Iowa Geological Survey Water Atlas No. 5

WATER RESOURCES OF SOUTH-CENTRAL IOWA

Rathbun Dam and Reservoir, Appanoose County, Iowa. Color infrared photograph, courtesy of Iowa Geological Survey Remote Sensing Laboratory, Iowa City, Iowa.

Iowa Geological Survey Water Atlas Number 5

Water Resources of South-Central Iowa

by

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This atlas presents information on the occurrence,
availability, quality, and utilization of water
in south-central Iowa.

Prepared by the U.S. Geological Survey
in cooperation with the Iowa Geological Survey.

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STATE OF IOWA
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FOREWORD

An adequate and safe water supply has always been one of man's fundamental needs. For man to meet this need and yet live in rational balance with the environment he must understand the hydrology of the supply area. Limits imposed by the quality and quantity of water available and the effects of development of alternative sources should be assessed before development plans are made.

This report presents a summary of the hydrology of south-central Iowa for both the long-range planner and developer and the individual water user. The areas chosen by the planner to establish solid and liquid waste-disposal sites, the spacing of major water-using developments, and the manner in which agriculture is managed should all be considered if wise use of our resources is to prevail. Individual users are of course most interested in the one fundamental need; location of an adequate, safe water supply. This report should be of significant use to both the planner and user.

Information presently available through the U.S. Geological Survey and the Iowa Geological Survey is presented in the report. These two agencies, however, have a continuing data-gathering program and new data accumulates daily. Persons requiring water-resources data and geologic information can use this report for a thorough, concise summary of information as of the date of publication. If more or later information is needed, inquiry directed to the Surveys is welcome.

Stanley C. Grant
Director & State Geologist
Iowa Geological Survey

Iowa City, Iowa
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CONTENTS

CONTENTS

Illustrations

CONTENTS

Illustrations

Tables

GLOSSARY

Abbreviations

cfs - cubic feet per second; 1 cfs equals 449 gallons per minute or about 0.65 million gallons per day.

cfsm - cubic feet per second per square mile.

gpm - gallons per minute.

mgd - million gallons per day.

mgy - million gallons per year.

mg/L - milligram per liter; equals 1 part per million.

Alluvium - Clay, sand, gravel, boulders, and other matter laid down by streams upon land not submerged beneath the waters of lakes or seas.

Anticline - A fold in rock strata in which the strata dip (slope) in opposite directions from a common ridge or axis. Opposite of syncline.

Aquifer - Rocks that contain and transmit water and thus are a source for water supplies.

Artesian water - Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well — does not necessarily rise to or above the land surface.

Average discharge - The arithmetic average of the streamflow or discharge of all the complete water years of record, whether consecutive or not. It represents the long-term total amount of water that a stream produces.

Basement complex - A complex of igneous and metamorphic rocks that lie beneath the sedimentary rocks in Iowa.

Climatic year - In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period beginning April 1 and ending the following March 31. The climatic year is designated by the calendar year in which it begins. It is used especially for low-water studies.

Confining bed - Rocks that will not transmit water fast enough to furnish an appreciable supply for a well or spring.

Contour - A line used to connect points of equal altitude, whether they be points on the land surface, on the bedrock surface, on the surface of a particular rock layer, on the water table, or on a potentiometric surface.

Contour interval - The difference in altitude between two adjacent contour lines.

Conversion factors - For those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
inches	$2.54 \times 10^{+1}$	millimeters
feet	3.048×10^{-1}	meters
mile	1.609	kilometers
square feet	9.29×10^{-2}	square meters
acre	4.047×10^{-3}	square kilometers
square mile	2.590	square kilometers
cubic feet	2.832×10^{-2}	cubic meters
gallon	3.785	liters
gallon	3.785×10^{-3}	cubic meters
gallons per minute	6.309×10^{-2}	liters per second
gallons per day	3.785×10^{-3}	cubic meters per day
million gallons per day	$3.785 \times 10^{+3}$	cubic meters per day
million gallons per year	$3.785 \times 10^{+3}$	cubic meters per year
billion gallons per year	$3.785 \times 10^{+6}$	cubic meters per year

Discharge - The volume of water (or more broadly, total fluids), that passes a given point within a given period of time.

Dissolved solids - The total dissolved-mineral concentration in water.

Dome - A roughly symetrical upfold of layered rocks; the layers dip (slope) in all directions, more or less equally, from a point.

Drawdown - The lowering of the water table or artesian pressure due to the pumping of a well.

Drift - A mixture of rocks, such as boulders, gravel, sand, or clay, transported by glaciers and deposited by or from the ice or by or in water derived from the melting of the ice.

Evaporite mineral - One of the sediments which is deposited from aqueous solution as a result of extensive or total evaporation of the solvent. In this report, the evaporites are gypsum and anhydrite deposited from sea water during the Devonian and Mississippian periods.

Evapotranspiration - A term embracing water returned as vapor to the air through direct evaporation from water surfaces and moist soil and by transpiration of vegetation, no attempt being made to distinguish between the two.

Fault - A rock fracture or fracture zone along which there has been displacement of the two sides relative to one another. This displacement may range from a few inches to many miles.

Gaging Station - A particular site on a stream where a continuous record of discharge is computed.

Glacial till - Non-sorted, non-stratified sediment carried or deposited by a glacier composed of material of all size fractions - from clay to boulders.

Head potential - The energy to move a fluid resulting from the difference in altitude of the fluid between two points. Usually expressed in feet.

Hydrostatic head - The height of a vertical column of water, the weight of which, if of unit cross section, is equal to the hydrostatic pressure at a point.

Hydrostatic pressure - The pressure exerted by the water at any given point in a body of water at rest. That of ground water is generally due to the weight of water at higher levels in the same zone of saturation.

Igneous rocks - Rocks formed by solidification of hot molten rock matter or magma.

Infiltration - The movement of water through the soil surface into the ground.

Joint - A fracture or parting which interrupts abruptly the physical continuity of a rock mass.

Mean discharge - The arithmetic average of a stream's discharge for a definite period of time, such as a day, month, or year.

Metamorphic rocks - Rocks that have formed in the solid state by recrystallization and reactions between rock matter in response to pronounced changes of temperature, pressure, and chemical environment.

Natural storage - Water naturally detained in a drainage basin in the stream channel, lakes, reservoirs, natural depressions, and ground-water reservoir.

Normal annual air temperature - The arthmetic average of air temperature values for a 30-year period ending with an even 10-year. In this report, the period is 1941-70.

Normal annual precipitation - The arthmetic average of annual quantities of precipitation for a 30-year period ending with an even 10-year. In this report the period is 1941-70.

Partial-record station - A particular site where limited stream-flow or water-quality data are collected systematically over a period of years for use in hydrologic analyses.

Percolation - Movement, under hydrostatic pressure, of water through the interstices of rock or soil.

Permeable rocks - Rocks having a texture that permits water to move through them perceptibly under the head differences ordinarily found in ground-water systems.

Potentiometric surface - The surface that everywhere coincides with the level to which the water from a given artesian aquifer will rise in wells.

Public water system - A system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. A public water system is either a "community water system" or a "noncommunity water system."

(a) "Community water system" means a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

(b) "Noncommunity water system" means a public water system that is not a community water system. These systems basically serve transients.

Recharge - The processes by which water is added to the zone of saturation.

Runoff - Water discharged through surface streams.

Sedimentary rocks - Rocks formed in a stratified fashion, layer upon layer, by the accumulation of sediment in water or on land.

Structural deformation - Warping and (or) faulting of the earth's crust by forces within the earth.

Suspended sediment - Fragmental material such as clay or mud particles, silt, sand, and small rocks that is transported by being held in suspension by moving water.

