

# AN OVERVIEW OF GROUND-WATER QUALITY DATA IN WISCONSIN



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PHIL A. KAMMERER, JR.

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U.S. GEOLOGICAL SURVEY  
Water Resources Investigations Report 83-4239



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**UNITED STATES DEPARTMENT OF THE INTERIOR**

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**GEOLOGICAL SURVEY**

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## CONTENTS

	Page
Abstract . . . . .	V
1.0 Introduction . . . . .	1
2.0 Approach to evaluating ground-water-quality information . . . . .	2
2.1 Sources of ground-water data . . . . .	2
2.2 Indicators of ground-water quality . . . . .	4
2.3 Data summary and evaluation methods . . . . .	6
3.0 Wisconsin's ground-water system . . . . .	8
3.1 Aquifers . . . . .	8
3.2 Ground-water provinces . . . . .	10
4.0 Ground-water quality . . . . .	12
4.1 Ground-water province I . . . . .	12
4.1.1 Chemical characteristics and hydrogeology . . . . .	12
4.1.2 Dissolved solids, chloride, and sulfate . . . . .	14
4.1.3 Iron and manganese . . . . .	16
4.1.4 Nitrate nitrogen . . . . .	18
4.2 Ground-water province II . . . . .	20
4.2.1 Chemical characteristics and hydrogeology . . . . .	20
4.2.2 Dissolved solids, chloride, and sulfate . . . . .	22
4.2.3 Iron and manganese . . . . .	24
4.2.4 Nitrate nitrogen . . . . .	26
4.3 Ground-water province III . . . . .	28
4.3.1 Chemical characteristics and hydrogeology . . . . .	28
4.3.2 Dissolved solids, chloride, and sulfate . . . . .	30
4.3.3 Iron and manganese . . . . .	32
4.3.4 Nitrate nitrogen . . . . .	34
4.4 Ground-water province IV . . . . .	36
4.4.1 Chemical characteristics and hydrogeology . . . . .	36
4.4.2 Dissolved solids, chloride, and sulfate . . . . .	38
4.4.3 Iron and manganese . . . . .	40
4.4.4 Nitrate nitrogen . . . . .	42
4.5 Trace constituents . . . . .	44

4.6	Hydrogen sulfide . . . . .	46
4.7	Ground-water contamination . . . . .	47
4.7.1	Instances of contamination investigated by the Wisconsin Department of Natural Resources . . . . .	48
4.7.2	Potential for contamination from surface impoundments . . . . .	50
4.7.3	Potential for contamination from landfills . . . . .	52
4.7.4	Potential for contamination from other sources . . . . .	54
4.8	Usefulness of available data for contamination evaluation . . . . .	56
4.9	Data needs . . . . .	57
5.0	Literature cited . . . . .	58

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## Abstract

This report contains a summary of ground-water-quality data for Wisconsin and an evaluation of the adequacy of these data for assessing the impact of land disposal of wastes on ground-water quality. Chemical analyses used in data summaries were limited to those stored in the USGS computer system (WATSTORE). Information on documented instances of ground-water contamination and sources of potential contamination from land disposal of wastes was provided by the Wisconsin Department of Natural Resources. Available data provide an overview of ground water quality but may be insufficient for assessment of ground-water contamination from

land disposal of wastes. Many sources of potential ground-water contamination (landfills, surface waste-storage impoundments, and buried tanks) are known. Some of these are probably causing local ground-water contamination that is not apparent from available regional data. Information needs for assessment of ground-water contamination from land disposal of wastes include improved understanding of ground-water hydrology and the chemical behavior of specific contaminants in the environment.

## 1.0 INTRODUCTION

# **The Adequacy of Available Ground-Water-Quality Data for Assessment of the Impact of Land Disposal of Wastes is Evaluated**

*Land disposal is an increasingly attractive option for disposal of wastes, but land disposal may cause ground-water contamination. There is, however, no clear understanding of the adequacy of available data to assess potential ground-water contamination. This report is intended to summarize information that might be useful in evaluating the impact of land disposal of wastes on ground-water quality.*

The U.S. Geological Survey (USGS) proposes to implement a multidisciplinary program to provide the nation with earth science information critical to improving waste disposal practices. The first phase of the program calls for preparation of evaluations, by state, of available ground-water quality and related hydrogeologic information.

The data summarized in this report are not comprehensive; time and manpower constraints limited the data that could be included, but sources and types of pertinent data that were not included are identified. Summaries of water-quality data were limited to data stored in machine-readable form that met quality-control criteria for chemical integrity of the analyses. Most water-quality data meeting these criteria are stored in the USGS data storage and retrieval system (WATSTORE). These data include USGS analyses and analyses compiled from other

sources during the course of investigations of ground-water resources of river basins, counties and other special study areas in Wisconsin. Sections of this report on potential and actual ground-water contamination and hydrogen sulfide in ground water were prepared from material compiled by T. A. Calabresa of the Wisconsin Department of Natural Resources (DNR) as part of a special study.

There is no clear understanding as to what data are necessary to evaluate potential ground-water contamination from land disposal of wastes or as to what criteria are pertinent for evaluating the data that are available. For this reason, the summaries and evaluations presented here are as objective and well defined as possible so that individual users can adapt them to meet their needs and, if necessary, re-evaluate the data in terms of their own criteria.

## **2.0 APPROACH TO EVALUATING GROUND-WATER-QUALITY INFORMATION**

### *2.1 Sources of Ground-Water Data*

## **Ground-Water Data Files are Maintained by Several State and Federal Agencies**

*Ground-water data range in accessibility, areal coverage, and quality. Obtaining, evaluating, and using supporting ground-water data are important parts of a thorough ground-water-quality investigation.*

Many state and federal agencies have responsibilities in ground-water quality management and protection and for collection of basic ground-water data. These data include water-quality information as well as the supporting hydrologic and geologic data needed to interpret and evaluate ground-water quality. The table on the facing page summarizes sources and types of available ground-water data for Wisconsin.

The Water Resources Division of the USGS investigates the occurrence, use, quality, quantity, and movement of ground water. Activities include collection of basic ground-water data (chemical analyses of water, water-level fluctuations, hydrologic characteristics of aquifers and geophysical logs), and interpretive water resources investigations. Many of the investigations are made in cooperation with local, state, and other federal agencies. Much USGS ground-water data are stored in computerized data bases. Chemical analyses of ground water from more than 3,000 wells in Wisconsin are stored in the WATSTORE system, and well data (including well construction, hydrologic, and geologic information) for more than 14,000 wells are stored in the Ground Water Site Inventory (GWSI) system.

The Wisconsin Geological and Natural History Survey (WGS) is the principal source of geologic information for Wisconsin. WGS prepares geologic maps and systematically compiles subsurface geologic data by examining drill cuttings, most of which are submitted by water well drillers, and by preparing geologic logs based on the cuttings. The WGS, through its Water Resources Program, cooperates with the USGS in collection, analysis, and cataloging of ground-water data.

The Wisconsin Department of Natural Resources (DNR) has broad responsibilities in ground-water management and protection, including conduct of federally mandated programs required by the U.S. Environmental Protection Agency (EPA). Most DNR ground-water data collection is carried out by Bureaus in the Division of Environmental Standards, primarily by the Bureaus of

Water Supply, Solid Waste Management, and Water Resources Management. Data collected include chemical analyses of water samples from public and private water supplies and monitoring wells at solid waste disposal sites, well construction information, and data obtained in the course of investigations of ground-water contamination and quality problems. Bureaus in the Division of Resource Management may also collect ground-water-quality data as part of resource appraisal or research projects.

Water-quality data collected during the National Uranium Resource Evaluation (NURE) program conducted for the U.S. Department of Energy are available for approximately the northern two-thirds of Wisconsin. These data have been summarized in published reports (Arendt and others, 1978a, 1978b, 1978c, 1978d, 1979, 1980, 1981) that are available at WGS and USGS offices in Madison.

Accessibility and documentation present problems when assembling or inventorying data from multiple sources. Much of Wisconsin's ground-water data are stored in conventional paper files. Documentation as to the type and amount of data available, data reliability, and data collection, analysis and quality control procedures generally are not available. The lack of documentation and the large commitment of time required to assemble, analyze, and evaluate data from conventional files reduces the usefulness of valuable historical data by effectively reducing its accessibility.

Considerable ground-water data are published. Bibliographies of publications relating to Wisconsin's ground water for 1851-1977 were compiled by Zaporozec (1974, 1978a, 1978b). A selected bibliography of reports summarizing or describing areal ground-water quality in Wisconsin is given in Kammerer (1981). Primary data gathering agencies (USGS, WGS, and DNR) have bibliographies of their publications available; most of their recent publications are available for sale or distribution.

TYPES AND SOURCES OF GROUND-WATER DATA FOR WISCONSIN

TYPE OF DATA	SOURCES OF DATA
CHEMICAL ANALYSES OF GROUND WATER	U. S. GEOLOGICAL SURVEY DEPARTMENT OF NATURAL RESOURCES, DIVISIONS OF ENVIRONMENTAL STANDARDS AND RESOURCE MANAGEMENT
GROUND-WATER CONTAMINATION AND QUALITY PROBLEMS	DEPARTMENT OF NATURAL RESOURCES, DIVISION OF ENVIRONMENTAL STANDARDS
HYDROLOGIC DATA: 1. WATER LEVELS, HYDRAULIC PROPERTIES OF AQUIFERS, QUANTITY AND AVAILABILITY OF GROUND WATER 2. WATER USE AND PUMPAGE 3. GROUND WATER/SURFACE WATER RELATIONSHIPS	1. U. S. GEOLOGICAL SURVEY; WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY 2. DEPARTMENT OF NATURAL RESOURCES, DIVISION OF ENVIRONMENTAL STANDARDS; U. S. GEOLOGICAL SURVEY 3. U. S. GEOLOGICAL SURVEY
GEOLOGIC DATA: 1. GEOLOGIC MAPS, GEOLOGIC LOGS 2. WELL CONSTRUCTION REPORTS 3. WELL INVENTORIES, GEOPHYSICAL LOGS	1. WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY 2. DEPARTMENT OF NATURAL RESOURCES, DIVISION OF ENVIRONMENTAL STANDARDS 3. U. S. GEOLOGICAL SURVEY; WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
PUBLISHED DATA AND REPORTS	U. S. GEOLOGICAL SURVEY WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY DEPARTMENT OF NATURAL RESOURCES UNIVERSITY OF WISCONSIN-MADISON WATER RESOURCES CENTER

**2.0 APPROACH TO EVALUATING GROUND-WATER-QUALITY INFORMATION**  
 2.1 Sources of Ground-Water Data

**2.0 APPROACH TO EVALUATING GROUND-WATER-  
QUALITY INFORMATION--Continued**  
*2.2 Indicators of Ground-Water Quality*

**Water-Quality Measurements Differ in Their Usefulness  
as Indicators of Overall Water Quality**

*Many common water-quality measurements are useful for describing general chemical water types but are of less use as indicators of ground-water contamination. Background concentrations of constituents that may be useful as indicators of contamination must be accurately defined as a first step in determining their usefulness as indicators.*

Concentration data for alkalinity, calcium, magnesium, sodium, potassium, chloride, and sulfate are used in subsequent sections of this report to describe the chemical characteristics of water from principal aquifers. Except for chloride and sulfate, these constituents are not of sufficient value as indicators of ground-water contamination to warrant further summary or evaluation here. More extensive summaries of concentration data for calcium, magnesium, sodium, potassium, and alkalinity are given by Kammerer (1981).

Substances named in regulatory standards are of interest in assessing ground-water quality because concentrations exceeding maximum allowable levels limit the use of the water. Maximum allowable levels (referred to in regulatory standards as "maximum contaminant levels") from Wisconsin's primary and secondary drinking water standards (Wisconsin Department of Natural Resources, 1978) are given in the table on the facing page. Primary standards represent minimum standards for protection of public health, and secondary standards are established for aesthetic reasons that do not affect public health.

Constituents for which concentration data are summarized and evaluated here (dissolved solids, chloride, sulfate, iron, manganese, hydrogen sulfide and various trace constituents) were selected because of their generally recognized potential as indicators of poor quality water, their role in recognized ground-water-quality problems, and maximum recommended levels in drinking water standards. Iron and manganese concentrations in uncontaminated ground water in Wisconsin commonly exceed maximum recommended levels; because of this, the range of concentrations found in uncon-

taminated ground water must be defined before these constituents are useful as indicators of ground-water contamination.

Other constituents (hazardous organic substances, pathogenic bacteria, and other toxic or hazardous substances) may be of greater interest in terms of their potential as indicators of contamination from land disposal of wastes, but concentration data generally are not available. In most cases, these constituents are absent in uncontaminated ground water.

High nitrate-nitrogen concentrations in ground water generally are due to contamination from waste-disposal sites, septic systems, livestock wastes, and agricultural fertilizers. It is the only constituent listed in the primary drinking water standards for which available data indicate potential ground-water contamination.

Trace inorganic constituents for which maximum contaminant levels are given in drinking water standards (arsenic, barium, cadmium, chromium, lead, mercury, selenium, copper and zinc) are commonly used as indicators of ground-water contamination. The occurrence and chemical behavior of these substances in ground water is poorly understood and concentration data are limited.

Hydrogen sulfide in ground water may be associated with contamination, but it is also a naturally occurring problem in some areas. As with iron and manganese, it is necessary to determine the extent and magnitude of natural occurrences before the impact of contamination can be evaluated.

SUMMARY OF WISCONSIN'S DRINKING WATER STANDARDS\*

CONSTITUENT	MAXIMUM RECOMMENDED LEVEL [all concentrations in milligrams per liter (micrograms per liter in parentheses) unless otherwise indicated]	
	PRIMARY (HEALTH) STANDARD	SECONDARY (AESTHETIC) STANDARD
<b>INORGANIC CHEMICALS:</b>		
ARSENIC	0.05 (50)	
BARIUM	1 (1000)	
CADMIUM	0.01 (10)	
CHROMIUM	0.05 (50)	
FLUORIDE	2.2	—
LEAD	0.05 (50)	
MERCURY	0.002 (2)	
NITRATE (AS N)	10	—
SELENIUM	0.01 (10)	
SILVER	0.05 (50)	
CHLORIDE		250
COLOR		15 units
FOAMING AGENTS (MBAS)		0.5 —
HYDROGEN SULFIDE		not detectable
IRON		0.3 (300)
MANGANESE		0.05 (50)
ODOR		3 threshold number
SULFATE		250
TOTAL RESIDUE		500
ZINC		5 (5000)
<b>ORGANIC CHEMICALS:</b>		
<b>CHLORINATED HYDROCARBONS</b>		
ENDRIN	0.0002 (0.2)	
LINDANE	0.004 (4)	
METHOXYCHLOR	0.1 (100)	
TOXAPHENE	0.005 (5)	
<b>CHLORO PHENOXY HERBICIDES</b>		
2,4-D	0.1 (100)	
2,4,5-TP (SILVEX)	0.01 (10)	

\*From Wisconsin Department of Natural Resources, 1978

**2.0 APPROACH TO EVALUATING GROUND-WATER-  
QUALITY INFORMATION--Continued**  
*2.3 Data Summary and Evaluation Methods*

**Evaluation of Water-Quality Data Includes Consideration of its  
Accuracy and its Adequacy for Specific Purposes**

*Accuracy of water-quality data is determined by methodology and quality control procedures used in data collection and analysis. Adequacy of the data is measured in terms of its usefulness in evaluating the impact of land disposal of wastes on ground-water quality.*

Detailed evaluation of analytical methods and quality-control procedures employed in the collection and analysis of the data summarized in this report is beyond the scope of this investigation, but some generalizations are possible. Most of the data are from government laboratories where standard analytical methods were used and quality-control procedures followed. Data from WATSTORE that are used in sections 4.0-4.5 of this report were reviewed and subjected to quality-control checks before computer entry.

An evaluation of the adequacy of data for a specific purpose should meet the needs of users of the evaluation and the data. The evaluation should be as objective and quantitative as possible so that potential users can adapt or expand on it to meet their needs.

Graphical and statistical methods were used to summarize and evaluate water-quality data by hydrogeologic unit. The basis for selection of these units is discussed in section 3.0 of this report. The intent in defining these units is to provide a framework for dividing the data into groups where the water quality is determined by a uniform set of hydrogeologic conditions.

General chemical water types (relative concentrations of calcium, magnesium, sodium, potassium, alkalinity, chloride, and sulfate) are shown on trilinear diagrams to provide a general comparison of water from different units. Other data (concentrations of dissolved solids, chloride, sulfate, iron, manganese and nitrate nitrogen) are analyzed statistically to provide a more quantitative basis for data evaluation.

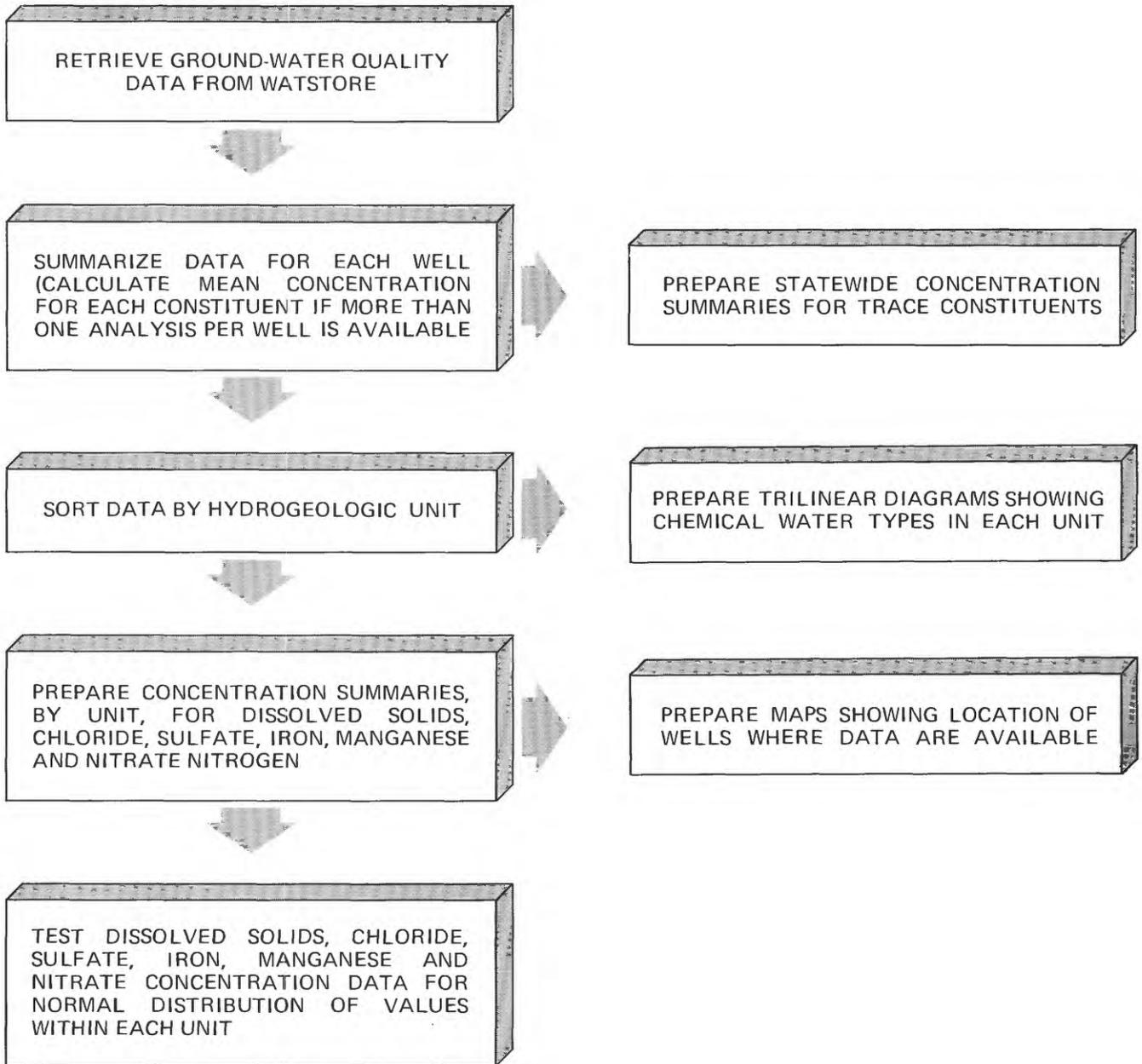
Dissolved-solids, chloride, sulfate, iron, manganese, and nitrate-nitrogen concentrations were tested for normal distribution of values within each unit; log transformation of the values generally was necessary for the data to approximate a normal distribution. Obtaining an approximately normal distribution of concentration values is inter-

preted as having successfully defined a hydrogeologic unit where factors influencing water quality are similar. In these cases, parametric statistics can be used to provide a description of the range, variance and central tendency of these "samples" of concentration values and their statistical relationship to the entire population of probable values in each unit. These analyses, together with location maps showing the distribution of wells, will aid data users in assessing the adequacy of the data for their particular purposes. Less comprehensive summaries were prepared for trace constituent concentrations because of the limited amount of data available.

Failure of concentration values to approximate a normal distribution is interpreted as a failure to define a homogenous hydrogeologic unit. This indicates that redefinition of the unit would be necessary to permit analysis of concentration variations.

Few data are available in WATSTORE for assessment of long-term trends in ground-water quality. Multiple analyses are available for water from some wells (primarily high-capacity industrial, irrigation, or public supply wells), but data for each well would have to be evaluated in detail to determine the significance of temporal water quality changes. It would be necessary to document changes in analytical methods, sampling techniques, and sampling schedules as well as shorter term or seasonal and areal variations in water quality. Evaluation of this detail was beyond the scope of this investigation.

