Water-Quality Data-Collection Activities in Colorado and Ohio: Phase III—Evaluation of Existing Data for Use in Assessing Regional Water-Quality Conditions and Trends

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Chapter C

Water-Quality Data-Collection Activities in Colorado and Ohio: Phase III—Evaluation of Existing Data for Use in Assessing Regional Water-Quality Conditions and Trends

By J. MICHAEL NORRIS, JANET HREN,
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CAROLYN J. OBLINGER CHILDRESS

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2295

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U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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FOREWORD

One of the challenges faced by the Nation is the development of reliable information that will guide the protection of our water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by academic institutions. Many of these agencies are collecting water data for many different purposes, including compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on water quality and quantity. The need for information of regional and national scope on the status and causes of current water-quality conditions and trends is prominent. Without this information, policy decisions may be based on information from only a few localized problems. Conversely, a lack of information may lead to a false sense that some problems do not exist. In the past two decades, billions of dollars have been spent on water-quality data-collection programs. However, only a small part of the data collected for these programs has been obtained specifically to assess the status, trends, and causes of ambient water-quality conditions at regional and national scales. In some instances, the utility of these data for present and future regional and national assessments is limited by such factors as the areal extent of the sampling network, frequency of sample collection, and the types of water-quality characteristics determined.

Water-quality data collected for permits and for compliance and enforcement purposes constitute a sizable source of information that may be suitable for regional and national assessments. However, such data need to be carefully screened before use. The needs, uses, and types of water-quality data vary widely, and data collected for one purpose are not necessarily suitable for other purposes. In fact, the use of unsuitable data in regional or national assessments may be much worse than a lack of information because the use of such data may lead to incorrect conclusions having far-reaching consequences.

Accordingly, the U.S. Geological Survey, with cooperation from other agencies and from universities, has undertaken a three-phase study in Colorado and Ohio to determine the characteristics of existing Federal and other public-agency water-quality data-collection programs and to evaluate the suitability of the data bases from these programs for use in water-quality assessments of regional and national scope. This report describes results of the third and final phase of this study. This study does not imply that past and present data-collection programs have failed or that they are inappropriate for their intended purposes. The data from those programs may fully meet individual agency needs and fulfill their mandated requirements, yet they may have only limited relevance to water-quality questions of regional and national scope.

This study has depended considerably on cooperation and information from many Federal, State, regional, and local agencies and academic institutions. The assistance and suggestions of all are gratefully acknowledged.

Philip Cohen
Chief Hydrologist

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CONVERSION FACTORS

For the benefit of readers who prefer to use metric (International System) units, conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06809	liter per second (L/s)
inch (in)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
square mile (mi^2)	2.590	square kilometer (km^2)
ton per day (ton/d)	0.0105	kilogram per second (kg/s)

Water-Quality Data-Collection Activities in Colorado and Ohio: Phase III—Evaluation of Existing Data for Use in Assessing Regional Water-Quality Conditions and Trends

By J. Michael Norris, Janet Hren, Donna N. Myers, Thomas. H. Chaney, *and* Carolyn J. Oblinger Childress

EXECUTIVE SUMMARY

During the past several years, a growing number of questions have been raised by members of Congress and others about current water-quality conditions in the Nation, trends in water quality, and the major factors that affect water-quality conditions and trends. One area of particular interest and concern has been the suitability of existing water-quality data for addressing these types of questions at regional and national scales. In response to these questions and concerns, the U.S. Geological Survey began a pilot study in Colorado and Ohio to determine (1) the characteristics of current water-quality data-collection activities of Federal, State, regional, and local agencies and universities and (2) how well the data from these activities, collected for various purposes and using different procedures, can be used to improve our ability to address the aforementioned questions.

Colorado and Ohio were chosen for the pilot study because they represent regions with different types of water-quality issues and programs. The results of the study are specific to the two States and are not intended to be extrapolated to other States.

The study was divided into three phases whose objectives were:

Phase I—Identify and inventory 1984 water-quality data-collection programs, including costs, in Colorado and Ohio, and identify those programs that meet a set of broad criteria for producing data that potentially are appropriate for water-quality assessments of regional and national scope.

Phase II—Evaluate the quality assurance of field and laboratory procedures used to produce the data from programs that met the broad criteria of Phase I.

Phase III—Compile the qualifying data from Phase II and evaluate the extent to which the resulting data base may be used to address selected water-quality questions for the two States.

This report presents the results of Phase III, focusing on (1) the number of measurements made at each data-collection site for selected constituents, (2) the areal distribution of those sites that have sufficient data for selected types of analyses, and (3) the availability of key ancillary information, such as streamflow, to address the broad-scope questions:

1. What are existing water-quality conditions?
2. Has the water quality changed?, and
3. How do existing water-quality conditions and changes in these conditions relate to natural factors and the activities of man?

In Phase I of this study, an inventory was made of all public organizations and academic institutions that had water-quality data-collection activities in Colorado and Ohio in 1984. Characteristics of each water-quality data-collection program were compared against five screening criteria:

1. Do the data represent ambient stream or aquifer conditions, as opposed to effluent or treated water?
2. Are the data available for public use?
3. Can the sampling sites be readily located?

4. Is quality-assurance documentation available?, and
5. Are the data in computer files?

Of the funds spent in 1984 on water-quality data-collection activities in the two States, probably less than half of the funds in Colorado and perhaps as little as one-tenth of the funds in Ohio were applied to activities that produced data suitable for use in addressing water-quality questions of regional and national scope under the above criteria. Although qualifying programs included both surface- and ground-water sampling, they emphasized surface water and produced few ground-water analyses. The most commonly collected data were for constituents and properties used to provide a gross measure of water quality, such as dissolved solids, dissolved oxygen, suspended sediment, and nutrients. Thus, the data bases contain a relatively large number of analyses useful in addressing issues of long-standing concern, such as salinity, sedimentation, sanitary quality, and eutrophication. The fewest analyses were for trace constituents, such as lead, phenol, and uranium. As a result, the data bases contain relatively few analyses for constituents needed to address issues of more recent concern, including contamination of water by potentially toxic organic compounds and trace metals.

In Phase II, information about field and laboratory practices was provided by each organization and its supporting laboratories and compared to a set of criteria developed from guidelines published by public agencies and professional organizations. Few of the analyses inventoried in Phase I of the study met all the screening criteria for both Phase I and Phase II. For both States, fewer than 15 percent of the analyses met the screening criteria judged necessary for the data to be included in a consistent data base suitable for addressing broad-scope water-quality questions. The screening criteria pertaining to field practices had a much greater effect on limiting the number of analyses that passed the Phase II screen than did the laboratory-practices criteria. Compared to all other criteria, the representative-sampling criterion was met by the smallest percentage of analyses. Analyses that failed this criterion were from stream samples that could not be verified as being representative of the entire cross section. Generally these were point (or "grab") samples, that is, samples collected from a single point near the water surface. In contrast, most of the analyses in both States met each of the laboratory-practices criteria.

In Phase III, 12 of the 20 constituents evaluated in Phase II were selected for further evaluation. For those constituents included in the surface-water and ground-water parts of the assessment, data that met the criteria for Phase I and Phase II were obtained for water years 1977 through 1984 and water years 1972 through 1984, respectively. Water year 1977 was used as the beginning of the surface-water data-analysis period because depth-width integrating sample-collection method equipment became commonly available at that time; this method generally is considered the best for sample collection at poorly mixed sites or at sites where the mixing characteristics are unknown. Water year 1984 is used as the end date because that was when the Phase I data were obtained. Water year 1972 was used for the beginning period for ground-water data analysis because the Clean Water Act of 1972 began then to provide guidance for protecting water quality. Major results of Phase III of this study are summarized below and in table E1.

1. *Number of measurements at each data-collection site*—One factor that has a large effect on the utility of existing surface-water data for meeting the goals and objectives of ambient water-quality assessments is the number of measurements made at each of the data-collection sites. Single, or few, measurements at sites often are adequate for describing current ground-water-quality conditions and are useful for reconnaissance-level assessments of streams. However, because of the large variations in water quality that may occur in streams, many measurements may be needed to develop an understanding of seasonal variations and long-term trends in water-quality conditions at a particular site. Although there is no single frequency of sampling or number of measurements that is ideal for all conditions, as a general guide, 10 surface-water analyses for the period 1980–84 were considered the minimum number of measurements needed to define existing surface-water-quality conditions. In contrast, because the quality of ground water tends to change more slowly than the quality of surface water, only one ground-water observation for the period 1980–84 was considered necessary to define existing ground-water-quality conditions. For the different constituents evaluated, on average, 123 (26 percent) of the surface-water-quality data-collection sites that met the Phase II criteria in Colorado and 36 (12 percent) of the sites that met the same criteria in Ohio yielded 10 or more analyses for the period 1980–84 for existing conditions analyses (see table E1, section B). All ground-water-quality data-collection sites that met the Phase II criteria that yielded at least one analysis are considered suitable for defining existing ground-water-quality conditions. Of the constituents evaluated, an average of 36 (6 percent) of the surface-water-quality data-collection sites in Colorado and 17 (4 percent) of the same type sites in Ohio had concurrent streamflow data and at least quarterly water-quality measurements that were collected over a 5-year period and thus were useful for trend analysis (see table E1, section D). For ground-water trend analysis for the constituents evaluated, on average, 10 (1 percent) of the ground-water-quality data-collection sites in Colorado and 23 (13 percent) of the same type sites in Ohio yielded at least one water-quality measurement per year for 5 years during the period of 1972–84 (see table E1, section F).

2. *Areal distribution of data-collection sites*—In both Colorado and Ohio, most data-collection sites with an adequate number of measurements tend to be clustered in relatively small areas with known or suspected water-

Table E1. Summary of Phase III results

Selected data	Colorado Number	Colorado Percentage[5]	Ohio Number	Ohio Percentage[5]
Average[1] numbers of surface-water-quality data-collection sites that met Phase II criteria.				
1980-84[2]	473	100	294	100
1977-84[3]	565	100	456	100
Average numbers and percentages of sites that met Phase III criteria				
A. Concurrent streamflow data				
1980-84	356	75	247	84
1977-84	523	93	448	98
B. Concurrent streamflow data and 10 or more water-quality measurements				
1980-84	123	26	36	12
1977-84	122	22	36	8
C. Daily streamflow data and 10 or more water-quality measurements				
1980-84	105	22	30	10
D. Concurrent streamflow data and at least quarterly water-quality measurements collected over 5 years.				
1977-84	36	6	17	4
E. Average numbers and percentages of ground-water-quality data-collection sites that met Phase II criteria.				
1980-84	145	100	76	100
1977-84	1,197	100	175	100
F. Average numbers and percentages of ground-water-quality data-collection sites that met Phase II criteria with at least 1 water-quality measurement per year for 12 years				
1972-84[4]	10	1	23	13

[1]The information in this table represents average numbers and percentages of data-collection sites sampled for 12 of the constituents evaluated in Phase II of this study. Constituents selected for evaluation in Colorado included dissolved solids, suspended sediment, and dissolved oxygen for surface water and dissolved solids, total-coliform bacteria, nitrate as nitrogen, and uranium for ground water. Constituents selected for evaluation in Ohio included dissolved oxygen, total phosphorus, total-recoverable lead, suspended sediment, and fecal-coliform bacteria for surface water and phenols, nitrate as nitrogen, total-recoverable iron, and total-recoverable manganese in ground water.

[2]1980-84--period used for describing existing conditions for surface water.

[3]1977-84--period during which depth-integrated sampling has been used to collect surface-water samples for trend analysis.

[4]1972-84--Period after passage of Clean Water Act (PL 92-500) was used for analysis of ground-water trends.

[5]Percentage of sites meeting specific criteria that met Phase II criteria.

quality problems and (or) high water use. In Colorado, for example, most of the surface-water-quality data-collection sites yielding data on streamflow and 10 or more observations of dissolved-solids and suspended-sediment concentrations are clustered in the northwestern part of the State. These sampling locations were placed in response to concerns about salinity levels in the Colorado River and the effects of mining. In Ohio, the largest number of sites yielding streamflow data and 10 or more observations of total phosphorus are in the Lake Erie basin, which is densely populated and is an area of relatively high water use. In both States, the ground-water data-collection sites are clustered in areas of high water use.

3. *Availability of ancillary data*—In addition to water-quality data, other types of information are needed in an assessment to standardize data for comparison or to help

explain assessment results. For example, streamflow data are needed for most surface-water-quality assessments because the concentrations of many constituents are affected by changes in streamflow. For the constituents evaluated in this study, more than 85 percent of the surface-water sites meeting the Phase II criteria also had concurrent streamflow data. If the objectives of an assessment include determining the cause(s) of certain conditions, other types of ancillary data may be needed. For example, two other types of information commonly used to help explain variations in water-quality data are geology and land use. In general, data for most supporting information commonly used in water-quality assessments (streamflow, geology, land and water use, and soil characteristics) are available and suitable for large-scale, regional assessments. Except for streamflow data, however, most of these data are not available in computer files. The utility of these data for testing hypotheses of cause and effect would be improved if these data were in digital format so that comparisons could be made using the computer.

4. *Conclusions*—Major conclusions about the extent to which existing water-quality data can be used to address selected water-quality questions for Colorado and Ohio are presented below.

A. *Suitability of existing data for describing existing water-quality conditions*—For both Colorado and Ohio, the types of data and the number and areal distribution of surface- and ground-water-quality data-collection sites are insufficient for describing existing water-quality conditions throughout each State. The largest amounts of data available (about 90 percent) are for surface water.

For both surface and ground water, too few data are available for either trace elements or organic compounds to provide reliable estimates of their occurrence and distribution. In some areas of both States, the number and distribution of data-collection sites with concurrent streamflow data and 10 or more water-quality measurements is sufficient to provide useful information on the spatial and short-term temporal variation of selected water-quality constituents useful in addressing issues of long-standing concern such as salinity, sedimentation, and eutrophication. These areas usually have known or suspected water-quality problems and have high water use or large populations. A similar number and distribution of stream sites yielding daily streamflow data and 10 or more water-quality measurements are available to estimate loads of water-quality constituents (table E1, section B).

B. *Suitability of existing data for determining changes in water quality*—For the constituents studied, less than 10 percent, on average, of the surface-water-quality data-collection sites in both Colorado and Ohio yield sufficient data for determining changes in water-quality conditions (table E1, section D). In Colorado, the number and location of these sites in the northwestern part of the State are suitable for detecting changes but there probably are too few sites in other parts of the State. In Ohio, there seem to be an adequate number of sites on major tributaries to Lake Erie and the Ohio River. With the exception of sites monitored for dissolved oxygen, however, there probably are too few in the central part of Ohio for determining changes in water quality.

On average, only 10 (1 percent) of the ground-water-quality data-collection sites in Colorado and only 23 (13 percent) of the sites in Ohio yield sufficient data for determining changes in water quality (table E1, section E). Most of these sites are clustered in small areas and provide only limited understanding of regional changes in water quality.

C. *Suitability of existing data for determining the relations of current water-quality conditions and changes in these conditions to natural factors and human activities*—The use of existing water-quality data in Colorado and Ohio for determining relations between water quality and natural factors and human activities generally is limited to relatively small stream segments, parts of river basins, and parts of aquifers, where the spatial density of sampling sites and number of observations at these sites is suitable for providing reliable estimates of descriptive statistics for concentrations, loads, and trends. In general, these areas reflect sampling by Federal, State, and local agencies in response to known or suspected water-quality problems, legislation, or treaty obligation. Ancillary data suitable for addressing regional-scope questions generally are available, but their utility would be enhanced if more of these data were in digital format so that comparisons could be accomplished by computer.

INTRODUCTION

National awareness of the importance of clean water has greatly increased during the past two decades. Environmental laws that have been passed addressing issues associated with protecting water quality include the Clean Water Act (1972, amended 1977, 1981, and 1987); the Safe Drinking Water Act (1974, amended 1986); the Resource Conservation and Recovery Act (1976); the Toxic Substances Control Act (1976); the Surface Mining Control and Reclamation Act (1977); and the Comprehensive Environmental Response, Compensation, and Liability Act (1980). In addition, Federal, State, and local agencies and industry have made substantial commitments to the protection of water quality. Expenditures for water-pollution abatement and control during the 1970's have been estimated at more than $100 billion (Conservation Foundation, 1982, p. 32–35). Water-quality data-collection programs have accounted for several billions of dollars during the past two decades. The purposes of these programs include assessing compliance with criteria and standards, establishing baseline conditions, and determining long-term trends. As a result of these programs, a large amount of water-quality data has been generated by a diverse group of organizations for widely differing purposes under varying collection conditions and quality control.

Questions have been raised by Congress about the usefulness of these water-quality data for addressing issues of regional and national scope and, especially, for characterizing the current quality of the Nation's surface and ground water (Blodgett, 1983). In spite of the large amounts of data being compiled, it has been difficult to make a reliable assessment of regional and national water-quality conditions. One reason for this is that water-quality data obtained specifically for broad-scope assessments constitute a relatively small part of the total available water-quality data. Water-quality data collected for other purposes constitute a sizable potential source of additional data for application to regional and national assessments, but the suitability of these data must be carefully evaluated. The needs, uses, and types of water-quality data differ greatly, and data collected for one purpose are not necessarily suitable for other purposes. If data from different programs are to be aggregated, it is important to ensure that available data have been produced with comparable sample-collection and analysis methods. In fact, the use of unsuitable data in regional or national assessments may be much worse than a lack of data because it may lead to incorrect conclusions having far-reaching consequences.

Sufficient information has not been available to determine the benefits and problems associated with aggregating available water-quality data for regional and national assessments. Consequently, the U.S. Geological Survey has undertaken a study of water-quality data collected by various agencies and academic institutions in Colorado and Ohio to determine the suitability of these data for use in water-quality assessments of regional and national scope.

Project Objectives and Approach

The objectives of this study were to: (1) determine the characteristics of recent (1984) water-quality data-collection activities of Federal, regional, State, and local agencies and universities; and (2) determine the extent to which the data from these activities, collected for various purposes and using different procedures, can be used to improve our ability to address broad-scope questions, such as:

1. What are existing water-quality conditions?
2. Has the water quality changed?
3. How do existing water-quality conditions and changes in these conditions relate to natural factors and the activities of man?

A three-phase approach was used; the objectives of these phases were:

Phase I—Identify and inventory water-quality data-collection programs, including costs, in Colorado and Ohio, and identify those programs that meet a set of broad criteria for producing data that potentially are appropriate for water-quality assessments of regional and national scope.

Phase II—Evaluate the quality assurance of field and laboratory procedures used to produce the data from programs that met the broad criteria of Phase I.

Phase III—Compile the data that qualified from Phase II and evaluate the extent to which the resulting data base can be used to address selected water-quality questions for the two States.

Two States, Colorado and Ohio, were chosen to serve as a small sampling of the Nation. These States represent regions with different types of water-quality issues and programs.

Colorado has a population of about 3 million (U.S. Bureau of the Census, 1981a). It is a lightly industrialized western State, and 36 percent of its land is federally owned (U.S. Bureau of Land Management, 1983). During 1980, freshwater withdrawals in Colorado averaged 16 billion gallons per day (81 percent surface water, 19 percent ground water) for public supply, rural domestic, livestock, industrial, and irrigation uses (Solley and others, 1983, p. 38). Eighty-eight percent of this water was used for irrigation and 6 percent for industry (including thermoelectric and other industrial cooling uses). Major water-quality concerns in Colorado include salinity from natural sources and from irrigation-return flows, contamination by potentially toxic trace elements from mining, sedimentation from land disturbances such as mining and agriculture, and the sanitary quality of surface- and ground-water supplies.

Ohio has a population of about 10.8 million (U.S. Bureau of the Census, 1981b). It is an industrialized eastern State with only about 1 percent federally owned lands (U.S. Bureau of Land Management, 1983). Freshwater withdrawals in 1980 averaged 14 billion gallons per day (93 percent surface water, 7 percent ground water) (Solley and others, 1983, p. 38). Eighty-six percent of the water was for industry (including thermoelectric and other industrial-cooling uses). Less than 1 percent of the water was used for irrigation. Major water-quality concerns in Ohio include contamination by potentially toxic trace elements and synthetic organic substances associated with industrial or municipal-waste discharge; sedimentation from land disturbances such as mining, agriculture, and other activities; and the sanitary quality of surface- and ground-water supplies.

Summary of Phase I and Phase II

Water-quality data are collected in Colorado and Ohio by a large number of organizations for diverse purposes that range from meeting statutory requirements to research on water chemistry. Combining these individual data bases could be an efficient and potentially cost-effective way to assess regional and national water-quality conditions. However, to accomplish this goal, data need to be applicable to the particular issues or questions of interest (for example, toxic contamination and sedimentation); these data need to be readily available; and the field and laboratory procedures used to produce these data need to be comparable and meet specific quality-assurance criteria. These factors were evaluated in Phase I and Phase II of this study.

Results of Phase I of this study are presented in Hren and others (1987), and results for Phase II are presented in Childress and others (1989). Major results from Phase I and Phase II are summarized in tables 1 and 2 of this report and are discussed below.

The information presented in table 1 represents the sums of samples analyzed for groups of constituents and properties (for example, nutrients, trace elements, and so forth). These sums represent all samples inventoried in Phase I, including the numbers of samples associated with both ambient and nonambient water-quality conditions (such as samples of effluents and processed drinking water). In contrast, the information presented in table 2 represents the sums of individual analyses and measurements that met the Phase I criteria for the 20 constituents and properties evaluated in Phase II.

Phase I

Agency involvement—Phase I identified 115 water-quality data-collection programs by 48 organizations in Colorado and 88 programs by 42 organizations in Ohio. Federal agencies had the largest number of data-collection programs in each State, accounting for about 50 percent of all programs in Colorado and 32 percent of all programs in Ohio. In addition, many of the State and local programs received funding and other support from Federal agencies.

