by boxplots (fig. 9). Often these comparisons of water quality are between different types of agricultural or urban land use, such as different crop groups or different categories of urban land—for example, suburban, industrial, and commercial.

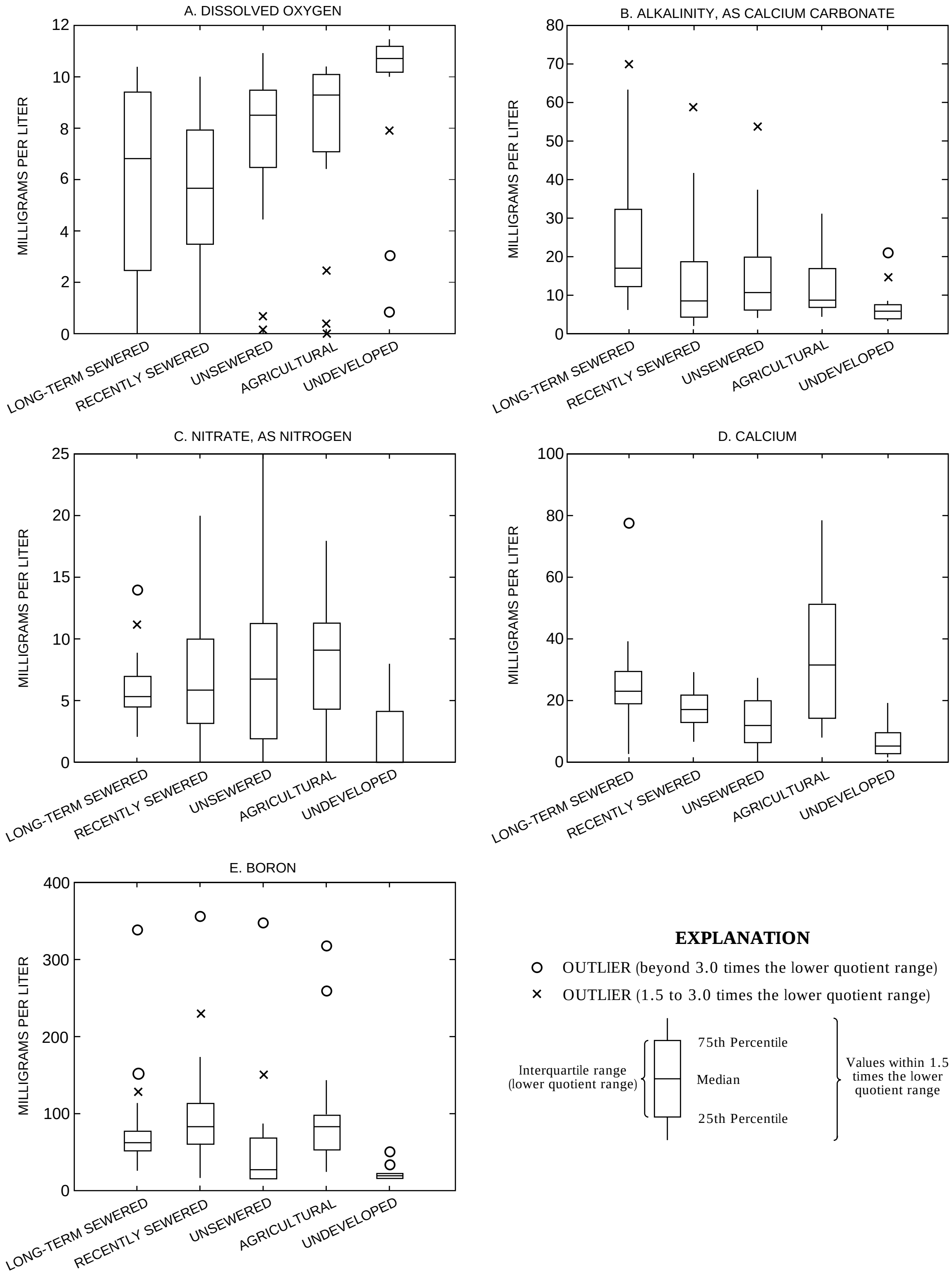

Figure 9. Statistical distribution of inorganic constituent concentrations in ground water near the water table in five study areas, Long Island, New York (modified from Eckhardt and Stackelberg, 1995).

Local-Scale Assessments and Research Studies of Ground-Water Quality

Attributes of local-scale (less than 1 square mile to several square miles) studies of ground-water quality are listed in table 18. Because of the range in possible project objectives, these attributes are quite general. Many local-scale studies, particularly on surficial hydrogeologic units, are based on newly constructed project wells, the locations of which are guided by patterns of flow in the local ground-water system. Examples of local-scale studies include (1) local-scale assessments, (2) early warning monitoring studies, (3) monitoring of point sources of contamination, (4) flow-path water-quality studies, and (5) local-scale studies of the interactions between ground water and surface water, which are discussed in the "Assessment of Effects of Interactions between Ground Water and Surface Water" section.

Table 18. General attributes of local-scale assessments of and research studies on ground-water quality

Attribute	Explanation
General objectives	Objectives of local-scale water-quality assessments and research studies range from a local-scale occurrence and distribution water-quality survey in a complex surficial setting to research studies on the transport and degradation of selected analytes, particularly in surficial hydrogeologic units. A salient feature of many local-scale water-quality studies is to relate water quality explicitly to the ground-water flow system.
Volume of earth material that is targeted for sampling	Most frequently, a small part of a surficial hydrogeologic unit.
Existing wells or new wells	Primarily new wells, possibly supplemented by existing wells.
Number of wells to be sampled	Variable, depending on objectives and project design.
Well-selection strategy	Depending on study objectives, locations for new wells may be selected nonrandomly—for example, in relation to the local ground-water flow system and additional physical and cultural features, such as surface-water bodies and sources of contamination—or randomly.
Temporal sampling strategy	Depends on study objectives; the objectives of many types of local-scale studies require multiple samples from at least some of the wells.
Selection of target analytes	Recommended minimum list of analytes (table 10) plus additional analytes that are targeted to meet study objectives.

Local-scale assessments typically are used for areas and volumes of hydrogeologic units in which potentially high concentrations of contaminants and locally high variability in water quality are expected. Possible examples include a monitoring study of shallow ground water that uses 50 sampling wells distributed over 1 square mile of a suburban area or a study that uses 50 sampling wells distributed over the area of a single medium-sized farm in the Midwest. Very few published results of studies that have consistently collected water-quality data are available for such settings at the local scale, in contrast to the usual broader scale land-use studies (see the "Broad-Scale Assessment of the Effect of Land Use on the Quality of Ground Water near the Water Table" section).

Early warning monitoring studies are conducted in areas where important ground-water bodies are vulnerable to gradual inflow of contaminated ground water. Examples are parts of hydrogeologic units that are near heavily pumped public water-supply wells and in which contaminated ground water is moving or may move toward the wells. Frequent sampling of monitoring wells is characteristic of these studies. This type of study is closely related to studies that evaluate the effectiveness of wellhead-protection programs.

Most studies that monitor point sources of contamination are local-scale assessments of water quality associated with contaminant plumes. These assessments may result in a plan for remediation, followed by monitoring to assess the effectiveness of the remediation strategy. Research into the transport and fate of selected contaminants frequently has been associated with this type of study. The literature on research and remediation and on the general design of contaminant-plume studies is voluminous (USEPA, 1981, 1986, 1987a, 1988b, 1989; National Water Well Association, 1986; Reilly and others, 1987; Nielsen, 1991).

Flow-path studies use single wells or nests of wells at different locations along an inferred ground-water flow path (fig. 10). Their general objective is to relate observed water quality to the ground-water flow system. The example map and section in figure 10 depict such a study in a surficial hydrogeologic unit, which (1) may focus on evaluating differences in water quality with depth, (2) may involve studies of transport and fate of selected constituents, or (3) may seek to relate water quality in the shallow ground-water system with the quality of a stream or other surface-water body into which the shallow ground water discharges, particularly at low flow of a stream. Age dating of ground-water samples greatly enhances this type of study.

Flow-path studies in surficial and in confined hydrogeologic units may extend for miles to tens of miles. These studies often focus on changes in water quality due to water/rock interactions, as well as to other possible factors, and often rely on sampling of existing wells, particularly in deep, confined regional aquifers.

