University of Wisconsin-Extension
GEOLOGICAL AND NATURAL HISTORY SURVEY

INFORMATION CIRCULAR
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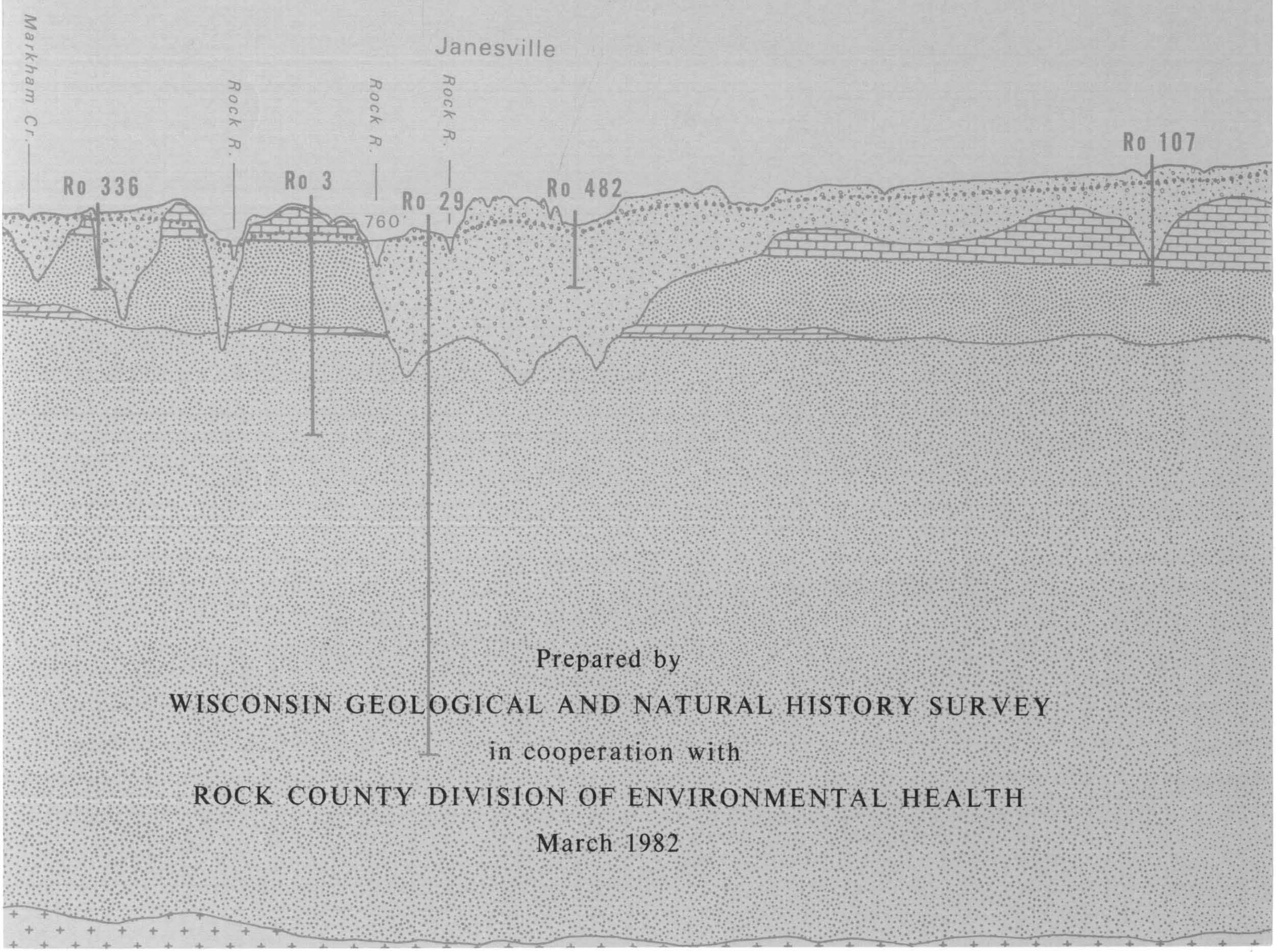
Ground-Water Quality of Rock County, Wisconsin

by
Alexander Zaporozec



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WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
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CONTENTS

ILLUSTRATIONS

Plates:

Page

Figures:

TABLES

Tables:

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply English units	By	To obtain metric units
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre (ac)	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (l)
gallon per minute (gpm)	0.06309	liter per second (l/s)
million gallons per day (mgd)	0.04381	cubic meters per second (m^3/s)
inch per hour (in./hr)	2.540	centimeter per hour (cm/hr)
foot per day (ft/day)	0.3048	meter per day (m/d)
gallon per day per square foot (gpd/ft^2)	0.0408	meter per day (m/d)
degree Fahrenheit (°F)	(°F-32)/1.8	degree Celsius (°C)

Ground-Water Quality of Rock County, Wisconsin

Alexander Zaporozec

Wisconsin Geological and Natural History Survey

ABSTRACT

Rock County has adequate supplies of ground water to cover the needs of its citizens, commerce, agriculture, and industry. Ground water is a vital natural resource of the county. In 1979, ground water was almost the sole source of water used in the county, and about 28 million gallons of ground water were withdrawn every day from the four aquifers: Pleistocene sand and gravel, the Platteville-Galena dolomite, the St. Peter sandstone, and the Upper Cambrian sandstone. All the aquifers are interconnected and closely related and act as a single ground-water system.

Recharge to ground water is derived almost entirely from precipitation and occurs locally throughout the county. The bedrock aquifers are recharged most easily in the southwestern part of the county along the ground-water divide between the Sugar River and Rock River systems where there is little or no overlying material.

Ground water in Rock County is a very hard, calcium-magnesium-bicarbonate type, having a median hardness around 320 milligrams per liter (mg/l). The chemical quality of water from the four aquifers is similar. Median values for total dissolved solids range between 334 and 445 mg/l. The overall natural quality of ground water is good, and it is suitable for many uses, but softening is required for most purposes to remove the excessive hardness. Natural impurities generally have acceptable concentrations, except iron and manganese, which may cause problems in some parts of the county.

Rock County does not have serious, large-scale pollution problems at this time. Nitrate is the most common identifiable pollutant. The county has the highest average occurrence of nitrate-nitrogen and the largest proportion of wells with water in excess of the established drinking water standard 10 mg/l in the state. All townships except the town of Milton had at least one occurrence of nitrate concentration above 10 mg/l, and almost 27 percent of the 406 analyses collected during the 1979-81 study exceeded 10 mg/l. Nitrate concentration varies between less than 0.5 and 46 mg/l, and has a median value of 6.0 mg/l. Higher concentrations occur more frequently in rural areas where the potential for ground-water pollution is higher because of barnyard runoff, animal wastes, use of fertilizers, and old wells. Except for nitrate, all documented pollution of ground water is of local nature.

The greatest potential hazard to ground water in Rock County comes from improper waste-disposal practices, some agricultural activities, open storage of chemicals on the ground, and spills and leaks of toxic and hazardous liquids. Most of the waste-disposal practices are regulated, and sanitary landfills, surface impoundments of liquid wastes, and septic tanks should pose few problems if located and operated according to existing state regulations.

From agricultural activities, the main threat is the spreading of fertilizers and pesticides on irrigated fields overlying permeable soils with a high water table and inadequate disposal or storage of animal wastes. These sources are difficult to control and cannot be completely eliminated in all cases. Minimizing their effects on ground water requires educational programs and the introduction of better management practices. The potential for pollution from other miscellaneous sources (such as poorly constructed or improperly abandoned wells, stockpiles, storage tanks, and pipelines) can be minimized by periodic inspection and maintenance of facilities, by improving operating procedures, or by building protective shelters and containment structures.

Before developing the strategy for a ground-water quality management program and instituting mechanisms for achieving the objectives of the strategy, the county should identify critical areas that are most susceptible to pollution and that require more protection than the others, undertake an inventory of major pollution sources including ranking the sources according to their pollution potential, and develop a format for a countywide educational program to make homeowners, farmers, business and industry leaders, and local officials conscious of the potential pollution sources and of methods for minimizing ground-water pollution.

SUMMARY OF FINDINGS AND IMPLICATIONS

1. Rock County has enough supplies of ground water to support its growing population, strong agricultural base, and viable, diverse manufacturing industry. Most water used for municipal, rural, and industrial purposes comes from subsurface reservoirs of ground water. Presently, only 18 percent of the total amount of water that infiltrates to the ground water is being withdrawn, and it is estimated that this number will have increased to 22 percent by 2000.

   Implication: Ground water is a vitally important natural resource of Rock County that needs to be used wisely and protected for the benefit of the economy and general welfare of the county.

2. Water temperature measurements indicate a rather shallow circulation of ground water.

   Implication: The primary sources of ground water in Rock County are the shallow aquifers, which are also most susceptible to pollution.

3. Much of the ground water originates from precipation that has fallen within the county and infiltrates into the ground within a radius of a few tens of miles from where it is found. Once underground, the ground water moves from high areas to low areas.

   Implication: Any pollutant released into ground water will travel in the direction of the ground water and, because of the relatively short paths of shallow ground water, is likely to stay within the county's boundaries, except where discharged into and carried out-of-county by streams.

4. The composition of ground water in Rock County is primarily a result of its movement through Pleistocene deposits and sedimentary rocks of Cambrian and Ordovician age that contain large amounts of carbonate minerals. Therefore the ground water is a slightly alkaline, very hard calcium-magnesium-bicarbonate type. Natural constituents of ground water generally have acceptable concentrations.

   Implication: The overall quality of ground water in the county is good, and it is suitable for most uses. However, softening is required for most purposes.

5. The quality of most ground water is much better than the quality required by the federal and state drinking water standards. Iron, manganese and nitrate are the three constituents, concentrations of which most commonly exceed the standards. Undesirable concentrations of iron and manganese are caused by natural factors that cannot be controlled. Nitrate is the most common identifiable pollutant in Rock County. Nitrate concentrations in excess of the recommended limit of 10 mg/l NO_3-N can be found in many places in the county, and the mean concentration is the highest in the state.

   Implication: Locally, treatment of water is necessary to remove undesirable concentrations of iron and manganese. Water containing more than 10 mg/l NO_3-N should not be given to infants under 6 months of age. In order to reduce the concentrations of nitrate, man-made sources contributing to nitrate pollution should be controlled. The proper management practices for common sources of nitrate (such as barnyards, feedlots, manure pits), the proper storage, handling and application of fertilizers, and the proper construction and continued inspection of septic tank fields and sewage lagoons can help to reduce nitrate levels.

6. Excessive concentrations of nitrate are more likely to be found in shallow wells (50 ft depth or less) than in deeper wells. Thirty percent of the samples taken from shallow wells contained 10 mg/l or more of nitrate nitrogen.

   Implication: Attention should be paid to eliminating unnecessary pollution of wells from the surface by proper location and construction of water wells. If problems persist even in a properly constructed well, they may be removed by deepening or relocating the well.

7. In the subsurface, pollutants travel as relatively compact and discrete bodies, elongated parallel to the ground-water flow direction, and move with nearly the same velocity as the ground water. Because ground-water movement is extremely slow it might take years or decades for pollutants to appear in water wells or at other points of surface discharge. By that time the aquifer might be polluted beyond repair.

   Implication: The hidden character of ground-water pollution and its slow movement require that Rock County concentrate its future protection efforts on the preventive program of minimizing the potential for ground-water pollution rather than on corrective actions to clean the polluted water.

8. Ground-water pollution can be caused by many human activities above, at, and under the ground. The quality of ground water in Rock County most commonly can be affected by inadequate disposal practices of wastes, excessive applications of fertilizers and pesticides, storage of chemicals or wastes on the ground, and spills and leaks of toxic and hazardous liquids.

   Implication: Because ground-water pollution by human activities cannot be completely eliminated, every effort should be made to effectively minimize it by controlling the pollution sources.

9. Careless disposal of wastes over the years has caused harm, which in turn has prompted new laws on the federal and state level to protect ground water against pollution.

   Implication: Any county ground-water quality management program should take into consideration the existing federal and state regulations.

10. Pollution sources in Rock County are of both point and nonpoint origin. Point sources include waste-disposal sites, poorly constructed or improperly abandoned wells, storage of chemicals and waste materials on the surface, and leaks in above-ground or underground tanks and pipelines. Nonpoint sources include urban runoff or runoff from barnyards and feedlots, irrigation, and fertilizers and pesticides spread on agricultural fields.

    Implication: The effects of waste-disposal sites are relatively easy to control through enforcement of existing regulations. Each waste-disposal site owner is required to ask for a permit to operate the site. Well construction and the abandonment of wells is regulated. Manure pits and other nondisposal point sources can be controlled by improving operating procedures, by periodic inspection of sites, or by building containment structures guarding against accidental spills and leaks of stored materials. As the last resort, it might be appropriate to develop a county-permit procedure to insure the proper location, design, and installation of these facilities that pose the greatest threat to ground water. The more diffuse, nonpoint sources are much more difficult to control than the point sources, and their effects cannot be completely eliminated.

Minimizing the effects requires the introduction of extensive educational programs, better management practices, economic incentives, or land-use controls.

11. The study was limited in time and money, and only basic data and information have been gathered. Therefore, the validity of some conclusions is as good as the data available at the time of the study, and may be subject to change with an increased data base.

    Implication: More data are needed to evaluate the effect of agriculture on ground water in the county and the potential of nonregulated point sources for polluting ground water. Field inspections should be made to identify the specific point sources and to rank them according to their potential for pollution.

12. Certain areas in the county are more susceptible to pollution than others or require more protection than the others. Among them are the recharge areas and areas where the thickness and permeability of unconsolidated materials and depth to water table are insufficient to allow for natural attenuation of pollutants.

    Implication: The initial step in the development of a ground-water quality management program should be an assessment of hydrogeologic limits for various land and water uses in the county and compilation of a pollution potential map. This map will aid in delineation of critical areas requiring the highest degree of protection, and such areas can be ranked according to their importance.

13. The background quality of ground water indicates that Rock County does not have serious, large-scale pollution problems at this time. Most documented pollution of ground water is local. However, potential for pollution is relatively high because recharge may occur locally anywhere in the county, and county soils, which have at least moderate permeability, may not inhibit infiltration of pollutants.

    Implication: It is in the best interest of the Rock County citizenry to preserve the high quality of its ground water by eliminating those sources that may carelessly pollute ground water.

INTRODUCTION

Background of Study

Rock County is a rapidly growing county, located near the major urban centers in the Midwest, within the Rock Valley Metro Council planning area. Its rate of growth in recent years has exceeded the state average as well as the rate of less urban counties in the surrounding area (Wis. DLAD, 1974). Rock County has a strong, diverse agricultural base and a viable, diverse manufacturing and resource-oriented industry. Some of the best agricultural land lies in the east central part of the county and is in the path of expansion of both Beloit and Janesville.

All significant amounts of water that are used in Rock County for residential, agricultural, and industrial purposes come from ground-water sources. No specific local protection programs exist to maintain the quantity and quality of the ground water. In fact, not much is known about the amount of water used or about the existing point or nonpoint sources of potential ground-water pollution and the problems they might create in the future. Even though the citizens of the county rely almost entirely on ground water, very few are knowledgeable about it or realize the danger of polluting the source of their drinking water.

The lack of adequate data to define the quality of the ground-water resource and potential danger from various land and water uses and waste-disposal practices to ground water created concern on the part of the Rock County Board of Supervisors who delegated the Rock County Division of Environmental Health (DEH) to initiate a study of ground-water quality conditions. In August 1979 the DEH approached the Wisconsin Geological and Natural History Survey (WGNHS) with a request to study the ground-water quality of the county on a cooperative basis. Formal agreement was signed in December 1979, with each party sharing half the cost.

Purpose of Study

The purpose of the project was to initiate a long-term study to provide an adequate data base for sound management and protection of the quality of ground water in the county, which would assist Rock County in the development and implementation of a ground-water protection and management program and local ground-water protection regulations, if needed.

The primary objectives of the study were as follows:

1. Inventory all monitoring points related to environmental resources.
2. Document the importance of ground water as a resource in Rock County and the need for its protection.
3. Discuss the physical and geological framework that controls the movement of ground water.
4. Discuss the principles of behavior of ground water and the processes affecting transport of pollutants in ground water.
5. Define the background quality of ground water in Rock County.
6. Identify existing and potential pollution sources and evaluate their impact on ground-water quality in the county.

7. Identify policy instruments for the development of a ground-water protection program in Rock County.

8. Develop material that could be used for educational programs on ground-water occurrence and pollution. For this purpose "textbook material" is included in this report, and basic principles of ground-water occurence, movement, and quality are discussed in greater extent than otherwise needed. A part of the material was developed outside of this report (slide set and popular summary of the report).

It is our intention to present the report in a form that would be useful to a technical as well as a general audience and that would serve not only Rock County officials but also serve others with similar problems.

Scope of Study

The study was begun in February 1980 and was divided into two phases. Phase I was an inventory phase and included compilation of information on ground water, ground-water use, ground-water quality, and pollution sources. This phase included primarily office work and literature search, lasting from February to December 1980.

Phase II (from July 1980 to December 1981) included evaluation of data, collection and analyses of water samples for nitrates, and development of educational material (slide set, information brochures on ground-water levels and ground-water quality). The last three months were devoted to the final report.

Water samples were collected by the staff of the Rock County Department of Health, John Haines and David Salmon particularly, and were analyzed by the State Laboratory of Hygiene in Madison.

Previous Investigations

Little detailed work pertaining directly to ground-water quality had been previously done within the county. General characteristics of ground-water quality are discussed in the cooperative WGNHS/USGS publications: a county report on ground water (LeRoux, 1963), Hydrologic Investigations Atlases HA-360 (Cotter and others, 1969) and HA-453 (Hindall and Skinner, 1973) and Ground-Water Quality Atlas of Wisconsin (Kammerer, 1981). Available chemical analyses of ground water were compiled by Holt and Skinner (1973), and are being currently updated by the U.S. Geological Survey (USGS) for a statewide appraisal of ground-water quality of Wisconsin's aquifers.

Potential problems of ground-water pollution originating from land disposal of wastes were discussed in two reports (Zaporozec, 1974; Rock County, 1976). Detailed hydrogeologic investigation of the city of Janesville landfill was done by Donohue and Associates, Inc. (1975). Individual cases of ground-water pollution within the county were documented in 1978 by the Wisconsin Department of Natural Resources (DNR) during the inventory of ground-water pollution incidents (Calabresa, 1981) and in 1980 by David Holman, Director of DEH. Gasoline pollution of seven wells in Beloit was investigated by the DNR (Scovill, 1970).

Cooperation and Acknowledgments

Appreciation is given to county and other local agencies who cooperated in the collection of basic information: University of Wisconsin Extension Office in Janesville, specifically to Dennis Nehring for providing information on pesticides and agricultural activities in the county; Rock County Planning and Parks Departments; city of Janesville, Division of Public Services and Engineering Office; Wisconsin Power and Light Company, Beloit; and to those citizens of Rock County who graciously permitted access to their wells.

Records of wells, measurements of water levels, and chemical analyses were provided from the long-standing cooperative water resources program of the WGNHS and USGS. Wisconsin DNR provided pumpage data, results of the 1980 inventory of surface impoundments, information on air quality, and chemical and nitrate analyses from their files. Especially appreciated are the help and suggestions of Bob Baumeister, Chief of DNR's Public Water Supplies Section. The author thanks Tom Calabresa for providing information on groundwater pollution cases from his report in preparation, and for providing results of the older nitrate analyses.

Special appreciation is due to the Rock County Board of Supervisors who allocated 50 percent of the study cost; to David Holman, Director, Environmental Health Division, and his staff, for enthusiastic support of the study, generous help in collecting water samples and in gathering basic data, and many valuable ideas and information; and to Dr. M.R. Seymour, County Health Officer and Director of the Rock County Health Department for his approval of this help.

PHYSICAL SETTING

Location

Rock County is located on the southern border of Wisconsin and Illinois, halfway between the Mississippi River and Lake Michigan (fig. 1). It consists of 20 townships and extends from lat 42°30'W. to 42°51'N. and from long 88°46'W. to 89°22'W. The county is nearly rectangular in shape, measuring approximately 30 miles in the west-east direction and 24 miles from north to south. Its total area is 726.8 mi^2 (465,000 acres), of which 5.6 mi^2 are covered by water (from 1977 Wisconsin Blue Book).

Topography

The land surface of much of the county ranges between 820 and 950 ft above the mean sea level (m.s.l.), which results in a landscape with little vertical differentiation. The southwestern townships and those parts of the county covered by the younger glacial deposits have relief of 220 ft or more. The greatest relief is in the towns of Magnolia and Harmony: 285 ft.

High land-surface elevations are generally found on the west-east morainal ridges rising above 950 or 1,000 ft. However, the highest elevations, above 1,080 ft, are in the western part of the county on a narrow bedrock ridge east of the Magnolia Bluff County Park. In the eastern part of the county, the highest elevations are on morainal ridges flanking the flat central outwash plain: on the northern edge, elevations of over 1,000 ft on a broad belt of morainal hills extending from section 12, T. 3 N., R. 14 E. to section 23, T. 3 N., R. 13 E., culminating on Mt. Zion in the town of Harmony (over 1,050 ft); and on the southern edge, elevations of over 1,000 ft in section 16, T. 2 N., R. 14 E. and section 5, T. 1 N., R. 14 E.

Low elevations, under 800 ft, are in the valleys of the Rock and Sugar rivers and their tributaries. The lowest elevation, 731 ft, is at the surface of the Rock River in Beloit where it leaves Wisconsin.

Physiography

The county area is nearly equally divided between the Western Uplands province and the Eastern Ridges and Lowlands province (fig. 2) as defined by Martin (1932). The Western Uplands are dissected by relatively steep-sloped

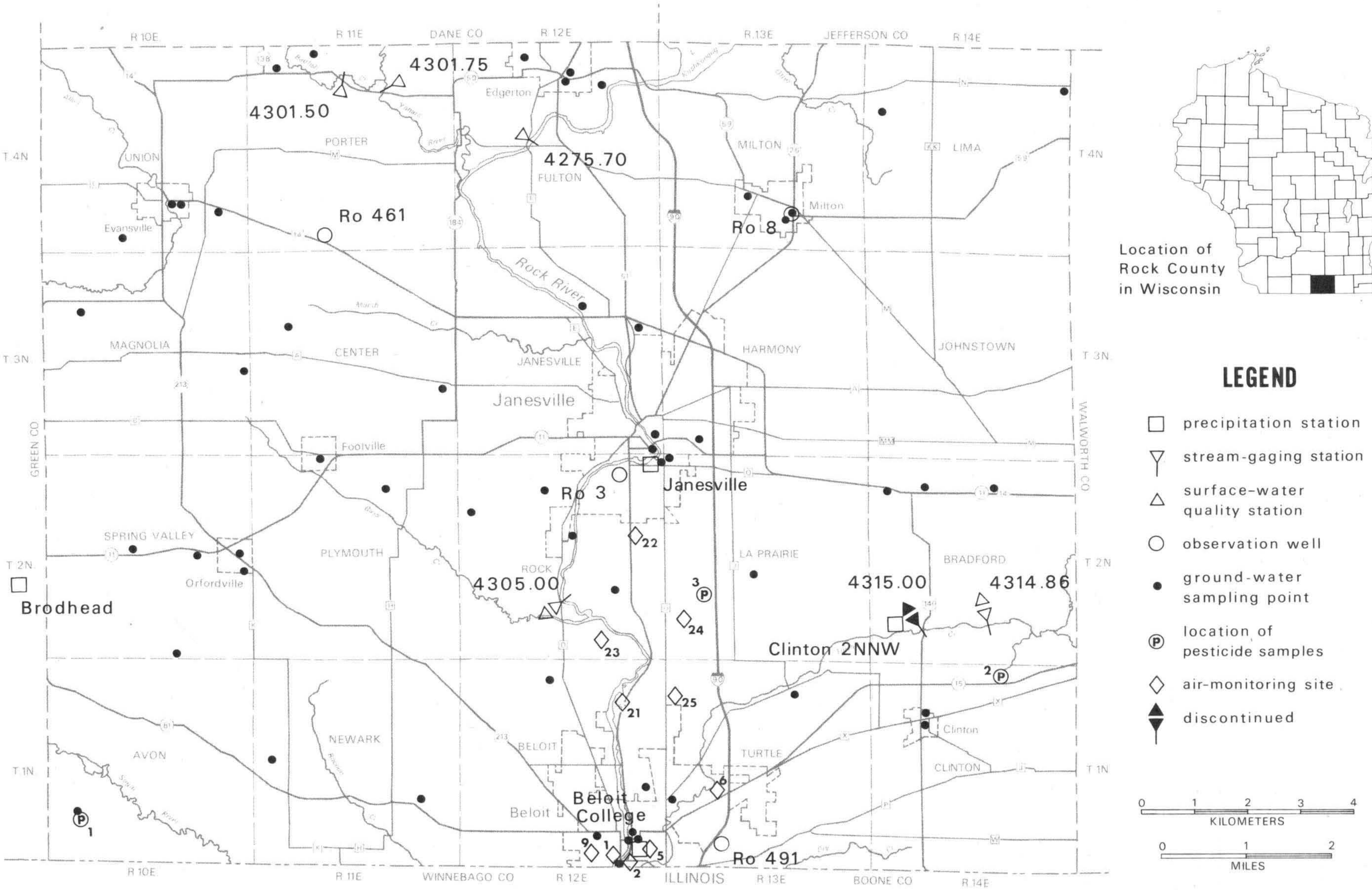


Figure 1. Map showing monitoring stations in Rock County (with index map showing location of Rock County in Wisconsin

valleys flanked by ridges of resistant bedrock units. The Eastern Ridges and Lowlands province has generally low relief and is gently rolling to modestly hilly, unless moraines or drumlins are encountered.

Physiographically, the county can be divided into four distinct areas (see figure 2). The first area comprises the high-relief end moraines of the Wisconsinan Stage in the northern part of the county. These undulating landforms were formed by earth material accumulated in front of the advancing continental glacier. South of this area, and largely east of the Rock River, is the flat outwash and alluvial plain. The third area, in southeastern Rock County, is formed by glacial material of low relief and gentle slopes. Here the terrain is controlled not only by glacial deposits but also by bedrock, which crops out in some places. The fourth area, south of the outwash plain and west of the Rock River, is almost entirely the result of differential erosion of the bedrock. Valleys and ridges are narrow and steep-sloped, and unconsolidated surface material is either thin or absent, except in deep preglacial valleys.

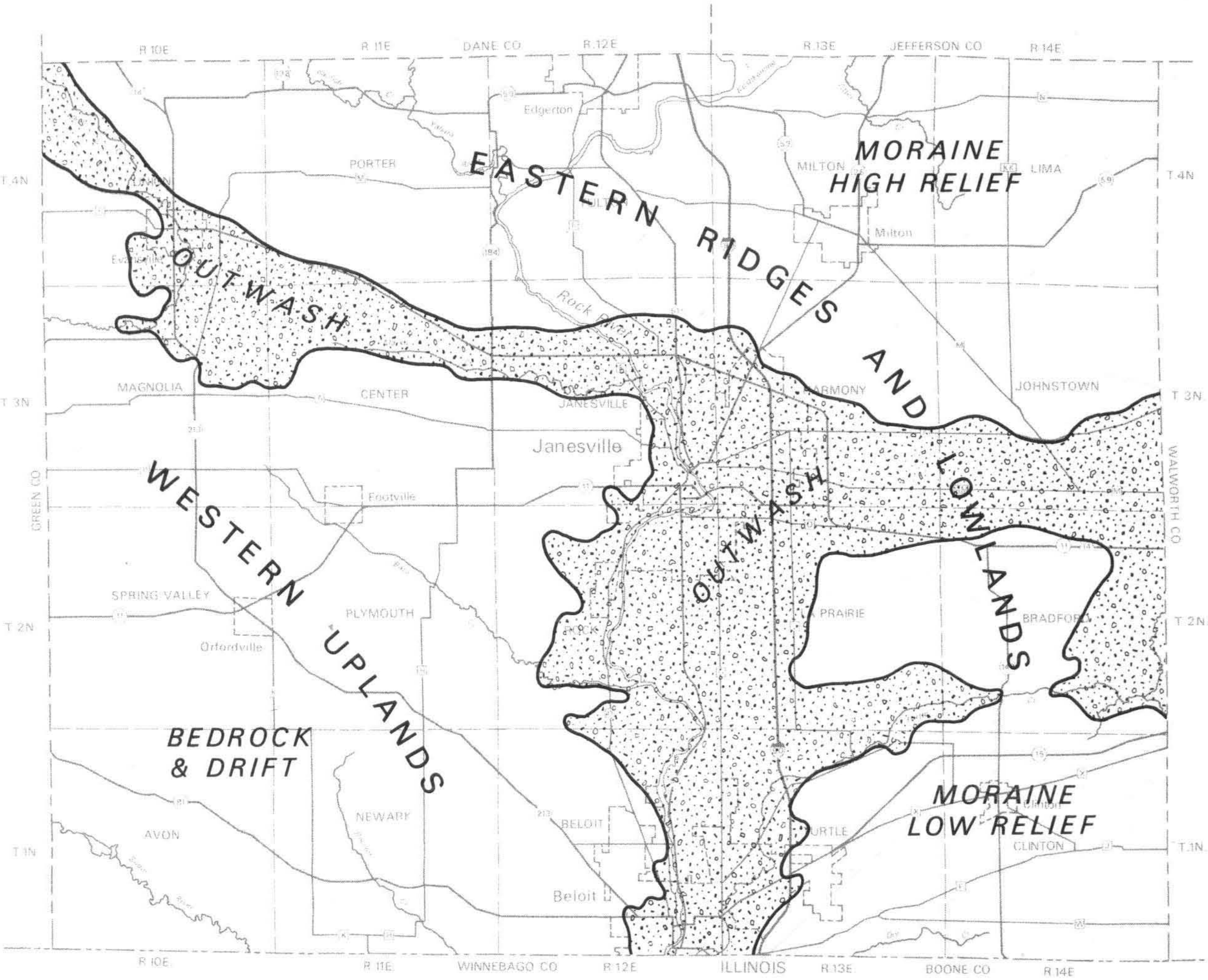


Figure 2. Map showing physiographic areas of Rock County

Climate

The location of Rock County near the center of the North American continent provides a typical temperate, subhumid to humid, continental climate. It is characterized by the regular alternation of four climatic seasons, with very cold winters and rather hot summers, and by moderate amounts of rainfall.

The temperature varies widely from season to season and also from year to year. The average annual temperature is 48° F. The hottest month is July, when the temperature reaches its annual maximum over 80° F. The coldest time is in late January when the average temperature drops below 20° F (fig. 3). The average date of the last freeze in the spring is May 1, and the first in the fall is October 13. Soil begins to freeze in the latter part of November and melts in late April. The average frost depth reaches maximum of 18 in. in late February (Wis. Stat. Rept. Service, 1978).

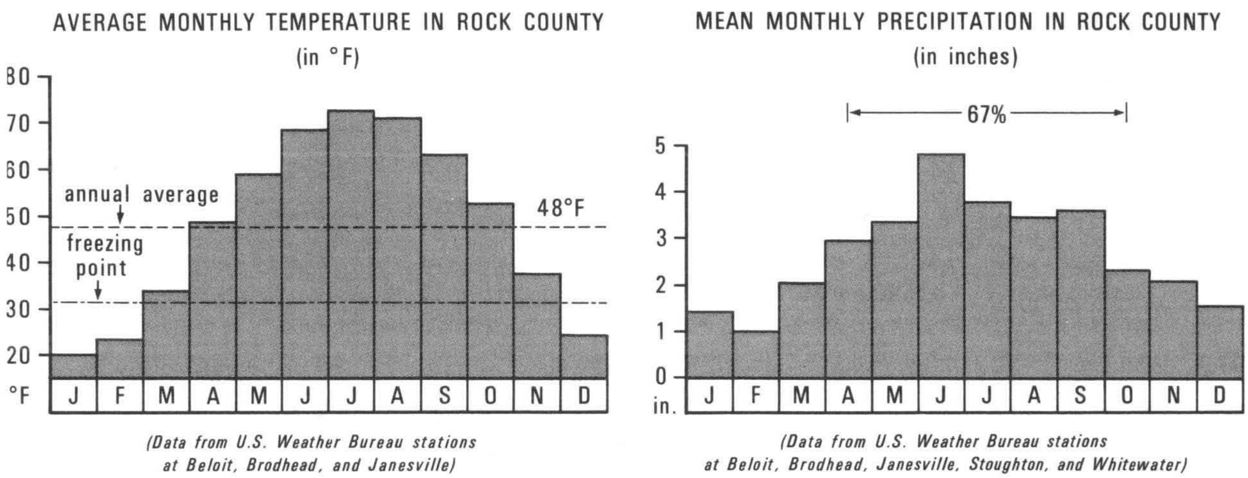


Figure 3. Average monthly temperature and mean monthly precipitation in Rock County

Precipitation is ordinarily adequate for the vegetation and water supplies of the county. Normal annual precipitation is about 32 in., with the greatest amount (67 percent of the total) concentrated in the six months of the growing season (April 15 to October 15). The wettest month is June (4.86 in.), while the driest month is February with 1.00 in. (see figure 3). Between 70 and 80 percent of the average precipitation is lost by evaporation and used by plants, and 20 to 30 percent runs off in streams (LeRoux, 1963; Cotter and others, 1969; Hindall and Skinner, 1973). Total streamflow is combined of overland flow and ground-water discharge into stream channels. Nearly two thirds of the streamflow is contributed by ground water (Cotter, 1976).