Sources of samples—More than 90 percent of all water samples collected in each State were surface-water samples. Ground-water samples represented only about 9 percent of the samples reported in Colorado and 4 percent of the samples in Ohio. Much of the sampling in both States was for mandated purposes such as meeting permit requirements for monitoring wastewater effluent or drinking water. Only about 42 percent of the samples in Colorado and 15 percent of the samples in Ohio reportedly were collected for characterizing ambient water-quality conditions.

Screening criteria—The water-quality data-collection programs were tested against a set of criteria (fig. 1) selected to evaluate the potential availability and applicability of the data for assessing regional ambient water-quality conditions and trends. Only 34 percent of all samples reported in Colorado and 5 percent of the samples reported in Ohio met all five criteria of the Phase I screen. Most samples that did not meet the Phase I criteria were permit-required samples of waste effluent or treated water and, therefore, were not considered representative of ambient water-quality conditions of streams or aquifers.

Costs—Total costs for programs in the two States could not be discerned from information available from the various agencies. However, about $63 million was estimated to have been spent in the two States during 1984 for laboratory analyses of water-quality samples. Laboratory costs generally amount to less than one-half the total cost of a water-quality data-collection program. Thus, about $100 million may have been spent for water-quality data-collection programs in the two States during 1984. Only about 31 percent of the analytical cost for Colorado and 6 percent of the analytical cost for Ohio were for samples that met all five Phase I screening criteria.

Properties and constituents—Reported sample analyses and measurements were divided into 11 major groups of water properties and constituents. Most data that met the Phase I screening criteria were for constituents and properties that broadly characterize water quality, such as pH, alkalinity, specific conductance, and dissolved oxygen. Therefore, these data bases include a relatively large number of analyses that are needed to address issues of long-standing concern such as sanitary quality and salinity. These measurements are inexpensive and are often done in the field. In contrast, there were few analyses for trace constituents, such as atrazine, polychlorinated biphenyl, and lead. These analyses are needed to address more recent concerns of contamination of surface and ground water by potentially toxic trace elements and synthetic organic compounds.

Phase II

Screening criteria—The water-quality programs that met the Phase I screening criteria were tested against a set of specific criteria for field and laboratory methods developed from guidelines published by public agencies and professional organizations (fig. 1).

Screening results—Relatively few of the analyses inventoried in Phase I met all the screening criteria for Phase II. Only about 11 percent of the analyses for Colorado and 14 percent of the analyses for Ohio met the screening criteria for both phases. That is, for both States, less than 15 percent of the analyses met the conditions (screening criteria) judged necessary for the data to be included in a consistent data base appropriate for assessing regional ambient water-quality conditions and trends.

Table 1. Summary of Phase I statistics

[<, less than]

Selected 1984 data	Colorado		Ohio	
Numbers and percentages of water-quality data-collection programs operated by:	Number	Percentage	Number	Percentage
Federal agencies	58	50	28	32
State agencies	17	15	22	25
Regional agencies	6	5	3	3
Local agencies	30	26	27	31
Academic institutions	4	4	8	9
All identified organizations	115	100	88	100
Approximate numbers and percentages of water-quality samples from:				
Surface-water sources	308,120	91	1,146,830	96
Ground-water sources	30,080	9	50,700	4
Ground- and surface-water sources (rounded)	338,000	100	1,198,000	100
Approximate numbers and percentages of samples for the main purpose of:				
Meeting permit requirements[1]	155,700	46	1,005,000	84
Compliance-and-enforcement activities[1]	39,000	12	15,800	1
Characterizing ambient water conditions	143,400	42	176,700	15
Total reported samples (rounded)	338,000	100	1,198,000	100
Approximate numbers and percentages of samples that met Phase I screening criteria, by major property and constituent groups:				
Physical properties	38,710	34	12,370	22
Inorganic constituents	28,660	25	7,990	14
Trace elements	7,310	6	5,040	9
Major metals	5,700	5	3,700	6
Nutrients	14,540	13	8,820	16
Organic substances	6,570	6	4,160	7
Priority pollutants	244	<1	1,100	2
Pesticides	90	<1	1,800	3
Radiochemicals	260	<1	50	<1
Biota	9,960	8	4,820	8
Sediment	2,120	2	7,100	13
All property and constituent groups (rounded)	114,000	100	57,000	100
Estimated laboratory costs, before and after Phase I screening, for samples collected for meeting permit requirements and other purposes (compliance-and-enforcement activities, and characterizing ambient water conditions):	Cost	Percentage	Cost	Percentage
Permit-required samples, total	$6,080,000	45	$35,700,000	72
Samples meeting screening criteria	$0	0	$0	0
Samples for other purposes, total	$7,410,000	55	$13,880,000	28
Samples meeting screening criteria	$4,120,000	31	$3,020,000	6
Samples for all purposes, total	$13,490,000	100	$49,580,000	100
Samples meeting screening criteria	$4,120,000	31	$3,020,000	6

[1]Predominantly effluent or nonambient samples (Hren and others, 1987).

Table 2. Summary of Phase II statistics

[Data from Childress and others, 1989]

Selected data	Colorado		Ohio	
Analyses and measurements at different phases	Number	Percentage	Number	Percentage
Inventoried in Phase I[1]	240,000	100	242,000	100
Passing Phase I screen	165,000	69	76,300	32
Passing Phase I and Phase II screen	26,400	11	34,900	14
Percentages of analyses and measurements meeting each Phase II screening criterion	Percentage		Percentage	
Field-practices criteria:				
Documented sample-collection techniques	100		96	
Collection of representative samples	18		67	
Other sample-collection practices	99		89	
Sample handling and preservation	91		72	
Field-instrument use and maintenance	100		84	
Laboratory-practices criteria:				
Quality assurance	96		75	
Quality control	100		99	
Analytical methods	94		93	
Numbers of analyses and measurements passing Phase I and Phase II screens				
Surface-water criteria	23,900		34,400	
Ground-water criteria	2,530		470	
Totals, rounded to nearest 100	26,400		34,900	

[1]Because of the differences in the Phase I and Phase II screening procedures, the screening results presented in this table cannot be compared readily with the results of the Phase I screening as presented by Hren and others (1987). Thus, the sums of analyses inventoried in Phase I that are reported here have been adjusted from those reported in Hren and others (1987) to allow for a meaningful comparison. For Colorado, 338,000 ambient and nonambient samples were inventoried in Phase I (Hren and others, 1987); when adjusted for comparison to Phase II, 240,000 ambient analyses and measurements of the 20 constituents of interest in Phase II were inventoried in Phase I. For Ohio, 1,198,000 ambient and nonambient samples were inventoried in Phase I (Hren and others, 1987); when adjusted for comparison with Phase II data, 242,000 ambient analyses and measurements of the 20 constituents of interest in Phase II were inventoried in Phase I.

Field practices—Screening criteria pertaining to field practices had the greatest limiting effect on the number of analyses that met the Phase II criteria. The representative-sample criterion was met by 18 percent of the analyses in Colorado and 67 percent of the analyses in Ohio. Analyses that failed this criterion were from stream samples that could not be verified as being representative of the entire stream cross section.

Laboratory practices—In contrast to the field practices criteria, most of the analyses in both States met each of the laboratory-practices criteria. This may be due, in part, to the more detailed description and widespread publication of guidelines for laboratory practices as compared to guidelines for field practices, particularly with regard to collection of representative samples.

Purpose and Scope of Report

Phase III of the study, described in this report, evaluates the extent to which existing ambient water-quality data (that met Phase I and Phase II criteria) in Colorado and Ohio can be used to answer major regional-scale questions such as:

1. What are existing water-quality conditions?
2. Has water quality changed?, and
3. How do the existing water-quality conditions and trends relate to natural and anthropogenic factors?

This evaluation focuses on questions 1 and 2 by evaluating the spatial distribution of sampling sites, the number of measurements of different constituents at sampling sites,

INVENTORY OF STATE-WIDE WATER-QUALITY DATA

↓

PHASE I SCREEN

Do the data represent ambient stream or aquifer conditions, as opposed to effluent or treated water?

Are the data available for public use?

Can the sampling sites be readily located?

Is quality-assurance documentation available?

Are the data in a computer file?

No ← Data eliminated from further analysis

↓ Yes

PHASE II SCREEN

FIELD PRACTICES:

Documented sample-collection techniques used?

Samples representative of stream or aquifer conditions?

Other established field practices used?

Established sample-handling and sample-preservation procedures used?

Analytical instruments used and maintained in the field in accordance with established procedures?

LABORATORY PRACTICES:

Quality-assurance program maintained?

Laboratory quality-control procedures maintained?

Appropriate analytical methods used?

No ← Data eliminated from further analysis

↓ Yes

PHASE III ANALYSIS

Data further evaluated in Phase III

Figure 1. Process used to inventory and screen data for regional-scale ambient water-quality assessments in Colorado and Ohio.

and the availability of key ancillary information needed to support analyses of current conditions and trends.

METHODS OF ACQUIRING, COMPILING, AND EVALUATING INFORMATION

Because of the large number of constituents of potential interest in water-quality assessments, this evaluation was limited to a few constituents that relate to water-quality concerns in Colorado and Ohio and that had a reasonably large number of observations remaining after the Phase II screening process. The constituents evaluated in Phase II and a summary of water-quality issues and related legislative acts and agreements are listed in table 3. As described earlier, major water-quality concerns in Colorado include salinity from irrigation-return flows, contamination from potentially toxic trace metals from mining, sedimentation from land disturbances, and poor sanitary quality resulting from domestic wastewater effluents and feedlot runoff. Accordingly, constituents selected for evaluation in Colorado included dissolved solids, suspended sediment, and dissolved oxygen for surface water; and dissolved solids, total-coliform bacteria, nitrate as nitrogen (hereinafter referred to as nitrate), and uranium for ground water (table 4).

Major water-quality concerns in Ohio include contamination from trace metals and synthetic organic substances associated with industrial or municipal waste discharge; sedimentation from agricultural, mining, and other activities; eutrophication; and sanitary quality. Accordingly, constituents selected for evaluation in Ohio included dissolved oxygen, total phosphorus, total-recoverable lead, suspended sediment, and fecal-coliform bacteria for surface water; and phenols, nitrate, total-recoverable iron, and total-recoverable manganese for ground water (table 4).

The 5-year interval, 1980 through 1984, was chosen arbitrarily as the period to represent recent conditions. The time period since the enactment of the Clean Water Act, 1972–84, was selected to evaluate the suitability of data for defining ground-water quality and the changes or trends in ground-water-quality conditions. A shorter time period (1977–84) was used for evaluating the suitability of data for defining trends in surface-water-quality data. The time period 1977–84 represents the period of record available since the depth-width integration technique became an accepted method of sample collection for streams. In evaluating trends in water quality, it is important that the methods of sample collection and analysis be consistent for the period of interest so that changes due to natural and anthropogenic factors can be discerned from other factors.

For this study, the surface-water evaluation was limited to streams; data from lakes and reservoirs were not included. There were no similar limitations placed on ground-water resources.

DESIGN CONSIDERATIONS OF WATER-QUALITY ASSESSMENTS

An evaluation of the suitability of available water-quality data for assessment purposes needs to address the following questions:

- What are the goals and objectives of the assessment?
- What is the scale of the assessment in space and time?
- Where are appropriate sampling sites?
- What data-analysis methods (for example, statistical tests) are appropriate?
- How many measurements are necessary and for what time period?

Table 3. Selected water-quality issues, causative factors, related policy and legislation, and related water-quality constituents and properties

[Constituents that are underlined were selected for evaluation in Phase III]

Issues (surface or ground water)	Causative factors	Related policy and legislation	Related water-quality constituents, properties, and constituent categories
Acid rain (surface water).	Industrial and auto emmissions, natural resources.	Clean Air Act and amendments.	pH, alkalinity, acidity, dissolved sulfate, nitrate as nitrogen, aluminum, and trace metals.
Eutrophication (surface water).	Runoff from agricultural and urban areas, septic tanks, wastewater discharges.	Clean Water Act and amendments, Great Lakes Water-Quality Agreement.	Water transparency, phosphorus, organic and inorganic nitrogen, silica, chlorophyll a.
Salinity (surface and ground water).	Road salt, irrigation return flow, mine discharges, evaporation, natural sources (such as geochemical composition of soils and mineralized ground water).	Clean Water Act and amendments, Surface Mine Control and Reclamation Act, Colorado River Basin Salinity Control Act.	Specific conductance, dissolved solids, dissolved chloride, sodium, calcium, other major minerals.
Soil erosion-sedimentation (surface water).	Agricultural practices, surface mines, natural processes.	Watershed Protection and Flood Prevention Act, Surface Mining Control and Reclamation Act, Clean Water Act and amendments.	Suspended sediment, bed sediment.
Toxic contamination (surface and ground water).	Municipal and industrial waste, pesticides, landfills, runoff, from urban areas, natural sources, irrigation return flows.	Resource Conservation and Recovery Act; Toxic Substances Control Act; Comprehensive Environmental Response, Compensation and liability Act (Superfund); Clean Water Act and amendments; Great Lakes Water-Quality Agreement.	Priority pollutants (organic and inorganic compounds, pesticides, industrial chemicals, toxic trace metals).
Mine drainage (surface and ground water).	Coal mines, mineral and gravel mines, mill tailings.	Surface Mine Control, and Reclamation Act, Clean Water Act and amendments.	Specific conductance, pH, dissolved solids, sulfate, iron, manganese, uranium, suspended sediment, heavy metals.
Sanitary quality-water supplies (surface and ground water).	Municipal and industrial waste effluents, feedlots, runoff from urban areas, natural sources.	Clean Water Act and amendments, Safe Drinking Water Act.	Dissolved oxygen, biochemical oxygen demand, ammonia as nitrogen, nitrate as nitrogen, iron, manganese, methylene-blue-active substances, suspended solids, dissolved solids, total- and fecal-coliform bacteria, fecal-streptococcus bacteria.

Table 4. Water-quality issues and related water-quality constituents selected for evaluation in Phase III for Colorado and Ohio

[Numbers in parentheses are the numbers of sites yielding data (in 1984) that met the Phase II screening criteria]

Issues	Related surface-water constituents		Related ground-water constituents	
	COLORADO			
Salinity----------	Dissolved solids	(883)	Dissolved solids	(2,561)
Sanitary quality---	Dissolved oxygen	(348)	Total-coliform bacteria.	(1,578)
Sedimentation------	Suspended sediment	(188)	Nitrate as nitrogen	(577)
Toxic contamination	-----------------	-----	Uranium	(72)
	OHIO			
Eutrophication-----	Total phosphorus	(236)	----------------	-------
Sanitary quality---	Dissolved oxygen	(594)	Nitrate as nitrogen	(300)
	Fecal-coliform bacteria	(54)	----------------	-------
Sedimentation------	Suspended sediment	(393)	----------------	-------
Toxic contamination	Total-recoverable lead	(52)	Phenol	(135)
Mine drainage------	----------------	-----	Total-recoverable iron.	(131)
	----------------	-----	Total-recoverable manganese.	(132)

Goals and Objectives

The first, and perhaps most important, step in evaluating assessment strategies is developing a clear definition of the goals and objectives of the assessment. These goals and objectives help determine appropriate design considerations.

As noted in Hren and others (1987), numerous Federal, State, interstate, and local agencies collect water-quality data for a variety of purposes that include:

- Assessing the adequacy of controls on the release or containment of contaminants;
- Detecting long-term trends, unplanned releases, or accidents and their causes;
- Determining or enforcing compliance with effluent or ambient standards;
- Establishing baseline data for future reference and long-range planning; and
- Determining the cause and effect of relations that control the levels and variability of constituent concentrations over space and time.

Sampling requirements for these objectives may be very different. For example, high sampling frequencies and (or) continuous monitoring are needed to estimate loads and for compliance and surveillance. Other examples are presented in table 5.

Cause-and-effect studies may require multiple stations per basin and high sampling frequencies because data at small time and space scales often are needed to estimate transfer coefficients and model parameters. Detecting trends in concentration over time usually requires long sequences of data collected monthly, bimonthly, or four times per year.

The mission of the U.S. Geological Survey is to assess the quantity and quality of a number of earth resources for the Nation, including energy, minerals, and water. Within this mission, the role of the U.S. Geological Survey in water-quality assessment is to provide the information and to facilitate the understanding of processes so that resource managers at the Federal, State, and local levels can make sound resource-management decisions. Assessment includes:

1. Measurement of the quantity and quality of surface and ground water;
2. Research to increase understanding of the processes that affect water quality; and
3. Interpretive studies to determine both the causes of observed conditions and the changes in water quality. These studies should then predict the likely effects of possible future changes in the use and management of land and water resources.

On the basis of this mission, the goals and objectives in table 6 were defined for regional-scale ambient water-quality assessments.

Spatial and Temporal Scales

Water-quality assessments may be done at several different spatial and temporal scales. Examples are given in

Table 5. Relative sampling requirements[1] for various water-quality assessment objectives

Objective	Density of sites: Low	Density of sites: High	Frequency of sampling: Low	Frequency of sampling: High	Duration of sampling: Short	Duration of sampling: Long
Spatial and temporal conditions (averages and ranges of concentration).	X		X			X
Loads	X			X		X
Trends	X		X			X
Compliance or surveillance	X			X	X	
Cause and effect		X		X	X	

[1]These are examples of general sampling requirements, and it should be noted that there could be tradeoffs. For example, for an objective of cause and effect, a low sampling frequency could be used with a long duration of sampling.

table 7. A small-scale assessment is one designed to describe the characteristics of an individual problem area associated with known point and nonpoint sources of contaminants. An example of a small-scale, surface-water-quality assessment would be the description of dissolved-oxygen depletion that occurs through a given stream reach. An example of a small-scale, ground-water-quality assessment would be the description of a contaminant plume from a sanitary landfill encompassing from several tens of acres to a square mile in area. The number and density of sampling sites needed to describe these occurrences could be relatively large—on the order of one or more per river mile to describe dissolved-oxygen depletion and tens of wells per square mile to describe a contaminant plume in three-dimensional space.

Regional ambient water-quality assessments are designed to characterize conditions in areas encompassing from thousands to tens of thousands of square miles. Depending on the nature of the resource and the spatial distribution of the constituent(s) of interest, results of regional assessments could be presented as: (1) maps showing the locations of large areas of contamination (tens of river miles or tens of square miles of an aquifer); (2) maps that distinguish stream reaches or parts of aquifers that have different average concentrations or frequencies of contamination; and (3) reports that relate geology, soils, land use, and other land information to contaminant concentrations or probabilities of contamination. Depending on the variation of water quality, the density of sampling sites in a regional assessment may be much less than in a small-scale assessment.

The two different spatial scales of assessments presented in table 7 are not alternatives to the other because both levels of information are necessary in water-resource management. Information from regional water-quality assessments may provide both a framework for smaller scale assessments and the technical foundation for public-policy debates on water quality. However, regional-scale assessments are not designed to characterize small-scale water-quality problems. Assessment of small-scale features is an important component of State and local water-resource management.

Water-quality assessments may provide information at different temporal scales. The shortest time scale is most

Table 6. Goals and objectives of regional-scale ambient water-quality assessments

<u>Goal 1: Describe current water-quality conditions</u>

<u>Objective 1a:</u> Provide information about the spatial distribution of water-quality constituents.

<u>Objective 1b:</u> Provide information about the short-term or temporal variation of water-quality constituents (surface water only).

<u>Objective 1c:</u> Estimate loads of water-quality constituents at key locations (surface water only).

<u>Goal 2: Define long-term trends in water quality:</u>

<u>Objective 2a:</u> Determine the direction and rate of change in the concentration and(or) transport (surface water only) of water-quality constituents at key locations.

<u>Goal 3: Determine how current water-quality conditions and the changes in these conditions relate to natural and anthropogenic factors:</u>

<u>Objective 3a:</u> Identify and describe the relations between the quality of surface and ground water and natural and human factors.

Table 7. Examples of water-quality assessments at different spatial and temporal scales

Temporal scale	Spatial scale: Small	Spatial scale: Regional
Transient	• Emergency response survey to a toxic-waste spill.	• Survey during low stream flows and high temperatures to identify worst-case conditions in streams in a basin.
	• Low-flow dissolved-oxygen survey downstream from a wastewater-treatment facility.	
Multiyear	• Survey to define the extent of contamination from a sanitary landfill or hazardous waste site.	• Fixed-station sampling at multiple points throughout a region to determine changes in water-quality conditions.
	• Compliance monitoring at sites downstream from a wastewater-treatment facility.	• Describing water-quality conditions throughout a regional aquifer.
	• Monitoring the raw drinking-water supply to a municipality.	

suitable for measuring changes in surface-water quality that occur at time scales ranging from minutes to a few days. Included in this category would be phenomena such as a fish kill caused by a lack of dissolved oxygen that might occur during low streamflow after a sustained period of warm, overcast weather or by a toxic-waste spill. These transient phenomena may pose threats to human health (via drinking water or harvested fish and (or) shellfish) or to ecosystems. Implicit in many transient-scale studies is the need to report results to managers rapidly for emergency response.

Information about water-quality conditions at the multiyear to multidecade scale also is necessary. Information at these scales is needed to estimate the probability distributions of concentrations and transport rates, the probability of exceedence of standards, and the long-term effects of water-quality changes on economic conditions, laws, regulations, waste-treatment processes, and other human activities. In most instances, data requirements for multiyear assessments require enough consistent data so that variation caused by changes in season, climate, and human activities can be distinguished from other factors.

This study is concerned with determining the suitability of existing ambient water-quality data for assessing regional ambient water-quality conditions and trends at the multiyear to multidecade scale.

