ILLINOIS GROUND-WATER OBSERVATION NETWORK

- A Preliminary Planning Document

By L. R. Frost, Jr.[1], Michael O'Hearn[2], J. P. Gibb[2], and M. G. Sherrill[1]

[1]U.S. Geological Survey
[2]Illinois State Water Survey

U.S. GEOLOGICAL SURVEY

Open-File Report 84-584

Prepared in cooperation with the

ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES,

STATE WATER SURVEY

Urbana, Illinois

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4th Floor
102 East Main Street
Urbana, IL 61801

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
[Telephone: (303) 234-5888]

CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO

INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use International System of Units (SI) the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06308	liter per second (L/s)

ILLINOIS GROUND-WATER OBSERVATION NETWORK

- A Preliminary Planning Document

By L. R. Frost, Jr.[1], Michael O'Hearn[2], J. P. Gibb[2], and M. G. Sherrill[1]

ABSTRACT

Water-level and water-quality networks in Illinois were evaluated to determine the adequacy and completeness of available data bases. Ground-water data in present data bases are inadequate to provide information on ground-water quality and water levels in large areas of Illinois and in the major geohydrologic units underlying Illinois and surrounding areas. Data-management needs indicate that a new data base is desirable and could be developed by use of carefully selected available data and new data. Types of data needed to define ground-water quality and water levels in selected geohydrologic units were tentatively identified. They include data on concentrations of organic chemicals related to activities of man, and concentrations of inorganic chemicals which relate either to man's activities or to the chemical composition of the source aquifer. Water-level data are needed which can be used to describe short- and long-term stresses on the ground-water resources of Illinois. Establishment of priorities for data collection has been deferred until existing hydrologic data files can be stored for usable data and until input from other local, State, and Federal agencies can be solicited and compiled.

INTRODUCTION

The purpose of a ground-water quality and ground-water level network is to provide accurate, timely, and complete water data for use by managers, regulators, and researchers. The purpose of this report is to review requirements for ground-water observation networks, to access the status of ground-water data availability in Illinois, identify deficiencies in the available data base, and outline procedures for establishing a new data base and a ground-water observation-well network in Illinois. The scope of this study included a statewide assessment of both the available data and data management needs.

---

[1]U.S. Geological Survey

[2]Illinois State Water Survey

The objectives of this report include:

1. identifying the uses for ground-water quality and levels in Illinois;

2. identifying the geohydrologic units that should be monitored in order to evaluate Illinois' ground-water resources;

3. identifying the sources of and assessing the quantity, usefulness, and manageability of available data;

4. establishing criteria for selecting data-storage and management systems and describing available systems; and

5. developing communications with Federal, State, and local agencies to establish a mutually beneficial and usable data base.

NEED TO OBSERVE GROUND-WATER QUALITY AND LEVELS

National Needs

A basic mission of the U.S. Geological Survey includes systematically determining and evaluating the quantity and quality of the Nation's water resources. Systematic observation and evaluation of principal hydrologic units are needed to accomplish this goal. Groundwork for this effort has been laid by the National Stream Quality Accounting Network (NASQAN) and Regional Aquifer Systems Analysis (RASA) programs. To date, only areally large aquifers have been included in the RASA program. Many significant aquifers remain for which water levels and water quality need to be evaluated to establish trends and to provide management information.

Interstate Needs

Mutual interstate pumping effects occur between the Chicago metropolitan area in Illinois and both southeastern Wisconsin and northwestern Indiana. Eight northeastern counties of Illinois and seven southeastern counties of Wisconsin are underlain by the hydrologically and stratigraphically continuous Cambrian-Ordovician aquifer (sandstone aquifer in Wisconsin). This aquifer, a major source for public and industrial supplies, is a classic artesian system. Pumpage in either Wisconsin or Illinois causes drawdown in the other State. Major overlapping cones of depression have developed around Chicago and Milwaukee. Similar, but less pronounced, effects occur near Chicago, Illinois, and the Gary-Hammond area in Indiana.

Although not presently occurring, there is the potential for interstate effects of continued ground-water pumpage from the Cambrian-Ordovician aquifer in Rockford, Illinois, and Beloit, Wisconsin. Rockford, the second largest city in Illinois, obtains large quantities of water from the Cambrian-Ordovician aquifer system. Likewise, Beloit, Wisconsin, obtains its water from the same aquifer and furnishes water to South Beloit, Illinois.

State Needs

Effective management of Illinois' ground-water resources requires comprehensive information, including:

1. geohydrologic definition of aquifers (extent, properties, flow patterns, and flow rates);
2. estimated safe yield of major aquifers;
3. amounts and locations of withdrawals;
4. effects of withdrawals on the system;
5. identification of critical recharge areas;
6. base-line water-quality data for all aquifers and recharge areas;
7. determination of water-level or water-quality trends and their causes;
8. inventory of potential sources of contamination;
9. concentration of synthetic organic chemicals in water;
10. accessible data storage and retrieval system with capability to compute statistics and summaries; and
11. periodic summaries of data (maps, graphs, and tables), possibly as often as yearly, to identify trends.

CHARACTERISTICS OF GROUND-WATER NETWORKS

The general objectives of an observation-well network are to provide information to describe and understand fluctuations and trends in distribution, magnitude, and quality of ground-water resources. An initial step in the design of such a system is to determine the anticipated uses to be made of the data. These uses should help define specific network objectives and subsequent collection of data to satisfy the objectives.

Once specific network objectives are defined, an assessment of available data should be made and other potential sources of ground-water data should be identified and assessed. These assessments, made in consideration of the network objectives, should define needs for additional data. Priorities can then be set for investigations and(or) additional sampling to satisfy network objectives. The frequency of measurement and parameters to be measured initially may be more intensive than ultimately needed to describe variations in particular ground-water systems. Conversely, the initial observations might yield information to indicate the need for more intensive sampling. Through stepwise modification of observation schemes and investigations, long-term sampling sites can be selected to represent important geohydrologic units and to define trends in ground-water conditions.

Recent observations of ground-water degradation and depletion at numerous sites in the nation have focused attention on needs for reliable information on ground-water resources. Federal and State environmental agencies have begun collecting ground-water quality and quantity data that are needed to better define existing conditions, identify problems, and define practical solutions. The U.S. Environmental Protection Agency (1980) has proposed a ground-water-protection strategy based on the classification of ground water according to its present and potential uses and its susceptibility to degradation. This classification requires a thorough understanding of present-day ground-water quality and ground-water flow systems.

There have been numerous reports on the planning and design of efficient multi-purpose ground-water observation networks. Ward (1978, 1981) emphasized the importance of matching activities to objectives. He also stressed that ground-water monitoring involves more than data collection and cites the need to include data analysis and anticipated information utilization in the planning process.

LeGrand (1968) suggested that the need for data be determined by, among other things, the probability and consequences of contamination in strategic areas, a concept based on the need for efficient use of time and money. Areas in Idaho with the greatest potential for contamination are emphasized in a statewide ground-water quality network proposed by Whitehead and Parliman (1979). This Idaho program was designed to detect changes in ground-water quality in 15 areas with the highest "priority indices" and to give resource managers information on the general quality of ground water in all areas of the State. Costs for implementing the program were estimated.

Remote sensing has been used successfully to detect the migration of leachate from active and abandoned landfills under certain conditions (Sangrey and Philipson, 1979). Although it cannot provide a direct indication of ground-water quality, remote sensing allows an investigator to examine a very large area in a relatively short time.

A comprehensive methodolgy for ground-water quality monitoring that can be applied at any location is suggested by Todd and others (1976). That study emphasized "source monitoring" which attempts to identify the quantity and quality of effluent from potential contamination sources. The study also presented a general stepwise strategy for determining the impact of human activities on ground-water quality. A companion report (Tinlin, 1976) presents some examples of how the method of Todd and others can be applied. Tinlin evaluated existing monitoring programs for five different sites and types of ground-water contamination, and suggested alternative approaches. Cost estimates for suggested optimal monitoring programs are included.

Stallman (1968) pointed out that the cost and value of ground water must be determined in order to optimize data collection and to evaluate the benefits derived from monitoring networks. A discussion of the economic theory associated with ground-water quality monitoring is given by Crouch and others (1976). They placed emphasis on a thorough analysis of the estimated benefits and costs associated with regulatory ground-water quality monitoring.

Heath (1976) discussed the evaluation of existing ground-water level observation programs with the intent of making them more productive and efficient. Heath stated that "before determining the adequacy of an existing program, it is first necessary to (1) identify the objectives of the program and (2) determine in fairly definite terms what wells are needed to meet these objectives. Once these two requirements are met, it is relatively simple to determine which wells in the existing program are providing useful data." Heath proposed three different water-level observation networks, each designed to satisfy a different set of management objectives.

Two types of monitoring-well networks form the basis for a ground-water level and quality-surveillance system for the State of North Carolina (Peek and Laymon, 1975). Their "base-line" network is designed to provide needed information on ground-water levels and quality in areas and aquifers that are relatively unaffected by human activities. Their "management" network provides the data needed to assess changes in ground-water quality resulting from human activities. The latter requires an inventory of potential sources of ground-water pollution.

According to Warner (1974) an accurate definition of water-quality monitoring might be "a scientifically designed program of continuing surveillance; including direct sampling and remote quality measurements, inventory of existing and potential causes of change, and analysis of the cause of past quality changes and prediction of the nature of future changes." Warner also stressed the importance of locating potential pollution sources and predicting rates and direction of ground-water movement in order to design an efficient and effective sampling program.

Marie (1976), in a preliminary evaluation of the State of Indiana's ground-water data network, stated, "A good ground-water data program provides the basic data needed to solve an anticipated water-related problem within the accuracy required at an acceptable cost." The Indiana study and a similar study for the State of Minnesota (Hult, 1979) both stressed the importance of tailoring the design of a statewide monitoring network to the specific requirements of the Federal or State agencies responsible for the management of the ground-water resource. This usually involves integrating the proposed plan with previous and ongoing data collection and information processing procedures. Similarly, both studies found that periodic reevaluation of the monitoring program is necessary to respond to changing conditions or information needs. Hult pointed out that a properly planned monitoring program provides the consistency of technique essential for data to be comparable over time and space.

DESCRIPTION OF GROUND-WATER CONDITIONS IN ILLINOIS

General Geohydrologic Conditions

Ground water in Illinois is obtained from unconsolidated sand and gravel deposits (largely from glacial drift), and from sandstone, limestone, and dolomite bedrock underlying the unconsolidated deposits. The northern one-third of the State has the most favorable conditions for producing large yields. Extensive deposits of water-yielding sand and gravel and bedrock are present in the north. Conditions also are favorable in the extreme southern part of the State. Elsewhere conditions are generally less favorable except where preglacial stream channels are filled with sand and gravel.

The distribution of sand and gravel aquifers in Illinois (including Cretaceous and Tertiary deposits) and estimated yields are shown in figure 1. Higher yields are normally associated with major glacial bedrock valleys.

Figure 2 shows the generalized bedrock geology in Illinois. Rocks in Illinois, above the Precambrian basement complex, are dominantly consolidated sandstone, limestone, dolomite, and shale that originally were deposited as marine sediments during the Paleozoic Era. From oldest to youngest, these units consist of the Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian Systems. Maximum thickness of the Paleozoic units exceeds 14,000 feet in the southern part of the State. The areal distribution of the Paleozoic rocks (fig. 2) is related to structure, unconformities, and the relief of the bedrock surface (Willman and others, 1975). Figure 3 shows producing areas and estimated yields from bedrock aquifers, which, for the most part, are Paleozoic rock units.

The Cretaceous System of the Mesozoic Era in Illinois consists of marine deltaic or near-shore sediments in relatively small areas in the south and west (fig. 2). These sediments generally are unconsolidated and have a maximum thickness of about 500 feet.