Even though Rock County is located in a humid climatic zone, drought periods (prolonged and abnormal moisture deficiencies) are quite common and may cause problems in agriculture and water supply by depleting soil moisture, by lowering ground-water and lake levels, and by reducing streamflow. For the study, a year was classified as a drought year when annual precipitation was 85 percent or less of normal. The longest period of precipitation record is available for the station at Beloit (fig. 4). The date when Beloit College became a weather station is not known. Regular weather observations began in

Table 1. Driest and wettest years at Beloit College
(long-term mean: 32.59 in.)

Driest Years (below 85%)					Wettest Years (above 114%)				
Year	Total Annual Precipitation				Year	Total Annual Precipitation			
	inches	% of mean	Interval in years	Overall rank		inches	% of mean	Interval in years	Overall rank
1867	26.85e	82.4	–	22.	1875	37.44	114.9	–	24.
1870	20.42	62.7	3	2.-3.	1876	40.47	124.2	1	12.
1871	26.56	81.5	1	20.	1877	40.81	125.2	1	9.
1872	21.77	66.8	1	5.	1878	41.14	126.2	1	6.
1895	20.42	62.7	23	2.-3.	1881	46.64	143.1	3	3.
1901	18.86	57.9	6	1.	1882	38.02	116.7	1	21.
1910	23.00	70.6	9	8.	1892	46.32	142.1	10	4.
1917	24.69	75.8	7	13.	1898	40.60	124.6	6	11.
1920	25.61	78.6	3	17.	1902	39.87	122.3	4	13.
1930	27.48	84.3	10	25.	1909	41.01	125.8	7	7.
1932	26.66	81.8	2	21.	1911	37.30	114.5	2	25.
1934	27.11	83.2	2	23.	1916	39.19	120.3	5	15.
1939	25.96	79.7	5	18.	1938	53.92	165.4	22	1.
1946	27.34	83.9	7	24.	1941	39.08	119.9	3	20.
1948	24.89	76.4	2	15.	1942	40.68	124.8	1	10.
1949	26.55	81.5	1	19.	1943	39.14	120.1	1	16.
1953	23.32	71.6	4	10.	1945	37.57	115.3	2	22.
1955	25.57	78.5	2	16.	1951	39.09	119.9	6	19.
1956	21.90	67.2	1	6	1954	37.51	115.1	3	23.
1958	24.85	76.3	2	14.	1959	40.90	125.5	5	8.
1962	21.70	66.6	4	4.	1961	39.13	120.1	2	17.
1963	24.13	74.0	1	11.	1965	41.68	127.9	4	5.
1966	23.30	71.5	3	9.	1972	50.31	154.4	7	2.
1974	24.42	74.9	8	12.	1973	39.31	120.6	1	14.
1976	22.41	68.8	2	7.	1978	39.12	120.0	5	18.

e = estimated

January 1850; however, the data are readily available starting with January 1866. During the 115-year period, there were 25 drought years at Beloit (table 1), the most serious being in 1901, 1870, and 1895. The wettest years on record were 1938, 1972, 1881, and 1892 when the rainfall amount exceeded 140 percent of normal.

Besides Beloit, precipitation data are available for two other stations in the county (Janesville and Clinton) and for Brodhead, just west of the county line (see figure 1).

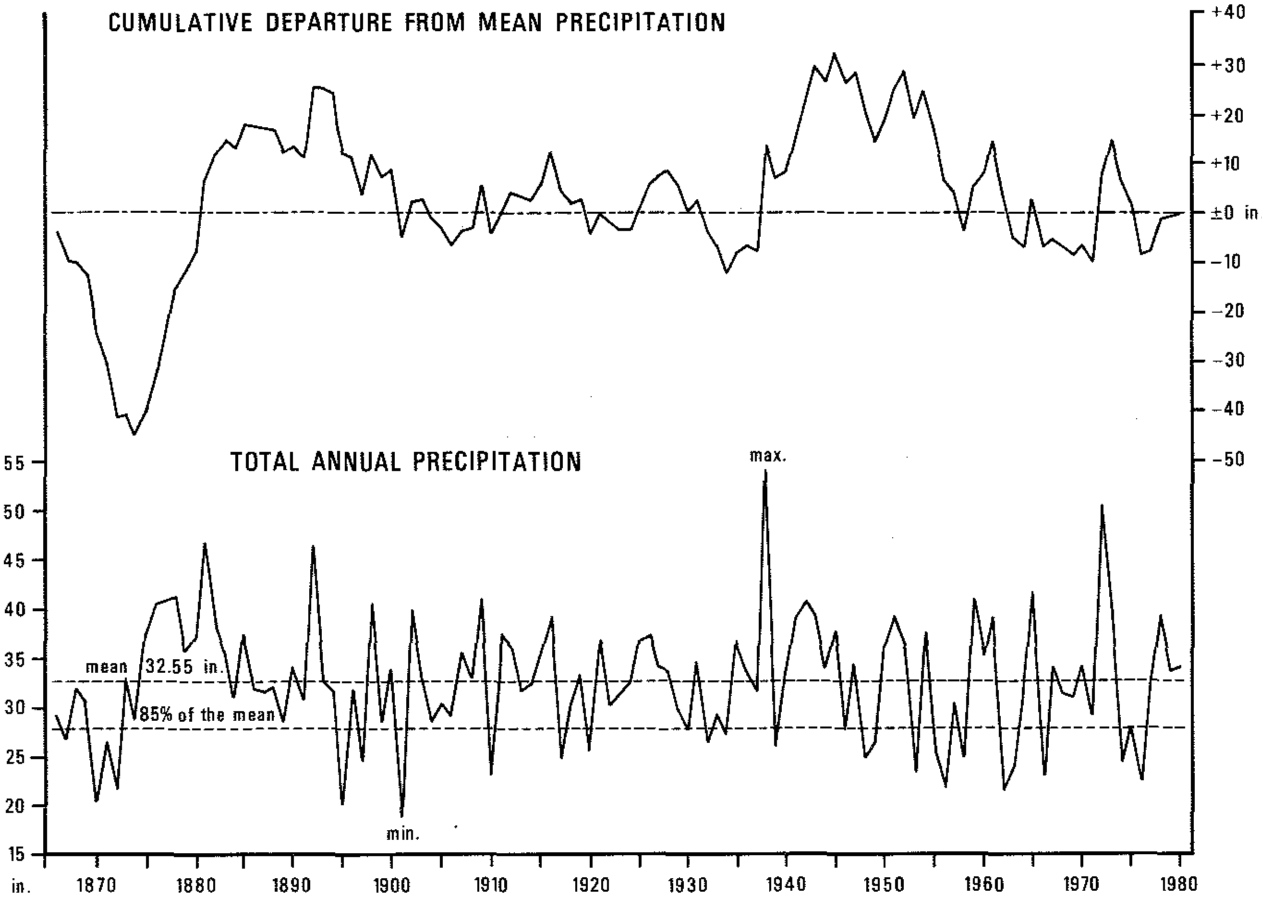


Figure 4. Precipitation at Beloit College, 1866-1980

Air-Quality Control

The quality of air is monitored by the DNR at five locations in the city of Beloit (site numbers 549001,2,5,6,9) and by the Wisconsin Power and Light Company at another five locations (site numbers 549021 to 549025) in the towns of Beloit, La Prairie, Rock, and Turtle (see figure 1). The main concern is the amount of suspended particulate matter, which is being measured at nine sites. The five industrial sites are also being checked for concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and hydrocarbons (NMHC). In addition, ozone (O_3) is monitored at three sites during the warm months of April through October (Wis. DNR, 1981). So far, there are no serious air-quality problems in the county. Only five sites in the center of Beloit slightly exceeded in 1980 the EPA secondary standards for particulate matter (annual geometric mean 60 mg/m^3).

Surface Water

Rock County has a relatively small supply of surface water, which covers only 0.77 percent of the county's total area. The 50 streams account for approximately two thirds of the water area, and the 72 lakes, ponds, and pits for one third (Ball and others, 1970). All of the streams belong to the Rock River drainage system. The Rock River almost bisects the county, entering from the southwestern end of Lake Koshkonong and flowing out in Beloit. Other major streams include the Yahara River, Turtle Creek, and Sugar River.

Drainage patterns reflect the physiography. In the Western Uplands area, numerous small streams flow into the Sugar River, which is the major stream of this part of the county. The general absence of young glacial deposits and nearly horizontal bedrock allowed the streams sufficient time to develop a dendritic network of deep valleys and flat-topped, often narrow ridges. The present drainage system is similar to the preglacial drainage.

The streams in the Eastern Ridges and Lowlands province are in a much younger stage of development, compared to the older systems of the Western Uplands province. Glaciation destroyed or diverted preglacial streams; most prominently the Rock River, which deviates westward from its preglacial course (see plate 2). Due to the relatively recent retreat of the continental glacier (about 10,000 years ago), streams have accomplished little in draining this area.

There are no large lakes in the county. Not counting the county's portion of Lake Koshkonong, the largest lake is Clear Lake, 2.5 mi northwest of Milton (82 acres). According to the latest account (Wis. DNR, 1978), there are 16 named and 57 unnamed lakes in Rock County. The named lakes cover over 95 percent of the total acreage of the lakes. Nearly all the lakes and ponds are in the northern one third of the county. The overall density of lakes in Rock County is 0.1 lakes per square mile, which is approximately the same as the statewide average. Most of the lakes appear to be ground-water dominated lakes defined by Born and others (1974) as lakes that are part of a dynamic ground-water flow system. Several of the smaller lakes and ponds are probably perched lakes, i.e., lakes not connected with the main ground-water body (LeRoux, 1963). Lake Koshkonong, Fulton Pond, and Mill Pond are examples of surface-water dominated lakes. These lakes are on a throughgoing drainage system, and surface water is more important for them than ground water (Born and others, 1974).

Data on streams and lakes were summarized in the Rock County Comprehensive Planning Program (Wis. DLAD, 1974). All named and unnamed lakes and streams are described in detail in DNR publications (Ball and others, 1970; Wis. DNR, 1978). There are five stream-gaging stations and three surface-water quality stations in Rock County (see figure 1).

The county can be subdivided into eight major hydrologic units for the purpose of surface-water management and planning (fig. 5). The units are summarized in table 2.

Geology

Rock County obtains its water supply from sedimentary rocks of Cambrian and Ordovician age that consist largely of stratified sandstone, with a lesser amount of carbonate rocks (limestone and dolomite--a magnesium-rich limestone), and some shale. Overlying this thick sedimentary sequence are unconsolidated deposits of Quaternary age, consisting predominantly of glacial and

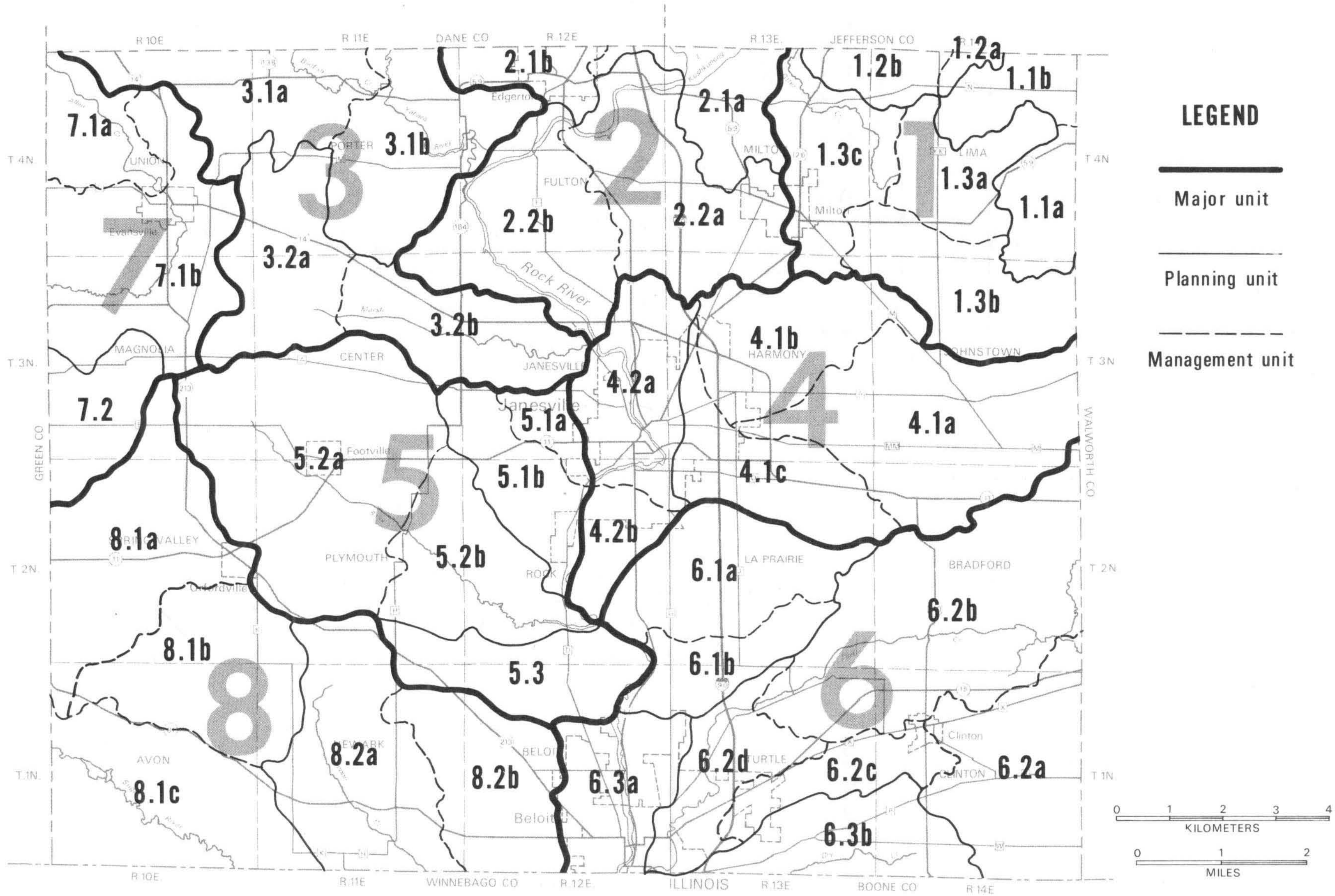


Figure 5. Proposed surface-water resource units

Table 2. Proposed surface-water management units for Rock County

Major Hydrologic Unit	Planning Unit	Management Unit
1. Rock River above the county line	1.1 Bark River (Whitewater Creek)	1.1a Spring Brook 1.1b Galloway Creek
	1.2 Allen Creek and Lake Koshkonong	1.2a Allen Creek 1.2b upper L. Koshkonong
	1.3 Otter Creek	1.3a Otter Cr. Marsh 1.3b southern drainage 1.3c lower Otter Creek
2. Upper Rock River	2.1 Saunders Creek and Lake Koshkonong	2.1a lower L. Koshkonong 2.1b Saunders Creek
	2.2 Rock River above Janesville	2.2a Milton drainage 2.2b Rock R. drainage
3. Yahara River - Marsh Creek	3.1 Lower Yahara River	3.1a Badfish Creek 3.1b below Badfish Creek
	3.2 Marsh Creek	3.2a upper Marsh Creek 3.2b lower Marsh Creek
4. Blackhawk Creek	4.1 Blackhawk Creek	4.1a upper Blackhawk Creek 4.1b northern drainage 4.1c Spring Brook
	4.2 Rock River at Janesville	4.2a Janesville drainage 4.2b airport drainage
5. Bass Creek	5.1 Fisher Creek and Markham Creek	5.1a Fisher Creek 5.1b Markham Creek
	5.2 Bass Creek	5.2a upper Bass Creek 5.2b lower Bass Creek
	5.3 Rock River below Afton	5.3a right drainage
6. Lower Rock River	6.1 Rock River below Afton	6.1a Happy Hollow drainage 6.1b left drainage
	6.2 Turtle Creek	6.2a Little Turtle Creek 6.2b upper Turtle Creek 6.2c Spring Brook 6.2d lower Turtle Creek
	6.3 Rock River in and below Beloit	6.3a Beloit drainage 6.3b Dry Creek
7. Upper Sugar River	7.1 Allen Creek	7.1a above Evansville 7.1b below Evansville
	7.2 Norwegian Creek	
8. Lower Sugar River	8.1 Sugar River below Little Sugar R.	8.1a Taylor Creek 8.1b Willow Creek 8.1c Sugar R. below Taylor Cr.
	8.2 Racoon Creek	8.2a West Fork 8.2b East Fork

fluvial deposits. The vertical sequence of the geologic units is shown by geologic cross section on plate 1 (cross-section line is shown on plate 2). The geologic history and geologic formations were described by LeRoux (1963). Wells used for the construction of the cross section and other wells shown on maps came from the WGNHS and USGS files, and they are identified by county prefix (Ro) and the well serial number.

Bedrock Geology

The Cambrian-Ordovician sedimentary rocks were deposited in shallow seas on an uneven and arched surface of igneous and metamorphic rocks of Precambrian age, which have not been reached by wells in Rock County. Both the Precambrian surface and the sedimentary rocks dip gently to the south and southeast (see plate 1). The sedimentary units thicken in the direction of dip from about 1,000 ft in the northwestern corner to over 1,500 ft in the southeastern corner of the county (LeRoux, 1963). However, the exact depth to Precambrian surface is unknown because the full thickness of the sedimentary sequence has not been penetrated.

The oldest formations of Cambrian age are, in ascending order, the Mt. Simon sandstone, Eau Claire sandstone, Wonewoc (formerly Galesville) sandstone, Tunnel City Group (formerly Franconia sandstone), and Trempealeau Formation, consisting of the Jordan sandstone and St. Lawrence dolomite. In the Rock River and Sugar River valleys these rocks of Cambrian age are overlain by unconsolidated Quaternary deposits. Elsewhere they are overlain by rocks of Ordovician age (see plate 1).

Rock formations of Ordovician age include, in ascending order, the Prairie du Chien Group (dolomite), the St. Peter Formation (sandstone), and the Platteville-Galena Formation--now called the Sinnipee Group--consisting of carbonate rocks (limestone and dolomite). The Prairie du Chien Group was greatly thinned by erosion or completely eroded before deposition of the St. Peter sandstone when the land was elevated above sea level. It is thin at Brodhead, Footville, Edgerton, Janesville, and Milton. Elsewhere it is absent, and the St. Peter Formation rests directly on sandstones of Cambrian age. Because it was laid down on an uneven erosional surface, the St. Peter Formation varies considerably in thickness. Bedrock surface in the western part of the county is formed primarily by the St. Peter sandstone. Bedrock east of the Rock River valley and ridge tops west of the valley are formed by the Platteville-Galena unit.

After the deposition of the sedimentary rocks, erosion over a long period of time produced a bedrock surface having a maximum relief of 1,000 feet in Rock County. The most significant feature of the bedrock surface is the ancestral Rock River valley more than 300 feet deep, subsequently filled with outwash and other fluvial deposits. East of the buried valley the bedrock has a flat, relatively undissected surface. West of the valley the bedrock surface is rugged and dissected.

Surface Geology

The Quaternary sediments consist of Pleistocene glacial and fluvial deposits (till and outwash) and of weathered and disintegrated bedrock material and alluvial sediments of Recent age. During the late Pleistocene time, about 10,000 to 30,000 years ago, major continental ice sheets advanced to and retreated from the county several times, leaving behind a variety of unconsolidated deposits of variable thickness, commonly called glacial drift. During each ice withdrawal there were periods of erosion in which much of the material deposited by the ice or meltwaters was moved, sorted, and redeposited.

Approximately the northern one third of the county is covered by end moraines (Johnstown and Milton moraines) formed during the late Wisconsinan time. Extensive outwash and other fluvial sediments associated with the Johnstown moraine extend southeasterly across the county south of the moraine and southward along the Rock River valley. The remainder of the county is covered largely by till of an earlier episode of Wisconsinan glaciation.

The end moraines in the northern part of the county consist largely of till, which is composed of unsorted and unstratified clay silt, sand, and gravel, including boulders, and the deposit is relatively thick. The older till in southeastern and southwestern Rock County is of a similar composition but generally is thin, highly weathered, and somewhat eroded. Outwash, deposited by meltwater streams beyond active glacier ice, consists largely of sand and gravel with some cobbles and boulders and silt and is well sorted and stratified.

Special glacial features in the northeastern part of the county are drumlins (oval hills molded from till and elongated in the direction of ice movement) and ice-block depressions (resulting from the melting of ice and the subsequent collapse of the overlying sediment) called kettles.

Surficial material of Recent Epoch was deposited by streams in the form of alluvial deposits of sand and clay or resulted from the weathering of bedrock formations. The composition of this disintegrated material depends on the character of parent rock (sandstone = sand, dolomite = clay).

Depth to bedrock ranges from nil to more than 400 feet (pl. 2). The greatest thickness of unconsolidated sediments reached by a well was 396 ft, close to the center of the buried valley of the ancient Rock River. However, this well did not reach bedrock. The thickness over 200 ft occurs in the deep preglacial valleys of the Rock and Yahara rivers and other streams in the western part of the county (pl. 2). In the eastern part, the thickness is generally less than 100 ft.

Soils

The soils of Rock County are, in general, good agricultural soils and are intensively cultivated. The amount of land in farming has been decreasing steadily. In 1979, about 80 percent of the county acreage was farmland (Rock County, 1979a), compared to 82 percent in 1969 (Wis. DLAD, 1974) and 96 percent in 1910 (Weidman and Schultz, 1915). Despite the high degree of industrialization, Rock County is an extremely productive agricultural county. Main crops are corn, soybeans, small grains, and peas. In 1978, the county ranked second in the state in grain-corn production and first in soybean production (Wis. Agri. Rept. Service, 1979).

Two thirds of the county is covered by three major soil associations: the Kidder-St. Charles association, on gently rolling till plains in the north; the Plano-Warsaw-Dresden association, on flat, sand and gravel outwash plains; and the Edmund-Rockton-Whalan association, on ridge tops and side slopes of dolomite in the southwest (USDA, 1974). Till in the southeastern part of the county is covered by the Pecatonica-Ogle-Durand association. Most soils have a good potential for irrigation where slopes are favorable, and a dependable water supply is available. Permeable soils on outwash plains, in particular, are well suited to irrigation and if irrigated have potential for intensive production of vegetables and truck crops. Most soil (84 percent) is well- to moderately well-drained silt and sandy loam, of medium to moderately coarse texture, moderate to moderately rapid permeability, and, with the exception of shallow soil in the southwest, deep to moderately deep. Wet soils are generally limited to relatively small areas along drainageways and depressions.

Soil characteristics (slope, depth, texture, and permeability) are perhaps the single most significant factor determining the rate and extent of ground-water recharge and potential for pollution. Soils in the county allow infiltration of precipitation water everywhere. Because their dominant texture is loamy, they have at least moderate permeability of 0.63 to 2.0 in./hr (USDA, 1974). Soils of moderately rapid and rapid permeability (2.0 to 6.3 in./hr and 6.3 to 20.0 in./hr) generally do not provide good protection against pollution of ground water. If the permeability of surface material is rapid, water-intake rate is rapid, and water from the surface rapidly recharges the aquifers. Rapid infiltration rate results in little amelioration of pollutants. Pollutants can enter ground water quickest where the soils of moderately rapid permeability have porous substratum with rapid permeability (pl. 3). The potential for ground-water pollution is reduced where the unconsolidated materials are thick or the water table is deeper, and pollutants have more time for attenuation.

Mineral and Other Natural Resources

The most important minerals produced in Rock County are sand, gravel, and crushed stone. In 1977, Rock County was one of the six counties producing more than 1 million tons of sand and gravel (Reuss and others, 1981). Seven pits produced 1.18 million tons vallued at 1.59 million dollars. Most of the crushed and broken stone produced in Rock County was dolomite from 14 quarries in the Platteville-Galena unit. Stone production in 1977 was 323,000 tons, worth approximately $629,000.

Historically, Rock County has not been a heavily forested area nor has it been covered by extensive wetlands, and even this meager amount has been declining. Wooded lots are being cleared out and wetland areas drained. In 1978 woods accounted for approximately 6.0 percent of land in the county as compared to 6.6 percent in 1968 (Rock County, 1979a). In the last 40 years about half of all the wetlands in Rock County have been eliminated. The last published inventory (Wis. DNR, 1969) indicated that only 18,077 acres of wetland remained (about 4 percent of the county's land area), from a total of 33,775 acres recorded during the 1939 Wisconsin Land Economic Inventory (Wis. Cons. Dept., 1959a).

GROUND WATER

Importance of Ground-Water Resources

Ground water is a valuable natural resource of Rock County, and also one of the most misunderstood and misused ones. There is ground water—more or less of it, more or less accessible, and of generally good quality—everywhere under the county. Everybody in the county drinks ground water, but very few people know where it comes from, how it moves, or how it can become polluted. Remote and sometimes mysterious to many people because it cannot be observed, ground water is often regarded as a common holding. People expect it to be instantly available in good quality, oblivious to the principles of ground-water occurrence and movement and to the need for its protection.

Everyone wants clean water for drinking, bathing, and other domestic, public, industrial, and rural uses, but not everybody appreciates the fact that we are often our worst enemy in achieving that goal. Increasing demands on ground-water resources because of population and industrial growth, and lack of conservation and periodic droughts have brought about the realization that, while large quantities of ground water do exist, careful and proper management will be necessary to conserve this valuable resource, both in quantity and quality.

The purpose of this chapter is to discuss the principles of ground-water occurrence and movement and the interrelations between ground water and geologic framework and between ground water and the hydrologic cycle. A knowledge of these principles is necessary for understanding the processes responsible for ground-water quality and its changes, and subsequently, for any sound ground-water protection program.

Ground-Water Use

The importance of ground water for the economy and general welfare of the county can be demonstrated by simple analysis of water use data for 1979 (table 3), when all but 0.6 percent of water came from ground-water sources. Every day in 1979, some 28 million gallons of fresh water were withdrawn from Rock County's aquifers. This is about 200 gallons of water for every man, woman, and child in the county, or 0.8 ton of water for each person each day. LeRoux (1963) estimated that in 1957 about 23 million gallons per day (mgd) were withdrawn, which means that ground-water use increased about 22 percent in the last 25 years.

About 73 percent of the county population is served by central water-supply systems, primarily publicly owned. Historical trends in municipal pumpage (table 4) demonstrate the increase in ground-water consumption. In the last 9 years only, public use in Rock County increased 25 percent. It was estimated that the municipalities will use about 24.7 mgd in 2000 (Rock County, 1979b), which constitutes another 21 percent increase over the next 20 years.

The growth in the population supplied by public systems is directly proportional to the growth in the total county population. In 1979, 73.2 percent of the population (over 102,000 people) was served by public water-supply systems. This proportion has been relatively stable over the last 45 years and has increased only slightly since 1935 when 71.9 percent of the population was served by public systems (see table 4).

Not only don't we care where the water we are using comes from but we also seldom realize how much of it we use. Even though the average person in the United States may consume no more than a gallon a day in liquid and solid foods, a household of four persons uses nearly 300 gallons per day (gpd) from public supplies because of the many other residential uses to which the water is put (Gehm and Bregman, 1976). Water in the home is primarily used for drinking, cooking, washing clothes and dishes, and bathing. A second principal use is for toilet flushing and household cleaning, and a third is lawn and garden sprinkling, and car washing. Together these are called domestic use. In 1979, the average per capita use in the state of Wisconsin varied between 36 and 72 gpd (USGS, 1980). Based on municipal metered data, the state average per capita residential use was 56 gallons per day. Rock County had the highest usage 72 gallons per day per capita (gpdc).

It can be estimated that typically a Rock County citizen living in an urban area would use daily the following amount of water:

Drinking and cooking	3 gallons
Personal hygiene	1 gallon
Dish washing and garbage disposal	5 gallons
Clothes washing	20 gallons
Tub and shower bathing	30 gallons
Toilet flushing	8 gallons
Household cleaning	2 gallons
Lawn and garden watering	2 gallons
Car washing	1 gallon

Table 3. Estimated use of water in Rock County, 1979

Type of Use	Water Use (in million gallons per day, mgd)						
	Residential	Industrial	Commercial	Irrigation	Stock	Other	TOTAL
PUBLIC							
Community Systems							
Municipal	7.34	3.73	3.26	0	0	6.00	20.33
Other	0.10	0	0	0	0	0	0.10
Noncommunity Systems	0	0.06	0.12	0	0	0.08	0.26
PRIVATE							
Ground-Water Sources	1.77	1.93	0.04	2.12	1.38	0.08	7.32
Surface-Water Sources	0	0	0	0.11	0.05	0	0.16
Subtotal							
Ground Water	9.21	5.72	3.42	2.12	1.38	6.16	28.01
Surface Water	0	0	0	0.11	0.05	0	0.16
TOTAL	9.21	5.72	3.42	2.23	1.43	6.16	28.17

Source: U.S. Geological Survey, 1980.

Table 4. Municipal pumpage of ground water in Rock County

Municipal Water Utility	Year System Instal.	1935[5]		1957[2]			1970[3]			1979[4]		
		Population[5]	Dly. Avrg. 1,000 gpd	Population[5]	Dly. Avrg. 1,000 gpd	Incr. in %	Population[6]	Dly. Avrg. 1,000 gpd	Incr. in %	Population[4]	Dly. Avrg. 1,000 gpd	Incr. in %
Beloit	1885	24,488	1,880	31,869	4,400	134	35,729	5,900	34	34,711	7,962	35
Clinton	1896	902	48	1,233	110	129	1,333	122	11	1,626	158	30
Edgerton	1897	3,086	163	3,852	330	102	4,118	426	29	4,580	1,055	148
Evansville	1902	2,295	176	2,760	290	65	2,992	276	-5	3,229	348	26
Footville	1935	409	23	641	50	117	698	73	46	744	80	10
Janesville	1888	22,310	1,800	32,084	6,300	250	46,426	9,220	46	51,500	10,151	10
Milton	1923	1,993	90	2,969	150	67	3,699	249	66	4,836	453	82
Orfordville	1938	-	-	628	40	-	888	57	42	1,146	132	132
TOTAL		55,483	4,180	76,036	11,670	178	95,083	16,323	40	102,372	20,339	25
Proportion of total population served by public systems		71.9%		70.7%			72.1%			73.2%		

Source: [1] Wis. State Board of Health, 1935; [2] LeRoux, 1963; [3] Wis. DNR, 1970;
[4] U.S. Geological Survey, 1980; [5] Estimated; [6] Wis. DLAD, 1974.

Residential use, although the largest of ground-water uses in Rock County, is not the only public use of water. Public water systems also supply schools and other institutions, government buildings, parks, recreational facilities, industries, and commercial establishments within city limits. Altogether the largest amount of ground water in Rock County in 1979 was used for public water supplies: 20.7 mgd, which is 74 percent of all water uses (fig. 6A). The other three major water uses, rural (including domestic and livestock consumption), irrigation, and self-supplied industry, used the remaining 26 percent and were supplied from private sources. About four fifths of the total amount of ground water used was pumped in urban areas, primarily in the heavily populated and industrialized area along the Rock River (fig. 6B). The main pumpage centers and principal ground-water users are shown in figure 7.

