WISCONSIN GROUND-WATER QUALITY

By Phil A. Kammerer

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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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About 70 percent of Wisconsin's population depends on ground water for its water supply; about 35 percent are served by public water supplies and 35 percent by private wells (U.S. Geological Survey, 1985). The population dependent on ground water is primarily inland from Lake Michigan (fig. 1*B*). Milwaukee, Green Bay, and many other communities located along the lake obtain their water supplies from Lake Michigan. Water in three major and other minor aquifers is generally suitable for domestic supply and most other uses (see fig. 2). Predominant dissolved constituents in the ground water are calcium, magnesium, and bicarbonate. Naturally occurring constituents and properties that cause local problems include iron, manganese, hardness, radium, hydrogen sulfide, and fluoride.

Activities or sources that have been identified as potential or actual contributors to ground-water contamination are land disposal of wastes, some agricultural practices, and underground petroleum storage tanks. Ground-water contamination has been detected at 7 of 12 Federal Resource Conservation and Recovery Act (RCRA) sites and 21 of 26 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites (fig. 3). In addition, the U.S. Department of Defense (DOD) has identified one site at one facility where contamination has warranted remedial action. The potential for contamination is also present at other sites. Contamination has been detected at landfills and wastewater-disposal sites by routine monitoring and incidental to investigation of other water-quality problems. Agricultural practices have caused ground-water contamination by the pesticide aldicarb in the central sand plain (all or parts of Portage, Waushara, Wood, and Adams Counties), and by other pesticides in other areas, and have probably contributed to nitrate contamination in many areas. Underground petroleum storage tanks have been implicated in many instances of ground-water contamination even though there is no regulatory monitoring program to detect this type of contamination. Bacterial contamination has occurred in eastern Wisconsin where fractured dolomite is near the land surface.

Reconnaissance sampling has indicated local instances of ground-water contamination by volatile organic compounds (VOC) and nitrate in scattered areas of the State. These substances can be from several sources. The most frequently detected VOC were trichloroethylene and tetrachloroethylene.

WATER QUALITY IN PRINCIPAL AQUIFERS

Wisconsin has three principal aquifers—the unconsolidated sand and gravel, Silurian dolomite, and sandstone aquifers (fig. 2*A*). More detailed descriptions of these aquifers, well characteristics, and water use are given elsewhere (U.S. Geological Survey, 1985, p. 447–450). Two minor aquifers—the Lake Superior sandstone aquifer and the Precambrian lava flows—also are discussed, because of their local importance. Precambrian igneous and metamorphic rocks that underlie the entire State and the Maquoketa Shale (which is also a confining bed) yield water to wells in some areas, but they are not discussed here because of their limited importance and lack of pertinent data.

Bedrock aquifers are hydraulically connected to one another except for the sandstone and Silurian dolomite aquifers in eastern Wisconsin that are separated by the Maquoketa Shale confining bed. Recharge to bedrock aquifers passes through the unconsolidated sand and gravel aquifer, where it is present, and through soils in most other areas. The dominant recharge area for the confined part of the sandstone aquifer is beyond the western edge of the Silurian dolomite aquifer, but some leakage also occurs through the Maquoketa Shale confining bed.

Ground-water quality is generally suitable for most uses, but treatment may be necessary for esthetic reasons to decrease naturally occurring hardness and iron or manganese concentrations exceeding drinking-water standards (Wisconsin Department of Natural Resources, 1978). Other naturally caused water-quality problems that affect water uses in local areas of some aquifers are radium, fluoride, and hydrogen-sulfide concentrations exceeding State drinking-water standards.

The predominant dissolved constituents in most of the State's ground water are calcium, magnesium, and bicarbonate. Differences in the concentrations of these constituents generally parallel differences in dissolved-solids concentrations, which are used here as one means of characterizing the background quality of ground water.

BACKGROUND WATER QUALITY

A graphic summary of selected water-quality variables compiled from the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) is presented in figure 2*C*. The summary is based on dissolved-solids, hardness (as calcium carbonate), nitrate (as nitrogen), iron, and manganese analyses of water samples collected from the principal aquifers in Wisconsin. Most of the data used in the summary were collected during the last 30 years. Nitrate plus nitrite concentrations are considered to be equivalent to nitrate (as nitrogen) concentrations for the purpose of this report. The ratios of these constituents within and among aquifers are discussed in greater detail by Kammerer (1984). Percentiles of these variables are compared to national standards that specify the maximum concentration or level of a contaminant in drinking-water supply 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, 300 μg/L (micrograms per liter), iron, and 50 μg/L manganese.