Syncline - A fold in rock strata in which the strata dip (slope) inward from both sides toward the axis. Opposite of anticline.

Terrace - Flat, horizontal or slightly inclined surfaces usually found along the edge of a stream valley or in isolated patches within the valley which are at perceptibly higher altitudes than the flood-plain surface.

Terrace deposits - Deposits that lie beneath and form a terrace.

Water stage - Height of a water surface above any chosen datum plane, often above an established low-water plane.

Water table - The upper surface of the zone of saturation except where that surface is formed by an impermeable body.

Water year - In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends.

Zone of saturation - The zone in which all pores in the rocks are saturated with water.

ACKNOWLEDGMENTS AND SOURCES OF INFORMATION

A substantial amount of the data used in the preparation of this report was obtained through the assistance and cooperation of many individuals and of state, county, and municipal agencies. These data have contributed significantly to the substance of this report.

Appreciation is expressed to the rural residents of south-central Iowa who furnished information about their water supplies and who permitted the sampling and measuring of their wells. Because rural-domestic and livestock supplies together constitute the largest percentage of the total water consumed in the study area, the information on rural supplies was most important in the preparation of this report.

Thanks are due the city and county officials who furnished information on sources of water supply and on many aspects of municipal water use. Water superintendents and city clerks were most helpful in this regard and their assistance is particularly acknowledged. During the test-drilling phase of the project, county engineers were most cooperative in permitting drilling along county road rights-of-way.

Thanks are especially due the well drillers in the area for furnishing drill cuttings and logs of wells.

Special acknowledgment is made to personnel of the Iowa Geological Survey, who through the past years have collected and analyzed many rock samples and other well and water-supply data. This information was essential in appraising the geology and hydrology of the counties in the area of this investigation. The Iowa Natural Resources Council supplied data on all types of ground-water and surface-water usage and the State Hygienic Laboratory made chemical analyses on many water samples collected especially for this study.

INTRODUCTION

Most parts of south-central Iowa have been chronically short of good-quality water. Municipalities have experienced serious problems in obtaining potable supplies adequate to keep pace with their growth and development; industrial expansion has been hindered and continues to be hindered by the shortage of good-quality water; and rural supplies for domestic and livestock use are difficult to obtain at many places. The increased use of water for all purposes and periodic drought conditions have greatly magnified an already serious problem of water shortage.

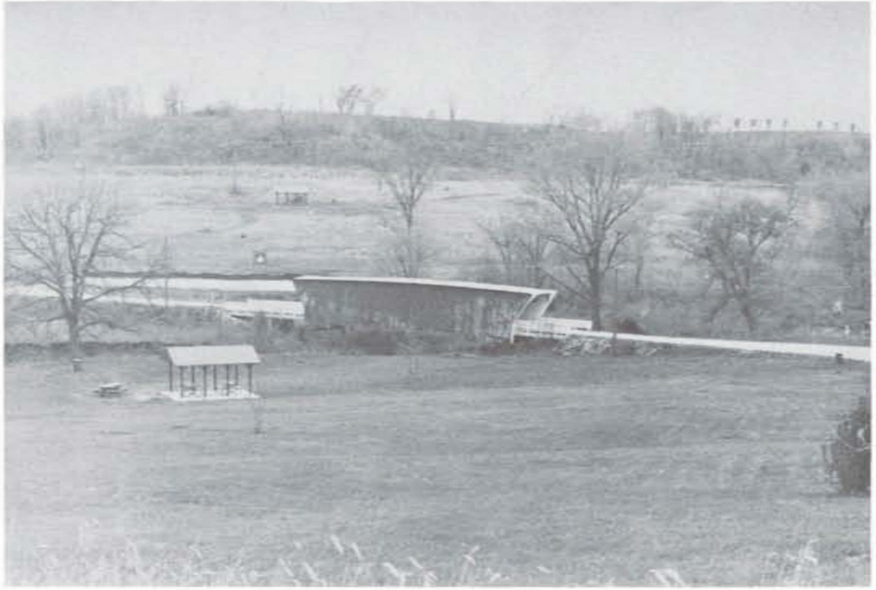
Some of the sources of water in the area yield insufficient amounts of water, some have erratic and unpredictable yields, some yield highly mineralized water, and some are not developed because the system is not understood. Collectively, these factors contribute to the water-shortage problem in the area.

Obviously the shortage of water could be alleviated by developing additional supplies of good-quality water from one or more of the sources in the area. Additional development, however, is dependent on a better understanding of the hydrologic system. In particular, more detailed information is needed on the occurrence, availability, and chemical quality of water from the unconsolidated deposits, on the sources and quality of water from the bedrock, and on the streamflow in the area. The need for information on water that could be made readily available to municipalities, industries, and individuals alike, prompted an investigation of the water resources of south-central Iowa.

The investigation in south-central Iowa of the sources of supply and the occurrence and potential of each source encompassed both ground-water and surface-water studies and culminated in this comprehensive regional report. The Water Resources Division of the U.S. Geological Survey in cooperation with the Iowa Geological Survey compiled this atlas that appraises the total water resources of an 11-county area in south-central Iowa.

The objective of this report is to present information on the water resources of south-central Iowa that will help solve the supply problems of the water users in the region and that will aid planners and water managers who must consider water resources on a regional basis. The information presented includes the availability, quality, and utilization of water from all known sources and the future demands upon the water resources.

Rathbun Water Association water tower at Williamson, Lucas County



Scene near Winterset City Reservoir, Madison County

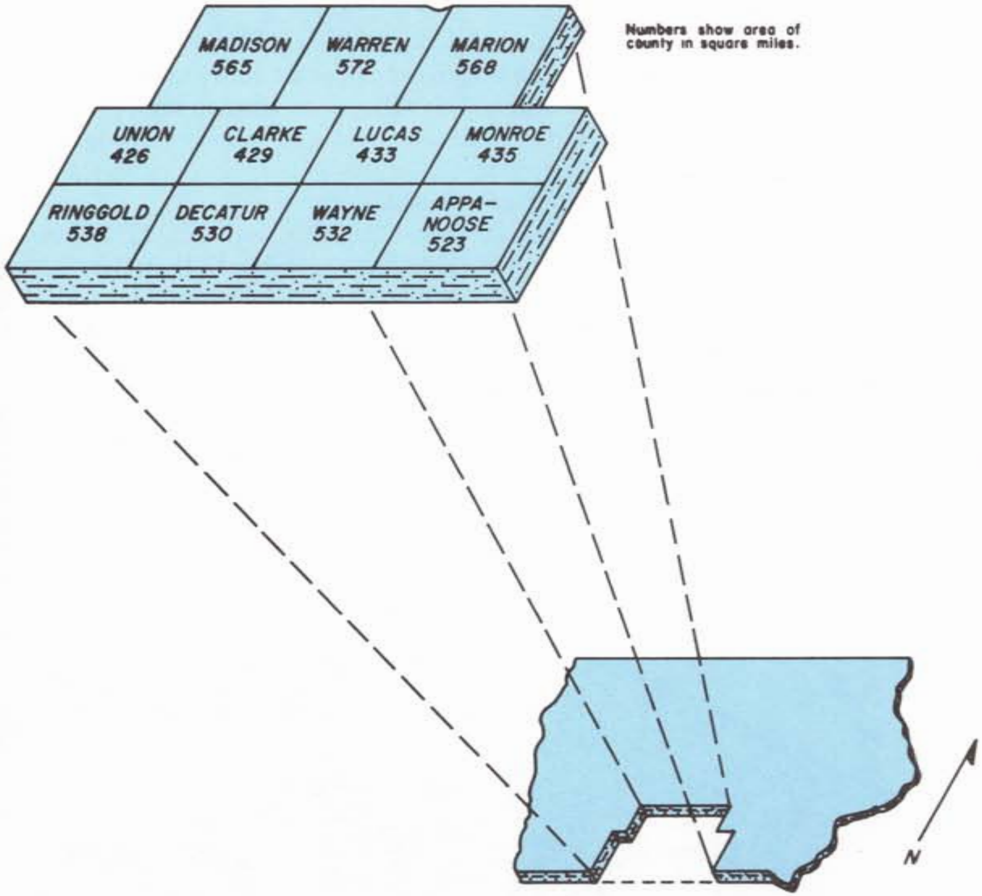


Figure 1.— The 11 counties in south-central Iowa

SOUTH-CENTRAL IOWA

The south-central Iowa area consists of 11 counties in the southern part of the state. These 11 counties cover 5,551 square miles — about 9.9 percent of the land area of Iowa.

