

OHIO GROUND-WATER QUALITY

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FOREWORD

This report contains summary information on ground-water quality in one of the 50 States, Puerto Rico, the Virgin Islands, or the Trust Territories of the Pacific Islands, Saipan, Guam, and American Samoa. The material is extracted from the manuscript of the *1986 National Water Summary*, and with the exception of the illustrations, which will be reproduced in multi-color in the *1986 National Water Summary*, the format and content of this report is identical to the State ground-water-quality descriptions to be published in the *1986 National Water Summary*. Release of this information before formal publication in the *1986 National Water Summary* permits the earliest access by the public.

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OHIO

Ground-Water Quality

In 1980, about 42 percent of Ohio's population of 11 million people (fig. 1) depended on ground water. About 740 Mgal/d (million gallons per day) of ground water for domestic, industrial, and agricultural use (Eberle and McClure, 1984) is withdrawn from more than 550 public supplies and nearly 1 million individual wells. About 2.8 million persons in Ohio are supplied by public ground-water systems, and 1.7 million persons are supplied by private ground-water systems (Joyce A. McClure, U.S. Geological Survey, oral commun., 1986). Ground water is the only practical source of water for many people in Ohio (Palmstrom, 1984).

Most ground water in Ohio has not been significantly contaminated and meets U.S. Environmental Protection Agency (EPA) primary and secondary drinking-water standards without treatment. Median concentrations of dissolved solids, hardness, nitrate (as nitrogen), chloride, and sulfate in water from 146 public-supply well fields and 20 individual wells indicate that ground water is generally suitable for human consumption and most other uses (fig. 2C). According to Palmstrom (1984), "ground-water contamination problems are generally of limited extent and involve no more than one or two wells close to a pollution source." The leading sources of ground-water contamination are onsite sewage systems (primarily septic tanks). From 1974 through 1985, the Ohio Department of Health (ODH) analyzed 217,185 samples from public wells and 177,366 samples from private wells to determine if water was contaminated by bacteria. Some of the wells were sampled more than once during that period. About 8 percent of the water samples from public wells and about 28 percent of the water samples from private wells were contaminated with coliform bacteria. In addition to septic-tank leach fields, other leading sources of contamination are hydrocarbon leaks and spills, pesticide application around the home, and oil and gas drilling (Palmstrom, 1984). Abandoned and active waste-disposal sites are potential sources for contamination and are most numerous in urban areas.

Changes in ground-water quality have not been well documented in Ohio. Although a large number of chemical analyses exist, consistent, long-term water-quality data at any given site are not available. Many analyses before the mid-1970's lack the quality control and quality assurance required for accurate appraisals. Many of the analyses are stored in paper-copy files in 88 county health department offices.

A study of glacial-outwash (sand and gravel) aquifers along the Great Miami River in southwestern Ohio (fig. 2A) indicates that some degradation may have occurred in parts of these aquifers (Evans, 1977). Analyses of water samples from a few of the wells in this area indicated significant increased concentrations of common constituents, such as calcium, magnesium, sulfate, and chloride. The increases occurred between the late 1950's and 1976 and probably are related to the effects of urbanization and industrial activities.

Surface mining of coal causes localized degradation of ground water in parts of eastern Ohio. For example, a study by Hren (1986) indicates that surface mining of coal caused significantly increased concentrations of dissolved solids, manganese, sulfate, and chloride in ground water in a mining area in Jefferson County. The increases occurred between 1980 (before mining started) and 1984 (about 3 years after mining stopped).

There are 771 known sites in Ohio where municipal and (or) industrial waste is being or has been disposed of (fig. 3). Ground-water contamination has been confirmed at 27 of the sites.

WATER QUALITY IN PRINCIPAL AQUIFERS

Ohio has seven principal aquifers (fig. 2A). The two types of unconsolidated aquifers (coarse-grained and fine-grained) are con-

sidered together as sand-and-gravel aquifers in this report. The four most productive aquifers are the unconsolidated sand and gravel aquifers, and the consolidated shaly sandstone and shale aquifers, sandstone, and carbonate. The consolidated shale and shaly carbonate aquifers, although very important for domestic supplies, are not productive enough for commercial or public supplies. Ohio has no ground-water-quality sampling network for the shale and shaly carbonate aquifers, and their water quality is not discussed in this report.