Entire data bases are subject to systematic bias resulting from criteria used to select the data they contain. It is likely that the data from WATSTORE that is used in this investigation is biased toward analyses of uncontaminated ground water. Data bases maintained by regulatory and enforcement agencies are more likely to contain data reflecting ground-water-quality problems or instances of ground-water contamination.



### 3.0 WISCONSIN'S GROUND-WATER SYSTEM

#### 3.1 Aquifers

## **Chemical Concentration Data are Sorted by Aquifer as a First Step in Summarizing the Data by Hydrogeologic Unit**

*Definition of Wisconsin's three major aquifers (sand and gravel, Silurian dolomite, and sandstone) is based on geology and the amount of hydrogeologic data available for most wells in each aquifer. Hydrogeologic data are sufficient to subdivide the sandstone aquifer into component geologic units to prepare concentration summaries. Minor aquifers are the Maquoketa Shale, Precambrian sandstone and lava flows, and the Precambrian rocks comprising the basement complex.*

The geologic section on the facing page shows the stratigraphic relationship of Wisconsin's aquifers to each other and to other geologic units. Geologic nomenclature used in this report follows the usage of the Wisconsin Geological and Natural History Survey (Ostrom, 1967; Mudrey and others, 1982).

The sand-and-gravel aquifer consists of unconsolidated deposits of sand and gravel mostly within the glacial drift that covers approximately 70 percent of the State. It is present in every county in Wisconsin, although its occurrence in 12 counties in the Driftless Area of southwestern Wisconsin is limited. The sand-and-gravel aquifer is not a continuous rock unit, as are most bedrock aquifers, but occurs as broad surficial outwash deposits, narrow valley fills, basal sand and gravel deposits directly overlying bedrock, isolated lenses of sand and gravel within less permeable glacial deposits, and other water-lain deposits. In the Driftless Area, the sand-and-gravel aquifer only occurs as valley alluvium within the flood plains of larger rivers.

The Silurian dolomite aquifer underlies all or part of 15 counties along the eastern boundary of the State. The aquifer is mostly dolomite of Silurian age, but a small area of dolomite and shale of Devonian age, extending from Milwaukee to Sheboygan along Lake Michigan, is also included.

The Maquoketa Shale is a useable aquifer in some areas, but it was not included here due to lack of data for wells drawing water exclusively from it.

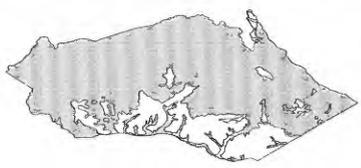
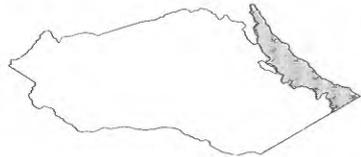
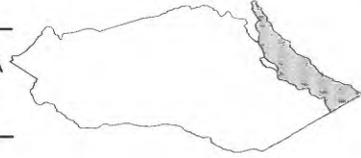
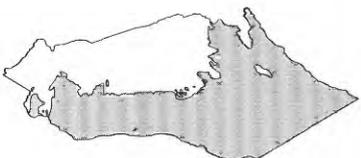
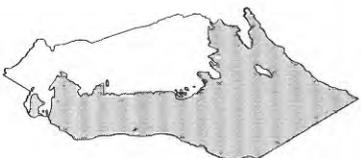
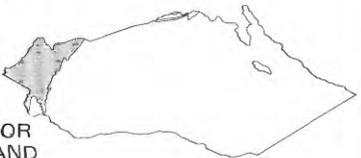
The sandstone aquifer is comprised of hydraulically connected sandstones and dolomites. In previous summaries and compilations of ground-water-quality data (Holt and Skinner, 1973; Kammerer, 1981), available hydrogeologic data were insufficient to determine which geologic units in the aquifer were

yielding water to wells. Because of this, no attempt was made to differentiate between these units with respect to water quality, and the data were summarized collectively. Recent improvements in USGS ground-water data bases allow differentiation between some units of the sandstone aquifer for the purpose of summarizing and evaluating ground-water-quality data.

The oldest and most extensive units in the sandstone aquifer are Cambrian sandstones which underlie 60 percent of the State. Differentiation between Cambrian sandstone units is difficult in most areas, but wells drawing water exclusively from the Trempealeau, Tunnel City, or Elk Mound Groups have been identified in some areas; wells open to a single unit are usually found in areas where one or more of the other units is missing. The approximate areal extent of Cambrian sandstone units is shown on the map of the sandstone aquifer on the facing page.

Ordovician units of the sandstone aquifer occur over progressively smaller areas along the western, southern, and eastern parts of the area shown on the map. The Prairie du Chien Group, a dolomite unit, overlies the Cambrian sandstones in the west, south, and east parts of the State. Overlying the Prairie du Chien Group, but smaller in areal extent, is the St. Peter Sandstone. Dolomite of the Sinipee Group overlies the St. Peter Sandstone in southern and eastern Wisconsin. It is an aquifer (the Galena-Platteville aquifer) only where it is the uppermost bedrock unit (not overlain by the Maquoketa Shale).

Most wells in Precambrian aquifers are in Precambrian sandstone and lava flows in the northwest and in igneous and metamorphic rocks of the basement complex in north-central and south-central Wisconsin.

GEOLOGIC AGE	GEOLOGIC UNIT	DOMINANT LITHOLOGY	AQUIFER
QUATERNARY	HOLOCENE ALLUVIAL AND PLEISTOCENE GLACIAL DEPOSITS	UNCONSOLIDATED SAND AND GRAVEL: VARIABLE AMOUNTS OF SILT, CLAY AND ORGANIC MATERIAL	SAND AND GRAVEL 
DEVONIAN	UNDIFFERENTIATED	DOLOMITE AND SHALE	SILURIAN DOLOMITE 
SILURIAN	UNDIFFERENTIATED	DOLOMITE	
ORDOVICIAN	MAQUOKETA SHALE	SHALE	MAQUOKETA SHALE 
	SINNIPEE GROUP	DOLOMITE	SANDSTONE 
	ST. PETER SANDSTONE	SANDSTONE	
	PRAIRIE DU CHIEN GROUP	DOLOMITE	
CAMBRIAN	TREMPEALEAU GROUP	SANDSTONE, SOME DOLOMITE	SANDSTONE 
	TUNNEL CITY GROUP	SANDSTONE	
	ELK MOUND GROUP	SANDSTONE	
PRECAMBRIAN	BAYFIELD GROUP, ORONTO GROUP, AND LAVA FLOWS	SANDSTONE AND SHALE; BASALT	LAKE SUPERIOR SANDSTONE AND LAVA FLOWS 
	IGNEOUS AND METAMORPHIC ROCKS	GRANITIC AND METAMORPHIC ROCKS	BASEMENT COMPLEX 

**3.0 WISCONSIN'S GROUND-WATER SYSTEM**  
3.1 Aquifers

### 3.0 WISCONSIN'S GROUND-WATER SYSTEM--Continued

#### 3.2 Ground-Water Provinces

## Division of the State into Ground-Water Provinces Completes the Definition of Hydrogeologic Units for Summarizing Water-Quality Data

*Several aquifers described in section 3.1 occur over large areas--because of this, a single aquifer may differ areally in lithology or be subject to different hydrologic influences. The State is divided into four ground-water provinces to reduce the effect of these differences on water-quality data summaries.*

The four ground-water provinces are delineated on the map of Wisconsin's bedrock geology on the facing page. The boundaries of the provinces were determined on the basis of areal extent of bedrock units, regional ground-water movement and divides, and physical geography.

#### Ground-Water Province I:

This province is comprised of deeply dissected Paleozoic rocks overlain by permeable glacial drift in the north and east. It is bounded on the north by the northern limit of Paleozoic rocks, on the northeast by an escarpment of the Prairie du Chien Group, and on the southeast by the eastern boundary of the recharge area for the deep artesian flow system in ground-water province II. Paleozoic rocks thicken toward the south and west, with younger rock units covering successively smaller areas toward these borders. Cambrian sandstones are the uppermost bedrock (or uppermost aquifer) in most of the province. Prairie du Chien Group dolomites occur in the south and along the western edge; Sinnipee Group dolomites are the youngest bedrock in the province except for small local areas of Maquoketa Shale and Silurian dolomite at the southern edge of the province. The Sinnipee Group occurs mostly in the south, where Paleozoic rocks are overlain by only thin soil or loess. The Paleozoic rocks in the south and west are deeply dissected by streams.

The province includes the Driftless Area where the only glacial deposits are valley alluvium within the flood plains of larger rivers. Very permeable outwash occurs in the central sand plain in the north-central part of the province.

#### Ground-Water Province II:

This province is comprised of thick Paleozoic rocks overlain by glacial drift. The west boundary of the province is, from north to south, the western limit of Paleozoic rocks, an escarpment of the Prairie du Chien Group, and the western edge of the deep artesian flow system in the

sandstone aquifer. Paleozoic rocks thicken to the east and south. Cambrian sandstones are the uppermost rocks only in the northwest; Ordovician rocks (Prairie du Chien Group, St. Peter Sandstone, and Sinnipee Group) overlie the Cambrian sandstones in the remainder of the province, covering successively smaller areas toward the east. A deep artesian flow system with long flow paths occurs in the sandstone aquifer where it is overlain by the Maquoketa Shale. The Silurian dolomite overlies the Maquoketa Shale along the east side of the province. A small area of Devonian age dolomite and shale on the east edge of the State is considered part of the Silurian dolomite aquifer.

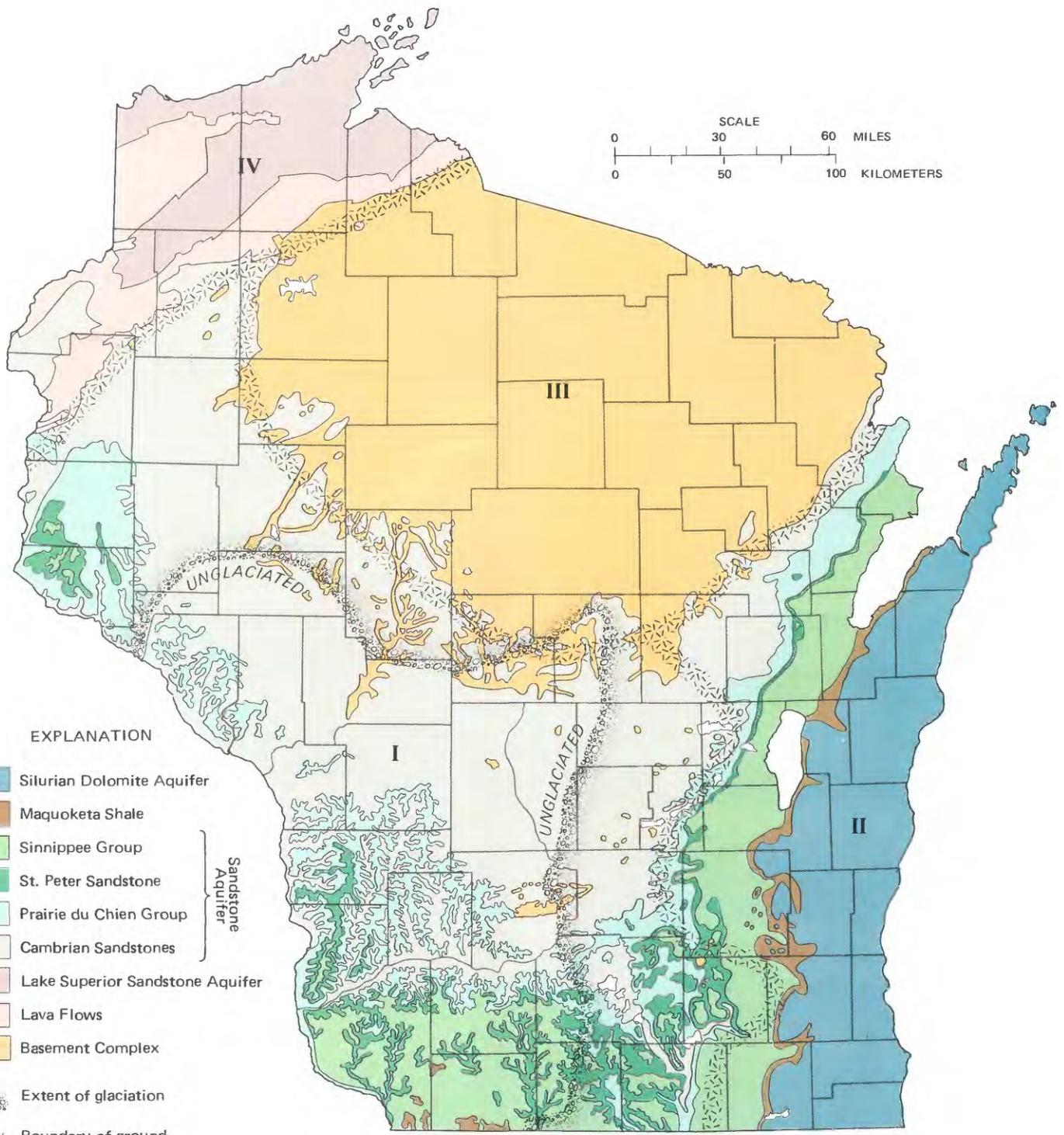
Moderately thin glacial drift overlies the province. Much of the drift is tight, clayey or silty till and lake deposits, but more permeable drift occurs in large areas along the west side of the province.

#### Ground-Water Province III:

This province is comprised of permeable glacial drift overlying relatively impermeable Precambrian crystalline rocks that form the basement complex underlying the entire state. Moderately thick, very permeable low carbonate drift overlies metamorphic and intrusive igneous rocks which include quartzite and granite. Water can be obtained from rocks of the basement complex in areas where they are weathered or fractured, but the principal aquifer is the glacial drift.

#### Ground-Water Province IV:

This province is comprised of glacial drift overlying Precambrian lava flows and sandstone. Stratigraphic relationships of these rocks are complex and poorly understood. In the lowlands along the northern border of the province, thick glacial deposits are capped by clay of low permeability; in the remainder of the province, the surficial glacial deposits are permeable.



**EXPLANATION**

- Silurian & Devonian**
  - Ordovician**
  - Cambrian**
  - Precambrian**
  - Sandstone Aquifer**
  - IV** Ground-water province number
- Silurian Dolomite Aquifer
  - Maquoketa Shale
  - Sinnerpee Group
  - St. Peter Sandstone
  - Prairie du Chien Group
  - Cambrian Sandstones
  - Lake Superior Sandstone Aquifer
  - Lava Flows
  - Basement Complex

- Extent of glaciation
- Boundary of ground-water province

*Geology modified from Wisconsin Geological and Natural History Survey, 1981.*

**3.0 WISCONSIN'S GROUND-WATER SYSTEM--Continued**  
 3.2 Ground-Water Provinces

## 4.0 GROUND-WATER QUALITY

### 4.1 Ground-Water Province I

#### 4.1.1 Chemical Characteristics and Hydrogeology

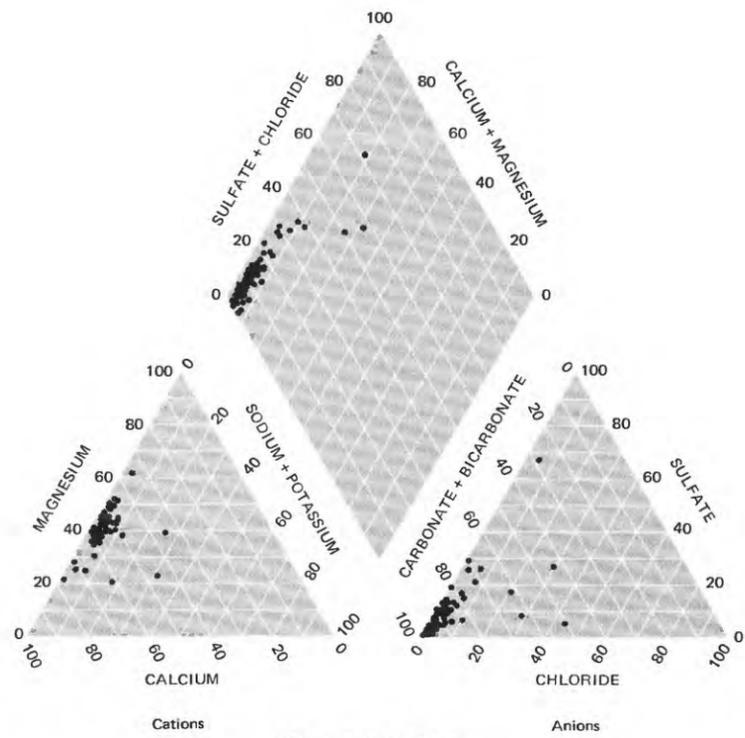
## Calcium Bicarbonate Type Water Predominates in All Units

*Water-quality data for specific geologic units generally are limited to the uppermost units yielding water to wells. Where the unit of interest is deeper, wells deep enough to tap it usually are also open to the upper units. Regional water movement in upper bedrock units is toward major rivers; in lower units, movement is parallel to the dip of Paleozoic rocks to the west, south, and east.*

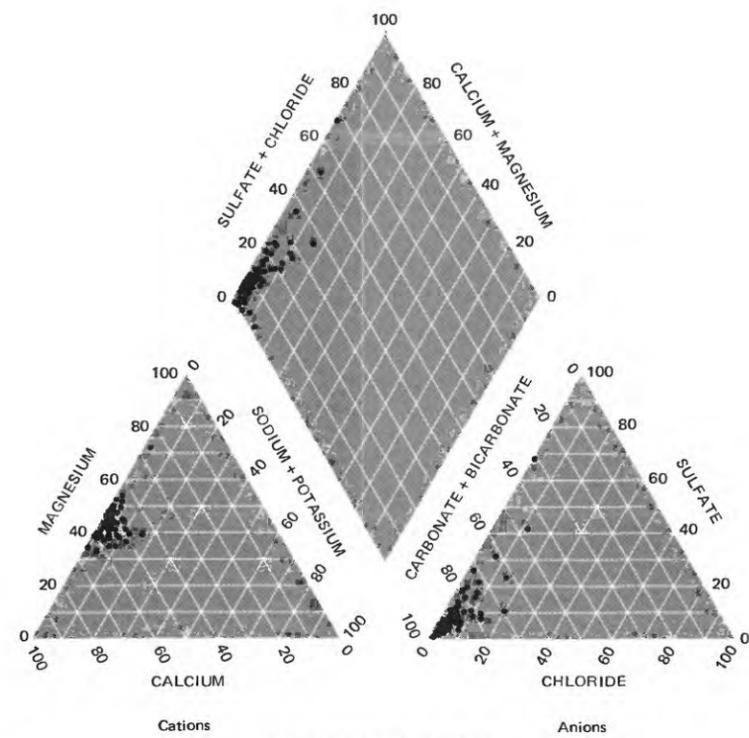
The trilinear diagram shows that the composition of water from wells in the sand-and-gravel aquifer is very uniform. Calcium and magnesium are major cations, with calcium usually predominant. The predominant anion is bicarbonate; the few moderately high chloride and sulfate concentrations shown on the diagram may indicate local ground-water contamination.

The chemical composition of water from wells in all units of the sandstone aquifer is very uniform. As in the sand-and-gravel aquifer, calcium is generally the predominant cation, but magnesium is also a major constituent. The predominant anion in all units is generally bicarbonate, but exceptions occur. Sulfate concentrations are moderately high in water

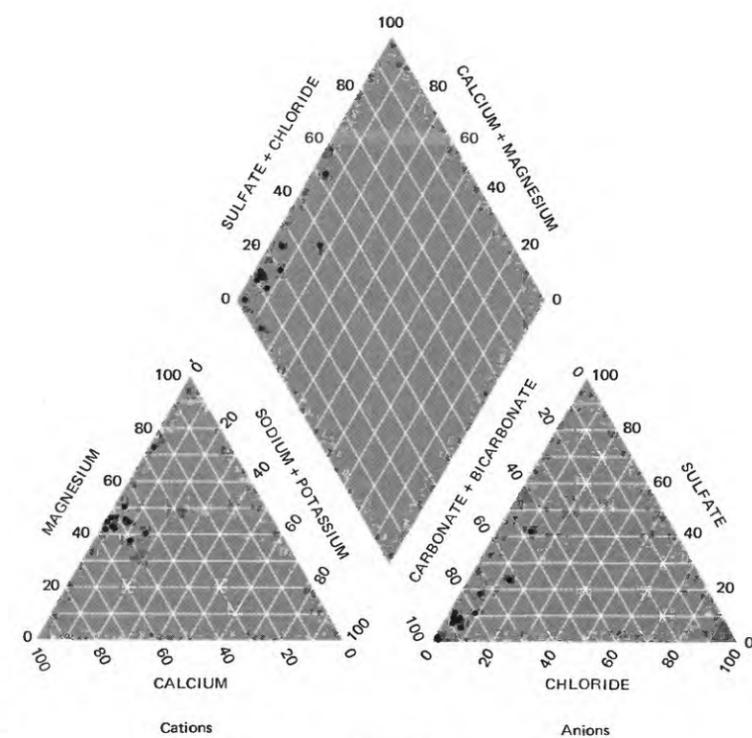
from some wells in Ordovician units. Water from some wells in Cambrian units has high sodium concentrations and correspondingly higher concentrations of sulfate or chloride or both. About 75 percent of the wells in Ordovician units draw water exclusively from the Sinnipee Group, the St. Peter Sandstone, or the Prairie du Chien Group. Data for these three units are also shown on separate diagrams to show the similarity in chemical composition of water from individual Ordovician units. About 60 percent of the wells in Cambrian units draw water exclusively from the Elk Mound Group; these data are also plotted separately for comparison with data for undifferentiated Cambrian units.