South-central Iowa includes parts of 6 large drainage basins. These are the Chariton, Des Moines, Nodaway, Platte, Skunk, and Thompson. Parts of 3 smaller basins also lie within the area. The Chariton, Nodaway, Platte, and Thompson basins drain into the Missouri River to the south, and the Des Moines and Skunk and the smaller basins drain into the Mississippi to the southeast.

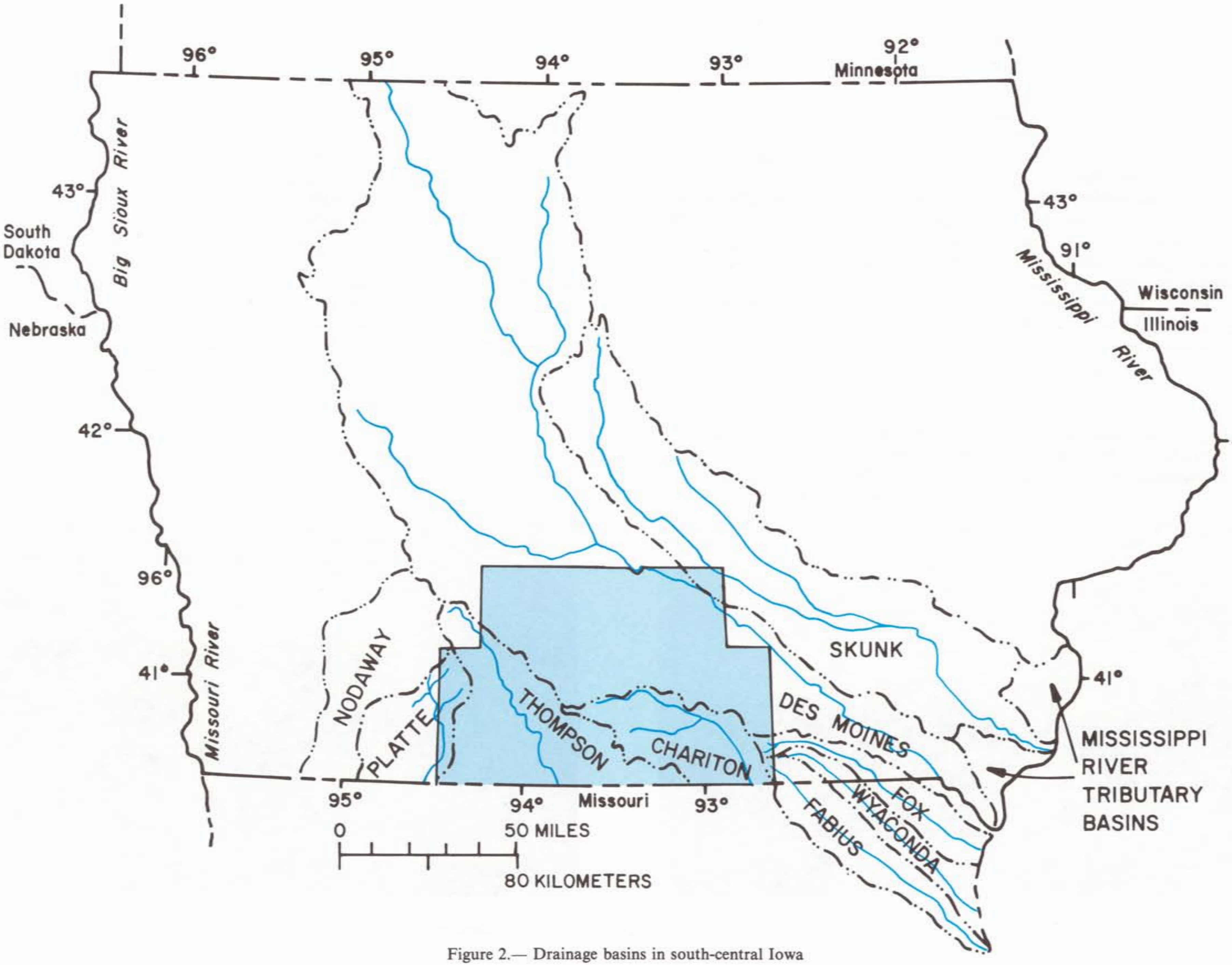


Figure 2.— Drainage basins in south-central Iowa

THE LAND SURFACE

The topography of south-central Iowa is largely the result of the dissection of the drift plain which formed the land surface during the Pleistocene Epoch (Ice Age). The area may be divided topographically into the flood plains and terraces, uplands, and sideslopes. The flood plains and terraces occupy the valleys of the principal streams and their tributaries and are underlain by alluvial deposits. The uplands are for the most part relatively rugged, moderately-to-highly dissected areas composed of hills, knobs, and ridges, but at places the uplands are gently rolling and only slightly dissected. The uplands are nearly everywhere underlain by drift.