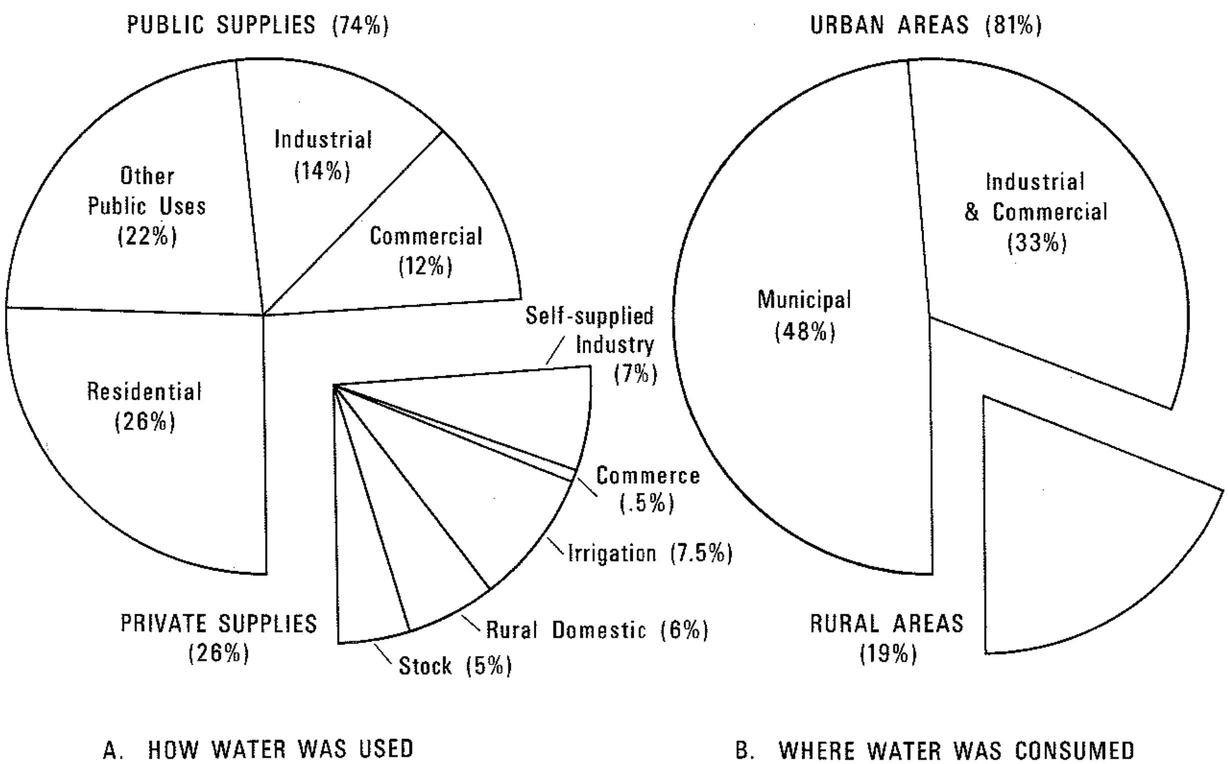


Figure 6. Ground-water uses in Rock County in 1979

Ground-Water Availability

Contrary to popular belief, ground water does not occur in huge underground lakes and rivers; it does not migrate thousands of miles through the earth; its behavior is neither mysterious nor occult; and it can be polluted even if it is deep underground. These and other common misconceptions result from lack of knowledge by the public of principles of ground-water occurrence and movement. There are few areas in the United States where the water may flow in large underground openings, such as caves and solution channels in

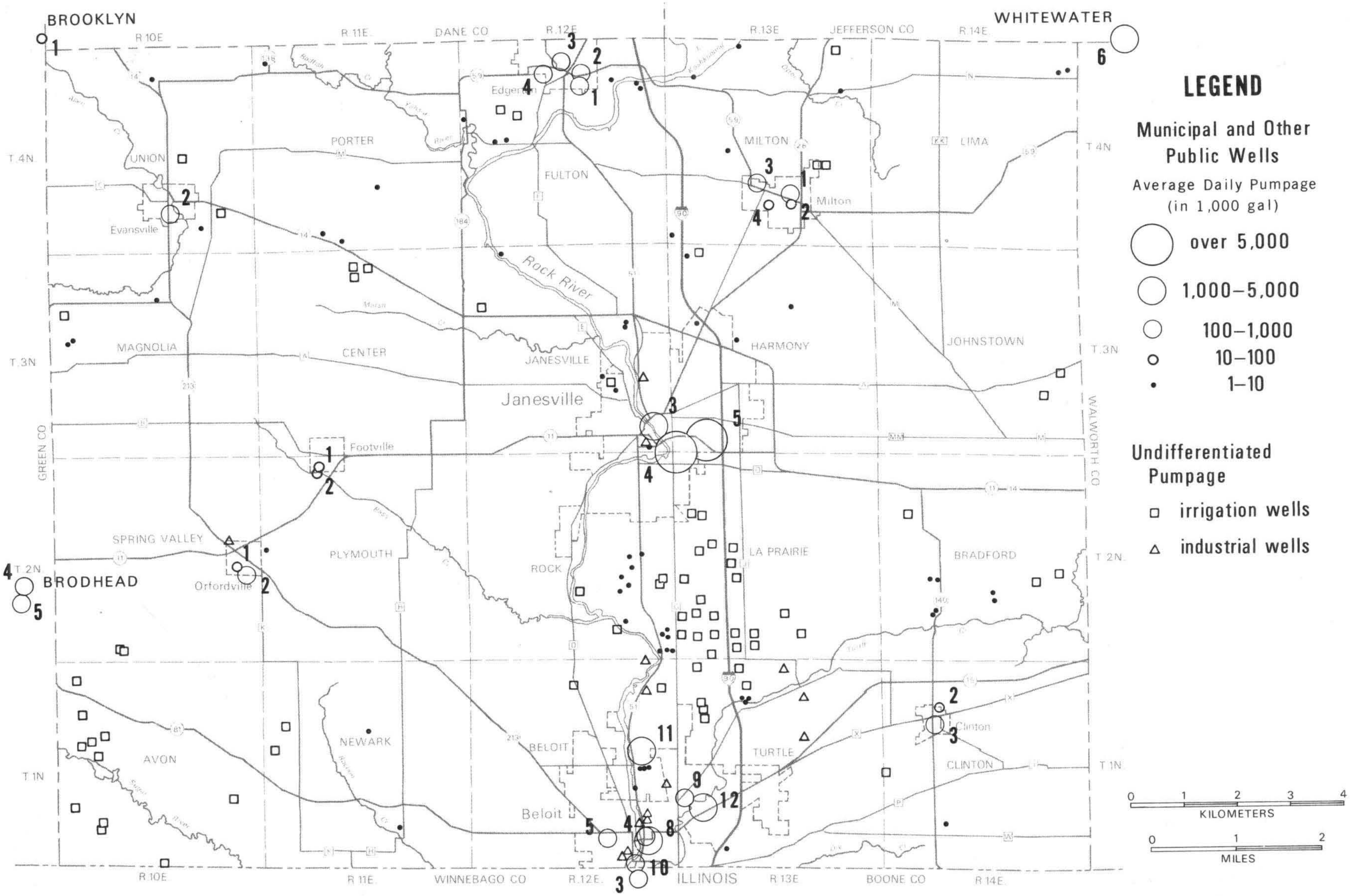


Figure 7. Major ground-water users in Rock County in 1979

limestone of Kentucky and Tennessee. In most places, ground water occurs in permeable rocks that have a sufficient number of interconnected small openings (pores or cracks) for the water to pass through them.

Ground-water availability depends primarily on the physical properties and thickness of these permeable, water-bearing rocks (called aquifers) and on the supply of atmospheric moisture. Each geographic area has its own unique soil-rock-water relationships because topography, geology, and climate vary regionally. On the basis of these three parameters, hydrogeologic units are grouped into broad areas, called hydrogeologic provinces, within which the conditions are generally similar. Rock County belongs entirely to one province: Drift-Paleozoic province (Meinzer, 1923), in which ground water occurs in both unconsolidated deposits of Quarternary age and sedimentary rocks of Cambrian and Ordovician age.

Rock County ground-water resources are plentiful, and adequate amounts for domestic supply are available everywhere within the county, usually at depths of less than 100 feet. Ground water in Rock County can be tapped from four major aquifers: unconsolidated Quaternary sediments, Ordovician dolomite (the Platteville-Galena unit), Ordovician sandstone (the St. Peter Formation), and Upper Cambrian sandstones.

Deposits of Quaternary age in Rock County vary greatly in thickness and lithology within short distances. The irregularity of the relief of bedrock surface causes much of the variation in thickness. Varying lithology is the result of glacial activity.

The most productive sources of ground water are the outwash and other fluvial deposits in stream valleys and in buried bedrock valleys, consisting of sorted and stratified medium to very coarse sand and gravel (fig. 8). The Rock River valley is the deepest preglacial valley in the county and contains over 300 feet of sand and gravel. Good aquifers are also present in the valleys of the Yahara River and its ancient tributary from Evansville, Sugar River, lower Taylor Creek, and Racoon Creek (see plate 2). One of the remarkable features of the outwash aquifers is its high permeability and transmissivity (hydraulic conductivity times saturated thickness), which sets it apart from the other water-bearing units. Pumping tests performed on Janesville and Beloit municipal wells, as reported by LeRoux (1963), yielded specific capacity of 280 to 1,250 gallons per minute (gpm) per foot of drawdown. Large yields of more then 500 gpm can be obtained in much of the sand and gravel deposits (fig. 9). All high-capacity industrial wells in the Beloit area and most irrigation wells are constructed in these aquifers.

The remaining area of the county covered by till will locally yield small amounts of ground water, especially in the northern part of the county where lenses of sand and gravel may yield enough water to supply small domestic and stock wells. In the northeastern and southeastern corners of the county glacial deposits yield no water (see figure 9). In southwestern Rock County the unconsolidated material is thin and is not an aquifer there.

Bedrock formations--the Platteville-Galena dolomite, St. Peter sandstone, Prairie du Chien dolomite, and Upper Cambrian sandstone (see figure 8)--may act as a single aquifer or, when separated by less permeable layers, as several aquifers of moderate to larger yields. Yields of 1,000 gpm or more can be obtained from Cambrian sandstones through the county (Devaul, 1975b). However, this deepest aquifer is generally not utilized for water supplies, except by municipalities with deep wells. Although the specific capacities of wells in Cambrian sandstones are relatively low (5 to 20 gpm/ft), the great saturated thickness of this unit (over 1,000 ft) permits the construction of high-capacity wells (LeRoux, 1963). The Prairie du Chien dolomite is not considered an important aquifer in the county because it is absent in many places.

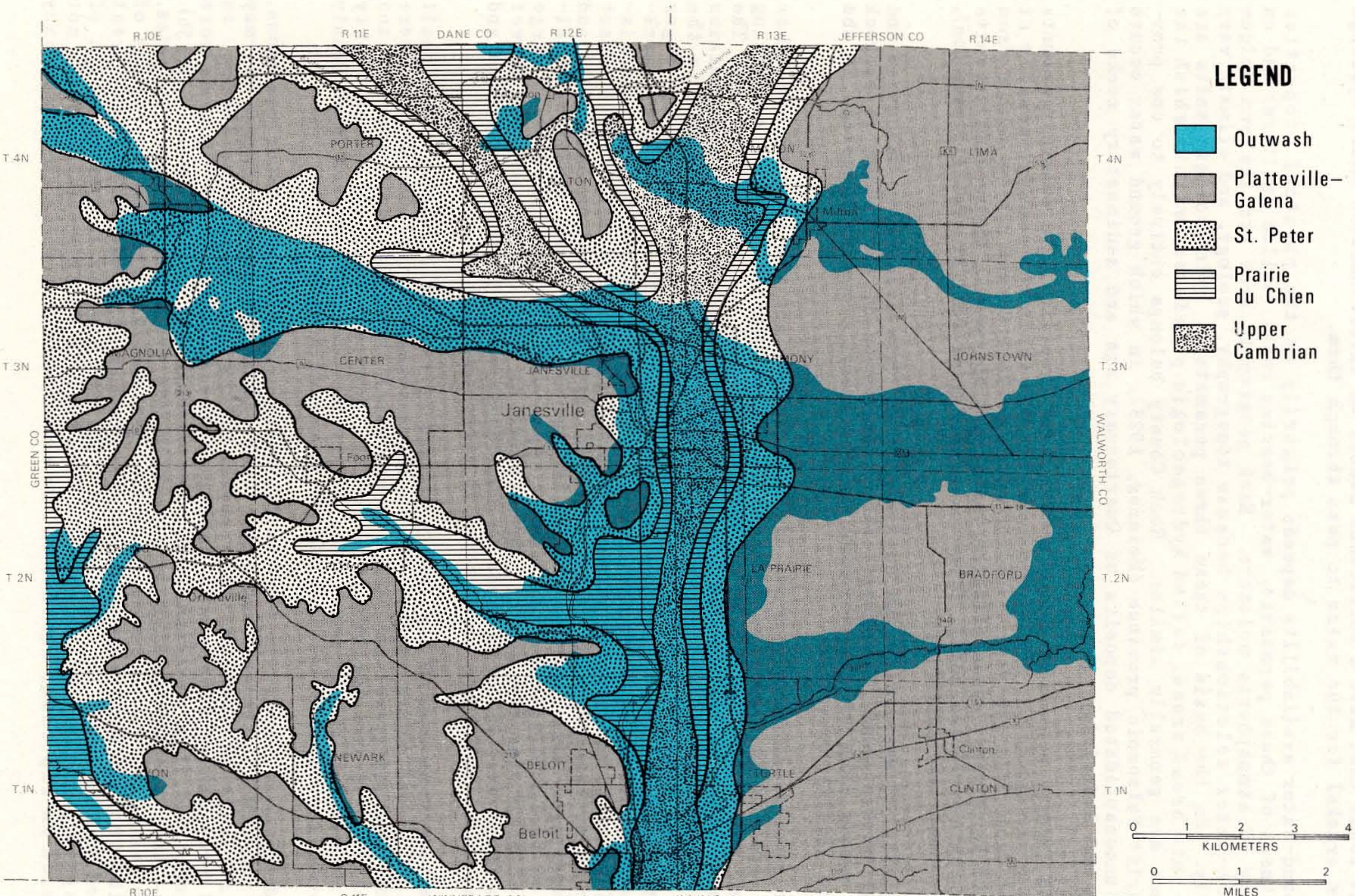


Figure 8. Generalized aquifer map of Rock County

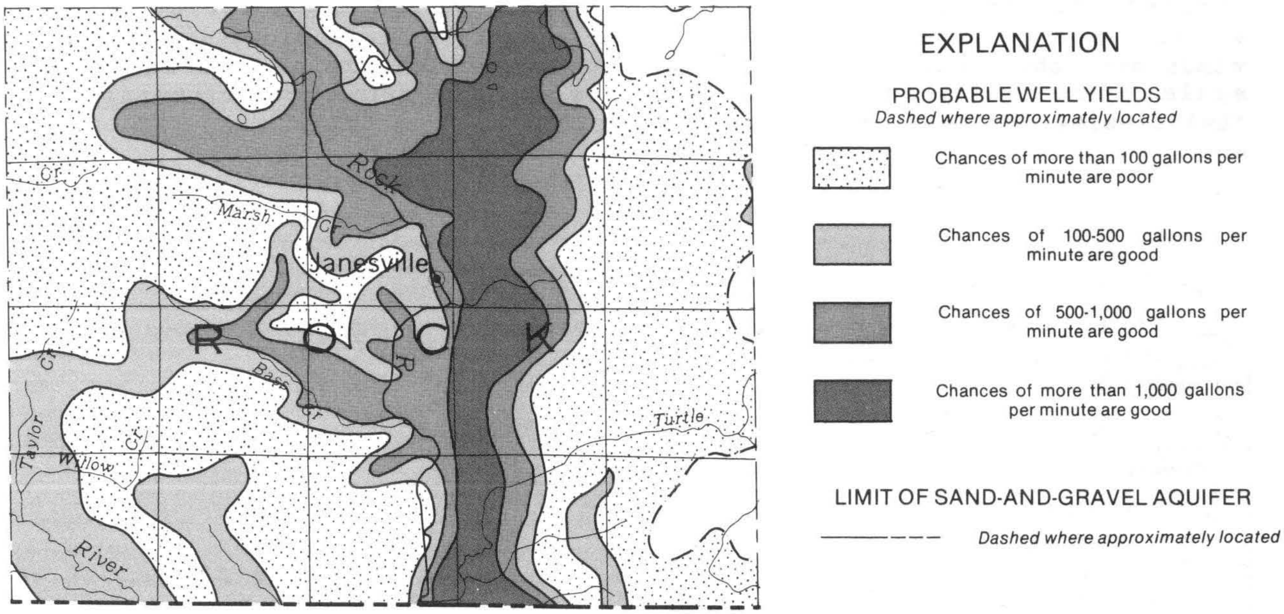


Figure 9. Map showing probable yields of wells in the sand and gravel aquifer, Rock County, Wis. (from Devaul, 1975a)

Adequate supplies of ground water for domestic, stock, and commercial uses are available from the Platteville-Galena and the St. Peter Formations. The Platteville-Galena dolomite is an important aquifer in the area east of the Rock River (see figure 8), where it yields adequate amounts of water. It is seldom necessary to drill into the underlying St. Peter sandstone, except for high-capacity irrigation wells. Rock fractures and solution channels provide paths for ground-water movement. The yield depends on the size and degree of interconnection of these openings and ranges from 10 to 100 gpm. West of the Rock River, the Platteville-Galena unit is tapped only in the lower-lying areas; there where it caps hills and ridges the yields are inadequate because much of the unit is above the zone of saturation. Therefore, in this area west of the Rock River, the principal aquifer is the St. Peter Formation (see figure 8), which consists of fine- to medium-grained sandstone. Ground water moves through the small pores between the grains as well as along fractures. The permeability of the formation is quite high, and the yields may exceed 100 gpm.

Hydrologic Budget

Understanding several hydrologic facts is crucial for understanding ground-water behavior. In order to evaluate the amount of ground water available for water supplies in the county, it is necessary to understand the relation of ground water to general circulation of water on the earth, called the **hydrologic cycle** (fig. 10). Ground water is directly related to the other two basic components of the hydrologic cycle: surface water and atmospheric water. Surface water and ground water are intimately associated, and they are in a continuous process of exchange. Discharge from ground water contributes substantially to streamflow and maintains it entirely during dry periods. In some areas the opposite process occurs, where water from streams recharges shallow aquifers. Ground water is dependent upon the supply of atmospheric water in the form of precipitation. When rain falls or snow melts, the first water is taken by soil and plants, some runs off directly to streams, most evaporates or is transpired by plants, and some infiltrates into the ground to become ground water. Ground water flows in the subsurface toward the streams and eventually discharges into them, contributing nearly two thirds of the streamflow. The streams in turn discharge into the ocean where the water evaporates and rises into the atmosphere. Moisture-laden clouds are blown by winds over the land, clash with cold air, and produce rain. The water falls again on the land and replenishes the streams and ground-water reservoirs, thus closing the never-ending hydrologic cycle.

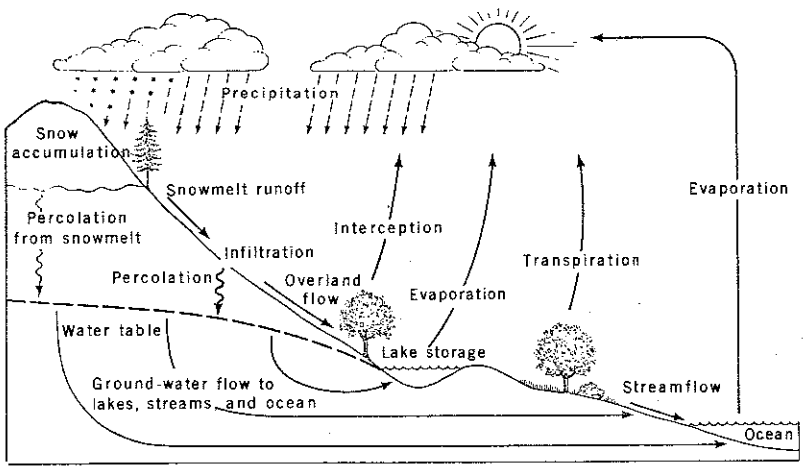


Figure 10.
Schematic diagram of the hydrologic cycle (adapted from **Water in Environmental Planning**, W.H. Freeman and Co., 1978)

The **hydrologic budget** is a simplified equation that balances the basic components of the hydrologic cycle. The water-balance equation is a quantified statement of the law of mass conservation, which says that water gains must be balanced by water losses, for a period of time, plus or minus changes in storage ($I = O + \Delta S$). This equation can be applied to systems of any size. For an annual period this equation would take the form

$$P + S_R + U_I = Q + \Delta S + U_O + ET \tag{1}$$

where P is the total annual precipitation, S_R is the surface water inflow, U_I is the ground-water underflow entering the county, Q is the average annual runoff, ΔS is the change in storage (ΔS_S of the surface-water reservoirs, ΔS_G of the ground-water reservoirs, and ΔS_M of soil moisture), U_O is the underflow leaving the county, and ET is the average annual evapotranspiration (loss by evaporation of water and by transpiration by plants).

Several items of the general hydrologic budget can be eliminated because they do not measurably affect the balance between water gains and losses. If we average over many years of records, the net change in storage is negligible, and it can be assumed that $\Delta S_S = \Delta S_G = \Delta S_M = 0$. For further simplification, we can eliminate surface-water inflow and ground-water underflow, which are negligible in Rock County. LeRoux (1963) indicated that Turtle Creek may recharge ground water between Shopiere and Beloit. The influent character of the creek in that stretch was also confirmed during the investigation of gasoline pollution in 1970 (Scovill, 1970). It was found, however, that the contribution of Turtle Creek to ground water is almost negligible. A small amount of ground water enters Rock County from Dane, Jefferson, and Green counties in the buried bedrock valleys. This input is probably counterbalanced by underflow leaving the county beneath the Rock River valley, estimated by LeRoux (1963) at about 40 mgd. Thus Eq. (1) becomes

$$P = Q + ET \tag{2}$$

where Q is a combination of surface-water component Q_s (overland flow, which reaches streams rapidly) and ground-water component Q_g (ground-water runoff, or base flow, which reaches streams gradually).

The components of the hydrologic budget fluctuate from year to year. Underflow and changes in storage remain fairly constant, major variations occur in precipitation and surface runoff, and evapotranspiration fluctuates proportionally to precipitation.

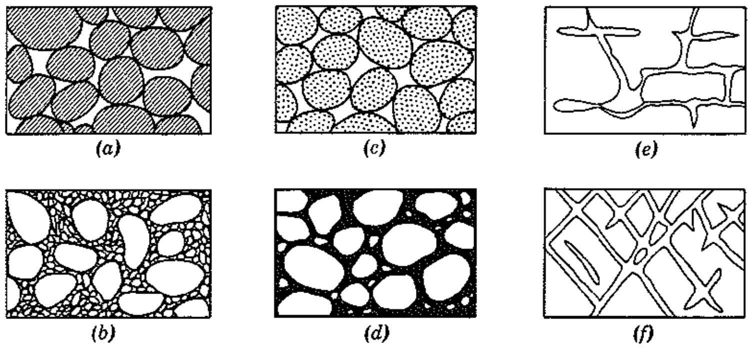
From the preceding paragraphs it is apparent that the source of practically all ground water in Rock County is precipitation that falls within the county. Precipitation annually brings about 32 in. of water to the surface area of the county, or on average about 1,107 million gallons of water per day. Of the total precipitation, part flows into streams and lakes as direct runoff, part infiltrates and becomes ground water, which later emerges as ground-water runoff in streamflow, and the remainder returns to the atmosphere by evaporation and transpiration. The average annual evapotranspiration in Rock County has been estimated to be between 70 and 80 percent (LeRoux, 1963, 70-80 percent; Cotter and others, 1969, 78.7 percent; and Hindall and Skinner, 1973, 71.6 percent). Evapotranspiration varies considerably from year to year, being higher in dry years and lower in wet years.

The total amount of water entering the county, 1,107 mgd, equals the total amount leaving the county by streamflow (calculated by Cotter and others, 1969, to be 7 in., or 243 mgd) and by evapotranspiration (864 mgd, estimated from the difference between precipitation and stream runoff). Cotter (1976) estimated that nearly two thirds of the average annual runoff (about 62 to 64 percent) is contributed by ground water. Assuming that 63 percent of runoff, or 14 percent of the total precipitation, becomes ground water, approximately 155 mgd could be withdrawn perenially from the aquifers in Rock County. Estimated daily use of ground water (see table 3) is about 28 mgd, which is only 18 percent of the total amount of ground water that infiltrates every year. If we assume that ground-water consumption will have increased by about 25 percent by 2000 (Rock County, 1979b), the resulting 35 mgd will still represent only 22 percent of ground water available for withdrawal.

Ground-Water Occurrence and Movement

The principal source of ground water in Rock County is precipitation. Part of the precipitation infiltrates into the ground and then, under the influence of gravity, moves downward through the soil and rocks to the water table, which is the imaginary upper surface of the zone of saturation. All openings in this zone are filled with water, called ground water, and it is this water that is tapped by wells or flows out from springs. The amount and movement of ground water is controlled by the size, number, shape, and distribution of the openings in rocks. The **porosity** of a rock is the ratio of the open space in a rock to its total volume. Figure 11 shows several types of rock openings and the relation of rock texture to porosity. Another property of a rock, related to its capacity to transmit water, is called **permeability**. Rock units that contain and transmit enough ground water to adequately supply wells are called **aquifers**.

In Rock County, ground water occurs in both unconfined (water-table) and confined (artesian) aquifers. Water in the unconsolidated material is commonly unconfined, and the water table, which is under pressure essentially equal to atmospheric pressure, defines the upper limit of the unconfined aquifer. In confined aquifers, the upper limit is defined by a confining bed, which separates the water from overlying aquifers. Water level in a well penetrating a confined aquifer will rise above the bottom of the confining bed to a level called piezometric surface. The confining material is not absolutely impermeable, and there is slow flow through the layers (leakage), so that the



(*a*) Well-sorted sedimentary deposit having high porosity; (*b*) poorly sorted sedimentary deposit having low porosity; (*c*) well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; (*d*) well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; (*e*) rock rendered porous by solution; (*f*) rock rendered porous by fracturing.

Figure 11.
Rock interstices and the relation of rock texture to porosity (after Meinzer, 1923)

water in aquifers separated by less permeable layers may be considered as a single water system rather than several water systems. If the artesian pressure is great enough to cause the water to rise in a well above the land surface, a flowing artesian well results. Several flowing wells can be found in the Rock River valley (such as two wells in the Riverside Park in Janesville). They are over 900 feet deep and tap Cambrian sandstone.

At any given point in an aquifer each water particle has the tendency or potential to flow toward the point of discharge. Ground water moves in response to differences in head that result from the frictional resistance that develops within the pores of the material when flow occurs. Movement of water from one point to another takes place whenever a difference in head occurs between two points. Head loss (difference in head between two points) over the distance between the two points creates hydraulic gradient (dh/dL), which is the "driving force" of ground-water flow. Hydraulic gradients are usually low, such as a fall of 1 foot per 1,000 feet (0.001) or 10 feet per 1,000 feet (0.01). The rate of ground-water flow varies directly with the hydraulic gradient. If the hydraulic gradient (head loss per foot of travel) is doubled, the rate of flow is also doubled.

Movement of ground water is very slow because the water has to squeeze through an intricately branched network of interconnected open spaces that offer natural frictional resistance to the flow. In Rock County, ground water moves a few feet or less per day except near pumping wells. Movement of a few tenths of a foot per day or even per year is common (compared to the flow in streams, which is measured in feet per second). An approximate range may be from 1 ft/year to 10 ft/day. It is very difficult to generalize or average the flow rate for the county, because the rate of flow depends on too many variables and greatly differs from place to place. In order to enable the reader to appreciate at least the order of magnitude of ground-water movement, the following estimates are given.

The **velocity of ground water**, v (in feet per day), can be estimated from the hydraulic conductivity, K (in older literature called the coefficient of permeability); hydraulic gradient, i; and effective porosity, n, of the material:

$$v = K\,i\,/\,7.48\,n \qquad (3)$$

where 7.48 is a constant representing number of gallons per cubic foot of rock to give the velocity in feet per day. The values of hydraulic conductivity and porosity can be estimated from various textbooks on ground water that list their ranges for different types of soils and rocks derived from laboratory or field measurements. Hydraulic gradient was estimated from the water-table map of the county (LeRoux, 1963). Generally, the velocities in the sand and gravel aquifers may range from 1 to 10 ft/day; and they would be less than 0.5 ft/day in the remaining aquifers. The estimates are summarized in table 5.

Table 5. Estimated average velocities of ground water by aquifer

Aquifer	Effective Porosity	Hydraulic Conductivity (gpd/ft^2)	Hydraulic Gradient *	Velocity of Flow (ft/day)
Sand and gravel	0.20	2,000	0.05 - 0.0015	5.3
Plat.-Galena dolomite	0.03	15	0.05 - 0.0015	0.3
St. Peter sandstone	0.10	20	0.01 - 0.0014	0.1

*Average value 0.004 (difference of 20 ft over the distance of 5,000 ft) was used for calculating the velocity.

These values are given for illustrative purposes only and cannot be used for any practical considerations. By including them, the author wants to demonstrate the extremely slow movement of ground water, which is the major obstacle for early detection of ground-water pollution. True velocities for specific areas can be determined only by laboratory or field tests.

Regional Ground-Water Flow

Ground water moves through the Rock County aquifers along precisely predetermined flow paths from points of recharge (usually in topographic high areas or uplands) to points of discharge (usually located in lowlands) such as springs, streams, lakes, drainage ditches, and wells. Ground-water flow direction can be measured by **fluid potential**. The fluid potential in any given point in an aquifer can be expressed in terms of total hydraulic head, which is represented by water level in a well at that point. The elevation of water level in the well represents the fluid potential at the point in the flow system where the well casing terminates. From the measurements it is possible to contour the positions of equal hydraulic head (equipotential lines) and construct, perpendicular to the equipotential lines, flowlines indicating the direction of ground-water flow.

Ground water moves along flowlines from areas of higher potential to those of lower potential, regardless of the direction in space (fig. 12). In a recharge area, the potential is decreasing with depth, which results in downward movement of water, away from the water table. In a discharge area, the potential is increasing with depth and the result is upward movement of water, toward the water table. Between these end areas, ground-water flow is predominately horizontal. Beneath the ridges there are basically vertical boundaries across which is no flow. These imaginary boundaries are known as ground-water divides, which in most places coincide with surface-water divides or topographic divides.

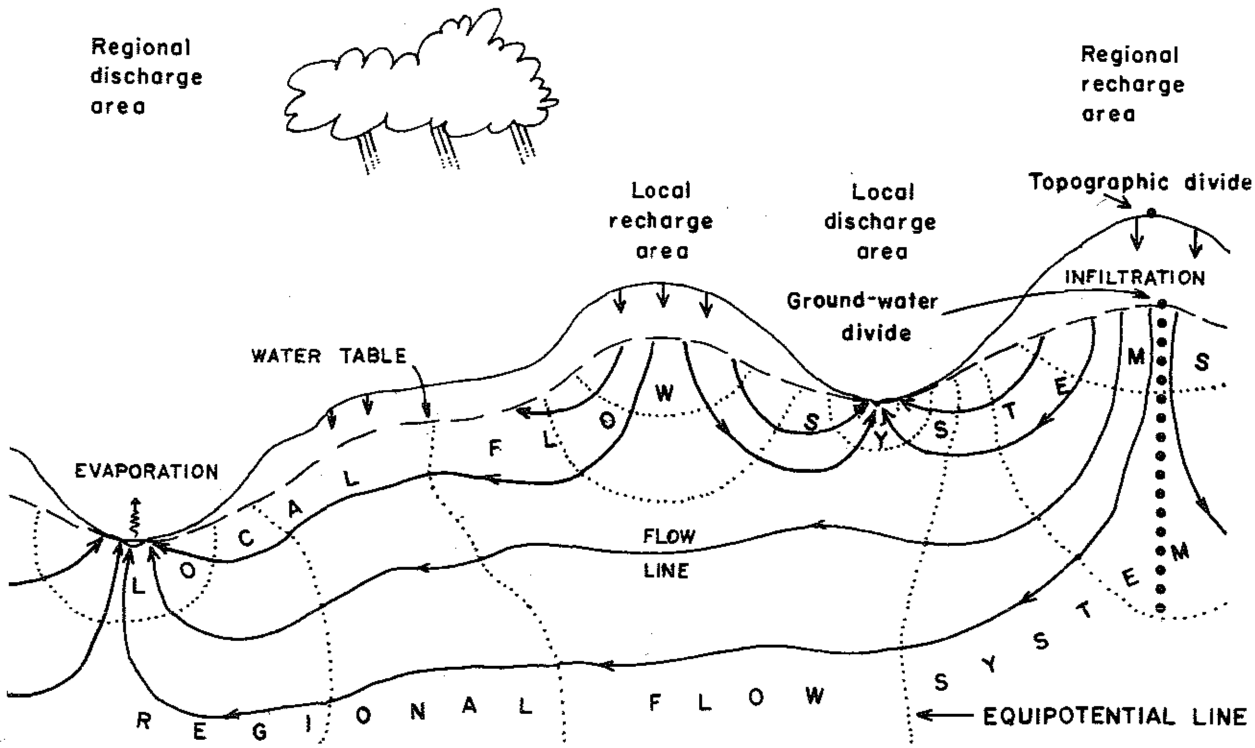


Figure 12. Idealized ground-water flow system

Rock County has one major ground-water divide separating ground-water flow systems in the Rock River drainage basin and in the Sugar River drainage basin (see fig. 13). Each of the two systems is composed of several subsystems separated by local ground-water divides. Part of the water that infiltrates enters the local flow systems and travels only a short distance. The remaining part, especially in the areas along the major ground-water divide, enters the deeper system and flows toward the Rock River or Sugar River.

An understanding of where the recharge and discharge areas occur is useful for determining the directions of ground-water flow and for indicating the spread of polluting substances. If a pollutant is introduced in a recharge area, resulting pollution threatens the entire aquifer. An introduction of pollutants near a discharge area may be of no less concern but at least its potential area of influence is reduced.

No tests or experiments have been made in Rock County to determine the depth of ground-water circulation. However, the **temperature of ground water** is related to the depth of circulation, direction of flow, and the rate of water movement. Not enough reliable ground-water temperature measurements (down-hole temperature measurements) are available from the county wells to aid in determining the direction and rate of ground-water flow. However, the measurements of ground-water temperature in 29 wells supply evidence of the depth of circulation. Also available are temperature measurements of 53 springs from the 1959 survey (Wis. Cons. Dept., 1959b).

The temperature of ground water discharging from wells averaged about 52°F, and the temperature of springs about 50°F. The temperature of water from bedrock wells was approximately 2°F warmer than that from shallow wells, 53 and 51°F, respectively. The difference between the highest and lowest measured temperature was about 10°F. Over two thirds of wells had temperature between 51 and 56°F, and the temperature of over two thirds of springs ranged from 48 to 50°F.

The mean annual air temperature of the region plus 2°C (3.6°F) is considered by various sources to be the typical temperature 60 feet below the surface. In the upper 60 feet, diurnal and seasonal variations in air temperature create a thermally transient zone where the temperature of ground water varies according to variations in the air temperature, and the magnitude of the fluctuations decreases with depth.

Below a depth of about 60 feet, the temperature within the earth increases, on the average, 1°C (1.25°F) with each 100 or 150 feet of depth. This increase is referred to as the **geothermal gradient** and is caused by the movement of heat from the earth's interior to the surface. Measurements made by Summers (1961) in central Wisconsin indicated that the average rate of temperature increase was less than 1°F per 100 ft or about 1°F per 110 ft of depth. With the mean annual air temperature of 48°F, we can assume the temperature of water at 60 feet below the surface to be about 52°F. Assuming the regional geothermal gradient 1°F per 110 feet of depth, the estimate depth of circulation of water discharged from measured bedrock wells is approximately 200 ft. The temperature of springs and shallow wells indicates the circulation of ground water within the thermally transient zone in the upper 30 to 60 ft, or just below it. However, these depths are estimates only, since no direct measurement of geothermal gradient has been done in the county.