Unconsolidated deposits of the Cenozoic Era include sand, silt, and clay in the Tertiary System, glacial drift materials in the Pleistocene System, and recent alluvial deposits. These Cenozoic deposits form the surface of almost the entire State and in some areas attain thicknesses up to 600 feet.

Geohydrologic Units in Northern Illinois

In the northern one-third of the State, large quantities of ground water for industrial, municipal, and domestic use are withdrawn from wells in glacial drift, from shallow dolomite of Silurian and Ordovician age, and from deep sandstone of Cambrian and Ordovician age. The generalized stratigraphy and water-yielding properties of geohydrologic units in northern Illinois are shown in Illinois State Water Survey Report of Investigations 43 (Walton and Csallany, 1962).

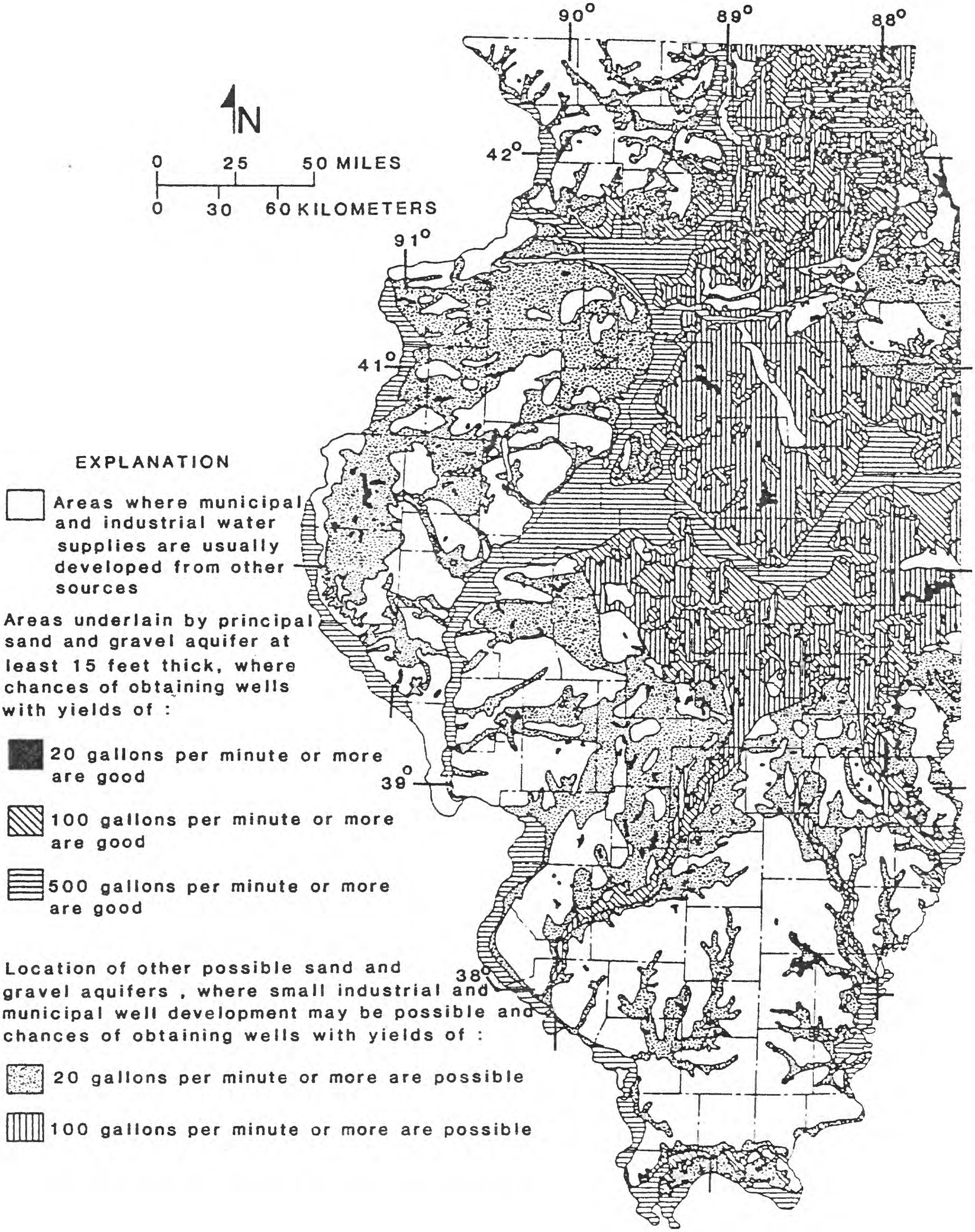

Figure 1.--Estimated yields of Pleistocene, Tertiary, and Cretaceous sand and gravel aquifers in Illinois (after Visocky and others, 1978).

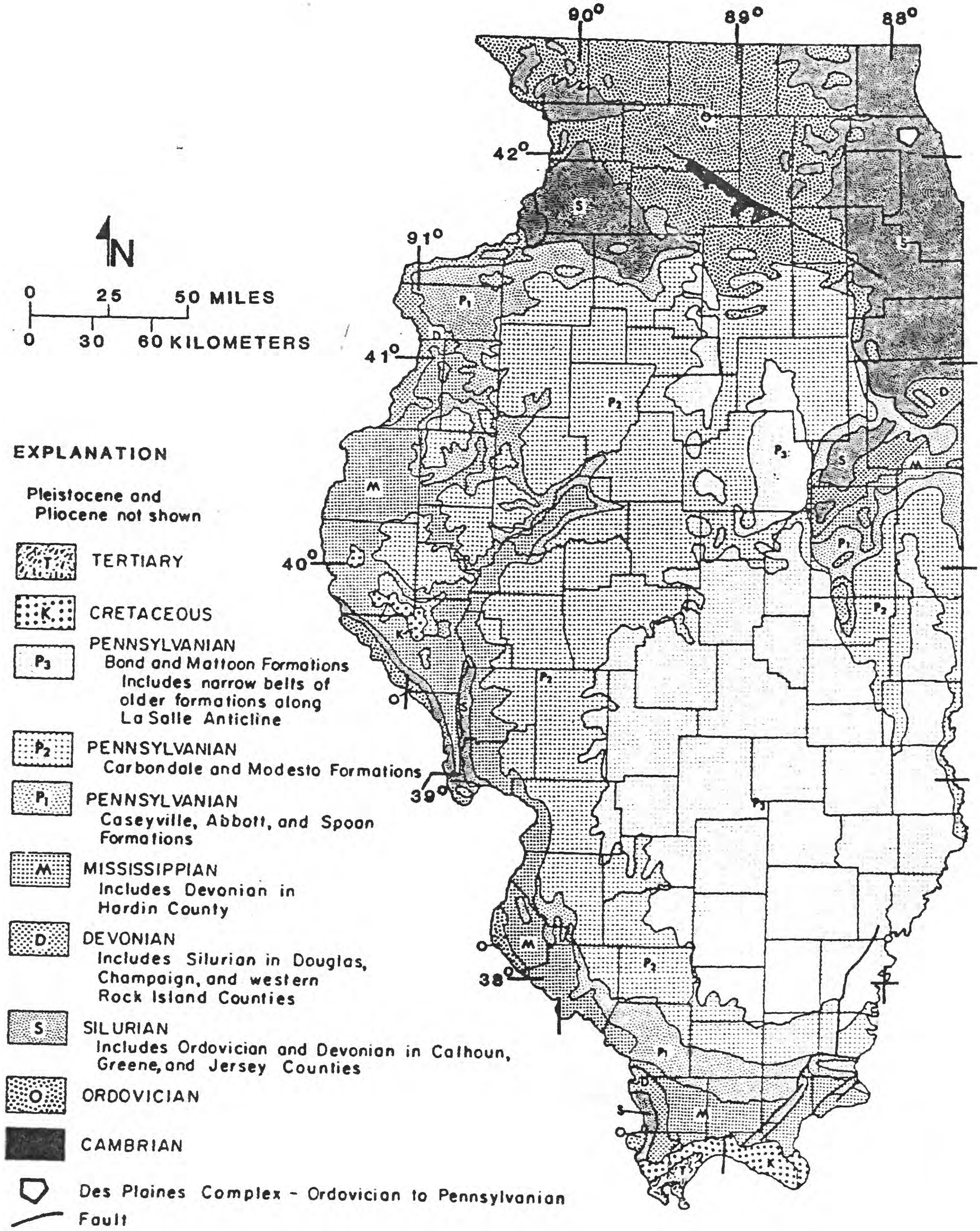

Figure 2.--Generalized bedrock geology in Illinois (after Willman and Frye, 1970).

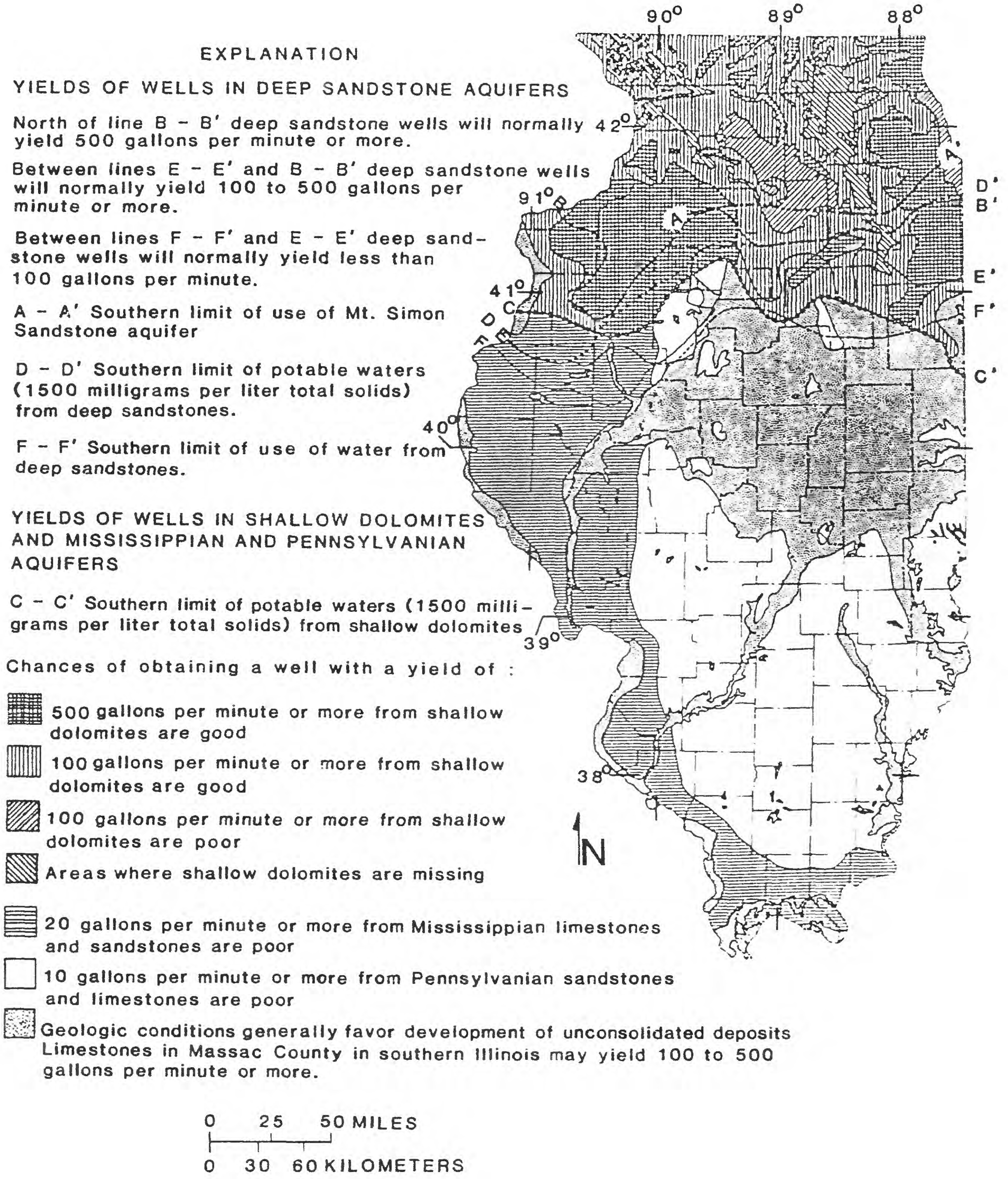

Figure 3.--Estimated yields of wells in bedrock aquifers in Illinois (after Visocky and others, 1978).