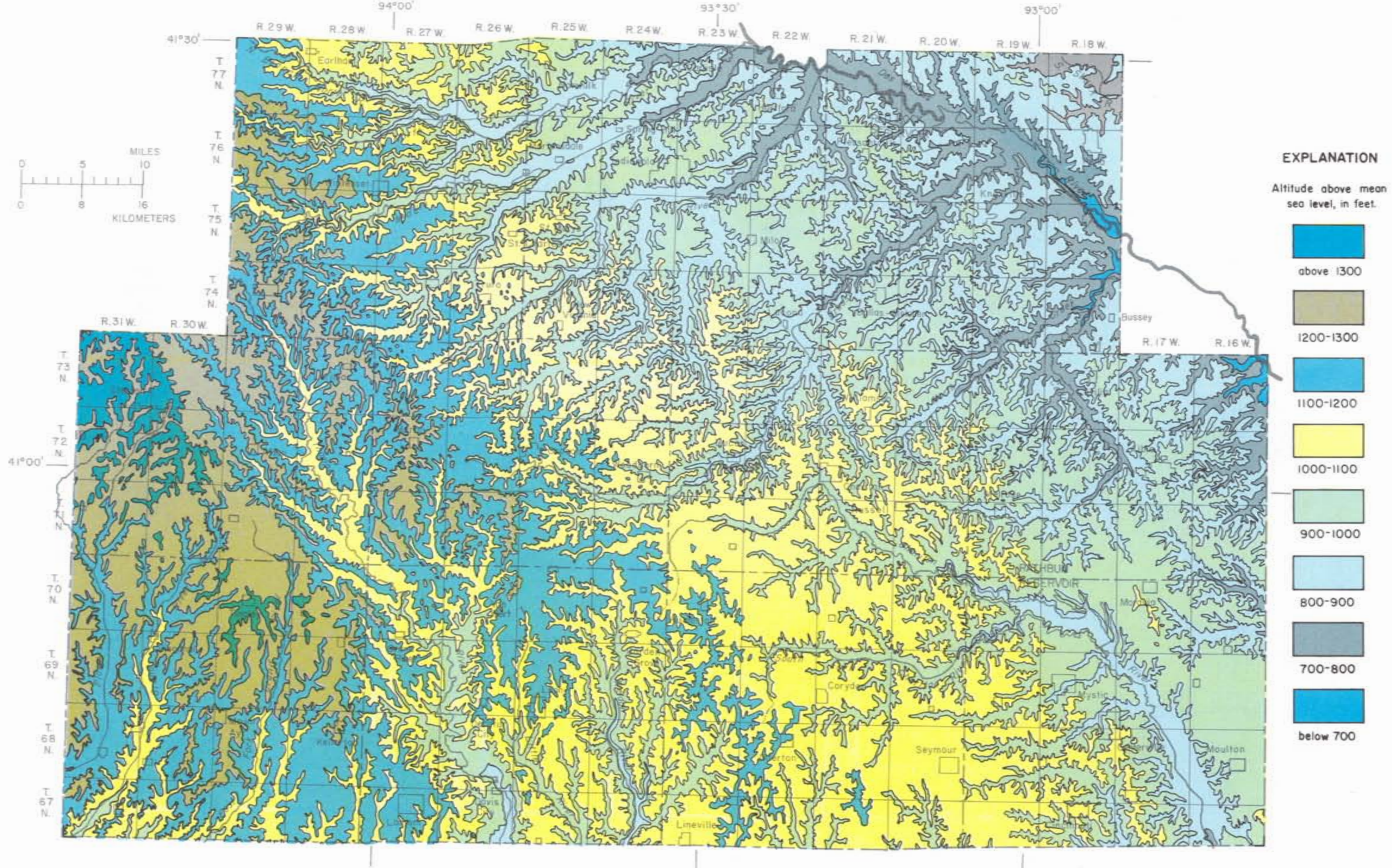
The alluvial valleys of the Des Moines, Skunk, Chariton, and Thompson Rivers are about 2½ miles wide at places, but the valleys of the other major streams seldom exceed 1 mile in width.

Land-surface altitudes in south-central Iowa are highest — a little more than 1,350 feet above mean seal level (msl) — on upland surfaces in north-central Ringgold and northwestern Union counties. As indicated on the topographic map (fig. 3), the lowest surface, a little less than 650 feet, is along the flood plain of the Des Moines River in the northeast corner of Monroe County. Thus the total topographic relief in the area is about 700 feet. The local topographic relief, that between the stream valleys and adjacent drainage divides, generally is between 100 to 200 feet and is greatest in the vicinity of Winterset in Madison County, where it is approximately 220 feet.

Figure 3 is a highly generalized map that shows land-surface altitudes and infers, by contour configuration and altitudes, the principal topographic features in the area. Land-surface altitudes need to be known to compute drilling depths and water-level depths, because aquifers and water levels are referenced to mean sea-level datum in this report. Because this topographic map shows altitudes at 100-foot intervals, it is inadequate for detailed work, but is useful for preparing preliminary estimates of altitudes and depths. Modern topographic maps, scale 1:24,000 with a contour interval of 10 feet, are available for parts of the report area. More generalized maps, scales 1:62,500 and 1:250,000, are also available. The areas mapped on scales of 1:24,000 and 1:62,500 are shown in figure 25 and the agencies through which the maps can be purchased are listed on page 33.

Gently rolling-to-dissected upland surface in Monroe County

Upland adjoins alluvial valley of North Cedar Creek, Lucas County



Topography and base modified from U.S. Geological Survey 1:250,000 topographic quadrangles.

Figure 3.— Topographic map of south-central Iowa

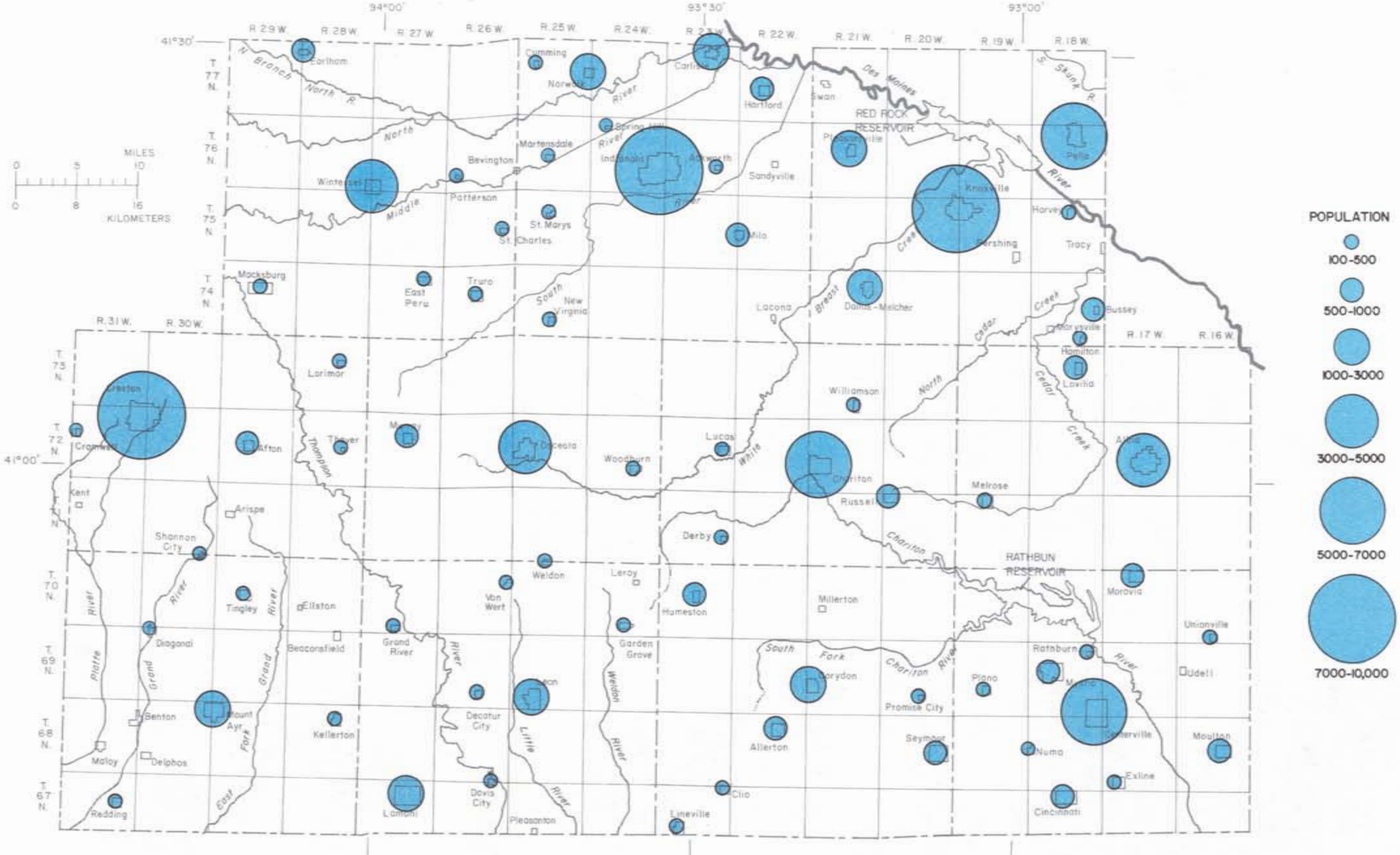


Figure 4.— Population of cities and towns in 1970

POPULATION

In 1970 there were 145,523 people residing in 11 counties in south-central Iowa. This was about 5 percent of the population in Iowa. Forty percent of the people lived in urban areas (places with more than 2500 persons).