Recharge

Much of the water in the subsurface originates in the county and infiltrates the ground within a radius of a few tens of miles from where it is found. Where the surface layers are of low permeability, more of the water must come from farther away, but rarely more than a few miles. Nearly all recharge is derived directly from precipitation. Some ground water enters from the adjoining counties (Dane, Green, and Jefferson) especially through the buried bedrock valleys of ancestral Rock, Yahara, and Sugar rivers. Small contribution to ground water may also come from Turtle Creek, which has a character of influent stream (loosing water to aquifers) in the area where it flows across the buried valley of the ancestral Rock River (LeRoux, 1963). Ground water in the deepest part of the Upper Cambrian sandstone aquifer is a part of a deep regional flow system moving through the county in the northwest-southeast direction. It is unlikely that any water infiltrating within the county recharges this deep flow, which is probably recharged in the uplands of Iowa County.

Rock County does not have any distinctive recharge area, and recharge to ground water occurs over the entire land area of the county, except in the narrow bands along the streams. Permeability of soils (see plate 3) is such that it does not impede the infiltration of precipitation. The bedrock aquifers are recharged most easily in areas where there is little or no overlying material, such as those along the ground-water divide (fig. 13); along the ridge at the southern edge of outwash deposits; and along state highway 81 in the western and southwestern parts of the county. The St. Peter sandstone is recharged either by water percolating through the Platteville-Galena unit or directly by precipitation. In the eastern part of the county the Platteville-Galena aquifer is recharged in several areas where it is at or near the surface. Poorly developed drainage indicates that recharge also occurs in the areas of outwash deposits east of the Rock River (LeRoux, 1963). The outwash deposits are covered by permeable soils of the Plano-Warsaw-Dresden associa-

Figure 13. Generalized map showing major recharge areas of bedrock aquifers

tion, which readily transmit water to the underlying stratified sand and gravel. Similarly rapid recharge occurs in the Sugar River and Taylor Creek valleys where the stratified sand is overlain by permeable soils of the Marshan-Gotham-Dickman association.

Water falling on the recharge areas will follow the longest path and traverse the greatest portion of the aquifer. It will move downward toward the base of the aquifer, then laterally, and finally upward to the discharge area as shown in figure 12. Each quantity of recharge entering the aquifer farther and farther from the recharge area follows a shorter and shallower path. The primary evidence for a recharge area is declining water table away from the area and decreasing potential with depth. The boundaries in figure 13 are not meant to indicate that recharge only occurs within those designated areas. They were drawn to delineate those areas where the predominate direction of ground-water flow is downward. Infiltration continues to enter the ground-water system even between recharge and discharge areas, and the entire land surface of the county contributes to recharge. Recharge occurs also within discharge areas during periods of flood flows.

The ground-water flow systems are complex and multilayered. In the intervening areas between the major recharge areas indicated in figure 13 and major discharge areas (the major streams of the county) are many local systems where the ground water flows from a local recharge area to a local discharge area. These shallow, local flow systems have short flow paths. Figure 13 indicates the general direction of ground-water flow. In western Rock County the recharge area shown in figure 13 is a major ground-water divide. West of it, the ground water flows toward the Sugar River and toward the smaller streams; east of it, the ground water flows generally toward the Rock and Yahara rivers and Bass Creek. In eastern Rock County the general direction of ground-water flow is toward the Rock River, except in the southeast where the ground water flows toward Turtle Creek.

Ground water is recharged intermittently in the periods of moisture surplus when precipitation exceeds evapotranspiration. Therefore, most of the recharge occurs in the spring due to recharge from snowmelt and early spring rains and to low evapotranspiration. Some recharge may occur in the late fall after the end of the growing season when evapotranspiration is again on the decline, if the fall rains come before the ground freezes.

Discharge

Discharge areas have characteristics exactly opposite to those of recharge areas: increasing potential with increasing depth and higher water table away from the area. One of the most significant differences between recharge areas and discharge areas is that discharge areas are much smaller in areal extent than recharge areas. They are normally limited to streams, lakes, and wetlands or springs (see figure 16). Ground water is also discharged by evapotranspiration, and artifically by wells and by drainage ditches. Water also moves out of the county as underflow in the ancestral Rock River valley. Contrary to the intermittent character of recharge, the ground-water discharge is continuous.

Ground-water discharge in Rock County is estimated to be about one seventh of the average annual precipitation of 32 in. (about 4.5 in.) and equals recharge if storage remains generally constant. However, storage varies seasonally and to some extent from year to year. Long-term water-level fluctuations (see figure 15) indicate that there may be a small gain in ground-water storage during the last 20 years.

Artificial discharge through wells accounts for about one fifth of the total ground-water discharge. Although most of the water pumped by wells is consequently discharged into streams and most of the water discharged from springs becomes part of streamflow, a small amount is lost by evaporation.

Streams and Lakes

The ground water discharged in Rock County goes mostly to streams and lakes, and makes up about two thirds of the annual streamflow. The Rock River valley is not only a major discharge area of the county, but it also serves as a regional discharge area of the regional ground-water flow originating on the regional divide between the Wisconsin and Rock River basins and flowing toward the southeast.

Most lakes and marshes in Rock County are ground-water dominated--ground water is more important for their regime than surface water. Ground-water lakes may have no surface-water connection, or they may have an inlet or outlet, but not both. Ground-water dominated lakes can be classified according to their position in the ground-water flow system. Recharge lakes are situated in ground-water recharge areas and contribute to the ground water through the entire lake bottom. Discharge lakes are situated in ground-water discharge areas and gain ground water through the entire lake bottom. And flow-through lakes are situated in areas of lateral ground-water flow and lose ground water on one side and gain it on the other side (Born and others, 1974). Classification of the Rock County lakes into these categories would require detailed measurement of the ground-water potential distribution around the lake shores or beneath the lake bottom. This type of detailed knowledge is useful for planning land and water uses in lake watersheds and for studying problems of ground-water pollution.

Springs

During the 1959 spring survey done by the Wisconsin Conservation Department (the predecesor to DNR), 83 springs were inventoried in Rock County (fig. 14), with 60 springs being active. Two of the springs discharged more than 200 gpm, 4 between 100 and 200 gpm, 9 between 11 and 35 gpm, and the remainder less than 10 gpm (Wis. Cons. Dept., 1959b). The majority of the springs were between 1 and 5 gpm. The largest discharge of 1,125 gpm was reported from a spring area southeast of Evansville, which is currently under water and could not be investigated. Its very large discharge and high temperature (62°F) suggest the possibility of its location on a bedrock fault. If the temperature measurement is correct, the water originates in Cambrian sandstone in a depth of about 1,000 feet and is brought along a fracture to the surface where it discharges in permeable outwash material in an area one-half mile long.

Most springs including the remaining five largest springs and practically all springs over 10 gpm are in the northern one third of the county. Discharge of these springs accounts for 85 percent of the total discharge of springs in the county (not counting the Evansville spring). The outwash and alluvial plain has only four springs, and they average 28 gpm. The ground moraine area in the southeastern part and the bedrock and drift area in the southwestern part of the county contain springs of a very small discharge, generally between 2 and 5 gpm.

Most of the Rock County springs can be classified as depression springs. They discharge in places where hillside depressions, valleys, gullies, and other low spots intersect the water table (fig. 15A). Several small springs of intermittent character in the southwestern part may be contact springs formed by accumulation of water at the base of the Platteville-Galena aquifer, which overlies less permeable layers of the Glenwood Member at the top of the St. Peter sandstone(fig. 15B). Their flow is extremely variable and is entirely dependent on the amount of precipitation.

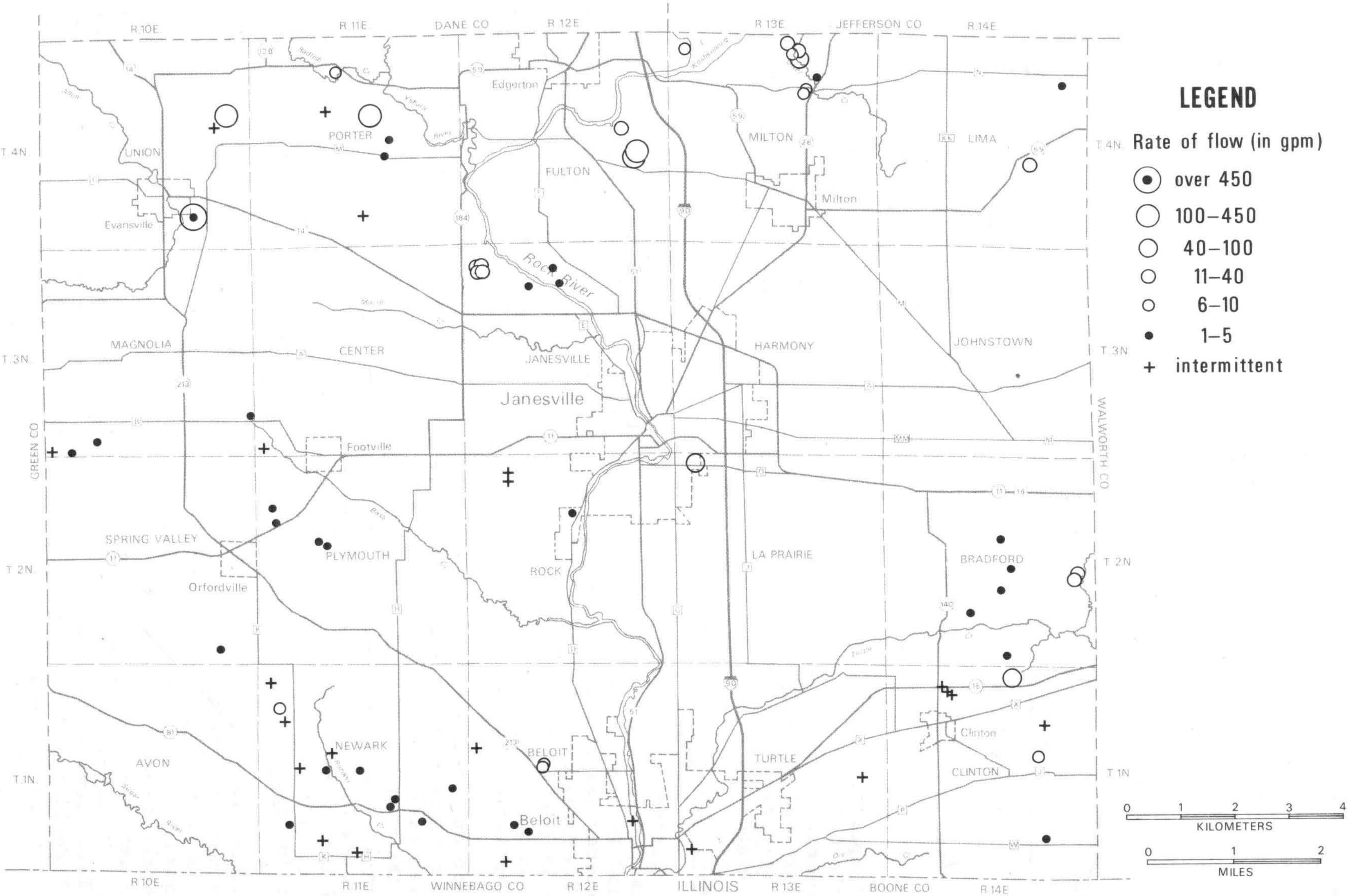


Figure 14. Map showing location of springs in Rock County, 1959 (data from: Wis. Cons. Dept., 1959b)

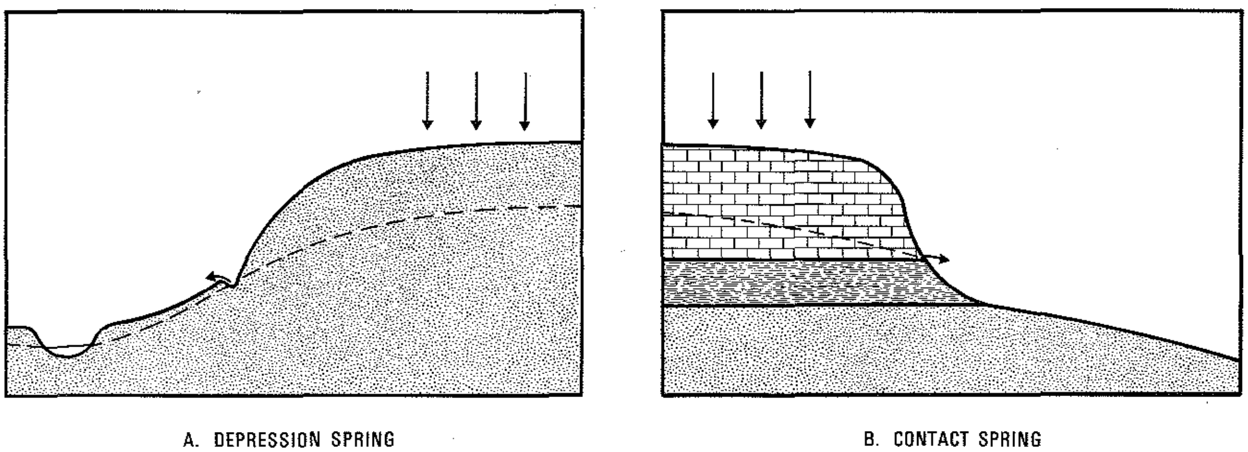


Figure 15. Common spring types in Rock County

The temperature of springs indicates a very shallow depth of circulation in the thermally transient zone, in the upper 30 to 60 feet, or just below it. The temperature of water in this zone responds to seasonal changes in air temperature and normally exceeds the mean annual air temperature by 2° or 3°F. Average temperature of springs was 50°F, with the lowest temperature of 45°F and the highest 55°F.

Ground-Water Level Fluctuations

The surface of a ground-water reservoir, the water table, is not flat or stationary and changes with location and time. Depth to the water table is controlled by the configuration of terrain, permeability of earth materials, and frequency and intensity of precipitation. The water table usually resembles a flattened form of the surface relief and tends to be closer to the surface in less permeable materials and in valleys or lowlands (discharge areas). It is deeper in relatively permeable materials and beneath hills and ridges (uplands, recharge areas).

Based on reports from well drillers, the depth to ground water ranges from the surface to about 200 ft below the land surface. Several wells in the Rock River valley are flowing wells with water level above the surface. In most of the county water can be found in depths between 10 and 70 ft. Shallow water levels, within 10 ft of the surface, are in stream valleys, and deeper levels, over 70 ft, at higher elevations (above 950 ft). Figure 16 shows the areas of high water table within 3 ft of the surface. Four wells are currently included in the statewide ground-water observation network. Their location is shown in figure 1.

Ground-water levels are fluctuating almost constantly, and they decline and rise within a relatively short period of time, mainly in response to changes in periodic recharge (amount of rainfall) and continuous discharge (contribution to streamflow, springs, and withdrawal of water from wells). Water levels respond to changes in precipitation only after a certain period of time, depending on the character of rocks and an aquifer, depth to ground water, and proximity to rivers. The time lag can be from a few days to a few years. Water levels usually rise when recharge is greater than discharge. A continual decline in water levels appears when discharge of ground water to streams, springs, and water well exceeds recharge by precipitation.

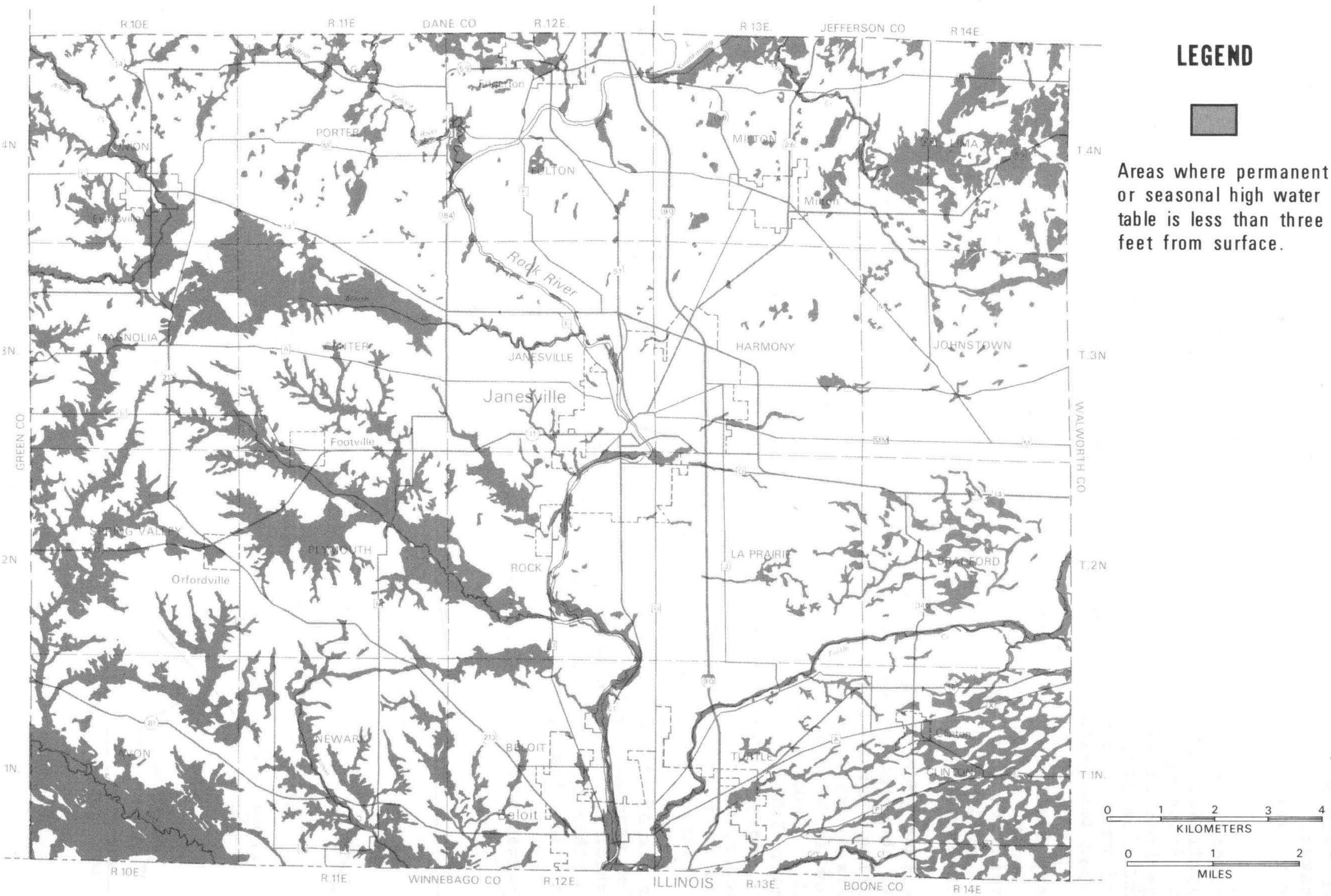


Figure 16. Areas of high water table (based on the soil map of the county and engineering properties of the soils; source: USDA, 1974)

Water levels experience fluctuations of short duration, seasonal variations, and gradual, long-term changes. Short-term fluctuations last from several minutes to several days and are caused by unusual events such as earthquakes, floods, passing trains, or surge pumping. Water levels drop or rise very rapidly and return to their previous position in a relatively short time.

Seasonal variations result from variations in precipitation, streamflow, and evapotranspiration, and from withdrawal of water for irrigation and other seasonal industry. Water levels rise relatively rapidly in the spring due to recharge from snowmelt and spring rains, reach their maximum during April or May, and then gradually decline throughout the summer when evapotranspiration (loss of water) exceeds precipitation. Most of precipitation during that time, when temperatures are high and vegetation is abundant, is lost by evaporation, consumed by plants, or used to restore depleted soil moisture, and only very little water is available for infiltration. A small rise in water levels occurs in the fall due to replenishment of ground water by fall rains. It is followed by a decline during the winter, when precipitation is stored on the land surface as snow, and the ground is frozen. Minimum levels usually occur in February.

Because precipitation is the major source of ground-water recharge, the rainfall abundance or deficiency has a direct bearing on ground-water storage. Alternating series of wet and dry years, in which rainfall is above or below the average, will produce long-term fluctuations of water levels. The change from low to high ground-water levels or vice versa is irregular and usually gradual. A comparison of the annual hydrograph of observation well Ro 3 (Wisconsin School for the Visually Handicapped in Janesville) and the 3-year running average of precipitation in Janesville (each successive average is obtained by moving the 3-year period forward one year) shows a rather close relation between the trends in precipitation and the trends in the average annual ground-water levels (fig. 17). The 36-year observation period of rainfall at Janesville is equally divided into 18 wet years and 18 dry years. However, 12 of 18 wet years were recorded in the last 22 years. This extended period of abundant rainfall has had a pronounced effect on water level in well Ro 3, which has been steadily increasing since 1958. In addition to precipitation, other factors (such as a change in pumping patterns) may have contributed to this increase, but it was not possible to determine these factors. In any case, the increasing water levels are evidence of the net increase in ground-water storage in this area.

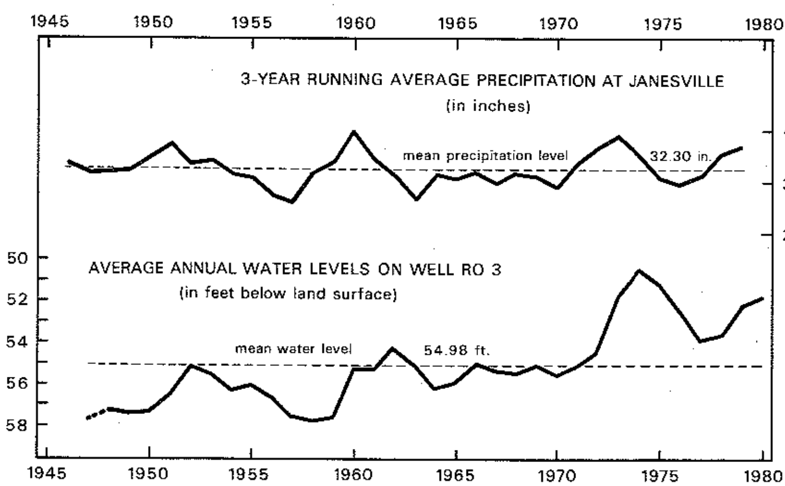


Figure 17.
Relation of ground-water levels in observation well Ro 3 to precipitation at Janesville

Even though the alternation of high and low levels is irregular, the examination of figure 17 reveals certain periodic or cyclic fluctuations. The high and low water levels recur on the average each seventh year, which corresponds with the intervals between peaks and lows on the graph of the 3-year running average of precipitation. It is important to emphasize the word "average"because this statistical term does not mean that the peaks and lows occcur regularly every 7 years but rather that they occur about 14 times in 100 years or, <u>on the average</u>, once every 7 years. This observation is very important for the management of water supplies and agriculture in the county, since it shows that we must think even now in the period of abundance of water about a possibility of drought, which may come again anytime and affect the water levels in wells.

GROUND-WATER QUALITY

Background Quality of Ground Water

The natural good quality of ground water and its nearly constant properties make it an ideal water supply. Water in nature is never "pure water," that is a substance consisting of molecules of only one type--those represented by the formula H_2O. Most water contains small quantities of dissolved mineral salts and other impurities . The term "quality of water" refers to its physical, chemical, and biological characteristics as they relate to the intended use of water. Water always possesses certain attributes, such as odor, taste, and clarity, and certain physical characteristics, such as temperature, density, pH (a measure of acidity or alkalinity), specific conductance (a measure of dissolved ionic substances), and radioactivity. It always contains suspended solids and dissolved solids and gases (so-called "common impurities"), acquired by contact of water with rocks and the atmosphere. And it usually contains bacteria and other microorganisms.

The chemical composition of ground water largely depends on the composition and physical properties (lithology) of rocks it contacts and on the duration of the contact. As water moves through the hydrologic cycle, various chemical, physical, and biological processes interact to change its quality. The original quality is given by the quality of precipitation water, which is further modified by reactions with soils, rocks, and organic matter over time, and furthermore by the activities of man. In general, ground-water quality tends to be relatively uniform within a given aquifer or basin, both with respect to location and time, but in different locations major contrasts in natural quality can be noted.

Knowledge of the chemical character of ground water is necessary for effective ground-water planning, management, and protection. The collection of information on ground-water chemistry provides the base for determining future changes in ground-water quality. The data available for Rock County are inadequate for fully describing the ground-water quality, but they do provide information on the general trends. Chemical analyses, available for 55 wells, were acquired as a part of cooperative investigations during 1967 and 1980 (Holt and Skinner, 1973; USGS, 1981). The location of the wells is shown in figure 1. For this study only 54 analyses were used; one (Ro 210) was judged nonrepresentative because of its extremely high values.

In Rock County, the chemistry of ground water is a result of its movement through and interaction with the unconsolidated materials and sedimentary rocks that contain large amounts of calcium-magnesium carbonate, $CaMg(CO_3)_2$. Therefore, the ground water is predominately of the calcium-magnesium-bicarbonate type, with only slight difference between individual aquifers (fig. 18). It is very hard as a result of large concentrations of calcium (Ca) and magnesium (Mg): and slightly alkaline, having a pH between 7.2 and 8.2, with the median 7.6. The overall quality of ground water is good and it is suitable for most purposes.

MEAN COMPOSITION OF WATER FROM MAJOR AQUIFERS

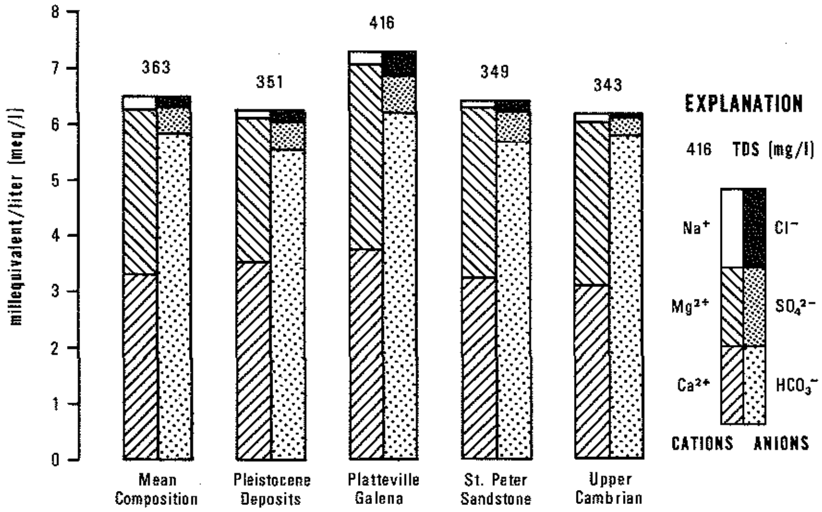


Figure 18.
Mean composition of ground water from major aquifers

The number of major dissolved constituents of ground water is quite small, and the natural variations are not as great as might be expected from the complex mineral and organic material through which the water has passed. Six major ions (indicated by an asterisk in the following table) normally form more than 95 percent of the total disssolved solids in water.

Common chemical constituents of ground water in Rock County include the following:

Cations	Anions	Undissociated
*Calcium (Ca)	*Bicarbonate (HCO_3)	Silica (SiO_2)
*Magnesium (Mg)	*Sulfate (SO_4)	
*Sodium (Na)	*Chloride (Cl)	
Potassium (K)	Fluoride (F)	
Iron (Fe)	Nitrate (NO_3)	
Manganese (Mn)		(*Major ions)

The maximum, median, and minimum values for all these common constituents and other chemical characteristics are summarized in table 6. Major chemical constituents and properties of water shown in figure 19 indicate that the quality of water differs somewhat between aquifers. From the four major aquifers, water in the Platteville-Galena unit is generally more mineralized, and water from the Cambrian sandstone less mineralized than others.

Common Constituents of Ground Water

The purpose of this section is to discuss the occurrence and natural variations of the various constituents and properties of ground water in Rock County and their sources and significance.

Table 6. Summary of chemical and physical characteristics of ground water in Rock County (all in milligrams per liter, mg/l, unless indicated otherwise)

Constituent or Property	No. of Samples	Maximum	Minimum	Median	No. over Limit*
Alkalinity (as $CaCO_3$)	41	358	189	284	-
Bicarbonate (HCO_3^-)	45	437	230	349	-
Calcium (Ca^{2+})	46	90	49	70	-
Chloride (Cl^-)	54	37	.4	3.9	0
Fluoride (F^-)	44	.7	.00	.2	0
Hardness (as $CaCO_3$)	54	423	240	322	-
Iron, total dissolved (Fe)	54	3.1	.01	.04	9
Magnesium (Mg^{2+})	46	52	24	35	-
Manganese, total dissolved (Mn)	54	.2	.00	.03	2
Nitrate-nitrogen (NO_3-N)**	51	60	.02	6.6	22
pH, lab (no units)	54	8.2	7.2	7.6	-
Potassium (K^-)***	19	2.5	.3	.7	-
Silica (SiO_2)***	20	20	8.7	14	-
Sodium (Na^+)	42	16.4	1.8	3.3	-
Specific conductance (micromhos)***	28	797	422	600	-
Sulfate (SO_4^{2-})	54	53	2.2	22	0
Total dissolved solids (TDS)	54	502	231	353	1

*For limits see table 8.

**This range includes only concentrations from the complete analyses of ground water. Results of the special sampling for nitrate are given in next chapter.

***Not determined in samples from the Upper Cambrian aquifer.

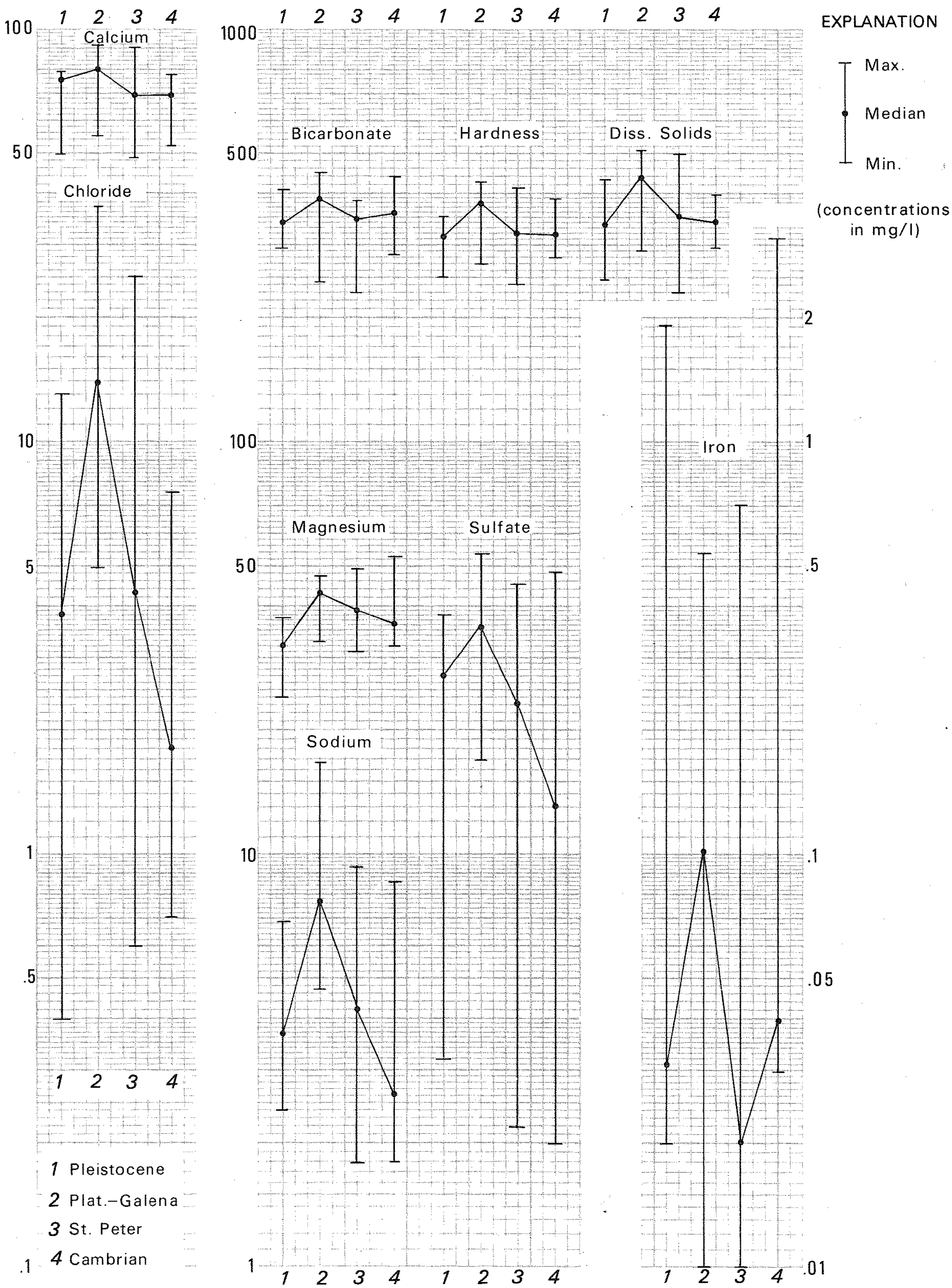


Figure 19. Range of major constituents of ground water by aquifer

Total Dissolved Solids (TDS)

The total concentration of minerals dissolved in water is a general indication of the overall suitability of a water for many types of uses. Total dissolved solids in a water sample include all dissolved mineral constituents derived from solution of rocks and soils. The values in this report represent the residue left after evaporation, followed by drying in an oven at 180°C. If the water contains less than 500 milligrams per liter (mg/l) TDS, it is generally satisfactory for domestic use and for many industrial uses. It is less desirable if it contains more than 1,000 mg/l. Mineralization of ground water in the county falls within a narrow range, mostly between 300 and 450 mg/l of TDS. Overall median concentration is 363 mg/l. One sample taken by the USGS in 1980 contained more than 1,000 mg/l. This high value was judged to be nonrepresentative and is not included in this report. Besides that, only one more well was found to have more than 500 mg/l. Areal distribution of TDS is shown on figure 20.