BACKGROUND WATER QUALITY

The primary sources of background ground-water-quality data in Ohio are public-water-supply analyses by the Ohio Environmental Protection Agency (OEPA). Most of the OEPA analyses used for this report were from samples collected during the late 1960's through the late 1970's. Public ground-water supplies typically are derived from a well field rather than a single well. Commonly samples were collected from a manifold containing untreated water from several pumped wells, particularly for larger public supplies. Each set of water-quality analyses from a municipal well field consisted of analytical results from 2 to 10 water samples taken at different times. About 20 of the 166 sets of water-quality analyses used to describe background water quality were taken from a report of ground-water quality in southeastern Ohio (Razem and Sedam, 1985). Those analyses were based on single samples collected during 1983 commonly from individual domestic wells.

A graphic summary of selected water-quality variables is presented in figure 2C. The summary is based on dissolved-solids, hardness, nitrate (as nitrogen), chloride, and sulfate analyses of water samples collected from 1965 to 1983 from four of the principal aquifers in Ohio. Percentiles of these variables are compared to national standards that specify the maximum concentration or level of a contaminant in drinking-water supplies as established by the U.S. Environmental Protection Agency (1986a,b). The primary maximum contaminant level standards are health related and are legally enforceable. The secondary maximum contaminant level standards apply to esthetic qualities and are recommended guidelines. The primary drinking-water standards include a maximum concentration of 10 mg/L (milligrams per liter) nitrate (as nitrogen), and the secondary drinking-water standards include maximum concentrations of 500 mg/L dissolved solids, 250 mg/L chloride, and 250 mg/L sulfate.

In much of Ohio, ground water is a calcium bicarbonate type (Stein, 1974). In southeastern Ohio, many aquifers are shallow and are associated with coal deposits. The water from those aquifers is a calcium magnesium bicarbonate type. Most ground water in Ohio is very hard. Median hardness (as calcium carbonate) ranges from 216 mg/L in the sandstone aquifers to 447 mg/L in the carbonate aquifers.

Sand and Gravel Aquifers

The sand and gravel aquifers (aquifer 1, fig. 2C) are located along many of the major streams of the State (fig. 2A). Median concentrations of selected constituents in water from the sand and gravel aquifers are: 413 mg/L dissolved solids; 337 mg/L hardness (as calcium carbonate); 0.10 mg/L nitrate (as nitrogen); 31 mg/L chloride; and 76 mg/L sulfate (fig. 2C). Iron concentrations are as large as 560 μ g/L (micrograms per liter) in a few locations within the Great Miami River valley (Evans, 1977) and the Scioto River valley (de Roche and Razem, 1981).

Most major ground-water withdrawals in Ohio are from sand and gravel aquifers (U.S. Geological Survey, 1985, p. 341). The sand and gravel aquifers have the largest yields, 25 to 500 gal/min

(gallons per minute) and many of Ohio's urban areas are located close to major streams, which are associated with the large sand and gravel aquifers. None of the sand and gravel aquifers from which major withdrawals are made are known to be contaminated to any significant extent.

The most extensively developed sand and gravel aquifers in Ohio are in the Great Miami River valley. The largest concentrations of population (fig. 1B) and industry in the Great Miami River valley are in Montgomery, Butler, and Hamilton Counties, where approximately 16 percent of Ohio's population resides. Although part of Cincinnati's public water supply comes from the Ohio River, most of the people and industry of the three-county area obtain their water from sand and gravel aquifers.

Other extensively developed sand and gravel aquifers are present in the State. Sand and gravel aquifers in Stark County are used in conjunction with the sandstone aquifers for public and industrial supplies (U.S. Geological Survey, 1985, p. 345).

Shaly Sandstone Shale Aquifers

The shaly sandstone and shale aquifers (aquifer 2, fig. 2C) are located in southeastern Ohio (fig. 2A). Median concentrations of selected constituents in water from the shaly sandstone and shale aquifers are: 435 mg/L dissolved solids; 263 mg/L hardness (as calcium carbonate); 0.45 mg/L nitrate (as nitrogen); 15 mg/L chloride; and 91 mg/L sulfate.

Most of the ground water from the shaly sandstone and shale aquifers is a calcium magnesium bicarbonate type, but a sodium bicarbonate type is also common (Razem and Sedam, 1985). The water quality of the shaly sandstone and shale aquifers is similar to the water quality of the sandstone aquifers except that the shaly sandstone and shale aquifers have larger nitrate and sodium concentrations.