A population breakdown can also be made on the basis of the incorporation status of a town or city regardless of population; on this basis about 60 percent of the population in the report area resided in incorporated places in 1970. Figure 4 shows the relative sizes of these incorporated communities. In 1970 there were no cities in south-central Iowa with populations of as much as 10,000; however, 6 cities had populations in excess of 5,000. These were: Indianola with 8976; Creston with 8234; Knoxville with 7755; Pella with 6668; and Centerville and Chariton with 6531 and 5009 residents, respectively.

The total population in south-central Iowa has shown an overall steady decrease from 1900 to 1970, but the population was fairly stabilized during the decades 1910-20, 1930-40, and 1960-70. The region had a net loss of about 60,000 residents during the 70-year period. The predictions of future populations illustrated in figure 5 show the population increasing only slightly or experiencing a modest increase of about 0.6 percent per year. This prediction would indicate a population of from 151,000 to 182,000 by the year 1990.

A steady change from a rural to an urban population has taken place in the past. In 1900 the urban population in south-central Iowa was 16 percent of the total, and by 1970 it had reached 40 percent. Projections indicate that by the year 1990 the urban population will be about 50 percent of the total. Future water demands probably will be commensurate with this new balance, and demands for domestic needs, as well as for industries will be concentrated even more in and around urban areas.

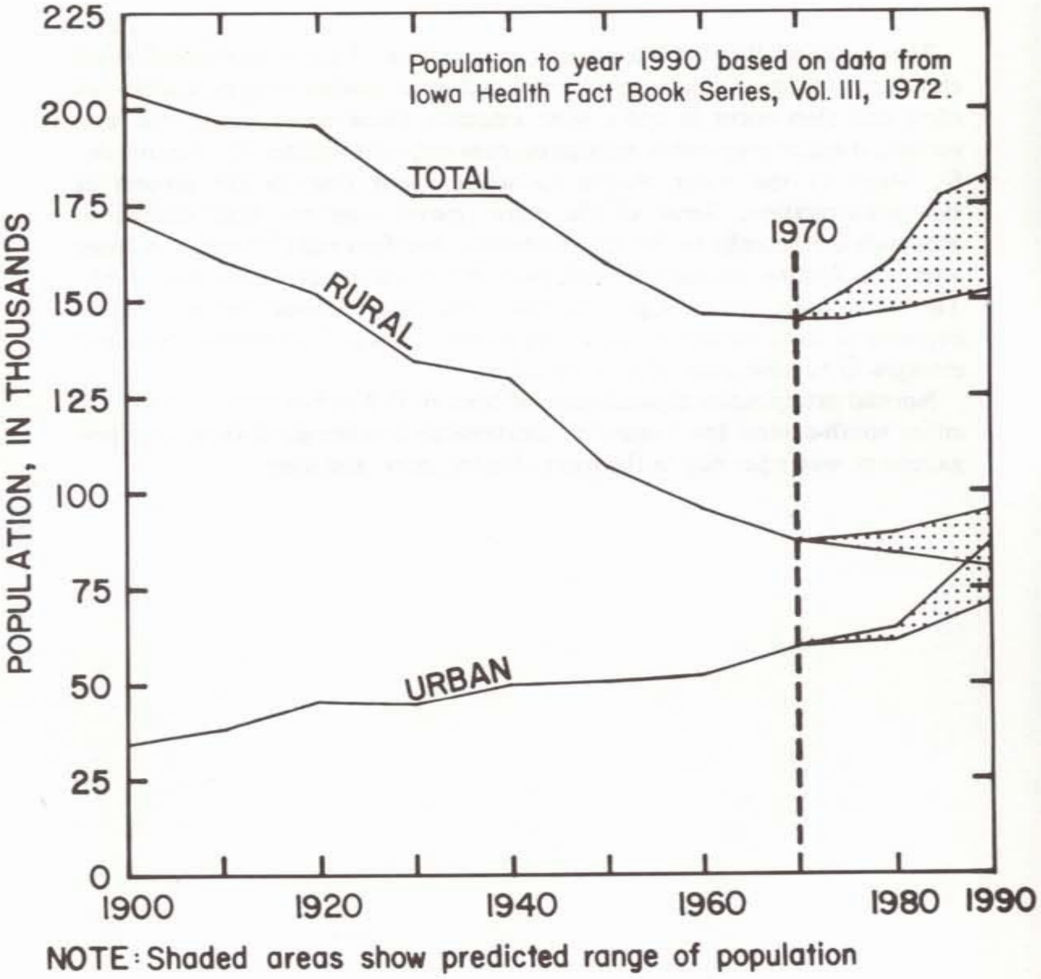


Figure 5.— Population trends in south-central Iowa

THE SOURCE OF OUR WATER

THE HYDROLOGIC CYCLE

The source of all our usable water is precipitation. Water vapor in the form of clouds moves across south-central Iowa and often condenses to rain, although snow and sleet occur in appreciable amounts. Once water reaches the land surface, it either evaporates, transpires, runs off, or infiltrates into the soil (fig. 6). Much of the water returns to water vapor through the process of evapotranspiration. Some of the water moves over the land surface to accumulate eventually in the stream channels and flow out of the area. A lesser amount infiltrates through the soil; part of this water reaches the water table. There the water becomes ground water and moves slowly through various deposits of earth materials and layers of rocks toward the streams, where it emerges to become part of the streamflow.

Normal precipitation in south-central Iowa is 33.7 inches per year. Over the entire south-central Iowa area, this amounts to an average of about 9 billion gallons of water per day in the form of rain, snow, and sleet.

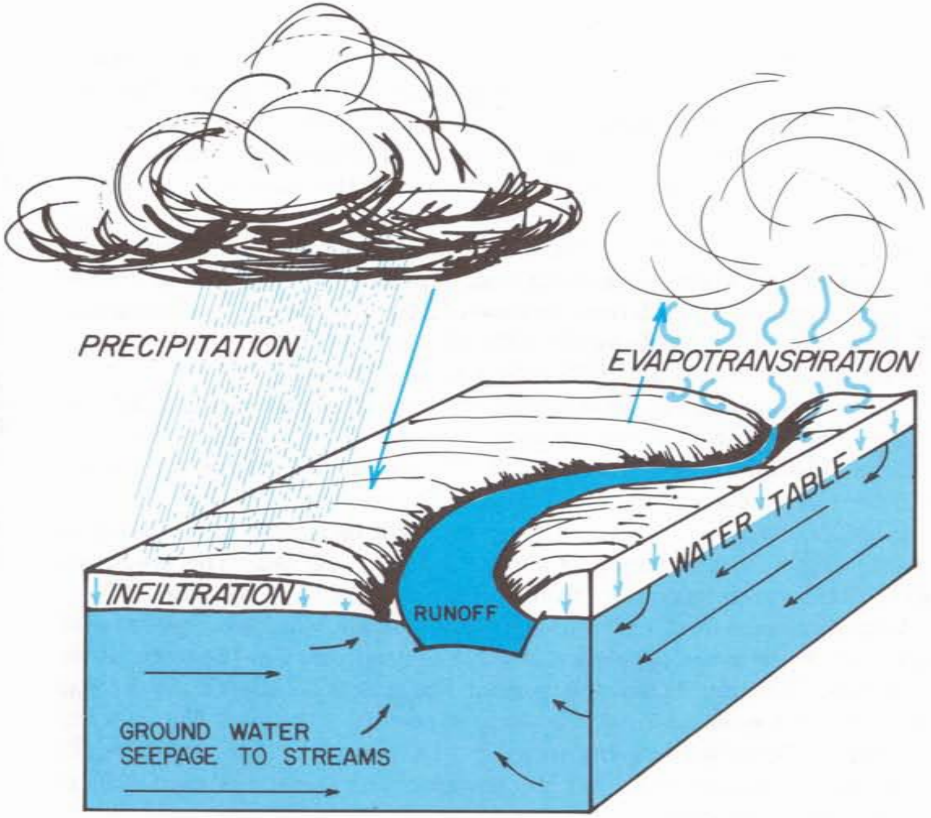


Figure 6.— The hydrologic cycle

A little more than three-fourths of the precipitation, an equivalent of about 26 inches, is returned to the atmosphere by the process of evapotranspiration. Once the water is converted to vapor, it is no longer available for use or manipulation by man. However it is not wasted, as the water transpired by native and cultivated vegetation has been useful to man and is vital to the agricultural economy.