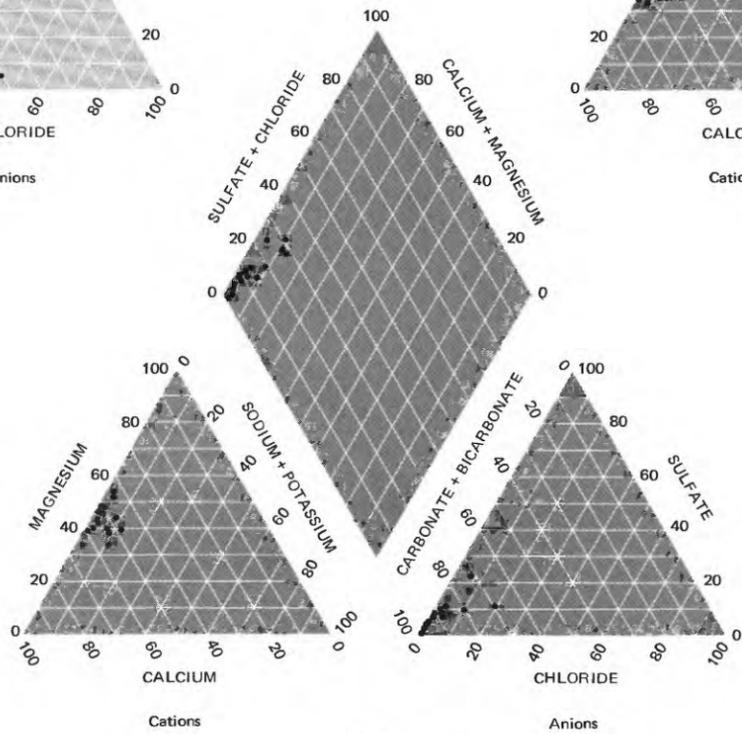
SAND-AND-GRAVEL  
AQUIFER



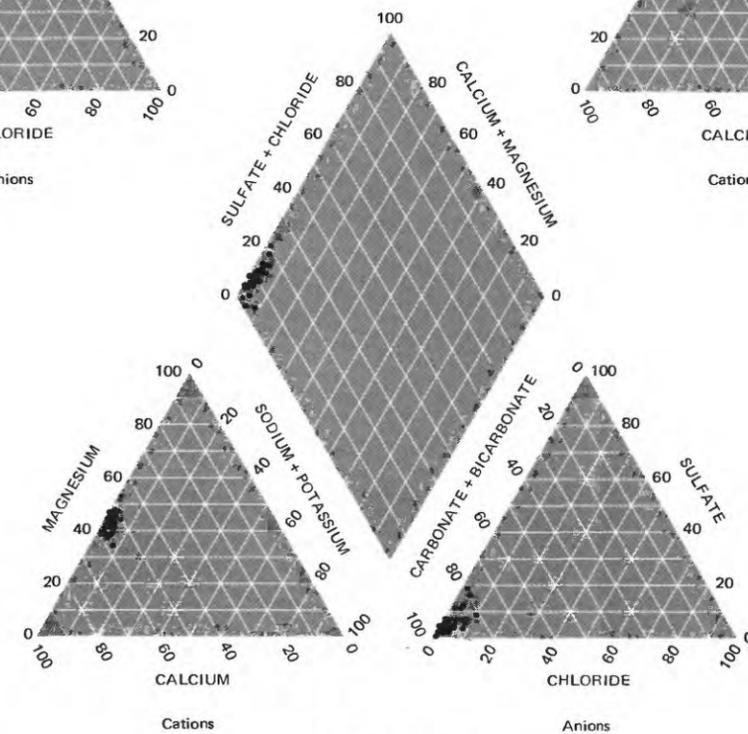
UNDIFFERENTIATED  
ORDOVICIAN UNITS



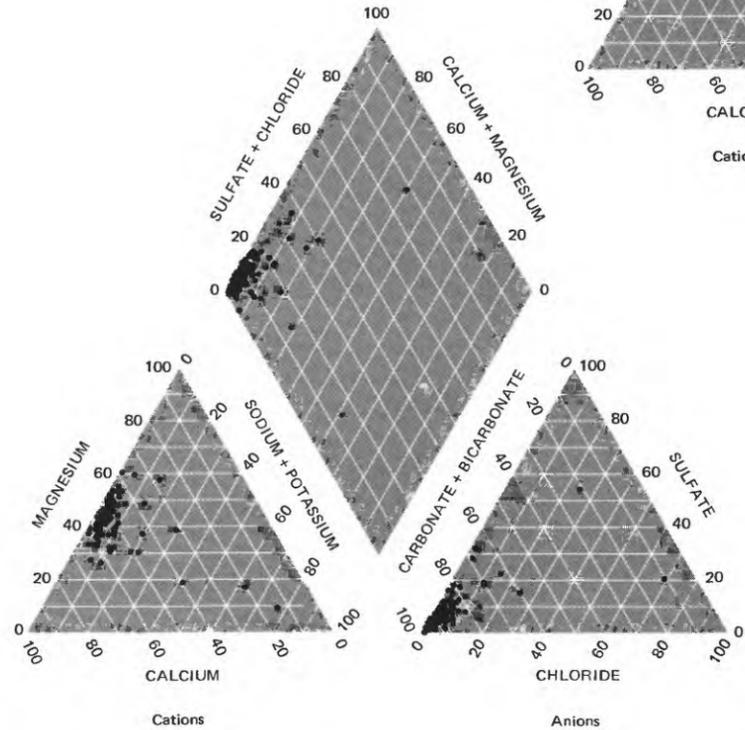
SINNIPEE  
GROUP



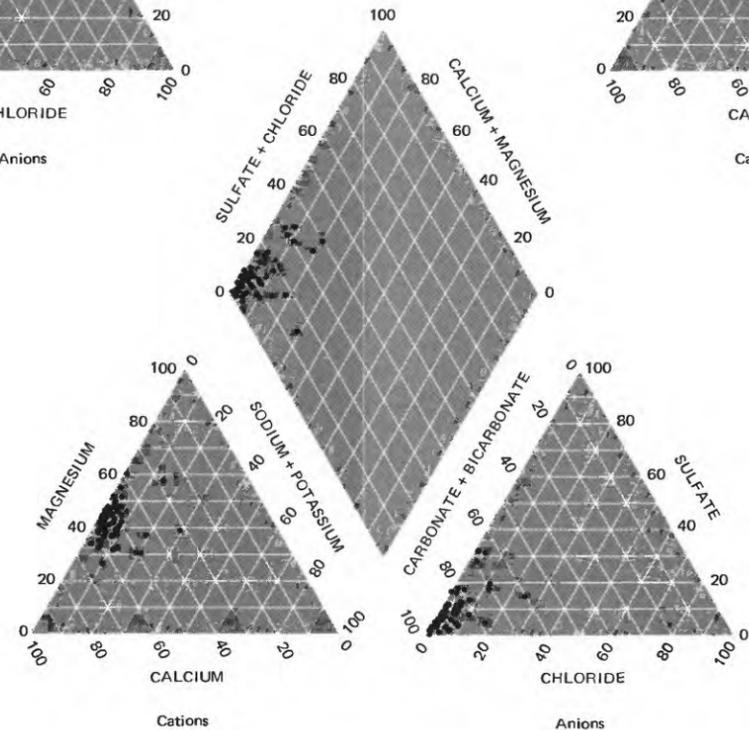
ST. PETER  
SANDSTONE



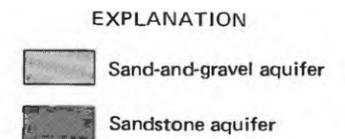
PRAIRIE DU CHIEN  
GROUP



UNDIFFERENTIATED  
CAMBRIAN UNITS



ELK MOUND  
GROUP



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.1 Ground-Water Province I--Continued

##### 4.1.2 Dissolved Solids, Chloride, and Sulfate

### **Dissolved Solids and Sulfate Concentrations are Objectionably High in Water from Relatively Few Wells**

*Dissolved solids concentrations are lowest in water from the sand-and-gravel aquifer and Cambrian units; the highest dissolved solids and sulfate concentrations are found in the Sinnipee Group. Chloride concentrations are low and the distribution of values is similar for all units. Few concentration data are available for large areas of deeper Cambrian units.*

The table shows the distribution of dissolved solids, chloride, and sulfate concentrations in water from wells in the sand-and-gravel aquifer and subdivisions of the sandstone aquifer. Major subdivisions of the sandstone aquifer are undifferentiated Ordovician units and undifferentiated Cambrian units. Where sufficient data were available, separate summaries were prepared for the Sinnipee Group, St. Peter Sandstone and Prairie du Chien Group in the Ordovician System, and for the Elk Mound Group in the Cambrian System. Log transformed dissolved solids, chloride, and sulfate concentration values were distributed normally for the individual units in the Ordovician System, but only approximated normal distributions for the other subdivisions. Further subdivision of these latter units by area or geologic unit would probably result in a more normal distribution of concentration values.

The maps on the facing page show the areal distribution of wells where dissolved solids, chloride and sulfate concentration data are available for each geologic unit. The sand and gravel aquifer is absent in the Driftless Area except for alluvium in major river valleys; the remainder of the aquifer is comprised of glacial outwash. Wells are fairly uniformly distributed where the aquifer is an important source of ground water.

Data for individual bedrock units are most plentiful where the unit is nearest the surface. Considerable data are available for wells in Ordovician units in the southern and northwestern parts of the province where the aquifer has sufficient thickness to produce water for domestic wells. Most data for wells in Cambrian units are from areas where overlying Ordovician units are thin or absent. About 150 wells open to both Cambrian and Ordovician units are not included in these summaries.

Recommended maximum concentrations for dissolved solids [(500 mg/L (milligrams per liter)], chloride (250 mg/L), and sulfate (250 mg/L) given in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) are exceeded in water from some wells. The dissolved solids standard is exceeded in water from almost 25 percent of the wells in the Sinnipee Group but in water from less than 10 percent of the wells in other units. The chloride standard is exceeded in water from only a few isolated wells. Sulfate concentration exceeds the drinking water standard in water from almost 10 percent of the wells in the Sinnipee Group, but only in water from a few wells in other units. Because chloride concentrations generally are low in water from all units, high chloride concentrations might be useful indicators of local ground-water contamination.

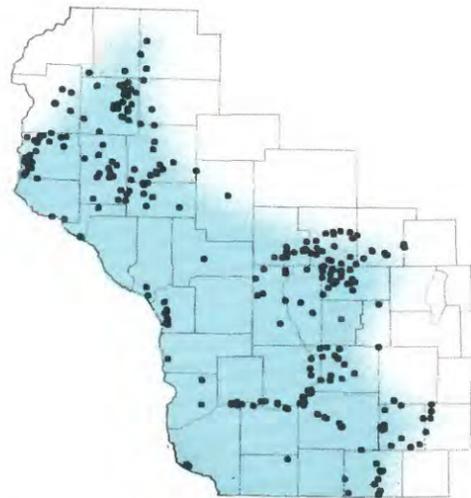
SUMMARY OF DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS  
(All concentrations in milligrams per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	331	610	360	300	218	131	92	37	197	115-337
	384	170	15	8.0	4.0	2.0	1.0	0.0	4.5	1.4-12
	389	140	33	18	11	6.9	3.6	0.0	11	4.4-26
UNDIFFERENTIATED ORDOVICIAN UNITS	208	1090	550	426	342	290	230	79	352	246-504
	217	110	27	12	5.8	2.7	1.5	0.0	6.5	2.0-18
	233	557	72	39	24	15	8.0	2.0	25	9.6-63
SINNIPEE GROUP	33	1090	729	493	386	336	303	229	426	299-608
	36	72	42	14	7.0	2.7	1.5	1.0	7.3	2.1-21
	40	470	238	52	38	24	12	2.8	40	15-109
ST PETER SANDSTONE	54	1010	475	408	337	290	224	79	333	230-480
	57	110	25	12	5.2	2.0	1.0	0.0	5.9	1.5-18
	59	91	45	30	23	14	7.4	2.0	20	10-40
PRAIRIE DU CHIEN GROUP	70	577	459	376	304	242	211	152	304	226-409
	75	46	22	11	6.3	3.0	1.6	0.5	6.2	2.2-15
	75	70	38	24	15	9.5	6.8	2.3	15	7.6-30
UNDIFFERENTIATED CAMBRIAN UNITS	487	2700	364	316	264	168	92	18	220	125-386
	502	1070	13	6.5	3.0	1.5	0.8	0.0	3.6	1.0-9.7
	499	450	27	18	13	6.6	3.2	0.4	11	4.6-26
ELK MOUND GROUP	281	659	331	281	224	121	80	18	185	103-331
	284	77	13	6.0	2.7	1.4	0.8	0.0	3.3	0.9-8.7
	284	114	23	17	12	5.7	2.3	0.4	10	4.0-24

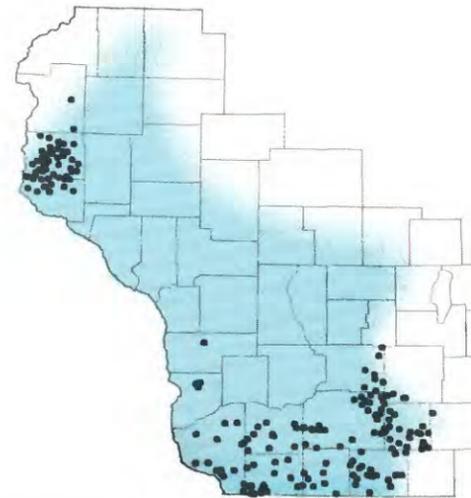
DISSOLVED SOLIDS = [light blue box] CHLORIDE = [medium blue box] SULFATE = [dark blue box]



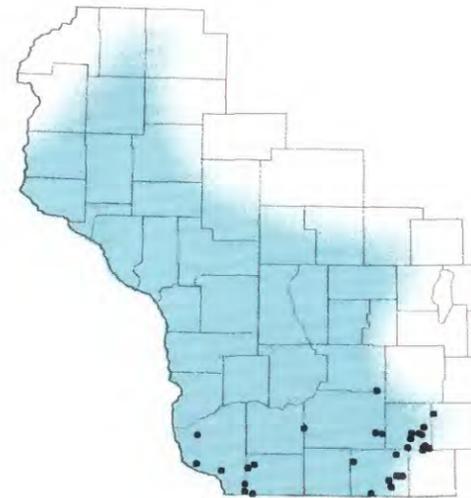
EXPLANATION  
 ● Sampling site for dissolved solids, chloride, and sulfate  
 [light blue box] Ground-water province I



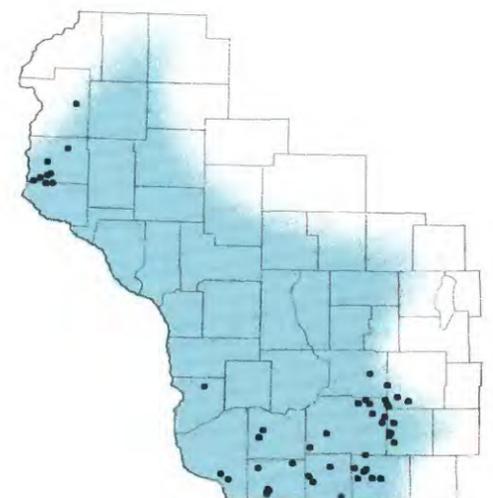
SAND-AND-GRAVEL AQUIFER



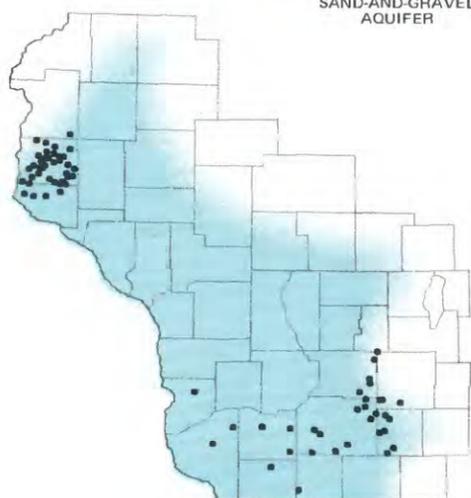
UNDIFFERENTIATED ORDOVICIAN UNITS



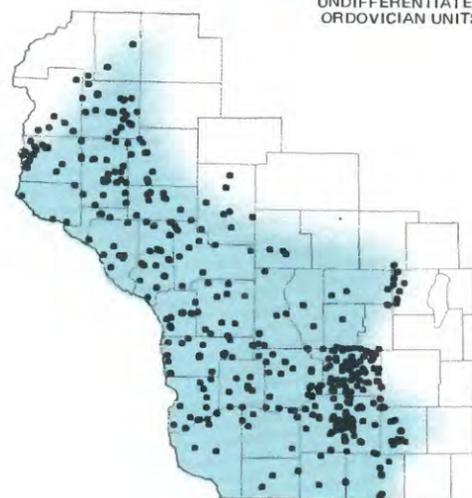
SINNIPEE GROUP



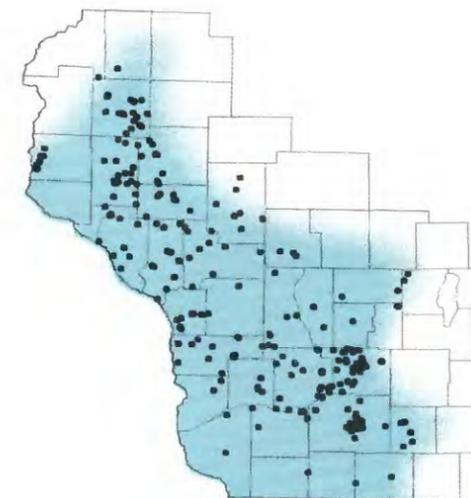
ST. PETER SANDSTONE



PRAIRIE DU CHIEN GROUP



UNDIFFERENTIATED CAMBRIAN UNITS



ELK MOUND GROUP

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.1 Ground-Water Province I--Continued

##### 4.1.3 Iron and Manganese

### **A Wide Range of Iron and Manganese Concentrations Occurs in Ground Water in this Province**

*Iron and manganese concentrations are high enough to be objectionable in water from many wells. The usefulness of these data as background for ground-water quality assessment is diminished by the wide range of concentrations, the lack of data showing the magnitude of local concentration variations, and the poor understanding of processes that influence iron and manganese concentrations in ground water.*

The summary table shows the distribution of iron and manganese concentrations in water from the sand-and-gravel aquifer, undifferentiated Ordovician units, three major units in the Ordovician System (Sinnipee Group, St. Peter Sandstone, and Prairie du Chien Group), undifferentiated Cambrian units and the Elk Mound Group of the Cambrian System. Log transformed iron concentration values approximate normal distributions for the Sinnipee Group, the St. Peter Sandstone, and the Prairie du Chien Group but poorly approximate or are not normally distributed in the other units; log transformation of manganese concentrations for all units produced poor approximations of normal distributions. With the exception of iron concentrations in the Sinnipee Group, St. Peter Sandstone, and Prairie du Chien Group, these data probably represent poorly the actual distribution of concentrations.

Recommended maximum concentrations for iron (300  $\mu\text{g}/\text{L}$ ) and manganese (50  $\mu\text{g}/\text{L}$ ) specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) are exceeded in an appreciable number of wells. The standard for iron is exceeded in water from more than 25 percent of the wells in all units except the Prairie du Chien Group. The manganese standard is exceeded in water from more than 25 percent of the wells in the sand-and-gravel aquifer and Cambrian units and in water from more than 10 percent of the wells in other units.

Chemical reactions that affect the solubility of iron and manganese can occur between the time a water sample is collected and the time it is analyzed.

Because of this, it is difficult to determine the relationship between analytical results and actual concentrations in the water at the time of sample collection. This is especially true for data where sample collection and analytical methods are poorly documented.

Data in these summaries include concentrations for dissolved iron or manganese and iron or manganese "in solution when analyzed". In the absence of documentation of sample collection and analysis methods, it may be difficult or impossible to determine actual iron and manganese concentrations in the ground water at the time the sample was collected.

The maps on the facing page show the areal distribution of wells in each unit for which iron- and manganese-concentration data are available. The sand- and-gravel aquifer is not present in the Driftless Area except in the flood plains of major rivers, but data are well distributed in areas where the aquifer is a major source of water. Data for specific bedrock units are most plentiful where the unit is nearest the land surface. Data for Ordovician units are most plentiful in the southern and northwestern parts of the province where these units yield adequate water supplies without drilling into underlying Cambrian units. Data for wells in Cambrian units are most abundant in areas where Ordovician units are thin or absent. There are no data included in this summary for about 170 wells open to both Ordovician and Cambrian units.