State drinking-water standards are the responsibility of the Wisconsin Department of Natural Resources (DNR). Current State standards (Wisconsin Department of Natural Resources, 1978) are, with minor exceptions, the same as national standards adopted by the U.S. Environmental Protection Agency (1986a,b). Recently enacted ground-water-quality standards (Wisconsin Department of Natural Resources, 1985) are discussed later.

Unconsolidated Sand and Gravel Aquifer

The sand and gravel aquifer is not a continuous aquifer as are most bedrock aquifers, but is present as discontinuous deposits whose origin and lithology differ areally. For the purpose of summarizing hardness and dissolved-solids data, the aquifer is subdivided into three subareas (fig. 2*A*), based on ground-water provinces used by Kammerer (1984, p. 10). The aquifer was subdivided to better define the effect of areal differences in aquifer characteristics in the summaries. Dissolved-solids and hardness concentrations are largest in the east (subarea II), where the aquifer overlies the Silurian dolomite aquifer, and in dolomite units of the sandstone aquifer. Concentrations are smallest in the north (subarea III), where the aquifer overlies Precambrian crystalline rocks, sandstones, and lava flows. Hardness of water in these subareas can be classified, in general, as moderately hard to hard (subarea I), very hard (subarea II), or moderately hard (subarea III).

Concentrations of iron, manganese, and nitrate (as nitrogen) do not appear to be affected by areal differences in aquifer characteristics. Therefore, their concentration distributions are summarized for the entire aquifer. Concentrations of iron and manganese exceed the drinking-water standards in water from more than one-third of the wells (fig. 2*C*). Nitrate (as nitrogen) concentrations shown in figure 2*C* represent the range of concentrations expected in uncontaminated ground water.

Silurian Dolomite Aquifer

The Silurian dolomite aquifer is mostly dolomite of Silurian age, but it also includes Devonian dolomite and shale in a small area along Lake Michigan. Water from this aquifer is very hard; hardness values are among the largest in the State. Dissolved-solids concentrations are also large, with concentrations exceeding 500 mg/L in water from about 25 percent of the wells sampled. Iron concentrations exceed drinking-water standards in water from about half of the wells. Manganese concentrations exceeding drinking-water standards occur less commonly, but present problems in many wells. The range of nitrate (as nitrogen) concentrations shown in figure 2*C* is small and probably represents natural conditions. Hydrogen sulfide has been detected locally (Kammerer, 1984, p. 46) in water from wells in the southeastern Kenosha County (the southeastern part of area B in fig. 3*B*).

Sandstone Aquifer

The sandstone aquifer consists of sandstone, dolomitic sandstone, dolomite, and some siltstone. Water-quality data used in the summaries in figure 2*C* are most representative of the unconfined part of the aquifer. The confined part of the aquifer (beneath the Maquoketa Shale) is an important source of ground water, but water-quality data for wells drawing water exclusively from it are scarce and under-represented in the summaries. Water from the aquifer is hard to very hard—hardness is largest in the western, southern, and eastern parts of the State where more wells draw water from dolomite. Dissolved-solids concentrations are generally smaller than 500 mg/L. Iron concentrations exceed drinking-water standards in water from about 33 percent of the wells; manganese concentrations exceed the drinking-water standard less frequently. Hydrogen sulfide has been detected in water from the upper part of the aquifer near Lake Winnebago and in the northeast in area B delineated in figure 3*B* (Kammerer, 1984, p. 46). Radium concentrations near and exceeding the State drinking-water standard of 5 pCi/L (picocuries per liter) have been reported locally, mainly in area A delineated in figure 3*B* (Hahn, 1984). Fluoride concentrations exceeding the State drinking-water standard of 2.2 mg/L are commonly found in water from wells in an area along the Fox River south of Green Bay.

Lake Superior Sandstone Aquifer and Precambrian Lava Flows

The Lake Superior sandstone aquifer and the Precambrian lava flows generally are used for water supplies only where adequate supplies are not obtainable from overlying unconsolidated materials. This situation occurs primarily in Ashland and Bayfield Counties along Lake Superior. Water is moderately hard to hard in the Lake Superior sandstone aquifer and moderately hard in the lava flows. Water from the Lake Superior sandstone aquifer contains a wide range of total dissolved-solids concentrations, and concentrations exceed 500 mg/L in water from more than 25 percent of the wells. Dissolved-solids concentrations in water from the lava flows generally do not exceed 500 mg/L. Iron concentrations exceed drinking-water standards in water from about 25 to 33 percent of the wells in these aquifers; manganese concentrations exceed the standards in water from a larger proportion of the wells in these aquifers than in wells tapping other aquifers. Nitrate (as nitrogen) concentrations are small in both aquifers.