Streamflow from this area amounts to about 8.5 inches or about one-fourth of the annual precipitation. A good portion of this runoff occurs during times of flood or high streamflow shortly after a rain. The rest of the time streamflow is sustained by ground-water discharge.

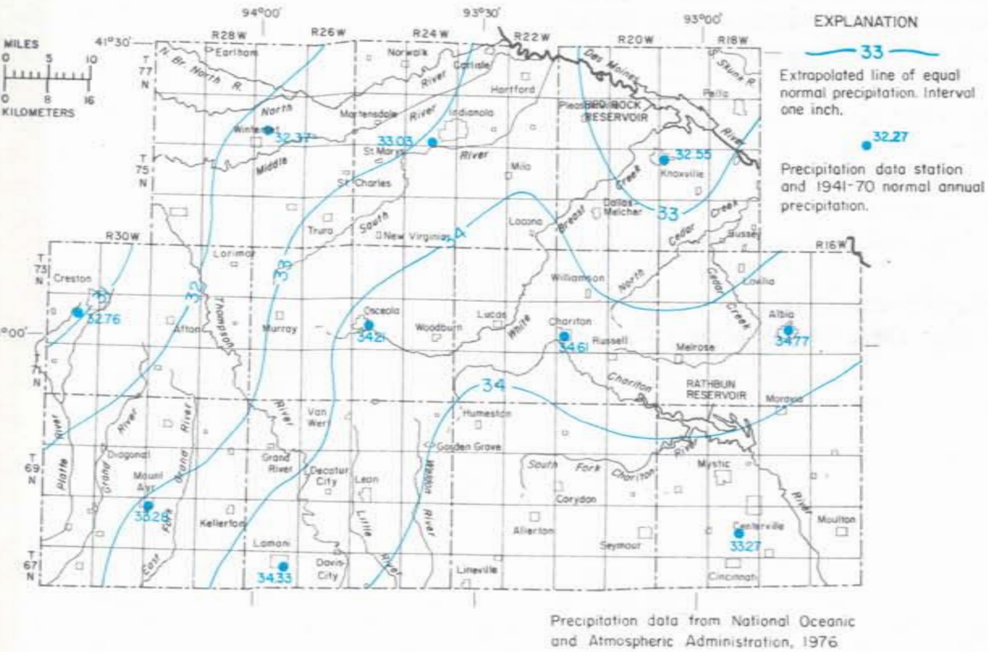
Probably less than 10 percent of the total precipitation infiltrates into the soil. Much of this is returned to the atmosphere by evapotranspiration. A small amount of the infiltrating water reaches the ground-water reservoir where it move through the open spaces in granular materials and through the cracks and small openings in the rocks. The water generally moves slowly, from less than a foot to several hundred feet per year, and at any one time constitutes a considerable amount of the water in storage. Most of the ground water eventually reappears at the surface to contribute to the streamflow. Discharge from the ground-water reservoir is a continuous although not a constant process, and storage in the reservoir is depleted by a decrease in recharge or an increase in discharge.

South-central Iowa is not entirely dependent for its water supply on the precipitation that falls within the area. The volume of water carried into south-central Iowa by the Des Moines and Skunk Rivers and a few smaller streams is several times the runoff contributed by the south-central Iowa area. Also much of the ground water beneath south-central Iowa is derived from recharge outside the area.

The water in the streams and ground-water reservoirs in south-central Iowa is available for management and use by man. These sources of supply are the main subjects of this report.

CLIMATE

The normal annual precipitation for stations operated by the Weather Service in south-central Iowa is 33.7 inches, but at various stations within the area it ranges from about 32 to 35 inches (fig. 7).



Precipitation data from National Oceanic and Atmospheric Administration, 1976

Figure 7.— Normal annual precipitation in south-central Iowa

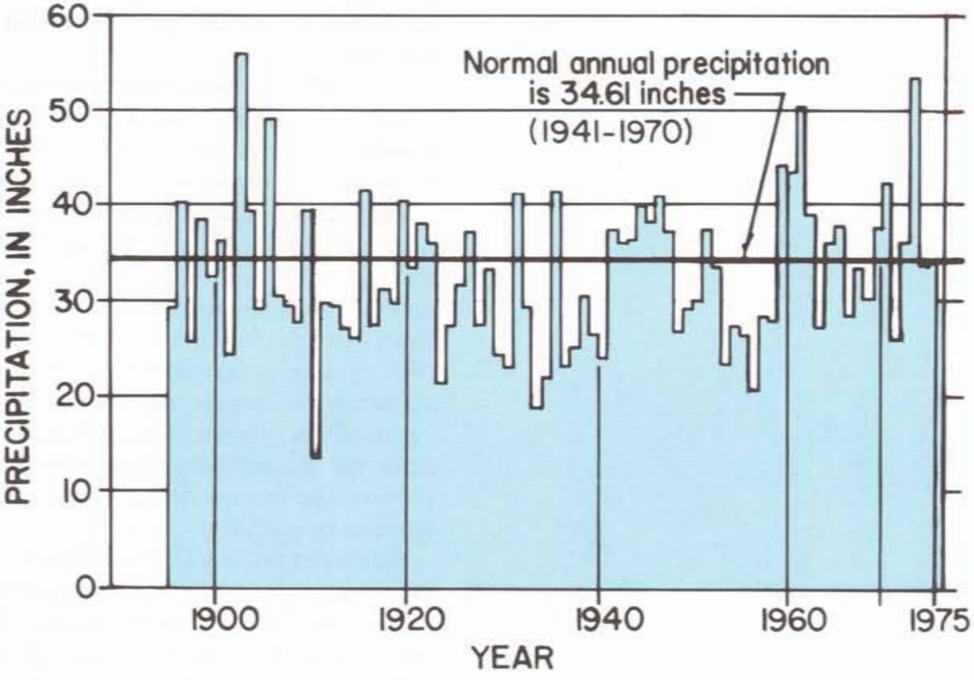


Figure 8.— Annual precipitation at Chariton, Iowa

Although the amount of precipitation varies from year to year, the departure from normal usually is less than 10 inches. The record from the station at Chariton (fig. 8), where the normal precipitation is 34.61 inches, illustrates the departure. The 82-year record shows that a departure of more than 5 inches from the normal occurred during 51 percent of the years, and a departure of more than 10 inches only about 11 percent of the years. The driest year was 1910 with 13.77 inches and the wettest year was 1902 with 55.95 inches. Records of other stations in the area exhibit similar departures.

Precipitation is greatest during the growing season in the spring and summer months when it is most needed for vegetation. Seventy percent of the precipitation normally falls during the 6-month period from April through September. Figure 9 shows that variations during any one month can be extreme from year to year. No precipitation or only a trace, has been recorded for most months at some stations in south-central Iowa during the period of record. April, May, August, and September are the only months when a measurable amount has always fallen at one or more stations in the area. Maximum recorded rainfall during any month has been as much as five times the normal monthly amount and for one September of record the rainfall was more than one-half the normal annual amount.