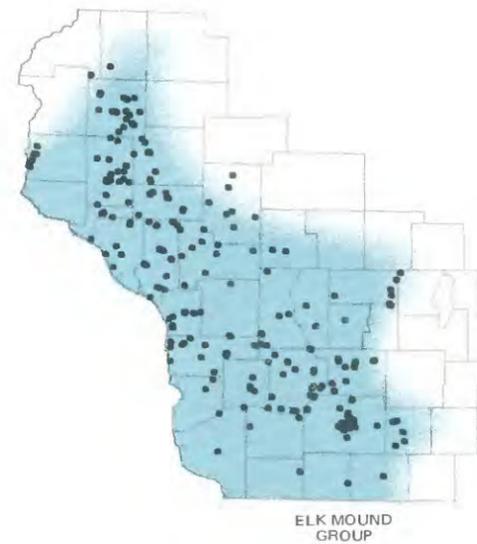
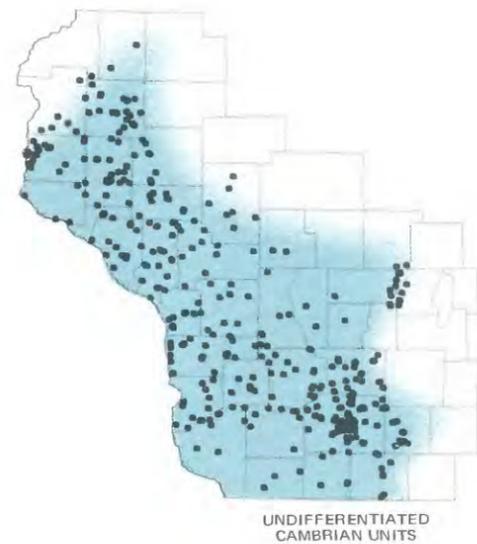
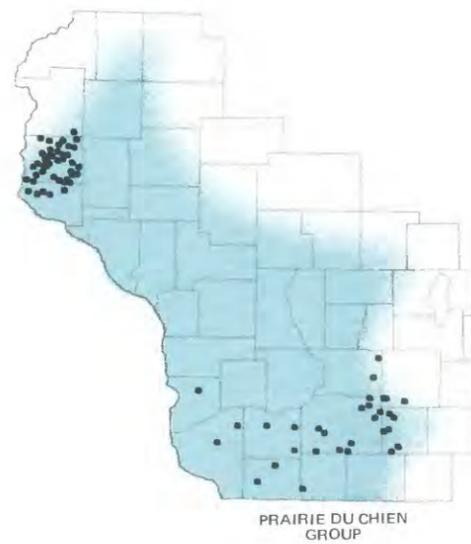
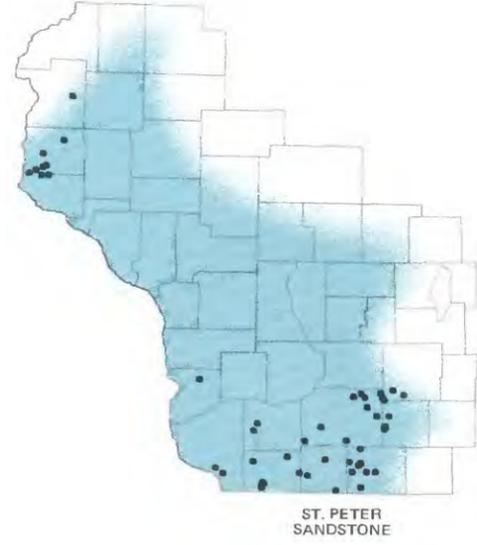
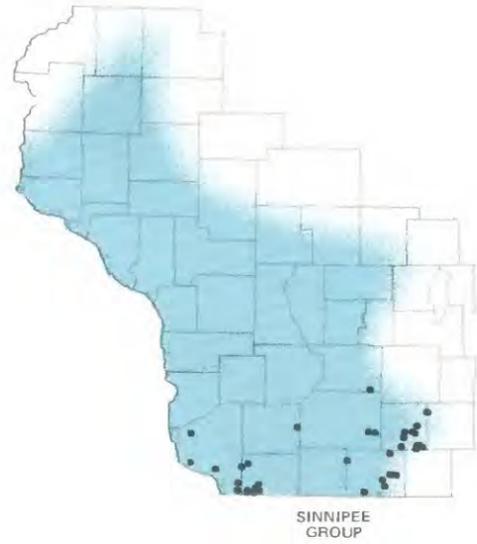
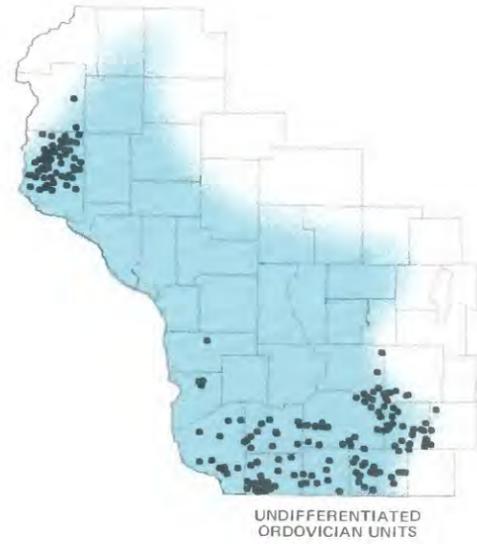
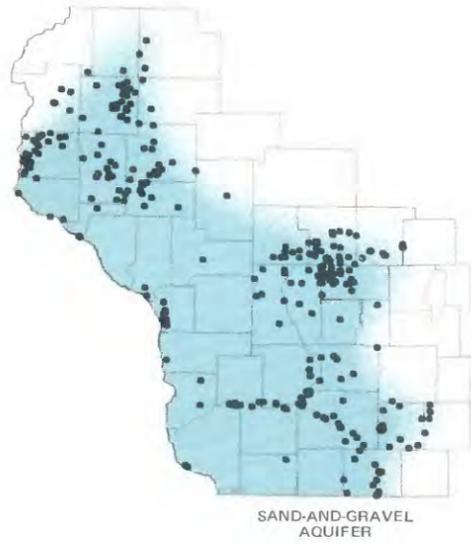
**SUMMARY OF IRON AND MANGANESE CONCENTRATIONS**  
(All concentrations in micrograms per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	376	21,000	3300	565	67	20	10	0	98	8-1120
	363	5170	351	120	30	10	0	0	26	3-202
UNDIFFERENTIATED ORDOVICIAN UNITS	221	46,000	1300	390	45	18	10	0	76	9-573
	219	1210	80	30	10	1	0	0	9	1-51
SINNIPEE GROUP	38	3900	3000	1050	175	40	10	3	188	25-1360
	39	160	70	40	20	2	0	0	11	2-58
ST. PETER SANDSTONE	51	3850	1170	540	40	20	10	3	80	12-502
	51	320	110	38	10	0	0	0	9	1-56
PRAIRIE DU CHIEN GROUP	73	46,000	628	65	20	10	10	0	36	4-254
	72	1000	89	25	10	10	0	0	11	2-51
UNDIFFERENTIATED CAMBRIAN UNITS	454	61,000	1800	600	160	30	10	0	145	20-1010
	435	5900	145	60	30	10	0	0	24	5-108
ELK MOUND GROUP	267	8450	2400	810	190	33	10	0	170	22-1270
	261	1130	160	74	30	12	0	0	25	5-122

IRON = [shaded area]      MANGANESE = [shaded area]



- EXPLANATION**
- Sampling site for iron and manganese
  - [shaded area] Ground-water province I



## 4.0 GROUND-WATER QUALITY--Continued

### 4.1 Ground-Water Province I--Continued

#### 4.1.4 Nitrate Nitrogen

## Data Indicate Some Nitrate-Nitrogen Contamination

*Nitrate-nitrogen concentrations exceed Wisconsin's drinking water standards in water from some wells. Previous investigations have found that the incidence of high nitrate-nitrogen concentrations is higher in rural private water supplies in some areas of the province than indicated by data in this report. Data base bias must be considered when evaluating nitrate-nitrogen concentrations in ground water.*

The summary table shows the distribution of nitrate-nitrogen concentrations in water from the sand-and-gravel and sandstone aquifers. In the sandstone aquifer, data are summarized collectively for undifferentiated Ordovician units with separate summaries for the Sinnipee Group, the St. Peter Sandstone and Prairie du Chien Group and collectively for undifferentiated Cambrian units with a separate summary for the Elk Mound Group. Nitrate-nitrogen concentrations are not distributed normally in any of the units, even with log transformation of the data.

Nitrate-nitrogen concentrations exceed the recommended maximum concentration of 10 mg/L specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) in water from approximately 10 percent of the wells in all units except those in the Cambrian System. Results of other investigations indicate that these data may not accurately reflect the amount of local nitrate-nitrogen contamination that occurs in some areas of the province, especially in private rural water supplies. A survey of 1,468 private rural water supplies in Dane and Columbia Counties (Schuknecht and others, 1975, p.94) concluded that 39 and 38 percent, respectively, of the wells sampled in these

counties had nitrate nitrogen concentrations exceeding 10 mg/L. Nitrogen containing materials from waste-disposal sites, livestock, septic systems, and agricultural fertilizers have been implicated in many instances of nitrate contamination of private rural water supplies in Wisconsin (Delfino, 1977).

The areal distribution of wells in the units where nitrate-nitrogen concentration data are available is shown on the maps on the facing page. The sand-and-gravel aquifer occurs only as valley alluvium in the Driftless Area, but is areally extensive in other parts of the province. Extensive fertilization and irrigation of agricultural crops in many areas of the province increase the likelihood of nitrate-nitrogen contamination in this aquifer. Concentration data for specific bedrock units are more plentiful in areas where the unit is closest to the land surface. Data for Ordovician units are more abundant in the southern and northwestern parts of the province where these units are thick enough to supply sufficient water for private water supplies without drilling into underlying Cambrian units. Data for Cambrian units are more abundant in areas where Ordovician rocks are thin or absent.

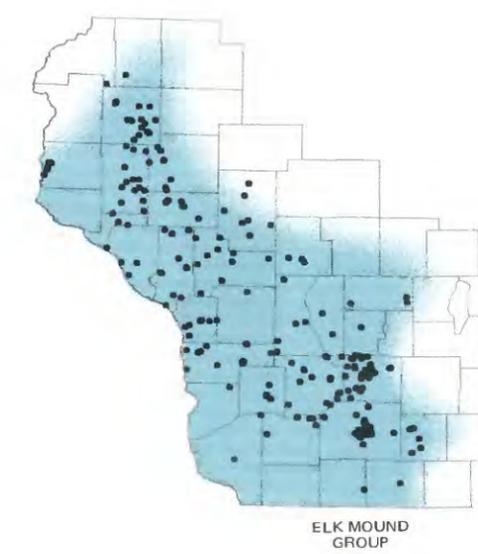
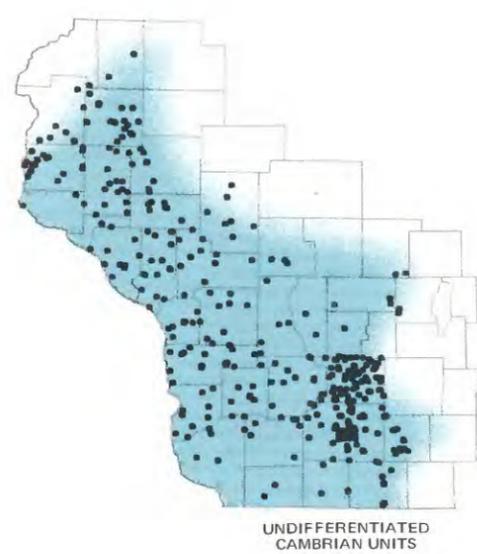
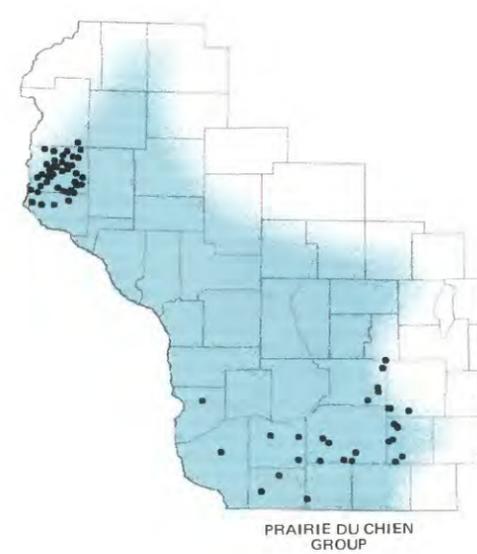
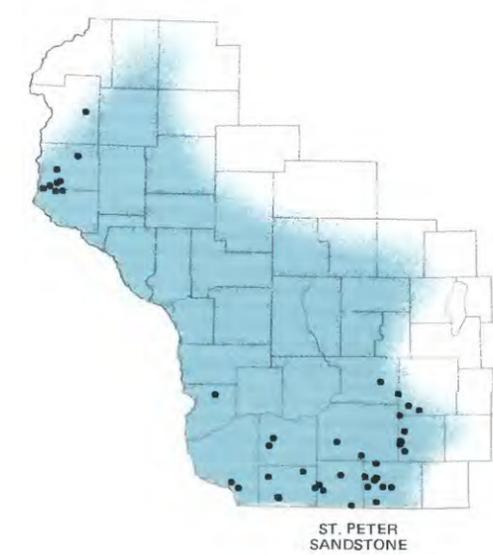
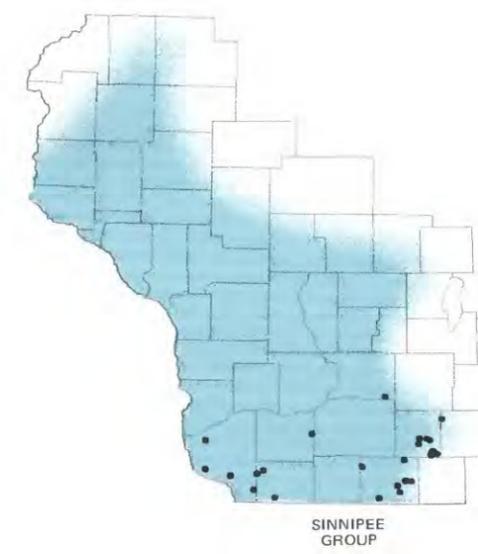
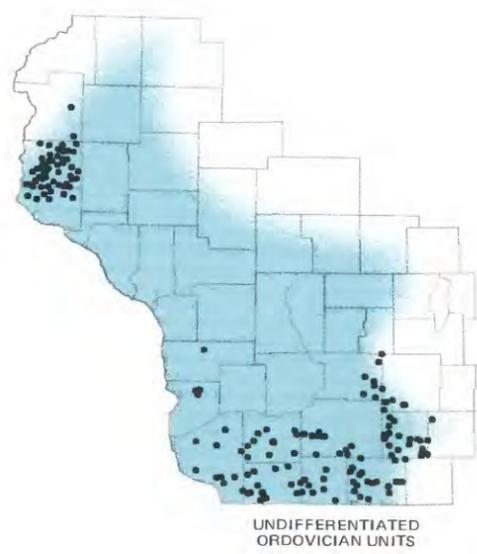
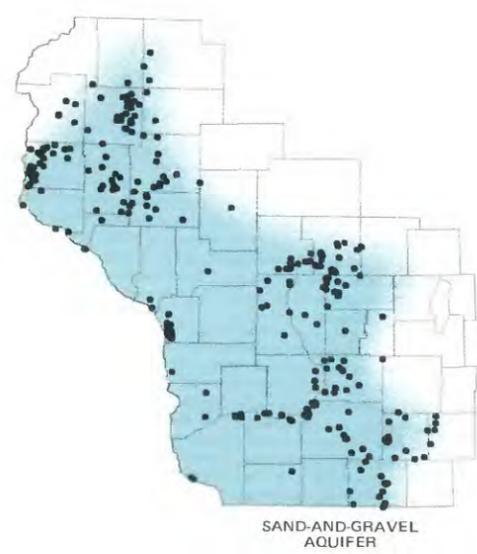
**SUMMARY OF NITRATE NITROGEN CONCENTRATIONS**  
(All concentrations in milligrams per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	335	32	8.1	4.8	1.9	0.3	0.0	0.0	2.0	0.3-5.9
SANDSTONE AQUIFER	UNDIFFERENTIATED ORDOVICIAN UNITS	180	10	5.9	2.2	0.4	0.0	0.0	2.2	0.3-7.0
	SINNIPEE GROUP	28	10	5.9	2.5	0.2	0.0	0.0	2.2	0.2-7.4
	ST. PETER SANDSTONE	45	20	13	4.2	1.6	0.2	0.0	1.8	0.1-6.1
	PRAIRIE DU CHIEN GROUP	69	18	11	6.3	2.8	1.0	0.0	2.6	0.6-7.4
	UNDIFFERENTIATED CAMBRIAN UNITS	413	17	5.3	2.0	0.6	0.1	0.0	1.0	0.0-3.0
ELK MOUND GROUP	231	16	4.0	1.7	0.4	0.1	0.0	0.8	0.0-2.5	



**EXPLANATION**

- Sampling site for nitrate nitrogen
- Ground-water province I



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.2 Ground-Water Province II

##### 4.2.1 Chemical Characteristics and Hydrogeology

### **Calcium Bicarbonate and Calcium Magnesium Bicarbonate Type Water Predominate**

*Water-quality data are available for only limited areas of some geologic units. Multiaquifer wells draw water from these units in other areas, but analyses of water from these wells generally are not useful for chemical characterization of water in individual units. Regional water movement is to the east in the lower sandstone aquifer and in the entire aquifer where it is confined by the Maquoketa Shale; regional movement is toward Lake Michigan or Green Bay and their tributaries in upper units.*

Trilinear diagrams on the facing page show the chemical composition of water from wells in the sand-and-gravel, Silurian dolomite, and components of the sandstone aquifers.

Composition of water from wells in the sand-and-gravel aquifer is fairly uniform. Calcium and magnesium are the predominant cations except for water with high sodium concentration from a few wells; bicarbonate is the dominant anion, but sulfate is a significant minor constituent in some cases and is the dominant anion in water from one well. Much available data are concentrated in a few counties that have been the subject of hydrogeologic investigations, so these characterizations are not necessarily representative of the entire extent of the sand-and-gravel aquifer. Water in this aquifer is recharged locally by precipitation and often is discharged to surface drainage systems within a few miles of the point of recharge.

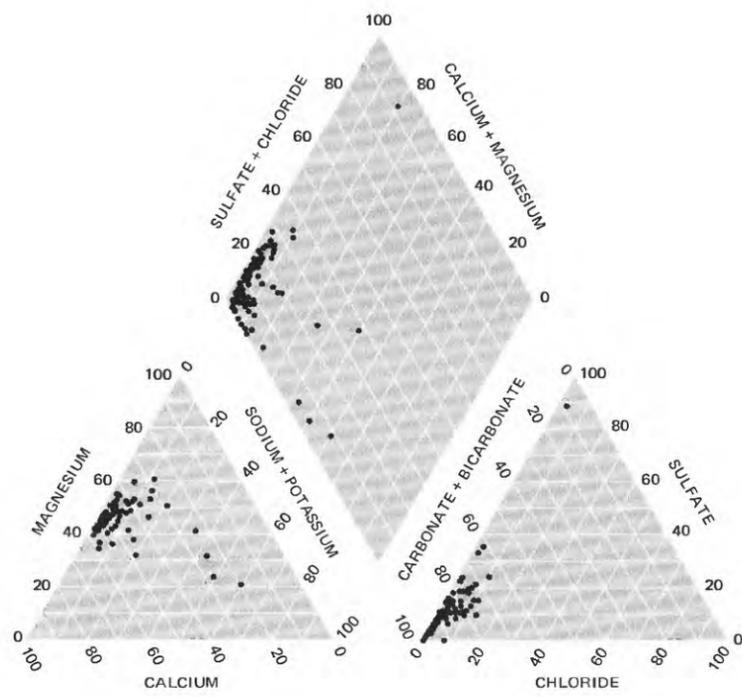
Calcium and magnesium generally predominate in water from the Silurian dolomite aquifer, but sodium predominates in a few areas. Bicarbonate is generally the predominant anion, but sulfate is significant or predominant in water from many wells. Chloride is sometimes present in greater concentrations than seen in the data from the overlying sand-and-gravel aquifer.

Much of the data for water from wells in the

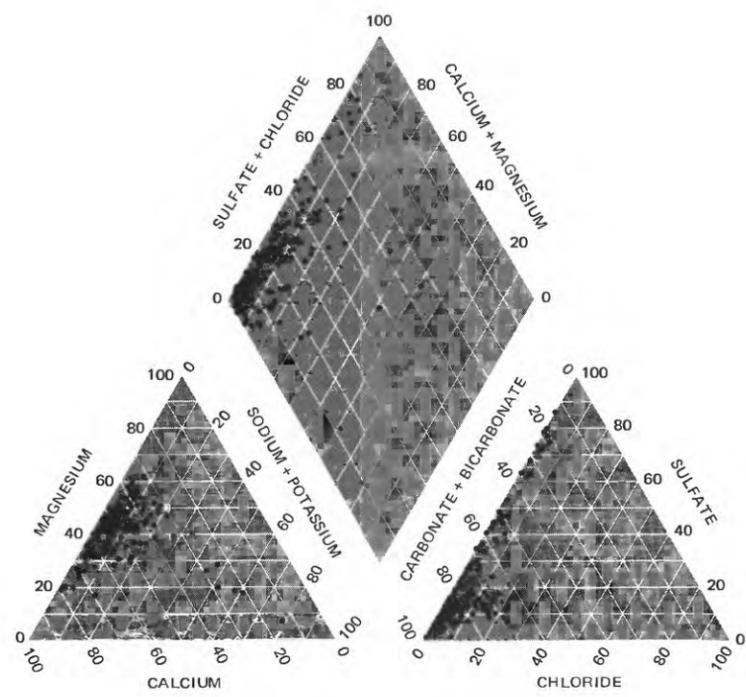
sandstone aquifer are from Ordovician units, primarily the Sinnipee Group and the St. Peter Sandstone, where they are unconfined. Few data are available for Ordovician units overlain (confined) by the Maquoketa Shale because most wells in these areas that are deep enough to reach Ordovician units are also open to the overlying Silurian dolomite aquifer. Calcium and magnesium are generally the predominant cations, but some water contains appreciable amounts of sodium. Bicarbonate is the predominant anion, but sulfate predominates in water from many wells, especially where sodium concentrations are high.