EFFECTS OF LAND USE ON WATER QUALITY

Water-quality changes have been linked to large-scale, easily identified activities (such as waste disposal and agricultural practices) as well as to incidents at specific sites (such as contamination from private septic systems or leaking underground storage tanks), which are more difficult to identify or anticipate. Some contaminants, such as nitrate and VOC, can come from a number of these sources. Some instances of contamination are detected through routine regulatory monitoring programs established in anticipation of water-quality problems (monitoring at waste-disposal sites, for example), but others are unanticipated and undetected until problems are encountered by a water user.

The relative importance of factors contributing to water-quality changes is indicated by records of water-quality problems investigated by the DNR. State ground-water regulations implemented in 1983 provide for compensation to individuals with contaminated domestic water-supply wells. In administering this program, the DNR has attempted to correlate compensation claims with known or suspected sources of contamination. Contaminants or their sources were identified for 706 wells for which contamination advisories were issued between 1983 and January 1, 1986. Principal causes of problems were landfills (36 percent), VOC (33 percent), pesticides (13 percent), underground petroleum storage tanks (8 percent), and other (10 percent) (Schreiber, 1986). Principal sources of contamination identified in an inventory of 197 ground-water contamination cases investigated by DNR between 1929 and 1980 were leakage from pipes and tanks (29 percent), waste lagoons (16 percent), landfills (12 percent), and accidental spills (10 percent). About one-third of all instances were related in some way to storage, treatment, or disposal of wastes (Kammerer, 1984, p. 48).

The perspective of an investigation or source of data is an important consideration in documenting the incidence of a particular water-quality change. This is illustrated by three separate surveys of nitrate contamination. The boxplots in figure 2*C* indicate a very small incidence of nitrate (as nitrogen) contamination. These plots are based on WATSTORE data which, for Wisconsin, are primarily from uncontaminated wells. Results of a 1979–80 sampling by the DNR of 11,396 noncommunity ground-water supplies (systems serving at least 25 people at least 60 days per year) reported by Strous (1986, p. 5) showed that nitrate (as nitrogen) concentrations exceeded the drinking-water standard of 10 mg/L in 2.6 percent of the wells. A considerably larger incidence of nitrate (as nitrogen) contamination is seen in data for private rural water supplies compiled by Delfino (1977). That study showed nitrate (as nitrogen) concentrations exceeding 10 mg/L in 9.2 percent of the 5,950 wells sampled statewide and in more than 20 percent of the wells sampled in some counties.

Figure 3*B* shows a general summary, by county, of the number of wells where contaminants have been detected at concentrations exceeding State ground-water-quality standards. Contaminants considered include only nitrate, VOC, and pesticides. Nitrate contamination data are from community and noncommunity public water supplies only.

The DNR began a VOC sampling program in July 1983. From July 1983 through June 1985, 409 community ground-water systems were tested, and 47 had at least one detectable VOC. The most commonly detected VOC were trichloroethylene (TCE) and tetrachloroethylene (PCE). The DNR is also testing private water-supply wells in "at risk" areas at a rate of about 600 wells per year. Of the 620 wells tested between July 1983 and June 1984, 92 had detectable concentrations of at least one VOC (Koth, 1985, p. 20–23).

Water in the Silurian dolomite aquifer has been contaminated by bacteria where the fractured dolomite of the aquifer is near the land surface. Affected areas include Door County and an area in northeastern Waukesha County (Koth, 1985, p. 8). Contamination potential is large in any area where fractured dolomite is the uppermost bedrock and overlying unconsolidated deposits are thin.

Waste Disposal

Ground-water contamination caused by land disposal of hazardous wastes has been detected at a number of sites. Undetected contamination may have also occurred at other hazardous-waste disposal sites.

Hazardous wastes that pose a threat to ground water have been disposed at 12 RCRA sites in Wisconsin (fig. 3*A*). Ground-water contamination has been detected at 7 of these 12 RCRA sites (Richard O'Hara, Wisconsin Department of Natural Resources, written commun., 1986). Hazardous wastes have been treated or stored at about 58 other sites that are subject to RCRA regulations (these sites are not included in figure 3*A*).

An additional 26 Wisconsin sites (fig. 3*A*) are included on the current National Priorities List (NPL) (U.S. Environmental Protection Agency, 1986c). These sites are eligible for Superfund-assisted remedial action provided for under the CERCLA program. Ground-water contamination has been detected at 21 of these sites (Richard O'Hara, Wisconsin Department of Natural Resources, written commun., 1986).