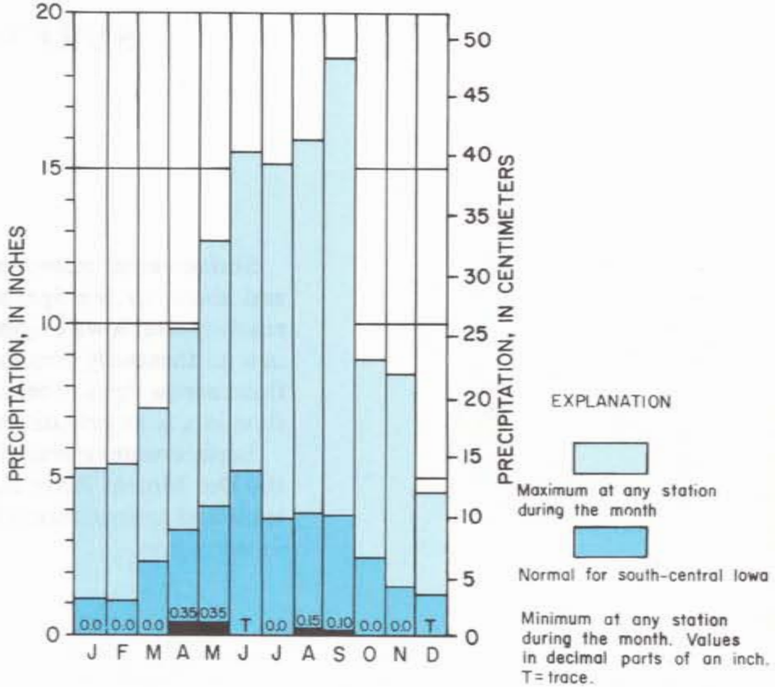


Figure 9.— Monthly extremes and normal precipitation

The normal air temperature in south-central Iowa is 50.5° F. Monthly mean temperatures throughout the area range from about 22° to 75° F. Figure 10 shows that extreme temperatures of more than 100° F have occurred someplace in south-central Iowa during the 5 months from May through September, and that temperatures have dropped below freezing at least once during every month except June, July and August.

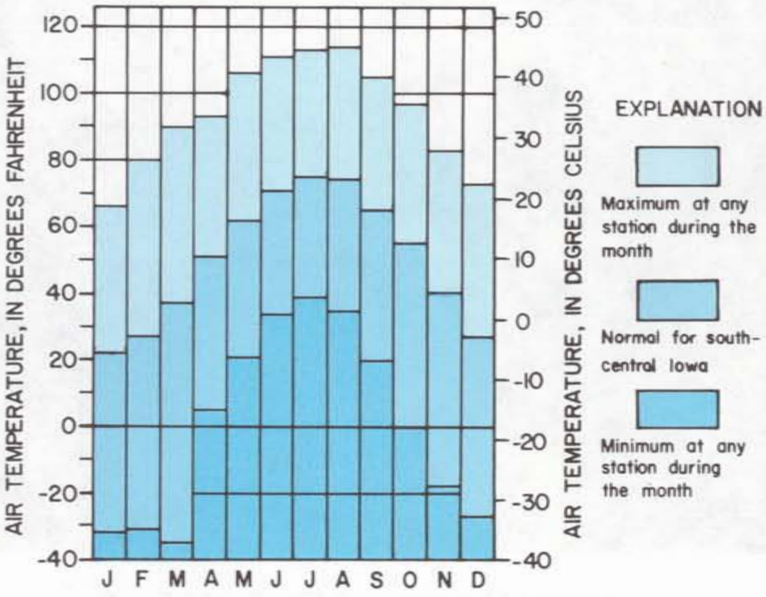


Figure 10.— Monthly extremes and normal air temperature

SURFACE-WATER RESOURCES

Surface-water resources for south-central Iowa include the Des Moines River and about 10 principal streams and their tributaries. Most of the streams in south-central Iowa originate in the region. About one-half of these streams flow in a northeasterly direction and are tributaries of the Des Moines River, which flows across the northeastern corner of the region. The other half of the streams flow in a southerly direction into Missouri.

Surface-water storage is provided by two major reservoirs, Lake Red Rock on the Des Moines River and Rathbun Lake on the Chariton River. Many small lakes and approximately 16,000 farm ponds also contribute to the water stored in the region.

Thompson River near Davis City, Decatur County

Portion of Rathbun Reservior, Appanoose County

The availability of surface-water resources is determined by the analysis of streamflow records obtained from the network of stream-gaging stations operated by the U.S. Geological Survey (U.S. Geol. Survey). In this report, gaging stations refer to gages where daily streamflow records are obtained. The locations of the gaging stations in south-central Iowa are shown in figure 11. Table 1 gives the names and periods of operation for these stations. The data for the gaging stations are analyzed to determine streamflow characteristics, such as average discharge, flood frequencies, low-flow frequencies, flow duration, and storage requirements.

In order to obtain additional low-flow information, discharge measurements have been made periodically at selected sites — termed low-flow partial-record stations — over a period of several years. Low-flow partial-record stations in south-central Iowa are listed in table 2. Discharge measurements made at partial-record stations can be correlated with concurrent discharges at nearby gaging stations which are hydrologically similar. If a satisfactory relationship between a gaged and a partial-record site is defined, streamflow statistics may be estimated for the partial-record site. Estimated streamflow characteristics are less accurate than are those based on the analysis of long-term stream-flow records. From a practical standpoint, however, these estimates add useful information to a regional study.

Information on streamflow can also be obtained by supplemental discharge measurements. Measurements during periods of low flow are sometimes made to define the areal distribution of flow and to obtain insight into ground-water flow in the region. Supplemental measurements made in the Thompson and Weldon River basins are listed in tables 3 and 4, respectively. These measurements are listed in downstream order with measurements at gaging stations and partial-record stations in the basins.

Regulation of streamflow by a reservoir alters the natural flow characteristics of a stream. The Des Moines River below Pella has been regulated by Lake Red Rock since March, 1969, and the Chariton River below Rathbun has been regulated by Rathbun Lake since November 1969.

Table 1.— Gaging stations in south-central Iowa

Station number	Name	Drainage area (mi²)	Average discharge (ft³/s)	Maximum discharge (ft³/s)	Lowest daily mean discharge (ft³/s)	Records used
	Des Moines River Basin					
5-4860	North River nr Norwalk	349	175	32,000	0	1941-75
5-4864.9	Middle River nr Indianola	503	258	34,000	0.66	1941-75
5-4874.7	South River nr Ackworth	460	246	34,000	0	1941-75
5-4879.8	White Breast Creek nr Dallas	342	190	9,430	0.07	1963-75
5-4880	White Breast Creek nr Knoxville	380	198	14,000	0.2	1946-62
5-4885	Des Moines River nr Tracy	12,479	4,660	155,000	40	1921-75
5-4890	Cedar Creek nr Bussey	374	196	29,300	0	1948-75
	Platte River Basin					
6-8187.5	Platte River nr Diagonal	217	130	6,420	0.21	1969-75
	Grand River Basin					
6-8979.5	Elk Creek nr Decatur City	52.5	32.4	8,130	0	1968-75
6-8980	Thompson River at Davis City	701	369	24,300	0.1	1919-24 1942-75
6-8984	Weldon River nr Leon	104	73.0	48,600	0	1959-75
	Chariton River Basin					
6-9034	Chariton River nr Chariton	182	103	6,320	0.1	1966-75
6-9035	Honey Creek nr Russell	13.2	7.74	4,100	0	1953-62
6-9037	S. F. Chariton River nr Promise City	168	102	7,660	0.09	1968-75
6-9039	Chariton River nr Rathbun	549	309	21,800	0.1	1957-75
6-9040	Chariton River nr Centerville	708	336	21,700	0.1	1939-59