Glacial Drift

The probability for development of ground water from glacial drift ranges from low to high depending on the thickness and permeability of the drift. The largest supplies are generally derived from permeable outwash sand and gravel in major valleys. Wells developed in this outwash commonly yield 1,000 gal/min (fig. 1).

Pennsylvanian, Mississippian, and Devonian Aquifers

Rocks of Pennsylvanian, Mississippian, and Devonian ages underlie the glacial drift at some locations in the southern part of northern Illinois (figs. 2 and 3). Wells in these rocks yield small quantities of water from jointed dolomite, limestone, and sandstone.

Shallow Bedrock Aquifers

The shallow bedrock aquifers include rocks of Silurian and upper Ordovician age. Silurian age rocks, mostly dolomite, are present beneath the glacial drift in eastern and southwestern parts of northern Illinois. They directly underlie the Mississippian and Devonian rocks in the southern part (figs. 2 and 3). Where the Galena-Platteville Dolomite is the upper bedrock unit, it is commonly productive. Ground water is present in joints, fissures, and solution channels. Some wells yield up to 1,000 gal/min.

Maquoketa Shale Confining Unit

The Maquoketa Shale overlies the Galena-Platteville Dolomite exclusive of the central and northwestern parts of the State. It generally does not yield water but acts as a confining bed between the shallow dolomite aquifer (Silurian) and the Cambrian-Ordovician aquifer.

Cambrian-Ordovician Aquifer System

This aquifer predominantly consists of rocks of Ordovician age--namely, the St. Peter Sandstone and the Ironton-Galesville Sandstone. On a regional basis, the entire sequence of rock strata of the Cambrian-Ordovician System seems to behave, hydraulically, as a single aquifer unit.

The St. Peter Sandstone is widely used for domestic, small municipal, and small industrial water supplies. These rocks are mostly fine- to medium-grained sandstone with dolomitic and shaley zones. It ranks third after the Ironton-Galesville Sandstone and Mt. Simon Sandstone in productivity and consistency of yield.

The Ironton-Galesville Sandstone forms the most productive aquifer in the Cambrian-Ordovician system, possibly yielding 50 percent of the system's total production. The Ironton-Galesville Sandstone is composed of fine- to coarse-grained material, some of which is dolomitic. The basal zone is commonly the least cemented and the best water producer.

Eau Claire Confining Unit

The middle and upper zones of the Eau Claire Formation are shales, dolomites, and shaley sandstones that commonly act as a confining bed between the overlying Ironton-Galesville Sandstone and the Mt. Simon Sandstone. In the southern part of northern Illinois, these zones greatly retard upward movement of highly mineralized water from the Mt. Simon Aquifer.

Mt. Simon Aquifer

Sandstones of the lower Eau Claire Formation and the Mt. Simon Sandstone are hydraulically interconnected and are collectively called the Mt. Simon Aquifer. The medium- to coarse-grained parts of this aquifer yield moderate to large quantities of water. Commonly, wells are constructed to penetrate only the upper few hundred feet because of highly mineralized water in the lower part. Because of the confining nature of the Eau Claire Formation, higher hydrostatic heads occur more often in the Mt. Simon Aquifer than in the shallower bedrock aquifers.

Geohydrologic Units in the Southern Two-Thirds of Illinois

Exclusive of Extreme Southern Illinois

Glacial drift aquifers

Sand and gravel deposits in the southern two-thirds of Illinois are mostly limited to the courses of present or preglacial stream channels. Among these aquifers are sand and gravel deposits of the Mississippi, Illinois, buried Mahomet, Wabash, Ohio, Kaskaskia, and Embarras Valleys (Willman and Frye, 1970). Elsewhere in the area, the glacial drift is normally thin and usually devoid of sand and gravel.

These deposits are sources or potential sources of municipal and industrial supplies. Locally, small supplies may be developed for domestic and farm purposes by installing large diameter dug or augered wells.

In much of the southern two-thirds of Illinois the glacial drift may be thin or relatively impermeable. Where there is little drift, wells in the thin sandstone and limestone of Pennsylvanian age and sandstone and limestone of Mississippian age yield small quantities of water. These units are commonly the only sources of water for domestic and small municipal and industrial supplies. Illinois State Geological Survey Circular 212 (Pryor, 1956) shows the generalized stratigraphy and water-yielding properties of geohydrologic units in southern Illinois.

Pennsylvanian aquifer

Pennsylvanian rocks form the bedrock surface in about four-fifths of Illinois (fig. 2). The rocks include shales, thin limestones, thin sandstone formations of limited areal extent, and coal beds. The Pennsylvanian rocks generally have low porosities and permeabilities and yield generally small amounts of water to wells from interconnected pores, fractures, crevices, joints, and bedding planes.

Mississippian aquifer

Mississippian rocks form the bedrock surface in parts of eastern, southern, and western Illinois (fig. 2). The Mississippian rocks are divided into three series which are, in descending order: the Chester Series, the Valmeyer Series, and the Kinderhook Series.

The Chesterian Series is composed of sandstone, limestone, and shale formations and has a maximum thickness of 1,400 feet. Domestic, farm, and small municipal water supplies are developed from sandstone and limestone formations where they form the bedrock surface or where overlying Pennsylvanian rocks are thin.

The Valmeyeran Series, which is composed largely of limestone, forms the bedrock surface in large areas in western and southern Illinois (fig. 2). Rocks in this series form a widespread and dependable aquifer for domestic and farm supplies and locally is a source of water for municipal and industrial supplies.

The Kinderhook Series consists largely of shale, thin limestone, and sandstone. Rocks in this series yield very little water to wells and are not considered important aquifers.

Devonian, Silurian, and Ordovician aquifers

These bedrock units have a limited outcrop area in southern Illinois (fig. 2). Where they do occur as surficial bedrock units, they produce dependable yields of water to wells from limestone and thin sandstone units. The yields are commonly adequate for domestic and farm supplies and locally are adequate for municipal and industrial supplies.

Extreme Southern Illinois

In the extreme southern tip of Illinois, conditions are favorable for ground-water supplies where there are sandstone, limestone, or extensive sand and gravel aquifers.

Tertiary and Cretaceous aquifers

Sand and gravel of Tertiary and Cretaceous age form thick deposits in the southernmost counties of Illinois. These deposits are excellent sources of ground water for domestic and farm supplies and some valleys offer potential for larger municipal and industrial supplies.

Mississippian, Devonian, and Silurian aquifers

The Mississippian, Devonian, and Silurian limestones, dolomites, and cherts are more weathered and fractured where the overlying unconsolidated materials of Tertiary and Cretaceous age are thin or absent. These creviced formations commonly yield water to domestic wells at depths of less than 200 feet and are potential sources of ground water for municipal and industrial supplies.

ASSESSMENT OF AVAILABLE DATA

Ground-Water Quality Data

The Illinois State Water Survey (ISWS) has been maintaining records of chemical analyses of ground water since 1890. Records of some 28,000 analyses by the ISWS, Illinois Department of Public Health (IDPH), and Illinois Environmental Protection Agency (IEPA) are in a machine-readable storage and retrieval system. These records include public water-supply wells, industrial wells, irrigation wells, and privately-owned domestic wells.

The creation of a computerized file for ground-water quality data was the first step toward making this information available for use on a large scale. However, as with any large data base, there are limitations to its efficient use and problems caused by omissions and errors in the data, the most significant of which is the omission of reliable source-aquifer information.

The three agencies that collected the data have operated seven different laboratories during the past 90 years. In addition to variations in results among laboratories, changes in personnel and laboratory procedures also contribute to differences in analytic results that might affect the comparability of the data in the ISWS data base.

The information in the file is not the result of random sampling and over the years certain biases have been introduced into the file. Chemical analyses of samples from domestic wells were performed principally by IDPH and

ISWS. Most of these samples were submitted voluntarily by well owners. There was no coordination of locations, what aquifers, or what wells were sampled. In many cases, "problem" wells yielding poor quality water are sampled to gain information needed to understand the problem. Wells producing high quality water are less likely to be represented in the file. Likewise, data for special ground-water quality studies are more apt to be for areas of known or suspected poor water quality regardless of whether the occurrence be natural or by degradation.

The majority of data are from the routine sampling of public water-supply wells and are less likely to be biased than those described above. Routine sampling of municipal water-supply wells to determine necessary treatment, changes in water quality, and compliance with recent regulatory requirements has resulted in a ground-water quality data base that is more uniform with respect to the types of data in each entry.

Types of data stored in the ISWS ground-water quality data file are given in table 1. Few samples have all the types of data listed in this table. Virtually no data are available for synthetic organic compounds in Illinois ground water. Dissolved solids (non-filterable residue), hardness, sulfate, nitrate, chloride, and iron are available for most samples. Evaluation of information in the file shows (fig. 4) that about 83 percent of the data were collected after 1940.

Gibb and O'Hearn (1980) made a cursory examination of the ISWS files from the past 40 years (1940 through 1979). Use of data from this period eliminated less than 17 percent of the total data base and minimized effects of trends and changes in analytical methods. The data were sorted by depth into five well or aquifer categories: (1) drift wells less than 50 feet deep, (2) drift wells equal to or greater than 50 feet deep, (3) Pennsylvanian aquifers, (4) shallow limestone and dolomite aquifers, and (5) deep sandstone aquifers. Median concentrations of total dissolved solids (TDS), hardness, sulfate, nitrate, chloride, and iron were plotted and mapped by township. The coefficient of variation and frequency distribution of each parameter also were determined in areas where adequate data were available. Ground-water-quality trend analyses were made on data for 21 public water-supply well fields. Seven well fields tapped sand and gravel deposits, one tapped Pennsylvanian age rocks, one tapped Mississippian age rocks, three tapped Silurian age dolomite, and nine tapped the deep sandstone aquifer. Water-quality trends were detected at two well fields in sand and gravel, three well fields in Silurian dolomite, and two well fields in the deep sandstone.

Category 4 includes different geologic units in three distinct areas of the State. In northeastern Illinois, where the Silurian age rocks are the uppermost bedrock unit (fig. 2), it includes Silurian and Devonian age dolomites. In northwestern Illinois, it includes the Maquoketa and Galena-Platteville (middle Ordovician) units which comprise the bedrock surface. For the remainder of the State, it includes Mississippian age limestones.

Category 5 includes the deep sandstones or Cambrian-Ordovician aquifer systems. In northeastern Illinois, the Cambrian-Ordovician aquifer includes all units from the Galena-Platteville through the deeper-lying Ironton-Galesville. In northwestern Illinois, the Galena-Platteville units are not considered to be part of the Cambrian-Orodvidian aquifer.