About 40 percent of the wells in Ordovician units draw water exclusively from the Sinnipee Group. The diagrams show the similarities in composition in water from wells in the Sinnipee group and water from wells in all Ordovician units. In general, sulfate concentrations are lower in water from the Sinnipee Group than in water from other Ordovician units.

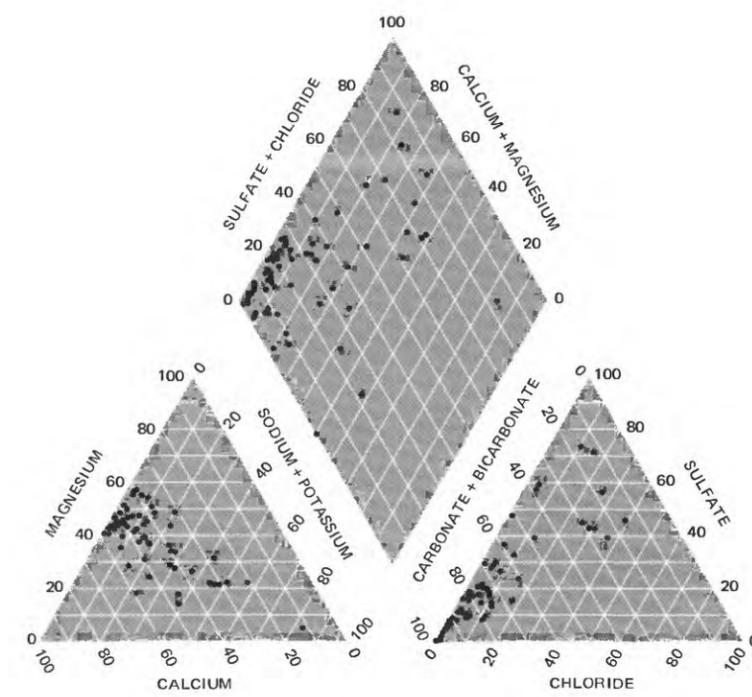
Little data are available for wells drawing water only from the Cambrian units of the sandstone aquifer. The wells where data are available are mostly on the western edge of the province where Cambrian units are closest to the surface. Calcium and magnesium are generally the predominant cations and bicarbonate is the predominant anion in water from wells in Cambrian units.



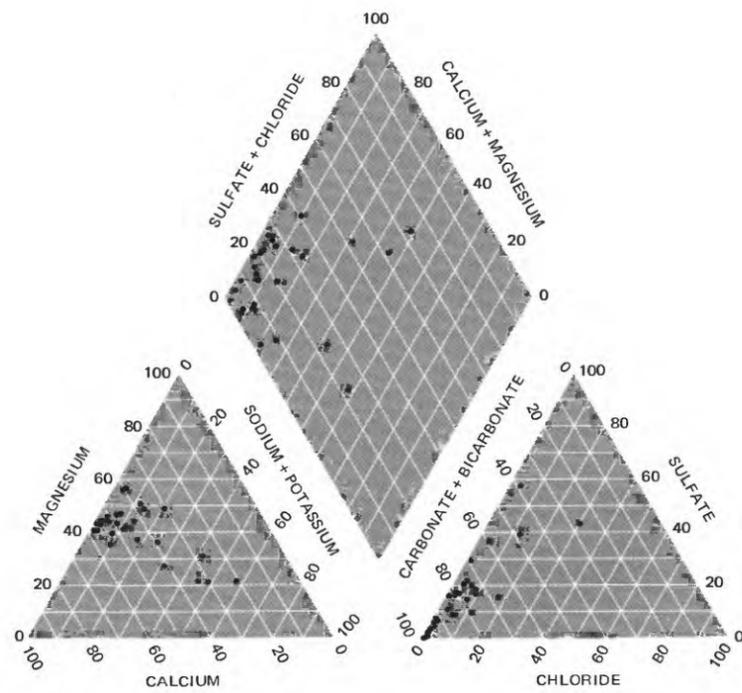
Cations  
SAND-AND-GRAVEL  
AQUIFER  
Anions



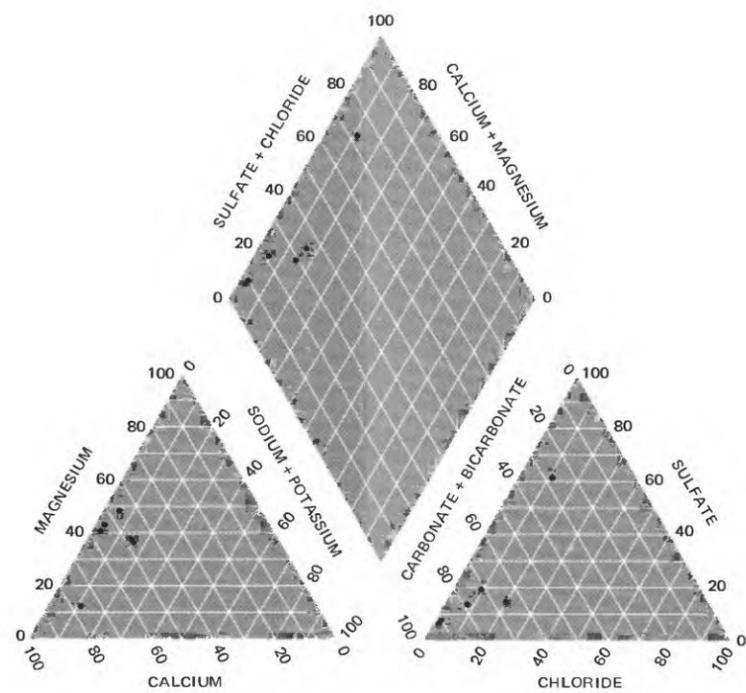
Cations  
SILURIAN DOLOMITE  
AQUIFER  
Anions



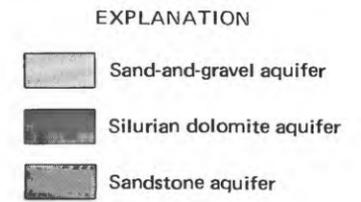
Cations  
UNDIFFERENTIATED  
ORDOVICIAN UNITS  
Anions



Cations  
SINNIPEE  
GROUP  
Anions



Cations  
UNDIFFERENTIATED  
CAMBRIAN UNITS  
Anions



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.2 Ground-Water Province II--Continued

##### 4.2.2 Dissolved Solids, Chloride, and Sulfate

### Concentrations of Dissolved Solids and Sulfate are Objectionable High in Water from Some Wells

*The distribution of concentration values for dissolved solids and chloride is similar for each of the geologic units considered here. Sulfate concentrations generally are higher in water from wells in the Silurian dolomite aquifer.*

*Data are not available for large areas of some units.*

The summary table shows the distribution of dissolved solids, chloride, and sulfate concentrations in water from wells in the sand-and-gravel and Silurian dolomite aquifers, undifferentiated Ordovician units, the Sennipee group, and undifferentiated Cambrian units. Log transformed dissolved solids and chloride concentration values are distributed normally for wells in the Sennipee Group and approximate normal distributions for wells in the other units. Log transformed sulfate concentration values are distributed normally or closely approximate normal distributions in all units. As a result, it is assumed that these data represent valid statistical samples of likely concentrations in areas of these units where data are available. Further subdivision of the data by area or geologic unit would probably result in more representative distributions of concentrations, especially in the case of undifferentiated Cambrian and Ordovician units.

Location maps on the facing page show the areal distribution of wells where dissolved solids, chloride, and sulfate concentration are available in each geologic unit. Data for wells in the sand-and-gravel aquifer are concentrated in three counties (Washington, Ozaukee, and Walworth) that have been the subject of recent hydrogeologic investigations, so the distribution of concentrations shown in the summary tables is not necessarily representative of the aquifer in other areas. The wells in the Silurian dolomite are fairly uniformly distributed over the entire areal extent of the unit.

Dissolved solids, chloride, and sulfate concentration data for the Ordovician components of the sandstone aquifer are primarily for wells in the Sennipee Group and the St. Peter Sandstone in areas where the aquifer is not overlain by the Maquoketa Shale and the Silurian dolomite aquifer. Few concentration data are available for Ordovician units

underlying the Silurian dolomite aquifer because wells that are deep enough to reach Ordovician units are usually also open to the overlying dolomite. About 40 percent of the concentration data for Ordovician units are from wells in the Sennipee Group. The Sennipee Group is not a productive aquifer where it is overlain by the Maquoketa Shale; wells in the part of this unit not overlain by the Maquoketa Shale are distributed fairly uniformly.

Very few data are available for wells open exclusively to Cambrian components of the sandstone aquifer. Wells where data are available are along the western edge of the province where Cambrian units are close to the surface and overlying Ordovician units are thin. Wells drawing water from Cambrian rocks in the remainder of the province are generally also open to overlying units.

Recommended maximum concentrations for dissolved solids (500 mg/L), chloride (250 mg/L), or sulfate (250 mg/L) in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) are exceeded in water from some wells. Dissolved solids concentrations exceed the standard in water from 10 percent or more wells in all units except the sand-and-gravel aquifer. Concentrations exceeding the standard are found in water from more than 25 percent of the wells in the Silurian dolomite aquifer. Sulfate concentrations exceeding the standard are found in water from approximately 10 percent of the wells in the Silurian dolomite aquifer. Chloride concentrations exceed the standard in water from only a few of the wells.

Because chloride concentrations generally are low, high chloride concentration might indicate local ground-water-quality degradation.

**SUMMARY OF DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS**  
(All concentrations in milligrams per liter)

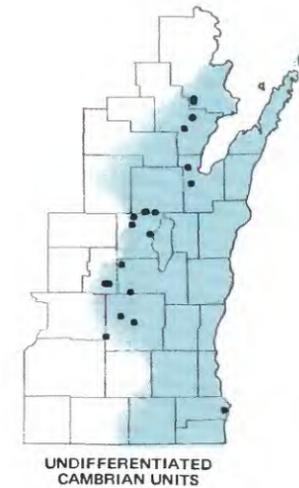
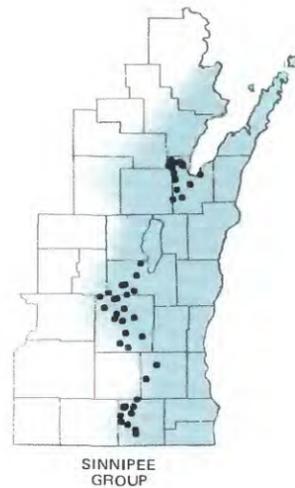
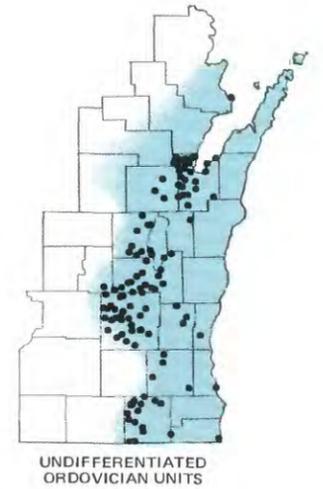
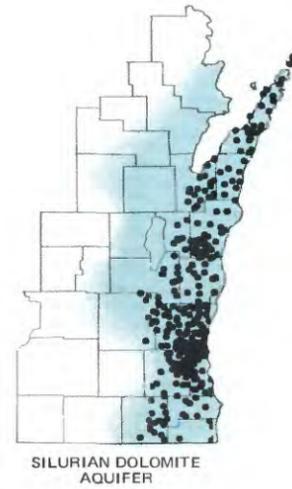
	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	189	1390	464	396	342	302	258	77	341	252-462
	192	325	23	10	4.2	2.0	1.0	0.0	5.2	1.3-16
	195	893	65	45	27	12	2.6	0.4	21	6.0-67
SILURIAN DOLOMITE AQUIFER	367	2340	764	508	379	314	264	130	417	270-644
	377	510	37	13	5.2	2.6	1.4	0.7	6.8	1.6-22
	378	1400	233	109	48	22	9.4	0.4	48	13-173
SANDSTONE AQUIFER UNDIFFERENTIATED ORDOVICIAN UNITS	118	2990	597	461	370	299	250	131	387	248-604
	121	270	53	15	6.1	2.8	1.5	0.0	8.0	1.7-29
	121	1500	162	74	40	15	4.6	0.0	34	7.7-139
SANDSTONE AQUIFER SINNIPEE GROUP	48	950	566	463	354	295	216	176	359	253-509
	48	160	30	15	4.1	2.2	1.2	0.0	6.1	1.3-21
	48	310	120	69	34	11	1.7	0.2	25	5.7-100
SANDSTONE AQUIFER UNDIFFERENTIATED CAMBRIAN UNITS	23	1020	779	352	312	290	238	224	344	234-505
	24	56	45	14	6.2	3.4	2.0	0.3	7.5	2.2-21
	23	477	277	48	18	14	9.8	8.0	27	9.0-78

DISSOLVED SOLIDS =  CHLORIDE =  SULFATE =



**EXPLANATION**

- Sampling site for dissolved solids, chloride, and sulfate
- Ground-water province II



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.2 Ground-Water Province II--Continued

##### 4.2.3 Iron and Manganese

### Distribution of Iron and Manganese Concentrations is Similar for All Units

*Concentrations of iron and manganese are objectionably high in water from many wells. The usefulness of these data as background information for evaluation of ground-water contamination is limited. The large range of "natural" concentration values, lack of data on the magnitude of local concentration variations, and the relatively poor understanding of the chemical and biological processes that control iron and manganese concentrations in the hydrogeologic environment make these data difficult to interpret.*

The summary table shows the distribution of iron and manganese concentrations in water from wells in the sand-and-gravel and Silurian Dolomite aquifers, undifferentiated Ordovician units, the Sinipee Group, and undifferentiated Cambrian units. Log transformed iron concentration values approximated normal distributions for each unit. Log transformed manganese concentration values approximated normal distributions for most units, but the distributions were skewed by large numbers of low concentration values. The concentrations for both constituents are assumed to be generally representative of the actual distribution of concentrations found in water from these units.

Recommended maximum concentrations for iron (300  $\mu\text{g}/\text{L}$ ) and manganese (50  $\mu\text{g}/\text{L}$ ) given in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) are exceeded in water from many wells. The standard for iron is equaled or exceeded in water from half or more of the wells in each unit. Recommended maximum manganese concentration is exceeded in water from more than one-quarter of the wells in the sand-and-gravel aquifer and more than 10 percent of the wells in the other units.

The areal distribution of wells for which iron and manganese concentration data are available for each unit is shown on the maps on the facing page. Data for wells in the sand-and-gravel aquifer are concentrated in three counties (Washington, Ozaukee, and Walworth) that have been the subject of recent hydrogeologic investigations, so these data do not necessarily represent conditions throughout the entire aquifer. Data for wells in the Silurian dolomite aquifer are distributed fairly uniformly over the entire aquifer. Wells open exclusively to component units of the sandstone aquifer (Ordovician units,

Sinipee Group, and Cambrian units) are mostly in areas where the Silurian dolomite aquifer is not present. Where the Silurian dolomite aquifer is present, wells reaching units of the underlying sandstone aquifer are generally also open to the overlying Silurian Dolomite aquifer. Because of this, few water-quality data are available exclusively for Cambrian and Ordovician units even though they are important sources of water in southeastern Wisconsin. Wells in the Sinipee Group account for about 40 percent of the wells in Ordovician units.

The Sinipee Group is not a productive aquifer where it is overlain by the Maquoketa Shale. Wells in the Sinipee Group for which iron and manganese data are available are distributed fairly uniformly over the areas of this unit that yield water to wells.

Chemical reactions that affect the solubility of iron and manganese in water may occur between the time that a water sample is collected and the time it is analyzed. This may lead to uncertainty as to the relationship between analytical results and actual concentrations present in the water at the time the sample was collected, especially for data where sample collection and analytical methods are poorly documented.

Concentration data in this summary include values for dissolved iron or manganese and iron or manganese "in solution when analyzed". The later designation applies to analyses where no attempt was made to account for iron or manganese removed from solution between collection and analysis of the sample. For some data, it may be difficult or impossible to determine which of these designations best describe the concentration values.

**SUMMARY OF IRON AND MANGANESE CONCENTRATIONS**  
(All concentrations in micrograms per liter)

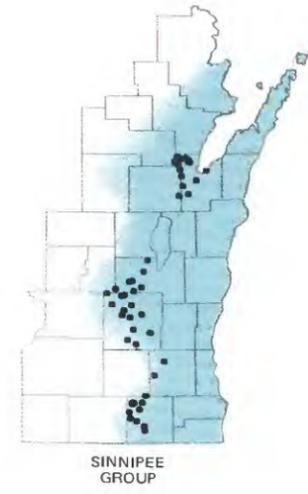
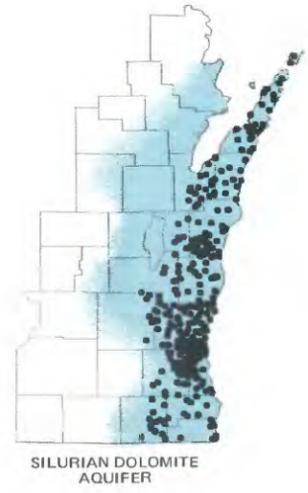
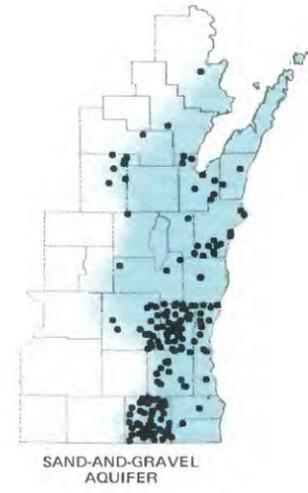
	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	193	10,000	3100	1600	380	100	20	0	328	45-2350
	187	350	90	60	30	18	0	0	22	5-96
SILURIAN DOLOMITE AQUIFER	379	11,000	1700	740	290	60	10	0	217	37-1250
	368	3300	67	40	30	14	4	0	21	5-74
UNDIFFERENTIATED ORDOVICIAN UNITS	120	11,000	3180	1200	400	120	50	0	349	51-2350
	106	360	61	35	20	3	0	0	10	1-55
SINNIPEE GROUP	48	11,000	3070	930	345	85	10	0	244	26-2190
	48	130	51	30	12	0	0	0	8	1-41
UNDIFFERENTIATED CAMBRIAN UNITS	24	9000	3550	1100	550	249	70	30	520	136-1980
	17	185	117	40	30	19	11	0	27	9-81

IRON =  MANGANESE =



**EXPLANATION**

- Sampling site for iron and manganese
- Ground-water province II



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.2 Ground-Water Province II--Continued

##### 4.2.4 Nitrate Nitrogen

### Nitrate-Nitrogen Concentrations are Low

*Nitrate-nitrogen concentrations in water from some wells exceed Wisconsin's drinking water standards, but data do not indicate widespread nitrate contamination. Local contamination could occur and not be reflected in these data. Data base bias is an important consideration in evaluating nitrate-nitrogen concentrations in ground water.*

The table shows the distribution of nitrate-nitrogen concentrations in water from wells in the sand-and-gravel and Silurian dolomite aquifers, undifferentiated Ordovician units, the Sennipee Group, and undifferentiated Cambrian units. The concentrations are not distributed normally for any of the units. The distributions are skewed by the large proportion of low and zero concentration values. The distribution of concentrations is similar for all units.

Nitrate-nitrogen concentrations exceed the recommended maximum concentration of 10 mg/L given in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) in water from relatively few wells, but local nitrate-nitrogen contamination could occur that is not reflected in these data. Nitrogen containing materials from waste-disposal sites, livestock, septic systems, and agricultural fertilizers have been implicated in many instances of nitrate contamination of private, rural wells (Delfino, 1977). The most heavily populated areas in the State are located in this province; this increases the probability of local ni-

trate contamination from waste-disposal sites and septic systems that is not reflected in these data.

The areal distribution of wells with nitrate concentration data in each unit is shown on the maps on the facing page. Wells in the sand-and-gravel aquifer are concentrated in three counties (Washington, Ozaukee, and Walworth) that have been the subject of recent hydrogeologic investigations. Wells are more uniformly distributed in the Silurian dolomite aquifer, but some areas have few data. Wells in units of the sandstone aquifer (undifferentiated Ordovician units, the Sennipee Group, and undifferentiated Cambrian units) are generally in areas where the respective unit is the uppermost bedrock aquifer. Where overlying aquifers are present, wells penetrating the lower units are generally multiaquifer.

Few nitrate-nitrogen concentration data are available in many areas. Because of this and the local nature of most instances of nitrate contamination, these data should be used cautiously for purposes other than general background information on nitrate-nitrogen concentrations in ground water that is relatively free of contamination.