Specific Conductance

The capacity of water to conduct an electric current is an index of dissolved mineral content. A specific conductance of 800 micromhos at 25°C is approximately equivalent to 500 mg/l TDS. For a very rough estimate of TDS in ground water, the specific conductance can be multiplied by a factor, which ranges between 0.55 and 0.75. Estimating TDS by measuring conductance is convenient because it can be determined quickly in the field. The range of specific conductance in Rock County is 428 to 797 micromhos (median 600 micromhos).

Hardness

In Rock County nearly all the hardness of ground water is a result of the dissolving of calcium and magnesium carbonate rock materials (limestone and dolomite). Hardness is reported in terms of equivalent concentration of calcium carbonate ($CaCO_3$) and is computed by multiplying the mean of milliequivalents per liter (meq/l) of calcium and magnesium by 50. Hardness in Rock County ranges from 240 to 423 mg/l $CaCO_3$, with the median of 322 mg/l. A water above 180 mg/l is considered very hard (Hem, 1970), and softening is required for most purposes. The effect of hardness on water uses is described later under individual constituents causing hardness.

Hydrogen-Ion Concentration (pH)

The relative concentration of hydrogen ions in water indicates whether the water will act like a weak acid or if it will perform as an alkaline solution. The hydrogen-ion concentration of water is expressed by its negative logarithm, a pH value. Water having the high concentrations of acid has a low pH (less than 7). Where carbonates, bicarbonates, or hydroxides are dominant, the pH is high (more than 7). A pH value of 7 indicates a neutral solution. Most natural waters range between pH 6 and 8. Ground water in Rock County has pH values ranging from 7.2 to 8.2, indicating their origin in carbonate rocks. There is very little differentiation between aquifers; 81 percent of samples range between 7.4 and 7.8 and the median for all aquifers is 7.6. These values were determined in the laboratory and are probably a little higher than the true values of the water in the aquifers.

Alkalinity

The alkalinity is an ability of water to neutralize acid, which depends on the concentration of carbonate and bicarbonate ions. Alkalinity of ground water in Rock County is due almost exclusively to bicarbonate ions because in the alkaline environment (pH between 7.0 and 8.2) the carbonate ions add

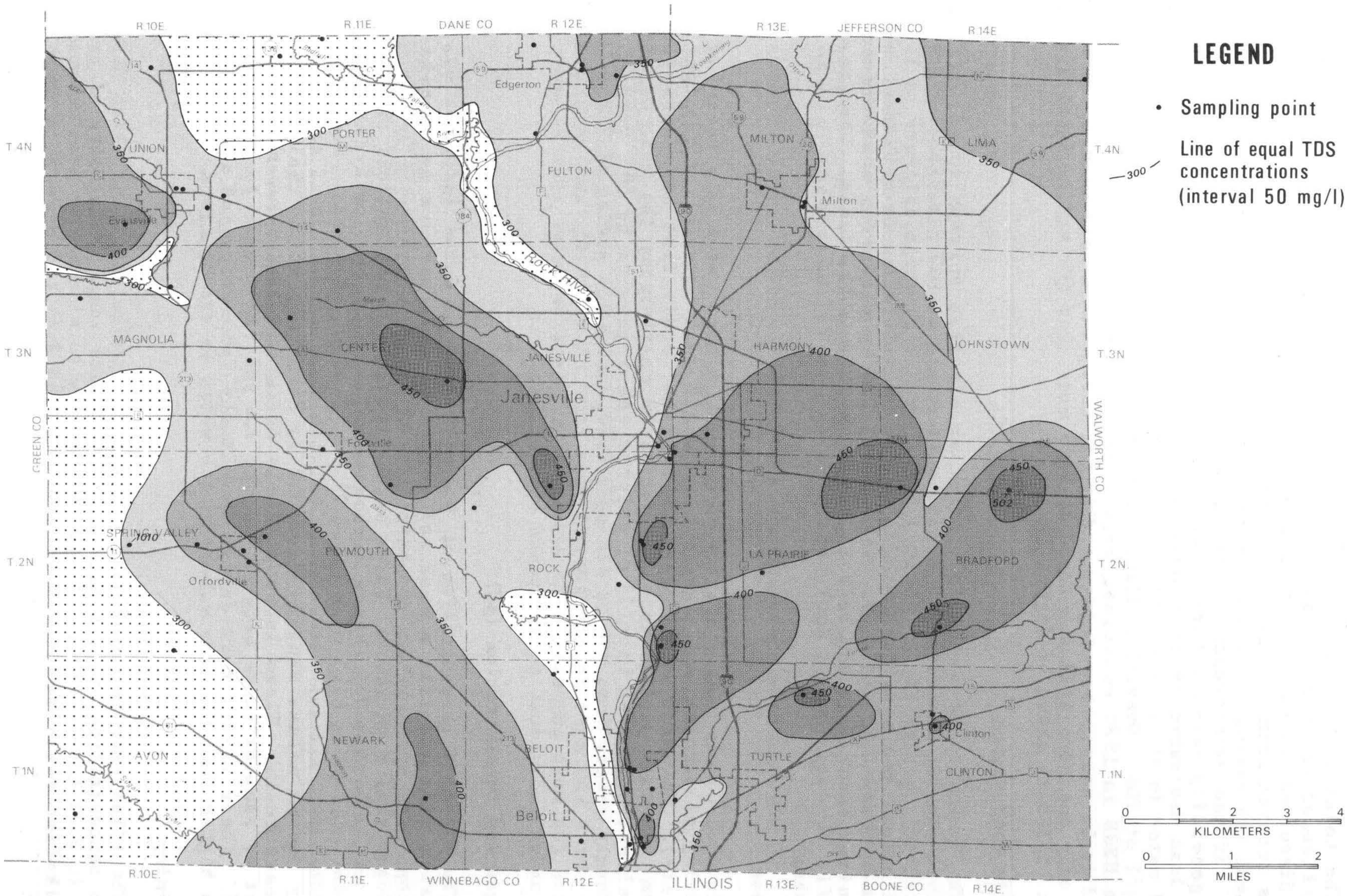


Figure 20. Generalized map showing mineral concentration of ground water in Rock County.

hydrogen to become bicarbonate ions: $H^+ + CO_3^{2-} = HCO_3^-$. The range of alkalinity in the county is 189 to 358 mg/l (reported in terms of an equivalent quantity of calcium carbonate, $CaCO_3$).

Bicarbonate (HCO_3)

Bicarbonate is the principal constituent in Rock County's ground water, forming 85 to 95 percent of the cations, or over 40 percent of all ions determined in the chemical analyses. It ranges from 230 to 437 mg/l, and averages 347 mg/l. The sources of bicarbonate are the carbonate minerals from which HCO_3 is dissolved by reaction with carbon dioxide in water. Bicarbonate content seems to be influenced by climate and tends to predominate in water in areas where vegetation grows profusely. Calcium and magnesium bicarbonates cause the excessive hardness of ground water in the county, form scales in boilers and pipes, and release corrosive carbon dioxide.

Calcium (Ca)

Calcium is a major constituent of Rock County's ground water. Calcium is a very widely distributed element found in many common minerals. In Rock County, it is derived from the solution of carbonate minerals in sedimentary rocks, and forms 50 to 60 percent of the cations in ground water. Its concentration is somewhat higher in Ordovician rocks, especially in the Platteville-Galena unit, and in Pleistocene deposits; however, the general range is very narrow: 40 to 90 mg/l. The most commonly noticed effect of calcium in water is its tendency to react with soap to form an insoluble residue. Ions of magnesium and other elements also cause a similar difficulty, called hardness, and must be precipitated before soap can either cleanse or lather.

Magnesium (Mg)

The source of magnesium in Rock County is dolomite. Despite the higher solubility of most of its compounds, magnesium is generally found in lesser concentration than is calcium, and it commonly forms 40 to 50 percent of the cations. The concentration of magnesium in the county ranges from 24 to 52 mg/l. Calcium and magnesium form about one half of all ions in ground water and are the principal components of hardness.

Silica (SiO_2)

Except for oxygen, silicon (Si) is the most abundant element in earth materials. Silicon combined with oxygen in the form of the oxide, SiO_2, is called silica. The silica in ground water comes from the decomposition of silicate minerals that are present in many rocks and soils. The concentration of silica in Rock County is less than 20 mg/l. Silica does not contribute to hardness of water. However, it forms a hard scale in boilers and pipes, which cannot be dissolved by acids or other chemicals that are used for chemical treatment of water. On the other hand, it inhibits deterioration of zeolite-type water softeners and corrosion of iron pipes.

Iron (Fe)

Practically all water in the county contains some iron, which can be a problem locally if the concentration is greater than 0.3 mg/l (the recommended limit for drinking water). Ten of the 54 sampled wells had concentrations that exceeded 0.3 mg/l. The maximum concentration was 3.1 mg/l. The areal distribution of iron is unpredictable. The sources of iron probably are the aquifers themselves because they contain minerals with large amounts of iron, such as iron oxides, sulfides, and carbonates. Also, decaying organic debris and waste may be a source of iron because iron is an essential element in both plant and animal metabolism. The iron in water is of considerable concern because even a small amount seriously affects the usefulness of water for some domestic and industrial purposes. On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate, which causes discoloration of water, staining of laundry, utensils, and plumbing fixtures, unpleasant odors, incrustation of well screens, and plugging of pipes.

Manganese (Mn)

Manganese resembles iron in its chemical behavior and in its occurrence in natural water. It is less abundant in earth materials than iron, and its occurrence in ground water is less common and the concentration is generally much less than that of iron. Its occurrence and distribution throughout Rock County is haphazard, and its concentration ranges from 0 to 0.2 mg/l. Commonly, the concentration of manganese is less than 0.04 mg/l. Only two of the sampled wells contained manganese in excess of recommended standard (0.05 mg/l): 0.16 and 0.20 mg/l, Even small concentrations of manganese may be objectionable and cause similar problems to those caused by iron. The stains caused by manganese are black and are more annoying and harder to remove than those caused by iron.

Sodium (Na) and Potassium (K)

Sodium and potassium belong to a group called the alkali metals. They are minor constituents of ground water in Rock County. The concentration of sodium ranges from 1.8 to 16.4 mg/l: and the concentration of potassium is less than one tenth the concentration of sodium: 0.3 to 2.5 mg/l. Common sources of sodium and potassium are the products formed by the weathering of sodium and potassium silicates, which are not abundant in the county. Sodium and potassium compounds are all quite soluble and therefore do not contribute to the hardness of water. Twenty mg/l of sodium is sometimes recommended as the upper limit for people limited to a very restricted sodium diet.

Sulfate (SO_4)

Naturally occurring sulfur compounds in sandstone probably are the main source of sulfate. Sulfate is not a major constituent of ground water in Rock County, and it forms less than 5 percent of the anions in ground water. The concentration of sulfate ranges from 2.2 to 53 mg/l, which is well below the recommended upper limit of 250 mg/l.

Chloride (Cl)

The element chlorine is a member of the halogen group, which also includes fluorine, bromine, and iodine. Generally, it is present as the chloride ion, Cl^-. It is dissolved from rocks and soils in small amounts, and it is one of the least abundant major constituents in ground water in the county. Other sources include animal wastes, sewage, and road salt. The concentration of chloride in ground water in the county is very small and ranges from 0.4 to 37 mg/l, but generally it is less than 15 mg/l. A chloride content of more than 250 mg/l is objectionable for water supplies; however, most people cannot taste even 300 to 400 mg/l, and few problems are encountered with waters having concentration less than 500 mg/l.

Fluoride (F)

The natural concentration of fluoride (F^-) appears to be limited by the solubility of the mineral fluorite (CaF_2) from which it is derived. Fluoride generally is present only in small concentrations in Rock County's ground water, commonly 0.1 to 0.2 mg/l. Because of this, supplemental fluoridation is commonly used in public water supplies. Fluoride in drinking water reduces the incidence of tooth decay (US PHS, 1962). Too much fluoride in the water may cause mottling of tooth enamel. Recommended optimum concentration of fluoride is based on annual average maximum daily air temperature (US PHS, 1962), and for Rock County is 1.0 mg/1.

Nitrate (NO_3)

Nitrogen (N) in the form of dissolved nitrate (NO_3) is the major nutrient for vegetation, and the element is essential to all life. Nitrate in ground water comes from organic sources (decaying vegetation, decomposition of organic material, animal wastes), discharge of sewage wastes, industrial chemicals, and nitrogen-based fertilizers. Lesser amounts are derived from precipitation and solution processes. Nitrate is the most common identifiable pollutant in ground water in the county. Nitrate is highly soluble in water and is not appreciably attracted to soil particles. It moves readily through the soil with percolating water, and a part of it is removed by growing plants or converted to gas by bacteria. The remaining part moves downward into the ground water.

The differences in nitrate content are great. In Rock County, the concentration of nitrate ranges from 0.02 to 60 mg/1. In all references to nitrate concentration in this study the nitrate is expressed in mg/1 as N. Small amounts have no effect on usefulness of water. The drinking water standards (US EPA, 1975) recommend the concentration of 10 mg/1 (as N) as maximum. The distribution of nitrate in Rock County's ground water and its potential sources are discussed in more detail in the chapter on ground-water pollution.

Secondary and Minor Constituents

Besides the more abundant elements already discussed, ground water in Rock County may contain a number of additional elements, which are generally present in concentrations less than 0.1 mg/1 (100 µg/1). Information concerning many of these minor constituents is scarce because they usually are not a part of routine chemical analyses. Among the constituents that were determined in chemical analyses of ground water in Rock County are arsenic, barium, cadmium, chromium, cobalt, copper, cyanide, lead, lithium, mercury, nickel, selenium, silver, strontium, and zinc (table 7). All of them are below the recommended limits.

Organic Constituents

Bacterial quality of ground water was not investigated in this study, but it is not considered a problem, except where improper well construction may have made individual wells subject to pollution from the surface.

Several samples taken by the DNR from community water supplies for determination of foaming agents (which may include synthetic detergents) showed concentrations of less than 0.1 mg/1 (see table 7).

Relation of Ground-Water Quality to Use

The term "water quality" has many meanings. While the dictionary may suggest that quality implies some sort of positive attribute or virtue of water, the fact remains that one of water's virtues is another's vice. Water quality is relative and must be associated with the intended use of the water. Water quality may be defined as its fitness for the beneficial uses to which the water is to be put. One of the primary purposes of water analysis is determining the suitability of water for a proposed use. In order to determine the suitability, the results of water analyses must be appraised according to established standards or tolerances or criteria given for the intended use. Many standards, tolerance levels, and criteria have been established for all three major water uses: domestic, agricultural, and industrial.

Table 7. Range of minor and trace constituents of ground water in Rock County (in micrograms per liter, μg/l)

Constituent	No. of Samples	Maximum Value	Minimum Value	Median	Maximum Limit
Arsenic (As)	32	<10	0	<10	50
Barium (Ba)	36	<400	100	<400	1,000
Cadmium (Cd)	32	3	<.2	<.2	10
Chromium (Cr)	32	<10	<3	<3	50
Cobalt (Co)	6	1	0	.5	-
Copper (Cu)	19	119	3	32	1,500
Cyanide (CN)	3	<.05	<.01	<.05	200
Foaming agents (as MBAS)	8	<100	<100	<100	1,000
Lead (Pb)	32	19	1	<3	50
Lithium (Li)	10	10	10	10	-
Mercury (Hg)	32	<.5	<.2	<.2	2
Nickel (Ni)	5	12	0	3	-
Selenium (Se)	32	<5	0	<5	10
Silver (Ag)	32	<.5	0	<.5	50
Strontium (Sr)	11	150	24	100	-
Zinc (Zn)	18	2,200	<20	50	15,000
<u>Radioactivity</u> (in pCi/l):					
Gross alpha	22	5.8	<1.3	<3	15
Gross beta	14	3.7	<1.6	<3.2	50

Source: DNR data from the Safe Drinking Water Act Surveillance Program; USGS files of chemical analyses of ground water.

Domestic Use and Public Supplies

Water that is to be used as a public supply may be employed for many purposes. Therefore, the standards used to evaluate the suitability of water for public supplies are generally more restrictive than those for a small domestic or farm supply. The most important of these standards are those established for drinking water (table 8). The recommended limits for concentrations of inorganic constituents and bacteriological contaminants in drinking water have existed for many years, the first being adopted in 1914 (US PHS, 1962).

In 1974, a new Safe Drinking Water Act was passed by Congress (Public Law 93-523) to provide the protection to public water-supply systems. On March 14, 1975, the Environmental Protection Agency (EPA) proposed the National Interim Primary Drinking Water Regulations (US EPA, 1975), which became effective June 24, 1977. In February 1978 the state of Wisconsin adopted standards (Wis. Adm. Code, chap. NR 109) based on the Safe Drinking Water Act, which set physical, chemical, microbiological, and radiological limits on drinking water

Table 8. Drinking water standards

Constituent of Property	Highest Desirable Level	Maximum Permissible Limit
Physical Characteristics		
Color (color units)	15[1]	50[3]
Odor (Threshold No.)	3[1]	
Taste	Unobjectionable[3]	
Temperature (°F)	54	
Turbidity (NTU)	1[1]	5[1]
Chemical Characteristics		
Hardness (in mg/l $CaCO_3$)	100[3]	500[3]
pH	7.0 - 8.2[3]	6.5 - 9.2[3]
Total dissolved solids (mg/l)	500[1]	1,500[3]
Inorganic Chemicals (all in milligrams per liter, mg/l)		
Calcium (Ca)	75[3]	200[3]
Chloride (Cl)	250[1]	600[3]
Copper (Cu)	1.0[1]	1.5[3]
Fluoride (F)	1.0[2]	2.2[1]
Iron (Fe)	0.3[1]	1.0[3]
Magnesium (Mg)		150[3]
Manganese (Mn)	0.05[1]	0.5[3]
Nitrate (as N)		10[1]
Sodium (Na)	20	
Sulfate (SO_4)	250[1]	400[1]
Zinc (Zn)	5[1]	15[3]
Potential Toxic Substances:		
Arsenic (As)	0.01[2]	0.05[1]
Barium (Ba)		1.0[1]
Cadmium (Cd)		0.01[1]
Chromium (Cr)		0.05[1]
Cyanide (CN)	0.01[2]	0.2[2]
Lead (Pb)		0.05[1]
Mercury (Hg)		0.002[1]
Selenium (Se)		0.01[1]
Silver (Ag)		0.05[1]
Dissolved Gases:		
Hydrogen sulfide (H_2S)	Not detectable[1]	
Organic Chemicals (all in mg/l)		
Carbon chloroform extract (CCE)	0.2[2]	
Chlorinated Hydrocarbons (pesticides):		
Endrin		0.0002[1]
Lindane		0.004[1]
Methoxychlor		0.1[1]
Toxaphene		0.005[1]
Chlorophnoxys (herbicides):		
2,4-D		0.1[1]
2,4,5-TP silvex		0.01[1]
Phenols	0.001[2]	0.002[3]
Polynuclear aromatic hydrocabons (PAH)		0.0002[3]
Synthetic detergents (as MBAS)	0.5[1]	1.0[3]
Radioactivity and Radionuclides (in picocuries per liter, pCi/l)		
Gross alpha activity	3[3]	15[1]
Gross beta activity	30[3]	50[1]
Radium-226 and radium-228, combined		5[1]
Strontium-90		8[1]
Tritium		20,000[1]
Microbiological Contaminants		
Total coliform bacteria	1 per 100 ml[1]	

Source: [1] Wis. Adm. Code, Chap. NR 109; [2] US PHS, 1962; [3] WHO, 1971.

(see table 8). The limits are continually being appraised and modifications occur from time to time. Recently there has been considerable controversy with regard to the specific organic constituents, especially pesticides residues, that should be included in drinking water standards and to the concentration limits that should be established for them.

Agricultural Use

Water required for nondomestic purposes on farms includes that consumed by livestock and that used for irrigation. Water to be used by livestock is subject to quality limitations of the same type as those relating to quality of drinking water for human consumption. Most animals, however, are able to use water that is considerably higher in dissolved-solids concentration than that which is considered satisfactory for humans. Concentration limits established by EPA for water used by livestock (US EPA, 1973) are listed in table 9.

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation. The portion of the irrigation water that is actually consumed by plants or evaporated is essentially free from dissolved material. The growing plants selectively retain some nutrients and a part of the mineral matter originally dissolved in the water, but these retained substances are not a large part of the total mineral concentration of the irrigation water. The bulk of the dissolved solids originally present in the irrigation water remains behind in the soil creating salinity problems in areas of inadequate natural drainage.

The process of exchange of ions alters the physical characteristics of the soil. When clay minerals carry an excess of calcium or magnesium ions, the physical properties of the soil are optimal for plant growth and cultivation. If the clay minerals take up sodium in exchange, the soil becomes sticky and slick when wet and has a very low permeability. It shrinks when dry into hard clods, which are difficult to break up by cultivation. Therefore, the amount of sodium is an important factor in irrigation. The irrigation water used in Rock County contains much more calcium and magnesium than sodium, and a sufficient amount of calcium and magnesium is retained in the clay particles of the soil to maintain good tilth and permeability.

In addition to problems caused by excessive amounts of dissolved solids, certain specific constituents in irrigation water are especially undesirable, and some may be damaging even when present only in small quantities. Recommended limits for undesirable constituents in irrigation water are given in table 9. There are not enough data available to appraise the effect of irrigation on ground water in Rock County.

Industrial Use

The quality requirements for industrial water supplies range widely, and almost every industrial application has its own standards. It is not the purpose of this report to review the industrial water-quality standards in any detail. Literature on water-quality requirements for industrial processes was summarized by Hem (1970). Generally, ground water is usable for most industrial purposes in the county. It requires treatment to remove hardness in boiler-feed water, and a relatively high content of bicarbonate or iron may be undesirable in some industries. Water used for processing food and beverages must also meet the drinking water standards.

Ground-Water Quality and Pollution

The term "water pollution" implies the presence of undesirable foreign matter in an otherwise "pure" or "natural" substance. We have learned, however, that natural water is never pure and always contains at least small

Table 9. Recommended concentration limits for water used by livestock and for irrigation crop production

Constituent	Recommended Limits (mg/l)	
	Livestock	Irrigated Crops
Total dissolved solids	3,000	
All crops		500
Sensitive crops		1,000
Tolerant crops		5,000
Aluminum (Al)	5	5
Arsenic (As)	0.2	0.1
Boron (B)	5	0.75
Cadmium (Cd)	0.05	0.01
Chromium (Cr)	1	0.1
Cobalt (Co)	1	0.05
Copper (Cu)	0.5	0.2
Fluoride (F)	2	1
Iron (Fe)	-	5
Lead (Pb)	0.1	5
Lithium (Li)	-	2.5
Mercury (Hg)	0.01	-
Nickel (Ni)	-	0.2
Nitrate (as NO_3-N)	100	-
Nitrite (as NO_2-N)	10	-
pH	-	4.5-9.0
Selenium (Se)	0.05	0.02
Zinc (Zn)	25	2
Pesticides	same as for drinking water	-

Source: US EPA, 1973.

quantities of impurities. Thus, the pollution of water is the addition of other, undesirable substances that deteriorate the quality of natural water.

Ground-water pollution, in the meaning used by the author, is the alteration or degradation of the natural quality of ground water resulting from natural processes or from human activities that may inhibit the use of ground water. In the case where the degradation may be harmful to people and may create hazards to public health, the author uses the term contamination.

Speaking of pollution, people generally refer to man-induced deterioration of ground-water quality and do not realize that some harmful substances occur naturally and are an indispensable part of our environment. The physical, chemical, and biological quality of water may range within wide limits even though there are no man-made influences.

Since humans have developed under the pressure of the natural pollutant stresses, they have adapted to exist and thrive in spite of them, and perhaps even evolved because of them. In addition to 12 bulk elements, which are the main building blocks of living tissue, there are several other elements that living tissue requires in order to function properly. These are the trace elements that are needed by the body in minute quantities but may become highly toxic in excessive concentrations (for example, copper or selenium). They are being released into the environment every day by various processes, natural and man-made. Natural processes responsible for releasing these elements and concentrating them to pollutant levels include volcanic activity, precipitation, weathering of rocks, and leaching. At the present time the concentration of trace elements in ground water in the county is below the maximum permissible limit (see table 7).

GROUND-WATER POLLUTION

Mechanism of Pollution

The mechanism of pollution involves an interaction between the pollutant source and the existing soil moisture and ground water. Many processes control the migration of pollutants in ground water, such as advection, dispersion, dilution, adsorption, and ion-exchange. The process by which dissolved substances (solutes) are transported by the bulk mass of the flowing ground water is known as advection. There is a tendency, however, for the solute to spread out from the path that it would be expected to follow according to advection. This spreading phenomenon is called hydrodynamic dispersion, and it causes dilution of the solute. It occurs as a result of mechanical mixing and molecular diffusion. A form of dispersion more important for the transport of pollutants in the subsurface is mechanical dispersion, and it is caused entirely by the motion of the water. Mechanical dispersion occurs because of the difference in pore size along the flow paths followed by water molecules, the drag in pore channels, and the tortuosity, branching, and interfingering of pore channels.

Reactive solutes behave in the transport as nonreactive solutes, but with the added influence of chemical reactions. Changes in concentration can occur because of various chemical reactions such as solution-precipitation reactions, oxidation-reduction reactions, adsorption-disorption reactions, and ion-exchange.

Shallow aquifers are the most susceptible to pollution. The entry of pollutants to shallow aquifers occurs most often by downward percolation through the zone of aeration or directly through improperly constructed or abandoned wells. The configuration of pollution entry into and movement within the subsurface is unique for each individual source of pollution. Some of the frequently occurring pollution entries are illustrated in figure 21. In the subsurface, pollutants travel first downward (within the unsaturated zone), and after reaching the top of the saturated zone (the water table) in the same direction as ground water.

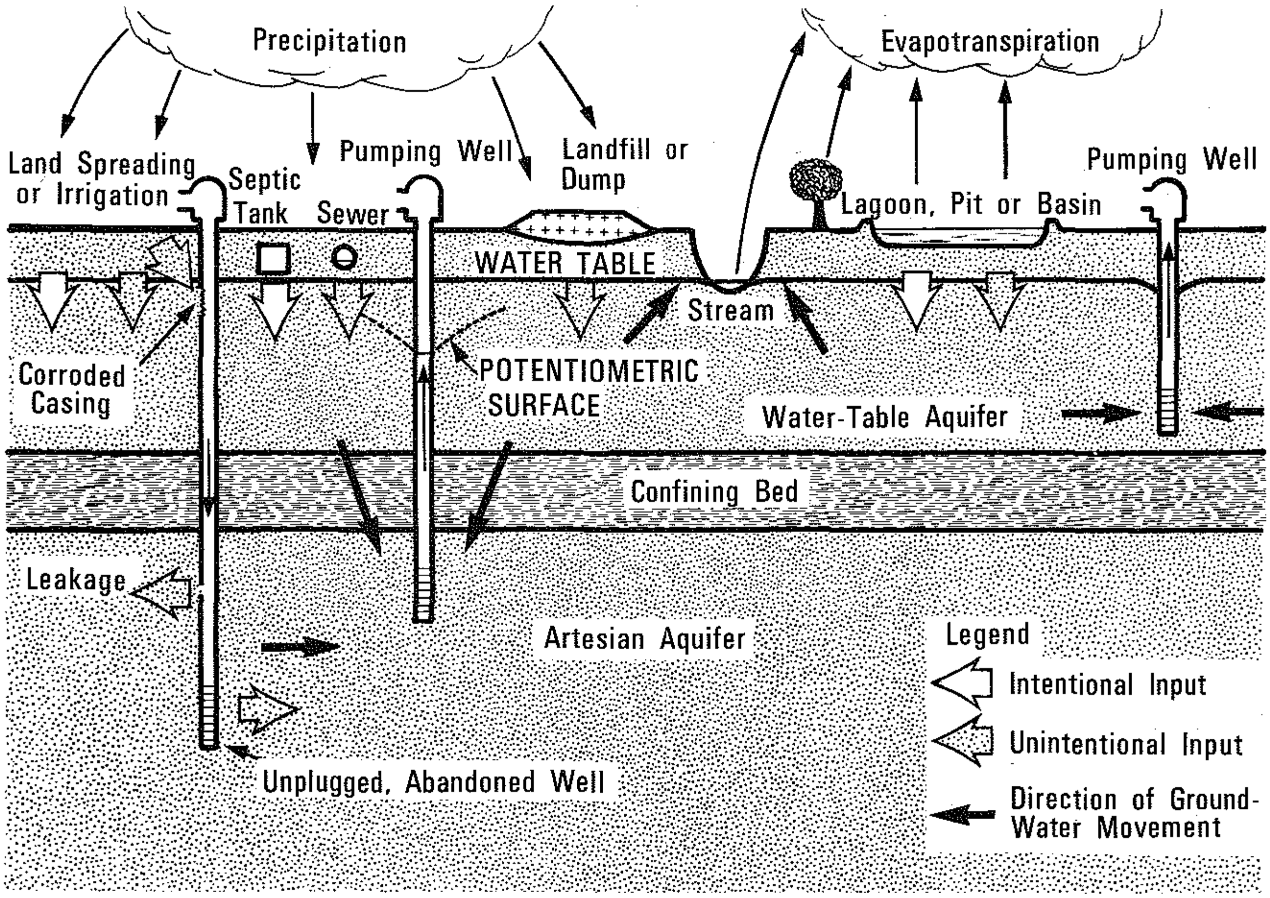


Figure 21. General mechanisms of the entry of pollutants to ground water (after Miller, 1977)

If it were possible to see zones of ground-water pollution from an aerial view, most would appear so small in relation to the total area of ground-water flow as to be termed scattered points of pollution. Pollutants from point sources travel in a relatively compact and well-defined body called **plume**. The shape and size of a plume depends upon the local geology, the ground-water flow, the type and concentration of pollutants, the continuity of the supply of pollutant, and any modifications of the ground-water flow system by man. A plume will tend to be long and thin where ground water is moving relatively rapidly or where the continuity of the supply is long. Where the flow rate is low or the supply of pollutant is short, a wider plume is formed.

Pollutants in ground water tend to be removed or reduced in concentration with time and distance traveled (Everett, 1980). Pollution from a point source moves outward until a low concentration level is reached. The rate of pollution attenuation is a function of the type of pollutant and continuity of its supply and of the local hydrogeologic framework. Mechanisms involved include decay, filtration, chemical processes (sorption, oxidation, and reduction), and dilution through dispersion processes.

Attenuation of pollutants in case of continuous, nonpoint sources is practically negligible, and pollution tends to accumulate with time. The only solution is to eliminate pollution at its source.

The character of aquifers, especially the character of the openings through which the water passes, is very important in the attenuation processes. Aquifers composed of fine-grained material (fine sand or sandstone) possess very large surface areas, which promote sorption processes. They also encourage dilution by dispersion because of the large number of small openings through which the ground water must flow. Clay is very effective in removing pollutants because it contains only very small openings and its particles have great capacity for adsorption and ion-exchange. Aquifers with large openings, such as coarse sand or gravel, permit a pollutant to advance rapidly underground with little reduction in concentration. The water in till generally loses most pollutants due to its slow downward movement through clay and sand of which the till is largely composed. In some places, however, water has formed more or less definite tubular channels through the material, and if such a channel is intercepted by septic tank, cesspool, or similar source of pollution, the water may become highly polluted and carry pollutants for relatively long distances because of the nature of the channel. Ground water in dolomites can be easily contaminated and unfit for use because it moves downward along cracks, fractures, and solution channels, which are ineffective in removing pollutants.

Specific statements cannot be made about the distances that pollutants will travel because of the wide variability of aquifer parameters, types of pollutants, and wide range of interactions between pollutants and the aquifers. Generally, in fine-grained unconsolidated materials, pollutants, such as bacteria, viruses, organic materials, pesticides, and most radioactive substances, are usually removed by attentuation processes (primarily adsorption) within distances of less than 300 feet (Everett, 1980). Most common ions in solution move unimpeded through the aquifers, subject only to dilution by mixing and chemical processes.

Potential Sources of Pollution

Classification of Pollution Sources

The sources of ground-water pollution are many and varied because in addition to natural processes practically every type of human-installed facility or structure and nearly all human activities may eventually contribute to ground-water quality problems. The sources of pollution are omnipresent. However, the intensification effect of urban and industrial areas on ground-water pollution is an important factor in considering the consequences of various sources of pollution. Since people are responsible for actions leading to ground-water pollution, it follows that a large proportion of the sources and causes of ground-water pollution are found in and near population centers.

The quality of ground water is most commonly affected by waste disposal, whether it be solid or liquid waste. Another major source of pollution is the storage of waste materials in excavations, such as pits or quarries. Water-soluble substances that are dumped, spilled, spread, or stored on the land surface or in excavations may eventually infiltrate to pollute ground water. Agricultural practices may impair the quality of ground water by overapplication of fertilizers and pesticides. Irrigation generally tends to increase the mineral content of ground water. Another major and widespread cause of ground-water quality deterioration is related to the development of ground-water resources. Pumping may induce the migration to the well of more mineralized water from surrounding strata or from polluted surface water. Improperly constructed or abandoned wells and boreholes may become a direct route for pollutants on the surface to enter the aquifers.

The potential sources of ground-water pollution would form a long and complex list. However, in terms of basic causes and primary influences on ground-water quality, the list can be condensed to a reasonable size. Ground-water pollution sources can be conveniently placed into five major groups: municipal, agricultural, industrial, ground-water development, and miscellaneous (Zaporozec, 1981). Table 10 summarizes the major sources of pollution, the type of source, and the type of pollutant present. Some of the sources, however, do not apply to Rock County.

For the purpose of discussion, the sources that may create pollution in the county are summarized according to the place of their origin in table 11. Man-induced ground-water quality problems are most commonly related to (1) water-soluble products that are placed intentionally or unintentionally on the ground and in streams and (2) substances that are deposited or stored in the ground, either (a) above the water table or (b) below the water table.