Table 1.--Types of data stored in the Illinois State Water Survey ground-water-quality data file

General Information

Location (county, township, range, section, 10-acre plot number)
Municipality number
Well number
Source code (not reliable?)
Date of analysis
Analysis number (source of analysis)
Well depth

Chemical Characteristics

Residue	Aluminum	Lithium
Residue (nonfilterable)	Ammonium	Magnesium
Alkalinity	Barium	Manganese
Chloride	Boron	Mercury
Cyanide	Cadmium	Nickel
Fluoride	Calcium	Potassium
Hardness	Chromium	Silver
Nitrate	Copper	Sodium
Nitrite	Iron (total)	Strontium
Phosphate (filtered)	Lead	Zinc
Phosphate (unfiltered)		
Silica		
Sulfate		
Arsenic		
Selenium		

Physical Properties

Color
Odor
pH
Temperature
Turbidity

Gases

Free carbon dioxide
Methane
Hydrogen sulfide

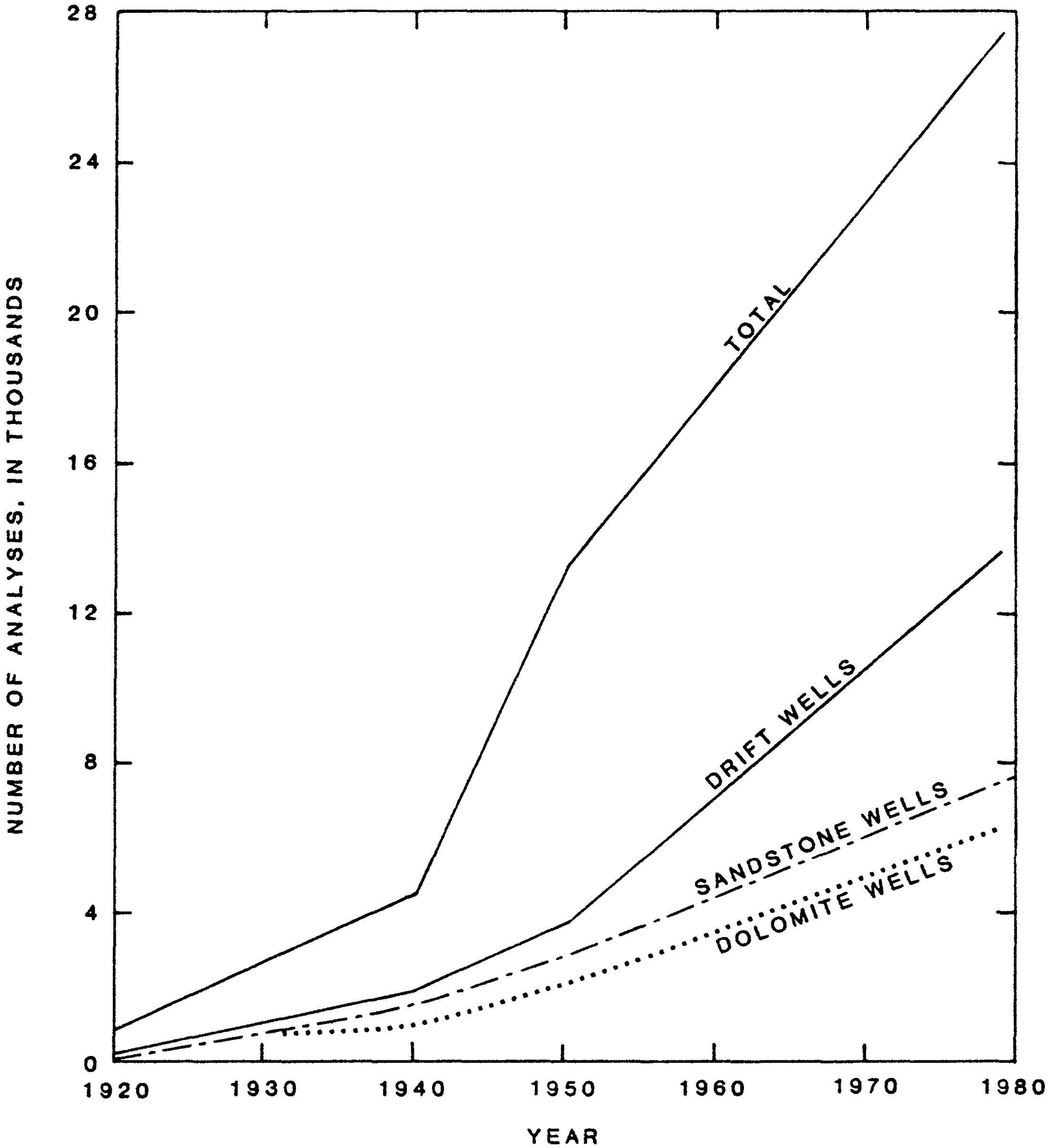

Figure 4.--Accumulated number of analyses in the Illinois State Water Survey ground-water quality data file for total dissolved minerals, 1920-78.

Maps obtained from the Illinois State Geological Survey (ISGS) were used to describe surface altitudes and thicknesses of the major geologic contacts and units, respectively.[1] Land surface altitudes of all bench marks printed on U.S. Geological Survey topographic maps for Illinois also were obtained from the ISGS.

The above information was used to compile the average land-surface altitude and average altitude of geologic contacts or aquifers for each township (approximately 36 square miles) in Illinois.[1] A second compilation included the average depths to the top and bottom of each aquifer category by township.[1] In townships with a large range in the altitudes of the major geologic units or in the land surface altitude, the accuracy of the geologic data is questionable.

The depths of the wells for which ground-water quality data were available were compared to the average depths of each aquifer category. The data were sorted into source-aquifer categories according to the deepest geologic unit penetrated. For bedrock wells, no attempt was made to account for the well bore being open to overlying units.

The U.S. Geological Survey is collecting ground-water-quality data for regional and local studies. From these studies, water-quality information has been obtained for particular aquifers. The regional studies from which data for Illinois are available include the Mississippi Embayment study and the regional study of the Cambrian-Ordovician aquifer system. Studies of areas of smaller geographic extent include ground-water modeling of the sludge-disposal, land-reclamation area in Fulton County, the hydrology of shallow ground water in McHenry County, modeling of ground water near strip-mined land in McDonough and Randolph Counties, and studies of ground-water quality at the Palos Forest Preserve and Sheffield low-level radioactive-waste disposal sites. As a part of each of these projects, existing wells were inventoried and(or) test wells were constructed. Water samples were collected from most of these wells for various types of chemical analyses including the major anions and cations, selected organic constituents, and, in the case of Palos Forest Preserve and Sheffield, radionuclide concentrations.

A number of privately owned wells were inventoried in the northernmost area of the Mississippi Embayment in southern Illinois. Water samples from these wells were analyzed for the major anions and cations.

As a part of the U.S. Geological Survey Regional Aquifer Systems Analysis (RASA) program, the Illinois portion of the Midwest Regional Aquifer study includes the Cambrian-Ordovician aquifer. For this part of the study, water samples from about 20 wells in the Rockford area were analyzed.[2] Samples from several other wells representing various units of the aquifer also have been analyzed.

---

[1] Unpublished maps prepared for a cooperative study of the Geology and Hydrology of Cambrian and Ordovician Systems in Northern Illinois being done by the U.S. Geological Survey, Illinois State Geological Survey, and Illinois State Water Survey.

[2] Unpublished data on file at the Illinois District Office of the U.S. Geological Survey.

Thirty-two privately owned wells were inventoried and 40 test wells were drilled in or adjacent to the Metropolitan Sanitary District of Greater Chicago's strip-mined, land-reclamation project in Fulton County (Patterson and others, 1982). Most privately owned wells were completed in a valley fill aquifer, and some were completed in a limestone aquifer. Test wells were completed in either glacial drift or in mine spoil material. Water samples from all of the test wells and some of the private wells were analyzed for inorganic constituents, including metals commonly found in the sludge, and selected organics.

In connection with a study of shallow ground water in McHenry County (Nicholas and Krohelski, 1984) and strip-mined land studies in McDonough County[1] and Randolph County (Borghese and Klinger, 1984), water samples from test wells and privately owned wells were analyzed for inorganic constituents.

An investigation of ground-water availability at the Argonne National Laboratory included an inventory of Silurian dolomite wells on and near the laboratory site. Samples were collected from a group of these wells for analysis of inorganic constituents.[1]

Twenty-nine Silurian dolomite wells were inventoried and 15 piezometers were installed in the saturated zone of the glacial drift as a part of the Palos Forest Preserve study. Water samples were collected periodically from each of these wells and analyzed for tritium and other radionuclides. Water samples also were collected from a group of Silurian dolomite and glacial drift wells for analysis of inorganic constituents.[1]

Of 58 test wells constructed as a part of the Sheffield low-level radioactive-waste disposal site study, 38 were selected for periodic sampling of water for determination of inorganic constituents (Foster and others, 1984). In addition, water samples were collected twice for analysis of selected organic constituents. Also, water samples were collected periodically from 37 U.S. Geological Survey wells and 10 private wells for radiometric analyses which included tritium concentrations and gross alpha, gross beta, and gross gamma radiation.

Ground-Water Levels

The Illinois State Water Survey (ISWS) has been operating a network of water-level observation wells since the early 1940's. The network was designed to gather data to describe fluctuations in water levels in shallow deposits, on a statewide basis, to show the regional effects of ground-water withdrawals from shallow dolomite and deep sandstone formations in northeastern Illinois, and to study selected sand and gravel formations in the Peoria and East St. Louis areas that are stressed by heavy pumping. Additional wells in special study areas where limited ground water is withdrawn for municipal or industrial use also are included in the network.

---

[1] Unpublished data on file at the Illinois District Office of the U.S. Geological Survey.

Water levels are measured on one of three frequencies--continuously by permanently installed recorders, monthly by steel-tape readings, or quarterly by steel-tape readings. Figure 5 shows the locations of observation wells where water levels are measured either with recorders or taped on a monthly frequency.

Tabulated water levels from the monthly taped readings and the recorder charts are maintained in paper files at the ISWS. Water-level information is presently being entered into an automated data-storage and retrieval system, and includes the monthly measurement each time the recorder is serviced and the maximum and minimum water levels recorded during each month.

The ISWS periodically conducts comprehensive water-level measurements in aquifer systems in three areas of Illinois. Since about 1940, water levels have been measured about every 5 years in the East St. Louis area, the Peoria-Pekin area, and in northern Illinois. Water-table and potentiometric-surface maps are included in various publications of the ISWS.

The ISWS files also contain water-level measurements made by well drillers during the construction of wells and measurements made by the ISWS staff during observation of pumping tests on new wells. Data from the comprehensive water-level measurement programs are tabulated in the previously mentioned publications, and the miscellaneous water-level data are stored in ISWS basic-data files.

Two continuous water-level recorders that monitor water levels in the Silurian dolomite aquifer have been operated by the U.S. Geological Survey at Argonne National Laboratory, Du Page County, since November 1948. Water levels in a dug well finished in glacial drift in Princeton, Illinois, have been measured since November 1942. These data are included in annual reports (Water Resources Data for Illinois) of the U.S. Geological Survey.

Other water-level records are available from the U.S. Geological Survey[1] for wells either inventoried or drilled as parts of projects described earlier in this report. In the case of project wells, water levels are available for at least each time that a water sample was collected for analysis. Other water-level data were obtained on a periodic (taped) or continuous (recorder) basis during each project study.

Surface-Water Quality and Streamflow

Surface-water data may be valuable in selecting ground-water sampling sites. The chemical quality and flow of unregulated streams are indicative of ground-water discharge to the streams. For this reason, the location of surface-water network sites should be considered in designing a ground-water observation network.