Ancillary Information

In addition to water-quality data, other types of information often are needed for assessment purposes. This information may be needed to standardize water-quality data for comparison or to account for some of the variability in the data. For example, for most objectives, streamflow data are needed for surface-water-quality assessments. Increased streamflow may cause either an increase or decrease in the concentration of water-quality constituents. Constituent concentrations may: (1) decrease as streamflow increases because of dilution (fig. 2*A*); (2) increase as streamflow increases because of increased surface runoff and erosion (fig. 2*B*); or (3) increase and decrease at different times. For example, the relation of total-phosphorus concentrations to streamflow in the Great Miami River, Ohio, is shown in figure 2*B*. Total-phosphorus concentrations at this site during low flows probably consist primarily of dissolved ions from ground water. These concentrations are diluted by gradual increases in surface runoff. At higher streamflows, increased erosion and transport of organic material and sediment, to which phosphorus is attached, may occur; this causes increased total-phosphorus concentrations.

For ground-water-quality assessments, information is needed about the sampled aquifer, depth to water, depth of casing, depth of well, well use (public-water supply, industrial, and so forth), pump type used, and casing material. These were criteria used in the Phase II evaluation that many of the wells in both States failed to meet.

If the goal of the assessment is to determine cause-and-effect relations that control the levels and variability of constituent concentrations over time and space, then other types of ancillary information are needed. Land and water

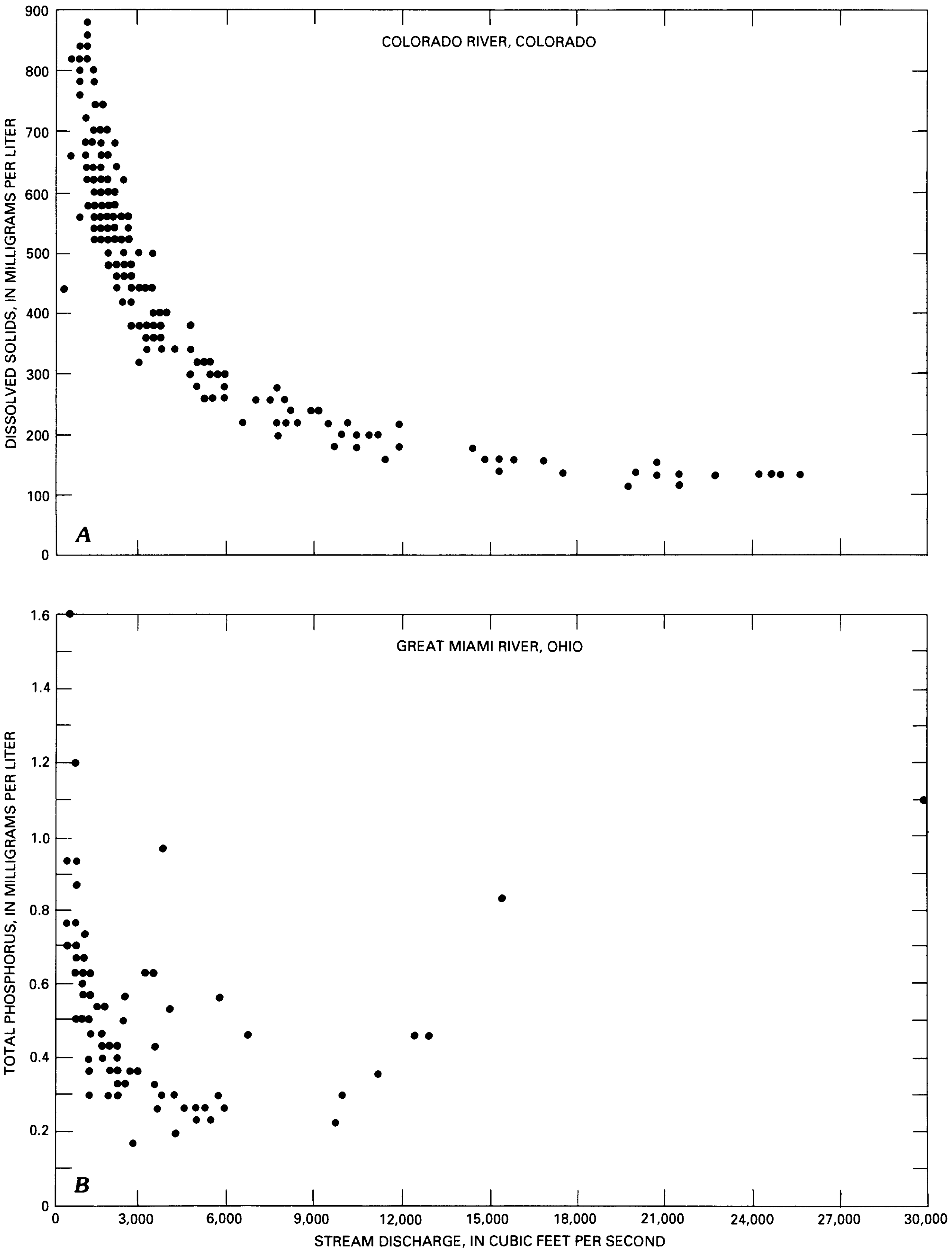


Figure 2. Relation between streamflow and concentrations of: *A*, Dissolved solids; *B*, Total phosphorus.

use, geology, soil types, population distribution, and location of contaminant sources are examples of such types of information. Of these, relations between water-quality characteristics and geology and land use are most frequently evaluated. Information about geology and land use can be used prior to sampling to provide insight as to which constituents should be included in the sampling program.

The scale of the water-quality assessment will determine the detail at which ancillary information is needed. Regional assessments generally require information at larger scales (for example, river-basin, aquifer, or State level). Smaller scale studies may require more detailed information, for example, by county, township, or by specific sampling site.

The ancillary information needed to describe the land-use settings of data-collection sites in this study was obtained from U.S. Geological Survey land-use maps at a scale of 1:250,000 (Anderson, 1970). Others have compiled similar maps: for example, the State of Colorado developed a statewide land-use map at 1:500,000 scale (Colorado Land Use Commission, 1974) from larger scale (1:250,000) U.S. Geological Survey land-use maps. Ohio's Department of Natural Resources has a similar 1:500,000-scale land-use map for that State (W. Channel, Ohio Department of Natural Resources, oral commun., 1987). A statistical summary of farming, ranching, and related activities such as type of crops grown and agricultural chemicals used (pesticides and fertilizers) is listed on a statewide and county basis by the U.S. Bureau of the Census (1984).

Maps of surficial geology are available at a scale of 1:500,000 for Ohio (Bownocker, 1981) and Colorado (Tweto, 1979). Location information, such as latitude and longitude, have become available recently for Ohio's wastewater discharges (Ohio Environmental Protection Agency, written commun., 1987). This information was used to locate data-collection sites potentially affected by human factors (point sources of wastewater discharge).

Estimated water use for surface and ground water in Colorado and Ohio during 1980 is given in a report by Solley and others (1983). For Ohio, water use in 1980 for thermoelectric, manufacturing, public and rural domestic supply, and livestock is given by county in a report by Eberle and McClure (1984).

However, even with the available ancillary information described above, it is difficult to relate this information to current water-quality conditions. First, little of the factor information is digitized or stored in computer-readable form. To develop relations between water quality and the ancillary information, the ancillary information must be rewritten into a mathematical expression, such as percent of the area covered by some particular type of land use. In many areas, this type of information is not readily available.

To relate changes in water-quality conditions to some of the ancillary information is even more difficult: sites yielding sufficient data for assessing changes in water-quality conditions that can be clearly related to the factors are less numerous than those yielding data for current water-quality conditions. In addition, some areas do not have information on how the factors may have changed over time. For example, land use in Colorado was mapped in 1974 by the Colorado Land-Use Commission. Prior to 1974 and after 1974, information on land use is available for only a few areas. In this case, it would be difficult to relate changes in water-quality conditions to changes in land use.

Relating water-quality conditions to natural or anthropogenic factors is complicated by considerations other than the lack of readily available data. For example, it often is difficult to determine which factors actually are influencing water quality, and there is often a correlation or other relation between factors or within factors.

Location of Sampling Sites

The locations of sampling sites in an assessment generally are determined by the goals of the assessment, knowledge of the factors that affect water-quality conditions in a basin (for example, geology and land and water use), and the suitability and accessibility of sites for sampling.

Surface Water

Although several techniques have been proposed for locating sampling sites for assessment purposes, the task does not lend itself easily to the formulation of a mathematical objective function. For the present, a less formal approach for locating sampling sites, such as that discussed in Sargent (1972), seems appropriate. Locations for sampling sites considered in the design of regional ambient water-quality assessments may include:

- The confluence of major tributaries and selected points on the main stems that account for a large part of the total basin runoff;
- Locations upstream and downstream from reservoirs and major land uses to isolate the factors suspected of affecting water quality;
- Sites located near major public water-supply intakes or other important water uses; and
- Locations where there are existing water-quality and (or) streamflow information.

Sampling sites need to be located so that local effects, such as road construction or stream channelization, do not affect the results. Sampling sites are located in this manner unless the local effects are the primary focus of the assessment. Finally, sample-collection sites need to be located, where possible, at sites having reasonable access.

Sometimes the number of sampling sites may be more important than the site location. For example, Lettenmaier (1978) used statistical criteria to suggest that the number of sites is more important than the location when evaluating basinwide-trend detectability and when there is a constraint on the number of samples that can be collected.

Ground Water

There are several difficulties associated with the selection of sampling site locations for regional ground-water-quality assessments that are not encountered in surface-water assessments. Ground-water flow occurs in a heterogeneous, three-dimensional framework of geologic materials, and the patterns of flow are complex. Whereas surface water is confined to a small percentage of land area, ground water occurs almost anywhere if drilling is done to sufficient depth. The chemical quality of ground water is a function of the quality of recharge and the reactions that occur along the flow path—particularly between the moving fluids and the geologic materials. The spatial variability of ground-water quality may be very large, both areally and with depth. Finally, ground water can be sampled only where a well is present, a test hole is drilled, or where a spring or seep occurs.

Depending on the objectives of the assessment, ground-water sampling-site locations may be selected randomly or nonrandomly. For a large-scale regional assessment, one approach is to select sampling sites through a statistical design wherein sampling locations are chosen randomly from the principal aquifers. The purpose of random selection of wells is to obtain a representation of ground-water quality that is unbiased toward specific known or suspected local problem areas. Sampling locations could be selected so as to obtain a set of samples that are well distributed throughout the principal aquifers, both areally and with depth. To obtain a good depth distribution of ground-water samples, the region could be subdivided into a small set of hydrogeologic units, some of which may be combinations of aquifers. In contrast, for aquifers with a large range of depths, a single aquifer could be subdivided into two or more hydrogeologic units based on depth. To achieve a good areal distribution of sampling locations, a grid could be overlain on a map of each hydrogeologic unit, and wells could be selected randomly from each grid cell.

Sampling from nonrandomly selected wells is useful for: (1) defining the areal extent of contamination of known problem areas; (2) determining whether hydrogeologic settings considered vulnerable to contamination are, in fact, contaminated (for example, shallow ground water in areas of particularly high pesticide use); and (3) assessing the condition of major drinking-water supplies or of water for other major uses.

As discussed in Childress and others (1989), important criteria for selecting wells for sampling include knowledge of well construction and local hydrogeology. For analysis of long-term trends, an additional criteria is knowledge of the age of the ground water being sampled (for example, less than 1 year, 1 to 10 years, 10 to 20 years, and greater than 100 years). For trend detection, wells that have been screened to enable sampling of younger waters would be most sensitive to recent water-quality degradation and, thus, would be of greatest interest.

Statistical Tests and Other Analytical Methods

Once the goals and objectives of the assessment have been defined, the type of statistical measurement(s) and tests to be used need to be considered so that data requirements can be determined and expectations of what information will be available can be quantified and understood.

Depending on the objectives of an assessment, the following types of information (measurements) may be needed for different constituents at one or more sampling locations:

1. Estimates of an annual or seasonal mean and variance of concentration or load;
2. Estimates of the minimum and maximum concentrations or loads;
3. Estimates of the frequency of occurrence or exceedence of a particular concentration; and
4. Estimates of the trend or consistent change in concentration and (or) load over time.

Estimation of Mean Concentrations

The distribution of concentrations can be used to estimate an average or mean concentration or to estimate the frequency of occurrence or exceedence of a concentration. Water-quality criteria or standards usually are expressed as concentrations (mass per unit volume), and, thus, mean in-stream or in-aquifer concentrations may be used for comparison with standards.

If the goal of the assessment is to estimate the annual-mean concentration of a constituent at a site at some prespecified variance, and it is assumed that the concentrations are normally distributed and are not correlated over time, then the number of samples needed can be estimated by the following equation (Gilbert, 1987, p. 30):

$$n=\frac{\sigma^2}{V+\sigma^2/N} \qquad (1)$$

where

n = the number of samples required,

σ^2 = the variance in concentration of the population,

V = a prespecified variance of the mean concentration, and

N = the total number in population.

If N is large relative to σ^2, equation 1 reduces to:

$$n=\frac{\sigma^2}{V} \quad (2)$$

Thus, if the variance in the population is known, it is relatively simple to determine the number of observations needed for any desired V. If the true variance, σ^2, is not known, it can be estimated from an initial set of measurements using equation 3.

$$s^2=\frac{1}{n-1}\Sigma(x_i-x)^2 \quad (3)$$

where

s^2 = the sample variance,

x_i = the measured value of the ith unit,

x = the mean of the sample, and

n = the number of observations.

The validity of estimates of n using these methods is dependent, in part, on the adequacy with which the variance of the system to be sampled is known or estimated. For example, in streams, if the high-flow events were not sampled, the estimated variance of the system could be underestimated and the calculated number of samples needed to achieve a prespecified variance of the mean could be too small.

Estimation of Loads

Estimates of constituent loads (mass per unit time) also are used in assessments to compare contributions of various constituents from different streams and to estimate rates of erosion, deposition, and reservoir sedimentation. The number of samples and frequency of sampling needed to estimate constituent loads in a stream is determined by the method selected to estimate loads and certain environmental factors, such as watershed size and variability of the constituent concentration with time and streamflow.

The most accurate method to determine loads is to measure streamflow and constituent concentration continuously. Although continuous streamflow data are available for many sites, continuous measurements of chemical constituents generally are not available and are not practical to collect. Two methods commonly are used to estimate loads. The first, an averaging technique, assumes that the concentration of a constituent associated with a sample is representative of the time period between sample collections. The concentrations and streamflows associated with individual samples are averaged to provide representative mean values for the period of record. This method may involve the use of only instantaneous streamflow values associated with individual water-quality samples, or it can use all of the streamflow record. Further discussion of this method is given by Porterfield (1972) and Yaksich and Verhoff (1983).

The second method used to estimate loads, referred to as the rating-curve method, involves developing a relation between constituent concentrations and streamflow. Long-term loads are estimated by summing individual loads from each flow period from long-term streamflow records. The rating curve is developed by linear or nonlinear regression and may involve a single curve or monthly, seasonal, or annual curves. Various rating-curve methods are evaluated in Yorke and Ward (1986).

Walling and Webb (1981) evaluated several strategies for each method of load estimation. They demonstrated that the different load-calculation procedures are characterized by different levels of accuracy and precision and, therefore, have different sampling-frequency requirements if they are to produce load estimates within given limits of the true value.

Yaksich and Verhoff (1983) concluded that, in rivers where concentration increases with increasing streamflow, loads can be estimated within 10 to 20 percent of the true load by sampling during the 2 to 3 highest streamflow events of the year and also by collecting 5 to 10 additional samples during low flows. Similar conclusions were reported by Antilla and Tobin (1978), Johnson (1979), Walling and Webb (1981), and Richards and Holloway (1987). However, because it is impossible to know in advance which events will be the largest, it often is necessary to attempt to sample all high-flow events to obtain reliable load estimates.

More intensive sampling programs were determined to be necessary in smaller watersheds to achieve load estimates of a given accuracy and precision (Richards and Holloway, 1987). Other factors being the same, load estimates in small watersheds are generally more variable and have a greater range of constituent concentrations and unit-area flows than larger watersheds. Small runoff events may not produce a measurable change in streamflow in large rivers, but such events often do produce measurable change in smaller basins. Closely spaced runoff periods often merge in larger rivers but may remain separated in smaller watersheds. These patterns, in part, are attributable to water routing within the river channels and, in part, to a more variable distribution of rainfall from a given storm over the area of a large watershed; this tends to decrease the range of responses shown by the river from storm to storm. The net effect of these differences is that flux variance over time relative to mean flux is greater in small rivers than in larger rivers. Thus, load estimates derived from a fixed sampling design would be expected to be less precise for a small river than for a larger one. In very small watersheds, hourly sampling may be required during runoff periods.

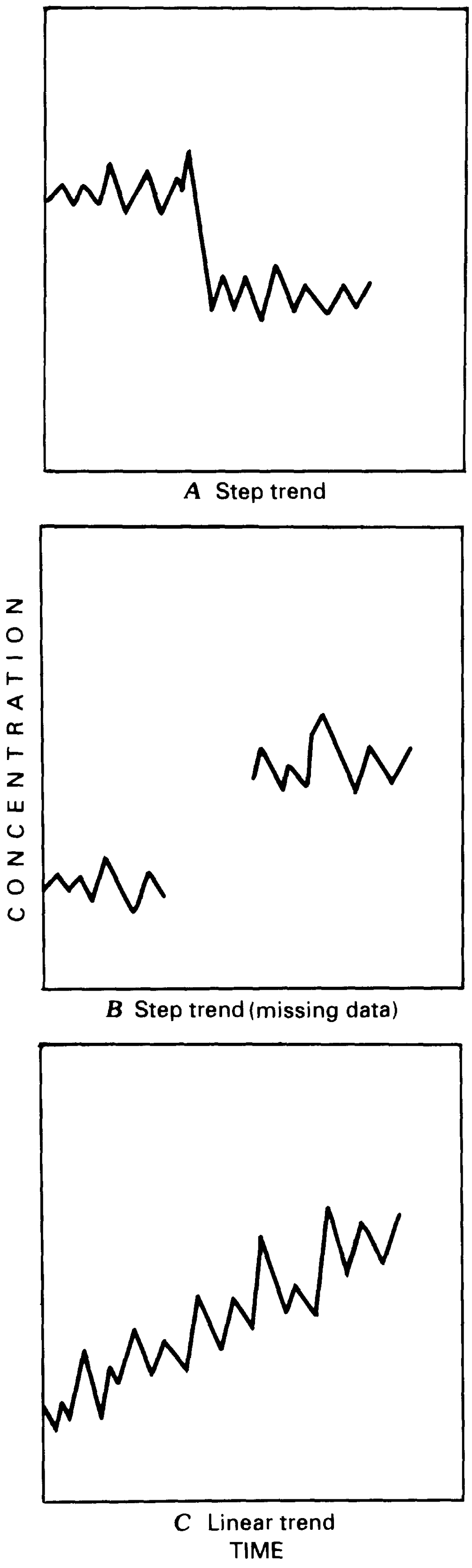
Estimation of Long-Term Trends

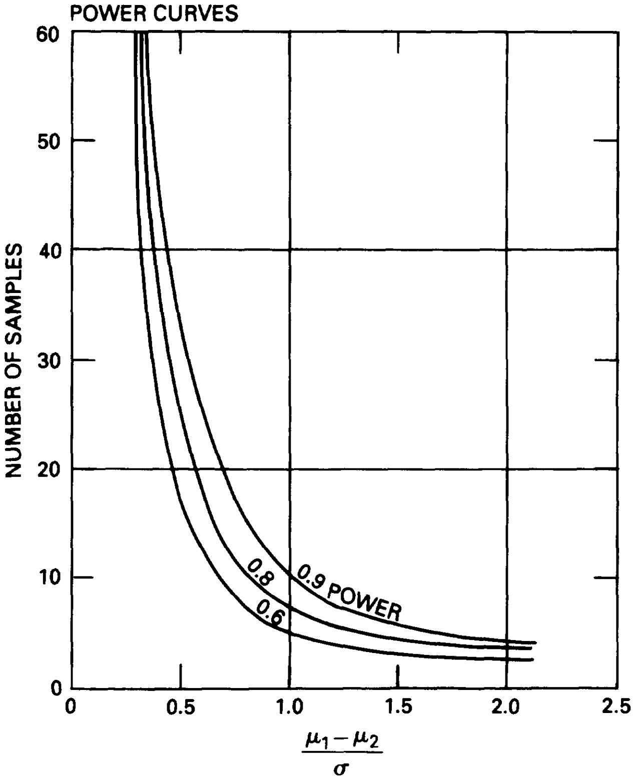
A trend is defined as a change, either an increase or decrease, in concentration or load over time at a sampling site or as a change with distance between sites. This discussion focuses on the former—trends with time. Two common types of trends are step trends and linear trends (Lettenmaier, 1978). A step trend is a statistical difference in the mean value of a measure between two time periods—a "before and after" type change (part *A* of the following figure, facing column). This type of change may result from an abrupt change in land use or activation of a pollution abatement program such as construction of a wastewater-treatment facility. A step trend also may apply to situations where there are two periods of data separated by a period of no data (part *B* of the following figure). A linear trend is a gradual change over some period of time (part *C* of the following figure). Trend data provide information about whether the quality of a water resource is improving, deteriorating, or remaining the same. Determination of trends in water quality is one way of evaluating the results of expenditures of large sums of public and private money for water-quality improvements.

Assessment programs designed to detect trends in water quality require different sampling strategies, numbers of samples, and periods of data collection than programs designed to determine average concentrations or loads. Unlike programs for estimating loads, which are enhanced by frequent flow-stratified sampling, data for detection of trends in concentration should be collected at uniform intervals for longer periods of time. Analysis of trends in loads requires that the data be reduced to some uniform time period. For example, flow-stratified samples may be used to compute annual loads that are then tested for trend. The period of data collection required depends on whether a step trend or a linear trend is to be detected.