As of September 1985, 27 hazardous-waste sites at 3 facilities in Wisconsin had been identified by the DOD as part of their Installation Restoration Program (IRP) as having potential for contamination (U.S. Department of Defense, 1986). The IRP, established in 1976, parallels the U.S. Environmental Protection Agency Superfund program under CERCLA of 1980. The EPA presently ranks these sites under a hazard ranking system and may include them in the NPL. Of the 27 sites in the program, 14 sites contained contaminants but did not present a hazard to the environment. One site at one facility (fig. 3*A*) was 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.

Wisconsin's Environmental Repair Fund (ERF) is used to pay for cleanup of hazardous substances that threaten ground-water resources. As of August 1986, ERF-funded remedial actions have been completed at 13 sites and are in progress at 9 additional sites (James Bakken, Wisconsin Department of Natural Resources, oral commun., 1986).

Landfills are potential sources of ground-water contamination. The DNR regulations requiring licensing of landfills and ground-water-quality monitoring in and around them took effect in 1976. Collection of background water-quality information and continued ground-water quality monitoring are now required as a condition of licensing at all new landfills. A "lookback" provision in the regulations allows the DNR to require monitoring at sites that were operated before these monitoring requirements. As of August 1986, there were about 1,050 active landfills; monitoring was required at 265 landfill sites, including both active and inactive sites (Jack Connelly, Wisconsin Department of Natural Resources, oral commun., 1986). Monitored sites presently receive about 95 percent of the waste disposed in landfills in Wisconsin (Richard Schuff, Wisconsin Department of Natural Resources, written commun., 1986).

Locations of the 1,050 active landfill sites and 562 inactive landfill sites are shown in figure 3*C*. The sites are predominantly municipal landfills, or private landfills that contract with municipalities, but some sites also receive nonmunicipal wastes. Inactive sites shown in figure 3*C* include only those that once had an operating license and represent only a small part of known inactive or abandoned waste-disposal sites. A recent inventory by the DNR (Bakken and Giesfeldt, 1985) identified 2,717 abandoned waste sites; these sites are mostly landfills but also include some industrial wastewater sites and sites of spills. A screening of 2,682 of these sites has resulted in the designation of 303 high-priority sites for followup investigation based on their known or potential threat to ground water. Most of the inactive sites shown in figure 3*C* are included in this inventory.

Land disposal of municipal and industrial wastewater has contributed to ground-water contamination. Most land-disposal systems are surface impoundments (seepage lagoons), but some ridge and furrow and spray systems also are in operation. As of October 1979, the DNR was aware of 1,802 surface impoundments at 1,071 facilities that were used for storage or disposal of liquid or semiliquid waste; about 95 percent of the sites were in active use. Principal waste types at these sites were agricultural (36 percent), industrial (35 percent), and municipal (28 percent) (Kammerer, 1984, p. 50). Ground-water-quality monitoring has been required by the DNR since 1976 at sites with large discharge volumes, but these sites are only a small part of the total known sites. As of August 1986, monitoring was required at about 135 facilities (David Sauer and Charles Ledin, Wisconsin Department of Natural Resources, oral commun., 1986).

Agriculture

Agriculture affects ground-water quality most commonly through contamination by nitrate and pesticides. Nitrate contamination has been linked to leaching of fertilizers resulting from intensive sprinkler irrigation of potatoes and other vegetables in Wisconsin's central sand plain (Hindall, 1978). Contamination is also likely in other areas where light sandy soils, shallow depths to water, and intensive irrigated agriculture occur. Results of a survey by Schuknecht and others (1975) of 793 private wells in Columbia County implicate agricultural practices as causes of nitrate contamination. Overall, water from 38 percent of the wells sampled had nitrate (as nitrogen) concentrations exceeding the drinking-water standard of 10 mg/L. If only wells less than 50 feet from a barnyard or on farms that had feedlots or liquid manure storage facilities were considered, this figure was 50 to 63 percent.

Pesticides have been detected in ground water in two sampling programs conducted by the DNR. Aldicarb, used primarily for pest control on potato plants, has been detected in the central sand plain and, to a lesser extent, in other potato-growing areas. The principal area where aldicarb has been detected in ground water is shown as human-induced contamination in figure 3*B*. Aldicarb contamination is a problem at specific sites, and delineation of this area does not imply uniform or widespread contamination. Samples were collected from 1,008 wells in susceptible areas in 21 counties during 1981–85; aldicarb was detected in water from 227 of these wells (Koth, 1985, p. 23). A more general sampling program is being conducted in areas susceptible to contamination Statewide to test for a broader range of pesticides. Pesticides included in the analyses were selected to represent local use. Samples from 57 of 524 private wells sampled between July 1983 and June 1985 had detectable concentrations of at least one pesticide (Koth, 1985, p. 23). A summary of the results of this sampling program through the end of 1985 by Schreiber (1986) indicates that the most commonly detected organic pesticides were the herbicides atrazine, alachlor, metolachlor, and cyanazine; these compounds were each detected in samples from more than 10 wells. Twelve other pesticides were each detected in less than 10 samples.