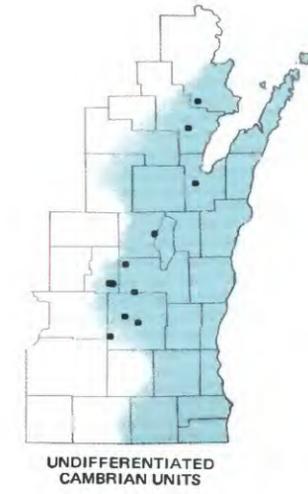
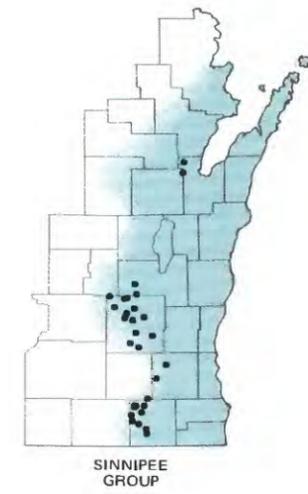
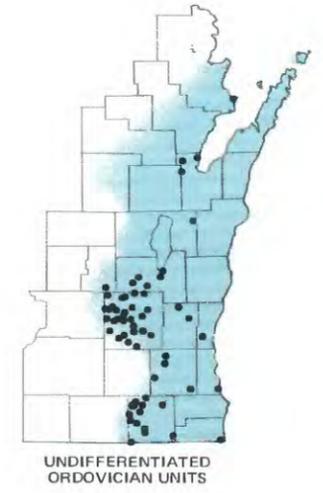
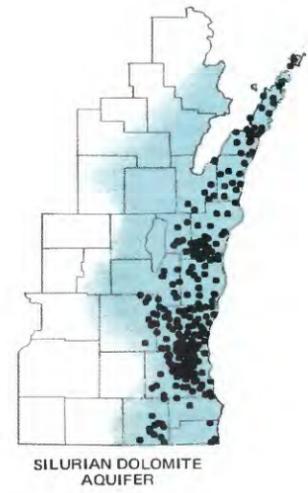
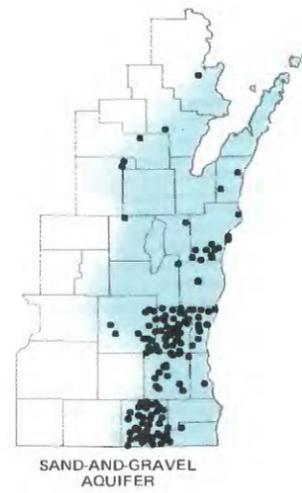
**SUMMARY OF NITRATE NITROGEN CONCENTRATIONS**  
*(All concentrations in milligrams per liter)*

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	158	16	3.4	0.9	0.1	0.0	0.0	0.0	0.6	0.0-2.0
SILURIAN DOLOMITE AQUIFER	299	21	3.2	0.6	0.2	0.0	0.0	0.0	0.5	0.0-1.8
SANDSTONE AQUIFER	UNDIFFERENTIATED ORDOVICIAN UNITS	65	2.1	0.4	0.1	0.0	0.0	0.0	0.4	0.0-1.5
	SINNIPEE GROUP	30	4.3	0.6	0.1	0.0	0.0	0.0	0.5	0.0-2.0
UNDIFFERENTIATED CAMBRIAN UNITS	12	5.1	3.9	0.5	0.1	0.0	0.0	0.0	0.4	0.0-1.3



**EXPLANATION**

- Sampling site for nitrate nitrogen
- Ground-water province II



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.3 Ground-Water Province III

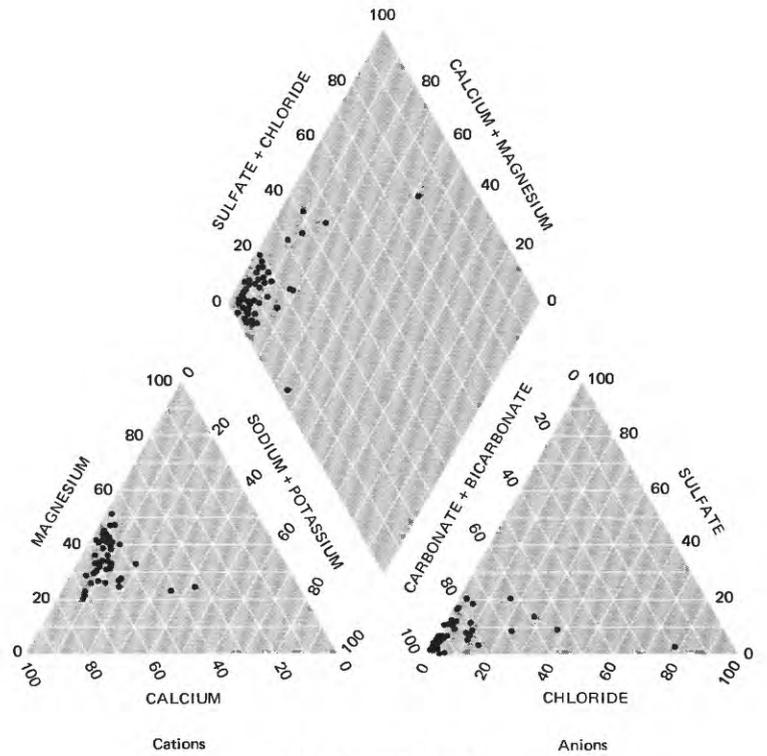
##### 4.3.1 Chemical Characteristics and Hydrogeology

### **Calcium, Magnesium, and Bicarbonate are the Major Dissolved Constituents in Ground-Water from Province III**

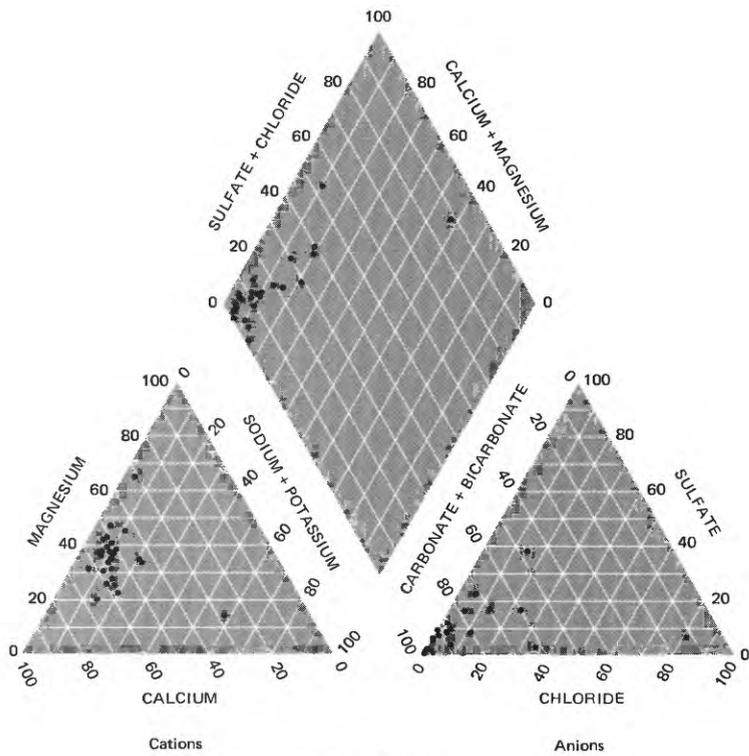
*There is little overall difference in the proportions of major dissolved constituents between water from wells in the sand-and-gravel aquifer and water from wells in the basement complex. Water from wells in the basement complex is derived from local recharge through overlying glacial deposits.*

Trilinear diagrams on the facing page show the similarity in the composition of water from the sand-and-gravel aquifer and water from the basement complex. Calcium and magnesium collectively comprise over 80 percent of the cations in water from all but four wells. Sodium and potassium generally are minor constituents. Bicarbonate generally accounts for more than 75 percent of the anions; the water from a few wells with smaller percentages of bicarbonate generally have higher proportions of chloride and, to a lesser extent, sulfate.

Ground-water movement in the sand and gravel aquifer is within local flow systems with recharge from precipitation and snowmelt and discharge to nearby lakes and streams. Water in the basement complex occurs in weathered and fractured zones in the granites and quartzites that are the principal bedrock types and is derived from local recharge through overlying glacial deposits. Ground-water movement in the basement complex is generally local.



SAND-AND-GRAVEL  
AQUIFER



BASEMENT  
COMPLEX

**4.0 GROUND-WATER QUALITY--Continued**  
 4.3 Ground-Water Province III  
 4.3.1 Chemical Characteristics and Hydrogeology

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.3 Ground-Water Province III--Continued

##### 4.3.2 Dissolved Solids, Chloride, and Sulfate

### **Background Concentrations of Dissolved Solids, Chloride, and Sulfate in the Ground Water Generally are Not Objectionably High**

*Differences in the distribution of concentrations for data from the sand-and-gravel aquifer and the basement complex are small for all three constituents. Background concentrations of chloride and sulfate are low enough that these constituents may be useful as indicators of local ground-water-quality degradation.*

The summary table shows the distribution of dissolved solids, chloride, and sulfate concentrations found in water from the sand and gravel aquifer and the basement complex. Log transformed dissolved solids, chloride, and sulfate concentration values for water from each of these units approximate normal distributions, so it is assumed that these data represent a valid statistical sample of concentrations in water from these units.

Chloride and sulfate concentrations do not exceed the recommended maximum concentration of 250 mg/L for each specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978), but dissolved-solids concentrations exceed the recommended standard of 500 mg/L in water from four wells (three in the sand-and-gravel aquifer and one in the basement complex).

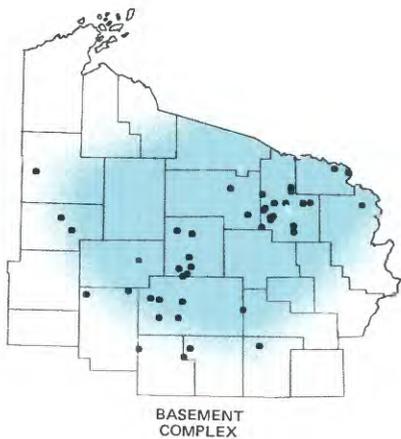
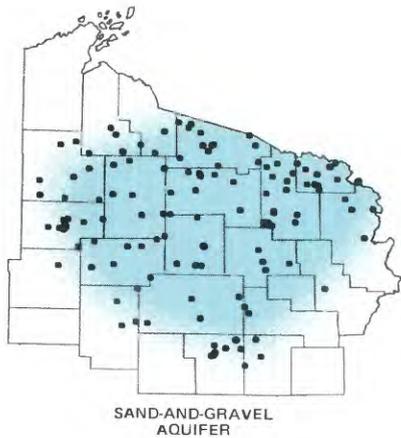
Maximum concentrations of sulfate and chloride are considerably higher than the concentrations equaled or exceeded in water from 10 percent of the wells. This, and the fact that concentrations are generally low for most wells, indicates that instances of high concentrations of either of these constituents may be indicators of local ground-water-quality degradation.

The maps on the facing page show the areal distribution of sites where concentration data for chloride and sulfate are available. The wells in the sand-and-gravel aquifer are distributed fairly uniformly over the areal extent of the province; wells in the basement complex are distributed less uniformly.

**SUMMARY OF DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS**  
(All concentrations in milligrams per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	165	940	254	190	146	111	71	28	142	83-242
	166	190	17	7.0	2.2	1.1	0.7	0.0	3.4	0.6-11
	166	149	20	12	7.2	5.0	2.9	0.5	7.7	3.2-17
BASEMENT COMPLEX	43	601	293	254	178	131	109	65	180	115-281
	43	153	33	16	3.3	1.1	0.9	0.5	5.3	0.9-20
	43	86	27	11	7.2	3.8	1.8	0.7	7.1	2.5-18

DISSOLVED SOLIDS =  CHLORIDE =  SULFATE =



**EXPLANATION**

● Sampling site for dissolved solids, chloride, and sulfate

Ground-water province III



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.3 Ground-Water Province III--Continued

##### 4.3.3 Iron and Manganese

### **A Wide Range of Iron and Manganese Concentrations is Found in the Ground Water**

*Iron and manganese concentrations are high enough to be objectionable in water from many wells. The wide range of iron and manganese concentrations and complex chemical and biological controls on their solubility in ground water limit the usefulness of these data as background data for evaluation of ground-water contamination.*

The summary table on this page shows the distribution of iron and manganese concentrations found in water from wells in the sand-and-gravel aquifer and the basement complex. Log transformed iron and manganese concentration values for each of these units approximate normal distributions, so it is assumed that these data represent valid statistical samples of concentrations from these units.

The concentrations in the summary table show that iron and manganese concentrations exceed recommended maximum concentrations for drinking water of 300  $\mu\text{g/L}$  and 50  $\mu\text{g/L}$ , respectively (Wisconsin Department of Natural Resources, 1978) in approximately one-quarter to one-half of the wells sampled.

The areal distribution of wells for which concentration data are available is shown on the location maps on the facing page. Wells in the sand-and-gravel aquifer are distributed fairly well over the entire areal extent of the aquifer in the province.

Wells in the basement complex are distributed less uniformly.

Chemical reactions that affect the solubility of iron and manganese may occur between the time of collection and the time of analysis of water samples. This may lead to uncertainty as to the relationship between analytical results and actual concentrations in the water at the time of sample collection. This is especially true for historical data, where sample collection and analytical procedures are poorly documented.

Data summarized here are a combination of concentrations of dissolved iron or manganese and iron or manganese "in solution when analyzed". The latter type of value applies to analyses where no attempt was made to account for iron or manganese removed from solution between sample collection and analysis. For some of the available data, it is not possible to determine which of these designations best describes the concentration value.

SUMMARY OF IRON AND MANGANESE CONCENTRATIONS (All concentrations in micrograms per liter)										
	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	150	19,000	4100	900	130	39	16	0	182	20-1600
	149	6000	540	110	45	13	0	0	41	6-260
BASEMENT COMPLEX	44	7000	2800	230	60	11	10	10	91	12-620
	43	2200	290	130	20	10	1	0	28	3-180

IRON =  MANGANESE =



SAND-AND-GRAVEL AQUIFER



BASEMENT COMPLEX

EXPLANATION

- Sampling site for iron and manganese
- Ground-water province III



## 4.0 GROUND-WATER QUALITY--Continued

### 4.3 Ground-Water Province III--Continued

#### 4.3.4 Nitrate Nitrogen

## Nitrate-Nitrogen Concentrations May Differ Locally

*Nitrate-nitrogen concentrations summarized here are generally low, but higher values are likely where ground-water contamination is a problem. Data base bias is a potential problem in evaluating nitrate concentrations in ground water.*

The summary table shows the distribution of nitrate-nitrogen concentrations in water from wells in the sand-and-gravel aquifer and the basement complex. The concentration values were not distributed normally, even after log transformation of the data. The distribution appeared to be skewed by a preponderance of low concentrations.

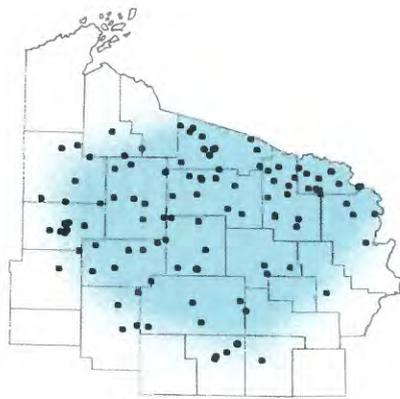
The areal distribution of wells for which nitrate-nitrogen concentration data are available is shown on the location maps. Data for wells in the sand-and-gravel aquifer are distributed fairly uniformly, but data for wells in the basement complex are clustered in the southwest part of the province. This disparity in the distribution of sampling sites must be considered when using the data to generalize as to the distribution of concentration values for the entire unit.

Nitrate-nitrogen concentrations exceeded the maximum recommended concentration of 10 mg/L for public water supplies (Wisconsin Department of

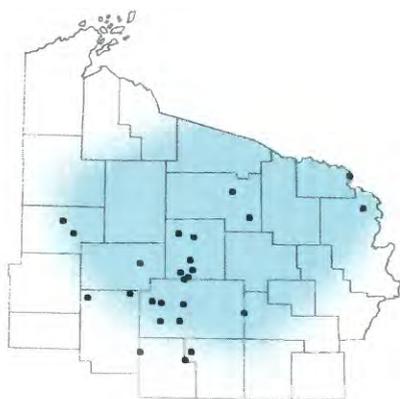
Natural Resources, 1978) in water from only five wells (three in the sand-and-gravel aquifer and two in the basement complex), but it is likely that high nitrate-nitrogen concentrations may be more common than these data indicate. The maximum concentration (41 mg/L) noted for water from wells in the sand-and-gravel aquifer was from a well in an area of heavy fertilization and crop irrigation where nitrate in ground water is known to be a problem. Wells in this type of area are under-represented in the data summarized here.

Nitrogen-containing materials from waste-disposal sites, septic systems, livestock wastes, and agricultural fertilizers have been implicated in many cases of high nitrate-nitrogen concentrations in ground water in private rural water supplies (Delfino, 1977). These may be major sources of nitrate contamination, especially in shallow wells that are common in this province.

SUMMARY OF NITRATE NITROGEN CONCENTRATIONS (All concentrations in milligrams per liter)										
	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	132	41	2.9	1.2	0.2	0.1	0.0	0.0	0.6	0.0-2.2
BASEMENT COMPLEX	25	21	9.4	4.3	0.9	0.1	0.0	0.0	1.5	0.0-5.2



SAND-AND-GRAVEL AQUIFER



BASEMENT COMPLEX

EXPLANATION

- Sampling site for nitrate nitrogen
- Ground-water province III



## 4.0 GROUND-WATER QUALITY--Continued

### 4.4 Ground-Water Province IV

#### 4.4.1 Chemical Characteristics and Hydrogeology

### Major Dissolved Constituents in Ground Water in Province IV Differ Areally and Between Aquifers

*The greatest variation in constituents found in the ground water occurs in water from the Lake Superior sandstone aquifer, where water moves in both local flow systems and in deeper regional systems. Less variation is found in water from the sand-and-gravel aquifer and from Precambrian lava flows; water movement in these systems is primarily local.*

The trilinear diagrams show differences in the composition of dissolved constituents in water from wells in the sand-and-gravel aquifer, the Precambrian Lake Superior sandstone aquifer, and Precambrian lava flows.

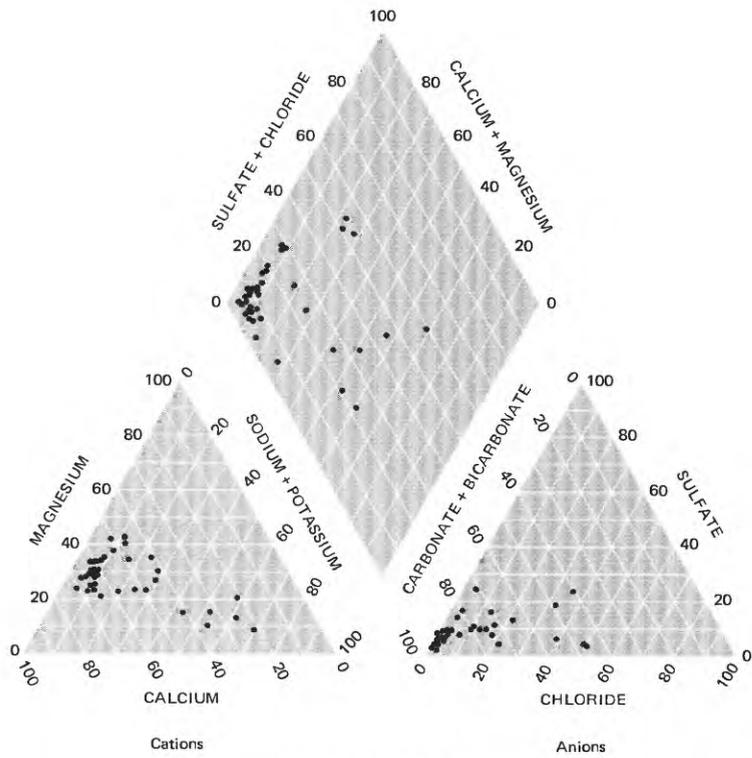
Calcium and magnesium constitute 90 percent or more of the cations in water from many of the wells in the sand-and-gravel aquifer with calcium being predominant, but sodium plus potassium predominate in water from a few wells and sodium concentrations are moderately high in water from others. Bicarbonate is the predominant anion in water from all but a few wells where high chloride concentrations occur.

In water from wells in the Lake Superior sandstone aquifer, cation composition ranges from predominantly calcium to predominantly sodium plus potassium. Water from many wells contains mixtures of calcium, magnesium, sodium, and potassium with no species predominant. Bicarbonate is the predominant anion in water from most wells, chloride and sulfate each predominate in a few wells. The ground-water flow system in this aquifer is

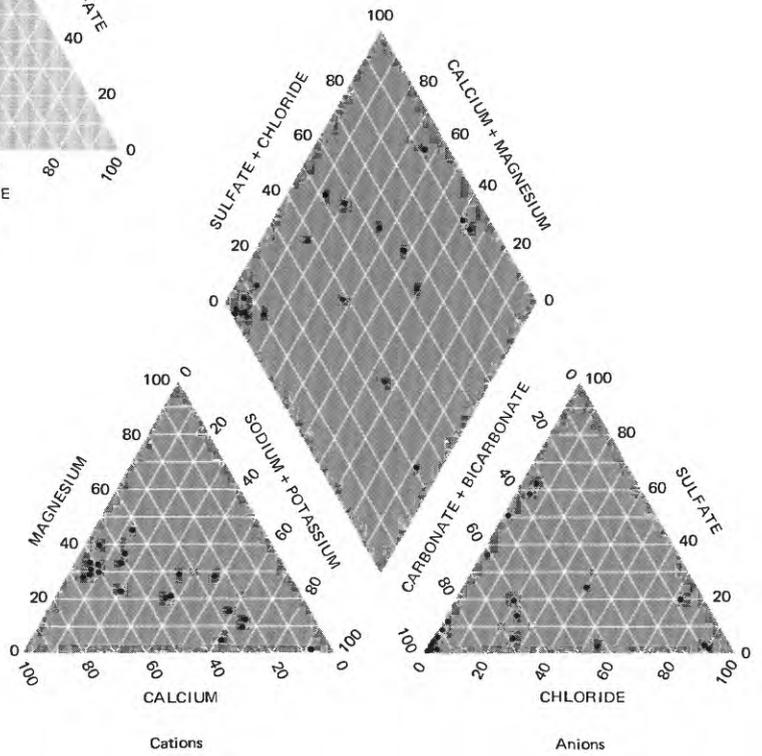
complex and poorly understood, and no attempt has been made to relate the areal variations in water quality to the hydrogeologic environment.