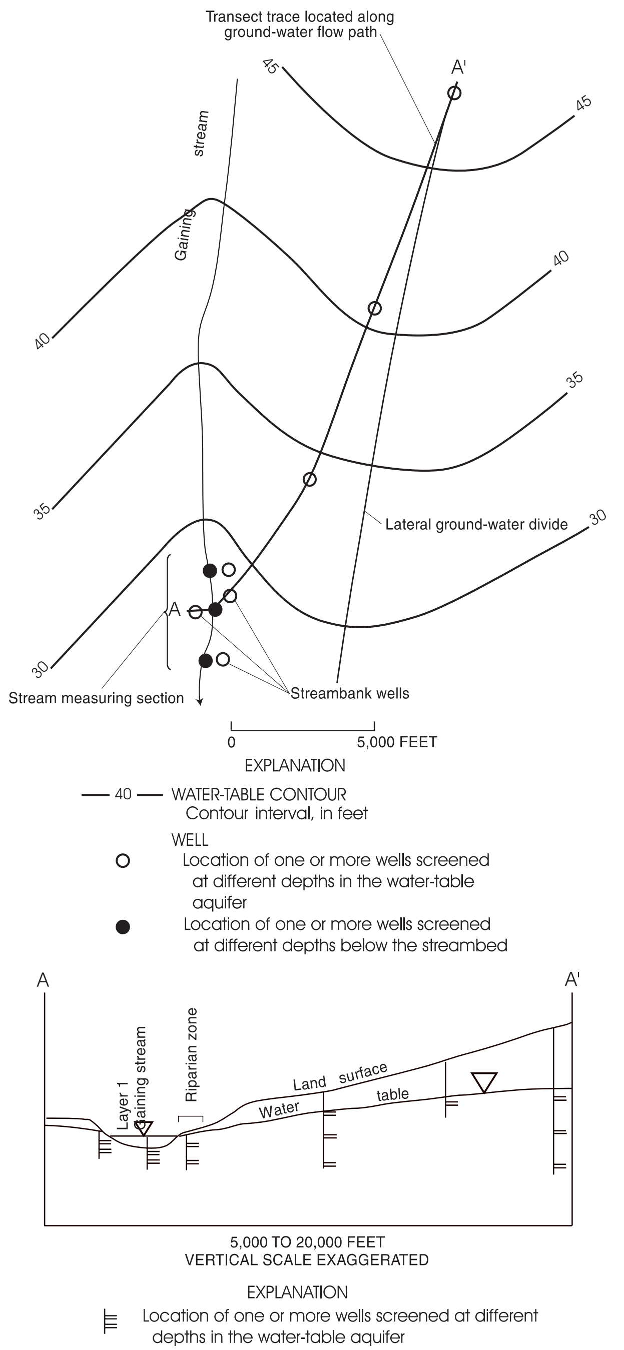

Figure 10. Typical well transect for a flow-path study assoc ated with a gaining stream (modified from Gilliom and others 1995).

Assessment of Effects of Interactions Between Ground Water and Surface Water

Of considerable practical concern to water managers and regulators today (1997) is the relative contribution of point sources (for example, sewage-treatment plants) and nonpoint sources (shallow ground water discharging along the stream channel or lake shore) to the quality of surface water (see USEPA, 1991d, for an overview of methods for determining the ground-water contribution to surface-water quality). Although the locations and approximate contributory loads of sewage-treatment plants are known, the loads of selected constituents that are contributed by ground water to a stream are less easy to determine, partly because the sources of these loads are spatially dispersed. Therefore, to address the concern, numerous studies are needed to determine the ground-water contribution to surface-water quality in different environmental settings. The reverse concern about the effect of surface water on ground-water quality also is highly relevant in some physical settings, as noted later in this section.

Selected examples of studies of ground-water and surface-water interactions that are or can be relevant to water-quality issues are listed in table 19 and illustrated in figures 11 and 12. The examples and comments in table 19 assume that the stream/ground-water system results in predominantly gaining streams (that is, streams that gain in discharge downstream due to the inflow of ground water into the stream channel). Therefore, studies related to hydrograph separation and sampling of ground-water discharge (table 19) are directly related to the concern discussed in the previous paragraph, and studies related to temporary rises in stream stage and to sources of water in shallow wells primarily address the effect of surface-water quality on ground-water quality. In physical settings that have predominantly losing streams, the viewpoint changes because surface water enters the ground-water system and usually does not return to the surface-water system, at least within short distances and in short time frames. In this situation, the quality of the former surface water may be modified by passage through the subsurface as ground water.

Table 19. Types of studies that evaluate water-flow and water-quality interactions between ground water and surface water

Type of study	Explanation
	Ground-Water Flow Contributions to Streamflow
Hydrograph separation	The objective is to divide the total streamflow hydrograph into two parts: (1) Storm runoff or quick-response flow that is related to storms and (2) ground-water runoff, which may augment storm runoff during storms, but occurs mainly as normal ground-water discharge to streams during periods of streamflow recession when there is no precipitation. Rules for hydrograph separation are arbitrary to a considerable degree, and the results of hydrograph separation are only approximations and not reliable for individual storms. Hydrograph separation is believed, however, to provide a useful index for the longer term proportion of streamflow that is derived from ground water, particularly when this index is used for comparative purposes—for example, between long-term averages for different seasons or periods of years for the same streamflow record or between records from different streamflow-gaging stations. Well-documented computer-software packages that automatically perform hydrograph separation using daily flow records include the package by Rutledge (1993).
	Sampling of Ground-Water Discharge to Streams
(1) Assessing base flow of streams	The objective of these studies is to quantify the contribution of ground water to the quality of total streamflow during different times of the year. The approach is to sample streamflow at times when the streamflow hydrograph indicates that all or most of the streamflow reasonably can be assumed to derive from ground water. To relate water-quality sampling to the streamflow hydrograph, sampling generally is done at or near a gaging station, or a stream-discharge measurement is made as part of the sampling process.
(2) Determining integrated ground-water inflow along stream reaches	The objective is to quantify the volume and quality of ground-water inflow along a particular stream reach. The approach is to select two measuring points on a stream at which flow and water quality are measured. The ground-water contribution to flow and water quality along the stream reach is determined by difference (fig. 11). These studies, therefore, are more focused spatially than assessing the base flow of streams [item (1) above].
(3) Evaluating ground water from shallow streambed and streambank piezometers	The objective is to determine the quality of shallow ground water that soon will discharge into the stream. The approach is to sample using streambed and streambank piezometers and, if feasible, to compare the ground-water quality with stream-water quality. A possibly valuable adjunct is direct sampling of ground-water discharge to streams by means of seepage meters. Sampling from shallow streambed piezometers can be used in reconnaissance surveys to identify reaches of streams where ground-water inflow is of poor and good quality. The design of these surveys is guided by knowledge of flow patterns in the shallow ground-water flow system and land use near the streams.
(4) Assessing spring and seep water	Springs are points of concentrated ground-water discharge from possibly large contributing areas and volumes of a surficial hydrogeologic unit and, as such, represent an opportunity to sample ground-water discharge directly. Although often difficult to determine, the contributing area of a sampling site is a useful concept for springs. The sampled water quality from a spring may vary for some constituents, depending on where and how the spring is sampled—for example, as ground water from a piezometer immediately upgradient from the orifice or as surface water after discharge. A seep is an area where ground water oozes from the earth in small quantities. Therefore, seeps can be viewed as a low-discharge end member of springs.

Table 19. Types of studies that evaluate water-flow and water-quality interactions between ground water and surface water--Continued

Type of study	Explanation
Determining Interactions Related to Temporary Increases in Stream Stage	
(1) Bank storage	The objectives of bank-storage studies (fig. 12) include determining (1) the volume and quality of surface water that enters the shallow saturated ground-water system during periods of rising stream stage and (2) the volume, time release, and quality of former surface water, possibly mixed with original ground water, that returns to the stream during periods of falling stream stage. These studies rely on determining the water quality of the surface water and of the shallow ground water near the stream.
(2) Overbank flooding	The objectives of overbank-flooding studies (fig. 12) (similar to the objectives for bank-storage studies) are to determine (1) the volume and water quality of surface water that recharges the shallow ground water from the flooded land surface, as well as surface water that enters the shallow ground-water system through the streambanks and streambed; and (2) the volume, time release, and quality of former surface water, possibly mixed with original ground water, that returns to the stream. Overbank flooding is closely related to and may be regarded as an extension of and as a limiting condition of bank-storage interactions. Given sufficient overbank flooding, parts of the underlying surficial hydrogeologic unit may become completely saturated to the land surface. The residence time of former surface water in the shallow ground-water system may be much longer for overbank flooding than for smaller rises in stream stage that result in exchanges of water only through the streambanks and streambed. Results of a recent overbank-flooding study that has water-quality implications are described by Squillace (1996) and Squillace and others (1996).
Determining Sources of Water from Shallow Wells	
Shallow wells located near a surface-water body	Generally, the objective is to determine the proportion of the pumped water that is derived from surface water and from ground water at different pumping rates. An additional objective may be to determine if pumping-induced movement of former surface water through the shallow ground-water system to the well results in changes in the original quality of the surface water; for example, whether the concentration of key contaminants from the surface water is decreased or eliminated before the stream water reaches the pumping well. Tools of analysis for this type of study and bank-storage/overbank-flooding studies include water-mixing models, analysis of isotope data, and local-scale simulation of the ground-water flow system.