Lettenmaier (1978) compared trend detectability in two alternate sampling strategies—uniform collection over time and time-stratified for both step and linear trends in constituent concentration. He determined that, when using autocorrelated data, the optimal strategy was biweekly to monthly uniform sample collection. However, this may vary depending on the correlation structure at each sampling site and with each individual constituent. For linear trends, trend detectability may be enhanced by increasing record length but not by increasing sampling frequency.

For step trends, the number of samples required is a function of the ratio of the change to be detected (the difference between the means of the two data sets) to the standard deviation and is also a function of the ability to detect that difference (Mar and others, 1986). That is, when the difference between the means is small relative to the uncertainty in the data, more samples are required to





EXPLANATION

μ_1 = mean of sample 1

μ_2 = mean of sample 2

σ = standard deviation

discriminate between the means at a given level of significance. These relations are illustrated in the figure above. Similar considerations apply to linear trends. Actual trends, which may represent only a small percentage of change annually, can be obscured by seasonal cycles or variations in streamflow. Longer periods of data collection are required to detect small trends and to account for variability in the system.

Thus, there is no single number of samples or frequency of sampling that is practical and ideal for all assessment goals and objectives or environmental conditions. For this study, a minimum of 10 observations was judged necessary for computing mean concentrations at a surface-water site; only one observation per site was required for describing ground-water-quality conditions. For a site to be judged to have adequate data to compute loads, it was necessary to have at least 10 observations and daily streamflow data. To compute trends for surface-water quality, it was necessary to have both streamflow data and at least quarterly water-quality data for 5 years. To compute ground-water-quality trends, one observation per year for 5 years was required. It should be noted that these requirements are probably conservative because they do not take into account the variability of the concentration of the constituent over time or streamflow.

Frequency, Duration, and Uniformity of Sample Collection

Numerous factors need to be considered when determining the appropriate frequency and duration of sampling in an assessment. These factors include:

- Environmental factors that affect the constituents of interest and their variation with time;
- The goal(s) and objective(s) of the assessment;
- Scales of interest;
- Statistical tests to be used when addressing the goals and objectives;
- The size of the object to be detected (for example, the magnitude of the trend or the critical concentration of interest);
- The error that can be tolerated in the assessment results; and
- Practical constraints, such as cost.

Water quality varies over time as a result of changes in temperature, rainfall, other seasonal and climatological factors, and human influence. The temporal variation in water quality of streams can be quite large. Water-quality changes in streams may occur hourly, as in the diurnal fluctuation in dissolved-oxygen concentrations (fig. 3*A*); seasonally, due to changes in natural and anthropogenic factors (for example, plant growth and the seasonal application of fertilizers to farm land) (fig. 3*B*); and over a period of years as a result of climatic cycles, (for example, periods of drought or heavy rainfall) (fig. 3*C*).

In contrast to streams, the temporal variation of ground-water quality usually is small because ground water travels at relatively slow velocities. Seasonal and short-term variations in ground-water quality are likely to be largest for shallow ground-water systems (Pettyjohn, 1976; Pettyjohn and others, 1981; Schmidt, 1977; and Spalding and others, 1983).

Because of the variation that can occur over time, particularly in streams, multiple samples often are needed at a site to describe current conditions. Determining the number of samples needed and an appropriate frequency of sample collection is difficult. Sampling too infrequently may result in information that does not have sufficient detail to achieve the goals of the assessment or that necessitates an extended period of observation to achieve the goals of the assessment. Sampling too frequently may result in redundant information and unnecessary expense.

For more detailed discussion of these topics, the reader is referred to Gilbert (1987, p. 26–43), Richards and

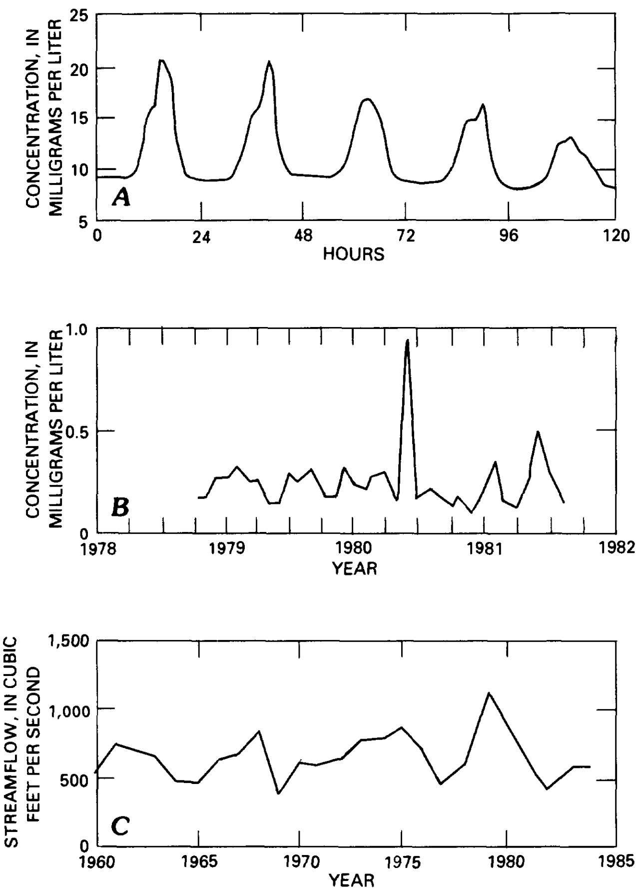


Figure 3. Changes in surface-water and water-quality data over different time periods: *A*, Daily changes in dissolved-oxygen concentrations in the Cuyahoga River, Ohio, April 1–5, 1986; *B*, Seasonal changes in total-phosphorus concentration in the Maumee River, Ohio, 1978–1981; and *C*, Climate-influenced changes in mean annual streamflow of Raccoon Creek, Ohio, 1960–1984.

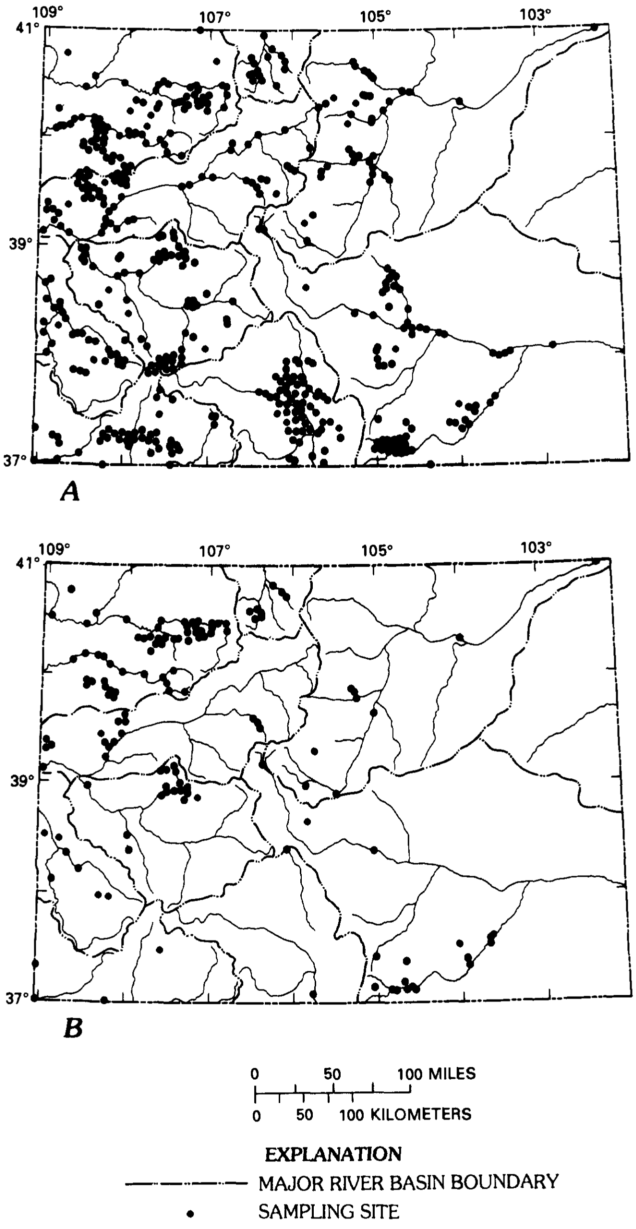


Figure 4. Location of surface-water sampling sites yielding data that met Phase II screening criteria, water years 1980 through 1984, Colorado: *A*, Dissolved solids; *B*, Suspended sediment.

Holloway (1987), Lettenmaier (1978), Nelson and Ward (1981), and Sanders and Adrian (1978).

EVALUATION OF EXISTING DATA FOR REGIONAL AMBIENT WATER-QUALITY ASSESSMENT

The following sections discuss the suitability of existing data in Colorado and Ohio for regional water-quality assessments. These discussions are based on only the constituents chosen for this phase of the study.

Current Water-Quality Conditions

Recent, or current, water-quality conditions are represented in this report by data collected during water years 1980 through 1984. Recent water-quality conditions for Colorado and Ohio are discussed in the following sections, first for surface water and then for ground water.

Surface Water

The numbers of surface-water sites yielding data that met the Phase II criteria for this time period for selected constituents in Colorado and Ohio are presented in column A of table 8. As noted earlier, the largest number of analyses available are for constituents commonly used as general

Table 8. Number of surface-water sites yielding streamflow data and ranges of observations of selected constituents for water years 1980 through 1984 in Colorado and Ohio

[NA, not applicable; numbers in parentheses are percentages of the values in column A]

Constituent	A Meeting Phase II criteria	B Sites from Column A with concurrent streamflow data available	C Sites from Column B with 3 or more observations	D Sites from Column B with 10 or more observations[1]	E Sites from Column B with 10 or more observations and daily streamflow[2]
COLORADO					
Dissolved solids-------	883	535 (61)	273 (31)	131 (15)	118 (13)
Dissolved oxygen-------	348	348 (100)	224 (64)	137 (39)	NA
Suspended sediment-----	188	185 (98)	134 (71)	102 (54)	92 (48)
OHIO					
Dissolved oxygen-------	594	535 (90)	426 (72)	58 (10)	NA
Suspended sediment-----	393	393 (100)	67 (17)	43 (11)	41 (10)
Total phosphorus-------	236	226 (96)	113 (48)	36 (15)	29 (12)
Fecal-coliform bacteria	54	30 (56)	25 (46)	20 (37)	NA
Total-recoverable lead-	52	51 (98)	24 (46)	22 (42)	21 (40)

[1]Sites potentially suitable for determining mean constituent concentrations.
[2]Sites potentially suitable for estimating constituent loads.

water-quality indicators that are relatively easy and inexpensive to measure (that is, dissolved solids, dissolved oxygen, suspended sediment, and total phosphorus). Relatively few analyses of total-recoverable lead were available.

Areal Distribution of Sites

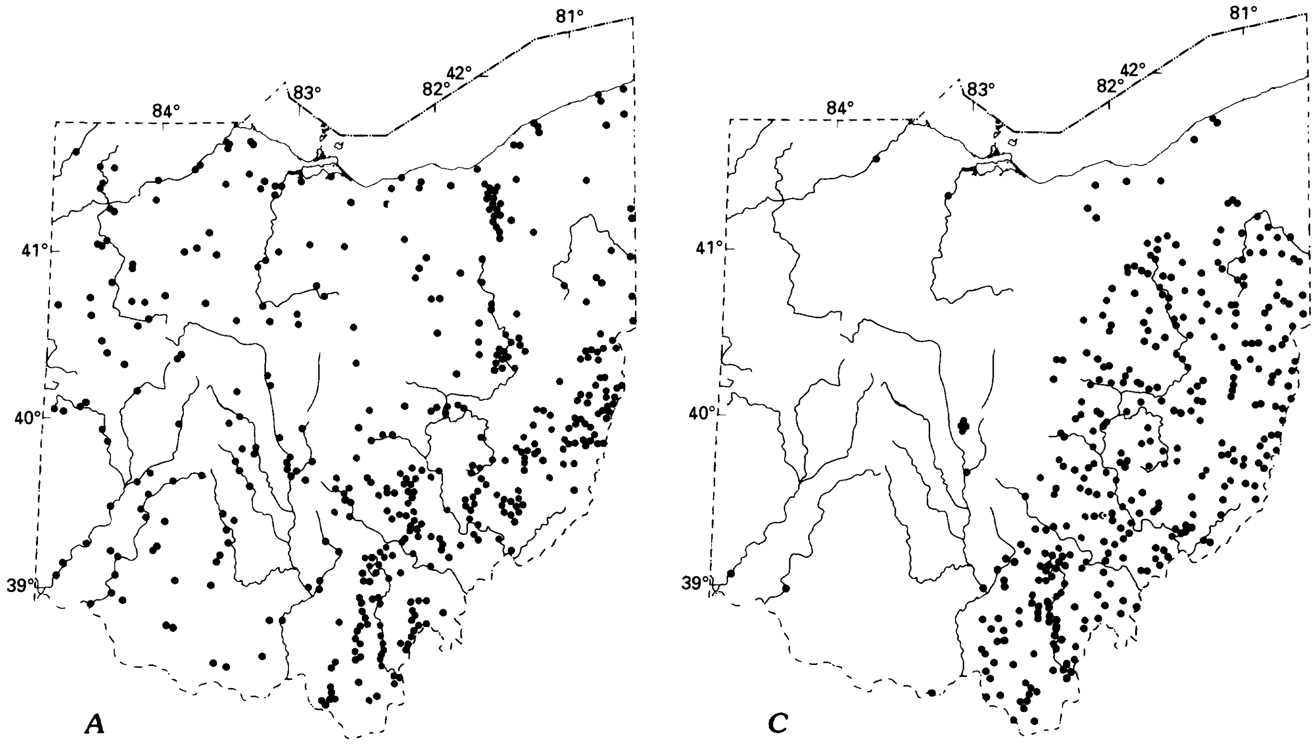
The areal distribution of sites in Colorado yielding surface-water data from water years 1980 through 1984 for dissolved solids and suspended sediment that met the Phase II screening criteria is shown in figure 4. For both constituents, most of the data collected were associated with irrigation drainage and mining concerns in the Colorado River and Yampa River regions in the western part of the State. Many of these sites were sampled in compliance with an international treaty that involved water-quality issues in the Colorado River basin. The sites that were sampled provide fairly good coverage for the western part of the State. Few data were collected in the eastern half of Colorado where there are not as many perennial streams or perceived problems associated with dissolved-solids and suspended-sediment concentrations.

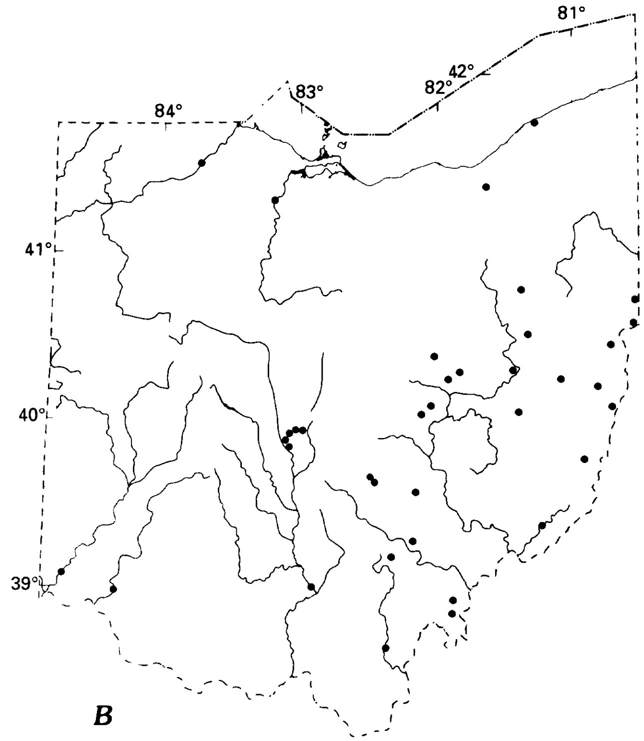
The areal distribution of surface-water sites in Ohio varies, ranging from generally good statewide coverage for dissolved-oxygen data (fig. 5*A*), to a more sparse and scattered distribution of data for total-recoverable lead (fig. 5*B*), to a very regionalized distribution for suspended-sediment data (fig. 5*C*). Dissolved oxygen is relatively easy and inexpensive to measure in the field and generally is measured as part of most surface-water-quality sampling programs in Ohio. Laboratory measurements of suspended sediment and total-recoverable lead are more expensive, and procedures for the collection and analysis of samples for these constituents are more exacting than field measurement of dissolved oxygen. As a result, these constituents are not measured as frequently. The high density of sites in the eastern one-third of Ohio (fig. 5*C*) resulted from several water-quality-assessment programs in the coal mining region of the State.

The number of sites in Colorado and Ohio where streamflow data were collected concurrently with water-quality samples is listed in column B of table 8. More than 85 percent of the sites in Colorado and Ohio with water-quality data also have concurrent streamflow data.

Number of Analyses

The one factor that had the greatest effect on the use of existing surface-water data for meeting the goals and objectives of regional-scale ambient water-quality assessment is the number of analyses collected at each of the data-collection sites. Depending on the constituent, between 31 and 71 percent of the sites in Colorado that met the Phase II criteria had concurrent streamflow data and three or more analyses (table 8, column C). In Ohio, the percentage of sites with three or more analyses ranged from 17 to 72





EXPLANATION

• SAMPLING SITE

0 50 100 MILES

0 50 100 KILOMETERS

Figure 5 (above and facing column). Location of surface-water sampling sites yielding data that met Phase II screening criteria, water years 1980 through 1984, Ohio: *A*, Dissolved oxygen; *B*, Total-recoverable lead; and *C*, Suspended sediment.

percent (table 8, column C). The number of sites with 10 or more analyses for individual constituents were relatively few and ranged from 102 (54 percent of the total) for suspended sediment to 131 (15 percent of the total) for dissolved solids in Colorado and from 20 (37 percent of the total) for fecal-coliform bacteria to 58 (10 percent of the total) for dissolved oxygen in Ohio (table 8, column D). Although there is no single frequency of sampling or number of analyses that is ideal for all conditions and objectives, 10 analyses were considered the minimum number of observations needed to meet most of the objectives for the assessment.

Areal Distribution of Sites with Suitable Data for Current Conditions Assessment

The areal distribution of surface-water-quality data-collection sites in Colorado yielding data for streamflow and 10 or more analyses of dissolved-solids and suspended-sediment concentrations is shown in figure 6. Most of these

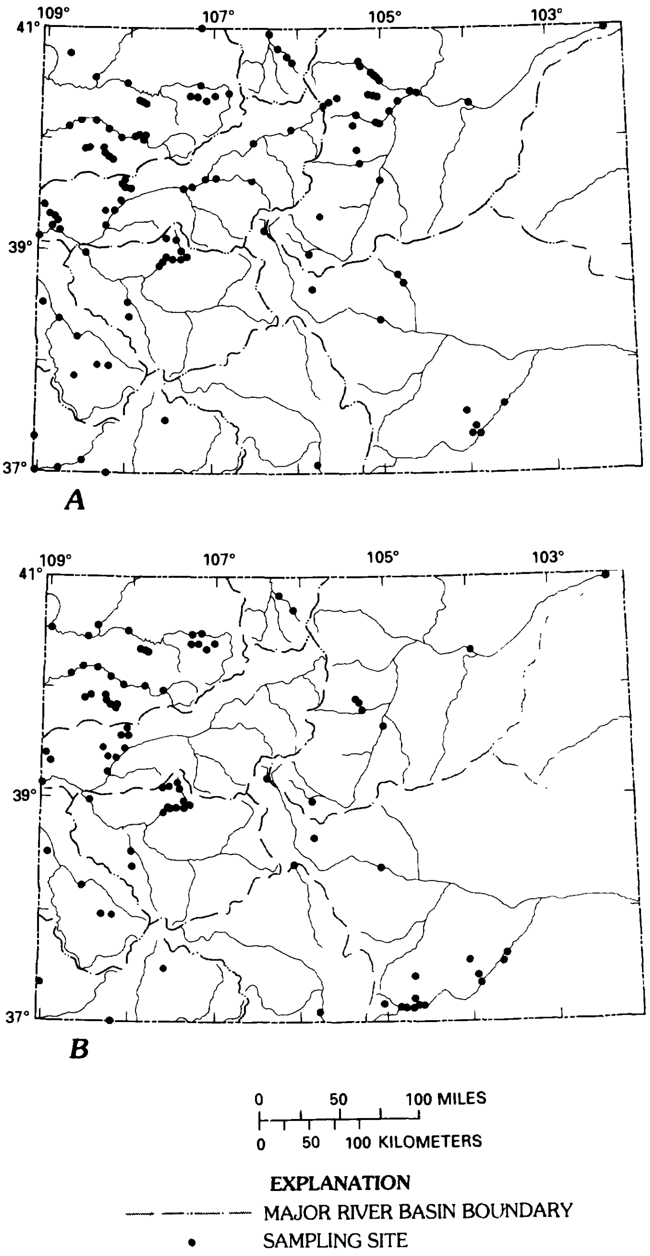


Figure 6. Location of surface-water sampling sites with 10 or more observations and concurrent streamflow data, water years 1980 through 1984, Colorado: *A*, Dissolved solids; *B*, Suspended sediment.

sites are in the northwestern part of the State, in the Colorado River basin, where there is considerable interest in concentrations of dissolved solids because of international agreements with Mexico.

For the major river basins in Colorado (fig. 7), the number of sampling sites yielding 10 or more analyses and concurrent streamflow for the various constituents are shown in table 9. For dissolved solids, most of the samples were collected in the Colorado River and White and Yampa River regions in response to concerns about the salt load in the Colorado River. For dissolved oxygen, the majority of the samples were collected in regions with higher population densities, such as in the South Platte River region (Denver), the Arkansas River region (Colorado Springs and Pueblo), and the Colorado River region (Grand Junction). The highest percentage of suspended-sediment samples were collected in the White and Yampa River region in response to mining activities in the region.