Wells are drilled in the Precambrian lava flows only in areas where the Precambrian sandstone is missing and upper layers of the lava flows are weathered or fractured. Water in these wells is generally derived from local recharge through the overlying glacial drift. Calcium and magnesium collectively are the predominant cations in water from five of the wells in the lava flows, but sodium and potassium predominate in water from three of the wells. Bicarbonate is the predominant anion in water from all but one well.

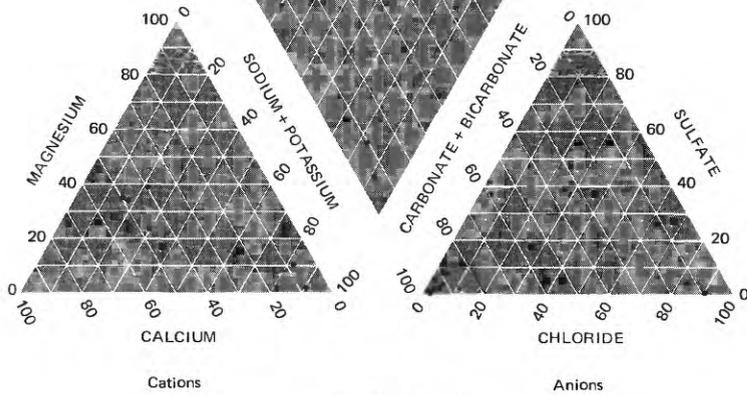
Available data are probably not adequate to describe chemical relationships in these geologic units, given the relatively large chemical variation in the limited amount of available water-quality data and the limited understanding of ground-water occurrence and movement in the Lake Superior sandstone aquifer and the Precambrian lava flows.



SAND-AND-GRAVEL  
AQUIFER



LAKE SUPERIOR  
SANDSTONE AQUIFER



PRECAMBRIAN  
LAVA FLOWS

**4.0 GROUND-WATER QUALITY--Continued**  
 4.4 Ground-Water Province IV  
 4.4.1 Chemical Characteristics and Hydrogeology

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.4 Ground-Water Province IV--Continued

##### 4.4.2 Dissolved Solids, Chloride, and Sulfate

### **Concentrations of Dissolved Solids, Chloride, and Sulfate are Objectionably High in Water from Some Wells**

*In this province, concentrations of dissolved solids, chloride, and sulfate are highest and have the greatest areal variability in water from wells in the Lake Superior sandstone aquifer. The distribution of sulfate concentrations and all but the highest concentrations of chloride are similar for water from the sand-and-gravel aquifer and the Precambrian lava flows.*

The summary table shows the distribution of dissolved solids, chloride, and sulfate concentration values for water from wells in the sand-and-gravel aquifer, Lake Superior sandstone aquifer, and Precambrian lava flows. Log-transformed concentration values are distributed normally, or approximate normal distributions for each of the three units, so it is assumed that these data represent valid samples of concentration values likely to occur in these units.

Dissolved solids and chloride concentrations exceed recommended maximum concentrations of 500 mg/L and 250 mg/L, respectively, specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) in water from approximately 10-25 percent of the wells in the Lake Superior sandstone aquifer. Concentrations are generally lower and exceed these standards less frequently in water from wells in the Precambrian lava flows. The recommended maximum concentration of 250 mg/L for sulfate (Wisconsin Department of Natural Resources, 1978) is exceeded in water

from some wells in the Lake Superior sandstone aquifer.

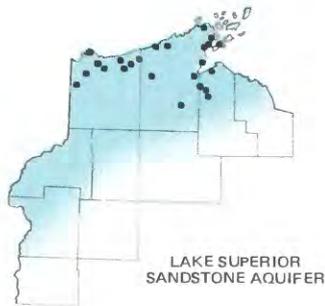
Chloride and sulfate concentrations in water from wells in the sand-and-gravel aquifer and Precambrian lava flows generally are low, so high concentrations of these constituents in water from these units might indicate local ground-water-quality degradation.

The maps show the areal distribution of wells in each of the aquifers where concentration data for dissolved solids, chloride, and sulfate are available. Data for wells in the sand-and-gravel aquifer are distributed fairly uniformly over the entire province. Data for wells in the Lake Superior sandstone and Precambrian lava flows are distributed less uniformly. Although they do not cover the entire areal extent of these units, they probably represent the areas where these units are most heavily used for water supplies.

**SUMMARY OF DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS**  
*(All concentrations in milligrams per liter)*

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	84	375	268	214	150	106	78	41	148	92-237
	90	88	26	8.7	2.5	1.2	0.5	0.0	3.9	0.6-14
	86	42	22	11	7.2	4.5	2.5	0.4	7.4	3.2-15
LAKE SUPERIOR SANDSTONE AQUIFER	29	7620	1560	525	244	138	95	67	308	104-909
	32	4100	687	183	16	1.6	0.5	0.0	26	1.4-297
	31	631	189	70	22	6.8	2.0	0.8	22	4.0-106
PRECAMBRIAN LAVA FLOWS	14	1025	768	228	182	131	86	64	192	93-376
	14	527	271	5.0	3.0	1.0	0.5	0.5	4.3	0.2-22
	14	22	20	12	8.4	4.8	2.8	2.8	7.9	4.1-14

DISSOLVED SOLIDS =  CHLORIDE =  SULFATE =



**EXPLANATION**

- Sampling site for dissolved solids, chloride, and sulfate
- Ground-water province IV



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.4 Ground-Water Province IV--Continued

##### 4.4.3 Iron and Manganese

### **A Wide Range of Iron and Manganese Concentrations is Found in the Ground Water**

*Iron and manganese concentrations in water from many wells are high enough to be objectionable. Their usefulness as background data for evaluation of contamination is limited by the wide range of concentrations and the poor understanding of the chemical and biological processes that control these concentrations.*

The summary table shows the distribution of iron and manganese concentrations in water from wells in the sand-and-gravel and Lake Superior sandstone aquifers, and Precambrian lava flows. Log transformed iron concentration values are distributed normally for each unit, and log transformed manganese concentration values approximate the normal distributions. Because of this, these concentration values are assumed to be valid statistical samples of iron and manganese concentrations in water from these units.

Both iron and manganese concentrations frequently exceed the recommended maximum concentrations of 300  $\mu\text{g/L}$  and 50  $\mu\text{g/L}$ , respectively, specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978). Iron concentrations exceed the standard in water from almost one-quarter of the wells in the sand-and-gravel aquifer and Precambrian lava flows and more than one-quarter of the wells in the Lake Superior sandstone aquifer. Manganese concentrations exceed the drinking water standard in more than a quarter of the wells in all three units.

The areal distribution of wells for which data are available in each of the three units is shown on the maps. The data for the sand-and-gravel aquifer are

distributed fairly uniformly throughout the province. Data for the Lake Superior Sandstone aquifer and the Precambrian lava flows are not distributed over the entire areal extent of these units, but they probably represent areas where these units are most heavily used for water supplies.

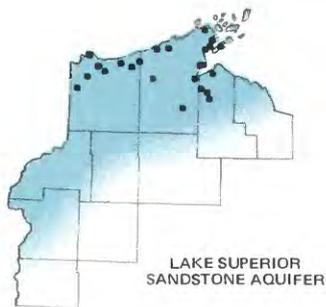
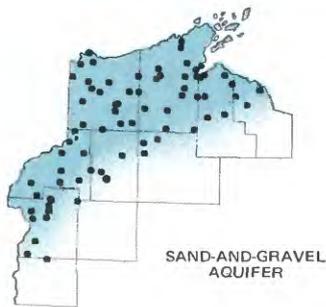
Chemical reactions that affect the solubility of iron and manganese may occur between the time that a water sample is collected and the time that it is analyzed. This may lead to uncertainty as to the relationship between analytical results and iron and manganese concentrations in the water at the time the sample was collected. This is especially true for data where sample collection and analytical methods are poorly documented.

The data summarized here include concentrations for dissolved iron or manganese and iron or manganese "in solution when analyzed". The latter classification applies to analyses where no attempt was made to account for iron or manganese removed from solution between the times of sample collection and analysis. For some data, it is not possible to determine which of these designations best describe the concentration values.

**SUMMARY OF IRON AND MANGANESE CONCENTRATIONS**  
(All concentrations in micrograms per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	86	18,000	1180	258	100	30	15	0	101	16-614
	85	850	312	100	30	10	0	0	30	5-171
LAKE SUPERIOR SANDSTONE AQUIFER	29	19,300	9020	640	100	40	23	0	169	19-1430
	29	610	325	82	40	10	0	0	26	3-166
PRECAMBRIAN LAVA FLOWS	14	825	578	290	145	95	70	70	168	83-340
	14	130	105	72	42	20	10	10	38	17-84

IRON = [Grey Box]      MANGANESE = [Light Blue Box]



**EXPLANATION**

- Sampling site for iron and manganese
- [Blue Box] Ground-water province IV



#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.4 Ground-Water Province IV--Continued

##### 4.4.4 Nitrate Nitrogen

### Nitrate-Nitrogen Concentrations are Low

*The nitrate-nitrogen concentrations summarized here do not indicate widespread ground-water contamination, but local contamination could occur and not be reflected in these data. Data base bias is a potential problem in evaluating nitrate-nitrogen concentrations in ground water.*

The summary table shows the distribution of nitrate-nitrogen concentrations in water from wells in the sand-and-gravel and Lake Superior sandstone aquifers and the Precambrian lava flows. The concentrations are not distributed normally in any of these units, even after log transformation of the data; the distributions are skewed by the preponderance of low and zero concentrations.

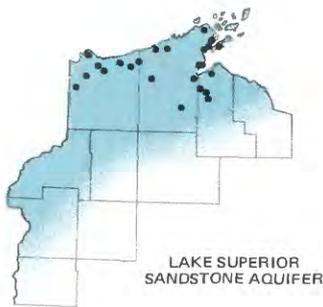
None of the concentration values exceed the maximum concentration of 10 mg/L nitrate-nitrogen specified in Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978), but some local contamination is likely. Nitrogen containing materials from waste-disposal sites, septic systems, livestock wastes, and agricultural fertilizers have been implicated in many instances of high nitrate concentrations in water from private rural wells in Wisconsin (Delfino, 1977). The highest

nitrate-nitrogen concentrations in this province were in water from the sand-and-gravel aquifer. Because this aquifer is the uppermost geologic unit, it is the most susceptible to nitrate contamination.

The areal distribution of wells for which nitrate-nitrogen concentration data are available in the sand-and-gravel and Lake Superior sandstone aquifers, and Precambrian lava flows is shown on the location maps. Data for the sand-and-gravel aquifer are distributed fairly uniformly over the entire province. Data for the Lake Superior sandstone aquifer and the Precambrian lava flows are not distributed over the entire areal extent of these units, but the distribution probably represents areas where these units are most heavily used for ground-water supplies.

**SUMMARY OF NITRATE NITROGEN CONCENTRATIONS**  
(All concentrations in milligrams per liter)

	NUMBER OF WELLS	MAXIMUM CONCENTRATION	PERCENT OF WELLS WHERE INDICATED CONCENTRATION WAS EQUALED OR EXCEEDED					MINIMUM CONCENTRATION	GEOMETRIC MEAN	RANGE OF VALUES WITHIN ONE STANDARD DEVIATION OF THE GEOMETRIC MEAN
			10	25	50	75	90			
SAND-AND-GRAVEL AQUIFER	71	9.5	3.9	1.3	0.2	0.0	0.0	0.6	0-2.0	
LAKE SUPERIOR SANDSTONE AQUIFER	26	1.8	0.6	0.2	0.1	0.0	0.0	0.2	0-0.4	
PRECAMBRIAN LAVA FLOWS	14	1.2	0.8	0.1	0.0	0.0	0.0	0.1	0-0.4	



**EXPLANATION**

- Sampling site for nitrate nitrogen
- Ground-water province IV



## 4.0 GROUND-WATER QUALITY--Continued

### 4.5 Trace constituents

#### **The Small Amount of Trace Constituent Data Available Indicates that Their Concentrations in Wisconsin's Ground Water are Generally Within Acceptable Limits**

*Trace constituents summarized here include metals (cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, and zinc), nonmetals (arsenic and boron), and organic carbon. The chemical behavior and occurrence of these constituents in ground water is poorly understood and caution should be exercised in drawing general conclusions from these data.*

Wisconsin's current primary drinking water regulations specify maximum concentrations for seven of the constituents summarized here. Maximum permissible concentrations of arsenic, cadmium, chromium, lead, mercury, and selenium are based on toxicity to humans from acute or chronic exposures. Hexavalent chromium is the chromium species toxic to human beings, but the maximum concentration is based on total chromium concentration because the analytical method for total chromium is relatively simple. Chromium in aerobic or chlorinated water is normally in the hexavalent state: thus, total chromium concentrations (which include hexavalent chromium), provide a reasonable, although conservative, estimate of hexavalent chromium concentrations. The maximum concentration for silver is based on cosmetic considerations. Ingestion of silver salts may cause permanent skin discoloration. Maximum permissible concentrations were exceeded in water from only five of the wells. The standard for lead was exceeded in water from three wells and the standards for arsenic and chromium were each exceeded in water from one well.

Recommended maximum permissible concentrations for copper and zinc are given in Wisconsin's secondary water standards (Wisconsin Department of Natural Resources, 1978). These limits are based on taste considerations. The copper concentration in water from one well exceeded the recommended limit.

Caution should be exercised in drawing conclusions from analytical data for trace metals in water from wells. Distribution systems (pumps, pressure tanks, and plumbing) are likely sources of trace metal contamination, especially for copper and zinc, and, to some extent, cadmium and lead.

Excessive boron in water used for irrigation may cause crop damage. The highest boron concentration found in water from the wells included in this summary was less than the recommended upper limit for boron in irrigation water.

Organic carbon concentration is a gross measure of the quantity of organic material in water. Measurements of organic carbon concentration have been used in various water-pollution investigations as indicators of the degree and extent of contamination by organic substances. The effectiveness of this technique is increased if background data for "natural" or uncontaminated water are available. The data summarized here (which includes values for dissolved and total organic carbon) indicate the general range of "natural" organic carbon concentrations in Wisconsin's ground water.

The table summarizes trace-constituent concentrations in Wisconsin's ground water. Maps showing locations of the wells where concentration data are available for each constituent are given by Kammerer (1981).

**SUMMARY OF TRACE CONSTITUENT CONCENTRATIONS IN WISCONSIN'S GROUND WATER**  
*(All concentrations in micrograms per liter unless otherwise indicated)*

Constituent	Number of wells	Number of non-zero concentration values	Maximum concentration	Minimum concentration	Median concentration	Maximum permissible concentration in public water supplies <sup>1</sup>	Number of wells where permissible concentration was exceeded
Arsenic	191	77	132	0	0	50	1
Cadmium	190	75	7	0	0	10	0
Chromium	76	11 <sup>2</sup>	20	<10	<10	50	0
Chromium (hexavalent)	123	42	80	0	0	50 <sup>4</sup>	1
Cobalt	190	62	20	0	0	-	-
Copper	203	89	2400	0	0	1000 <sup>5</sup>	1
Lead	238	204	62	0	2	50	3
Mercury	176	22 <sup>2</sup>	0.8	0.0	<0.5	2	0
Nickel	76	47	27	0	1	-	-
Selenium	170	27	9	0	0	10	0
Silver	163	5	1	0	0	50	0
Zinc	243	216	4400	0	60	5000 <sup>5</sup>	-
Boron	178	144	650	0	20	750 <sup>5</sup>	-
Organic carbon	317	317	41 <sup>3</sup>	0.1 <sup>3</sup>	4.4 <sup>3</sup>	-	-

<sup>1</sup> Wisconsin Department of Natural Resources, 1978

<sup>2</sup> Concentration values qualified as "less than" (<) were counted as "zero" values

<sup>3</sup> Concentration in milligrams per liter

<sup>4</sup> Standard for total chromium

<sup>5</sup> Recommended limit; National Academy of Sciences, National Academy of Engineering, 1973

From Kammerer, 1981

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.6 Hydrogen Sulfide

(By T. A. Calabresa, Wisconsin Department of Natural Resources)

### Hydrogen Sulfide Causes Local Ground-Water Quality Problems in Eastern Wisconsin

*Hydrogen sulfide in ground water may result from natural chemical and biological processes or from contamination. The natural occurrence of hydrogen sulfide must be documented before its presence can be useful as an indicator of ground-water contamination.*

Hydrogen sulfide gas is objectionable in drinking water supplies because of its characteristic "rotten egg" odor. Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978) recommend that hydrogen sulfide be undetectable in drinking water supplies but do not recommend a specific maximum concentration.

The map delineates areas where hydrogen sulfide in ground water is reported to be a problem. The information used in compiling the map was obtained from a survey of well drillers. The affected wells in southeastern Wisconsin are in the Silurian dolomite

aquifer and the affected wells in other areas draw water from the Sinnipee Group.

Hydrogen sulfide problems reported here probably are due to natural geochemical processes such as anaerobic decomposition of underground organic deposits, chemical and biological transformations of sulfur-containing minerals, and biochemical reduction of sulfate. Decomposition of solid and liquid wastes is a potential source of hydrogen sulfide contamination in ground water.



AREAS WHERE HYDROGEN SULFIDE  
IN GROUND WATER HAS BEEN REPORTED

**4.0 GROUND-WATER QUALITY--Continued**  
*4.7 Ground-Water Contamination*

**Ground-Water Contamination has Occurred in Wisconsin and Sources of Potential Contaminants are Plentiful**

*A summary of documented instances of ground-water contamination and identification of potential contaminant sources provides useful background information for evaluating the adequacy of available data for contamination evaluation and planning for future needs.*

Subsequent sections of this report (sections 4.7.1-4.7.4) summarize known instances of ground-water contamination that have been documented by the Wisconsin Department of Natural Resources (DNR) and identify potential sources of ground-water contamination, particularly from land disposal of wastes.

Comparison of the number of documented instances of ground-water contamination to the actual number of potential contaminant sources illustrates that a relatively large number of instances of local

ground-water contamination probably exist that are not identifiable from available water-quality data.

Comparison of the constituents implicated in the documented instances of ground-water contamination with the constituents for which concentration data are routinely collected during water resources investigations (sections 4.1-4.4 of this report) shows that much of the available data are not directly applicable to evaluation of ground-water-quality problems caused by ground-water contamination.

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.7 Ground-Water Contamination

##### 4.7.1 Instances of Contamination Investigated by the Wisconsin

Department of Natural Resources

(By T. A. Calabresa, Wisconsin Department of Natural Resources)

### Ground-Water Contamination Cases Investigated by the Department of Natural Resources are Representative of Ground-Water Contamination Problems that Occur in the State

*An inventory of 197 ground-water contamination cases shows that major sources of contamination are leakage from pipes or tanks, seepage from surface impoundments storing liquid wastes, leachate from landfills, and accidental or deliberate spills. Petroleum products are associated with more than one-third of the incidents.*

The cases of ground-water contamination summarized here occurred during 1929-80. The most frequent source of the contaminant was leakage from pipes or tanks, with 29 percent of the incidents either known or suspected to be due to this cause. Other common contaminant sources were seepage from waste lagoons (16 percent), leachate from landfills (12 percent), and accidental spills (10 percent). About one-third of the incidents were related in some way to storage, treatment, or disposal of wastes.

Privately owned septic systems are not shown as a major source of ground-water contamination (approximately one percent of the instances documented) in the information presented here even though they are suspected in many instances. This is due in part to the difficulty in positively identifying an individual septic system as the source of contamination. Only those incidents where there was positive evidence that a septic tank was the cause of the contamination were included in this summary.

One hundred of the 197 incidents have affected private or public water supply wells. Approximately 1,200 water supply wells were affected; all but 20 are private water supplies.