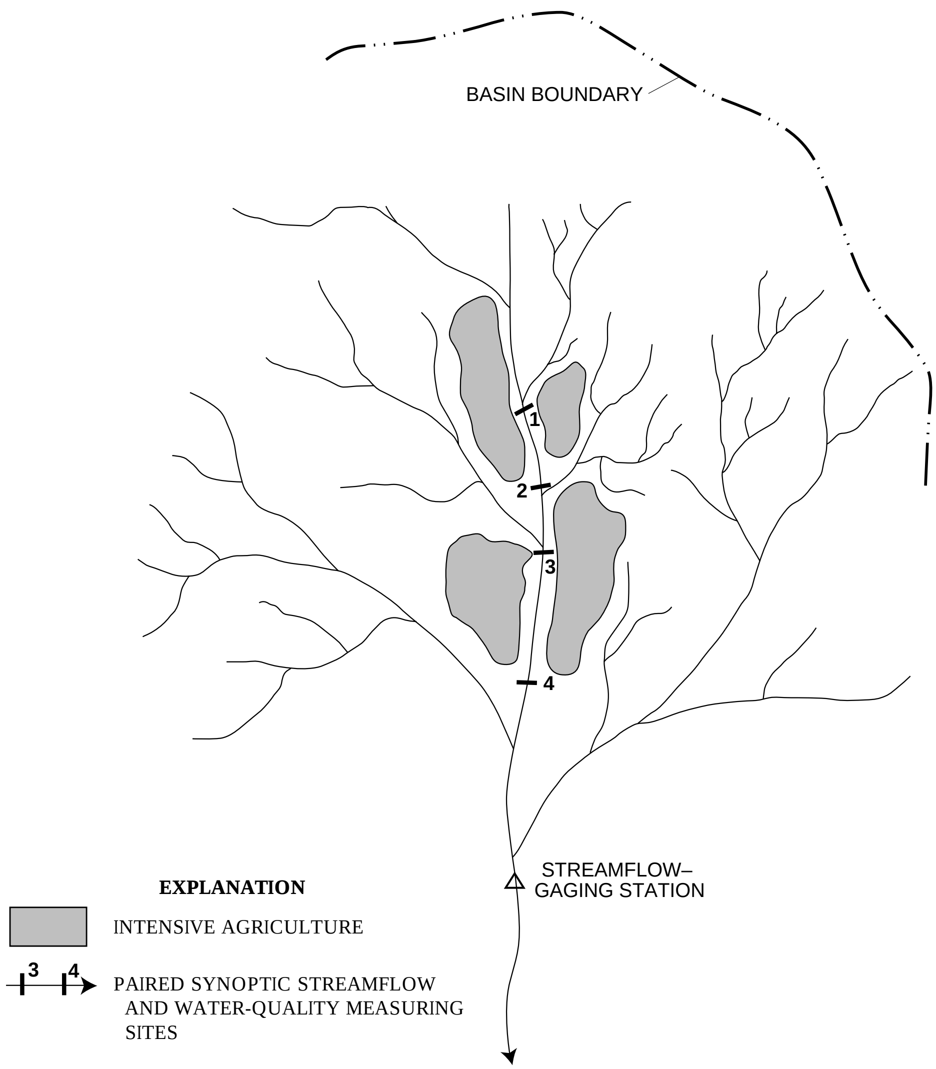

Figure 11. Location of stream reaches in relation to the stream network and local land use that may be suitable for determining the effect of discharging ground water on the quality of the stream water.

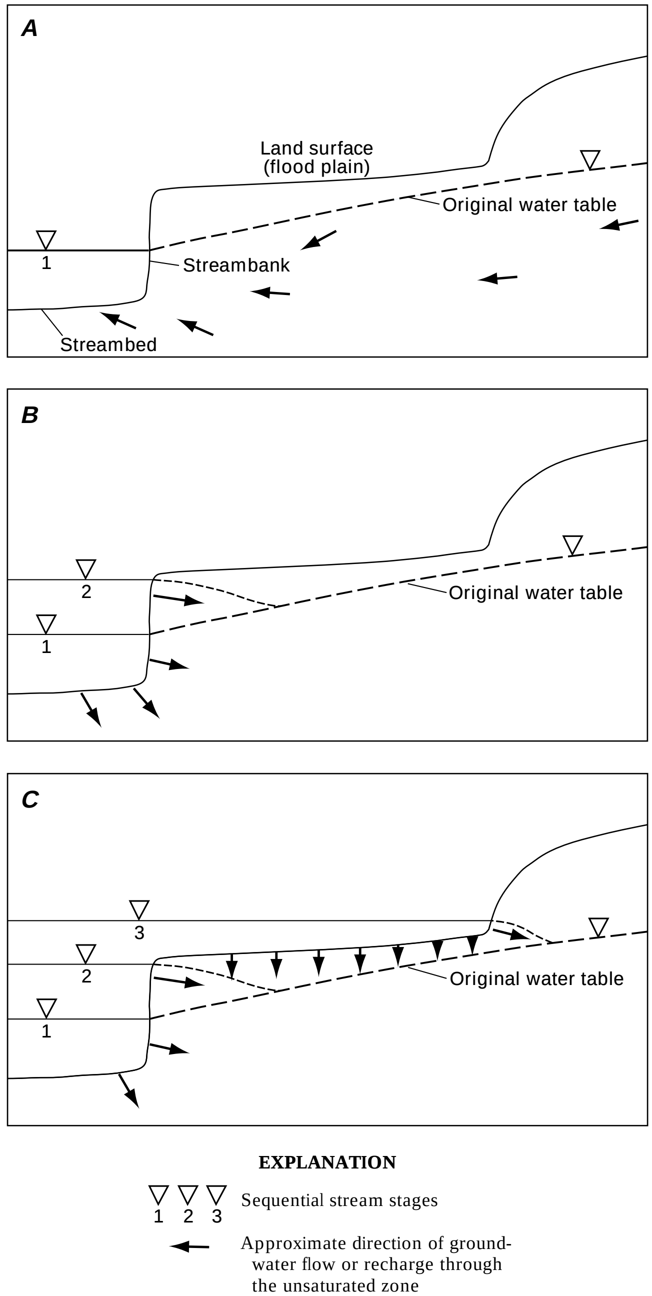

Figure 12. Ground-water and surface-water interactions related to temporary increases in stream stage. Stream stage 1, streamflow is derived primarily from ground-water inflow during an extended period of no precipitation. Stream stage 2, rise in stream stage results in an increase in bank storage that is manifested by flow from the stream into the adjacent shallow hydrogeologic unit through streambanks and streambed. Stream stage 3, stream stage continues to rise until overbank flooding occurs; flow from stream into the adjacent hydrogeologic unit occurs through the streambanks and the streambed as in stream stage 2 and also through the land surface, which recharges the water table. After the storm, the stream stage falls, and the shallow ground water drains slowly toward the stream; if sufficient time elapses before another increase in stream stage, the ground-water flow regime will approach the situation depicted for stream stage 1.

The predominantly near-stream and instream studies listed in table 19 can be enhanced by flow-path studies, an example of local-scale studies that is discussed in the "Local-Scale Assessments and Research Studies of Ground-Water Quality" section. The flow-path studies can provide water-quality information and insight into ground-water quality upgradient from the stream and also can link directly with near-stream ground-water quality in streambank and streambed piezometers, as shown in figure 10.

Some recent studies have reported that the quality of ground water moving to discharge into a stream can be changed substantially in a narrow zone, sometimes 1 foot or less, directly beneath the streambed. (An integrated series of articles in the Journal of the North American Benthological Society, vol. 12, no. 1, March 1993, provides an overview and extensive bibliographies of near-stream saturated-zone studies, including studies of biology and ecology.) This zone may contain strongly reducing conditions even though the remainder of the ground-water flow system has oxidizing conditions. The possibility of such rapid and substantial changes in water quality needs to be considered in the design of ground-water and surface-water interaction studies because standard configurations of ground-water sampling points, even streambank piezometers, may not sample this zone. Generally, the detection of this zone, if present, depends on meticulous small-interval streambed sampling.

Assessment of Ground-Water Quality for Other Objectives

Other important types of ground-water-quality monitoring studies, which have not been discussed in this report, include: (1) surveys of the ground-water resource (raw water, not tap water) derived from particular types of wells—for example, rural domestic wells or public-supply wells screened in a specified hydrogeologic unit or group of units—and (2) evaluation of the effects of changes in agricultural practices [best-management practices (BMP's)] on the quality of shallow ground water.

CONCLUDING REMARKS

Evaluation of past programs for the collection, compilation, and use of water-quality data has indicated that, despite vast expenditures on these efforts at Federal, State, and local levels, the resultant data were largely inadequate to guide regional water-resource management and related decisionmaking. In response, the GWFG of the ITFM suggests a national approach for the design and implementation of ground-water-quality data-collection and monitoring activities, and encourages the greatest practical degree of intergroup collaboration in such activities and the widest possible exchange of reliable water-quality data.