Concentrations of nitrate from the shaly sandstone and shale aquifers are significantly larger than those from the other major productive aquifers in Ohio. The median concentration of nitrate (as nitrogen) is 0.45 mg/L for the shaly sandstone and shale aquifers, 0.1 mg/L for the sand and gravel aquifers, and less than or equal to the detection limit for the sandstone and the carbonate aquifers. Twenty of the 32 analyses for the shaly sandstone and shale aquifers were from rural domestic wells sampled in a study of ground-water quality in southeastern Ohio (Razem and Sedam, 1985); most rural landowners in this area have onsite sewage disposal, are engaged in livestock production, and use agricultural fertilizers.

The shaly sandstone and shale aquifers have the smallest yield (1 to 5 gal/min) of the productive aquifers in Ohio (U.S. Geological Survey, 1985, p. 342). Well yields are so small in some areas that domestic ground-water supplies are supplemented with cisterns. Even though the aquifer yields are small, the shaly sandstone and shale aquifers are very important to southeastern Ohio because they offer the only practical water supply to many people of that area.

Sandstone Aquifers

The sandstone aquifers (aquifer 3, fig. 2C) are located in east-central and northeastern Ohio (fig. 2A). Median concentrations of selected constituents in water from the sandstone aquifers are: 322 mg/L dissolved solids; 216 mg/L hardness (as calcium carbonate); 10 mg/L chloride; and 36 mg/L sulfate. The median concentration of nitrate (as nitrogen) was less than the detection limit. The median concentrations of dissolved solids, hardness, chloride, and sulfate are smaller for the sandstone aquifers than for the other three major productive aquifers in Ohio. The sandstone aquifers of northeastern Ohio generally contain saline water below 300 feet. Many of the major ground-water withdrawals in northeastern Ohio involve both sandstone and sand and gravel aquifers (U.S. Geological Survey, 1985, p. 345).

The population and industry of northeastern Ohio, except for those close to Lake Erie, are very dependent on the sandstone aquifers for water supplies. Suburban and rural populations also depend on the sandstone aquifers for their domestic and agricultural supplies. In many rural areas, the sandstone aquifers are the only practical source of supply.

Carbonate Aquifers

The carbonate aquifers (aquifer 4, fig. 2C) are located in west-central and northwestern Ohio except for extreme northwestern Ohio, where sand and gravel aquifers are present (fig. 2A). Median concentrations of selected constituents in water from the carbonate aquifers are: 617 mg/L dissolved solids; 447 mg/L hardness (as calcium carbonate); 16 mg/L chloride; and sulfate, 176 mg/L. The median concentration of nitrate (as nitrogen) was less than or equal to the detection limit. The median concentrations of dissolved solids, hardness, and sulfate are larger for the carbonate aquifers than for the other three major aquifers.

The quality of water from carbonate aquifers is more variable than that of the other three major aquifers (Norris, 1974). Norris found that ground water becomes progressively more mineralized as it moves down the potentiometric gradient. Concentrations of all major ions except bicarbonate increase in the direction of ground-water flow. The water is a calcium bicarbonate type in the areas of regional recharge and a calcium sulfate type in principal discharge areas. Bicarbonate exceeds 80 percent of the total anions in the recharge areas but decreased to less than 40 percent of the total anions in the discharge areas. Data collected during an earlier study (Norris and Fidler, 1973) show that calcium concentrations in the carbonate aquifers averaged 88 mg/L for five wells in regional recharge areas and 323 mg/L for five wells in regional discharge areas; dissolved-solids concentrations averaged 435 mg/L in the recharge area and 1,826 mg/L in the discharge area; chloride concentrations averaged 5 mg/L in the recharge area and 28 mg/L in the discharge area; and sulfate concentrations averaged 69 mg/L in the recharge area and 981 mg/L in the discharge area.

Several population centers and a large rural area depend on the carbonate aquifers for their water supply. Most industrial, agricultural, and domestic supplies in west-central and northwestern Ohio come from the carbonate aquifers, and they are the only practical source of water for many persons in the area.

EFFECTS OF LAND USE ON WATER QUALITY

Ohio has an economy supported predominantly by service industries, manufacturing, and agriculture. Throughout eastern and northwestern Ohio, oil and gas are produced, and coal is mined in eastern Ohio. All of these land uses can lead to contamination of ground water.