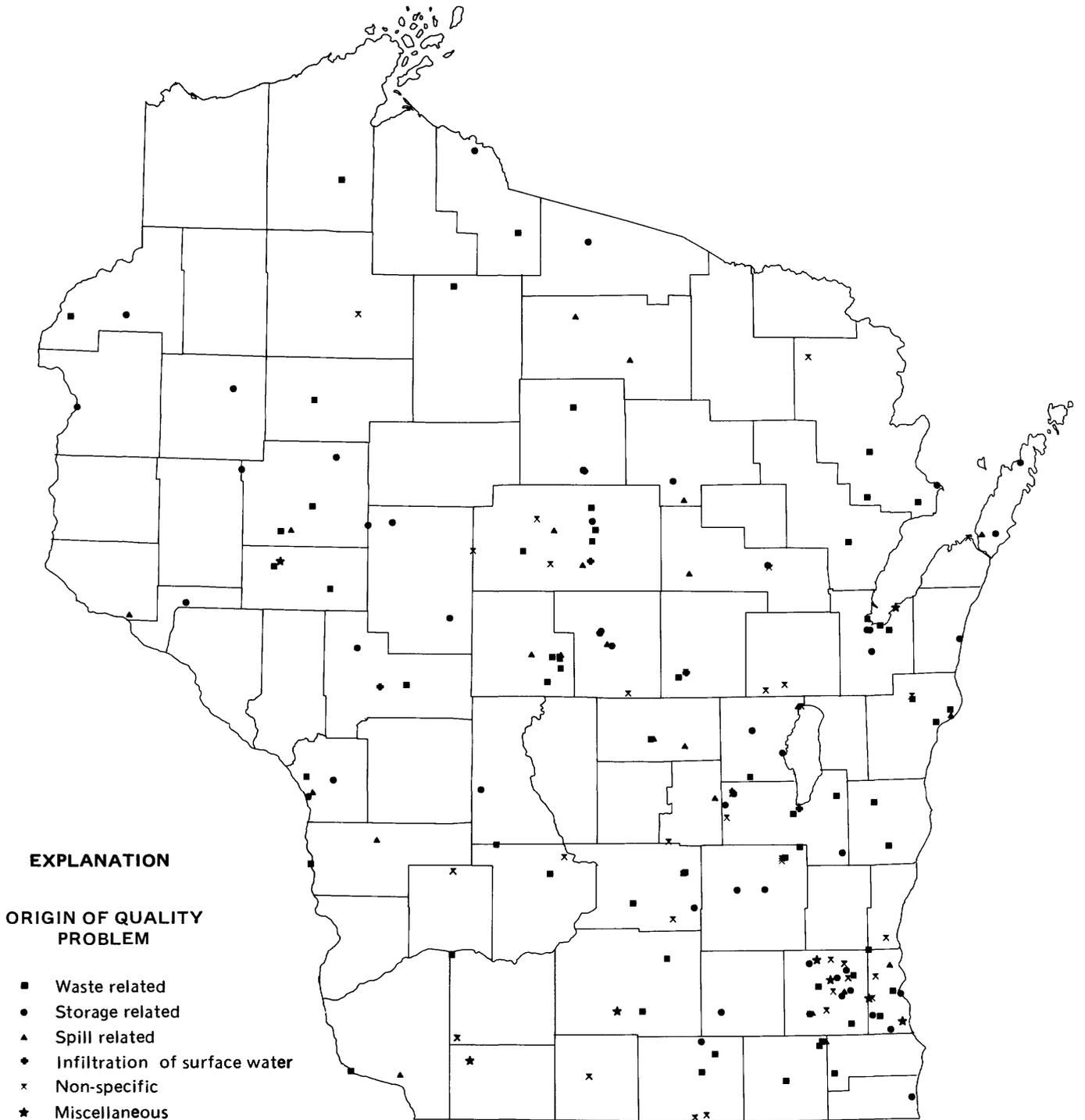
The following table gives the frequency of occurrence of types of water-quality problems that were detected in the 197 cases summarized. Some of the problems are directly attributable to contamination (detection of petroleum products, for example) but others may be secondary problems triggered by a

contaminant, or a naturally occurring problem that was aggravated by contamination or detected incidentally during the investigation. The total exceeds 100 percent because more than one constituent was involved in some of the cases.

Types of water-quality problems detected	Percent of incidents in which the problem occurred
Petroleum product	36
High chloride concentration	25
Chemical oxygen demand	18
High dissolved solids	15
Bacterial contamination	14
High iron concentration	14
Biochemical oxygen demand	13
Excessive hardness	11
Objectionable odor	11
Objectionable color	11

The map on the opposite page shows the locations of the 197 instances of contamination summarized here.

Most instances of contamination affected only the uppermost aquifer and occurred where the water table was close to the land surface. In 86 percent of the cases, average depth to water was less than 40 feet. Fifty-eight percent of the cases affected only the sand-and-gravel aquifer and another 22 percent affected dolomite aquifers.



LOCATIONS OF DOCUMENTED INSTANCES OF GROUND-WATER CONTAMINATION.

**4.0 GROUND-WATER QUALITY--Continued**

*4.7 Ground-Water Contamination*

*4.7.1 Instances of Contamination Investigated by the Wisconsin Department of Natural Resources*

#### **4.0 GROUND-WATER QUALITY--Continued**

##### *4.7 Ground-Water Contamination--Continued*

##### *4.7.2 Potential for contamination from Surface Impoundments*

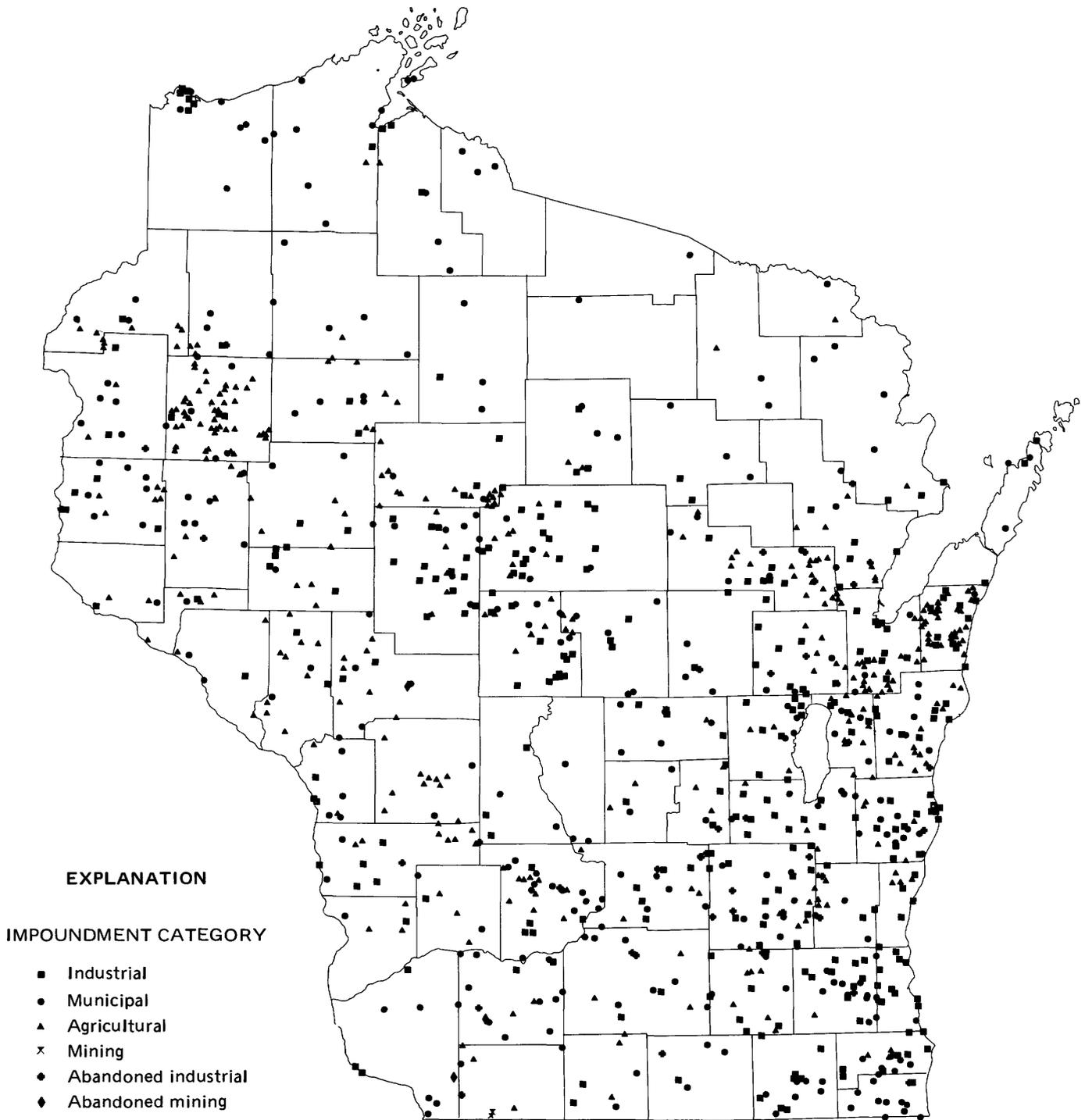
*(By T. A. Calabresa, Wisconsin Department of Natural Resources)*

### **Surface Impoundments for Storing Liquid Wastes are a Potential Source of Ground-Water Contamination**

*Seepage from surface impoundments (commonly known as pits, ponds, and lagoons) was the contaminant source in 16 percent of the ground-water contamination cases documented by the Department of Natural Resources. These impoundments are potential sources of additional ground-water contamination.*

As of October 1979, the Department of Natural Resources was aware of 1,802 impoundments at 1,071 sites; the impoundments were used for storage and disposal of a variety of liquid and semiliquid wastes. The sites may be classified according to their principal use. The largest number of sites (36.5 percent) were for disposal of agricultural wastes

followed by industrial (35 percent), municipal (28 percent), and mining (0.5 percent). Approximately 95 percent of the sites were in active use as of October 1979. Location of the sites and their principal uses are shown on the map.



SURFACE IMPOUNDMENT SITES FOR STORAGE OF LIQUID AND SEMILIQUID WASTES AS OF OCTOBER, 1979.

**4.0 GROUND-WATER QUALITY--Continued**

*4.7 Ground-Water Contamination--Continued*

*4.7.2 Potential for Contamination from Surface Impoundments*

#### **4.0 GROUND-WATER QUALITY--Continued**

##### *4.7 Ground-Water Contamination--Continued*

##### *4.7.3 Potential for Contamination from Landfills*

*(By T. A. Calabresa, Wisconsin Department of Natural Resources)*

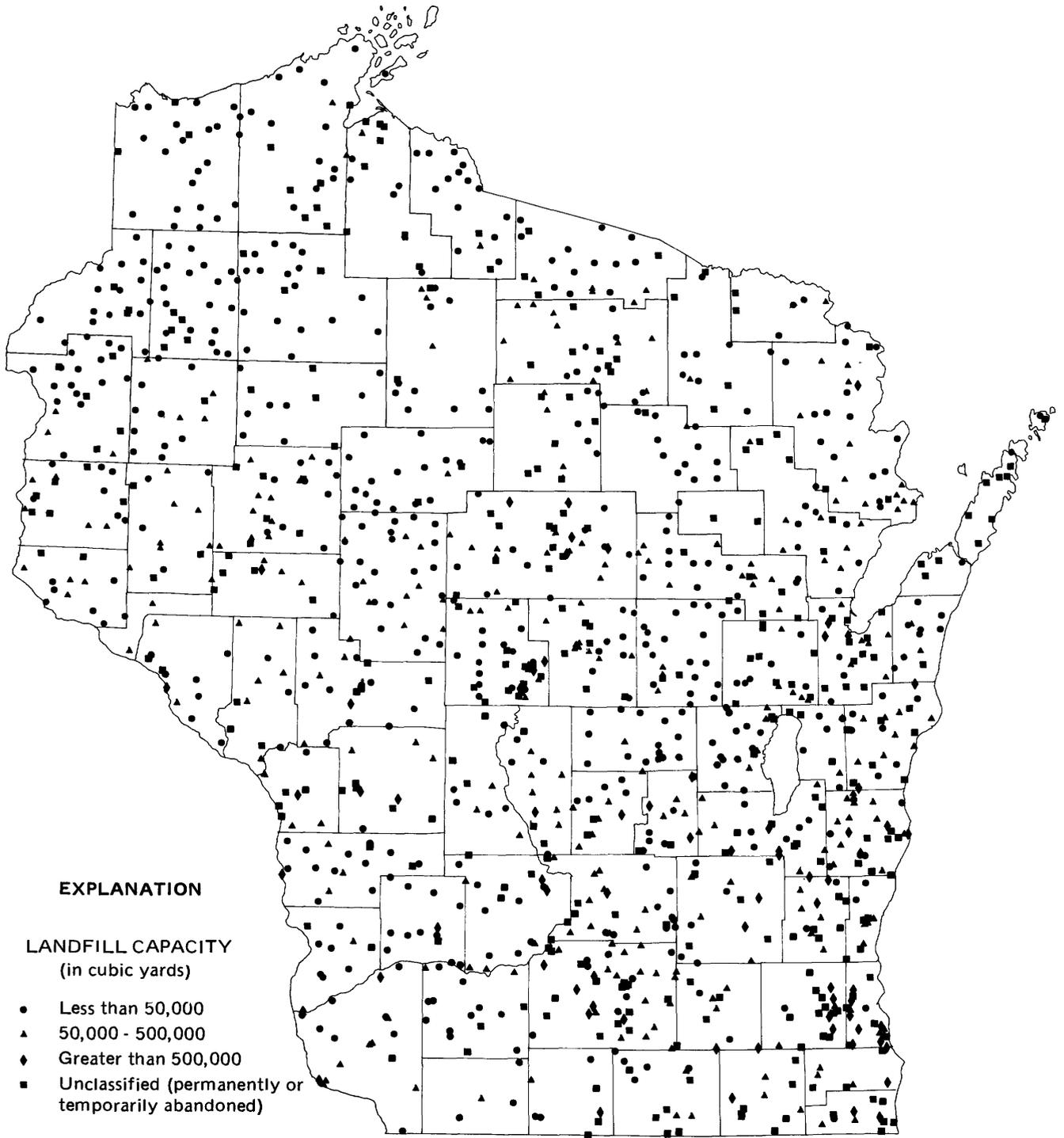
### **Landfills are a Potential Source of Ground-Water Contamination**

*Leachate from landfills was a contaminant source in 12 percent of the ground-water contamination cases documented by the Department of Natural Resources. It is likely that many as yet unidentified instances of ground-water contamination from landfills have occurred.*

As of February 1981, there were 1,358 landfill sites registered with the Department of Natural Resources. The locations of these sites and their approximately capacities are shown on the map. Mitigation of ground-water contamination was considered in the design of only about 250 of these sites, and ground-water-quality monitoring is carried out at about 200 sites.

At 83 percent of the sites where ground-water

contamination has been documented, the contamination was detected in monitoring wells. Monitoring wells are required at many new landfills and will probably be installed at older landfills as needed. Thus, it is assumed that the number of documented instances of ground-water contamination from landfills will increase as the number of landfills with monitoring wells increases.



LANDFILL SITES REGISTERED WITH THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES AS OF FEBRUARY, 1981.

#### **4.0 GROUND-WATER QUALITY--Continued**

##### *4.7 Ground-Water Contamination--Continued*

##### *4.7.4 Potential for Contamination from Other Sources*

*(By T. A. Calabresa, Wisconsin Department of Natural Resources)*

### **Spills and Leakage from Buried Storage Tanks are Potential Sources of Ground-Water Contamination**

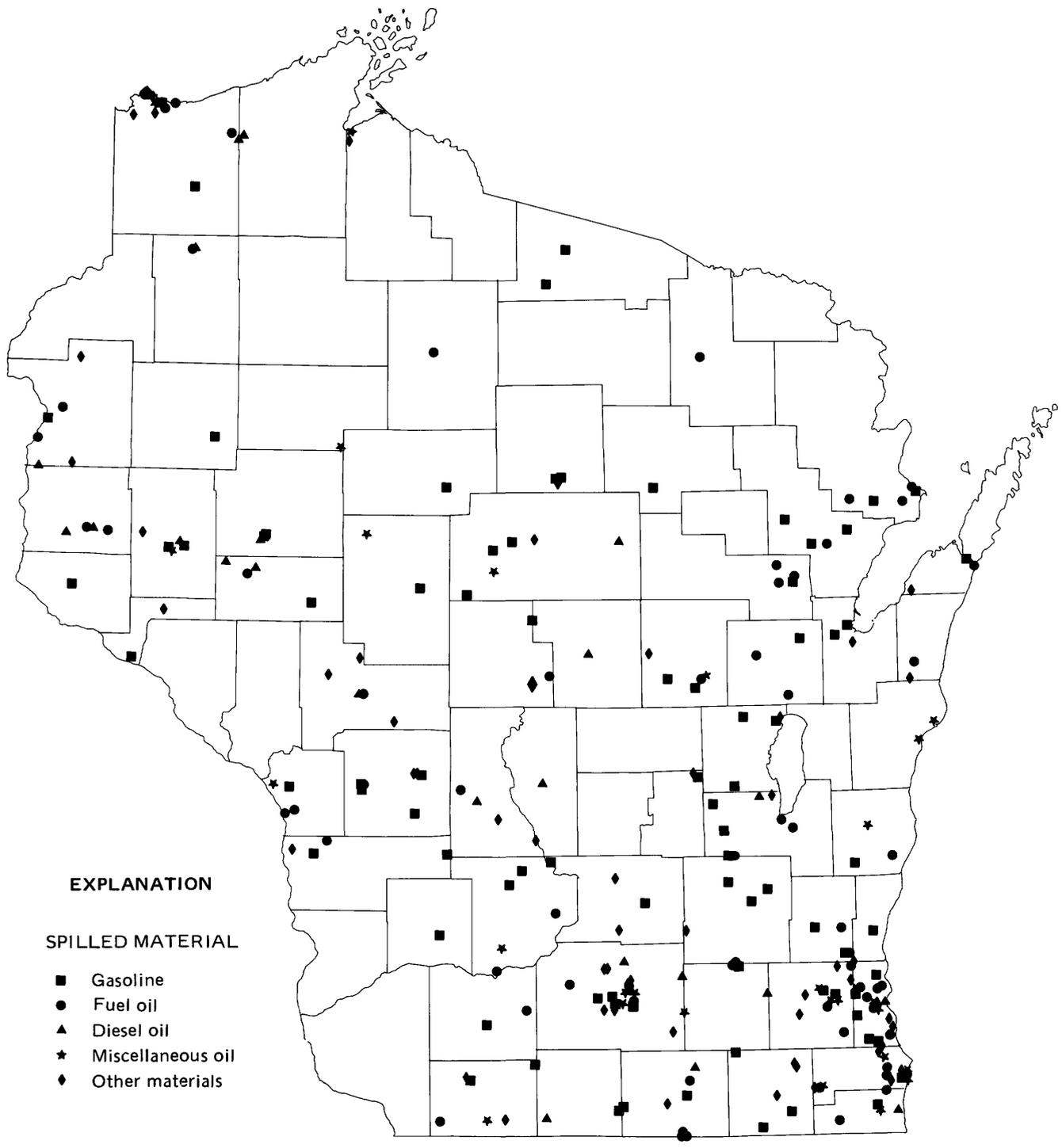
*Leakage from buried pipes and storage tanks was the contaminant source in 29 percent of the ground-water contamination cases documented by the Department of Natural Resources. In almost half of the spills reported, the contaminant reached the water table.*

Most leaks from buried pipes or tanks involve petroleum products from gasoline stations and private fuel oil storage facilities. Inspection and surveillance of these facilities are limited and improper abandonment is common. Because of this, these facilities are a continuing threat to ground-water quality.

A spill is considered here as any intentional or accidental discharge of a substance that may be a substantial present or potential hazard to human health or the environment. The Department of Natural Resources received reports of 2,076 spills between

1968 and 1980; of these, 54 percent involved less than 1,000 gallons and only 6 percent involved more than 5,000 gallons. In 74 percent of the spills, the contaminant was gasoline or another petroleum product. About half of the spills occurred at a "fixed facility" (the material spilled was not in transit).

The map shows a representative sampling (about 10 percent) of the locations and types of spills reported in 1968-1980. Accurate location information is not available for many spills.



LOCATIONS OF REPRESENTATIVE REPORTED SPILLS, 1968-1980.

**4.0 GROUND-WATER QUALITY--Continued**

*4.7 Ground-Water Contamination--Continued*

*4.7.4 Potential for Contamination from Other Sources*

#### 4.0 GROUND-WATER QUALITY--Continued

##### 4.8 Usefulness of Available Data for Contamination Evaluation

### **Available Data Provide an Overview of Ground-Water Quality, but are Generally Insufficient for Evaluation of Ground-Water Contamination**

*Most documented instances of ground-water contamination in Wisconsin have had only local effects on ground-water quality, and intensive site specific investigations were necessary to evaluate their impact. The most commonly occurring contaminants are exotic materials whose behavior in ground water is poorly understood.*

Many potential sources of ground-water contamination exist (landfills, surface waste-storage impoundments, buried storage tanks), and some of these are undoubtedly causing local ground-water contamination that is not readily apparent from existing regional data.

Much pertinent data held by State agencies were not included in this report because it is not readily accessible (organization and accessibility of conventional files, data not in machine-readable format) or because quality-control procedures, analytical methods, and sample collection methods are not documented. Furthermore, much of this ground-water quality data is not correlated with supporting well construction and hydrogeologic data. The analytical data from WATSTORE that were used in this report are correlated with available well construction and hydrogeologic data.

Entire data bases may be biased because of consistent differences in analytical methods or the reason for collecting the data. Much of the historical ground-water-quality data in WATSTORE, for ex-

ample, was accumulated for the purpose of defining "natural" ground-water quality and, because of this, it may not accurately reflect existing ground-water contamination. This is illustrated by the relatively low nitrate-nitrogen concentrations in WATSTORE compared to concentration data reported in other investigations and data bases that concentrate on problems of nitrate contamination of ground water.

Temporal changes in ground-water quality are of interest in ground-water contamination assessment, but few pertinent long-term data are available, and data that are available have not been evaluated statistically for the significance of long-term trends.

Available regional water-quality data form a useful starting point for planning the collection of site-specific data needed for contamination assessment. Design of an effective data collection program for contamination assessment requires knowledge of background concentration distributions for the constituents of interest.

#### **4.0 GROUND-WATER QUALITY--Continued**

##### *4.9 Data Needs*

### **Contamination Assessment Requires a Basic Understanding of the Hydrogeologic Environment and the Chemical Behavior of the Potential Contaminant**

*The direction and rate of ground-water movement must be determined as a first step in evaluating the impact of a potential contaminant on ground-water quality. Secondly, knowledge of the chemical behavior of potential contaminants in ground water is necessary to predict how they will change chemically or be attenuated as they move with the ground water.*

In addition to basic research on ground-water hydrology and water chemistry, empirical study of existing ground-water contamination could provide practical knowledge of the behavior and movement of various contaminants in ground water.

Monitoring programs designed for the dual pur-

pose of adding to general understanding of the movement and fate of specific contaminants in various hydrogeologic environments and complying with statutory requirements appear to be an effective means of providing new data for assessment of potential ground- water contamination.

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