Surface-water withdrawals, by county, in 1985 for Colorado are shown in figure 8. Comparing figure 6 to figure 8, it can be seen that most of the surface-water-quality sampling sites are in the northwestern part of the State, where most of the higher surface-water-withdrawal areas also are located.

The distribution of sites in Ohio yielding data for streamflow and 10 or more analyses is shown in figure 9*A* for dissolved oxygen, figure 9*B* for total-recoverable lead, and figure 9*C* for suspended-sediment concentration (the number of sites are listed in table 8, column D). There are more sites yielding dissolved-oxygen data than the other constituents, and their statewide distribution is more widespread. Some of the sites yielding dissolved-oxygen data are part of the National Stream Quality Accounting Network (NASQAN), operated by the U.S. Geological Survey. These sites are located at the mouths of large river basins to provide an integrated indication of water quality leaving the basins (Ficke and Hawkinson, 1975). Other sites yielding dissolved-oxygen data are located downstream from large cities to monitor the effect of municipal-waste water discharges on in-stream dissolved-oxygen concentrations.

Most of the sites yielding streamflow data and 10 or more observations of total-recoverable-lead concentration are also NASQAN sites. Most sites with suspended-sediment data are located in eastern Ohio and are related to coal-mining activities.

The numbers of sites in each of the major river basins in Ohio with 10 or more analyses and concurrent streamflow are listed in table 10. The southern Lake Erie basin (northeastern Ohio) has the largest number of sites although it is the smallest basin. This area is densely populated and is also an area of substantial surface-water use (fig. 10). Several agencies collected water-quality data that met the Phase I and II criteria; this contributed to the larger number of sites in this basin.

Except for the Great Miami River basin, the number of sites in the other river basins in Ohio is fairly uniform despite differences in drainage areas and surface-water usage (table 10, fig. 10). The Great Miami River basin in southwestern Ohio has nine sites with dissolved-oxygen data but only two or less for other constituents. The area along the Great Miami River between Dayton and Cincinnati is densely populated with high surface-water

Table 9. Number of sites in major river basins with 10 or more analyses and concurrent streamflow information for selected constituents, water years 1980 through 1984, Colorado

River basin	Drainage area (square miles)	Number of sites with 10 or more analyses and concurrent streamflow		
		Dissolved solids	Dissolved oxygen	Suspended sediment
South Platte-----	29,394	30	41	8
Arkansas---------	27,915	13	28	16
White-Yampa------	10,409	35	31	36
Colorado---------	9,694	24	21	10
Gunnison---------	7,884	16	4	16
Rio Grande-------	7,449	1	1	3
San Juan---------	5,721	6	7	4
Dolores----------	4,277	6	5	4

Table 10. Number of sites in major river basins and hydrologic subregions with 10 or more analyses and concurrent streamflow information for selected constituents, water years 1980 through 1984, Ohio

River basin and hydrologic subregions	Drainage area (square miles)	Number of sites with 10 or more analyses and concurrent streamflow				
		Dissolved oxygen	Total phosphorus	Suspended sediment	Fecal-coliform bacteria	Total-recoverable lead
Western Lake Erie tributaries------	8,402	7	7	4	0	2
Muskingum River----	8,051	5	4	7	3	4
Scioto River-------	6,517	6	5	7	0	5
Upper Ohio River tributaries------	5,265	8	3	9	4	3
Lower Ohio River tributaries------	4,751	10	6	4	2	5
Great Miami River--	3,946	9	2	1	1	1
Southern Lake Erie tributaries------	2,882	13	9	11	10	2

usage. There has been a great deal of interest recently concerning the effects of the municipal and industrial discharges on dissolved-oxygen concentrations in the Great Miami River.

Loads

Daily streamflow data are needed to estimate loads of constituents. The number of sites that yielded daily streamflow data and 10 or more analyses for the constituents of interest in Colorado and Ohio are listed in column E of table 8. Compared with Colorado, there are fewer sites in Ohio that can be used to estimate loads, but the Ohio sites are distributed more uniformly. Most of the sites in Ohio are located near the mouths of tributaries to Lake Erie or the Ohio River. The large number of sites in northwestern Colorado in the Colorado River basin should provide a good understanding of the relative contribution of dissolved solids and suspended sediment from different parts of the basin.

Ground Water

The number of ground-water sites in Colorado sampled for selected constituents during 1980 to 1984 that met the Phase I and Phase II screening criteria are: dissolved solids (399), nitrate (155), uranium (24), total-coliform bacteria (0); and for Ohio: total-recoverable iron (62), total-recoverable manganese (64), nitrate (86), and phenols (91).

Similar to the characteristics of the Colorado surface-water data base, concentrations of some ground-water constituents, such as dissolved solids, that are relatively inexpensive to measure and are general indicators of water-

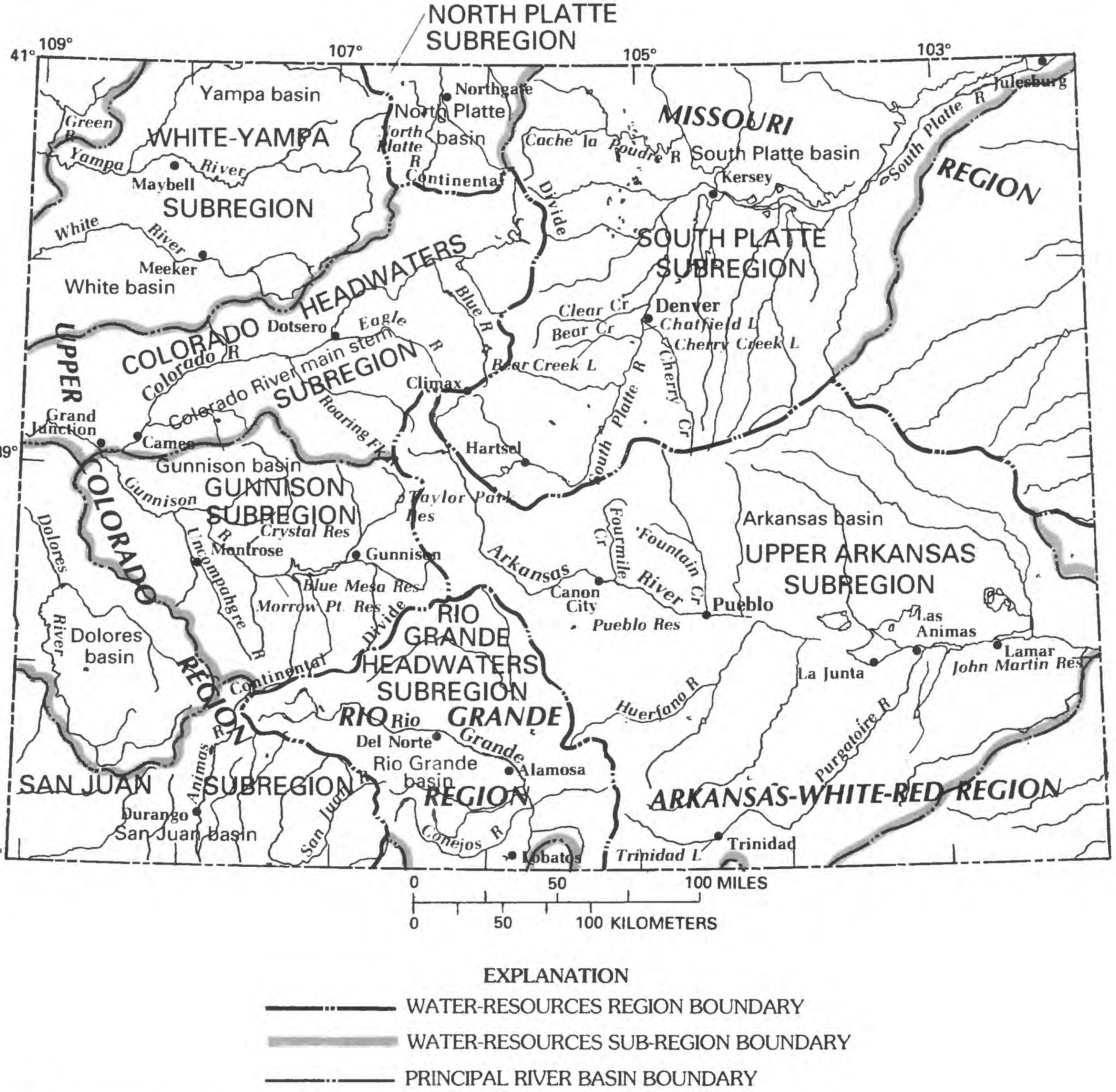


Figure 7. Principal river basins and related surface-water resources development in Colorado.

quality conditions were measured in samples collected from many sites. For Ohio, there was a smaller difference in the number of analyses made for each of the constituents of interest.

Areal Distribution of Sites

The areal distribution of ground-water sites sampled in Colorado and Ohio between 1980 and 1984 yielding data that met the Phase II criteria are shown for selected constituents in figures 11 and 12. In general, many of these ground-water sites occur in groups in certain parts of each State. For example, in Colorado, the grouping of ground-water sites shown in figure 11*A* for nitrate concentration is related to areas of potential nitrate contamination from fertilizer applications and (or) areas of high ground-water use. In Ohio, the statewide distribution of sites yielding nitrate data generally is more uniform than sites yielding iron data: ground-water sampling sites yielding iron data tend to be more clustered in the coal-mining regions of Ohio.

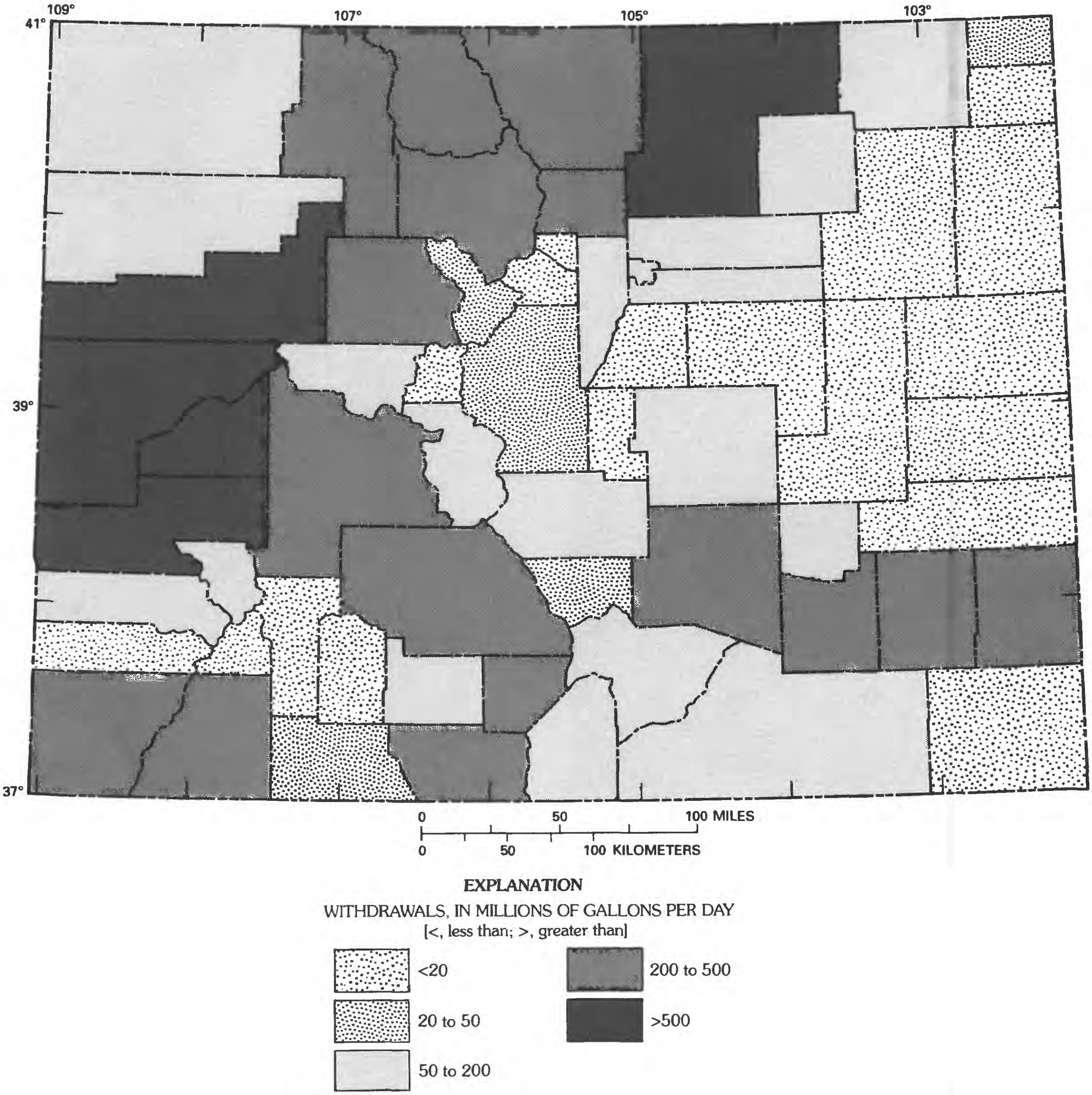


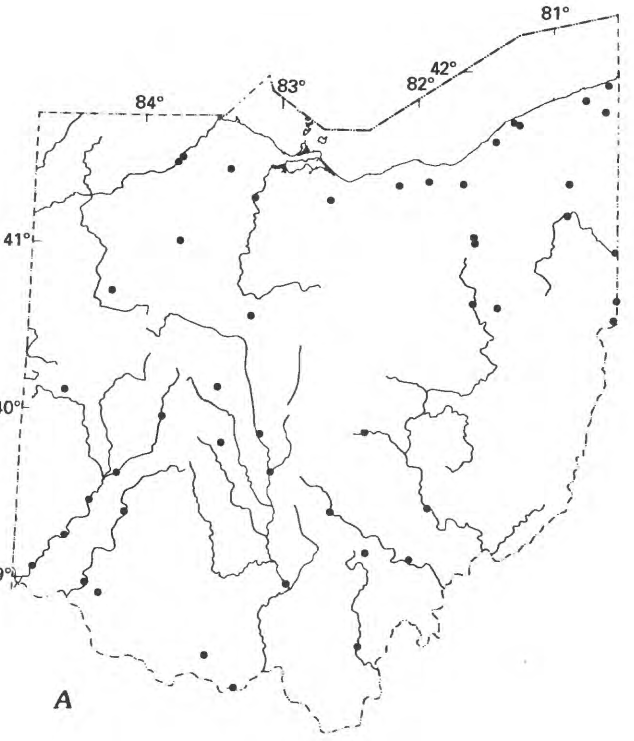
Figure 8. Surface-water withdrawals by county, Colorado, 1985.

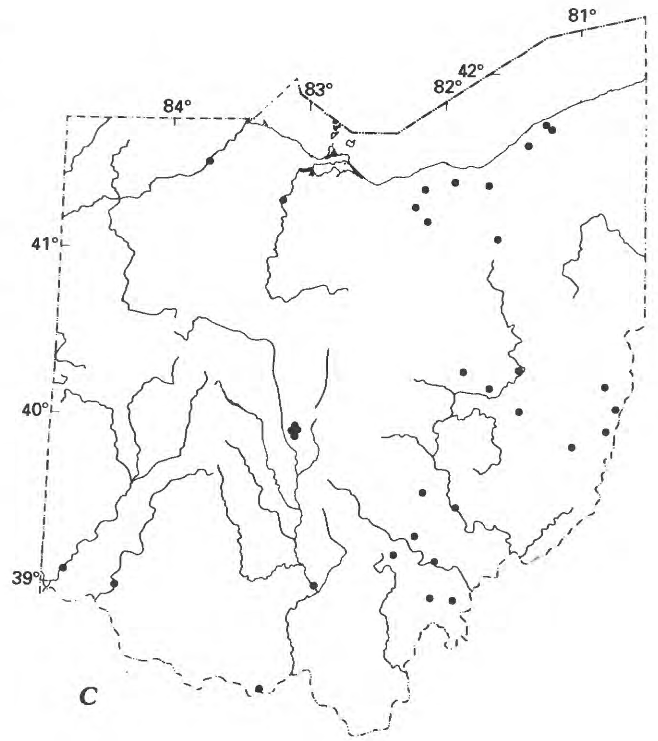
For Colorado, none of the principal aquifers (fig. 13) seem to have sufficient data coverage for the constituents of interest (fig. 11) to allow determination of current (1980–84) ground-water-quality conditions. Many of these aquifers provide drinking water and irrigation water.

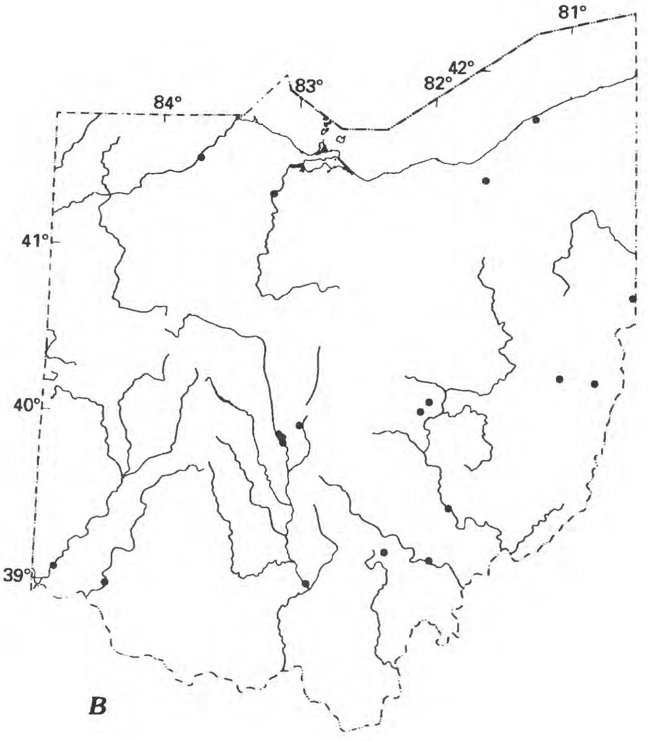
Aquifer Characteristics and Water Use

Selected characteristics of the principal aquifers in Colorado are presented in table 11 along with the number of samples collected during water years 1980 through 1984 for various constituents. Ground-water withdrawals for 1980 are shown in figure 14. As shown in figure 14, most ground-water use in Colorado is from the South Platte and Arkansas alluvial aquifers. Much of this water is used for agriculture, but some also is used for domestic uses. Very little ground water is used in western Colorado.

Comparing figures 11 and 14, one can see that there is little relation between ground-water use and ground-water-quality sampling in Colorado, other than in the







EXPLANATION

• SAMPLING SITE

0 50 100 MILES

0 50 100 KILOMETERS

Figure 9 (above and facing column). Location of surface-water sampling sites with 10 or more analyses and concurrent streamflow data, water years 1980 through 1984, Ohio: *A*, Dissolved oxygen; *B*, Total-recoverable lead; and *C*, Suspended sediment.

Denver basin aquifer system and the South Platte alluvial system (fig. 13).

The most productive aquifers in Ohio are the unconsolidated coarse-grained sand and gravel deposits along major rivers (fig. 15). In all but one of the 19 principal areas of ground-water withdrawal, based on 1980 data, ground water from these glacial outwash aquifers is the primary source of potable water (fig. 16). Most of the ground-water data collected from 1980 through 1984 was from wells in these unconsolidated aquifers and from the shaly sandstone and carbonate aquifers in southeastern Ohio (table 12).

Other important sources of ground water are sandstone aquifers in northeastern Ohio and the carbonate aquifers in northwestern Ohio (fig. 15). There are fewer ground-water sampling sites within these aquifers, and they are not well distributed; the sites tend to be clustered in small areas that have known or suspected contamination.

The common depth of wells in Ohio generally is less than 300 ft (table 12). Approximately two-thirds of the wells evaluated in this study are less than 100 ft deep; about

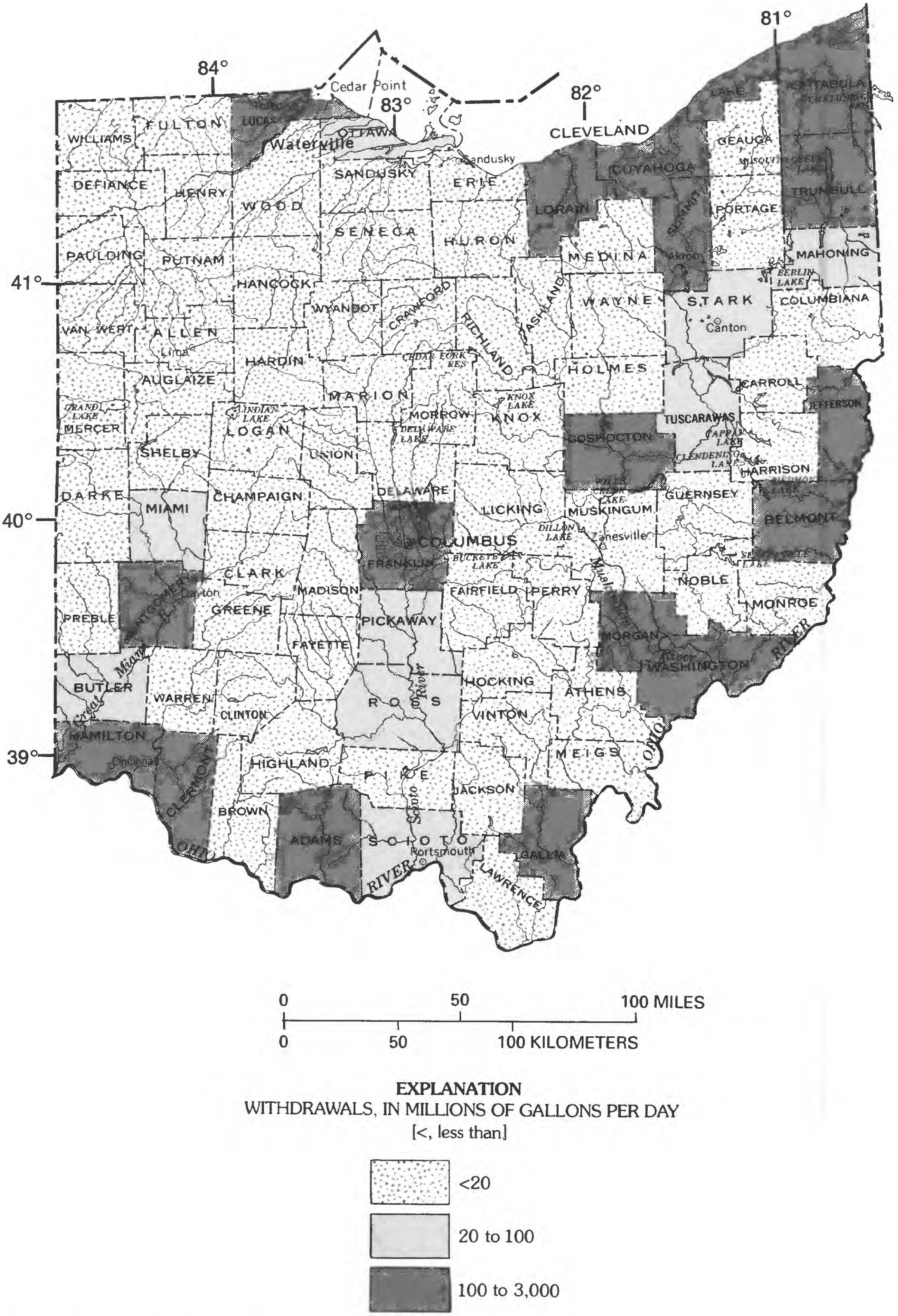


Figure 10. Surface-water withdrawals by county, Ohio, 1980.