In the past, the shortcomings in and uncertainties with water-quality data, especially the data for ground water, have derived less from laboratory procedures than from field procedures or uncertainties about hydrologic conditions related to the samples. Accordingly, the approach described in this report emphasizes ways to minimize the problems of the past and to improve the broad-scope usefulness of ground-water-quality data by:

(1) An effective collaboration between agencies and other organizations having vested interests in reliable ground-water-quality data for possible sharing of costs, training, and other efforts, as well as sharing the data and related information.

(2) The implementation of appropriate QA/QC plans and complete documentation of sampling protocols and of water-quality and supporting environmental data.

(3) A logical sequence of program steps and support functions that would enable the broadest usefulness and greatest reliability of resultant ground-water-quality data and at a reasonable cost. (Also see the summary of principal recommendations in the "Applying Conceptual Frameworks to Ground-Water-Quality Monitoring Studies with Different Objectives" section.) The proposed national approach is feasible not only by the avoidance of past problems, but especially by the ever-increasing knowledge of environmental settings, by computer networks and electronic data bases, and by the availability of the digital GIS.

In presenting this national approach, the GWFG attempts to maintain the point of view of water-resource professionals who are engaged in and managing ground-water-quality studies and data-collection activities, while recognizing the special considerations of State and local agencies, including the constant pressures to do more with less—less funds and less personnel. Accordingly, the report emphasizes that less can actually be more in terms of the overall value of ground-water-quality data. That is, a relatively few reliable ground-water analyses, which include a broad spectrum of analytes and are carefully designed to meet short- and long-term needs, may be of greater benefit than a large number of reliable samples that have only a few targeted analytes, which are designed to meet short-term needs.

Implementation of the national approach in this report is voluntary, but the advantages for participants can be significant. In addition to opportunities for sharing training and other costs through collaboration and for building a more readily available base of reliable ground-water data, participation in the national approach can provide a common direction to guide monitoring programs and dissemination of their resultant data into the future.

GLOSSARY

The primary purpose of this glossary is to serve the immediate needs of a reader of this report. Useful glossaries on general geology (Bates and Jackson, 1987), general hydrology (Lo, 1992), and hydrogeology, ground-water hydrology, wells, and ground-water monitoring (Driscoll, 1986, p. 885-891; Fetter, 1988, p. 565-580; Lohman and others, 1972; Nielsen, 1991, p. 637-693) are available.

Analyte—Substance measured in an analytical procedure and, thereby, assigned a quantitative value for concentration or amount of substance present.

Anisotropic—A medium, the physical properties of which vary with direction.

Annulus—The space between the borehole wall and the well casing.

Aquifer—A saturated, permeable geologic formation that can store, transmit, and yield substantial quantities of water under ordinary hydraulic gradients.

Aquifer test—A controlled field test to determine the hydraulic characteristics of an aquifer.

Artesian well—A well tapping an artesian (confined) aquifer in which the water level stands above the top of the confined water body the well taps.

ASTM—American Society for Testing and Materials.

Background concentration—The concentration of a chemical in ground water that is within the existing general range of concentrations in an area, in contrast to a concentration that is attributable to a particular source.

Base flow—Sustained or fair-weather streamflow. In most streams, base flow consists largely of ground-water effluent.

Bedrock—The solid rock that is naturally present at the surface of the Earth or underlies all soil, sand, clay, gravel, and other loose materials at the surface of the Earth. Unfractured bedrock is effectively impermeable, whereas fractured bedrock may store and transmit ground water.

Best management practices (BMP's)— Operating procedures used in a specific commercial or industrial process to decrease the risk of environmental contamination. Also, operating procedures used in agriculture to achieve a desirable goal, such as to decrease soil erosion or to decrease fertilizer use.

Bias—Systematic error inherent in a method. It may be either positive or negative.

Blank sample—Sample of blank water (water that is certified to be free of target analytes at a specified limit of detection) that is used for various types of quality control (QC) in the process of sampling through laboratory analysis.

Blind sample—A sample submitted for analysis, the composition of which is known to the submitter, but unknown to the analyst. Its purpose is to test the proficiency of the laboratory-measurement process.

Borehole—A hole drilled or bored into the ground to obtain water, gas, oil, samples of earth materials and fluids, and other types of information about the subsurface environment.

Casing—An impervious, durable pipe, usually consisting of steel or polyvinyl chloride (PVC), installed as part of well construction to prevent the collapse of the walls of the borehole, to prevent pollutants from entering the well, and to house the pump or pipes, or both.

CERCLA—Comprehensive Environmental Response, Compensation, and Liability Act of 1980, otherwise known as Superfund (Public Law 96-510). This law establishes the Nation's policy and procedures for responding to uncontrolled, abandoned hazardous-waste sites, most of which present direct threats to ground water. The Act creates a multibillion-dollar fund, the Superfund, that is used to pay for remediation activities at these sites. State and responsible-party funds also help finance remediation activities.

Classification guidelines—A system for distinguishing among ground waters, often based on their use, value, or vulnerability. Ground-water classification can be incorporated in monitoring, regulatory siting, and permitting decisions.

Confined aquifer—An aquifer that is overlain by a confining bed. The confining bed has a substantially lower permeability (hydraulic conductivity) than the aquifer.

Confining bed—A geologic formation that does not transmit or yield large quantities of water under ordinary hydraulic gradients and, thus, impedes the flow of water.

Constituent—As used in this report, a specific chemical present in water; the chemical may be present as an element, a combination of elements, or a compound.

Data element—The most elemental piece of data; also called data item or data field. Data that cannot be subdivided into other data types and retain any meaning to users of the data.

Data model—A diagram or other representation that shows the types of data used in a system and the relations between the data types.

Derived data—Data that are calculated or transformed from other data.

Drilling fluid—Water- or air-based fluid used in well drilling to remove cuttings from the borehole, clean and cool the bit, decrease friction between the drill string and the sides of the borehole, and seal the sides of the borehole.

Environmental sample—Field sample of a medium (water, soil, bed sediment, tissue) that is targeted for study, in contrast to various types of QC samples.

Equipment blank—Chemically pure solvent (generally, reagent-grade, distilled, or deionized water) that is passed through a piece of field-sampling equipment and returned to the laboratory for analysis to determine the effectiveness of equipment-decontamination procedures.

ERT—Environmental Research and Technology, Information Center, Concord, Massachussetts.

Field blank—A laboratory-prepared sample of reagent-grade water or pure solvent that is transported to the sampling site for use in evaluation of field-sampling procedures. See equipment blank and trip blank.

Filter pack—Sand, gravel, or glass beads placed in the annulus of the well between the borehole wall and the well intake to prevent aquifer material from entering the well intake.

Geographic Information System (GIS)—A computer-software package, the purpose of which is to store, retrieve, edit, overlay, manipulate, and characterize large quantities of spatial data.

GPS—Global Positioning System.

Ground-Water Protection Standard—A contaminant concentration limit or pollution-prevention performance measure that is used to identify threats to ground water and set priorities for remediation and protection activities. Maximum contaminant levels (MCL's) or other health-based standards are frequently used as reference points for protection or remediation efforts for State and Federal programs.

Grout—A fluid mixture of bentonite or cement and water with additives that can be forced through a pipe into the annular space between a well borehole and casing to form an impermeable seal.

GWFG—Ground-Water Focus Group of the Intergovernmental Task Force on Monitoring Water Quality.

HSWA—Hazardous and Solid Waste Amendments of 1984. The HSWA amended the Resource Conservation and Recovery Act by incorporating restrictions on disposal on land, an increased emphasis on delegation of hazardous-waste management programs to States, a new focus on waste minimization, and a greater emphasis on the clean-up of contamination at hazardous-waste management facilities.

Hydraulic conductivity—A coefficient of proportionality that describes the relative ease with which a fluid can move through a medium. Hydraulic conductivity is a function of the medium and the fluid flowing through the medium. Equivalent to permeability.

Hydraulic gradient—The change in hydraulic head per unit of distance in a given direction. The direction generally is understood to be that of the maximum rate of decrease in head.

Hydraulic head—The head in ground-water studies is the height above a standard datum of the surface of a column of water that can be supported by the static water pressure at a given point.

Hydrogeologic unit—Any porous water-bearing formation, bed, stratum, or unit consisting of rock or unconsolidated earth material. This term includes aquifers, confining units, and any other terms that indicate relative permeability of the unit or availability of water to wells tapping the unit.

Hydrograph—A graph showing a hydrologic variable, such as stream discharge, compared to time.

Indicator, environmental—Measureable feature or features that provide managerially or scientifically (or both) useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality (paraphrased from ITFM, 1995, Technical Appendix A, p. 3).

Indicator, ground water—As used in this report, any physical, chemical, or biological measurement on or analysis of ground water, for which a standard protocol exists, that provides managerially or scientifically useful evidence, or both, of environmental quality or reliable evidence of trends in quality.