Underground Storage Tanks

Leakage from underground storage tanks has been implicated in a relatively large number of instances of local ground-water contamination. This condition is especially noteworthy considering that no regulatory water-quality monitoring is required to detect problems of this sort. Regulation of underground tanks is now being given high priority in the State. Gathering data to evaluate the extent of ground-water contamination from buried storage tanks is a high priority of problem-assessment monitoring conducted by the DNR. The Wisconsin Department of Industry, Labor, and Human Relations (DILHR) is in the process of conducting an inventory of existing tanks that are either in use or have been improperly abandoned. The information obtained will be used to develop an enforcement program to decrease the potential for ground-water contamination from this source.

POTENTIAL FOR WATER-QUALITY CHANGES

The concern for protection of Wisconsin's ground-water quality is reflected in the activities of State, regional, county, and local agencies. Water-quality monitoring has been greatly increased, waste disposal is more closely regulated, and the public concern is intensified. Legislation has enabled more monitoring and regulation. However, in spite of the resulting improvement in the control of pollutants contaminating our ground water, much work remains to be done.

In evaluating the potential for changes in water quality, it is important to consider changes that have already occurred but have not been documented. Instances of contamination from land disposal of solid and liquid wastes have been documented, and much of the documentation is from monitoring well data. Because monitoring wells are presently installed at only a small number of these disposal sites, contamination that may have occurred at unmonitored sites remains undetected. Increased monitoring and regulatory efforts will continue to locate local contamination from leaking underground storage tanks.

Protecting recharge areas from contamination is important. Contaminants introduced in the recharge area have the potential for irreversible contamination of large areas of the aquifer. For the sand and gravel aquifer and uppermost bedrock aquifers, recharge (and the potential for contamination) occurs over their entire areal extent. For confined aquifers, such as the sandstone aquifer in eastern Wisconsin, the predominant recharge area can be a considerable distance from the point of ground-water withdrawal.

Changes in land use create the potential for water-quality changes. Acreage of irrigated agricultural crops in areas such as the central sand plain is expected to increase, thereby increasing the potential for ground-water contamination by fertilizers and pesticides. Conversion of rural land to suburban and urban uses poses a number of threats to ground water, including discharges from septic systems and increased use of road salt.

GROUND-WATER-QUALITY MANAGEMENT

Ground-water management practices in Wisconsin changed substantially in 1983 with the passage of comprehensive ground-water legislation contained in Wisconsin Act 410. Chapter 160 of the Wisconsin Statutes, created as part of this legislation, defines the responsibilities of State agencies with respect to ground water and provides for establishment of ground-water-quality standards, coordination of nonregulatory ground-water activities, compensation to owners of contaminated water-supply wells, and certification of water-quality laboratories. Existing regulations covering well-construction codes and registration of well drillers remain in place.

The DNR has lead responsibility for ground-water management. Within the DNR, the Bureau of Water Resources Management has responsibility for coordination of DNR programs, planning, data management, and development of ground-water-quality standards. Other programs in the DNR that have responsibilities related to ground water are in the Bureaus of Water Supply, Wastewater Management, and Solid and Hazardous Waste Management, and the Office of Technical Services.

Other State agencies also have responsibilities related to ground-water management. The Department of Health and Social Services (DHSS) advises the DNR on toxicology and has a major role in developing the ground-water-quality standards. The DILHR is responsible for regulation of private sewage-disposal systems (septic systems) and buried petroleum storage tanks. The Department of Agriculture, Trade, and Consumer Protection (DATCP) regulates fertilizer storage, animal-waste management, and pesticides; responsibilities for pesticides include enforcement of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and regulation of the manufacture, sale, and use of pesticides in Wisconsin. The Department of Transportation (DOT) regulates the bulk storage of road salt. The Wisconsin Geological and Natural History Survey (WG&NHS) is responsible for the inventory and mapping of geologic and hydrologic resources of the State; programs include basic-data collection and research. The University of Wisconsin has responsibilities for education, basic and applied research, and technical assistance in ground-water management. Both the WG&NHS and the DNR have cooperative ground-water resources programs with the U.S. Geological Survey.