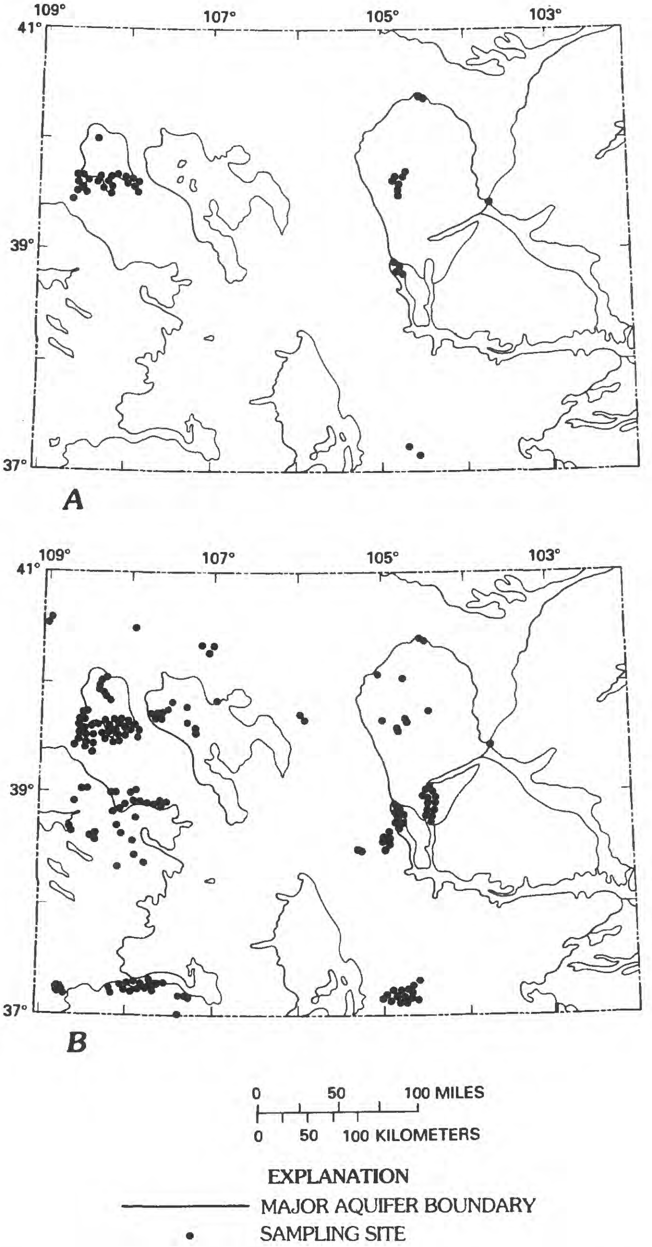


Figure 11. Location of ground-water sampling sites, water years 1980 through 1984, Colorado: *A*, Nitrate as nitrogen; *B*, Dissolved solids.

20 percent range from 100 to 200 ft; and only about 6 percent are greater than 200 ft deep. Many of the wells evaluated in this study are private domestic-supply wells and, thus, tend to be shallow.

Trends in Water Quality

Surface Water

The number of sites yielding data that met the Phase II screening criteria collected from water years 1977 through 1984 for constituents used in this study are listed in column A of table 13 for Colorado and Ohio. Distribution of these sites is shown in figure 17 for Colorado and in figure 18 for Ohio.

Sites with Suitable Data for Trend Analysis

As a general guide, to detect changes in water quality at a site, constituent concentrations and stream discharge need to have been measured concurrently at least quarterly for 5 years (20 measurements). Using these criteria, the number of sites in Colorado and Ohio for defining trends are listed in column B of table 13. There are fewer than 50 sites potentially suitable for trend analysis in Colorado (5 to 8 percent of the sites that met Phase II screening criteria) and fewer than 30 sites in Ohio (2 to 33 percent of the sites that met Phase II screening criteria).

Areal Distribution of Sites

The areal distribution of sites in Colorado yielding data suitable for trend analysis of concentrations of dissolved solids and suspended sediment is shown in figure 19. For both constituents, most sites are in the northwestern part of the State (Colorado River and White and Yampa River regions). Several sites yielding data suitable for defining trends in dissolved-solids concentration also occur in the Platte River basin in the north-central part of the State. The number and distribution of sites in the White, Yampa, Colorado, and South Platte River basins seem sufficient to define trends in dissolved-solids concentrations for these regions.

The distributions of sample-collection sites in Ohio yielding data suitable for determining changes in water quality for dissolved-oxygen, total-recoverable lead, and suspended-sediment concentrations are shown in figure 20. Many of these sites are part of the U.S. Geological Survey's National Stream Quality Accounting Network that has been in operation since 1972 (Ficke and Hawkinson, 1975). These sites are generally at the mouths of the larger rivers in Ohio and therefore provide an integrated measure of water quality leaving the basin. However, for most constituents, the distribution of sites is too sparse to provide a representative picture of water-quality changes either within river basins or on a statewide basis.

Ground Water

The numbers of ground-water sampling sites in Colorado and Ohio that yield data adequate for trend analysis are listed in table 14. In Colorado, no sites yielded uranium or total-coliform data adequate for detecting changes in ground-water quality. Trend analysis for dissolved solids and nitrate is possible only for about 20

Table 11. Principal aquifers and number of sampling sites per aquifer, water years 1980 through 1984, Colorado

[Ft, feet; gal/min, gallons per minute; ft^2/d, feet squared per day; mg/L, milligrams per liter; ft^3/s, cubic feet per second. Sources: Reports of the U.S. Geological Survey, Colorado Water Conservation Board, and Colorado Geological Survey]

Aquifer name and description	Well characteristics: Depth (ft) Common range	Depth (ft) May exceed	Yield (gal/min) Common range	Yield (gal/min) May exceed	Remarks	Number of Sites: Dissolved solids	Nitrate as nitrogen	Uranium
Unconsolidated sedimentary rock aquifers								
South Platte alluvial aquifer: Interbedded gravel, sand, silt, and clay; contains some cobbles and boulders; unconsolidated. Generally unconfined.	30-150	250	100-1,500	3,000	Provides water for public supplies and supplemental irrigation. Transmissivity ranges from 2,000 to 200,000 ft^2/d. Dissolved-solids concentration ranges from 100 mg/L in areas overlain 'y dune sand to about 4,000 mg/L in some downstream areas. Water hard to extremely hard. Local areas show significant water-level declines.	29	50	0
Arkansas alluvial aquifer: Boulders, cobbles, gravel, sand, and clay. Generally grades from fine sand near the surface to coarse sand and gravel at the base. Generally unconfined.	25-100	200	100-1,200	1,500	Principal source of water for irrigation public supply, and industrial wells. Transmissivity ranges from 1,000 to 150,000 ft^2/d. Dissolved-solids-concentration ranges from about 800 to 5,000 mg/L. Water hard to extremely hard.	102	55	14
High Plains aquifer: Gravel, sand, silt, and clay; contains some *caliche*. Poorly to moderately consolidated. Generally unconfined.	200-400	450	350-2,000	2,000	Primary source for irrigation, public supply, and domestic use. Transmissivity ranges from 3,000 to 30,000 ft^2/d. Dissolved-solids concentration generally ranges from 200 to 500 mg/L. Widespread water-level declines affecting well production and increasing irrigation costs.	0	0	0
San Luis Valley aquifer system:								
Unconfined aquifer: Clay, silt, sand, and gravel; unconsolidated. Alluvial and lacustrine. 0 to 200 ft thick.	50-150	150	500-1,200	2,000	Provides supplemental irrigation water. Withdrawals greatest in Rio Grande and western Alamosa Counties. Transmissivity ranges from 100 to 34,000 ft^2/d. Dissolved-solids concentration ranges from 72 to 31,200 mg/L. Local areas show water-level declines.	0	0	0
Consolidated sedimentary rock aquifers								
Denver Basin aquifer system:								
Dawson aquifer: Sandstone and conglomerate with interbedded shale, siltstone. Confined except near outcrop area.	200-1,000	1,400	5-150	300	Sandstone thickness ranges from 100 to 400 ft. Dawson is uppermost aquifer in group. Primarily used for rural and public supply. Potential local contamination from Lowry landfill in Arapahoe County. Less than 200 mg/L dissolved solids.	18	9	0

Aquifer name and description	Well characteristics: Depth (ft) Common range	Depth (ft) May exceed	Yield (gal/min) Common range	Yield (gal/min) May exceed	Remarks	Number of Sites: Dissolved solids	Nitrate as nitrogen	Uranium
					Consolidated sedimentary rock aquifers--Continued			
Piceance basin aquifer system:								
Upper aquifer: Coarse- to fine-grained silty sandstone and siltstone of the Uinta Formation and fractured dolomite marlstone of the Parachute Creek Member of the Green River Formation above the Mahogany zone. Generally confined.	500-1,000	1,400	10-500	2,000	Potential of aquifer not developed. Water almost exclusively in fractures. Transmissivity ranges from 10 to 600 ft^2/d. Dissolved-solids concentration generally ranges from 400 to 2,000 mg/L.	34	13	2
Lower aquifer: Fractured dolomitic marlstone of the Parachute Creek Member of the Green River Formation below the Mahogany zone. Generally confined.	600-2,000	2,800	2-50	100	Potential of aquifer not developed. Transmissivity ranges from 10 to 600 ft^2/d. Water commonly contains dissolved gas. Dissolved-solids concentration ranges from about 500 to 40,000 mg/L.			
Leadville limestone aquifer: Gray dolomitic limestone with some sandstone and chert. Confined.	--	2,000	--	500	Potential of aquifer not developed. Some exploratory wells drilled in Eagle County. Spring on Rifle Creek, north of Rifle, Colo., discharges 11 ft^3/s.	0	0	0
					Other aquifers			
Dakota aquifer: Sandstone with interbedded siltstone and carbonaceous shale; contains many conglomerate lenses near base. Confined.	200-1,000	2,000	1-25	500	Includes the Cheyenne Sandstone in the Arkansas River basin; also in southern one-half of western Colorado. Many wells flow at surface. Water ranges from sodium bicarbonate to calcium bicarbonate type. Dissolved-solids concentration ranges from 300 to 3,500 mg/L.	49	0	1
Morrison aquifer: Fine- to medium-grained, thin-bedded sandstone, and varicolored red and green shale.	250-600	1,000	1-10	15	In the southern one-half of western Colorado. Water is calcium bicarbonate type. Dissolved-solids concentration ranges from 200 to 300 mg/L.			
Entrada aquifer: Medium- to very fine-grained sandstone with some silt and clay. Confined.	500-700	1,200	1-25	35	In the southern one-half of western Colorado. Water generally sodium bicarbonate type. Some water contains dissolved hydrogen sulfide gas. Average value for transmissivity in Grand Junction area is 20 ft^2/d.			
Not part of principal aquifer system						167	28	7

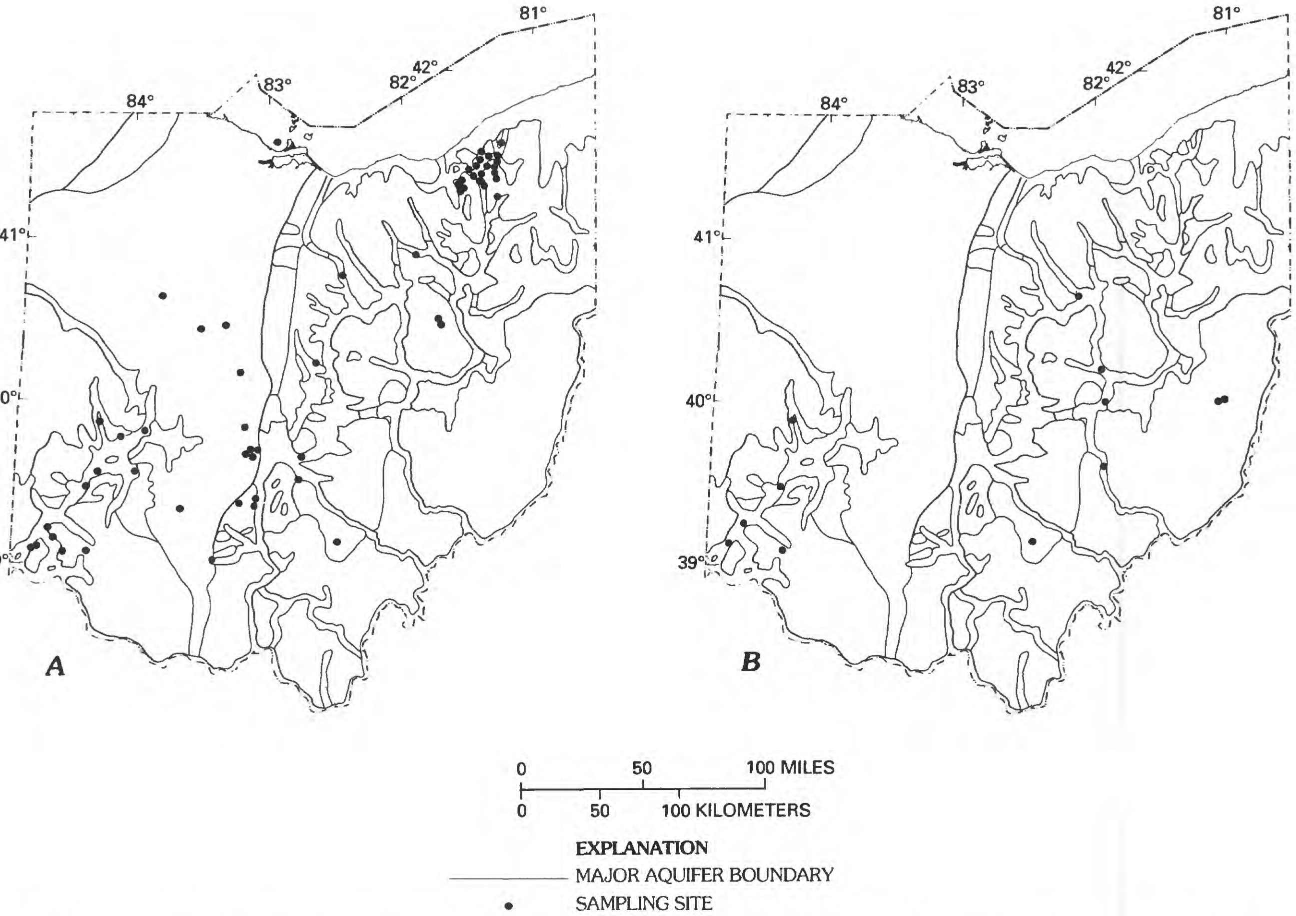


Figure 12. Location of ground-water sampling sites, water years 1980 through 1984, Ohio: *A*, Nitrate as nitrogen; *B*, Total-recoverable iron.

(2 percent) of the sites in Colorado that met the Phase II screening criteria (fig. 21). Most of these sites are clustered at the northern end of the Denver basin aquifer system.

The distribution of sites yielding nitrate- and iron-concentration data potentially suitable for trend analysis in Ohio is shown in figure 22. Iron and manganese data were available for about twice the number of sites as nitrate and phenol; however, because of clustering, the distributions appear similar. Iron and manganese occur abundantly in the Earth's crust and historically have been measured as part of most ground-water investigations in Ohio. More recently, nitrate and phenols have been measured as indicators of ground-water pollution. Most of the ground-water data evaluated in this study were from investigations that focused on areas of known or suspected problems—thus the clustering of sites in small areas.

IMPLICATIONS OF STUDY RESULTS

This study was undertaken, in part, because of concerns and criticism raised by members of Congress that existing water-quality monitoring programs are "* * * fragmented, duplicative, and wasteful, and in many cases, * * * devoid of scientific validity and leadership" (Blodgett, 1983, p. 3). Insufficient information has been available to determine whether these criticisms are accurate. Accordingly, the U.S. Geological Survey conducted this study in Colorado and Ohio to determine the extent to which existing data could be aggregated into a consistent and technically sound data base that would be appropriate for water-quality assessments of regional and national scale. Although the results of this study are specific to Colorado and Ohio, many conclusions from the study have implications for national water-quality assessment.

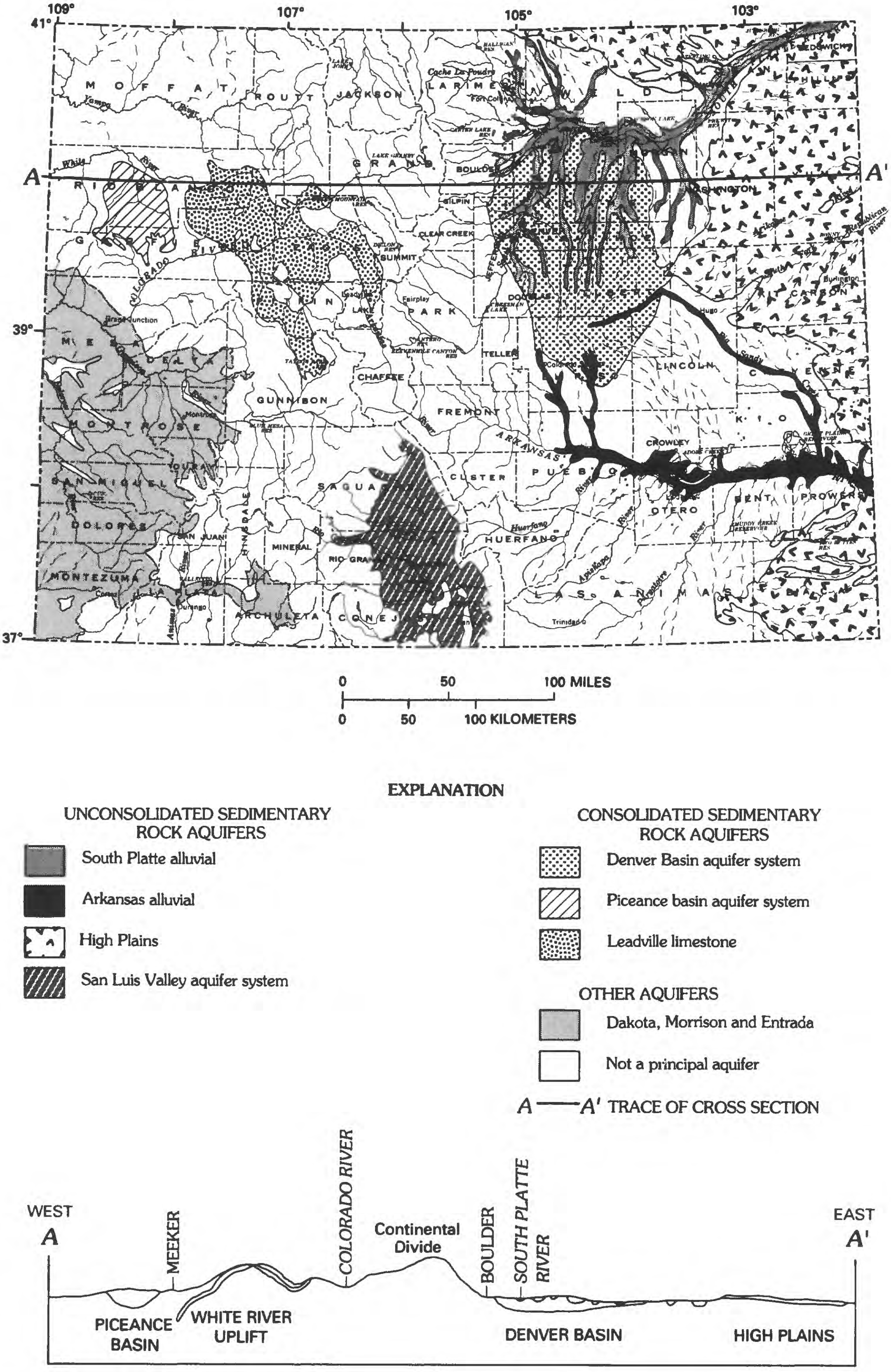


Figure 13. Principal aquifers in Colorado.