Isotropic—A medium, the physical properties of which are the same in all directions.

ITFM—Intergovernmental Task Force on Monitoring Water Quality.

Maximum contaminant level (MCL)— Established under the Safe Drinking Water Act (Public Law 93-523), MCL's are numerical criteria that express concentration limits for specific contaminants in drinking water. MCL's are set as close to MCLG's as possible, considering economic and technical feasibility.

Maximum contaminant level goal (MCLG)— MCLG's represent contaminant concentrations in drinking water that present absolutely no risk to human health. MCLG's are nonenforceable health goals used in the process of setting MCL's.

Method detection limit (MDL)—The MDL is determined from analysis of a sample in a given matrix that contains the analyte and represents the minimum concentration of a substance that can be measured and reported with a 99-percent confidence that the analyte concentration is greater than zero. In this definition, the analyte has been through all steps (extraction, isolation, and analysis) of the method. In addition, the MDL is matrix specific; for example, the MDL for DDT in wastewater will be higher than the MDL for DDT in reagent grade water.

MTBE (methyl tert-butyl ether)—A volatile organic compound that is a gasoline additive designed to decrease air pollution.

Monitoring well—An excavation that is constructed, using a variety of techniques, for extracting ground water for physical, chemical, or biological testing or for measuring water levels.

NAWQA—U.S. Geological Survey's National Water-Quality Assessment program.

NEIC—National Enforcement Investigations Center of the U.S. Environmental Protection Agency.

Nested wells—Monitoring wells that consist either of a series of wells that are closely spaced laterally, but have intakes at different depths, or multiple short-intake wells constructed in a single borehole.

Nonpoint-source pollution—Pollution in runoff from broad areas, such as city streets, farmland, or mining sites, rather than from discrete points.

NWQMC—National Water-Quality Monitoring Council, the successor of ITFM.

Parameter—Any measured quantity that describes the state of a system; for example, an aquatic system.

Parameter, field—A parameter that is necessarily or typically measured at a field site; for example, temperature and specific conductance.

Percolation—Movement of water through the interstices of rock, soil, or other earth materials.

Permeability—See hydraulic conductivity.

Piezometer—Nonpumping well, usually of small diameter, that is used to measure hydraulic head.

Pollution (or contamination) plume—An elongated volume of contaminated water, formed by the contaminants entrained in the saturated ground-water flow, that extends downstream from the contaminant source.

Porosity—The ratio of the volume of openings or voids in soil or rock to the total sample volume, usually expressed as a percentage.

Potentiometric surface—A surface that represents the hydraulic head. For an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface. Potentiometric surface replaces the older term "piezometric surface."

Primary data—Data from direct observations or measurements that are not derived from other data.

Primary drinking water standards—Standards established under the Safe Drinking Water Act (Public Law 93-523) that include either MCL's (see maximum contaminant levels) or treatment-technique requirements.

Priority pollutants—A group of 129 specific toxic pollutants evaluated by the USEPA in setting effluent guidelines for the best available technology economically achievable under the Clean Water Act (Public Law 92-500).

Public-water systems—A water-supply system that serves 25 or more people.

Quality assurance (QA)—A management function that establishes QC protocols and evaluates and documents their outcomes.

Quality control (QC)—Technical and operational procedures that investigate and confirm the proper conduct of activities of an organization. Often, the term refers specifically to all aspects of data management.

RCRA—Resource Conservation and Recovery Act of 1976 (Public Law 94-580). It established a cradle-to-grave system for the management of hazardous wastes. Its chief implementing tool is a permit system; all hazardous-waste treatment, storage, or disposal facilities must meet certain standards, most often outlined in permits, to remain in operation. Many of the permit standards outlined by RCRA focus specifically on protecting ground water from contamination.

Recharge area—The area at the land surface through which water infiltrates to recharge an aquifer.

Reference material sample—A sample, prepared and certified by a laboratory, that has a strictly defined chemical composition. Its purpose is to test the proficiency of the laboratory-measurement process.

Saline water—Water containing more than 1,000 milligrams per liter of dissolved solids.

Sample matrix—May consist of water, sediment, organic tissue, or air. In this report, the sample matrix is ground water.

SARA—Superfund Amendments and Reauthorization Act, enacted in 1986. The act increased the amount of money in the Superfund Trust Fund, streamlined many of the procedures used by the USEPA in addressing abandoned or uncontrolled hazardous-waste sites, put a greater emphasis on permanent solutions to clean-up, and introduced new authorities, such as the Community Right To Know Program.

Saturated zone—The zone below the deepest water table in which all voids are filled with water under pressure greater than atmospheric.

SDWA—Safe Drinking Water Act, first enacted in 1974 (Public Law 93-523). This law mandates a national set of drinking-water standards for public-water supplies to protect public health and welfare. SDWA also mandates regular testing of public-water supplies to ensure that drinking-water standards are achieved. The act was amended in 1986 to include provisions for wellhead-protection programs.

Secondary drinking water standards—Federal guidelines regarding the taste, odor, color, and other nonaesthetic properties of drinking water. These standards are considered as guidelines for the States.

Seepage meter—A device for determining seepage discharge from ground water to surface-water bodies through a small area (a few square feet).

Sole-source aquifer—An aquifer that may be given special protection because it has been designated under article 1424(e) of the SDWA as an aquifer that is the sole or principal drinking-water source for an area and that, if contaminated, would create a substantial hazard to public health.

Solubility—The ability of a compound or fluid to dissolve into another fluid.

Spiked sample—An environmental sample (usually soil or water) to which a known amount of a specific constituent has been added. Generally, it is used as a means of checking laboratory performance.

Spring—A place where ground water flows naturally from a rock or the soil onto the land surface or into a body of surface water.

Surficial—Occurring at or near the land surface.

Time of travel—The time needed for a chemical constituent to move in the saturated zone from a specific point to a well or other reference point.

Transmissivity—The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Trip blank—A sample container filled in the laboratory with reagent grade, distilled, or deionized water that is transported to the sampling site, handled the same as the other samples, and then returned to the laboratory for analysis as a QC measure to check sample-handling procedures.

UIC—Underground Injection Control is a Federal program under the SDWA to prevent the contamination of underground sources of drinking water by keeping injected fluids in an injection well and in the intended injection zone.

Unconfined aquifer—An aquifer in which a water table forms the upper boundary of the saturated zone. Also referred to as a water-table aquifer.

Underground source of drinking water—An aquifer that provides public or private drinking-water supplies.

Unsaturated zone—The zone between the land surface and the water table. Generally, some of the voids in this zone contain air or other gases at atmospheric pressure, and water is under less than atmospheric pressure. Also referred to as the vadose zone.

USEPA—U.S. Environmental Protection Agency.

USGS—U.S. Geological Survey.

Variability—Degree of random error in independent measurements of the same quantity.

Viscosity—A property of a fluid that determines its resistance to flow; the more viscous a fluid, the greater its resistance to flow.

Volatility—A measure of the tendency of a given component to escape from a liquid phase or solution into the gaseous phase (evaporate).

Vulnerability—Susceptibility to contamination.

Wastewater—Water that has come into contact with or contains biological, inorganic, organic, or radioactive contaminants. Wastewater can be process water that has come into contact with the production or use of any raw material, intermediate product, finished product, by-product or waste product, or water containing domestic sewage.

Water table—The surface in a ground-water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

Well—An artificial excavation, usually a dug, bored, or drilled hole or tunnel, that penetrates a water-yielding bed and allows water to flow or to be pumped to the land surface.

Well screen—The opening in the well casing through which water enters the well. Screens may consist of slots cut in the well casing [for example, in polyvinyl chloride (PVC) or metal casing] or wire mesh inserted at the bottom of the well or at specified depths in the well casing.

Well log—A record that includes information on details of well construction, descriptions of geologic formations penetrated, locations of well tests, and well-development techniques.

Wellhead protection areas (WHPA's)—Areas designated for limited development or other protection to prevent ground-water contamination. WHPA's are located around public drinking-water wells or recharge areas and may be delineated by several means (for example, by set distances or time of travel of ground water).

Wellhead Protection Program—As specified under the SDWA, the program establishes efforts to protect underground sources of drinking water from contamination by delineating wellhead recharge areas, inventorying contaminant sources, and implementing pollution-prevention programs.

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APPENDIX A

APPENDIX A: OUTLINE OF A GROUND-WATER-QUALITY MONITORING FRAMEWORK

Outline of a Ground-Water-Quality-Monitoring Program (modified from ITFM, 1995, Technical Appendix L)

I. Purpose.

   A. Purposes and expectations of participating agencies and customers.

      1. What data are being collected and why?

      2. How will the data be stored and displayed?

      3. How will the results be evaluated?

      4. What does each agency contribute and receive from the monitoring program?

   B. Some objectives of the monitoring program.

      1. Need for a general overview (background and ambient monitoring) of ground-water quality in specific aquifers.

      2. Need to identify trends in ground-water quality that are related to regional land-use and nonpoint sources of contamination. Need to identify localized trends in ground-water quality that are related to specific contaminant sources (facility-based/compliance monitoring).