Waste-Disposal Sites

There are 27 Resource Conservation and Recovery Act (RCRA) sites 27 Comprehensive Environmental Response Compensation and Liability Act (CERCLA) sites, sites, and 5 Installation Restoration Program (IRP) sites in Ohio (fig. 3A). Ground-water quality is being monitored systematically at the CERCLA and RCRA sites. In addition, Ohio has 69 licensed landfills that accept industrial as well as municipal waste; these landfills are referred to as "other" sites in figure 3A. Ground-water contamination has been confirmed at 13 of the CERCLA sites and at 14 of the "other" sites (fig. 3A). There is no known ground-water contamination at 14 CERCLA sites, at any of the 27 RCRA sites, and at 55 of the "other" sites.

As of September 1985, 28 hazardous-waste sites at 5 facilities in Ohio had been identified by the DOD as part of their IRP as having potential for contamination (U.S. Department of Defense, 1986). The IRP, established in 1976, parallels the EPA Superfund program under the CERCLA of 1980. The EPA presently ranks these sites under

a hazard ranking system and may include them in the National Priorities List (NPL). Five sites at two facilities (fig. 3A) were considered to present a hazard significant enough to warrant response action in accordance with CERCLA. The remaining sites were scheduled for confirmation studies to determine if remedial action is required.

Ohio also has 140 licensed landfills that receive only municipal waste (fig. 3B). Some of the predominantly rural counties have no licensed landfills, whereas some of the densely populated or industrialized counties have several. None of the landfills is known to have contaminated local ground water; however, the quality of ground water near licensed landfills is not monitored routinely.

The concentration of urban areas and industry along the sand and gravel aquifers has resulted in an increased number of waste-disposal sites near those aquifers, particularly in southwestern Ohio (figs. 2A, 3A, and 3B). Most of the CERCLA and RCRA sites in Ohio are within or close to major urban areas. Chloride concentrations are elevated (25 percent are more than 43 mg/L) in some urban areas. There are numerous waste-disposal sites in the area of the sandstone aquifers in northeastern Ohio (figs. 2A), some of which may have caused ground-water contamination of limited extent. Many of the waste-disposal sites are near population centers (fig. 1B). The area of the carbonate aquifers in west-central and northwestern Ohio is primarily rural and tends to have fewer waste-disposal sites than the other productive aquifer areas of the State (fig. 3A). The area of the shaly sandstone and shale aquifer has fewer CERCLA and RCRA sites, but a similar number of licensed landfills, compared with the areas of the other major productive aquifers. There are 503 unlicensed or closed landfills in Ohio that have not been classified as CERCLA and RCRA, or "other" sites; the distribution of these landfill sites in each county is also shown in figure 3B. None of these sites is known to have caused contamination of ground water.

In summary, there are 771 known sites in Ohio where municipal and (or) industrial waste is being or has been disposed of. About 500 of those sites are unlicensed or closed. Ground-water contamination has been confirmed at 27 of the sites.

Oil and Gas Production

Brines associated with oil and gas production can contaminate ground water during drilling operations or by improper handling or disposal of the brines. The ODNR Division of Oil and Gas has records of 62 private wells that yielded water with concentrations of chloride greater than 250 mg/L from March 1984 through July 1986.

Domestic Sources

Bacterial contamination affects the water from more wells for which records are available than any other form of contamination in Ohio. Most bacterial contamination of ground water is from onsite sewage systems (Palmstrom, 1984). The Ohio Department of Health (ODH) has compiled a list of water samples that were analyzed for bacterial contamination (total coliform). About 8 percent of the samples from public-supply wells and about 28 percent of the samples from private wells were contaminated by bacteria. The ODH compilation shows that 18,123 ground-water samples collected from 1974 through 1985 from public water supplies were bacterially contaminated, 1 colony per 100 mL (milliliters) Ohio Environmental Protection Agency, 1980), and that 49,970 samples from private wells were bacterially contaminated (3 colonies per 100 mL; Ohio Environmental Protection Agency, 1981). A summary of the ODH bacterial sample analyses is shown in figure 4 for each of the five districts that ODH and the Ohio Environmental Protection Agency (OEPA) have established to administer their programs.

Onsite sewage systems are the source of bacterial contamination in some areas of Ohio. In a residential division in Wood County,

for example, the carbonate aquifers are generally less than 40 inches below the land surface, and each home is served by a domestic well and its own sewage system (Ohio Department of Health, 1982). Each of 10 wells sampled in this subdivision showed contamination from domestic sewage. Three of the 10 wells had coliform or nitrate (as nitrogen) concentrations that exceeded primary drinking-water standards (1 colony per 100 milliliters and 10 mg/L, respectively).