The 1983 ground-water legislation requires that DNR adopt ground-water-quality standards. Chapter NR 140 of the Wisconsin Administrative Code (Wisconsin Department of Natural Resources, 1985) was enacted to meet this requirement. Chapter NR 140 sets two levels of standards—an enforcement standard set at the maximum allowable concentration, and a preventive action limit (PAL) set at 10 to 20 percent, depending on the constituent, of the enforcement standard. The PALS serve as an early-warning system to trigger an evaluation of the need for possible remedial action. As of June 1986, public health standards have been set for 39 constituents, and esthetic or public welfare standards have been set for 10 constituents and properties. Enforcement standards for constituents and properties covered by State drinking-water standards are set at the maximum allowable level specified in the drinking-water standards. All State agencies that regulate potential sources of ground-water contamination are required to use these standards. The DNR also is required to develop a monitoring program to ensure compliance with the standards.

Chapter 160 of the Wisconsin Statutes establishes the duties of the Wisconsin Groundwater Coordinating Council. Members of the Council include the State Geologist and representatives from the Governor's office, the University of Wisconsin, and each State agency responsible for ground-water management. The Council is required to advise and assist State agencies in coordination of nonregulatory programs and exchange of information related to ground water. The Council must report annually to the Legislature on its progress.

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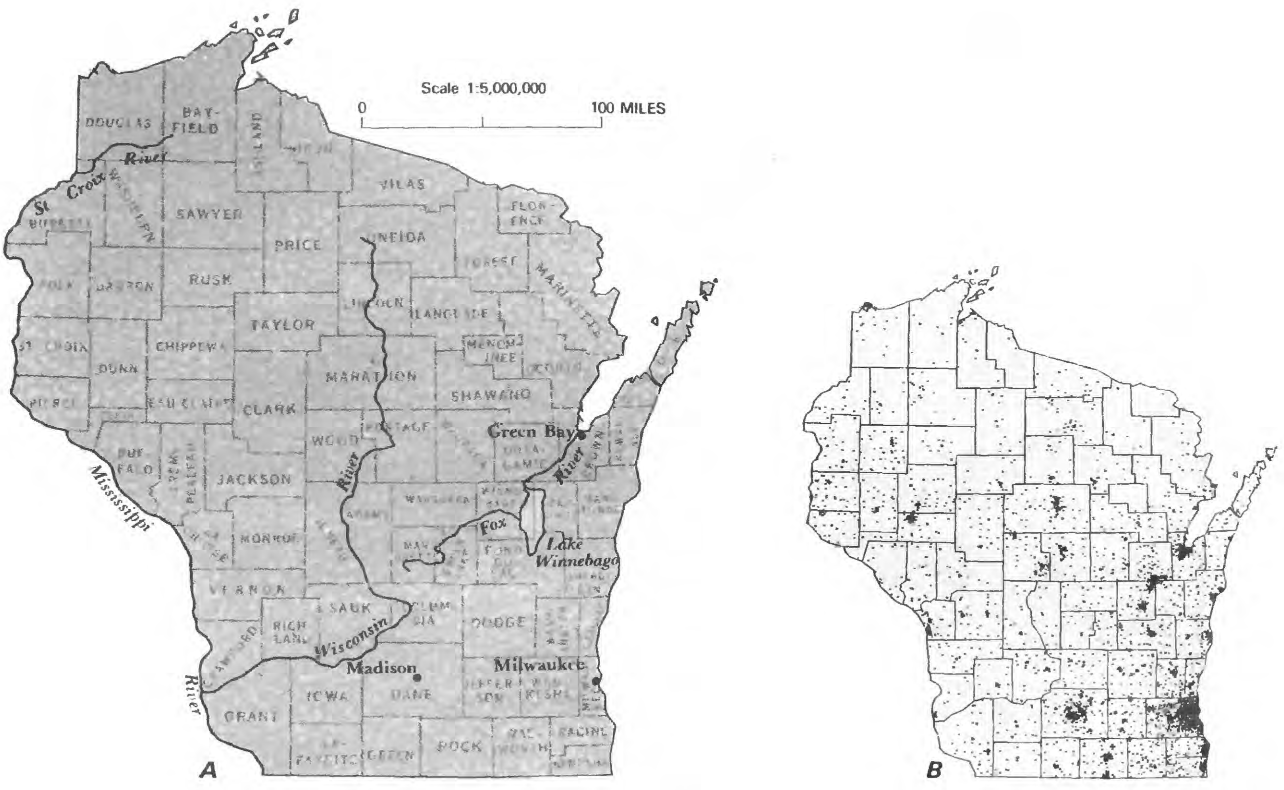