---

[1] 102 East Main Street, Urbana, IL 61801

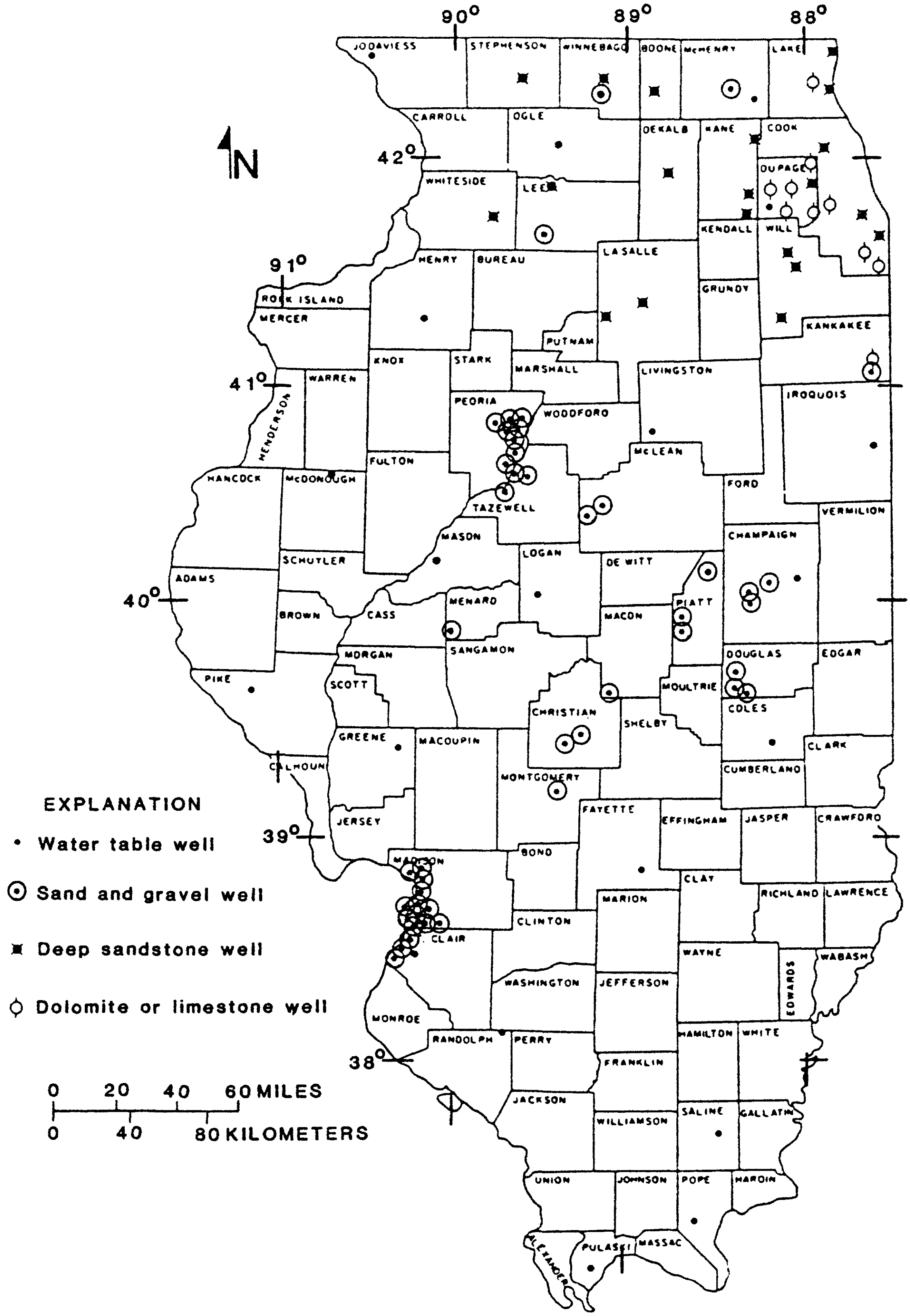

Figure 5.--Location of wells in the Illinois observation-well network.

The most comprehensive surface-water-quality network in Illinois is operated jointly by the Illinois Environmental Protection Agency (IEPA) and the U.S. Geological Survey. The network consists of 191 stations, 181 of which are sampled by the IEPA with the remainder being sampled by the U.S. Geological Survey. Samples are analyzed for a variety of common constituents, minor elements, nutrients, suspended sediment, coliform bacteria, and physical properties. The suites of analyses vary among drainage basins and land uses.

A smaller network (13 stations) is operated in by the U.S. Geological Survey as part of the National Stream Quality Accounting Network (NASQAN). These stations are located in downstream reaches of major surface-water hydrologic units outlined by the U.S. Geological Survey in cooperation with the U.S. Water Resources Council (U.S. Geological Survey, 1975).

The NASQAN stations (516 nationwide in 1981) are sampled at monthly or bimonthly frequencies for some common inorganic constituents, nutrients, minor elements, biological indicators, and physical properties. A smaller nationwide network of pesticide monitoring stations was incorporated into the NASQAN network; three stations in Illinois are included in this network.

Streamflow data are collected by the U.S. Geological Survey at 170 sites in Illinois. Many of the stream-gaging stations are coincident with sampling stations in the water-quality networks.

Data for both the water-quality and streamflow network stations are stored in the U.S. Geological Survey national data file (WATSTORE) and are published annually by the U.S. Geological Survey in Water Resources Data--Illinois, Volumes 1 and 2.

Water Use

A water-use program in Illinois is being conducted jointly by the U.S. Geological Survey and ISWS. The program provides information on current and projected stresses on the ground-water resources of Illinois, and on the amount of surface water and ground water withdrawn for irrigation, public water supply, and other uses.

Ground-Water Information Obtained from Measurements of Surface Water

Ground water and surface water form an interactive system. O'Hearn and Gibb (1980) implied that as much as 60 or 70 percent of annual streamflow in Illinois is derived from ground-water discharge. Ground water is much more difficult to monitor than surface water because of its relative inaccessibility; holes must be drilled and wells installed to obtain water-level and water-quality information from the subsurface environment.

Ground water can be sampled where it emerges as seeps and springs and as base flow in streams. However, chemical changes may occur when ground water leaves the usually anaerobic subsurface environment and enters the usually aerobic environment of a stream channel. Chemical, physical, and biological processes may significantly affect the concentrations of certain chemical constituents. The chemical relationships between ground water and base flow need to be better understood in order to use analyses of base flow in streams to represent the chemistry of ground water.

A ground-water observation program should include shallow observation wells adjacent to stream-sampling stations in order to compare data over a period of time. The comparison may show that base-flow samples, though not necessarily representing ground-water chemistry, may be useful in detecting general water-quality changes in aquifer-stream systems. Such a procedure might be useful for detecting changes in ground-water quality in shallow drift deposits where numerous sampling sites would be economically impractical.

ADDITIONAL DATA NEEDS

Ground-Water Quality

Few data are available on concentrations of synthetic organic compounds in Illinois' ground waters. Yet, these compounds have been identified in numerous public and domestic water wells across the nation, especially in industrialized areas. Many of these compounds are toxic, persistent, mobile, and produced in large amounts. As a group they may represent the greatest ground-water contamination threat of all chemical compounds identified in ground water. Reconnaissance sampling is needed to assess the condition of the major aquifers with respect to concentrations of synthetic organic compounds.

Gibb and O'Hearn (1980) indicated areas and aquifers in Illinois where inorganic chemical data are needed to determine current water quality and to determine which aquifers are undergoing significant, long-term changes in water quality. Figures 6 to 11 show the number and areal distribution of inorganic chemical analyses of samples collected between 1970 and 1978 from the principal aquifers in Illinois. The number of analyses of other inorganic chemical constituents generally is smaller than that for dissolved solids upon which figures 6 to 11 are based.

Ground-Water Levels

Water-level data for the shallow drift aquifers probably are not adequate to meet the needs of an integrated quality-quantity observation program. For example, extensive data are needed to monitor water levels in the river-lowland deposits of Illinois where large ground-water withdrawals are common. Other areas where water-level data are inadequate or lacking are along the Wabash River, along the Mississippi River, and in the Havana Lowland area in Mason County (fig. 5).

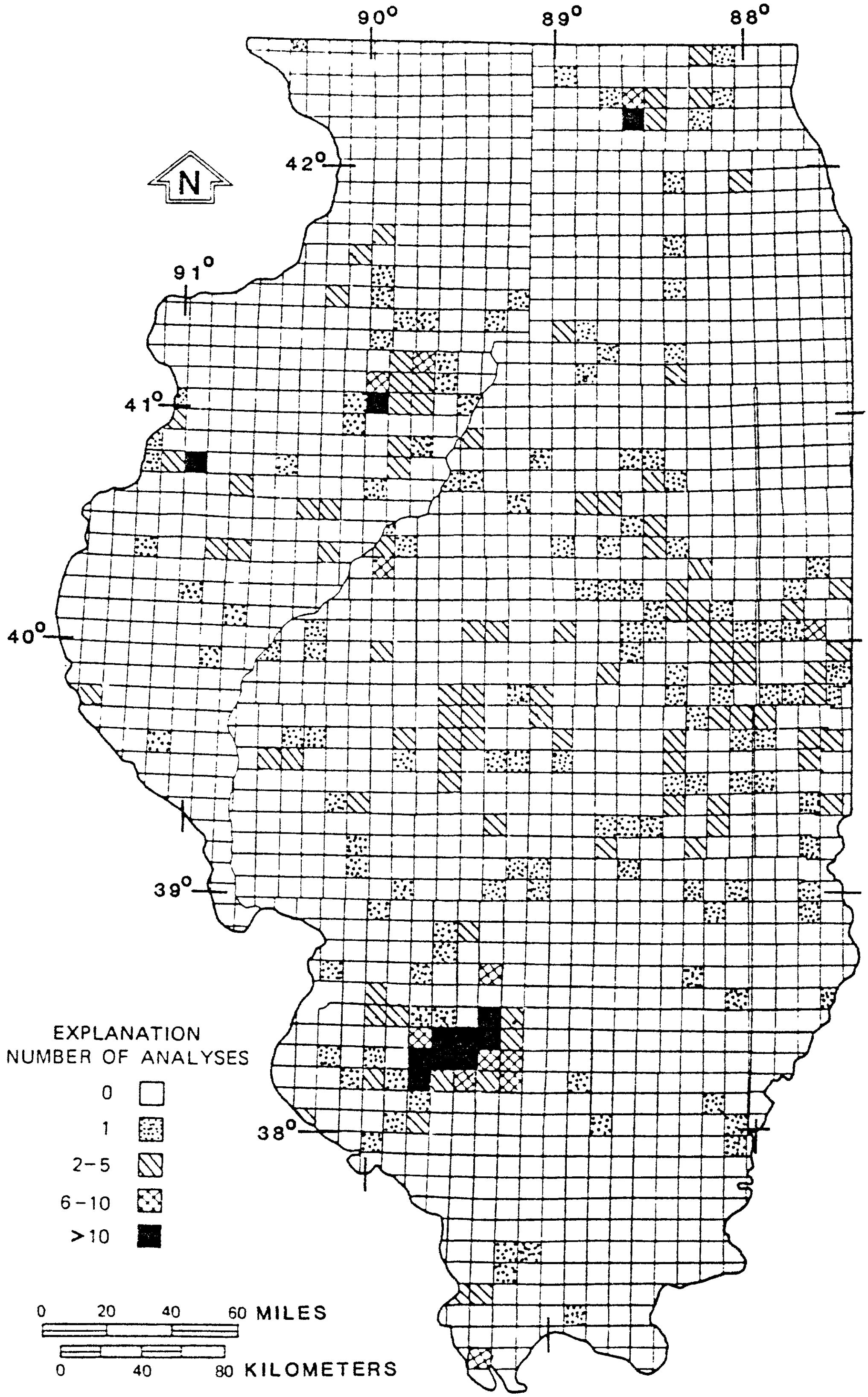

Figure 6.--Distribution of chemical analyses for shallow drift aquifers in Illinois (1970-78).