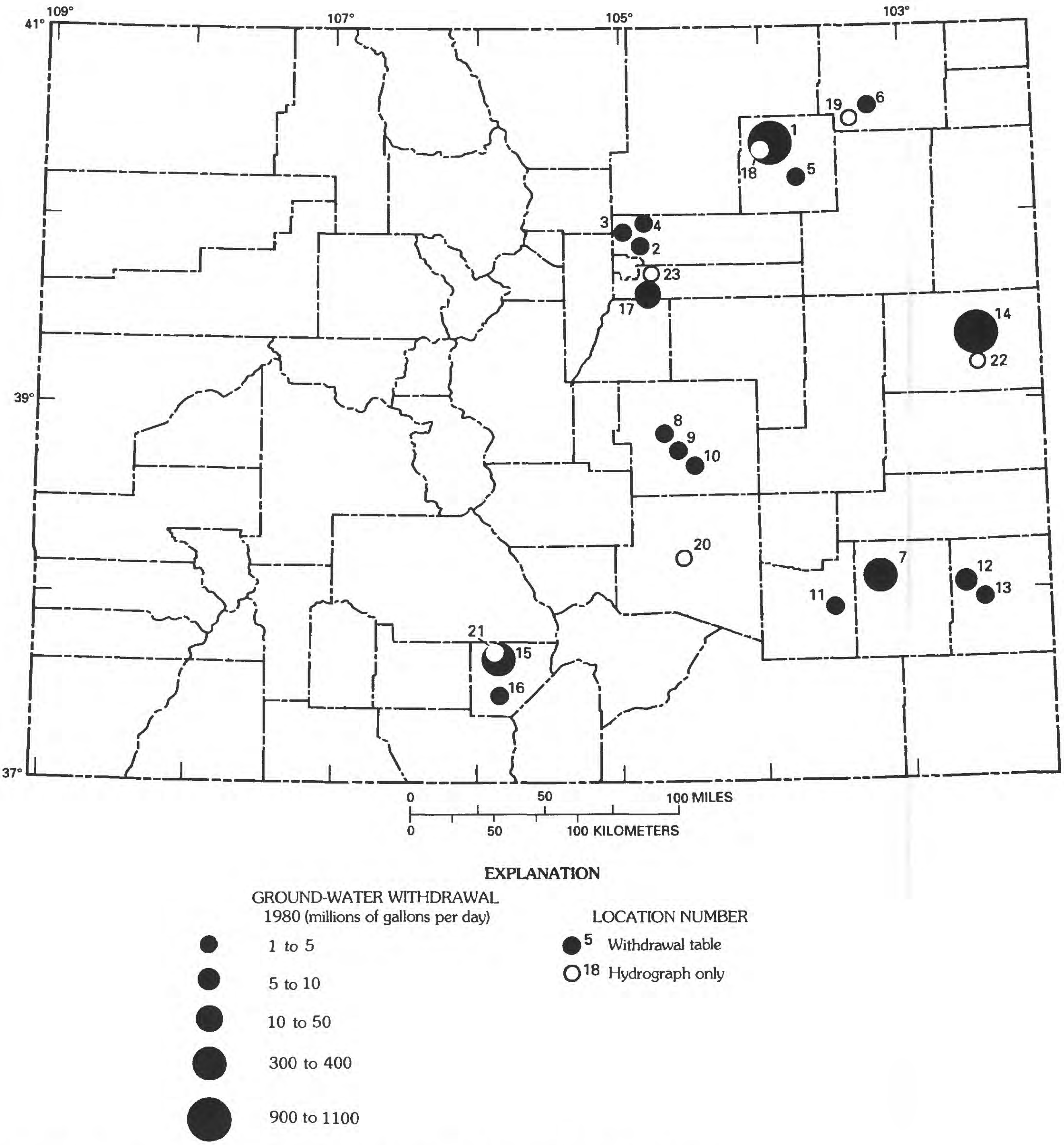


Figure 14. Areal distribution of major ground-water withdrawals, 1980, Colorado.

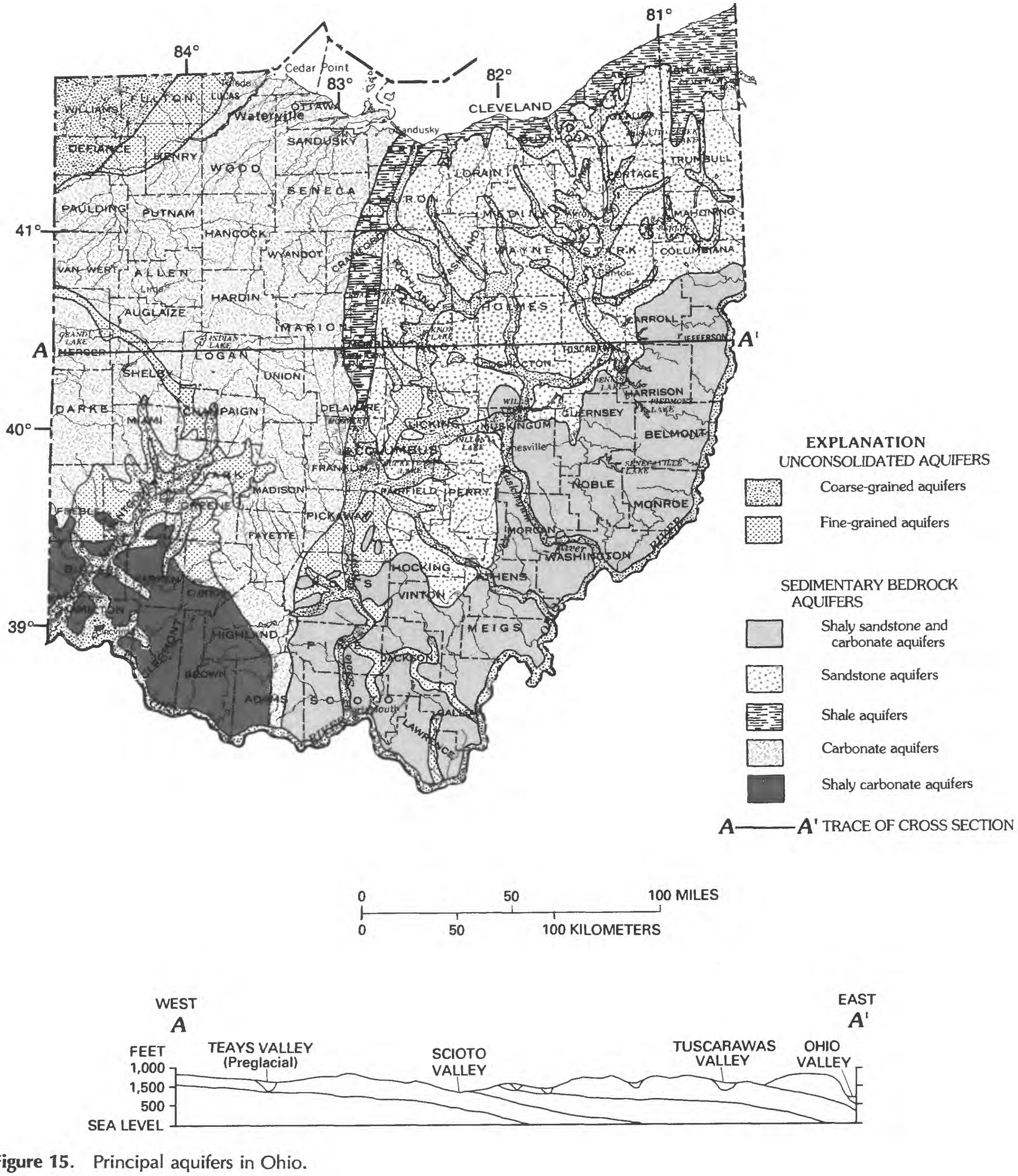


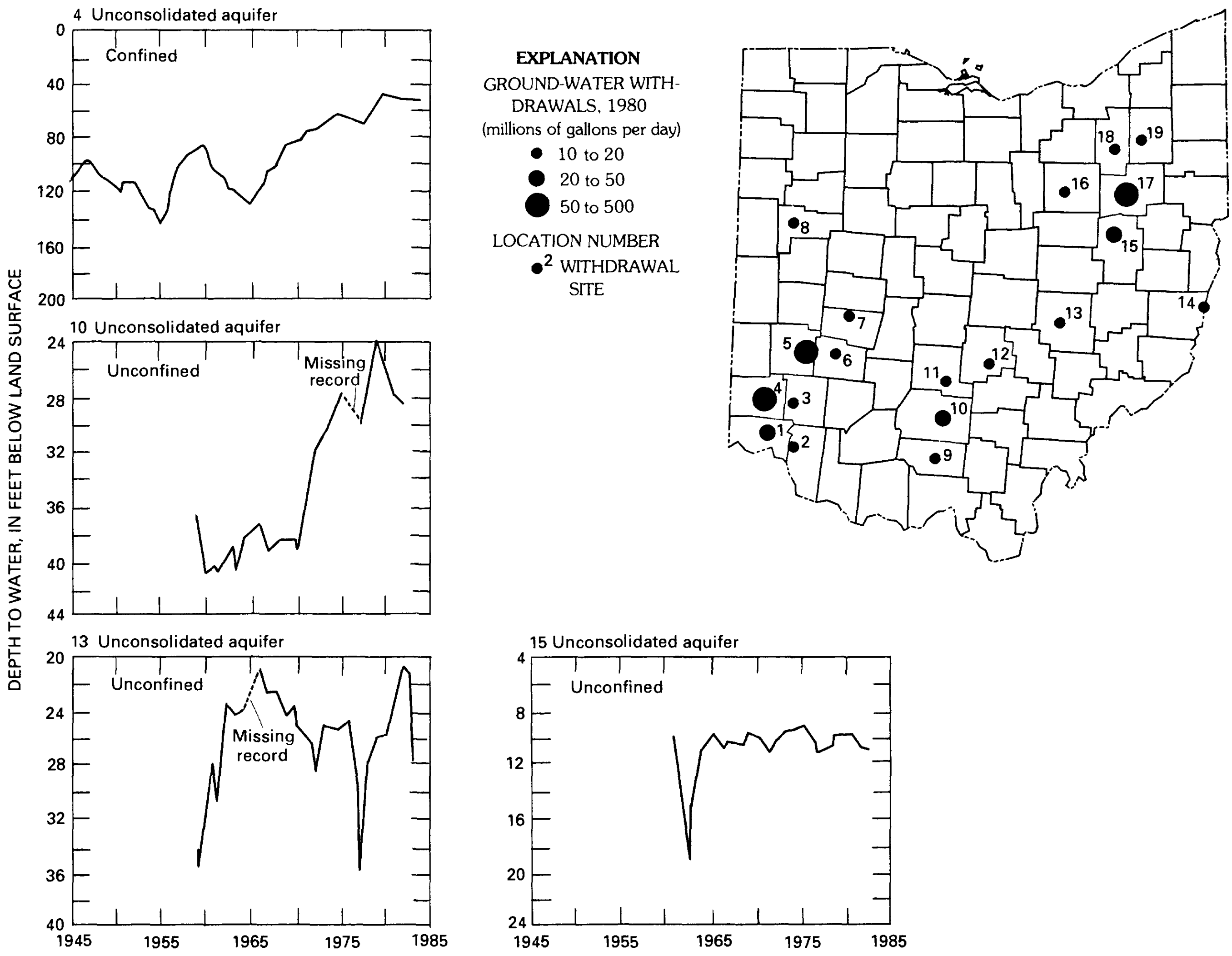
Figure 15. Principal aquifers in Ohio.

Table 12. Principal aquifers and number of sampling sites per aquifer, water years 1980 through 1984, Ohio

[Ft, feet; gal/min, gallons per minute]

Aquifer name and description	Well characteristics				Remarks	Number of sites			
	Depth (ft)		Yield (gal/min)						
	Common range	May exceed	Common range	May exceed		Nitrate as nitrogen	Total-recoverable iron	Total recoverable manganese	Phenol
Unconsolidated aquifers:									
Coarse-grained aquifers: Sand and gravel, generally course, with admixtures of clay and silt. Generally unconfined.	25-200	300	100-500	2,000	Watercourse deposits comprising State's most productive aquifers. Glacial outwash and alluvium also found in terrace and other deposits in upland areas, in buried valleys, and within till layers having favorable recharge characteristics. Large iron content common.	53	15	16	36
Fine-grained aquifers: Sand, generally fine, with clay, silt, and gravel. May be locally confined by clay or till.	25-200	300	25-50	100	Valley fill of abandoned stream valleys; thick to thin lenses within till layers. Permeability often reduced by high clay and silt content. Deposits in many places lack hydraulic connection with recharging stream. Large iron content common.				
Sedimentary bedrock aquifers:									
Shaly sandstone and carbonate aquifers: Fine- to medium-grained sandstone interbedded with shale, coal, clay, siltstone, and thin limestone. Confined and unconfined.	25-100	300	1-5	25	Strata of Mississippian, Pennsylvanian, and Permian age. Permeable, saturated rocks lack continuity. Recharge limited in upland areas; vertical permeability low. Water in some places soft. Iron and chloride content may be large locally. Despite meager yeilds, section important source of domestic supply for much of southeastern Ohio.	13	47	48	45

Aquifer name and description	Well characteristics: Depth (ft) Common range	Depth (ft) May exceed	Yield (gal/min) Common range	Yield (gal/min) May exceed	Remarks	Number of sites: Nitrate as nitrogen	Total-recoverable iron	Total recoverable manganese	Phenol
Sedimentary bedrock aquifers--Continued:									
Sandstone aquifers: Massive to thin-bedded units of fine-grained to conglomeratic sandstone, mostly quartz cemented by calcite, silica, iron, and clay. Confined and unconfined.	25-300	400	5-25	250	Mississippian rocks of regional extent, such as Berea and Black Hand Sandstones and less extensive Pennsylvanian rocks in Pottsville and Allegheny Formations. Pennsylvanian rocks generally are open textured and, where situated favorably with respect to recharge, are important sources of domestic and small public supplies. Water quality generally good, but saline downdip and generally below 300 ft.	10	0	0	0
Shale aquifers: Shale and sandy shale. Generally confined.	0-50	100	0-3	5	Devonian and Mississippian age. Mostly overlain by glacial sediments of low permeability. Hydrogen sulfide common in the shale.	1	0	0	0
Carbonate aquifers: Limestone and dolomite, mostly massive. Some shale and gypsiferous interbedding. Generally confined.	25-300	400	5-300	500	Silurian and Devonian age. Certain areas have very good yields to wells from fractures and preglacial weathered rocks. Water generally very hard and may be highly mineralized with calcium and magnesium sulfates. Hydrogen sulfide prevalent in gypsiferous units. Water saline below 500 ft. An important source of water over a large area despite quality problems.	9	0	10	0
Shaly carbonate aquifers: Thinly interbedded gray shales and limestones. Generally confined.	0-50	100	0-5	10	Ordovician age. Repetitious sequence of shale and limestone. Yields are meager, especially in upland areas.	0	0	0	0



WITHDRAWAL SITES			
No. on map	Geographic area	Aquifer	Principal uses
1	Cincinnati area	Unconsolidated	Industrial, public supply
2	Clermont County	do	Public supply
3	Lebanon-Franklin area	do	Do
4	Hamilton-Middletown area	do	Industrial, public supply
5	Dayton area	do	Public supply, industrial
6	Xenia area	do	Do
7	Springfield area	do	Public supply
8	Auglaize County	Carbonate, unconsolidated	Industrial, public supply
9	Piketon area	Unconsolidated	Industrial
10	Chillicothe area	do	Industrial, public supply
11	Circleville area	Unconsolidated, carbonate	Do
12	Lancaster area	Unconsolidated, sandstone	Public supply, industrial
13	Zanesville area	do	Do
14	Bellaire-Martins Ferry area	Unconsolidated	Public supply
15	Tuscarawas County	Unconsolidated, sandstone	Industrial, public supply
16	Wooster area	do	Public supply, industrial
17	Canton area	do	Do
18	Akron area	do	Do
19	Portage County	do	Do

Figure 16. Areal distribution of major ground-water withdrawals, Ohio. (Sources: Withdrawal data from Eberle and McClure, 1984; water-level data from U.S. Geological Survey files.)

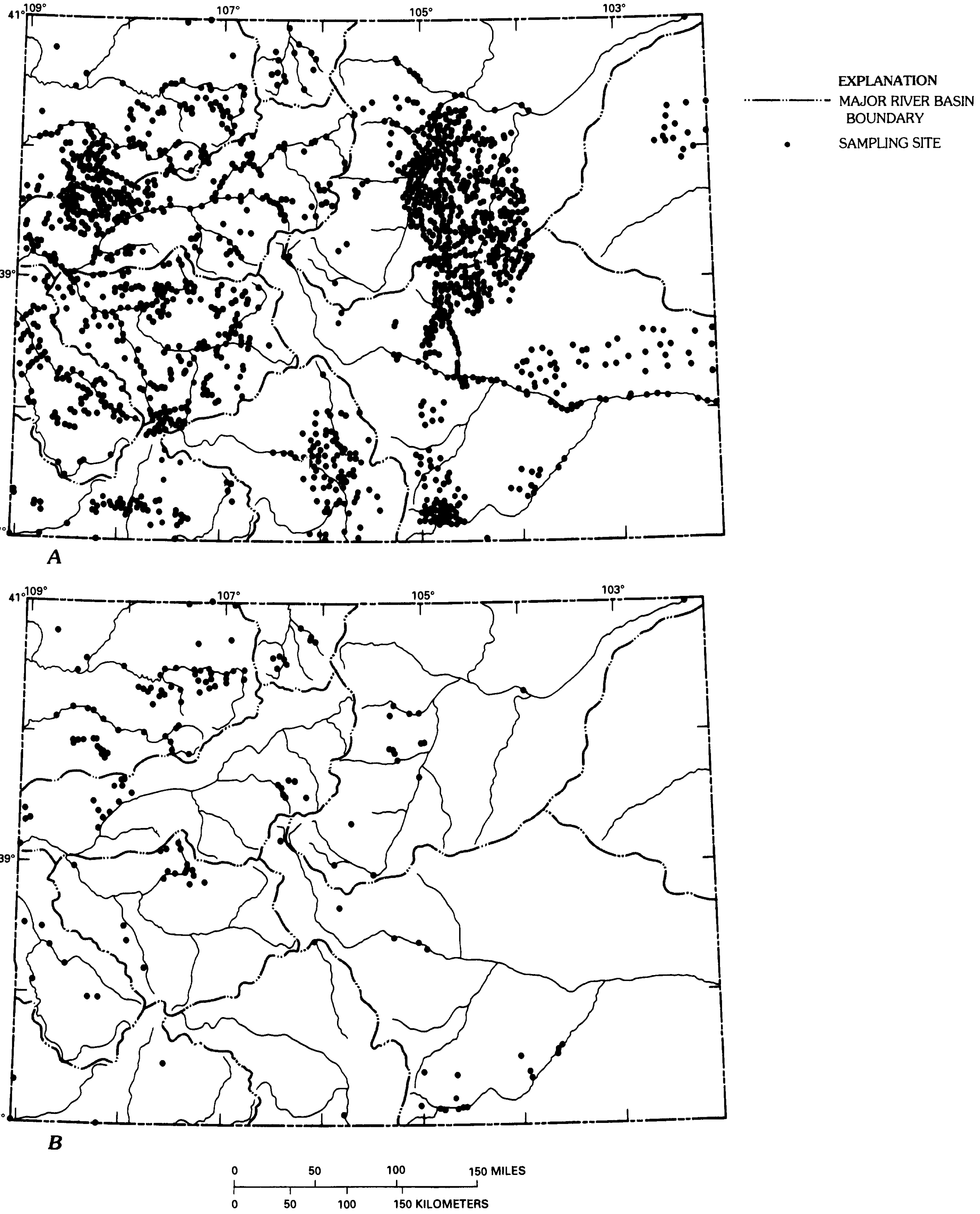


Figure 17. Location of surface-water sampling sites, water years 1977 through 1984, Colorado: *A*, Dissolved solids; *B*, Suspended sediment.

Table 13. Number of surface-water sites yielding data potentially suitable for determining trends in selected constituent concentrations, water years 1977 through 1984, Colorado and Ohio

[Numbers in parentheses are percentages of the values in column A]

Constituent	A Number of sites meeting Phase II criteria	B Number of sites with data potentially suitable for determining trends[1]
	COLORADO	
Dissolved solids---------	993	50 (5)
Suspended sediment-------	217	18 (8)
Dissolved oxygen---------	486	39 (8)
	OHIO	
Dissolved oxygen---------	1,148	28 (2)
Total phosphorus---------	477	13 (3)
Total-recoverable lead---	203	10 (5)
Fecal-coliform bacteria--	54	18 (33)
Suspended sediment-------	400	14 (4)

[1]Sites with concurrent streamflow data and at least quarterly observations for selected constituents over 5 years.

Table 14. Number of ground-water sites yielding data potentially suitable for determining trends in selected constituent concentrations, water years 1972 through 1984, Colorado and Ohio

[Numbers in parentheses are the percentages of sites meeting Phase II criteria suitable for determining trends]

Constituent	Number of sites meeting Phase II criteria	Number of sites with data potentially suitable for determining trends[1]
	COLORADO	
Dissolved solids---------	2,561	20 (1)
Nitrate as nitrogen------	577	19 (3)
Uranium------------------	72	0 (0)
Total-coliform bacteria--	1,578	0 (0)
	OHIO	
Total-recoverable iron---	131	32 (24)
Total-recoverable manganese.	132	30 (23)
Nitrate as nitrogen------	300	14 (5)
Phenols------------------	135	16 (12)

[1]Sites with at least one observation per year collected over 5 years.