   C. Purposes and expectations of monitoring agency.

      1. Short- and long-term requirements and needs that include coordination and collaboration with other agencies and customers, data management, periodic evaluation of monitoring effort, QA/QC considerations, laboratory and field analytical support and services, and training.

      2. Prioritize objectives for monitoring strategies. Prioritization may be based on principal hydrogeologic units, well type, analytes of concern, relation of water quality to land use, surficial aquifers/artesian aquifers, and timeframe for monitoring activity.

   D. Environmental indicators—Selection of environmental indicators to measure achievement of monitoring agency objectives and purposes.

      1. Select indicators on the basis of the type of monitoring activity—ambient (baseline), evaluation or detection, and compliance (response and remediation).

      2. Select indicators on the basis of other objectives of the monitoring program from coordinators and collaborators.

II. Coordinate/collaborate.

   A. Identify potential participants.

      1. Establish a working relation with Federal, State, tribal, local, academic, and private agencies.

      2. Communicate project objectives and goals.

   B. Define roles of participants.

      1. Participants may provide financial or technical information; interpretation of data; and resource, technical, or regulatory management expertise.

   C. Define needs of users and establish data-quality objectives.

      1. If possible, incorporate needs of other agencies/groups who use the information into the purposes of the program.

      2. Ensure the inclusion of data qualifiers with stored data so others know the accuracy and precision of the environmental data that are being collected and analyzed.

III. Design

A. Define objectives and scope of project.

1. Hydrogeologic units to be monitored.
2. Analytes of concern.
3. Well types.
4. Land use.
5. Timeframe.
6. Financial considerations.
7. Personnel considerations.
8. Analytical considerations.
9. Data-management considerations.
10. Other resources and constraints.

B. Existing environmental setting—Identify and describe the existing environmental setting, which includes its hydrology (surface and ground waters), biota, and resource use.

1. Geohydrology.
   a. Delineate aquifers and confining units of the geohydrologic framework. Identify their vertical and lateral extent and degree of confinement and the lithostratigraphic and hydraulic characteristics of each unit.
   b. Conceptualize and describe the ground-water-flow regime, which includes flow paths, sources of recharge and discharge, water budget, ground-water/surface-water interactions, flow rates and age of water at different points in the regime. Design a model as necessary.
2. Biota.
   a. Identify biological communities that can be affected by ground-water quality in aquifers and confining units.
   b. Identify biological communities that can be affected by the quality of ground water that discharges to surface waters and wetlands.
3. Resource use.
   a. Identify past, current, and potential ground-water users and how quality may affect ground-water use.
   b. Identify past, current, and potential ground-water users and how use may affect ground-water quality.
   c. For the ground-water-supply system, determine the past, current, and potential withdrawals and recharge in terms of volume, location, and aquifer name. Identify changes in ground-water-flow paths and aquifer hydraulic characteristics that result from ground-water use.

C. Existing water-quality problems—Evaluate available information to provide a current conceptual understanding of existing ground-water-quality problems; depict the known or suspected ground-water-quality conditions, problems, or information gaps; and identify management concerns and alternatives.

1. Provide a current conceptual understanding of factors that affect spatial and vertical distribution in water quality.
   a. Identify historical, present, and possible future land use/land cover and expected water-quality effects of the land use/land cover.
   b. Identify geochemical conditions in aquifers and confining units that affect water quality, which include mineral content of sediments as it affects ion exchange and other water/mineral

reactions and organic and mineral content of sediment as they affect oxidizing and reducing conditions.

  c. Hydrologic system.

  d. Effects of flow paths on contaminant transport, which include effects of age of water on likely presence of contaminants.

2. Evaluate past and present water quality on the basis of existing information. Evaluate existing information in terms of quality, representativeness, and usefulness; for example, effects of well construction or heterogeneities in the natural system on water quality.

3. Identify management concerns and alternatives. Identify and prioritize problems, needs, and information gaps.

D. Environmental indicators and data parameters—Determine the appropriate or applicable environmental indicators and related chemical, physical, biological, and ancillary data parameters to be monitored. Indicator selection is related to the following criteria:

1. Program objectives (ambient, detection/evaluation, and response/compliance).

2. Existing hydrogeology.

3. Natural setting (physiography, climate, land cover).

4. Condition/character of the sampling site (well, spring, lysimeter).

5. Past/present land-use activities.

6. Designated uses of ground water (drinking water, recharge to surface water to support recreation).

E. Reference conditions—Establish reference conditions for environmental indicators that can be monitored to provide a baseline ground-water-quality assessment.

F. Confidence level—Define the level of confidence needed for the data to support testing management alternatives.

G. Data-set characteristics.

1. Determine basis for monitoring design that will allow successful interpretation of the data at a resolution (scale) that meets project purposes.

2. The basis for monitoring should include statistical reliability and geographic, geohydrologic, geochemical, biological, land use/land cover, and temporal variability.

H. Quality-assurance plan—Develop a quality-assurance plan that documents data accuracy and precision, representativeness of the data, completeness of the data, and comparability of data relative to data collected by others.

I. Monitoring design—Design a sampling plan for existing or proposed sites. Design may include sampling-site distribution and location (wells and springs) and environmental indicators (physical, chemical, biological, ancillary).

1. Design the general ground-water monitoring network on the basis of the conceptual study design and the study and characterization of the area.

2. Select and characterize the specific sites. Document the basis for the selection of each existing or proposed site as it fits the conceptualization, network design, and data-quality objectives.

  a. Historical and present adjacent land use/land cover.

  b. Availability of existing data and collection points.

  c. Hydrogeologic setting—Aquifers, location in the flow path and so forth.

  d. Accessibility.

3. Design the collection points at the site(s).

a. Sampling sites include wells, lysimeters, spring boxes, or other sample-collection points.

b. Locations.

c. Construction specifications.

4. Identify personnel and equipment needs.

5. Estimate costs of network.

6. Ground-water indicators selected may be constituent based, administrative, or part of a tiered or screening monitoring approach (refer to the ITFM, 1995, Technical Appendix L, tables 1 and 2).

J. Data-collection methods—Develop sampling plans and identify applicable protocols and methods, and document data to enable data comparison with other monitoring programs in accordance with QA/QC requirements. Refer to program-specific guidelines. Identify personnel and equipment needs.

1. Develop a plan for sample collection.

a. Frequency and timing.

b. Collection.

c. Sample handling.

d. Preservation.

e. Shipping (chain of custody).

2. Develop data documentation plan/chain of custody/labeling.

3. Identify personnel, equipment, and training needs.

4. Develop health and safety documents.

5. Estimate cost of data collection.

K. Timing—Describe duration of sampling program and frequency and seasonality of sampling.

L. Field and laboratory analytical support—Identify applicable field and laboratory protocols or performance-based criteria, which include detection level, accuracy, precision, turnaround time, and sample preservation.

1. Identify personnel, equipment, and other support needs for field and laboratory.

2. Identify field and laboratory QA/QC requirements.

3. Select performance-based criteria for evaluation of analytical capabilities and results.

a. Criteria include detection levels, accuracy, precision, sample-holding times, sample preservation, performance-evaluation samples (replicates, blanks, spikes), data turnaround time, and mechanisms and format for reporting data.

b. Personnel needs, which include training and turnover.

c. Facility and equipment needs.

4. Estimate cost of field and laboratory analytical support.

M. Data management—Describe data-management protocols, which include archiving, sharing, and security. Ensure the inclusion of metadata, such as location (latitude and longitude), date, time, a description of collection and analytical methods, and QA data.

1. Define user requirements.

a. Data format—Hard copy and digital (geographic and spatial data).

b. Interface—How the user sees the system.

c. Data types—Primary and ancillary data.

d. Input, storage, and verification mechanisms.

e. Applications.

f. Output format.

g. Security—Who needs access to what?

2. Considerations for the conceptual design of the digital system.

a. Requirements, which include such types of data as ancillary, metadata, and water-quality-data parameters.

b. Minimum data set or recommended ground-water-data elements (USEPA, 1992a; ITFM, 1995, Technical Appendix M).

c. Uses—Storage, retrieval, graphic and tabular presentation, complex analysis, desired procedures, access, and data dissemination.

d. Inventory available hardware and software.

e. Estimate costs for acquisition of hardware and software, training, implementation, operation, and maintenance.

f. Benefits.

3. Test plan and standards—Basis for hardware and software selection or development of a digital system.

4. Functional analysis of a digital system.

5. Physical design of a digital system—System selection and (or) development.

a. Hardware.

b. Data-base structure (ASCII, spreadsheet, relational).

c. Software.

d. User training and support.

e. System administration—Backup, recovery, maintenance, security, documentation.