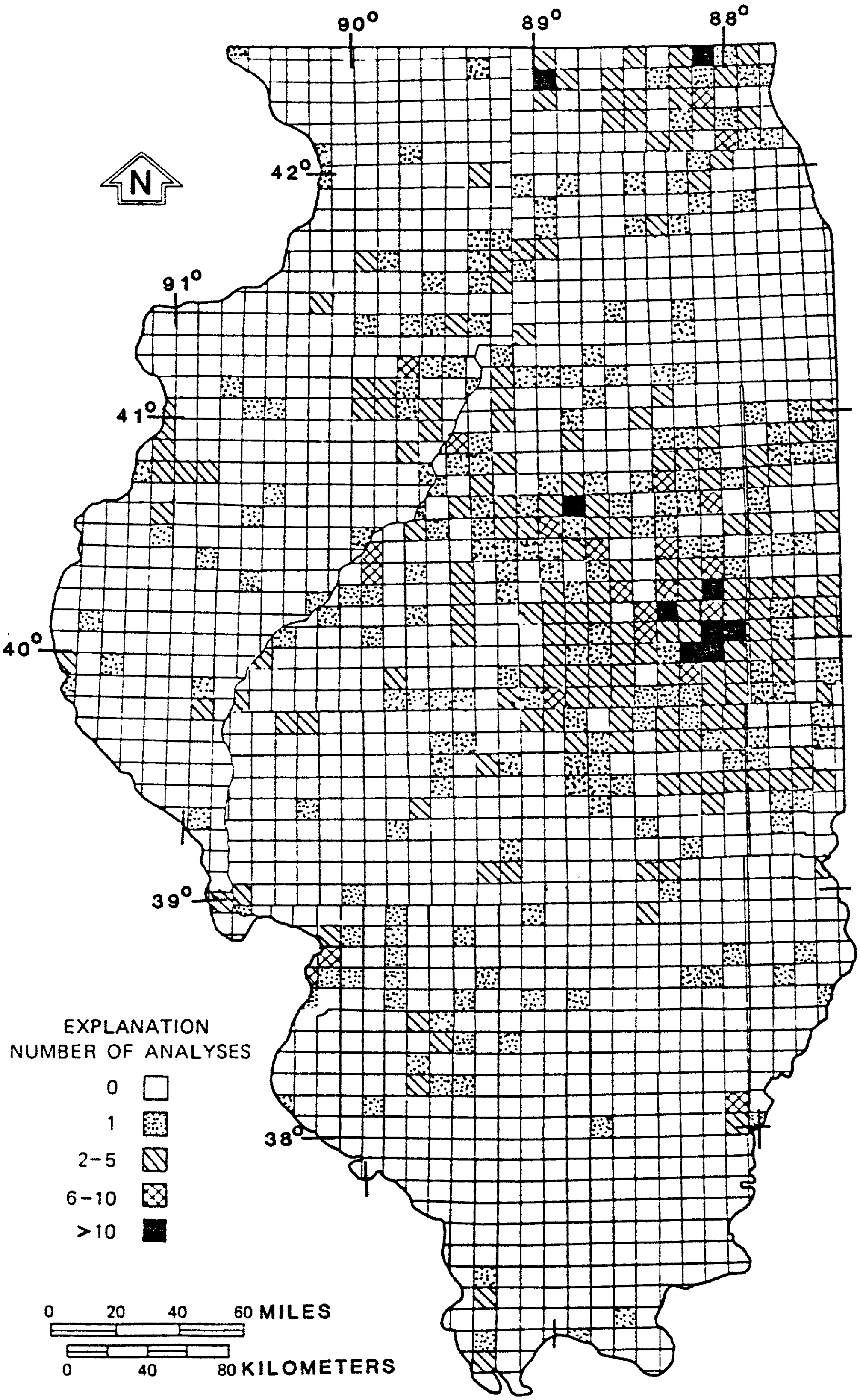

Figure 7.--Distribution of chemical analyses for deep drift aquifers in Illinois (1970-78).

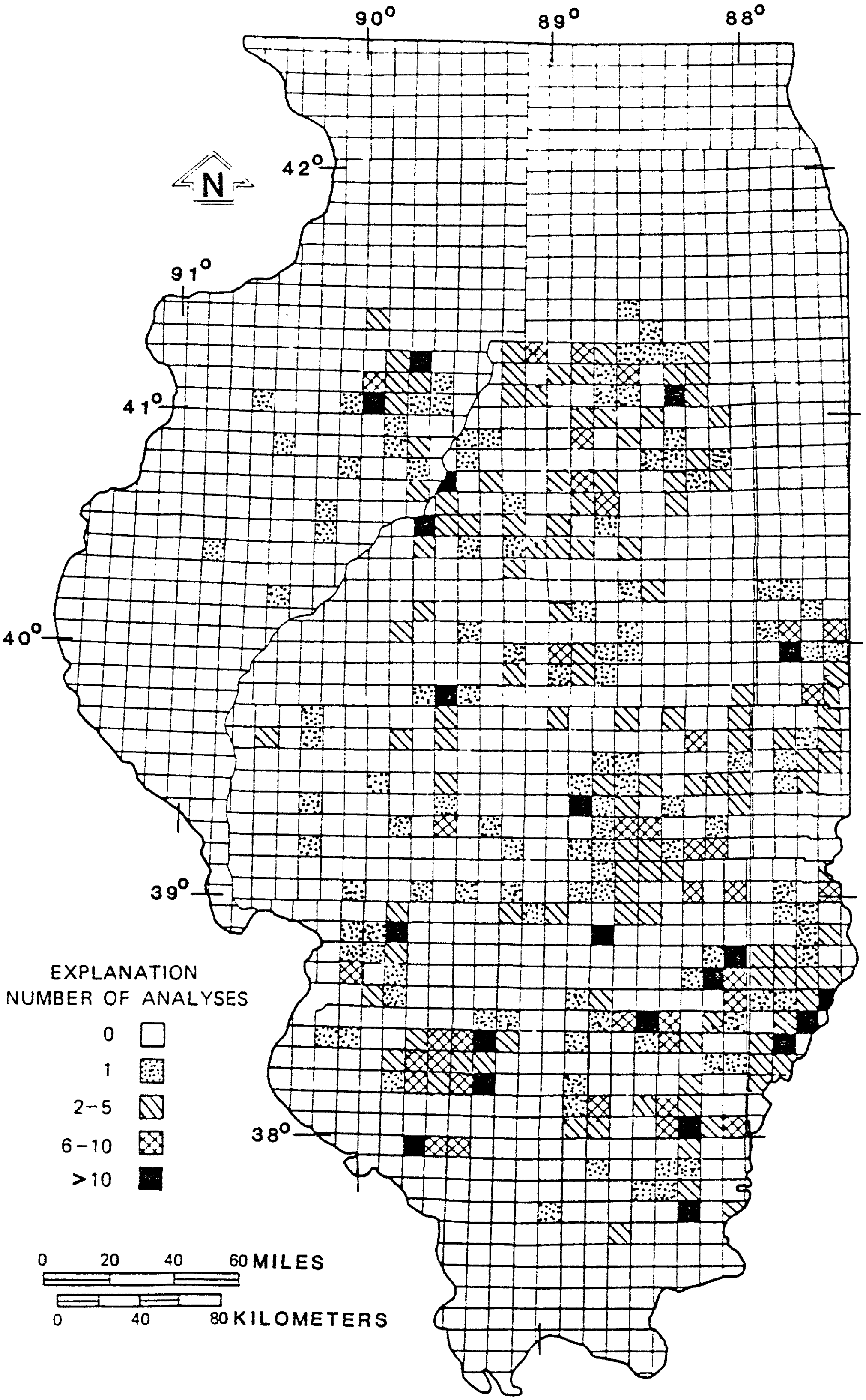

Figure 8.--Distribution of chemical analyses for Pennsylvanian aquifers in Illinois (1970-78).

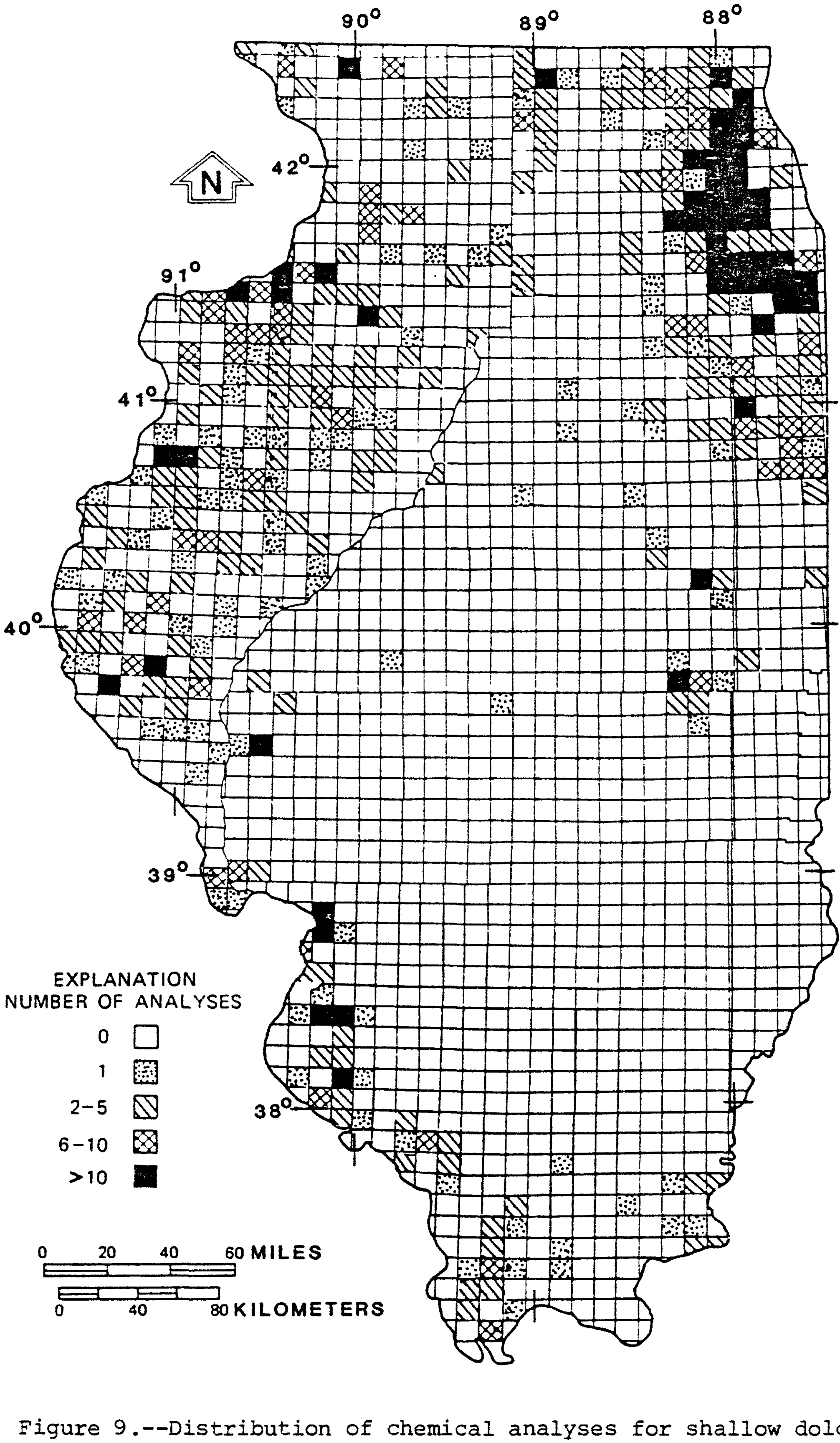

Figure 9.--Distribution of chemical analyses for shallow dolomite and limestone aquifers in I-linois (1970-78).