The greatest potential hazard to ground water in the county may come from waste-disposal practices, agricultural activities, storage of chemicals on the ground, and spills and leaks of toxic or hazardous liquids.

Ground-Water Quality Problems Originating on the Ground

In the first category (see table 11), the principal source of ground-water quality problems is the land disposal of wastes, both liquid and solid.

Disposal of wastes on the open ground at industrial and commercial facilities is an important source of ground-water pollution. If the waste material contains soluble products, they will leach out when exposed to rain and infiltrate and may lead to ground-water pollution. The principal pollutants usually involved are chloride, nitrate, hydrocarbons, and heavy metals (Miller, 1977). Similar problems result from spreading manure and sludge on the ground. The disposal of municipal or industrial liquid wastes by spray irrigation or spreading on the ground is not practiced in the county.

Open dumps are the most common source of ground-water pollution. The practice of disposing the solid wastes in open dumps was abandoned in the early 1970s. During an inventory conducted by Rock County in 1969 (Rock County, 1970), 114 solid-waste disposal sites were documented (see figure 24). Most old sites were small operations handling small amounts of waste.

As rainwater infiltrates through trash and garbage in a dump, it accumulates a variety of chemical and biological substances. The resulting liquid, leachate, may be highly mineralized and grossly polluted. As the leachate infiltrates, some of the substances it contains are removed or degraded in the zone of aeration. Eventually the leachate may reach the water table, where it flows in the direction of ground-water flow or toward a pumping well (fig. 22). Similar problems occur in the vicinity of various types of stockpiles and other waste material deposited on the land surface.

There are many liquids and solids that are placed on, or sometimes in, the ground for temporary storage. Unprotected **stockpiles** may result in ground-water pollution, particularly where substantial leaching into the soil occurs. There are stockpiles for storage of raw materials, chemicals, products, by-products, and wastes at industrial sites; piles of raw materials awaiting use and waste placed for temporary storage at construction sites: stockpiles of chemicals, manure, agricultural products, and half-empty containers in agricultural areas; and stockpiles of salt for road deicing. Some are kept in the open, and some are kept in enclosures. The simplest

Table 10. Major sources and causes of ground-water pollution

Source	Source Category: Point	Source Category: Non-point	Primary Type of Pollutant: Inorganic Chemical	Primary Type of Pollutant: Organic Chemical	Primary Type of Pollutant: Trace Elements	Primary Type of Pollutant: Bio-logical
Municipal						
Sewage effluent	x	x	x	x		x
Sewage sludge	x		x	x	x	x
Sewer leakage	x		x	x		x
Solid waste	x		x	x	x	
Urban runoff	x	x		x		
Lawn fertilizers		x	x			
Agricultural						
Animal waste	x	x	x			x
Fertilizers		x		x		
Pesticides and herbicides		x		x		
Irrigation return flow		x	x			
Stockpiles and waste piles	x		x	x		
Crop residues		x		x		
Industrial						
Liquid waste	x	x	--------variable--------			
Injection and disposal wells	x		--------variable--------			
Tank and pipeline leaks	x			x		
Stockpiles	x		x	x		
Mining wastes	x	x	x		x	
Ground-Water Development						
Improper well construction	x		------------variable------------			
Abandoned wells and holes	x		------------variable------------			
Induced flow of polluted surface water	x	x	--------variable--------			
Aquifer interchange through wells	x		--------variable--------			
Saltwater intrusion		x	x			
Miscellaneous						
Septic tanks and cesspools		x	x			x
Highway deicing salts		x	x			
Graveyards and burial pits	x					x

Source: Everett, 1980.

Table 11. Activities which may create ground-water quality problems in Rock County

Originating on the Land	Originating Below the Land
Land disposal of waste:	Above the water table:
solid waste (dumps) liquid waste (sewage) sludge manure	Septic tanks, cesspools Surface wastewater impoundments
	Manure pits
Agricultural activities:	Sanitary landfills
animal wastes fertilizers pesticides and herbicides	Waste disposal in dry excavations
irrigation (return flow) silage crop residues	Leakage: underground storage tanks underground pipes
Piles:	sewers
stockpiles	Sumps, dry wells
waste piles refuse piles	Below the water table:
Highway deicing (salting)	Waste disposal in wet excavations
Accidental spills	Illegal disposal wells
Infiltration of polluted precipitation and surface water	Ground-water development: improper well construction abandoned wells and holes overpumping aquifer interchange

solution is to cover the stockpile--and thereby prevent the formation of any leachate--and to keep the material enclosed in bins or shelters to prevent accidental spreading or spilling.

Perhaps the prime example of ground-water pollution caused by stockpiles is the **salt used for highway snow and ice control** in the cold climatic zones. Not uncommonly, tons of salt are simply piled on the land surface awaiting use. The rainfall can dissolve the salt, which then seeps into shallow aquifers. Also the salt spread on roads can run off with melted snow and ice and cause deterioration of stream and lake water quality and damage to water supplies, vegetation, wildlife, structures in the vicinity of highways, airport runways and paved parking lots, and vehicles.

Spills of liquid waste, liquid fertilizer, toxic materials, gasoline, and oil can occur anywhere in the county. Local problems can result from hazardous liquids that are discharged onto the ground in an uncontrolled manner or spilled accidently, and then seep into the underlying soil. If the volume of liquid is sufficiently large, the pollutants can migrate down to the water table and degrade the quality of ground water. Accidental spills are an unavoidable hazard inherent in storing and transportation of chemicals and toxic materials and can occur at many locations: industrial sites, city streets, along highway and railroad rights-of-way, and airports. Presently

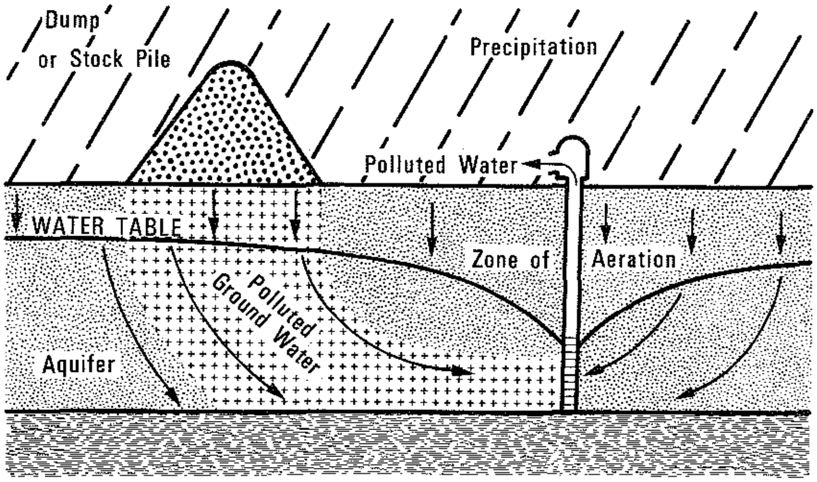


Figure 22. Ground-water pollution caused by infiltration of pollutants from a surface source

there are practically no controls on transportation of these materials. It is in the handling of spills after they have taken place that better protection of ground water can be achieved.

In addition, individual cases of ground-water pollution from the surface can be caused by infiltration of polluted surface water and precipitation or by "nonaccidental" spills of agricultural waste, such as dumping the cheese-factory waste in ditches.

Another source of ground-water problems originating on the ground is **agriculture**, which may introduce pollutants to the ground water by disposal or storage of animal wastes or agricultural products, by irrigation, and by the application of fertilizers and pesticides.

Livestock wastes can create local ground-water problems if not handled properly. Runoff from barnyards, exercise yards, and feedlots may carry high concentrations of pollutants, especially bacteria and nitrate, into ponds, streams, and ground water.

Irrigation may also degrade the quality of ground water. Irrigation is used in the county to intensify agricultural production. It is practiced throughout the county but is concentrated primarily in the towns of La Prairie and Avon (see figure 7). About one half to two thirds of the total volume of water applied during irrigation is used consumptively (by plants and by evaporation). The remainder, called irrigation return flow, returns to the ground water with an increased concentration of salts. The salinity of irrigation return flow increases gradually and may range from three to ten times that of the applied water (Everett, 1980). Irrigation return flow is not yet a major problem in the county because it is used only intermittently to supplement natural rainfall. However, irrigated water may contribute to ground-water quality problems mainly by carrying chemical additives that are applied to the land surface (fertilizers and pesticides) through the soil into the underlying ground water.

An increasing amount of both fertilizers and pesticides is being used each year in agricultural production, and sometimes at rates much higher than those recommended by manufacturers.

The overapplication of **fertilizers** to agricultural land usually results in a portion of the fertilizer being leached through the soil and into the underlying ground water. The most important constituents are compounds of nitrogen and phosphorus. Even though data are not available to prove that overapplication of nitrogen-based fertilizers is responsible for high content of nitrates in ground water in Rock County, studies in other parts of the state related the irrigation and fertilizer practices to the quality of the ground water (Saffigna and Keeney, 1977) and showed that high levels of nitrate were found in the soils similar to those of Rock County, when excessive rates of fertilizer (300 #/A of N) were applied annually (Walsh, 1969). When the recommended rate of fertilizer (100 #/A of N) was applied, nitrates did not accumulate in the subsoil (Walsh, 1969).

Leaching of nitrogen is a problem primarily on sandy soils, which also have the potential for best crop production if irrigated. Only about one inch of water is stored in one foot of sandy soil, and a small amount of rain or irrigation water can carry nitrates down into the saturated zone (Walsh, 1969). If excessive amounts of fertilizer are applied, the crops will recover only a portion of the nitrogen and the rest will be flushed into the ground water (Saffigna and Keeney, 1977). This excess of nitrogen does not contribute to crop yield, and degrades ground-water quality. The challenge facing agriculture is to maintain maximum crop production while keeping ground-water pollution to a minimum.

The overapplication of **pesticides** may also result in ground-water pollution. The term "pesticide" is here broadly interpreted to include any material used to control, destroy, or mitigate pests, such as insecticides, herbicides, and others. Pesticides include a great many organic compounds, among them chlorinated hydrocarbons and organophosphorus (in insecticides) and chlorophenoxys (in herbicides), which eventually may create hazards to ground water. Many of these substances are highly toxic, and even in minute concentrations may create serious consequences in terms of the potability of the water.

Pesticides that are not taken up by plants or broken by soil organisms, sunlight, or chemical reactions are carried by rainwater or irrigation water into and through soil, where they undergo further breakdown. The movement of pesticides in the subsurface is affected by the amount and timing of percolating water, water solubility of the pesticide, and its breakdown products, and by their interactions with soil particles. Many pesticides are relatively insoluble in water, many also are readily adsorbed on soil particles (Everett, 1980). Pesticide residue and by-products not adsorbed or broken down are carried down to the ground water where additional breakdown may be provided by hydrolysis. Once in ground water, the pesticides might be expected to persist for long periods of time; especially, chlorinated hydrocarbons (such as DDT, endrin, and lindane) are particularly resistant to decay, and are very stable in soil (Miller, 1977). The use of some (e.g., DDT and chlordane) has been eliminated or greatly restricted due to adverse environmental effects. The greatest potential for pollution is again, as in the case of fertilizers, in irrigated sandy soils. They have rapid infiltration rates, and the pesticide does not have enough time for breakdown. The surface of soil particles available for adsorption is much smaller than that in finer, clayey, or organic soils.

Preventive measures would include regulation of the timing and rate of application of pesticides, and protection against leaching and infiltration of pesticides stored or spilled at large agricultural centers.

Silage-making leads to local concentrations of a highly polluted liquid--even though of relatively small volume. This silage juice is a highly polluted liquid having a biological oxygen demand (BOD) in the range of 12,000 to 60,000 mg/l and containing high concentrations of phenol and sulphate.

Even though Rock County does not yet have serious ground-water problems resulting from agricultural activities, the potential is there. The use of fertilizers and pesticides is extensive in the county, and continuous overapplication may create ground-water pollution problems in the future.

Ground-Water Quality Problems Originating Above the Water Table

In the second category (see table 11), the number 1 problem is again disposal of wastes.

The **disposal of domestic wastewater** in unsewered areas of the county is accomplished through use of septic tanks and soil absorption fields (fig. 23). Anaerobic decomposition of wastes takes place in the septic tank, which also traps settleable solids. The liquid waste is carried to a drain tile field where it seeps through the ground to the water table. The soil system to which the effluent is discharged is relied upon to provide natural attenuation of pollutants. This is primarily achieved through aerobic decomposition and by filtering and sorption. Bacteria and viruses are normally removed by the soil system. Phosphorus is generally retained by the soil, but significant concentrations of nitrogen can, depending upon local soil and vegetation conditions, be added to ground water.

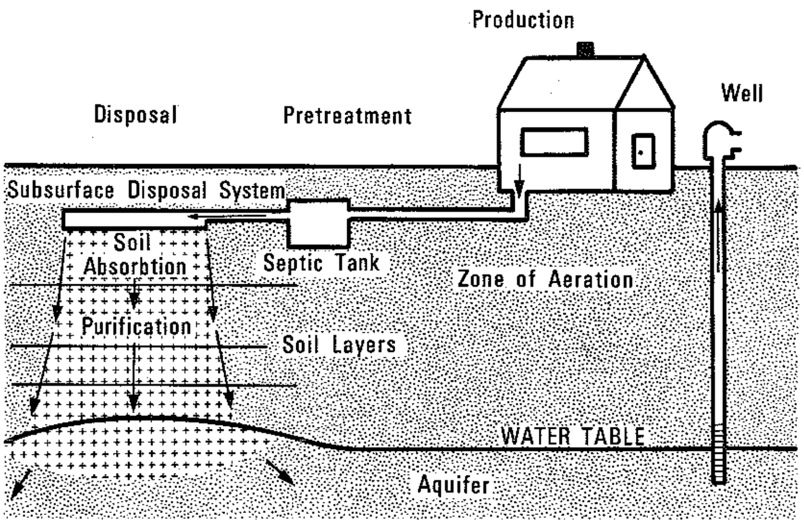


Figure 23.
Soil absorption of septic tank effluent

By sheer volume of wastewater discharged, septic tanks must be rated as the key potential hazard to ground water in the county. However, if the system is properly installed in suitable soil and located a sufficient distance from a water-supply source, the pollutants are removed or degraded during percolation through the zone of aeration and undergo further attenuation before they can reach the water supply. Local problems may develop in areas of larger density of individual septic tank installations or around large septic systems in housing subdivisions or trailer parks.

In areas where soils have severe limitations for septic tanks, an alternative on-site disposal system can be built. Instead of building a seepage bed below the land surface, it is built inside a mound of sandy soil fill material on top of the original soil surface.

Regular inspection and maintenance of septic systems can prevent unnecessary cases of ground-water pollution. Where a septic system fails and the soil is overloaded with contaminants, the wastewater may carry bacteria, phosphates, nitrates, and other minerals into the ground water where they can be recycled through the nearby wells that tap the contaminated aquifer.

Surface impoundments are used in the county for disposal of municipal and industrial waste and for storage of animal waste.

The **disposal of municipal or industrial liquid wastes** is not a major source of pollution in the county. In most communities the wastes, both municipal and industrial, are collected and treated in sewage treatment plants, and sewage effluent is released to streams. There are only a few communities and industries who use lagoons or basins for disposal of liquid wastes (see figure 25). Industrial settling ponds are located close to streams, which are used for disposal of wastewater after the settling process. From the data under the Wisconsin Pollutant Discharge Elimination System (WPDES) it appears that use of ponds or lagoons is generally limited to low-hazard wastes, including wastewaters and cooling water (table 12). Low-hazard wastes from municipalities may introduce BOD, nitrate, and some other troublesome pollutants into the ground water. The single toxic and hazardous waste-absorption system located in Janesville (see table 12) is under stringent control.

As discussed in the section on soils, permeable soils of Rock County usually do not constitute effective barriers to pollutant movement. Therefore, any waste handling or disposal practice that places wastes on or in the ground must be regarded as a potential hazard to ground-water quality. Mechanism of ground-water pollution by surface impoundments of liquid waste is shown in figure 24.

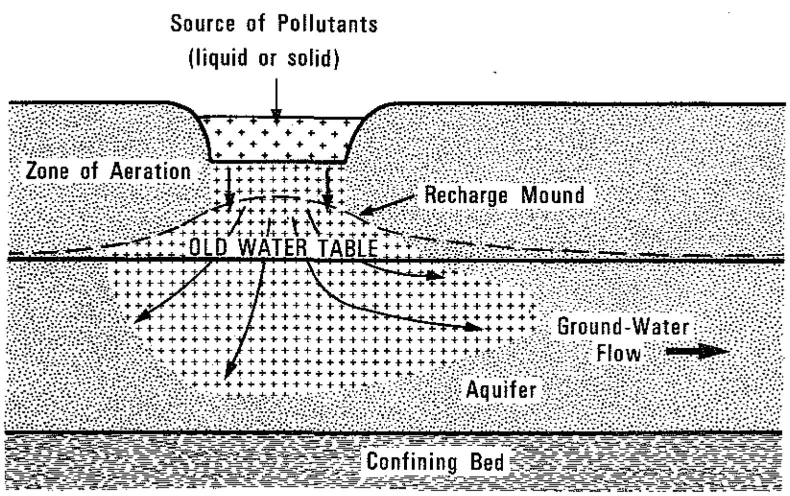


Figure 24.
Ground-water pollution caused by percolation of pollutants originating from a source in the of aeration

Degradation of ground-water quality beneath absorption ponds receiving these wastes may be minimized by proper engineering design and operational procedures. Ponds should not be sited in areas of shallow ground water, hydraulic loading rates should be limited, and resting periods should be provided to renew the soil's capacity for aerobic decomposition of waste. Siting and operation of surface impoundments should be in conformance with the DNR's existing rules (Wis. Adm. Code, Chaps. NR 110 and NR 214). Monitoring wells should be used for early detection of potential ground-water problems around older sites not designed according to the guidelines. Even abandoned

Table 12. Land disposal of liquid waste in Rock County

Location*	Owner	Facility	Waste Type
Town of Beloit (Rock River Generating Sta.)	Wis. Power and Light Co.	Settling basins	Effluent from ash transporter wastewater system
Town of Fulton	Koshkonong Consol. Sanitary Dist.	Sewage pond	Sewage effluent
Town of Janesville (Janesville)	City of Janesville	Filtration beds	Toxic and hazardous petrochemical wastes
Town of Milton (Milton)	City of Milton	Sewage lagoons	Municipal sewage effluent
Town of Plymouth (Hanover)	Town of Plymouth Sanitary Dist.	Sewage pond	Domestic sewage effluent
Town of Plymouth (Footville)	Triangle Paper and Tube Co.	Settling pit	Contact cooling water
Town of Union (Evansville)	Evansville Water and Light Co.	Sedimentation basin	Effluent from iron treatment process

Source: DNR's Wisconsin Pollutant Discharge Elimination System permit program.

*Location of these impoundments is shown on figure 25.

impoundments for disposal or storage of liquid waste may threaten ground-water quality through continued leaching, unless all solid waste residues are removed.

The single major use of surface impoundments that is not now subject to regulation is for storage of animal waste. **Manure storage ponds (pits)** are becoming an increasingly common type of animal-waste handling facility in Wisconsin. There are no exact data available on the number and construction of these facilities in Rock County, although the U.S. Soil Conservation Service (SCS) office in Janesville estimates that in 1981 there were about six earthen animal waste storage facilities in the county (SCS, personal communication). Earthen storage basins have various designs (Graves, 1976). Some have concrete floors, some are lined with bentonite or fine-grained soil material, and some are just dug from the earth. Properly located and constructed, the basins appear not to pose a threat to ground-water quality. According to the findings of the 1980 DNR study of surface impoundments in Wisconsin (Wis. DNR, 1980a), many have been constructed without technical assistance and could be a significant source of ground-water pollution.

A biological seal forms on the bottom and the sides of manure storage pits soon after they are filled. The seal, however, may be lost on pond sides, when manure is removed and the sides are exposed to natural forces. When the pond is refilled, manure seeps from the pit until the seal forms again.

A recent study by the Wisconsin Geological and Natural History Survey of manure pits improperly designed and constructed in conditions similar to Rock County (permeable soil overlying outwash sand and gravel) found that they were contributing nitrate and chloride to ground water in the immediate area downgradient from the facilities (Fred Madison, WGNHS, personal communication). In Rock County, there is one recorded case of ground-water pollution traced to a manure pit (see table 16). However, unless adequate location, design, and construction features are provided to prevent leakage, increased use of manure storage ponds could be expected to increase the number of these local contamination incidents.

A similar mechanism that creates ground-water quality problems under the surface impoundments is involved in the **disposal of solid wastes in sanitary landfills or dry excavations** (see figure 24). The land disposal of solid wastes constitutes an important potential source of ground-water pollution in the county. Currently the municipal and industrial wastes are disposed of in sanitary landfills. However, solid wastes are often disposed of in the excavations created by removal of sand and gravel, clay, limestone, or other natural resources that are commonly left unattended and used as unregulated dumps.

Sanitary landfills generally are constructed by placing refuse in excavations above the water table and covering the deposited material with soil daily--thus the term **sanitary**, to indicate that garbage and other refuse are not left exposed to produce odor and smoke or to harbor vermin and insects. In 1980, there were 15 sanitary landfills in the county (fig. 25); six of them converted from dumps, and the rest new sites.

In humid climate with excess moisture, the landfills will eventually produce leachates. Leachate is produced in a landfill when a significant portion of the refuse has a moisture content equal to field capacity. Factors that influence generation and movement of leachates from a landfill site are the nature of leachates, geologic structure, location of the landfill with respect to topography and ground-water flow system, available moisture, and the rate at which water comes in contact with refuse (Zaporozec, 1974).

In order to minimize leachate production by eliminating the contact of refuse with ground water, disposal above the seasonally high water table is generally practiced. To further reduce the rate of leachate production, rainwater and surface runoff are diverted from the fill area so that refuse can be compacted and covered without becoming saturated. To prevent leachate production from abandoned landfills, the final cover is compacted clayey soil, which retards infiltration. The clay cover is a more important factor in reducing the rate of leachate formation than the location above the water table. Water accumulates in most landfills, which raises the water table to form a mound under the landfill site (see figure 24). Under these conditions, only infiltrating water can move through the refuse, even if the base is below the water table.

Some substances are removed from the leachate as it moves through the zone of aeration, but leachate may grossly pollute ground water. Natural attenuation of leachate can be provided for by locating sites in clay with high ion-exchange capacity or in soils of low natural permeability (0.20 in./hr or less), which allow only small amounts of infiltration and slow ground-water movement. This reduces the volume of leachate produced and retards the movement from the site. Where the conditions are unsuitable for the natural attenuation process, leachate can be collected from the site and then treated by conventional methods for wastewater. The effects of land disposal of solid waste on ground water can be minimized if proper geologic siting and engineering designs are followed (Wis. Adm. Code, Chap. NR 180).

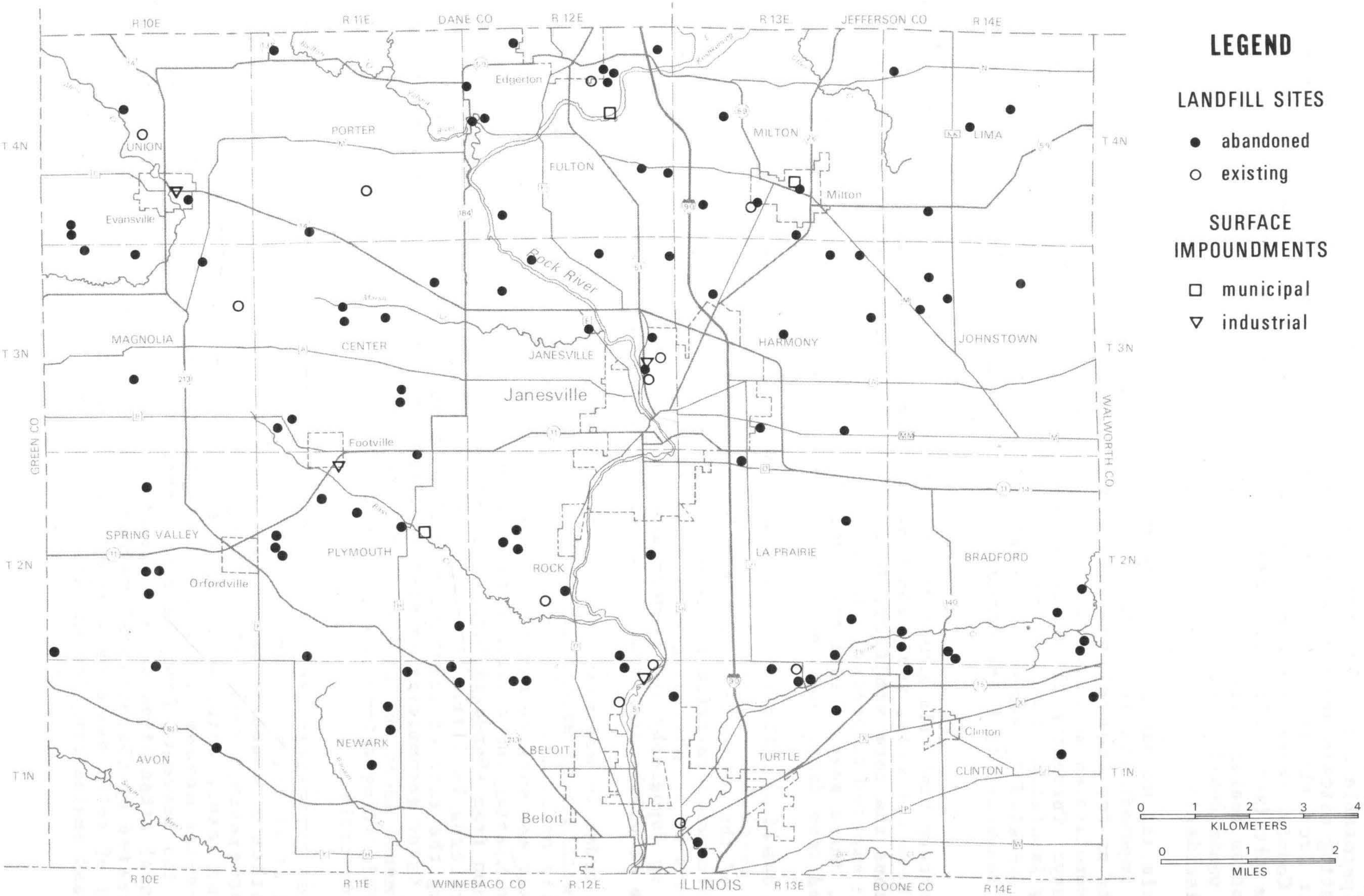


Figure 25. Map showing location of solid waste disposal sites and surface impoundments in Rock County (source: Rock Co., 1969; DNR's Wisconsin Pollutant Discharge Elimination System permit program)

Pollutants escaping from leaky or ruptured buried pipes, including sewers, and storage tanks are another common source that can affect ground-water quality. Tanks that have been abandoned and still have hazardous materials in them are of considerable concern. **Leakage** is particularly frequent from small installations such as gasoline-station and home-fuel storage tanks. Tank testing has not been widely used and owners have little legal responsibility to test their tanks. Regular inspection, including pressure testing, or replacement of metal tanks with tanks constructed from noncorrodable material may be the only way to alleviate this problem. It would be impractical to regulate the location of gasoline stations on the basis of potential ground-water pollution. However, requirements for careful site selection can be applied to major petroleum storage and handling areas such as tank farms.

Underground storage and transmission of a wide variety of fuels and chemicals is a common practice for commercial, industrial, and individual uses. Petroleum and petroleum products are the most common potential pollutants. Leaks in buried tanks and pipelines at industrial facilities and in petroleum-product transmission lines are a continuing problem. Gasoline, being less dense, floats on the ground-water surface and penetrates into basements, sewers, wells, and springs, rendering drinking water objectionable because of taste and odor and causing explosions and fires (Lehr and others, 1976).

There are thousands of miles of buried pipelines crisscrossing under the surface of the land. The pollution zone from a leaking pipline forms a ridge rather than a mound (as in the case of a waste disposal site) and can be classified therefore as a line source rather than a point source of pollution (fig. 26). Leaks may be difficult to detect and locate, and they usually go unnoticed until the pollutants reveal themselves. And even then it is very difficult to determine the source of pollution if more than one underground installation is in the vicinity of a polluted well. An investigation of such a case in the town of Beloit is described later.

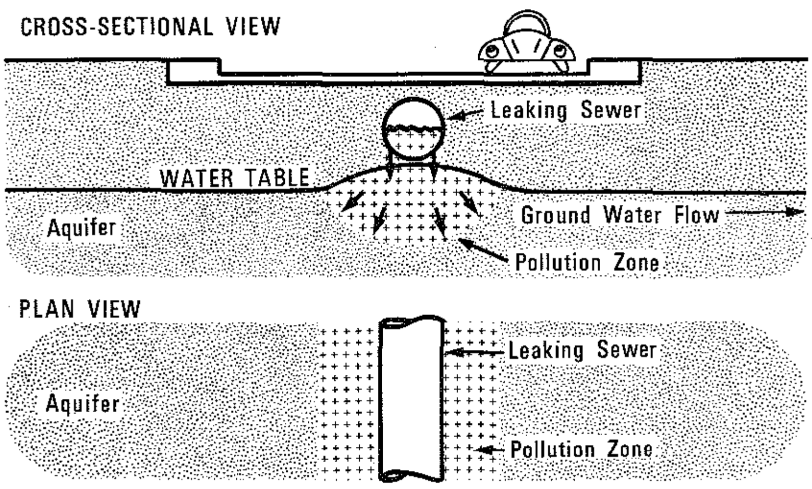


Figure 26. Ground-water pollution caused by a leaking sewer (after Miller, 1977)

Ground-water pollution may be caused by leakage of sanitary or storm sewers or cesspools. The leakage may result from poor workmanship, cracked or defective pipe section, pipeline breakage by tree roots, or rupture by superimposed heavy loads (Miller, 1977).

Local ground-water pollution problems can originate from **sumps and dry wells**. These wells are typically installed to solve surface drainage problems, so they may transmit to ground water whatever pollutants are flushed into them.

Ground-Water Quality Problems Originating Below the Water Table

A serious threat to ground-water quality is the disposal of wastes in **wet excavations**, such as open mining pits, sand and gravel pits, and quarries. Following the cessation of various mining activities, the excavations are commonly abandoned, and eventually they may fill with water. Very commonly they have been used as dumps for both solid and liquid wastes. The wastes, being in direct contact with ground water in an aquifer, may cause extensive pollution. In addition, highly concentrated leachate may be generated from the waste in dry excavations subjected to seasonal fluctuations of the water table.

The last but not unimportant category of human activities having an effect on ground-water quality is **ground-water development**, which is a less obvious but nevertheless very common source of ground-water pollution. It may cause many problems either through excessive pumping or through improper construction, maintenance, and abandonment of wells.

In certain situations pumping, or **overpumping**, of ground water can cause induced infiltration of polluted surface water, interaquifer leakage, and intrusion of inferior water in wells.

Properly designed and constructed water wells are not normally sources of ground-water pollution. But when they are in a state of disuse or disrepair, casing and screens begin to corrode and the wells can serve as important means of ground-water pollution by becoming conduits through which pollutants can travel vertically.

The common example of an **improperly constructed well** is the lack of a seal or an inadequate seal in the annular space between the casing and the borehole, which can connect aquifers of different water quality or allow surface runoff to enter the well along the exterior of the surface casing. Many private wells are not protected against contamination from surface runoff containing storm water, barnyard wastes, or septic-tank effluents (fig. 27). Ground-water pollution can also occur by temporary flooding of a well located in a floodplain. Polluted runoff or surface water can enter around the well casing if the well has been improperly sealed at the ground surface.

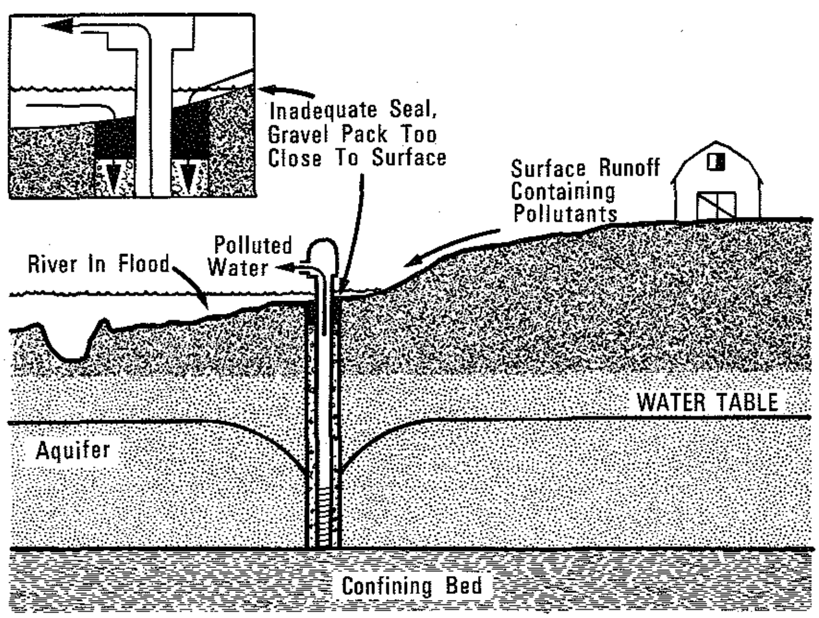


Figure 27.
Ground-water pollution caused by polluted surface water entering the aquifer along an improperly constructed well

Substances Causing Ground-Water Quality Problems

In contrast to some areas of the nation where ground-water abuses and mismanagement have rendered ground water unfit to drink, most of Rock County has ground water of good quality. The quality of most ground water is much better than the quality required by minimum drinking water standards. From the five groups of constituents listed in table 8, only a few have caused or have a potential to cause ground-water quality problems.