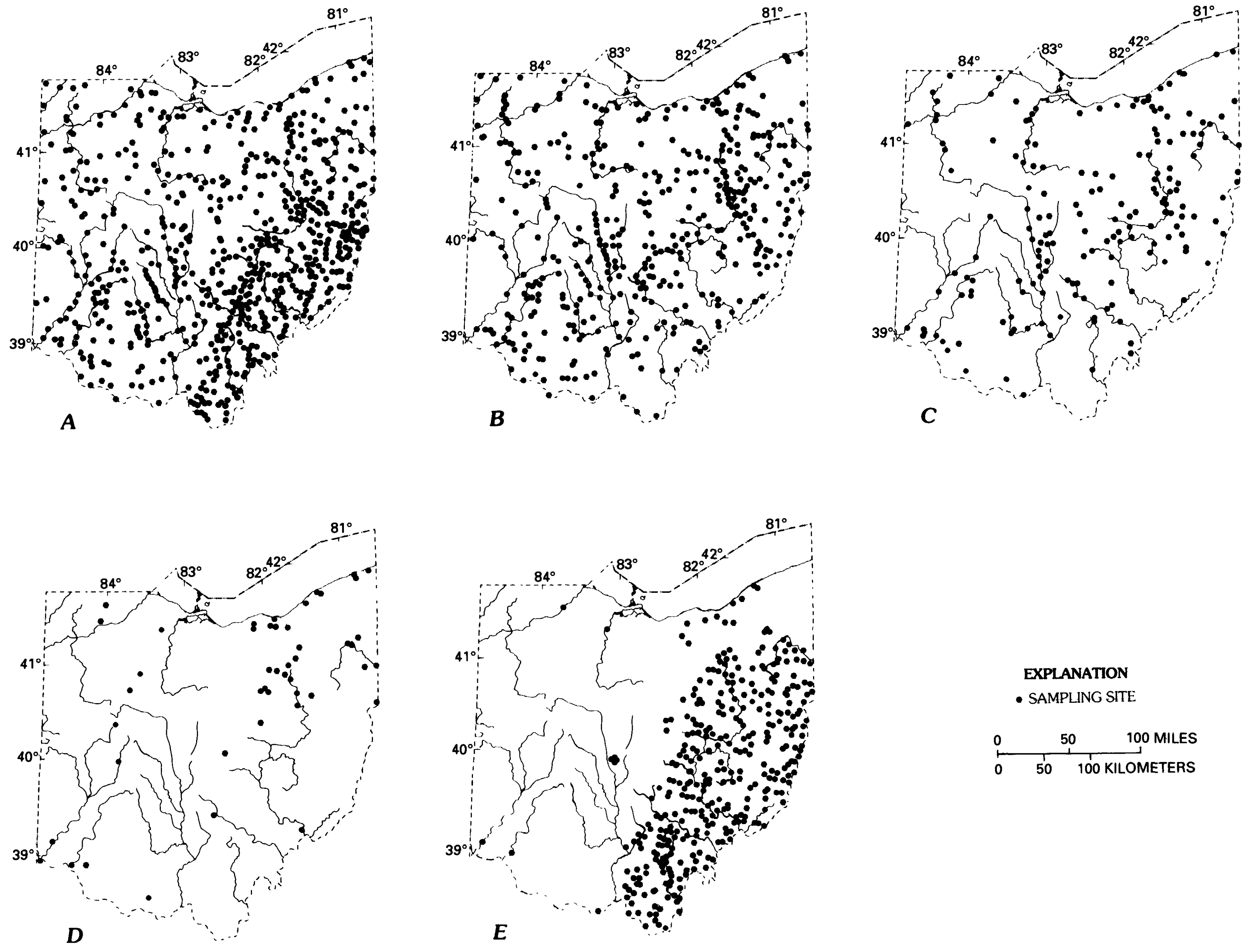


Figure 18. Location of surface-water sampling sites, water years 1977 through 1984, Ohio: *A*, Dissolved oxygen; *B*, Total phosphorus; *C*, Total-recoverable lead; *D*, Fecal-coliform bacteria; and *E*, Suspended sediment.

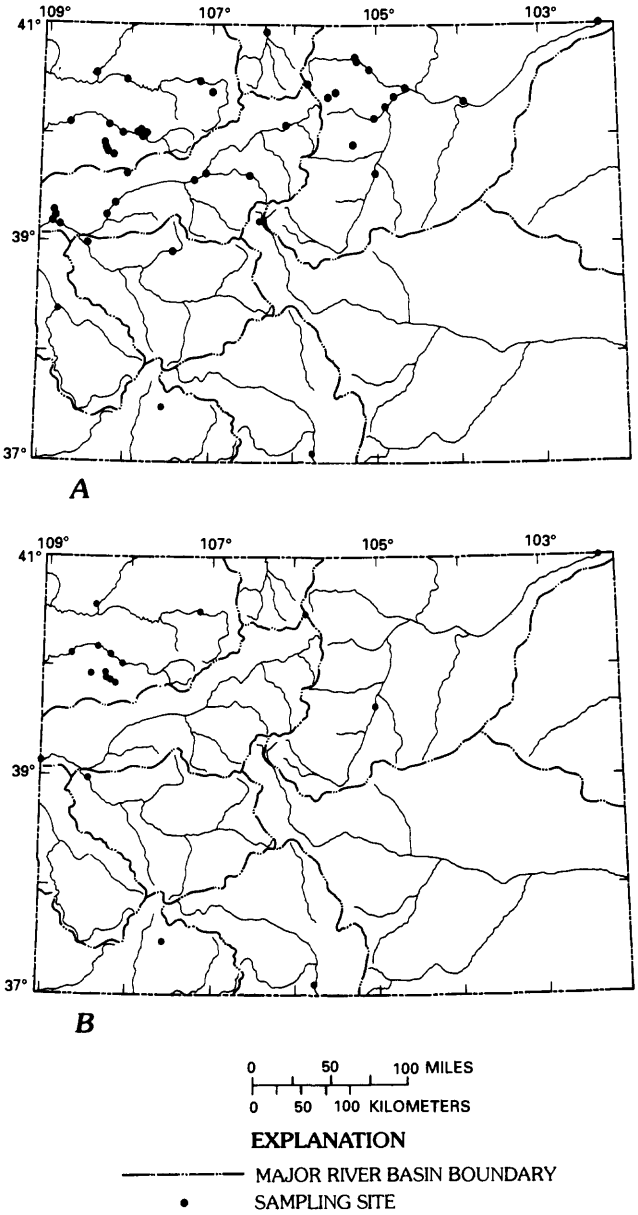


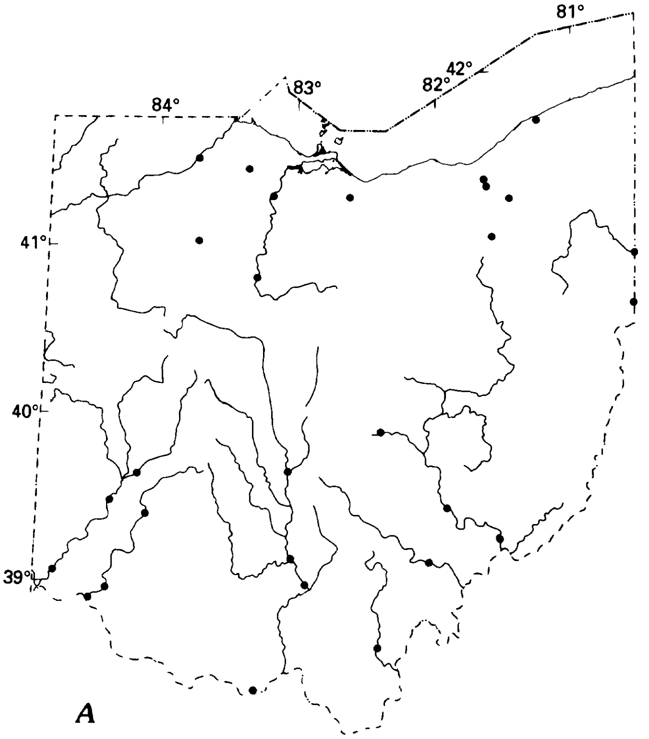
Figure 19. Surface-water sites yielding data suitable for determining changes in water quality, water years 1977 through 1984, Colorado: *A*, Dissolved solids; *B*, Suspended sediment.

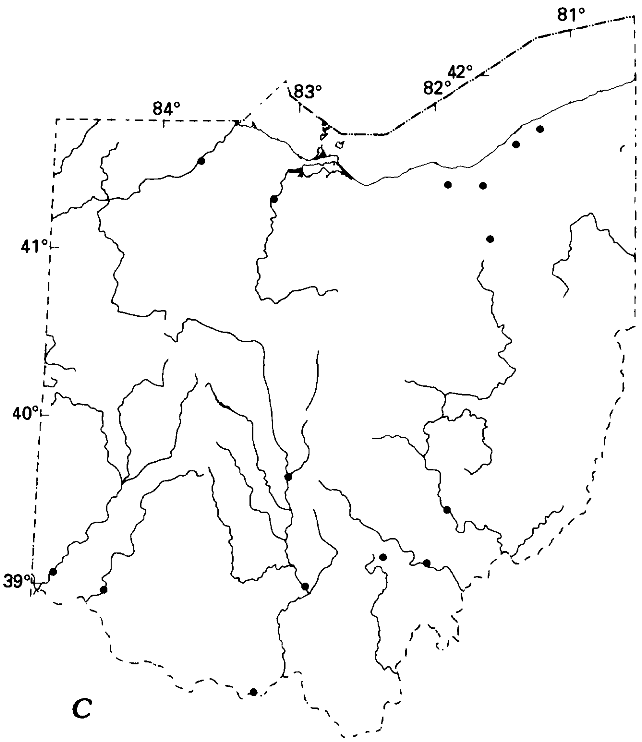
Expenditures for water-quality data-collection activities in the Nation are large and difficult to estimate. In Colorado and Ohio, about $60 million was estimated to have been spent for laboratory analyses of water-quality samples in 1984. Laboratory costs represent only a part (generally less than 50 percent) of the total costs of water-quality data-collection programs. Assuming that these costs are representative, on the order of $2.5–3.0 billion is spent annually on water-quality data-collection activities in the United States.

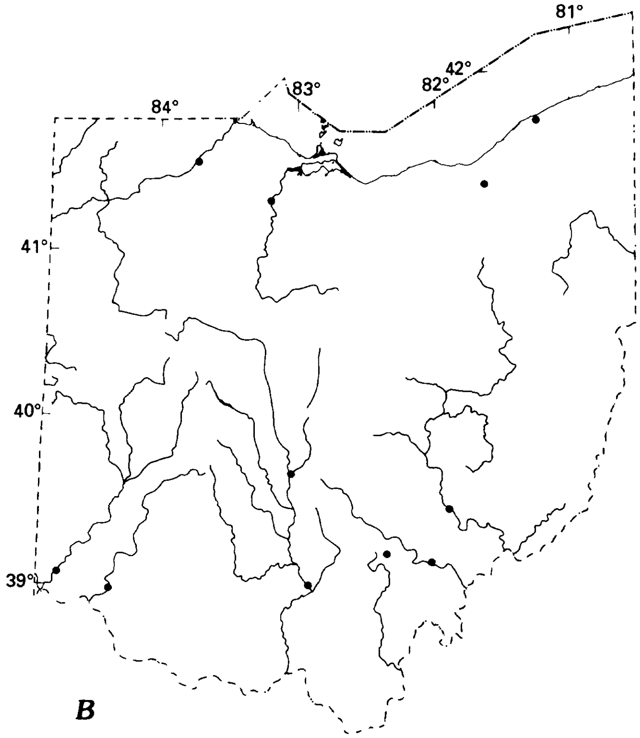
The magnitude of funding for water-quality data-collection activities is not a reliable indicator of the quantity or usefulness of data for assessing regional and national water-quality conditions and trends. Most funding is for water-quality programs that have limited potential for producing data of the kind needed for regional-scale ambient assessment. For example, in 1984, 45 percent of the estimated laboratory costs in Colorado and 72 percent of the costs in Ohio were for samples that represented effluent or treated water conditions rather than ambient stream or aquifer conditions.

Several key aspects of water-quality data-collection programs seem to be out of balance. For example, more than 90 percent of the samples inventoried during the studies in Colorado and Ohio were from surface-water sources; less than 10 percent were from ground-water sources. The dominance of surface-water samples reflects both a greater use of surface water than of ground water in the two States and the knowledge that ground water moves and changes much more slowly than surface water. The level of effort focused on ground water may be modified in view of growing concerns about ground-water contamination. Another area of imbalance is the level of effort directed toward the determination of constituents relevant to the issue of toxic contamination. Of the samples meeting basic screening criteria in Colorado and Ohio, samples for the determination of priority pollutants, pesticides, and radiochemicals amounted to only one-half of one percent of the samples in Colorado and five percent of those samples in Ohio. In contrast, most of the samples were analyzed for constituents and properties that are relevant to issues of long-standing concern, such as acidification, sanitary quality, salinity, and eutrophication.

There is an apparent imbalance in the spatial and temporal scales of water-quality assessment. Most of the sampling effort in Colorado and Ohio is directed toward small-scale, transient assessments that are useful in characterizing individual problem areas associated with known or suspected point and nonpoint sources of contaminants. There are large areas in both States where there is inadequate information to perform an unbiased assessment of regional surface- and ground-water quality conditions. Similarly, there are relatively few sites in either State where sufficient samples have been collected over a period of years so that changes in water quality can be quantified.







EXPLANATION

• SAMPLING SITE

0 50 100 MILES

0 50 100 KILOMETERS

Figure 20 (above and facing column). Surface-water sites yielding data suitable for determining changes in water quality, water years 1977 through 1984, Ohio: *A*, Dissolved oxygen; *B*, Total-recoverable lead; and *C*, Suspended sediment.

Another major implication of this study is the need for additional emphasis on field procedures by organizations collecting water-quality data, especially collection of representative water samples. Improvements in this regard could result in a large increase in the amount of water-quality data suitable for water-quality assessments. Maintaining high quality-assurance standards in the laboratory is equally important, but there is little benefit from precise analyses if samples are unreliable.

Results of this study indicate the two most important screening criteria for determining whether water-quality data are potentially suitable for broad-scope assessments

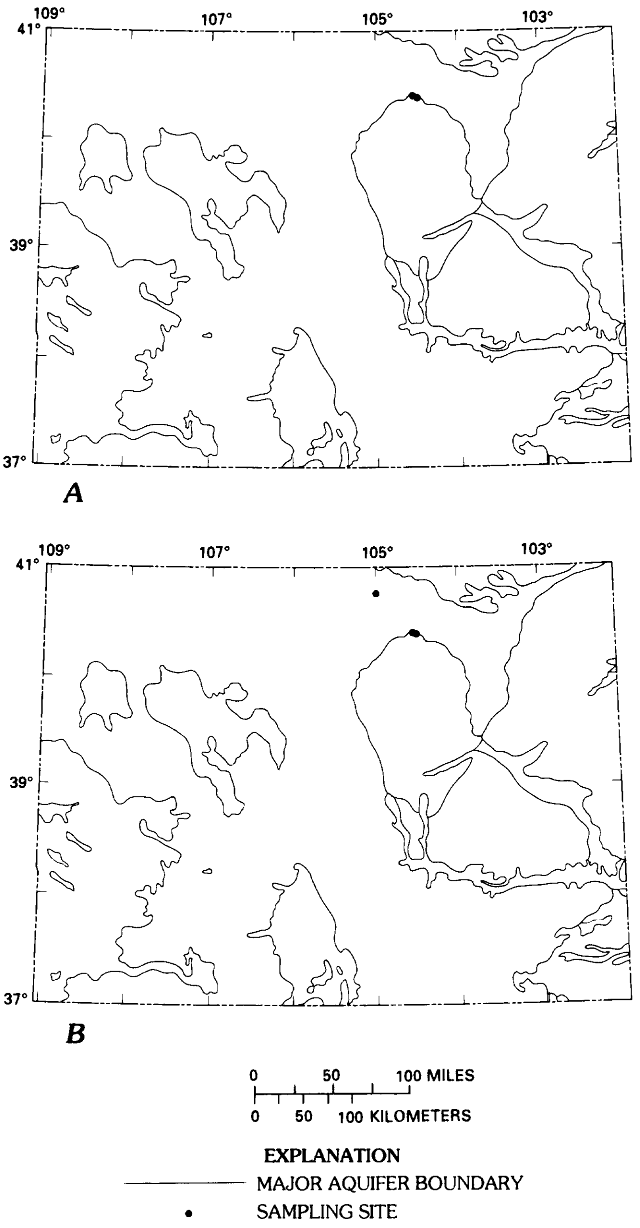


Figure 21. Location of ground-water sampling sites with 5 or more years of data, water years 1972 through 1984, Colorado: *A*, Nitrate as nitrogen; *B*, Dissolved solids.

are: (1) Are (were) the data intended to represent ambient water conditions?, and (2) are (were) stream samples collected by a method that ensures that data are representative of in-stream or in-aquifer conditions?

In spite of the criticisms of long-term water-quality sample-collection networks (U.S. General Accounting Office, 1981), for many constituents these networks are the only ones available with adequate data for regional-scale water-quality assessments. This is especially true if changes in water quality are to be detected. Even though many of these sites have water-quality samples collected only once each month, the period of record is sufficiently long that the range of flows is generally well represented. The data are adequate to define not only the water quality at a site but also, in conjunction with synoptically collected data around a river basin, to describe general water quality and changes in water quality for many constituents in a basin.

Limitations on the usefulness of the data for broad-scope regional and national water-quality assessments became progressively apparent as the screening criteria were applied during the three phases of this study. In Phase I, programs that did not meet the Phase I screening criteria and the data those programs produced were eliminated from further evaluation. In Phases II and III, the amount of data was reduced further through screening steps. The elimination of these programs and their data does not indicate that data not meeting the screening criteria are not useful or that they do not meet the needs for which they were collected. Excluded data may be adequate to fulfill the requirements of the data-collection agencies, even though these data were judged inadequate for inclusion in a data base needed for broad-scope regional and national water-quality assessments.

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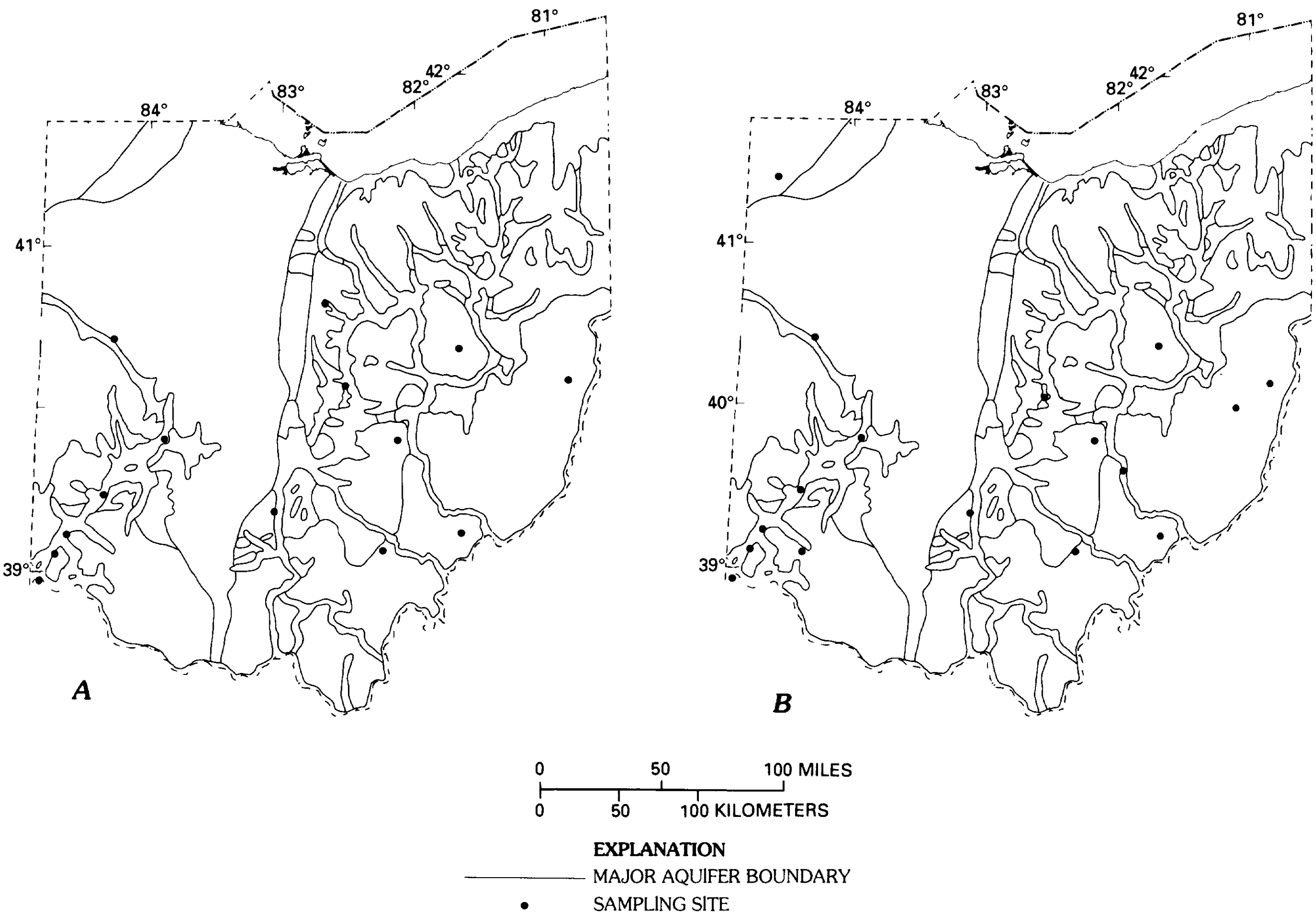

Figure 22. Location of ground-water sampling sites with 5 or more years of data, water years 1972 through 1984, Ohio: *A*, Nitrate as nitrogen; *B*, Total-recoverable iron.

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