Mining

Coal has been mined extensively throughout most of eastern and southeastern Ohio during this century, but it is difficult to determine how many freshwater aquifers may have been contaminated from the mining of coal and how many persons may have been affected because ground-water quality has not been monitored regionally in Ohio except at some waste-disposal sites and for public water supplies. Water from some observation wells sampled by the U.S. Geological Survey in coal mining areas of southeastern Ohio was contaminated (Hren, 1986; Razem, 1983). However, no water-supply wells have been sampled, so that no public or private water supplies are known to be directly affected.

POTENTIAL FOR WATER-QUALITY CHANGES

Most of the sand and gravel aquifers in Ohio are along the major streams and near major urban areas where the probability of toxic spills and mismanagement of waste materials is greater than in sparsely populated areas. These aquifers are very susceptible to contamination because they are recharged close to or at land surface, with only limited travel distance and limited adsorption of any contaminants in soils through which the recharge water percolates. Thus, the proximity of the sand and gravel aquifers to the land surface in areas where population densities are greatest affords the greatest chance of contamination. Some instances of increased specific conductance and concentrations of calcium, magnesium, chlorides, and sulfates in urbanized parts of the Great Miami River valley have been reported (Evans, 1977).

The mining of coal could affect additional areas of the shaly sandstone and shale aquifers and the southern part of the sandstone-aquifer area. Many of the domestic wells in eastern Ohio where coal is mined, particularly those in the shaly sandstone and shale aquifers, are somewhat shallow (50- to 100-foot depth) and yield less than 5 gal/min (Razem and Sedam, 1985). Many of these aquifers also have limited geographic extent. The surface mining of coal has been shown to affect the quality of ground water, but its effects have not been well documented in Ohio.

Oil and gas production could affect the sandstone aquifers of northeastern Ohio. Enforcement of brine-disposal regulations is difficult. As an example, a brine-disposal well in Geauga County accidentally discharged brine at land surface when the injection pressure within the well exceeded the recharge capacity of the formation (Jeffrey T. de Roche, U.S. Geological Survey, oral commun., 1986). This accident caused contamination of nearby wells.

A few suburban communities are mandating residential use of public sewage systems rather than private septic tanks while continuing to use private residential wells for water supply. The ground water affected by bacterial contamination in those communities may decrease in the future.

GROUND-WATER-QUALITY MANAGEMENT

The protection of Ohio's ground water has emerged as one of the important environmental concerns of this decade. Increased public awareness regarding the safety of drinking water has resulted in increased efforts by all levels of government to develop and implement new programs for comprehensive resource protection.

The State's efforts to study, evaluate, and protect its ground-water resources are performed in conjunction with a number of

Federal, State, and local agencies. The U.S. Geological Survey, has conducted numerous hydrologic studies of ground-water flow and ground-water quality. The studies have ranged in scope from regional (southeastern Ohio) to small areas consisting of one or two townships. Many of the studies cover single counties. Most of the studies were conducted in cooperation with State and local agencies. The most prominent ground-water program functions at the State level are within the Department of Natural Resources, the Department of Health, and the Environmental Protection Agency.

The Ohio Department of Natural Resources (ODNR), Division of Water, has conducted a ground-water program for nearly 40 years and is responsible for the quantitative evaluation of the resource. Specific functions include ground-water mapping; administering Ohio's well-log and drilling-report law; special hydrogeologic investigations; and technical assistance to municipalities, industries, and the general public regarding local geology, well drilling and development, and quantitative problem assessment. The Division has completed county ground-water availability maps for nearly three-fourths of Ohio and has recently initiated a new mapping program to show ground-water pollution potential. Approximately 9,000 new well logs and more than 5,000 technical-assistance requests are received and responded to each year.

The ODNR Division of Oil and Gas administers rules and regulations to insure optimum management of oil and gas reserves and the control of pollution from activities associated with production. Major functions that directly relate to ground-water protection include controls over well drilling, well casing, and well-abandonment techniques; and the regulation of storage and disposal practices for associated waste fluids. The Division also administers the State's underground injection control program for more than 4,000 Class-II and Class-III injection wells (U.S. Environmental Protection Agency, 1984).

The Ohio Department of Health (ODH) is responsible for programs to regulate the siting, design, operation, and maintenance of private residential water-supply systems and sewage-disposal systems, both of which may have direct impacts on local ground-water quality and drinking-water safety. ODH has developed rules governing specific well-construction practices and a well-permit system that are administered in cooperation with local health departments. Other ground-water-related activities include a registration program for private water-system contractors and a local inspection and sampling program for noncommunity public water-supplies.