N. Training.

1. Activities related to monitoring that require training; these include designing, collecting, managing, interpreting, and reporting and communicating water-quality data.

2. Support activities that require training; these include data-management activities and laboratory analysis.

O. Interpretation—Identify statistical/analytical methods that are relevant to the data within specified confidence levels for program purposes.

1. Understand the sample size.

2. Understand the parameters.

3. Identify statistical/analytical methods (refer to Section V of this outline).

P. Communications.

1. Identify technical and lay audiences.

2. Identify mechanisms and formats for presenting/distributing information; for example, press releases, public meetings, agency meetings, conferences, popular publications, agency reports, journal articles, and World Wide Web.

Q. Costs.

1. Determine the program costs and sources of funding.

2. Include in the cost estimates, implementation, interpretation, and communication activities of the monitoring program.

R. Program modification—Develop feedback mechanisms to fine-tune/improve design.

IV. Implementation.

A. Establish and document sites (selected during design and planning stages).

1. Construct wells, shelters, gage houses, staff gages, and other structures as needed in preparation for data collection.

2. Document ancillary data for sites.

B. Collect data.

1. Collect data according to specified monitoring design and protocols.

2. Coordinate with other agencies as appropriate.

C. Review results.

1. Review data-collection activities to ensure that protocols and the QA plan are being followed.

2. Review data-collection activities to ensure that data are complete and meet stated purposes.

D. Store and manage data.

1. Archive data so that the accuracy and precision are maintained.

2. Review data in accordance with data-management plan.

E. Share data—Provide data to other agencies upon request.

F. Prepare data summaries.

1. Provide information to managers periodically.

2. Provide information to collaborators and cooperators according to schedules.

V. Interpretation.

A. Data reliability—Define the accuracy and precision of the hydrogeologic and ancillary environmental data.

B. Interpret data to meet stated program purposes—Interpret the data, which include a description of the ground-water-resources system, by using existing environmental and ancillary data to provide information necessary to make management decisions related to water quality.

1. Geohydrologic systems analysis.

a. Temporal and spatial analysis.

b. Climatic impacts on ground-water systems.

c. Ground-water/surface-water interaction; for example, discharge and recharge effects.

2. Hydrogeochemical analysis.

a. Water/rock interactions.

b. Effects of land use.

3. Comparison of data to monitoring objectives.

C. Statistical methods and model documentation—Use statistical packages and deterministic models that are well documented.

D. Assess management impacts—Evaluate management alternatives and assess their impacts on the resource.

E. Coordinate interpretations—Coordinate the interpretations of data with collaborators and the user community.

VI. Evaluate monitoring program.

A. Meet goals and objectives—Determine if monitoring program goals and objectives are being met.

1. Assess usefulness of project data/information for local, regional, and national assessments.
2. Evaluate the need for program modifications and develop appropriate recommendations for ground-water monitoring.
3. Evaluate organizational concerns and coordination for private sector interface and local, State, and Federal interface.

B. Identify problems—Identify any monitoring problems associated with collecting and analyzing samples; storing, disseminating, and interpreting data; and reporting the information to managers and the public.

1. Evaluate the strengths and weaknesses of the monitoring-program design.
2. Evaluate the data-collection and the interpretation methods.
3. Evaluate the information-transfer methodologies used to report the data and information to resource managers, the public, and the scientific community.

C. Evaluate costs—Evaluate the costs of the monitoring program.

D. Feedback—Use results of evaluating monitoring program to identify current and future needs.

VII. Communication.

A. Coordinate—Participate in the distribution of information to and with other agencies and interested groups, such as environmental, industrial, and agricultural constituencies.

B. Prepare and distribute technical reports—Describe current water-quality conditions; spatial distribution; temporal variability; and sources, causes, transport, fate, and effects of contaminants based on monitoring results on humans, aquifers, and ecosystems as appropriate.

C. Communicate with multiple audiences—Prepare lay reports or executive summaries for nontechnical audiences and peer-reviewed reports for technical audiences.

D. Presentations—Make presentations to assist management and the public in understanding the significance of results. Presentations could involve the use of public information networks, which include newspapers, radio, television, and World Wide Web.

E. Provide available data—Provide available data for other data users as needed.

APPENDIX B

APPENDIX B: TYPES OF PROJECT-SUBMITTED QUALITY-CONTROL SAMPLES FOR GROUND-WATER STUDIES

Table B–1. Types of project-submitted quality-control samples for ground-water studies (from Franceska Wilde, U.S. Geological Survey, written commun., 1996)

[QC, quality control]

Sample type	Description	Purpose
	BLANK MATRIX SAMPLES	
	[Blank water, the matrix of blank-matrix samples is certified to be free of target organic analytes (organic-free water) or target inorganic analytes (inorganic-free water) at a specified limit of detection]	
AMBIENT BLANK (Atmospheric blank)	Blank water that has had the same exposure as environmental samples to the ambient atmosphere in the collection and processing area by being poured (1) from the same source as the field blank water (2) into the same type of bottle used for environmental samples and (3) being preserved (if required) at the field site. Synonymous with atmospheric blank.	Estimate constituent concentrations entering the sample from exposure to environmental conditions during sample collection and processing or from pre-field conditions.
	Ambient blanks need to be treated with a chemical preservative if the purpose of the blank is to accompany an equipment or field blank that requires preservation. If preservative is added to the ambient blank, the analytical results will include any constituent present in the preservative, as well as those entering the sample from brief exposure to the air. This is not the same QC sample type as a preservative blank, for which preservative is added to blank water under the controlled atmosphere of a laboratory hood.	An ambient blank is extremely useful when submitted in conjunction with the equipment field blank—it will distinguish between contamination related to the sampling environment and that related to equipment.
EQUIPMENT BLANK (Bottle blank, sampler blank, filtration blank, system [process] blank, and so on)	Blank water processed through an individual component of the equipment used for collecting and processing environmental samples, usually processed after decontamination under controlled conditions of the office or other facilities.	
System blank	Organic-free or inorganic-free water passed through the equipment to be used for collecting and processing environmental samples, prior to field work and under controlled conditions of office or other facilities. Equipment blanks are collected after the equipment has been decontaminated.	Identify any effects of the sampling equipment or its individual components on analyte concentrations.
Field blank	Organic-free or inorganic-free water passed through all the equipment to be used for collecting and processing environmental samples during field work alongside collection of environmental samples.	Identify any effects of the sampling equipment on analyte concentrations under true field conditions and verify adequacy of field decontamination procedures.
	Field blanks are collected after the equipment has undergone field decontamination procedures.	Collect an associated ambient blank to distinguish between contamination from equipment alone in contrast to contamination from the field environment.

Table B–1. Types of project-submitted quality-control samples for ground-water studies (from Franceska Wilde, U.S. Geological Survey, written commun., 1996)--Continued

[QC, quality control]

Sample type	Description	Purpose
PRESERVATION BLANK	Organic-free or inorganic-free water poured into a sample bottle into which corresponding preservatives for a given analysis are added. Preservatives must be from the same batch being used for the environmental samples. Preservatives are added by personnel under controlled environmental conditions, preferably under a hood.	Determine if sample contamination was caused by the preservative or preservation process.
Shelf blank	Organic-free or inorganic-free water poured into the same type of bottle used for environmental samples and stored adjacent to archived environmental samples on the shelf in field laboratories, sample holding areas, or other facilities. Personnel should prepare shelf blanks under controlled environmental conditions, preferably under a hood.	Determine if sample contamination was caused by the preservative or preservation process.
Refrigerator blank	A specialized case of a shelf blank.	Determine level of contamination from storage and holding facilities; determine blank-water degradation.
TRIP BLANK	The trip blank is a sample of organic-free or inorganic-free water supplied from the laboratory in a regular sample bottle that travels with the project crew throughout the field process and is stored and shipped with project samples. Trip blanks are returned unopened to the laboratory with the samples collected in the field.	Determine if shipping, storage, and field transport has caused sample contamination or cross-contamination.
ENVIRONMENTAL MATRIX SAMPLES [The term "environmental QC matrix sample" is a ground-water sample used for quality-control purposes and collected using methods identical to the ground-water sample]		
BACKGROUND SAMPLE	Sample that is considered pristine with respect to natural or anthropogenic effects on water quality being investigated. Background samples are located onsite or as near to the study site as possible and should be collected first (prior to collecting samples downgradient or from contaminated formation water). The background sample is considered one of the most useful types of QC samples (USEPA, 1988b, c; Keith, 1992).	Indicates the background (ambient) chemical composition of the formation waters being sampled. Serves as a control for interpretation of ground-water quality. Example: samples collected upgradient from a known area of contaminated ground water.
SEQUENTIAL SAMPLE	A type of replicate sample, collected immediately after the initial sample and considered essentially identical in composition. Replicates are submitted to the same or different laboratories and are assigned unique collection times for the same station identification.	Estimate combined effects of field and laboratory reproducibility on analytical measurements.