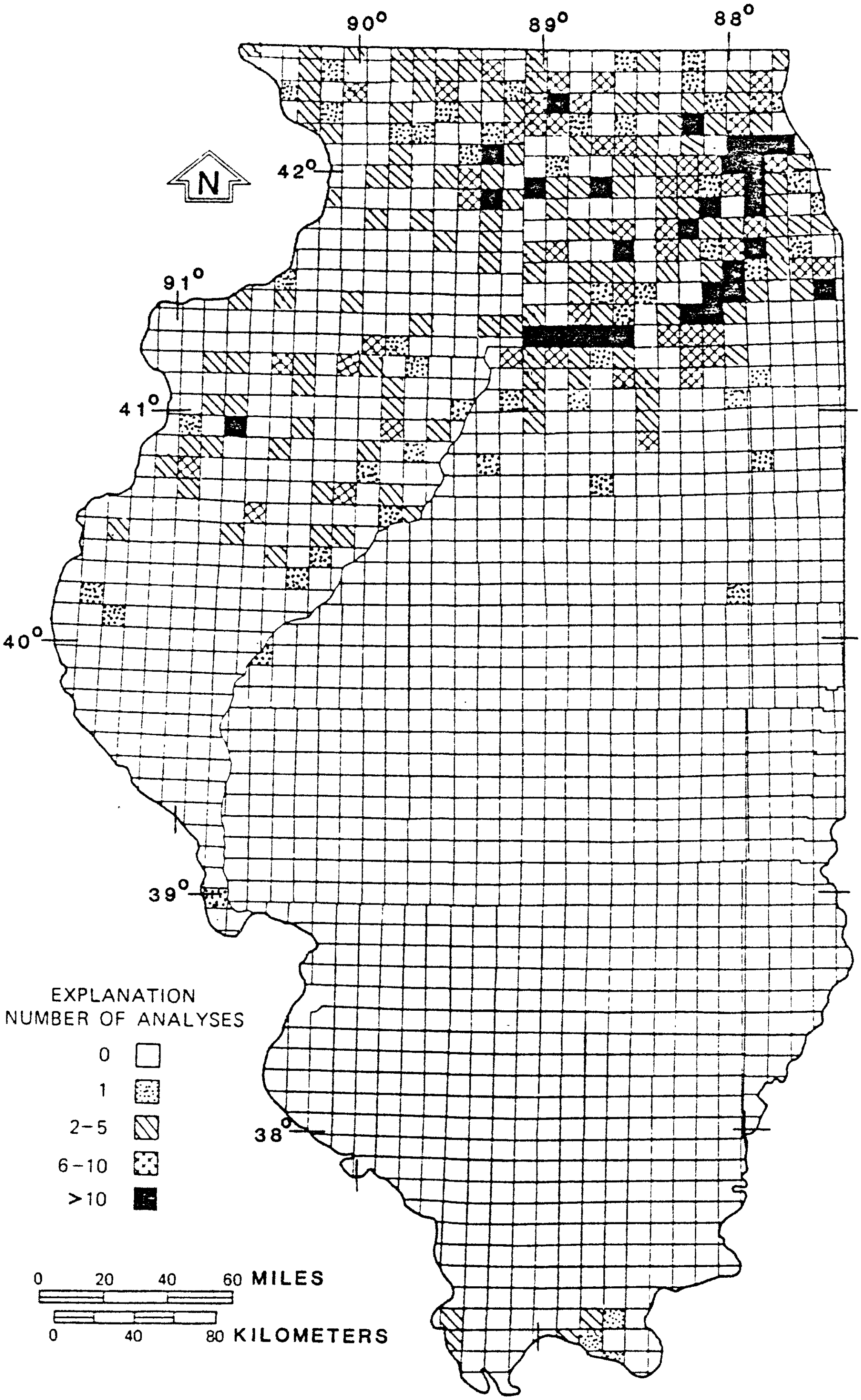

Figure 10.--Distribution of chemical analyses for the Cambrian-Ordovician (deep sandstone) aquifer in Illinois (1970-78).

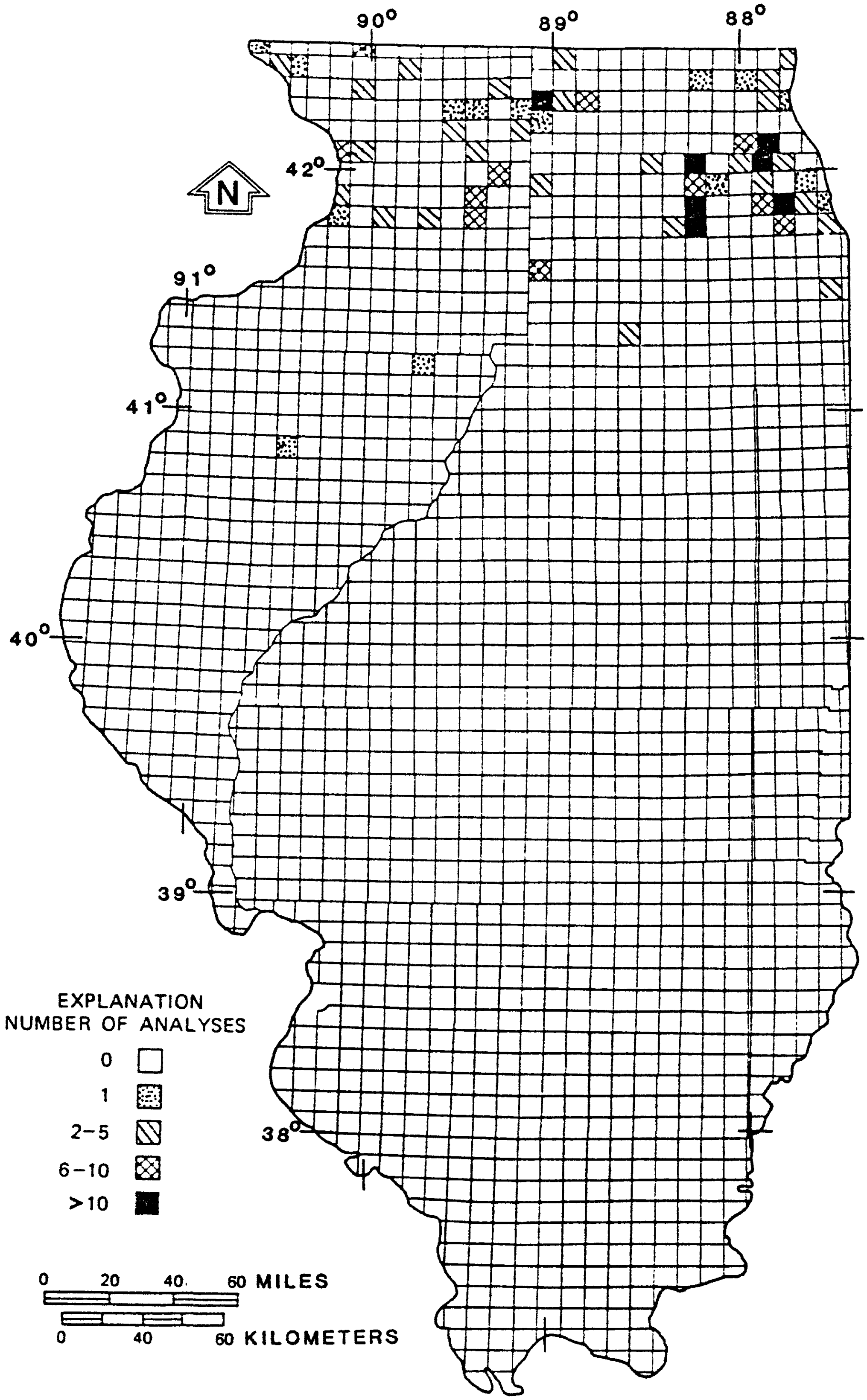

Figure 11.--Distribution of chemical analyses for the Elmhurst-Mt. Simon aquifer in Illinois (1970-78).

A moderate amount of water-level data is available for deeper sand-and-gravel aquifers, with the exception of those in extreme northeastern Illinois (Lake and McHenry Counties). Areas lacking adequate water-level data will probably be identified by the network.

Water-level data for the Pennsylvanian age rocks is sparse. Several sites for water-level observations in this aquifer are needed.

Water-level data for wells in the shallow dolomite and limestone aquifers are limited to the areas of heavy pumpage in northeastern Illinois. Better areal coverage of the Silurian, Galena-Platteville, and Mississippian rocks is needed.

Water-level data from wells tapping the Cambrian-Ordovician aquifer systems seem to be adequate for meeting objectives of the observation program. Very few data are available for wells tapping only the deep-lying Elmhurst-Mt. Simon aquifer.

Future Studies

Designing and implementing a new network for observing water levels and water quality in Illinois' aquifers may identify needs for additional studies. Some areas may be deficient in geohydrologic data or data-collection activities of various local, State, and Federal agencies may overlap. Detailed studies of some geohydrologic units might be required to select representative sampling sites.

An inventory of current ground-water sampling will provide information upon which future studies can build. The inventory also should minimize the need for new observation or test wells in areas where wells are available.

DATA MANAGEMENT

The selection of a data-management system should be made on the basis of the following criteria:

1. Capability of handling the data required to accomplish the network objectives, both short and long term

    a. The system should be capable of handling a variety of site identifiers and a data-source identifier to facilitate initial and possible continuing input from several agencies.

    b. The system should be flexible to the extent that accuracy remarks can be assigned to all data items.

2. Utility in report writing and data analysis

   a. Retrieval procedures should be kept simple to allow access and use by any interested agency.

   b. The system should allow polygonal retrieval as well as township retrievals to satisfy reporting needs by geohydrologic units or subdivisions thereof, as well as political subdivisions.

3. Control of data input

   a. The data base should be locally managed and all inputs edited by a data-base administrator.

Illinois State Water Survey System

The main features of the ISWS ground-water quality data-management system are described in the previous section of the report entitled "Assessment of Available Data." As data are received from ISWS laboratories and other sources, they are entered into temporary computer files on a monthly basis as time and manpower permit. Once a year, these files are added to a main file that is stored on an IBM 4341[1] computer and is compatible with the CDC CYBER 175 system.

The ISWS system has many disadvantages that affect its suitability for use in the proposed statewide ground-water monitoring program. The data file contains chemical analyses of water from wells, springs, test holes, partially completed wells (sampled during drilling), rehabilitated wells, contaminated wells, and finished water samples. No provisions are in the system for indicating the circumstances surrounding the collection and analysis of water samples from these various sources.

Water-level information from the ISWS recorder network is stored in a separate file that is not compatible with the chemical-quality data base. Monthly summaries are prepared utilizing computer programs for statistical analysis and comparison with historical data.

To avoid the "major overhaul" that would be necessary to use the present system, a new data file is needed. As wells (index wells) are selected to be included in the observation network, historical data for these wells can be retrieved from the present data file, corrected or amended as necessary, and placed in a new file to form the foundation of the new data-management system.

Some advantages of creating a new data base from selected historical data in the present data base are: (1) the new data base would tend to maximize the use of existing wells and data, (2) it would provide for excellent control over those data entered in the new file thus eliminating the "clutter" of unreliable or incomplete data for sample sources which are part of the monitoring network, and 3) it would preserve (in the old file) all historical data.

---

[1] Use of firm and trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

The concept of creating a new data base and identifying usable data is a prerequisite for the next phase of the program, which is to consider information requirements in detail, to close an appropriate data-management system following the solicitation of input from other agencies, and to select wells and water-quality characteristics for use in compiling the new data base.