The activities of the Ohio Environmental Protection Agency (OEPA) are directed toward ground-water-quality monitoring and assessment and evaluation and control of ground-water pollution from existing and proposed waste-disposal sites. Technical assistance is provided to government officials, industries, and the general public on the identification, prevention, control, and abatement of ground-water pollution from a wide range of land-use activities.

The OEPA's Division of Ground Water functions as a technical-support unit for all other programs of OEPA to provide technical expertise on local hydrogeology and ground-water quality. Among the specific activities of the ground-water staff are responses to formal complaints about ground-water problems and the review of plans and site-feasibility reports to insure that adequate and sufficient ground-water protection and surveillance measures are incorporated into land-disposal sites and facilities. The staff currently is redesigning the State's ground-water-monitoring network, which will include more than 500 individual wells sampled semiannually to measure ambient water quality in major aquifers and the effects of pollution near selected waste-disposal sites and facilities. Each year, the ground-water staff investigates and assesses ground-water conditions at approximately 350 sites and responds to more than 1,000 requests for technical assistance.

Ground-water-related functions within other Divisions of OEPA include the public-water-supply supervision program (as

authorized by the Federal Safe Drinking Water Act); administration of the federally mandated underground injection program for Class-I, IV, and V injection wells (U.S. Environmental Protection Agency, 1984); and management of the required programs of the RCRA for preventing and abating ground-water pollution from regulated and unregulated hazardous-waste facilities. The OEPA also maintains an office of Emergency Response, which responds to and assists in the clean-up of about 300 spills, accidents, and other sudden releases annually that might affect ground water. The OEPA's Planning Coordinator reviews and administers Federal grant awards to local planning agencies for water-quality-management plans and studies.

Other State and local agencies with ground-water-protection responsibilities include the State Fire Marshall, who administers the underground storage tank program; the ODNR, Division of Reclamation, which issues surface coal-mining permits with requirements that insure adequate ground-water protection; and county health departments, which inspect new private water and sewage systems for compliance with State rules. The Hazardous Waste Facility Board, consisting of representatives from several agencies and the governor's office, issues hazardous-waste permits. Those permits contain terms and conditions designed to protect ground water. These terms and conditions are enforced by OEPA.

The OEPA, in cooperation with other State agencies, currently is engaged in the final stages of developing a comprehensive ground-water-strategy framework and action plan that will emphasize the prevention of ground-water pollution from all future sources, and the identification and control of pollution from existing sources. Five major initiatives have been identified in the strategy that must be addressed for Ohio to protect its water resources efficiently and effectively:

1. Strengthen controls (which are currently deficient) over all existing and potential sources of pollution through increased regulatory, institutional, and enforcement capabilities;
2. Improve ground-water-information systems and data bases to define more clearly the resource, define resource problems, and provide easier access to reliable information;
3. Improve interagency and intra-agency coordination among the numerous State offices, which often share jurisdiction over various ground-water-related activities;
4. Provide stronger safeguards for public water supplies and critical aquifer areas that comprise essential sources of drinking water; and
5. Encourage greater participation by local governments to undertake additional responsibilities in providing more effective ground-water protection and management.

Throughout 1987, government agencies and a public-advisory group will be developing a ground-water strategy-implementation plan and schedule. Among the specific program initiatives under consideration will be exploration of options for developing an aquifer-classification system and ground-water-quality standards. These particular management techniques are not currently in effect in Ohio, but soon will be seriously considered for development.

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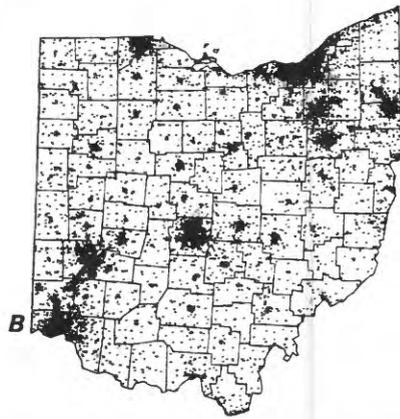


Figure 1. Selected geographic features and 1985 population distribution in Ohio. *A*, Counties, selected cities, and major drainages. *B*, Population distribution, 1985; each dot on the map represents 1,000 people. (Source: *B*, Data from U.S. Bureau of the Census 1980 decennial census files, adjusted to the 1985 U.S. Bureau of the Census data for county populations.)