Physical and Chemical Properties

Physical characteristics of ground water in Rock County are excellent. With rare exceptions, it has a good taste, it is clear, has no odor, does not contain suspended solids, and its temperature range is within natural limits. Since disposal of wastes through wells, including warmed water from cooling processes, is prohibited in Wisconsin, potential for thermal pollution is practically nil.

Chemical characteristics in part are affected by natural factors, which cannot be controlled. Hardness was found objectionably high in all well waters sampled. It always will be a problem in the county because it is caused by composition of rocks from which the constituents causing hardness are dissolved by passing ground water. Hydrogen-ion concentration (pH) is within the normal range. High concentrations of total dissolved solids may occur locally. Concentrations over 500 mg/1 do not pose a health hazard, but they may be objectionable because of disagreeable taste, economic consequences (unsuitability for some uses and consequently, treatment of water, and corrosion), and possible physiological effects (laxative effect). Two wells in the county showed concentration over 500 mg/1: Ro 91 (502 mg/1) and Ro 210 (1,010 mg/1). The cause of the abnormal concentration of the 1,010 mg/1 should be investigated.

Inorganic Chemicals

Iron, manganese, and nitrate are the three constituents whose concentrations most commonly exceed recommended or mandatory drinking water standards. **Iron and manganese** are natural substances that affect the suitability of water for some uses, and their concentration over recommended levels (0.3 and 0.05 mg/1) is objectionable because of taste and aesthetic reasons. However, amounts many times higher than these limits produce no adverse effects on either humans or animals.

Nitrate concentrations create certain health concerns in the county. An unusually large amount of nitrate in well water may indicate pollution from privies, cesspools, and barnyards, and even when it is not a problem in itself, it may serve as an indicator and a warning that the water may contain harmful bacteria, which also may be carried into the aquifer from these sources of pollution.

In recent years considerable interest has been expressed in the nitrate content of water supplies in the county. The concern with nitrate (NO_3) is that under favorable conditions, it can be reduced to nitrite (NO_2) by denitrifying bacteria in the upper digestive tract of some infants. High concentration of nitrates can result in a serious, though easily treated, blood disorder in infants called infantile methemoglobinemia (or cyanosis), and in extreme cases in death (Wis. DNR, 1980b). The reaction of nitrites with the hemoglobin of the blood reduces the capability of the blood to carry oxygen to the body tissues. Because the skin of affected infants takes on a bluish tone, similar to that which would occur from suffocation, infants are called **blue babies.** Prompt medical treatment normally results in quick recovery.

Infants under 6 months of age are most susceptible to this disease, but not all infants are affected. Many infants have drunk water with nitrate concentration higher than 10 mg/l and have not developed the disease. In Wisconsin no fatalities associated with nitrates in drinking water have ever been reported, and the actual occurrence of the disease is thought to be quite rare (Wis. DNR, 1980b). The standard of 10 mg/l nitrate-nitrogen (NO_3-N) is based on the medical observation that no known cases of methemoglobinemia have been reported when water contained less than that. Older children, adults, and animals can consume water with larger concentrations with no known ill effect, because their stomach juices are more acidic than those of infants and do not promote the growth of denitrifying bacteria.

In order to determine the content of nitrates in ground water, 406 analyses have been collected from various sources (DNR community and noncommunity public water systems surveys and methemoglobinemia files, USGS chemical analyses, and County Sanitarian records) including 167 samples taken from private wells for this study. Most analyses were performed at the Wisconsin State Laboratory of Hygiene, except some collected by the U.S. Geological Survey.

Table 13 shows that almost 27 percent of the samples (or 108 samples) exceeded the established maximum in drinking water standards of 10 mg/l and that 21 of the 108 samples contained more than 20 mg/l. More than one half of the samples contained between 1.0 and 9.9 mg/l, and 18 percent had less than 1.0 mg/l. The concentration ranges between less than 0.5 and 46 mg/l. Median value for the county is 6.0 mg/l. The town of Center had the highest median value of 13.5 mg/l. The town of La Prairie was second with 13.0 mg/l. The town of Milton had the lowest median of 1.1 mg/l, and in the remaining townships the median ranged between 3.2 and 9.7 mg/l.

Even though it is probable that nitrate in the county varies through the years and also seasonably, as can be anticipated from studies in areas similar to Rock County (Crabtree, 1972; Everett, 1980; Saffigna and Keeney, 1977), there are no data available to support it.

Because of time and funding limits, no attempt was made in this study to correlate nitrate concentration with various soil types and with proximity to common sources of nitrate in wells, such as barnyards, feedlots, manure pits, and septic tank fields.

Nitrate concentrations vary both in space and time. Areal distribution of nitrates is shown in figure 28. All townships except the town of Milton had at least one occurrence of concentration above 10 mg/l. Higher concentrations occur more frequently in rural areas where the potential for groundwater pollution is larger because of barnyard drainage, animal wastes, use of fertilizers, and greater number of septic tanks. Urban areas are served by public water supplies that are less likely to be affected by local contamination. The map shows only an areal distribution (nitrate concentration projected on the surface) and does not take into consideration changes in concentration with depth. Therefore it is possible that at greater depths nitrate concentrations may be lower even in areas showing 10 mg/l or more.

The relation between well-casing depth and nitrate concentration is shown in Table 14. This relation is somewhat distorted by the fact that it was possible to locate well data for only a little more than one half of the wells sampled. The results show less nitrate at depth, indicating that the shallow wells are more likely to contain excessive amounts of nitrates than the deeper wells. Only a few data were available on the very shallow wells (0-24 ft): 4 wells. Therefore the interval 0-24 ft was lumped together with the interval 25-49 ft. The largest number of samples with concentration more than 10 mg/l was found in wells with casing less than 50 ft deep. Only 24 percent of the samples having concentrations higher than 10 mg/l, and no sample over 20 mg/l, were found in depths below 100 feet. Wells with casing of 150 ft and

Table 13. Rock County nitrate survey, 1979-81

Township	Nitrate-Nitrogen (NO_3-N) in mg/l: 0-0.9, No. of samples	0-0.9, %	1.0-9.9, No. of samples	1.0-9.9, %	10.0-19.9, No. of samples	10.0-19.9, %	20.0 and over, No. of samples	20.0 and over, %	Wells Sampled: Total No.	% of wells w/ NO_3-N 10.0 and more	Highest Value: mg/l	Date
Avon	2	18.2	8	72.7	1	9.1	-	-	11	9.1	15.6	07/19/81
Beloit	5	12.8	26	66.7	8	20.5	-	-	39	20.5	13.7	10/31/80
Bradford	4	28.6	9	64.3	1	7.1	-	-	14	7.1	13.9	10/30/79
Center	-	-	4	36.4	3	27.3	4	36.4	11	63.6	33.0	08/07/80
Clinton	5	31.3	6	37.5	3	18.7	2	12.5	16	31.3	46.0	08/20/79
Fulton	5	20.0	19	76.0	1	4.0	-	-	25	4.0	15.6	03/05/79
Harmony	2	8.7	13	56.5	6	26.1	2	8.7	23	34.8	45.0	09/22/80
Janesville	7	23.3	18	60.0	5	16.7	-	-	30	16.7	15.8	05/30/79
Johnstown	5	27.8	7	38.9	3	16.7	3	16.7	18	33.3	28.0	09/19/79
La Prairie	-	-	5	26.3	12	63.2	2	10.5	19	73.7	28.0	09/12/81
Lima	6	37.5	4	25.0	6	37.5	-	-	16	37.5	15.5	11/12/80
Magnolia	2	18.2	8	72.7	1	9.1	-	-	11	9.1	18.9	10/01/80
Milton	10	43.5	13	56.5	-	-	-	-	23	0	7.4	03/06/79
Newark	1	6.2	9	56.3	5	31.3	1	6.2	16	37.5	24.0	08/16/81
Plymouth	-	-	13	81.3	2	12.5	1	6.2	16	18.8	21.0	08/18/80
Porter	5	27.8	9	50.0	3	16.7	1	5.5	18	22.2	20.0	09/16/80
Rock	6	15.0	26	65.0	7	17.5	1	2.5	40	20.0	20.0	06/27/79
Spring Valley	1	6.2	8	50.0	5	31.3	2	12.5	16	43.8	43.0	06/12/81
Turtle	2	6.5	18	58.0	9	29.0	2	6.5	31	35.5	28.0	08/15/81
Union	4	30.8	3	23.1	6	46.1	-	-	13	46.1	19.5	09/12/81
TOTAL	72	17.7	226	55.7	87	21.4	21	5.2	406	26.6	46.0	(Clinton)

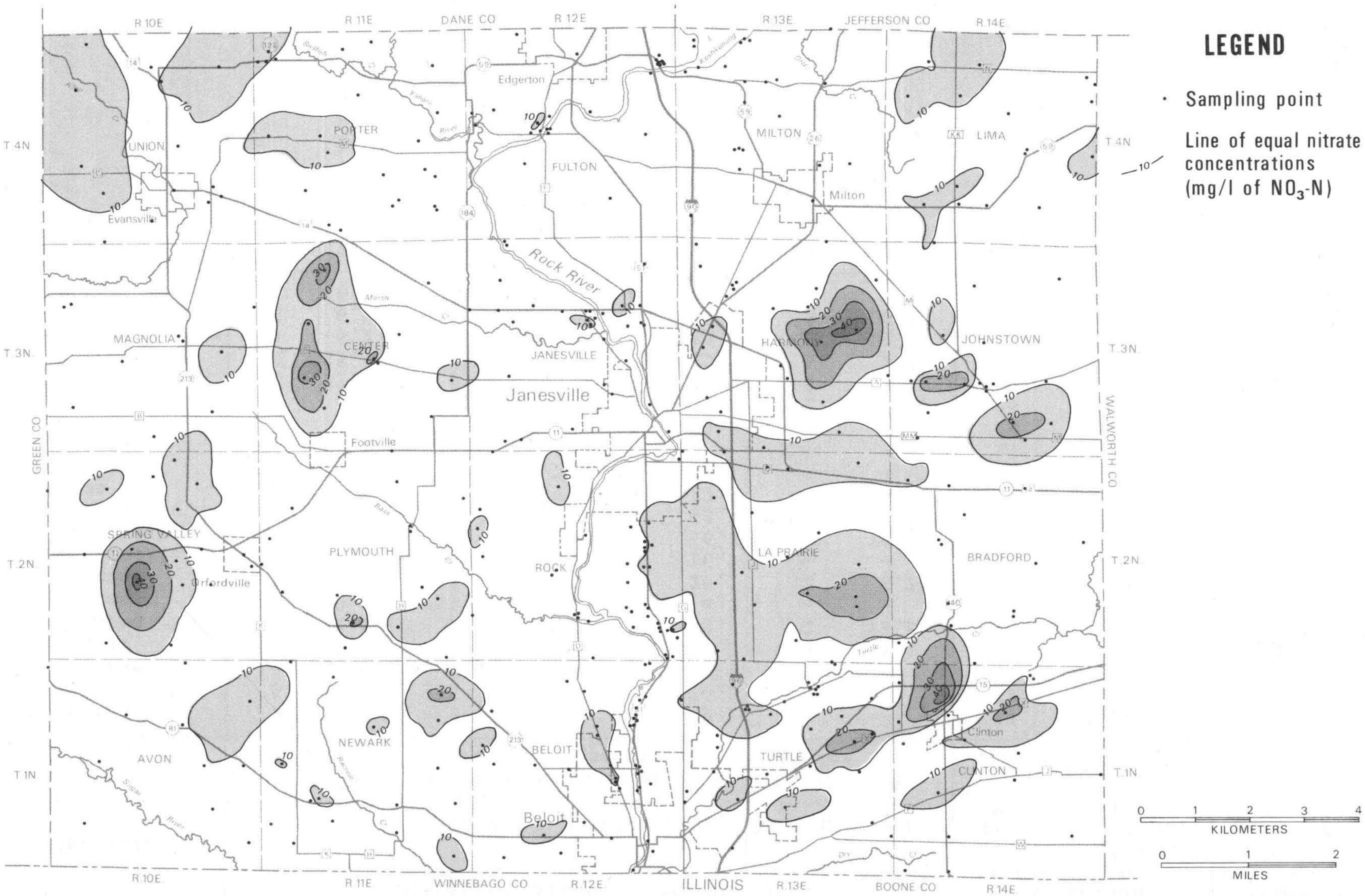


Figure 28. Generalized map of nitrate concentration in Rock County, 1979-81

deeper seem to have the largest number of samples with concentrations less than 1.0 mg/1.

Table 14. Well-casing depth versus nitrate content

Casing Depth (ft)	Number of Wells	NO_3-N Concentrations (in mg/1)							
		0-0.9		1.0-9.9		10.0-19.9		20.0 and more	
		No. of wells	%	No. of wells	%	No. of wells	%	No. of wells	%
0 - 49	72	9	13	42	58	18	25	3	4
50 - 74	39	6	16	20	51	9	23	4	10
75 - 99	30	4	13	17	57	7	23	2	7
100 - 149	26	5	19	14	54	7	27	0	-
150 - 199	23	9	39	11	48	3	13	0	-
200+	16	9	56	6	38	1	6	0	-
TOTAL	206	42	20	110	54	45	22	9	4

A comparison with the study of nitrate concentration in private wells in Wisconsin from 1969 to 1971 (Schuknecht and others, 1975) shows that the proportion of wells with nitrates of 10 mg/1 and more has not changed significantly. In that period 25 percent were over 10 mg/1 (which was the second largest percentage in the state), while the data for 1979-81 show 27 percent.

Rock County was listed as high in nitrate concentration also in a recent DNR study (Wis. DNR, 1980b), when it had the highest median value in the state. This higher-than-average occurrence of nitrate suggests a possibility of the impact of highly productive agriculture on ground-water quality.

There are two basic options in dealing with the nitrate problem: (1) reduce the nitrate intake at the source and (2) develop an alternative source of water. The first option includes proper location, construction, and operation of waste-storage and waste-disposal sites; protection of fertilizers stored on land surface against rainfall; containment of runoff from barnyards, feedlots, and manure-storage areas; and proper application of fertilizers based on soil tests, recommended rates of application, and timing. The removal of nitrate from water is difficult and can be accomplished only by demineralizing of water or by distillation; boiling of water does not remove nitrate. Thus, if a reduction in nitrate concentration is desired, the remaining option is to use water from an unaffected source or to reconstruct or relocate the well.

It would be advisable to make follow-up analyses for nitrates in wells that were found to have more than or near to 10 mg/1 of NO_3-N. If the problem persists, the owners should be informed about the potential health problem and about the remedial options.

Toxic substances in sampled wells occurred in levels below the maximum limits (see table 7). However, caution is required in handling and disposal of the effluent at sewage-treatment plants, sludge, and industrial liquid waste and in temporarily storing wastes at industrial sites. All of these may contain large concentrations of toxic substances and therefore, are potential sources of pollution.

Organic Chemicals

The data on the content of organic chemicals in ground water in the county is scarce. Eight samples taken by the DNR from municipal wells and wells at gasoline stations for the analysis of **synthetic detergents** showed that their concentration was less than the recommended limits (see table 7).

Pesticides are widely used in the county for insect and weed control in corn and soybeans, but there are no data to suggest their widespread presence, or absence, in ground water at this time. The most commonly used kinds are listed in table 15.

Determining the presence of pesticides in ground water requires expensive specialized equipment as well as specially trained personnel. For this reason, pesticides are not part of routine chemical analyses. Three samples taken during the study (see figure 1) were analyzed by the Environmental Task Force Laboratory of the University of Wisconsin-Stevens Point for the ten insecticides listed in table 15. The samples were run together with a blank control sample, on a Varion 3700 gas chromatograph with an ECD and a column packed with 1.5% OV-17/1.95% OV-210.

The results showed that samples 2 and 3 contained no detectable levels of the ten tested pesticides, and that sample 1 might have been contaminated by Dyfonate or by another unknown pesticide not included in the list (Shaw, 1982). However, this result is inconclusive because the laboratory was not able to determine exactly the presence or the character of pesticide. Therefore, it is recommended to take another sample from well Ro 311 and run it at a laboratory equipped with equipment capable of determining if Dyfonate or possibly another pesticide is present.

Radioactivity and Microorganisms

The natural **radioactivity** and amount of radionuclides in ground water in Rock County is small (see table 7).

Microbiological contamination is strictly a local problem, and it has not been part of this study. Coliform bacteria, which are harmless themselves, are used as indicators of sanitary quality of ground water, and their presence may indicate the presence of other more harmful microorganisms. A leading cause of bacterial contamination is poorly constructed or located wells. This problem can be reduced if the wells are constructed according to existing well construction code (Wis. Admin. Code, Chap. NR 112) and located in a sufficient distance and appropriate direction from a potential pollution source (septic tank, manure pit, feedlot, etc.).

Incidents of Ground-Water Pollution

Ten ground-water pollution cases documented by the DNR (Calabresa, 1981) and by the Rock County Division of Environmental Health (Holman, 1981) are shown in figure 29. All of them were related either to waste-disposal activities (numbers 3 to 8 in table 16) or to storage problems (numbers 1, 2, 9, and 10 in table 16). In most cases the actual extent of pollution is unknown. With the exception of gasoline pollution in Beloit and leachate occurrence around the city of Janesville landfill, the incidents were not investigated in detail. However, the cases recorded by the Rock County DEH were inspected in field. The pollution was minor and only local. At the time of the inspection

Table 15. Pesticides used in Rock County

Insecticides	Herbicides
Counter (terbufos)	Amiben (chloramben)
diazinon	atrazine
Dyfonate (fonofos)	Banvel (dicamba)
Furadan (carbofuran)	Basagran (bentazon)
Imidan (phosmet)	Bladex (cyanazide)
Lorsban (chlorpyrifos)	Dual (metolachlor)
malathion	Eradicane (EPTC + safener)
Mocap (ethoprop)	Lasso (alachlor)
Sevin (carbaryl)	Lasso + Lorox (linuron)
Thimet (phorate)	Princep (simazine)
	Sencor or Lexone (metribuzin)
	Surflan + Sencor or Lexone
	Sutan^{+} (butylate + safener)
	2,4-D amine or ester

Source: Dennis Nehring, UW Extension Agricultural Agent, personal communication.

Note: The chemicals are listed under commercial names (starting with a capital letter). Their common names start with a small letter.

of sites, pollutants seemed to be limited to the immediate vicinity of the source (less than 800 ft). At the insistence of the DEH, the sources of problems were eliminated.

Only one remedial action was taken to renovate the subsurface environment, when DNR ordered removal of 3 feet of contaminated soil at a chromium plant in Beloit (case 9) to reduce the leaching of chromium into ground water (David Holman, DEH, personal communication).

The investigation of gasoline pollution of water wells in part of the Morgan Terrace subdivision of the city of Beloit was instigated by a complaint received from a resident whose well was polluted. The DNR's Private Water Supply Section personnel conducted a field investigation during December 1969 and February 1970 (Scovill, 1970). Seven wells were found to be polluted by petroleum products. Four gasoline stations were located some 3,000 feet upgradient from the polluted wells. One of them was reported to have an underground leakage of gasoline about 3 years before the first pollution case occurred. Another buried gasoline storage tank was located at the city of Beloit fire station, about 1,500 feet upgradient from the polluted wells. The investigation failed to find positive evidence as to the specific source of pollution. No remedial action was taken, and the affected homes are now served by the municipal water-supply system.

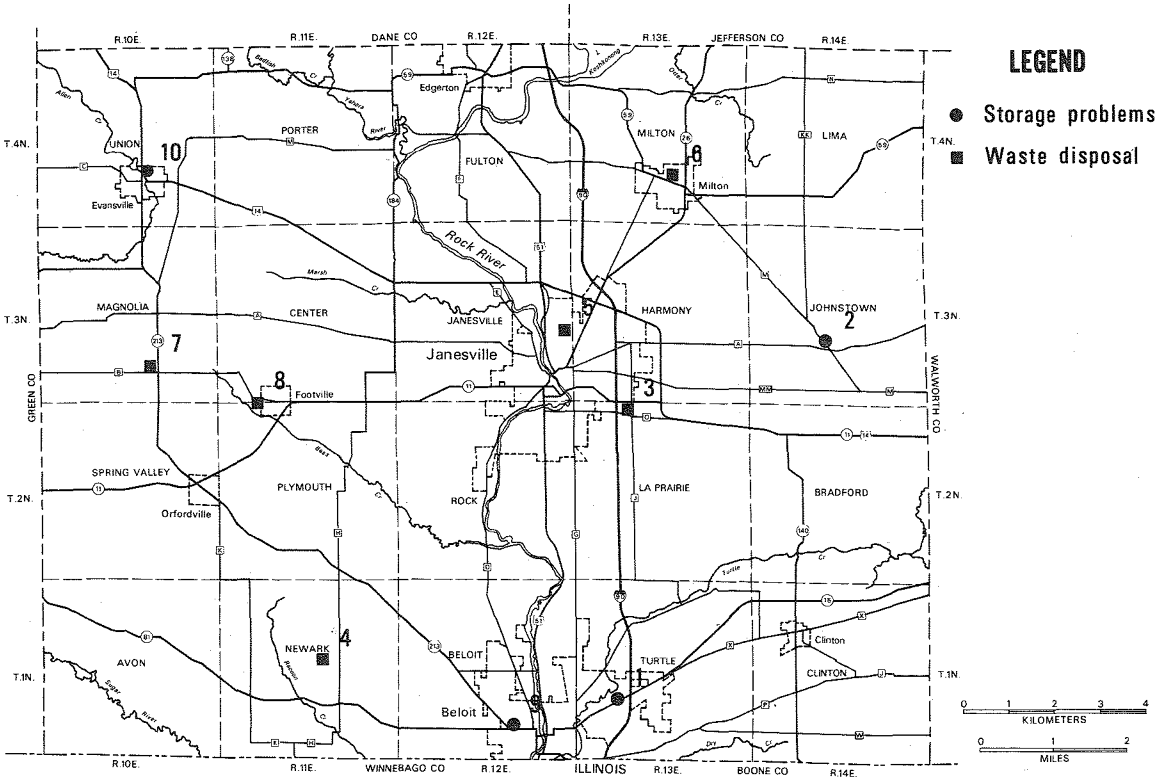


Figure 29. Map showing incidents of ground-water pollution in Rock County (source: Calabresa, 1981; Holman, 1981)

The city of Janesville sanitary landfill was investigated in 1975 by Donohue Associates, Inc. (1975) at the request of the DNR. They found evidence of leachate beneath part of the site (especially the former open dump) but concluded that the water-quality degradation was not excessive and that the extent of ground-water pollution would be effectively controlled by natural attenuation processes. Eight observation wells and ten piezometers were installed around the landfill to determine ground-water flow. The water samples were analyzed for specific conductivity, chloride, sulfate, iron, pH, phenol, nitrate, chemical oxygen demand (COD), and color. Specific conductivity reached the maximum of 1,410 micromhos, which indicates concentration of total dissolved solids around 900 mg/l. The concentration of iron and color were in excess of limits set by drinking water standards. Iron, especially, reached high concentrations (more than 100 mg/l). Also the concentrations of phenol and COD were high. It was suggested that iron and possibly chloride might eventually reach the Rock River (about 0.5 mile west), but that the volume of streamflow is sufficient to dilute any pollutants that may enter the stream through the flow of ground water. The landfill was abandoned in 1978 when the city moved the waste-disposal operation immediately east of the site.

PREVENTING GROUND-WATER POLLUTION

The Existing Legal Framework

Ground water is a vitally important resource that has been taken for granted and given little protection until very recently. Congress enacted

Table 16. Ground-water pollution incidents in Rock County

Map No.	Date of Incident	Location	Soil Type and Depth	Geologic Formation	Type of Pollutant	Suspected Source	Effect of Pollution
1	1969[1]	Morgan Terrace Subd., Beloit	Silt loam (4-5 ft)	Pleist. sand and gr. (over 70 ft)	Gasoline	Leaking buried storage tank	Polluted private wells (7)
2	1972[2]	Tn. Johnstown, SW1/4 SE1/4 S. 21	Silt loam (over 5 ft)	Pleist. till (over 70 ft)	Silage juice	Open silage pit	Polluted private well (1)
3	1973[2]	Tn. La Prairie SE 1/4 NE1/4 S. 5	Abandoned gravel pit	Pleist. sand and gr. (300 ft)	Paint solvents	Unlicensed dump	Monitoring wells
4	1973[2]	Tn. Newark SW1/4 SW1/4	Loam (2-3 ft)	Ordov. dolomite	Leachate (unknown)	Town dump (now closed)	Unknown
5	1975[1]	Black Bridge Rd. Janesville	Sand and gravel pit	Pleist. sand and gr. (over 200 ft)	Leachate (COD, Fe, Cl)	City landfill (now closed)	Monitoring wells (11)
6	1977[1]	STP Milton	Silt loam (5 ft)	Pleist. sand and gr. (270 ft)	Na, Cl, B, PO_4 NH_4, pesticides	Municipal seepage lagoon	Monitoring wells (2)
7	1978[2]	Tn. Magnolia SE1/4 SE1/4 S. 27	Loam (3-5 ft)	Ordov. dolomite	Nitrates	Manure pit	Polluted private well
8	1979[2]	Tn. Plymouth NE1/4 S. 5	Silt loam (3 ft)	Alluv. sand and gr. (50-75 ft)	Domestic effluent	Septic tank Drain pipe	Polluted private well
9	1980[2]	Tn. Beloit SW1/4 SW1/4 S. 27	Loam (over 5 ft)	Ordov. dolomite	Chromium	Surface discharge of plant waste	Polluted private wells (2)
10	1981[2]	Tn. Union NW1/4 NE 1/4 S. 27	Silt loam (3 ft)	Pleist. sand and gr. (100 ft)	Herbicide (Bladex)	Storage tank	Polluted plant well

Source: [1] Calabresa, 1981; [2] Holman, 1981.

several statutes that provide an initial framework for control of ground-water pollution, but unfortunately, no comprehensive federal ground-water legislation exists. The state of Wisconsin has undertaken various protection efforts, and authority for regulation of landfills, surface impoundments, septic tanks, well injection, and mining impacts now exists. However,a coordinated state policy for ground-water protection does not exist.

The discussion of federal and state laws and regulations is presented here to show that they contain a number of valuable tools that the county can use in implementing its own projects for the protection of ground water.

The **Federal Water Pollution Control Act (FWPCA) Amendments of 1972** (PL 92-500) and the **Clean Water Act of 1977** (PL 95-127) that amended the FWPCA delegated some authority over ground-water pollution to the U.S. Environmental Protection Agency (EPA). The scope of EPA authority is ambiguous, and it is not an enforcement authority; however, some provisions have been used to increase ground-water protection, such as section 208. The Wisconsin DNR administers two programs established in response to this legislation--the Wisconsin Pollutant Discharge Elimination System (WPDES) and the state and areawide planning program under section 208. The authority for WPDES was granted to the DNR by Chapter 147, Wis. Statutes. Pollution sources regulated by this authority are wastewater absorption ponds and sludge disposal (see table 17).

The **Safe Drinking Water Act (SDWA) of 1974** (PL 93-523) set up a federal regulatory mechanism to insure the quality of publicly supplied drinking water and provided the states with the primary responsibility for the establishment and enforcement of minimum drinking water standards. The Gonzales Amendment, section 1424 (e) of the Act (so-called sole source aquifer provision) provides local and state agencies a legal mechanism to protect the recharge zones of special aquifers. In Wisconsin, the authority for the protection of public health in the obtaining of safe drinking water is granted to the DNR by Chapters 144 and 162, Wis. Statutes. Before the SWDA was signed into law on December 14, 1974, the DNR had already established minimum quality standards for drinking water (NR 111.22). In February 1978 these standards were superseded by Chap. NR 109--Safe Drinking Water, which adopted bacteriological, physical, and chemical limits according to the SWDA.

The **Resource Conservation Recovery Act (RCRA) of 1976** (PL 94-580) provides for control of another major source of ground-water pollution, namely, land disposal of municipal waste and disposal of hazardous waste. Chapter 144, Wis. Statutes, which gives the DNR authority for regulation of solid waste handling and disposal, was amended to incorporate changes made by RCRA. In response to RCRA, the DNR has also updated the solid waste management rules from 1973 (NR 151) and replaced them in 1980 by a new version (NR 180). Disposal of hazardous waste is regulated by Chap. NR 181.

The **Surface Mining Control and Reclamation Act (SMCRA) of 1977** (PL 95-87) also provides for protection of ground water. In Wisconsin, waste disposal in tailings ponds and settling and seepage lagoons is presently dealt with under the WPDES permit program and is also included under revised solid waste rules. Ground-water protection provisions also are included in the DNR regulations on metallic mineral prospecting (NR 131) and metallic mineral mining (NR 132) and in the proposed Chap. NR 182 on regulation of metallic mining wastes.

Other laws such as the **National Environmental Policy ACT (NEPA) of 1969** (PL 91-190), the **Toxic Substances Control Act (TOSCA) of 1976** (PL 94-469), and the **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Amendments of 1978** (PS 95-396) do not explicitly include protection of ground water but can be used for control of ground-water quality. NEPA requires that, when applicable, ground-water quality should be considered in any environmental impact statement that would be prepared. Similar requirements are included in the **Wisconsin Environmental Protection Act of 1971** (Chapter 274, Wis. Statutes).

The TOSCA and FIFRA have the clear potential in certain circumstances to restrict the use of or ban substances that are of particular danger. In Wisconsin, the rules of DNR (NR 80) and of the Department of Agriculture (Ag 29) require precautions in handling pesticides or pesticide spray equipment so that they do not enter wells and springs.

Other potential sources of pollution regulated by state rules are septic tanks (chapters H 63, H 65, and NR 113) and abandoned wells (NR 111.26 and NR 112.21). The current status of control of major sources of ground-water pollution is summarized in table 17.

Principles of Ground-Water Protection

Ground-water pollution by the activities of humans cannot be completely eliminated, but it can be minimized. We have to accept the fact that pollution (in any form) is the price the civilized world must pay for its existence, and counter it by selecting effective and reasonable solutions for reducing ground-water pollution to an absolute minimum. Strategies for ground-water pollution control must be based on an understanding of the distinctive hydrogeologic, socioeconomic, and environmental influences on ground-water quality and on understanding of the vulnerability of ground water to pollution.

Ground-water pollution is, in the broadest sense, a quite different process from pollution of surface waters. In the case of streams, lakes, and other surface-water bodies, the sources of pollutants are commonly visible, as are the effects of the pollution. Once in the ground, however, the pollutants are hidden from view and slowly begin to move through the geologic framework until they inevitably enter the ground water that may be in use as a source of water supplies. When pollutants enter the hidden subsurface environment, they rarely can be detected by normal monitoring methods, and usually their presence only becomes evident if they reemerge in water wells or other points of surface discharge. Certain pollutants may remain in the aquifers for years, decades, or centuries because the residence time (turnover) of ground water is very slow. Some aquifer sections may remain polluted indefinitely, even if the source of pollution is removed.

Compared with polluted surface water, the rehabilitation of polluted aquifers is an extremely difficult and sometimes impossible task. Well-planned and orderly preventive action based on a thorough knowledge of ground water and its environment is much better than the emergency measures needed for the restoration of polluted ground water. However, an effective ground-water quality management program should include both the preventive and corrective actions: preventing the pollution from occurring and handling the pollution once detected.

Strategies for ground-water quality management should be source-oriented and may range from nondegradation (careful protection of critical areas) to "controlled" or limited degradation and even complete dedication of a closed-system aquifer not used for water supply to convey and treat wastewater. The last strategy, however, is not advisable for the county. There are several alternatives for implementing a ground-water protection program: keeping pollutants from the ground-water system, controlling land use, controlling waste disposal, and minimizing the effects of nondisposal and nonpoint sources on ground-water quality. An indispensable part of the program is enforcement of instituted controls and monitoring of ground-water quality.

Eliminating Pollution Sources

This alternative of ground-water protection is based on the same premise as surface-water quality control: reduction of the pollution potential of a source and elimination of those pollutants or uses of ground-water reservoirs

Table 17. Major sources of ground-water pollution and current state approaches to control

Pollution Source	Current Control Efforts
<u>Waste-Disposal Sources</u>	
Landfills and Other	Rules of DNR--Solid Waste Management, Adm. Rules, v. 9, chap. NR 180.
Surface Impoundments	General regulations: Chap. 144, Wis. Statutes.
Sewage and Sludge Lagoons	Rules of DNR--Sewerage Systems, Adm. Rules, v. 9, chap. NR 110.
Wastewater Absorption or Settling Ponds	Must be permitted under the WPDES (Chap. 147, Wis. Statutes): also: Rules of DNR--Land Disposal of Liquid Waste, Adm. Rules, v. 10, chap. NR 214.
Sludge Disposal	Chaps. 144 and 147, Wis. Statutes: a WPDES permit required.
On-site Disposal Systems	Rules of Dept. of Health and Social Services--Private Sewage Systems, Adm. Rules, v. 3, chap. H 63, and Subdivisions not Served by Public Sewers, chap. H 65: also: Rules of DNR--Servicing Septic Tanks, Seepage Pits, Grease Traps or Privies, Adm. Rules, v. 9, chap. NR 113.
Hazardous Waste	Rules of DNR--Hazardous Waste Management, Adm. Rules, v. 9, chap. NR 181.
Underground Injection Wells	The use of any well for disposal of solid wastes, sewage, or surface or wastewater drainage is prohibited under sec. NR 112.20, Wis. Adm. Code.
Mining Wastes	A WPDES permit required for surface impoundments: solid waste regulated under chap. NR 180 until new regulation of metallic mining wastes is adopted (chap. NR 182).
<u>Non-Disposal Sources</u>	
Agricultural Practices	Generally not subject to state regulations. Chaps. NR 80 and Ag 29 require precaution in handling pesticides or pesticide spray equipment so that they do not enter wells and springs.
Manure pits	Not subject to state regulations. Financial and technical assistance provided by the state for design and construction under chap. 144, Wis. Statutes.
Stockpiles	Not subject to state regulations.
Accidental Spills	State assistance available for cleaning the spills.
Underground Storage Tanks and Pipelines	State standards for construction: no inspection program.
Poorly Constructed and Abandoned Wells	Rules of DNR--Well Construction and Pump Installation, Adm. Rules, v. 9, chap. NR 112, and Requirements for the Operation and Design of Community Water Systems, chap. NR 111.
Mining Operations	Rules of DNR--Metallic Mineral Prospecting, chap. NR 131, and Metallic Mineral Mining, chap. NR 132, include measures for the prevention of ground-water pollution and for ground-water monitoring.

that represent the greatest danger to usable ground water. There are obviously some substances that should not be permitted to enter ground water. These include concentrated pollutants with the potential for irreversible long-term damage, highly toxic substances, petroleum products, oils, and radioactive materials.