Table B–1. Types of project-submitted quality-control samples for ground-water studies (from Franceska Wilde, U.S. Geological Survey, written commun., 1996)--Continued

[QC, quality control]

Sample type	Description	Purpose
SPLIT SAMPLE	A type of replicate sample in which a larger sample volume is divided into two or more samples; samples can be submitted to the same or to different laboratories. Each split is assigned a unique collection time. The disadvantage of the two-way split is the difficulty in being able to interpret disparate analytical results. Split-sample results are difficult to interpret at low-level concentrations. The advantage of splitting the sample into thirds is that the third sample helps interpreting disparate analytical results between the splits. The disadvantage of the three-way split is expense.	Estimate reproducibility (precision)—relative to the given sample matrix—in a single laboratory's measurements, or compare differences in measurements obtained from different laboratories.
	REFERENCE-MATERIAL, SPIKE, AND BLIND SAMPLES	
REFERENCE-MATERIAL SAMPLE	Sample prepared and certified by a laboratory and having a strictly defined chemical composition. A material or substance, one or more properties of which are sufficiently well established to be used for the assessment of a measurement method or for assigning analyte concentration values to materials.	Tests proficiency of the laboratory measurement process (as distinguished from combined laboratory and field process) and checks interlaboratory and intralaboratory analytical results as long as the sample is prepared in a controlled environment.
BLIND SAMPLE	A sample submitted for analysis whose composition is known to the submitter, but unknown to the analyst—this could be an environmental sample, a blank sample, or a standard reference sample. Every blind sample analyzed should have an associated reference to the source and the preparation procedure. Blind samples may be prepared from a reference material.	Tests proficiency of the laboratory measurement process (as distinguished from combined laboratory and field process) and checks interlaboratory and intralaboratory analytical results as long as the sample is prepared in a controlled environment.
SPIKE SAMPLE	Sample spiked (fortified) in the field with known concentrations of target analytes (usually organic compounds) without substantially changing the matrix of the original sample. Every sample spiked should be documented as to the spike solution, the volume of spike solution added, and the sample volume. Each spiked sample must be accompanied by an unspiked replicate or split. The sample matrix may be environmental, blank, or reference material. Spike solution: a solution with one or more well-established analyte concentrations that is added in known quantities to an environmental sample to form a spike sample.	Estimate the recovery of targeted analytes relative to selected objectives; for example: (1) determine precision and accuracy of analyte recovery relative to sample matrix; (2) determine analyte degradation during transportation; (3) compare recoveries between laboratories using replicate spike samples.

APPENDIX C

APPENDIX C: COMMENTS ON APPLICATION OF IMMUNOASSAY FIELD-SCREENING TESTS FOR PESTICIDES IN WATER

Introduction

In recent years, there has been increasing awareness of and interest in the use of immunoassay field-screening tests for pesticides in water. This appendix provides an overview of the application of these screening tests in ground-water-quality studies. The following text is quoted and paraphrased from internal technical memoranda issued by the USGS during the past several years.

Applications of Immunoassay Tests

The primary function of immunoassay tests is to provide a qualitative to semiquantitative screening for detecting the presence or absence of a targeted chemical compound or chemical family. For example, if the purpose of a study is to examine atrazine in a specific hydrologic setting where it is the predominant herbicide applied, then the immunoassay test can be used to examine the variation in concentrations in water samples over time and space. A water sample could be screened in the field or office to decide whether or not the sample needs to be sent to the laboratory for quantitative analysis. Thus, a large percentage of the samples that are less than the detection limit of the target analyte can be eliminated. (This approach assumes that the immunoassay-test detection limit is equal to or less than the laboratory reporting limit for the targeted compound.) The immunoassay-test cost is about $10 to $20 for each water-sample test compared to $100 to several hundred dollars for laboratory quantitative analysis of a pesticide group.

The errors inherent in immunoassay tests may produce false positives (that is, a detection by an immunoassay test, but not by laboratory analysis), but seldom produce false negatives (that is, a nondetection by an immunoassay test, but detection by laboratory analysis). In practice, several investigators have reported that the triazine concentrations measured by immunoassay tests are equal to or greater than the sum of concentrations for individual triazine compounds as analyzed by gas chromatography/mass spectrometry (GC/MS). This characteristic of triazine results in immunoassay tests makes the tests a conservative and useful screening tool for pesticides.

A second, related function of immunoassay tests is to provide almost real-time information in the field about the presence or absence of a chemical or chemical family. The field analysis takes about 15 minutes to complete and, thus, has the potential to guide the selection of sampling locations and frequency for a project. Even for this purpose, however, these field immunoassay tests are not meant to be quantitative and cannot replace standard laboratory analyses on samples that indicate the target analyte(s) is (are) present.

A different approach, which is viewed by some investigators as the greatest asset of immunoassay tests, is to analyze dozens, even hundreds of samples, in batches of 10 to 50 in a laboratory environment (Thurman and others, 1992; Moody and Goolsby, 1993; Goolsby and others, 1994). Laboratory immunoassay tests are generally more accurate and more sensitive than the field tests because the procedures are more rigorously controlled and reaction times for the analyses can be longer, resulting in lower detection limits for the laboratory tests compared to the field tests. Additional considerations are that more equipment is needed (adding to the cost), the equipment setup is more efficient for performing analyses than in the field, and more skill is needed by the analyst to get precise results. The laboratory approach, however, allows the investigator to oversample in space and time and to screen many samples semiquantitatively. As a result, for a given investment of resources, more information about the distribution of a few pesticides is obtained than would be possible by using standard laboratory analyses alone. An integral part of this approach is the analysis of 10 to 30 percent of the samples by GC/MS to confirm the presence and concentrations of the targeted compounds and to identify compounds not analyzed by field immunoassay tests.

Limitations of Immunoassay Tests

Important limitations of the immunoassay screening tests include:

(1) The user cannot be certain which particular compound of a chemical family has elicited a response in an immunoassay test because the test is chemically nonspecific. Although each test is designed to be most sensitive to a particular chemical, the test may have some level of sensitivity to the whole family of chemicals and their metabolites. For example, a positive result in the triazine test could come individually from atrazine, simazine, other triazine herbicides, a metabolite, or some combination of these compounds. If the positive response in the immunoassay test is from more than one compound, a laboratory analysis could report all target chemicals as less than the reporting limit. For example, if it is assumed that the immunoassay test and the corresponding laboratory analytical procedures for a family of pesticides have detection-reporting limits of 0.1 ppb (part per billion), and if it is further assumed that concentrations of three compounds in the family are 0.05 ppb in a water sample, the sum of these concentrations, 0.15 ppb, would elicit a positive result from the field-screening test, but individually, the three compounds would receive less than detection values (< 0.1 ppb) from the laboratory analyses.

(2) Many, but not necessarily all, of the current (1996) immunoassay tests for pesticides may have detection limits for the target analytes that are greater than the reporting limits at the laboratory used by the project. If an immunoassay test has a greater detection limit than the laboratory for the project, the test may not be suitable even as a screening tool. As immunoassay tests improve, this limitation should diminish.

(3) To calculate the cost savings of immunoassay tests compared to laboratory analyses, the test costs and the personnel time need to be considered. There is a substantial savings if one immunoassay test is performed and indicates no need for a laboratory analysis. However, if more than two or three immunoassay tests are performed for different compounds in one water sample, the cost savings might rapidly diminish if all the compounds are available in one schedule from the laboratory for the project. For example, three different field immunoassay tests are presently (1996) used to screen for atrazine, alachlor, and metolachlor; however, all three compounds may be available in one quantitative analysis from the laboratory for the project.

(4) Field immunoassay tests probably are not appropriate in general reconnaissance or pesticide-occurrence studies. In these studies, the project objective generally is to determine which pesticides are present, where they are present, and at what concentration levels they are present. To use one immunoassay test as a screening tool in this type of study, which pesticide (and immunoassay test) should be used as a surrogate for all pesticides needs to be decided. In most hydrologic settings throughout the Nation, one pesticide generally cannot be used as a surrogate for all others. In some parts of the country, such as the upper Midwest, using atrazine as a surrogate for many (not all) other pesticides in ground water may be acceptable, but this conclusion has been reached only after many pesticide-occurrence studies have been conducted there. Extrapolation of the usefulness of the triazine immunoassay test from the Midwest to other parts of the country cannot be justified without further scientific evidence.

Documentation of and Data Storage from Immunoassay Tests

As in all aspects of water-quality studies, immunoassay tests need careful documentation in reports and in the data base for the monitoring program. In particular, this documentation needs to include a description of and the detection limit for each test because tests for the same chemical or chemical family, particularly the detection limit, may differ among supply companies and may change with time for the same company as the technology develops. Parameter codes for immunoassay tests may be obtained from the USEPA.