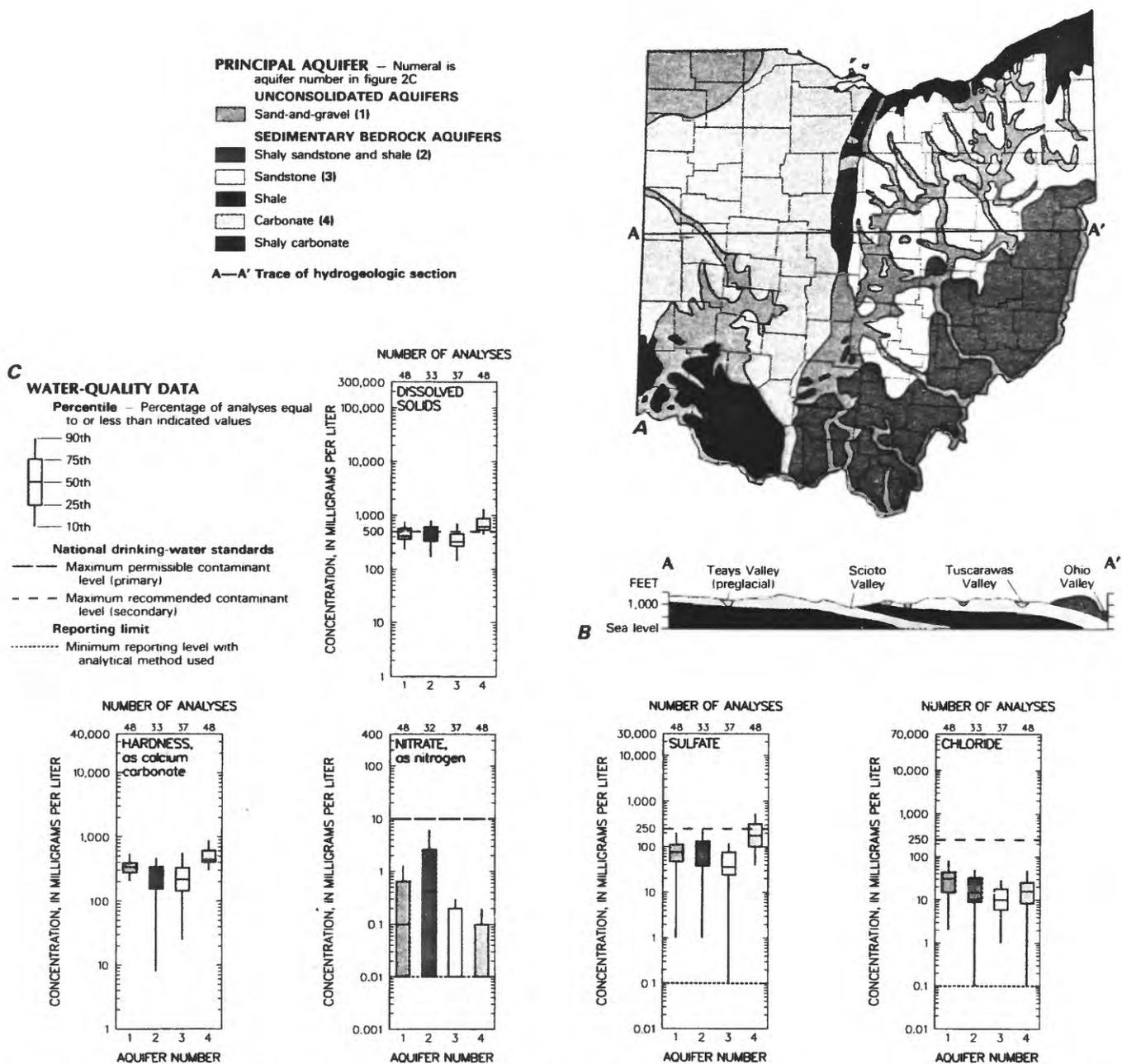
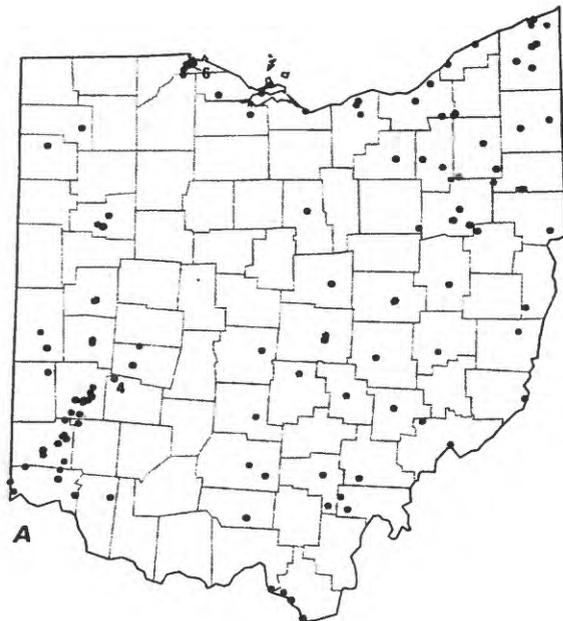
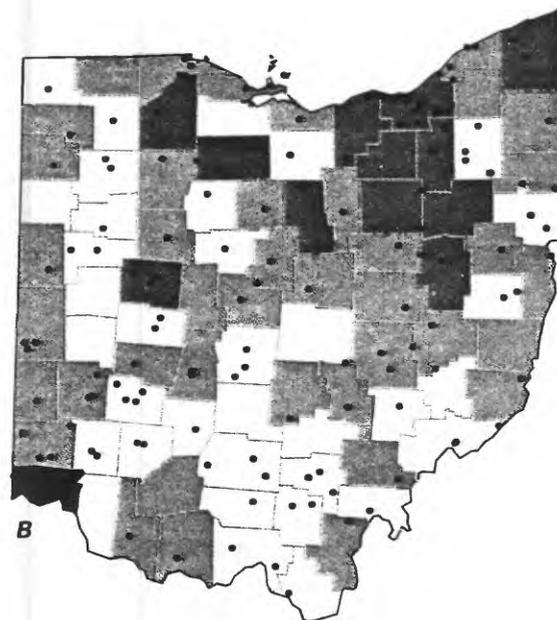