Figure 1. Selected geographic features and 1985 population distribution in Wisconsin. *A*, Counties, selected cities, and major drainages. *B*, Population distribution, 1985; each dot on the map represents 1,000 people. (Source: *B*, Data from U.S. Bureau of the Census 1980 decennial census files, adjusted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

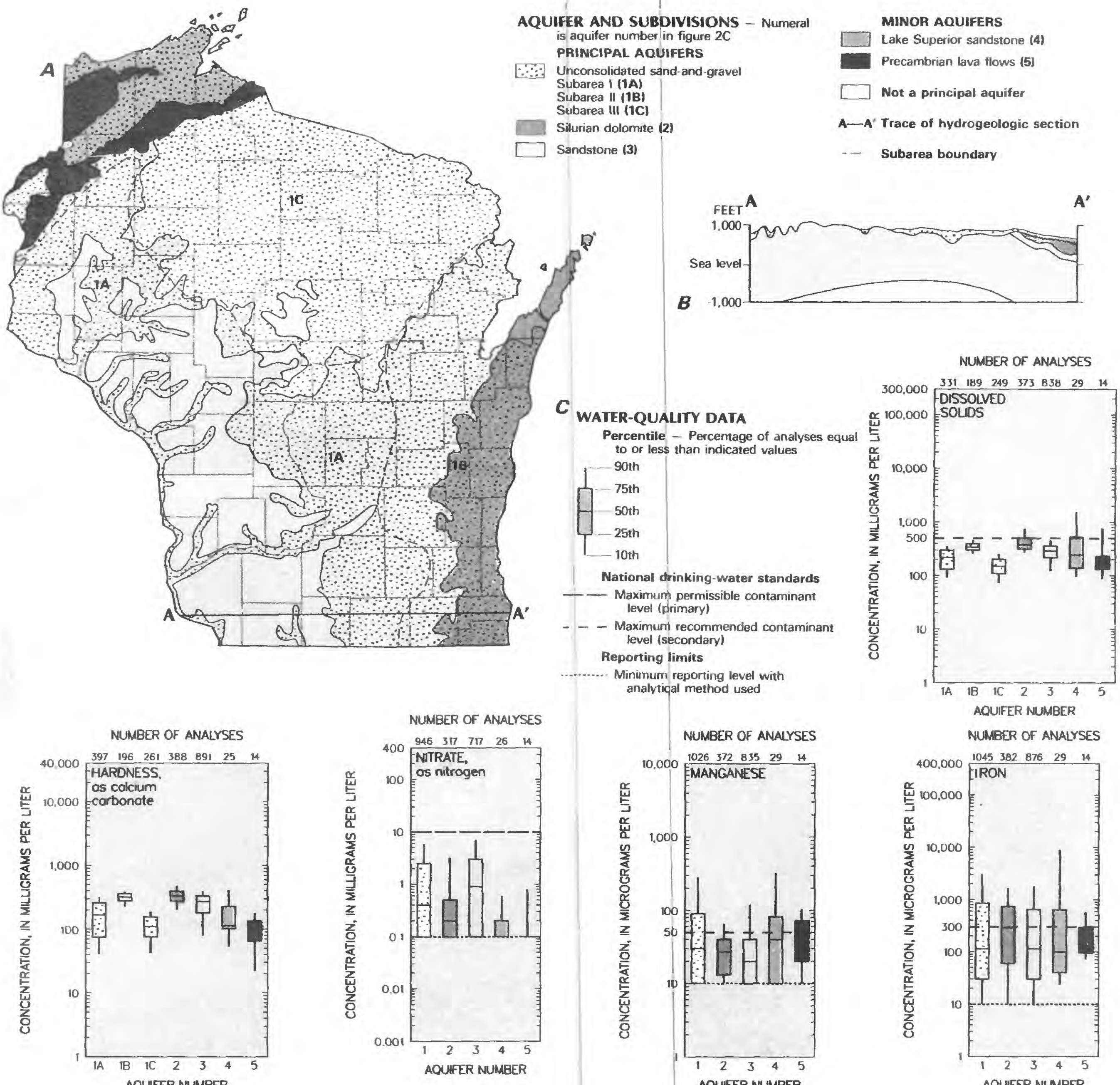

Figure 2. **Principal aquifers and related water-quality data in Wisconsin.** *A*, Principal aquifers; *B*, Generalized hydrogeologic section. *C*, Selected water-quality constituents and properties, as of 1983. (Sources: *A*, *B*, Modified from U.S. Geological Survey, 1985; Kammerer, 1984. *C*, Analyses compiled from U.S. Geological Survey files; national drinking-water standards from U.S. Environmental Protection Agency, 1986 a,b.)