U.S. Geological Survey System

The U.S. Geological Survey's ground-water data-management system, Ground Water Site Inventory (GWSI) File, is described in the following excerpts from Volume 2, Chapter IIA (Baker and Foulk, 1975, revised 1980) of the Users' Manual for the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE):

> The Ground Water Site Inventory (GWSI) File of the Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) is a national repository for data from sites where ground water has been, is, or can be withdrawn. The Water Resources Division of the U.S. Geological Survey maintains this data base for storing data collected by Federal, State, and local organizations active in the field of water resources. The system is operated and maintained on the central computer facility at the U.S. Geological Survey National Center in Reston, Virginia.
>
> The data base contains the following categories of data:
>
> - Site identification
> - Site location
> - Site description
> - Ownership history
> - Other agency identification
> - Site visit history
> - Field visit water quality test results
> - Site construction data
>   - Hole dimensions
>   - Casing descriptions
>   - Opening descriptions
> - Production data (flowing or pumped)
> - Lift data
>   - Major pump data
>   - Standby power capability
> - Availability of additional data
> - Availability of logs
> - Water quality collection, periods of
> - Water level measurement, periods of
> - Water withdrawal measurement, periods of
> - Geohydrologic unit descriptions
>   - Aquifer contribution
> - Cooperator data
> - Hydraulic test results
> - Pertinent remarks
> - Water level data
> - Miscellaneous values
>
> Because of the importance of valid data, the U.S. Geological Survey has developed a system which makes every effort to ensure the correctness of the data. An automated system can evaluate the reasonableness of data submitted, but only the data collector can verify the true validity of the data. For instance, the computer system can check that the code entered for Water-Use is one of the list of legal water usage codes and can ensure that the specified

altitude is within the range of altitudes possible for the State in which the site is located. However, it cannot ensure that the code submitted and the altitude reported are valid. For example, if the minimum and maximum altitudes for State X are specified as 10 feet and 3,521 feet, respectively, and an altitude of 402.9 is reported, the computer system must accept the value as correct, even though the true value may be 40.29 feet.

It is mandatory, therefore, that the data collector not only enter data correctly, but also verify that what was intended to be entered into the data base was entered. This is not only to imply he must remeasure the altitude, but rather that he should ensure that what was reported to or collected by him was what was entered into the system without error.

The ground-water data are managed and maintained through a generalized Data Base Management System called SYSTEM 2000. The organizaton of a SYSTEM 2000 data base is an hierarchical structure, with inverted lists of indexes. All the data about a single major item (in this case, a well, spring, or other site) comprises an entry in the data base. Individual pieces of information within each entry, such as altitude of the site or the temperature of the water, are schema items; logically related schema items are grouped into blocks called schema records.

Under the concept of the hierarchical structure, every schema item "belongs to" a schema record and every schema record "belongs to" a higher-level schema record. Thus, information about the casings in a well "belongs to" the set of information about the well's construction: the construction information "belongs to" the well; and the well, the entry, is a schema record belonging, in turn, to the data base as a whole.

A fundamental aspect of the schema record is that it can occur once, many times, or not at all. Each entry "contains" all the information about an individual site, and because the entry is a schema record that can occur many times, there can be information about many sites in the file. Similarly, for any particular entry (site) there can be data on several owners.

The various schema records have been defined for this schema (data base). They are arranged in a logical data structure representing their hierarchical relationship to each other. Data in a lower level schema record may be stored only if all mandatory items for each schema record at higher levels in its hierarchy have valid entries.

An important aspect of the system is that entries can be of varying length, since, if a schema record is not required, it is not stored and no space is reserved for it. If information that belongs in a nonexistent schema record is added later, the schema record is created and stored in any available space, with pointers being automatically established to relate it back to the correct entry.

The participating organizations (U.S. Geological Survey offices, State cooperators, and other users) are responsible for collecting and preparing the data for submission to the GWSI File. Once prepared, the data are forwarded to the GWSI Data Base Administrator (DBA), located at the U.S. Geological Survey's National Center in Reston, Virginia, who will control the final update process.

The user is given the opportunity to execute preliminary edits, which perform all the functions of a data submission, except for the creation of the "good transaction" file. The preliminary edit provides the user with an opportunity to purge or correct detected errors prior to the data's submission for update processing. In this way, the user can be more confident that the data finally submitted will be completely processed as intended. If errors are detected during scheduled update processing, these data will be rejected and corrections will not be processed until the following scheduled update.

The update of the data base is performed by the GWSI/DBA. This update method provides protection for all users against accidental or deliberate modification or deletion of data by other users. It also minimizes the update processing time during which the data base is vulnerable to a system failure, such as a disk head crash or software error. If a system failure does occur, data may continue to be retrieved but no further updating can be performed until the data base is re-established.

SUGGESTED PROCEDURES FOR ESTABLISHING A GROUND-WATER OBSERVATION NETWORK

The multiplicity of objectives that can be addressed by the proposed comprehensive ground-water observation network suggests that representatives from the U.S. Geological Survey and the Illinois State Water Survey should not, by themselves, select the areas of greatest concern or the water-quality characteristics that need to be monitored, but should work to involve as many interested agencies as possible in determining program goals and priorities of the proposed ground-water network. A means or achieving this involvement is to solicit input from other State agencies in Illinois that have interests related to ground-water resources.

The involvement of representatives of interested agencies would facilitate prioritization of data-collection needs through identification of current problem areas and areas where future activities might affect the ground-water resource. Also, data-collection activities of the various agencies contribute to the observation program, and their involvement in the network operation would be mutually beneficial. The coordination of data collection and data management could substantially reduce the overall expense of manpower and funds for data collection and management and result in a more useful and comprehensive data base.

The planning and implementation of the proposed ground-water network can be facilitated by performing the following sequence of tasks.

During the first year:

1. Arrange a meeting with the potentially interested State agencies, explain the objectives of this project, and solicit input on their needs for ground-water data. Following this meeting, arrange for interested agencies to be represented in a workshop that would have the objectives of making known what data are available from within each of the agencies, establishing priorities for the areas where data should be collected, and of selecting a group of water-quality parameters that would satisfy the needs of most agencies.

2. Select one of the available data-management systems or, if necessary, design one to satisfy the particular needs of the network.

3. Describe the quality-assurance procedures to be followed in selecting monitoring sites and in collecting data.

4. Begin selecting and editing water-level and water-quality data from existing data bases to provide a starting point for expansion of the current monitoring effort.

5. Prepare a progress report that will identify priorities for data collection and describe the selected data-management system.

During the second year:

1. Decide upon frequencies of water-level collection for the diffirent geohydrologic units, select water-quality parameters, and set sampling frequencies.

2. Initiate entry of data into the selected data-management system.

3. Initiate data collection in high priority areas.

4. Assess network and prepare a report showing the progress of network implementation.

SUMMARY

There is a need to develop a new ground-water observation network in Illinois to improve data collection and water-resources management. Effective management of Illinois' ground-water resources requires comprehensive information on ground-water quality and water levels in all areas of the State. Although some information is available from hydrologic data bases of the Illinois State Water Survey and the U.S. Geological Survey, large areas of Illinois lack adequate ground-water data to provide water managers with the information needed to protect and manage the State's ground-water resources.

Numerous studies regarding the planning, design, and implementation of effective ground-water observation networks in other parts of the country provide the foundation for developing a ground-water observation network in Illinois that would fulfill the data requirements of the State of Illinois, the U.S. Geological Survey, and other potential users of the data. Based on previous studies, the availability of data in U.S. Geological Survey and Illinois State Water Survey data bases, and the needs of these agencies and other users, the proposed network is feasible. The network could be developed by the cooperative efforts of the U.S. Geological Survey and the Illinois State Water Survey with advice, support, and input from other agencies who have an interest in managing Illinois' ground-water resources in an effective manner.

The suggested procedure for establishing the proposed ground-water observation network are designed to lay the foundation for further dialogue with, and planning by, all interested parties.

REFERENCES

Baker, C. H., Jr., and Foulk, D. G., 1975, revised 1980, National Water Data Storage and Retrieval System--Instructions for preparation and submission of ground-water data: U.S. Geological Survey Open-File Report 75-589, 173 p.

Borghese, J. V., and Klinger, A. R., 1984, Hydrology of a surface coal mined area in Randolph County, Illinoiis: U.S. Geological Survey Water-Resources Investigations Report 84-4256, 36 p.

Crouch, R. L., Eckert, R. D., and Rugg, D. D., 1976, Monitoring groundwater quality--economic framework and principles: U.S. Environmental Protection Agency, EPA-600/4-76-045, 97 p.

Foster, J. B., Erickson, J. R., and Healy, R. W., 1984, Hydrogeology of a low-level radioactive-waste disposal site near Sheffield, Illinois: U.S. Geological Survey Water-Resources Investigations Report 83-4125, 83 p.

Gibb, J. P., and O'Hearn, Michael, 1980, Illinois groundwater quality data summary: Illinois State Water Survey Contract Report 230, 60 p.

Heath, R. C., 1976, Design of ground-water level observation-well programs: Ground Water, v. 14, no. 2, p. 71-77.

Hult, M. F., 1979, Design of a network for monitoring ground-water quality in Minnesota: U.S. Geological Survey Open-File Report 79-1164, 44 p.

LeGrand, H. E., 1968, Monitoring of changes in quality of ground water: Ground Water, v. 6, no. 3, p. 14-18.

Marie, J. R., 1976, Preliminary evaluation of the ground-water data network in Indiana: U.S. Geological Survey Water-Resources Investigations 76-24, 50 p.

Nicholas, J. R. and Krohelski, J. T., 1984, Water in sand and gravel deposits in McHenry County, U.S. Geological Survey Water-Resources Investigations Report 83-4048, 34 p, 1 plate.

O'Hearn, Michael, and Gibb, J. P., 1980, Groundwater discharge to Illinois streams: Illinois State Water Survey Contract Report 246, 31 p.

Patterson, G. L., Fuentes, R. F., and Toler, L. G., 1982, Hydrologic Characteristics of Surface-Mined Land Reclaimed by Sludge Irrigation, Fulton County, Illinois: U.S. Geological Survey Water-Resources Investigations 82-16, 30 p.

Peek, H. M., and Laymon, L. L., 1975, Groundwater quality management and monitoring program for North Carolina: North Carolina Department of Natural and Economic Resources Circular No. 16, 34 p.

Pryor, W. A., 1956, Groundwater geology in southern Illinois--a preliminary geologic report: Illinois State Geological Survey Circular 212, 25 p.

Sangrey, D. A., and Philipson, W. R., 1979, Detecting landfill leachate contamination using remote sensors: U.S. Environmental Protection Agency, EPA-600/4-79-060, 78 p.

Stallman, R. W., 1968, Groundwater data--too much or too little: American Water Resources Association, Proceedings of the National Symposium on the Analysis of Water-Resources Systems, Proceedings Series No. 5, p. 126-132.

Tinlin, R. M., ed., 1976, Monitoring groundwater quality--illustrative examples: U.S. Environmental Protection Agency, EPA-600/4-76-036, 81 p.

Todd, D. K., Tinlin, R. M., Schmidt, K. D., and Everett, L. G., 1976, Monitoring groundwater quality--monitoring methodology: U.S. Environmental Protection Agency, EPA-600/4-76-026, 154 p.

U.S. Environmental Protection Agency, 1980, Proposed ground water protection strategy: Office of Drinking Water, 97 p.

U.S. Geological Survey, 1975, Hydrologic unit map - 1974, State of Illinois: Reston, Virginia, scale 1:500,000.

Visocky, A. P., Wehrmann, H. A., Kim, K. W., and Ringler, R. W., 1978, Assessment of public groundwater supplies in Illinois: Illinois State Water Survey Contract Report 209, 193 p.

Walton, W. C., and Csallany, Sandor, 1962, Yields of deep sandstone wells in northern Illinois: Illinois State Water Survey Report of Investigation 43, 47 p.

Ward, R. C., 1978, Regulatory water quality monitoring--a system perspective: U.S. Environmental Protection Agency, EPA-600/7-78-228, 23 p.

----- 1981, Ground-water quality monitoring--what information is to be obtained?: Ground Water, v. 19, no. 2, p. 130-132.

Warner, D. L., 1974, Rationale and methodology for monitoring groundwater polluted by mining activities: U.S. Environmental Protection Agency, EPA-680/4-74-003, 76 p.

Whitehead, R. L. and Parliman, D. J., 1979, A proposed groundwater quality monitoring network for Idaho: U.S. Geological Survey Open-File Report 79-1477, 70 p.

Willman, H. B., and Frye, J. C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Willman, H. B., and others, 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, 261 p.