Figure 2. Principal aquifers and related water-quality data in Ohio. *A*, Principal aquifers; *B*, Generalized hydrogeologic section. *C*, Selected water-quality constituent and properties, as of 1983. (Sources: *A*, Ohio Department of Natural Resources, Division of Water files. *B*, Ohio Department of Natural Resources, Division of Geological Survey files. *C*, Analyses compiled from U.S. Geological Survey files; national drinking-water standards from U.S. Environmental Protection Agency, 1986a,b.)



WASTE SITE – Darker symbol indicates site where contaminants were detected in ground water. Numeral indicates more than one site at same general location

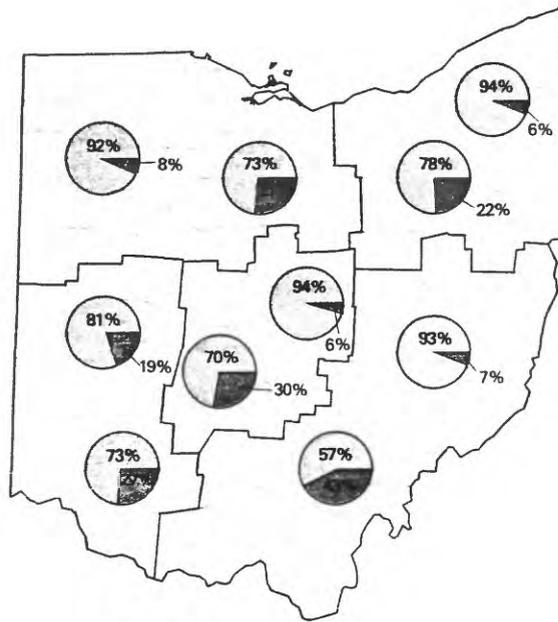
- CERCLA (Superfund)
- 6 • RCRA
- 4 • IRP
- Other



LANDFILL SITE

- Licensed active municipal
- Unlicensed or closed, by county
- 0
- 1-3
- 4-10
- 11-20
- 21

Figure 3. Selected waste sites and ground-water-quality information in Ohio. *A*, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites, as of 1986; Resource Conservation and Recovery Act (RCRA) sites, as of 1986; Department of Defense Installation Restoration Program (IRP) sites, as of 1985; and other selected waste sites, as of 1986. *B*, Licensed, unlicensed, and closed municipal landfills, as of 1986. (Sources: *A*, Ohio Environmental Protection Agency files; U.S. Department of Defense, 1986. *B*, Ohio Environmental Protection Agency files.)



EXPLANATION

— Boundary for Ohio Department of Health and Ohio Environmental Protection Agency districts

Water-supply wells



Figure 4. Categories of water-supply wells, based on total coliform bacteria analyses from 1974 to 1985. (Source: Compiled by R. I. Lane from Ohio Department of Health annual reports.)