Protecting Critical Areas

The initial step in the development of a long-range ground-water quality management program is an assessment of hydrogeologic limits for various land and water uses. An understanding of pollution potential can allow distributing land-use and waste-disposal controls in a way that offers maximum long-term ground-water protection.

Numerous methods are available for compiling maps that show the limits of the environment for various land uses or its susceptibility to pollution, called land suitability maps or pollution potential maps (Hopkins, 1977). The maps are actually graphical interpretations of several characteristics of a specific area and may include physical, biological, land-use, and social and cultural limiting factors. Of the physical factors, the following are most commonly shown: soil characteristics (primarily permeability), thickness of unconsolidated materials, depth to ground water, type and character of bedrock, land slopes, and position of a pollution source in the ground-water flow system relative to points of water withdrawal. The methods range from a simple graphical interpretation of two or three factors to a complex numerical index of multiple factors and numerical scoring of their importance.

One of the more popular approaches is the method of transparent overlays in which the individual limiting-factor maps are combined and overlaid to produce a composite map. In this map lighter areas indicate a relative absence of limiting factors; and darker areas, the presence of numerous limiting factors or of several limiting factors with a high degree of severity. Several maps recently compiled in Wisconsin can serve as an example.

Regional studies usually involve evaluation of only a few factors. The Fox Valley Water Quality Planning Agency assessed the potential for ground-water contamination in the Fox Valley region on the basis of the depth to bedrock and permeability of unconsolidated material (Bohrer and others, 1981). Sherrill, in his study of contamination potential in eastern Wisconsin (1979), used a combination of three factors (drift thickness, permeability, and depth to water) to show high, moderate, and low degrees of pollution potential.

The numerical approach was used by the Dane County Regional Planning Commission in the search for a new landfill site (Lane and McDonald, 1981). Six criteria were used and each was mapped and assigned a score from 1 to 3. In the compilation of a composite map a 40-acre grid pattern was superimposed over each map and a composite score calculated from six grids--the more limitations, the larger the score.

It is necessary to emphasize the generalized nature of these maps, and that small areas of less severe limitations may be found even within the areas of high pollution potential and vice versa. The composite map is a very useful planning tool for screening purposes--to separate areas of high pollution potential from those that have low potential. However, it is only a time-saving basic guide, which does not replace the need for detailed study but does reduce the number of sites to be studied in detail.

A pollution potential map would be a useful tool for the Rock County ground-water quality program, and it would be relatively easy to prepare. Pollution potential should be based on the rate at which recharging water can enter the aquifers. Critical factors in evaluating this rate are the permeability of soils, thickness of unconsolidated materials, and thickness of the zone of aeration, combination of which provides for the attenuation of pollutants. This map would be important for the next step of the ground-water quality management program: the delineation and ranking of critical areas that require the highest degree of protection. These include the areas with high pollution potential and all critical recharge areas. The nondegradation policy could be the central objective for these areas. Identification and designation of such areas involves policy decisions regarding the value of ground water to the county.

Land-use controls offer the greatest opportunity for protecting critical areas. Reliance on land-use controls stems from the intimate connection between land use and ground-water quality. Local government has the planning, zoning, and regulatory powers to decide which areas will be protected and to restrict activities inside the critical areas to those compatible with the nondegradation objective. Zoning is the major technique. It can protect ground water directly through protection districts or zones for critical areas. Indirect means include performance zoning or cluster zoning. The use of zoning and other land-use restrictions to protect drinking water quality are legitimate exercises of the police power and have been widely upheld in court, even though strongly challenged (Tripp and Jaffe, 1979).

Waste-Disposal Controls

Regulation of waste-disposal sites in Wisconsin (except agricultural wastes) involves some sort of permit system and performance standards that must be met to receive a permit. State regulations include the nondegradation of ground-water quality among these performance standards. Waste-disposal sites are point sources, and these are easier to control than nonpoint sources, at least from the technical standpoint. The sites should be selected and designed to minimize potential damage. Technology is available to develop a site in almost any conditions without affecting the quality of ground water.

The permits for construction, operation, and maintenance of solid waste disposal sites, absorption ponds, and other similar liquid waste facilities, sludge disposal, and septic tanks are required by state regulations.

The disposal of water-soluble waste materials in wet excavations should not be allowed because there are no totally effective means presently available that can immobilize the waste.

Attention should be paid to illegal dumping of chemicals on the ground and to discarding unused fertilizers or pesticides.

Minimizing the Effects of Nondisposal Activities

Nondisposal activities can be divided into point sources and nonpoint sources. **Point sources** in Rock County include stockpiles and wastepiles, underground and above-ground storage tanks, pipelines (including sewers), manure storage ponds, and poorly constructed and improperly abandoned wells.

Stockpiles and wastepiles should be protected against infiltration of rainfall and against surface runoff. There is such a wide variety of materials and methods used for stockpiling that the development of regulations would be impractical. The easiest technical control is the covering of piles with plastic sheets and placing the soluble materials in sheds. Attention should be paid to stored agricultural products that may rot when exposed to water and consequently contaminate nearby wells. Large stockpiles and stockpiles of hazardous materials should be excluded from designated critical areas.

Underground storage tanks deteriorate and can leak. Obviously, a leaky tank or pipeline is difficult to detect and locate. Periodic inspections, careful monitoring of fluid levels and inflow-outflow comparisons, and a voluntary pressure-testing program would minimize the danger of ground-water pollution. Pressure-testing equipment is relatively inexpensive and can be purchased by the county and leased to operators of storage tanks for testing. In critical areas, underground storage tanks of hydrocarbons or hazardous materials should be of double-wall construction. Above-ground facilities should be constructed in controlled containment areas sized to capture any spillages from ruptures or leaks. Containment dikes and impermeable liners should be required not only at industrial facilities but also at liquid fertilizer tanks.

Better housekeeping at industrial and agricultural sites handling chemicals can prevent careless accidents resulting from boilovers, overpumping, dumping of used oil or unused chemicals on the ground, and poor control of waste discharges.

Perhaps it might be appropriate to develop a county permitting procedure for earthen manure storage pits to ensure their proper location, design, and installation.

The actual construction of a water well is extremely important to the maintenance of good ground-water quality. Commonly, well-pollution cases can be traced to faulty construction, mostly the watertightness of the seal between the surface and the lower end of the casing. A schematic diagram of a typical well is shown in figure 30. The sanitary protection of the well is provided by the casing surrounded by the grout seal. If the space around the casing is not carefully sealed, polluted water from surface drainage can move downward and pollute the aquifer (see figure 27). Construction requirements for wells finished in various geologic environments are given in the Wisconsin Well Construction Code (NR 112).

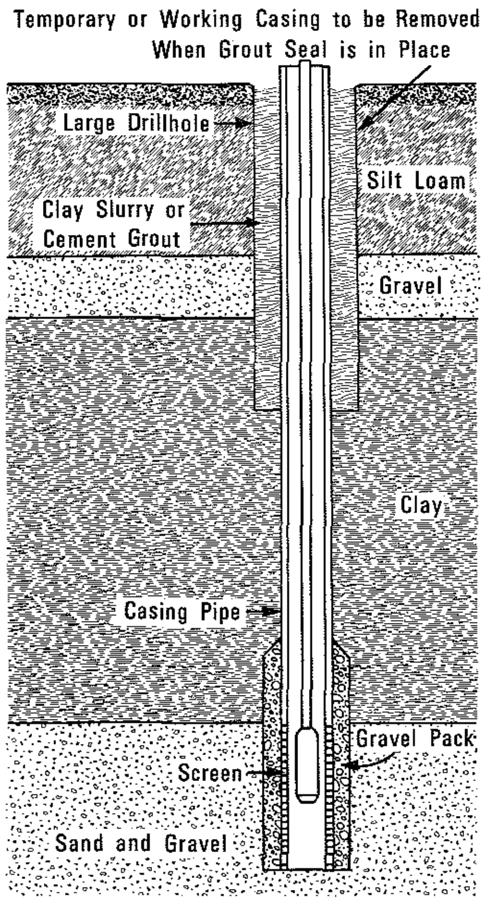


Figure 30. Schematic diagram of a typical gravel-pack well

A well should be located on the highest ground practicable, and certainly higher than nearby sources of pollution. The well casing should terminate above the ground, and the ground surface at the well should slope away. Minimum distances from a well to possible sources of pollution should be great enough to provide reasonable assurance that seepage of contaminated water will not reach the well. Barnyards should be down-slope from the well and 25 to 50 feet away depending on drainage conditions. The following minimum separating distances are required by the Wisconsin Well Construction Code (NR 112.07):

Cast iron sanitary or storm sewer or polluted water drain	8 feet
Clear water waste drain or rainwater downspout outlet	10 feet
Sewer-connected foundation drain	15 feet
Septic tank; sewer other than cast iron; pressurized sewer; barn gutter; or silo without pit	25 feet
Seepage pit and other similar waste-disposal unit; privy; animal yard; silo with pit; loose-jointed field-drain pipe; or sanitary or storm sewer	50 feet
Manure storage; underground storage tank; or grave site	100 feet
Sewage treatment plant	150 feet
Sludge disposal site	200 feet
Absorption pond or ridge-and-furrow or spray irrigation waste-disposal site	250 feet
Sanitary landfill	400 feet

Abandoned wells must be carefully sealed to prevent pollution of ground water from the surface, to conserve aquifer, and to prevent poor quality water from moving between aquifers. A well should be checked before it is sealed in order to insure that there are no obstructions that may interfere with sealing operations. The owner has the responsibility to fill and seal the well in a manner prescribed by the Wisconsin Well Construction Code (NR 112.21) and to report to the DNR that the well has been permanently abandoned. Ground-water pollution caused by abandoned wells could be practically eliminated through education of well drillers and well owners.

The more diffuse, **nonpoint**, or multipoint sources are much more difficult to control than the point sources, and the best that can be done at this time is to minimize their effects on the ground water. Barnyards, animal yards, agricultural fields, and road salt application are common nonpoint sources that may cause ground-water pollution.

The effect of agriculture on ground water can be minimized by fertilizing only when the crops need the nutrients; by avoiding excessive applications: by using slow-release fertilizers; by using biodegradable pesticides and minimizing the amounts by incorporating them into integrated pest management schemes; and by better management and recycling of manure and other waste products. The most widespread effects result from the use of fertilizer. There are many documented cases of high nitrate concentrations beneath agricultural lands in the state. Based on the results of studies done in soil conditions similar to Rock County, it is very probable that fertilizers contribute to the higher-than-average concentration of nitrates in Rock County. Pollution by pesticides must also be listed as an important potential hazard. The handling of pesticides and pesticide spray equipment is controlled by state regulations (see table 17). Special attention should be paid to discarded containers and disposal of unused fertilizer and pesticides. It is not unreasonable to expect that the use of agricultural chemicals may eventually cause parts of some aquifers to become polluted.

There appear to be only two options for dealing with this problem. The first option, aimed at farmers to reduce application rates, would be a well-organized educational campaign to include information on how these chemicals may pollute the water they drink, the development of schemes for reasonable application of chemicals in the county, and possibly some sort of award for farmers who would follow these schemes. The second option would be the development of a strategy for controlling the activities within critical areas.

The effects of road salt application on ground water in the county have not been investigated. The main problem appears to be the storage areas for road salt, which can be easily protected against runoff and precipitation.

Monitoring and Remedial Actions

Monitoring does not protect ground-water quality; it only detects the ground-water quality problems. It is usually done when there is a need to determine the ground-water quality at a particular location and its changes with time or when it is necessary to determine if the designed protective measures work.

There are several monitoring programs in the county today. The largest one is aimed at the protection of public water supplies. By assuming the primary enforcement responsiblity under the Safe Drinking Water Act, the DNR assumed the responsibility for monitoring the community and noncommunity water systems that supply water to the public. The community systems are tested for potential toxic substances and pesticides listed in table 8, for nitrate and fluoride concentrations, for coliform bacteria, and for radioactivity. Monitoring of noncommunity systems includes nitrate and coliform bacteria.

The need for and degree of monitoring required for waste-disposal sites is at the discretion of the regulatory authority, which in Wisconsin is the Department of Natural Resources. Currently there are two monitoring systems required by the DNR. One system consisting of 11 observation wells is around the city of Janesville sanitary landfill. This system also serves as a control for the nearby filtration beds used for disposal of hazardous liquids. The city collects quarterly samples for COD, pH, Cl, Fe, SO_4, and specific conductivity. Another system monitors the quality of ground water around the city of Milton seepage lagoons. Two observation wells are sampled twice a year for alkalinity, hardness, pH, TDS, Cl, SO_4, and nitrogen in all forms (organic, ammonium, nitrate, and nitrite).

Because of the nature of ground-water pollution, random countywide monitoring would be of little use in detecting individual cases of pollution. The sampling network using wells scattered over the county is likely to miss most pollution plumes, thus producing misleading results. However, it is advisable to monitor the overall quality of ground water on a countywide basis to detect the effects of areawide, nonpoint sources (like fertilizing, which may result in nitrate concentration, or irrigation, which may result in increasing total mineral concentration) and to determine the quality of ground water coming from adjacent counties. Since the nitrate concentration is the main ground-water quality problem, the county may wish to learn more about it and establish a monitoring program for determining the variations in nitrate concentration with time (seasonal variations) and the distribution of nitrate under irrigated fields and manure storage ponds. The programs would be of limited time scale, from 2 to 3 years. Other monitoring programs should be source-oriented and should concentrate on the potentially polluting sites to detect if pollution is occurring.

Monitoring around such sources would primarily be done for determining the migration of pollutants. Pollutants that enter an aquifer move in the direction of ground-water flow, generally forming a well-defined plume that disperses only slowly. Because of that, pollution of a portion of an aquifer need not have an effect on safe use of the rest of the aquifer. The prediction of how pollutants move in the affected aquifer and where and when pollutants may show up in water wells would make it possible to take remedial action before the health and well-being of those in the path of the pollution plume are affected.

Such remedial action could consist of stopping the pollutant at its source; removing polluted soil; reversing the pollutant movement by pumping in the plume or in disposal areas; creating a cone of depression around a new well installed for the purpose of withdrawal of the polluted water; intercepting an affected portion of the ground-water flow via trenches, and pumping polluted water away for treatment; developing alternate water supplies for those threatened by the pollution; or a combination of these techniques. The importance of establishing an effective sampling and monitoring program at the first signs of pollution cannot be overemphasized because well-planned and orderly preventive action is much better than the emergency measures necessary when it is too late.

Developing a Ground-Water Quality Management Program

Most of the ground water in Rock County is of excellent quality, but that is no reason to sit back and relax. The county government should be commended for its initiative in trying to protect and maintain the good quality of its water. Ground water in Rock County is valuable economically as well as environmentally. Clean water is needed for the county citizens, agriculture, and industries.

Developing a ground-water quality management program is a slow and painstaking process. Control of ground-water pollution necessarily begins with the development of strategies and guidelines to prevent future ground-water pollution and to maintain existing ground-water quality at the highest degree practicable. Strategies must take into account all aspects and all implications involved in the mechanism for achieving the objectives of the strategy. It is extremely difficult to find good solutions that would appeal to all interest groups affected by this mechanism. Every ground-water reservoir user may be faced with the need to give up one or more totally independent actions in order to achieve common benefit. It is difficult for an individual user to be concerned with the long-term advantages of ground-water quality management if he feels that his own actions are jeopardized. Therefore any strategy would include a compromise between what is theoretically desirable and practically achievable.

There are several management schemes the county can choose from:

(1) Do-nothing strategy; relying on existing regulations and state approaches to control ground-water pollution.

(2) Source-oriented strategy; regulating all identified pollution sources.

(3) Nondegradation strategy; protecting all reasonable ground-water uses, and maintaining quality levels according to present and future uses.

It is obvious that each of these strategies has certain problems and none of them alone would suffice for the county's intentions. Existing state regulations apply to only a part of the pollution sources. Regulating all individual sources of pollution in the county would be largely impossible because of the number and diversity of the sources. In addition, no existing technology can control the nonpoint pollution sources. General policies of nondegradation of ground water are easy to prescribe but virtually impossible to realize.

An effective management program should include a combination of the three strategies: enforcement of existing state regulations; identification of the most important sources of pollution and developing a program for minimizing their effects on ground water; and identification of areas most susceptible to ground-water pollution and critical recharge areas, and their protection under the nondegradation policy.

Many mechanisms for achieving the objectives of the ground-water quality program are available:

--Educational campaign to help homeowners, farmers, commercial establishments, industry, and local officials become more conscious of all kinds of potential pollution sources and of methods for minimizing ground-water pollution.

--Best management practices or operating and design requirements for activities that may pollute ground water and periodic inspection of compliance with the requirements.

--Economic incentives to reduce ground-water pollution, particularly for nonpoint sources of pollution.

--Inventory of potential pollution sources and instituting regulation (within county powers) of those that immediately threaten ground-water quality.

--County ordinances, of which the currently adopted Public Health Ordinance (Rock County, 1981) including ground-water pollution as a public nuisance would be a very effective management tool.

--Prohibition of waste-disposal facilities within designated critical areas unless no feasible alternative exists and the facility will not endanger ground water.

--Regulation of land use in critical areas and explicitly integrating ground-water protection into existing land-use planning processes.

To ease the implementation of the ground-water quality management program, the county should consider the establishment of well-data files and pollution-cases files.

Well-data files would include well-construction data, geologic information, water-level measurements, water-quality data, and any documentation of well pollution. Wells could be assigned a number by township as they are acquired for the file. All licensed well drillers are now required by the new Rock County Public Health Ordinance (1981) to submit a copy of well-construction reports to the County Department of Health. The well file will provide county and local officials and planners with readily available data needed for their planning and decision-making processes. If recorded on the property deed, the well file can protect an unsuspecting buyer against "inheriting" the polluted well.

Pollution-cases files should include all occurrences of ground-water pollution, their date, type of pollution, extent and effects of pollution, methods of inspection and investigation, and remedial actions taken.

It is hoped that the Rock County ground-water quality management program, if and when implemented, would serve as an example and guide to other counties that are as interested in the protection of ground-water resources as Rock County is.

REFERENCES CITED

Ball, J.R., R.J. Poff, and C.W. Threinen. 1970. Surface water resources of Rock County: Wis. Dept. of Natural Resources, Madison, WI.

Bohrer, M.L., and others. 1981. Groundwater--a survey of contamination potential in the Fox Valley region: Fox Valley Water Quality Planning Agency, Menasha, WI.

Born, S.M., S.A. Smith, and D.A. Stephenson. 1974. The hydrogeologic regime of glacial-terrain lakes, with management and planning implications: UW-Extension, Madison, An Inland Lake Renewal and Shoreland Management Demonstration Project Report.

Calabresa, T.A. 1981. As assessment of Wisconsin's ground-water availability and quality; a special report to the DNR Secretary: in preparation (completion scheduled for 1982).

Cotter, R.D., and others. 1969. Water resources of Wisconsin, Rock-Fox River basin: U.S. Geological Survey, Hydrologic Investigations Atlas HA-360.

Cotter, R.D. 1976. Water resources in Wisconsin, in Mineral and water resources of Wisconsin: U.S. 94th Congress, Senate Document, Interior and Insular Affairs Committee Print, Washington, D.C., p. 148-150.

Crabtree, K.T. 1972. Nitrate and nitrite variations in ground water: Wis. Dept. of Natural Resources, Technical Bulletin No. 58.

Devaul, R.W. 1975a. Probable yields of wells in the sand-and-gravel aquifer, Wisconsin: Wis. Geol. and Natural History Survey/U.S. Geological Survey map, scale 1:1,000,000, 1 sheet.

Devaul, R.W. 1975b. Probable yields of wells in the sandstone aquifer, Wisconsin: Wis. Geol. and Natural History Survey/U.S. Geological Survey map, scale 1:1,000,000, 1 sheet.

Donohue and Associates, Inc. 1975. Hydrogeologic investigations, city of Janesville landfill: Donohue and Assoc., Inc., Sheboygan, WI.

Everett, L.G. (editor). 1980. Groundwater monitoring: General Electric Co., Schenectady, NY 12300.

Gehm, H.W., and J.I. Bregman (editors). 1976. Handbook of water resources and pollution control: Van Nostrand Reinhold Co., New York, NY.

Graves, R.E. 1976. Earth storage basins for liquid manure: UW-Extension, Madison, Publ. A2795.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural waters: U.S. Geological Survey, Water-Supply Paper 1473 (2nd ed.).

Hindall, S.M., and E.L. Skinner. 1973. Water resources of Wisconsin, Pecatonica-Sugar River basin: U.S. Geological Survey, Hydrologic Investigations Atlas HA-453.

Holman, D. 1981. Point source ground-water pollution--case histories: written communication, Rock Co. Health Department, Janesville, WI, Jan. 23, 1981.

Holt, C.L.R., Jr., and E.L. Skinner. 1973. Ground-water quality in Wisconsin through 1972: Wis. Geol. and Natural History Survey, Information Circular No. 22.

Hopkins, L.D. 1977. Methods for generating land suitability maps: a comparative evaluation: Jour. of Amer. Inst. of Planners, v. 43, no. 4, p. 386-400.

Kammerer, P.A. 1981. Ground-water quality atlas of Wisconsin: Wis. Geol. and Natural History Survey, Information Circular No. 39.

Lane, W.N., and R.R. McDonald. 1981. Land suitability analysis for sanitary landfill siting: UW-Extension, Madison, WI., Proc. 4th Annual Conference on Applied Research and Practice on Municipal and Industrial Waste, Sep. 28-30, 1980, Madison, p. 53-73.

Lehr, J.H., and others. 1976. A manual of laws, regulations and institutions for control of ground-water pollution: U.S. Environmental Protection Agency, Washington, DC, Rep. EPA-44019-76-006.

LeRoux, E.F. 1963. Geology and ground-water resources of Rock County, Wisconsin: U.S. Geological Survey, Water-Supply Paper 1615-X.

Martin, L. 1932. The physical geography of Wisconsin: Wis. Geol. and Natural History Survey, Bulletin No. 36 (3rd ed.).

Meinzer, O.E. 1923. The occurrence of ground water in the United States: U.S. Geological Survey, Water-Supply Paper 489, p. 309-314.

Miller, D.W. (editor). 1977. The report to Congress--Waste disposal practices and their effects on ground water: U.S. Environmental Protection Agency, Washington, DC.

Reuss, J.L., P. LaTour, and T.J. Evans. 1981. The mineral industry of Wisconsin. A chapter from U.S. Bureau of Mines Minerals Yearbook 1977: Wis. Geol. and Natural History Survey, Reprint Series.

Rock County. 1970. A study of solid waste disposal and a roadside count of unlicensed automobiles and unused machinery in Rock County, Wisconsin, 1969: County Planning and Zoning Committee, Janesville, WI.

Rock County. 1976. Rock County solid waste management study: County Planning, and Environmental Protection Departments, Janesville, WI.

Rock County. 1979a. Rock County agricultural preservation plan (draft): County Planning Department, Janesville, WI.

Rock County. 1979b. Rock County water supply and wastewater facilities report: County Planning Department, Janesville, WI.

Rock County. 1981. County of Rock Traffic and General Ordinances, Chapter XIII. Public Health.

Saffigna, P.G., and D.R. Keeney. 1977. Nitrate and chloride in ground water under irrigated agriculture in central Wisconsin: Ground Water, v. 15, no. 2, p. 170-177.

Schuknecht, R., and others. 1975. Nitrates in Wisconsin ground water: Environnmental Letters, v. 9, no. 1, p. 91-98.

Scovill, R.D. 1970. Report on alleged gasoline pollution of water wells at Morgan Terrace Subdivision, Beloit, Wisconsin: Wis. Dept. of Natural Resources, mimeographed report.

Shaw, B.H. 1982. Results of water samples from Rock County: written communication, College of Natural Resources, Univ. Wis.-Stevens Point, Jan. 11, 1982.

Sherrill, M.G. 1979. Contamination potential in the Silurian dolomite aquifer, eastern Wisconsin: U.S. Geological Survey, Water-Resources Investigations 78-108.

Summers, W.K. 1961. Water temperatures in a well near Wild Rose, Wisconsin: Wis. Acad. of Sciences, Arts, and Letters, v. 50, p. 221-232.

Tripp, J.T.B., and A.B. Jaffe. 1979. Preventing groundwater pollution: towards a coordinated strategy to protect critical recharge zones: Harvard Environmental Law Review, v. 3 - 1979, p. 1-47.

U.S. Dept. of Agriculture. 1974. Soil survey of Rock County, Wisconsin: USDA, Soil Conservation Service.

U.S. Environmental Protection Agency. 1973. Water quality criteria 1972: US EPA, Washington, DC, Rep. EPA-R3-73-033.

U.S. Environmental Protection Agency. 1975. Water programs--National interim primary drinking water regulations: Federal Register, v. 40, no. 248, Dec. 24, 1975, p. 59570-59571.

U.S. Geological Survey. 1980. Water use in Wisconsin, 1979: unpublished document based on (1) data collected from Wis. PSC and DNR files, (2) data received from several other public agencies, and (3) estimates by personnel of USGS and DNR: USGS, Madison, WI (publication expected in 1982).

U.S. Geological Survey. 1981. Water resources data for Wisconsin, water year 1980: USGS, Madison, WI, p. 475-480.

U.S. Public Health Service. 1962. Drinking water standards: U.S. Dept. of Health, Education, and Welfare, US PHS Publ. No. 956, Washington, DC.

Walsh, L.M. 1969. The fate of nitrogen in soils: mimeographed paper for UW-Madison, Soil and Water Management Workshop, Dec. 17-18, 1969.

Weidman, S., and A.R. Schultz. 1915. The underground and surface water supplies of Wisconsin: Wis. Geol. and Natural History Survey, Bulletin No. 35.

Wisconsin Administrative Code--Chapters addressing the ground-water protection are listed at the end of references.

Wisconsin Agricultural Reporting Service. 1979. 1979 Wisconsin agricultural statistics: Wis. Dept. of Agriculture, Madison, WI.

Wisconsin Conservation Department. 1959a. Rock County wetlands.

Wisconsin Conservation Department. 1959b. 1959 spring head survey, Rock County: mimeographed report.

Wisconsin Department of Local Affairs and Development. 1974. Comprehensive planning program for Rock County, Wisconsin, Volume I: Wis. DLAD, Bur. of Regional Planning and Community Assistance.

Wisconsin Department of Natural Resources. 1969. Resource inventory report--Rock County.

Wisconsin Department of Natural Resources. 1970. State of Wisconsin, Public water supply data, 1970: Wis. DNR, Div. of Environ. Protection.

Wisconsin Department of Natural Resources. 1978. Wisconsin lakes: Wis. DNR Publ. 7-3600 (78).

Wisconsin Department of Natural Resources. 1980a. Final report on Wisconsin surface impoundment study: Surface Impoundment Assessment staff, Wis. DNR, Madison, WI.

Wisconsin Department of Natural Resources. 1980b. Nitrate levels in small public water systems of Wisconsin: Wis. DNR, Bureau of Water Quality.

Wisconsin Department of Natural Resources. 1981. 1980 air quality data report: Wis. DNR, Bureau of Air Management.

Wisconsin State Board of Health. 1935. Public water supplies of Wisconsin: Bureau of Sanitary Engineering, p. 12-19 and 22-23.

Wisconsin Statistical Reporting Service. 1978. Snow and frost in Wisconsin: Wis. Dept. of Agriculture, Madison, WI.

World Health Organization. 1971. International standards for drinking water: WHO, Geneva, Switzerland (3rd ed.).

Zaporozec, A. 1974. Hydrogeologic evaluation of solid waste disposal in south central Wisconsin: Wis. Dept. of Natural Resources, Technical Bulletin No. 78.

Zaporozec, A. 1981. Ground-water pollution and its sources: GeoJournal (Wiesbaden, Germany), v. 5, no. 5, p. 457-471.

WISCONSIN ADMINISTRATIVE CODE--chapters related to ground-water protection:

Rules of Dept. of Agriculture (v. 1 of Administrative Rules)

Chap. Ag 29 (1981), Pesticide use and control.

Rules of Dept. of Health and Social Services (v. 3 of Administrative Rules)

Chap. H 63 (1980), Private sewage systems.

Chap. H 65 (1975), Subdivisions not served by public sewers.

Rules of Dept. of Natural Resources (v. 8 to 10 of Administrative Rules)

Chap. NR 80 (1980), Use of pesticides on land and water areas of the state of Wisconsin.

Chap. NR 109 (1979), Safe drinking water.

Chap. NR 110 (1979), Sewerage systems.

Chap. NR 111 (1979), Requirements for the operation and design of community water systems.

Chap. NR 112 (1981), Well construction and pump installation.

Chap. NR 113 (1979), Servicing septic tanks, seepage pits, grease traps or privies.

Chap. NR 131 (1979), Metallic mineral prospecting (in revision).

Chap. NR 132 (1979), Metallic mineral mining (in revision).

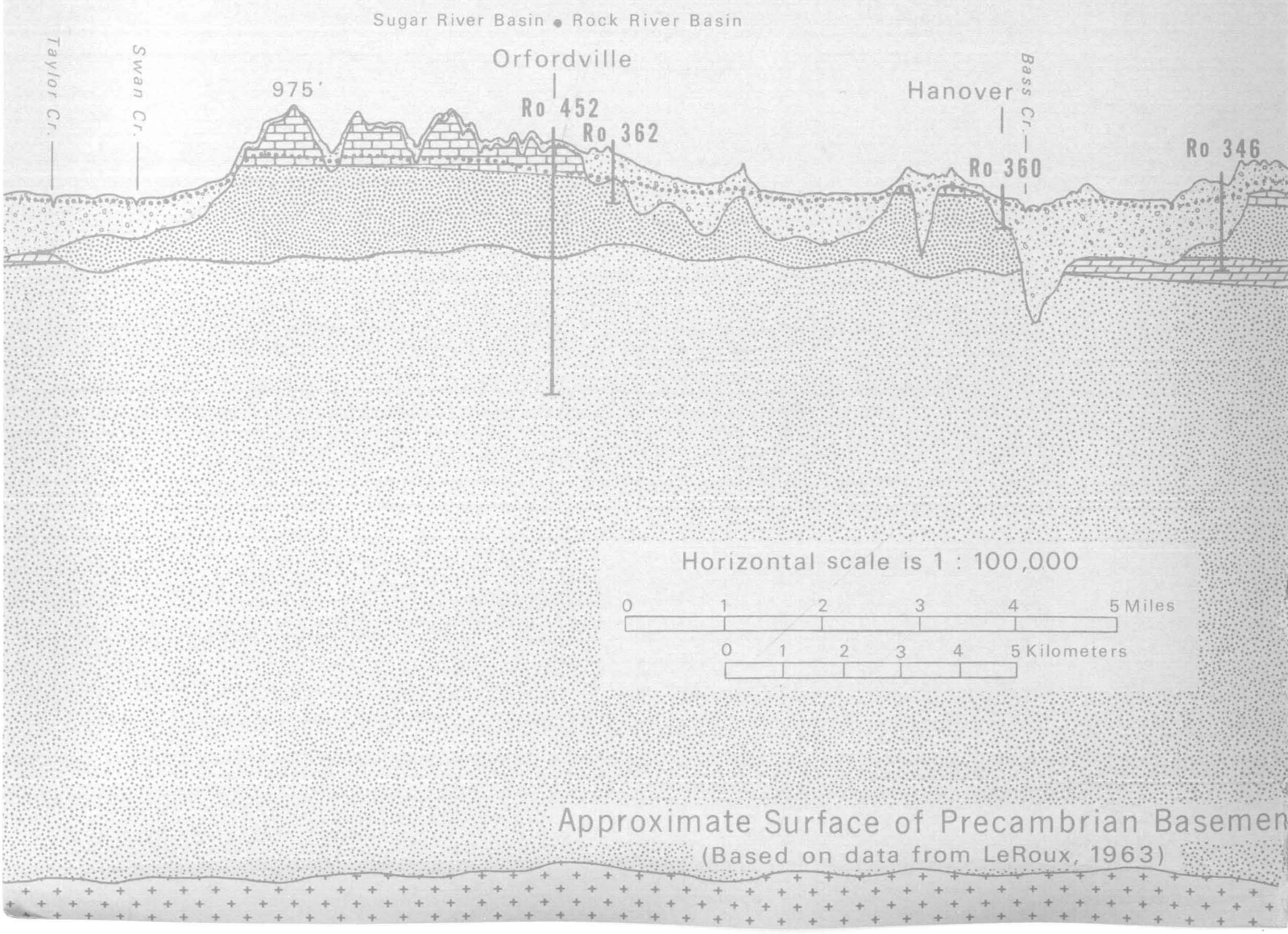
Chap. NR 180 (1980), Solid waste management.

Chap. NR 181 (1981), Hazardous waste management.

Chap. NR 182 Regulation of metallic mining wastes (in preparation).

Chap. NR 185 (1979), Solid waste management planning criteria.

Chap. NR 214 (1979), Land disposal of liquid wastes.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