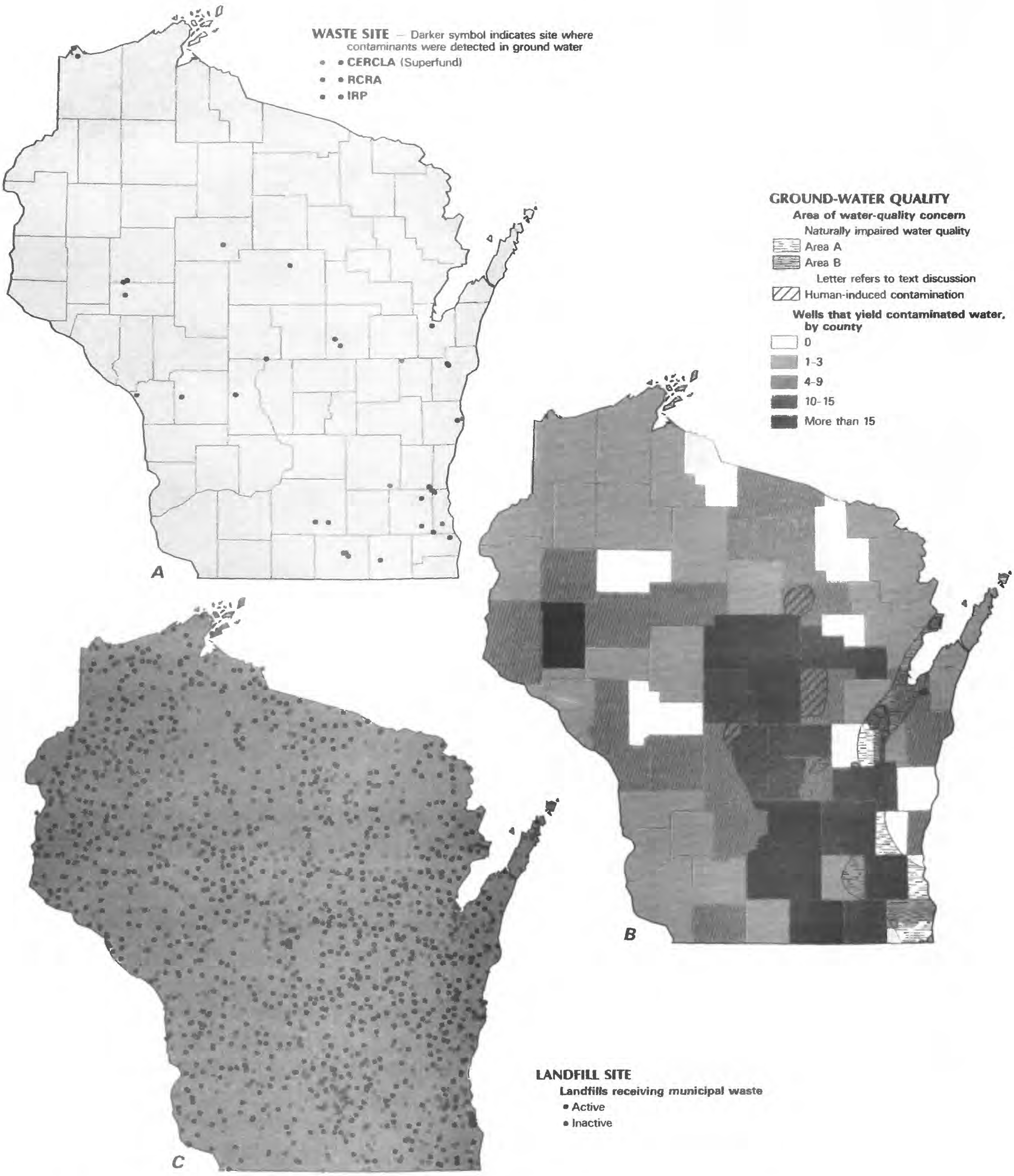

Figure 3. Selected waste sites and ground-water-quality information in Wisconsin. *A*, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites; Resource Conservation and Recovery Act (RCRA) sites; and Department of Defense Installation Restoration Program (IRP) sites, as of October 1985. *B*, Areas of naturally impaired water quality, areas of human-induced contamination, and distribution of wells that yield contaminated water, as of October 1985. *C*, Landfills receiving municipal waste, as of October 1985. (Sources: *A*, Richard O'Hare, Wisconsin Department of Natural Resources, written commun., 1986; U.S. Department of Defense, 1986. *B*, Modified from Hahn, 1984; Kammerer, 1984; and Koth, 1985. *C*, Jack Connelly, Wisconsin Department of Natural Resources, written commun., 1986.)