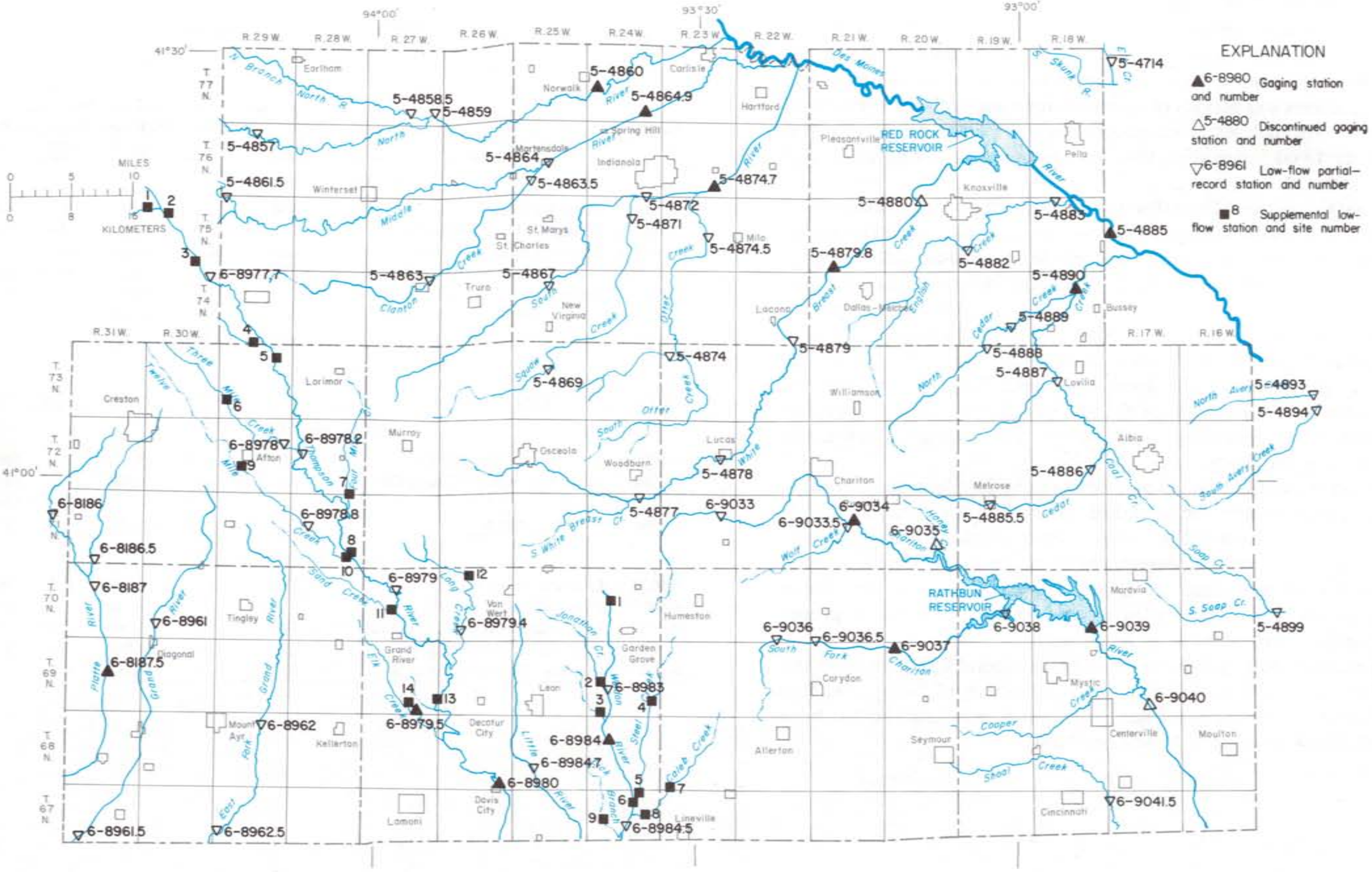


Figure 11.— Gaging stations, low-flow partial-record stations, and supplemental low-flow stations in south-central Iowa

Table 2.— Low-flow partial-record stations in south-central Iowa

Station number	Stream and location	Drainage area (mi²)	Computed average discharge (ft³/s)	Computed low-flow		Lowest measured discharge	
				7-day Q_2 (ft³/s)	90 percent duration (ft³/s)	ft³/s	year
		Skunk River basin					
5-4714	Elk Creek nr Taintor	59.9	36	0.4	0.3	0.46	1966
		Des Moines River basin					
5-4857	North River nr Earlham	68.9	41	<0.1	<0.1	0	1957, 63
5-4858.5	N.B. North River nr Winterset	74.7	44	<0.1	<0.1	0	1957, 63
5-4859	North River nr Winterset	203	114	0.1	0.1	0	1957, 63
5-4861.5	Middle River at Middle River	164	93	2.0	2.0	1.67	1963
5-4863	Clanton Creek at East Peru	84.5	50	<0.1	<0.1	0	1963
5-4863.5	Clanton Cr nr Martensdale	159	90	0.4	0.3	0.24	1957
5-4864	Middle River at Martensdale	451	241	4.8	4.5	2.50	1957
5-4867	South River nr New Virginia	65.4	39	0	0	0	1957, 58, 63
5-4869	Squaw Creek nr Jamison	60.8	37	0	0	0	1957, 58, 63
5-4871	Squaw Creek nr Indianola	134	77	0.5	0.4	0.13	1957
5-4872	South River nr Indianola	278	153	1.5	1.2	0.32	1957
5-4874	Otter Creek nr Norwood	102	60	<0.1	<0.1	0	1957, 58, 63
5-4874.5	Otter Creek nr Milo	155	88	0.3	0.2	0	1958
5-4877	White Breast Cr nr Woodburn	82.9	49	<0.1	<0.1	0	1958
5-4878	White Breast Creek at Lucas	128	74	0.1	0.1	0	1963
5-4879	White Breast Cr nr Newbern	243	135	0.4	0.3	0	1958
5-4882	English Cr nr Knoxville	73.0	43	<0.1	<0.1	0	1958, 61, 63
5-4883	English Creek nr Harvey	108	63	<0.1	<0.1	0	1963
5-4885.5	Cedar Creek at Melrose	23.9	15	<0.1	<0.1	0	1960
5-4886	Cedar Creek nr Albia	102	60	0.1	0.1	0	1964
5-4887	Cedar Creek nr Lovilia	211	118	0.6	0.5	0.26	1957, 63
5-4888	N Cedar Creek nr Lovilia	61.3	37	<0.1	<0.1	0	1963
5-4889	N Cedar Cr nr Marysville	111	64	0.1	0.1	0.01	1966
5-4893	N Avery Cr nr Chillicothe	60.1	36	<0.1	<0.1	0	1966
5-4894	S Avery Cr at Chillicothe	51.6	31	0	0	0	1958, 66, 68
5-4899	Soap Creek nr Ash Grove	97.3	57	0.1	0.1	0	1957
		Platte River basin					
6-8186	Platte River nr Kent	77.9	46	0.6	0.5	0.60	1957
6-8186.5	E Platte R nr Knowlton	66.8	40	<0.1	<0.1	0	1957
6-8187	Platte River nr Knowlton	179	101	0.9	0.8	1.59	1963
		Grand River basin					
6-8961	Grand River at Knowlton	67.5	40	0.2	0.1	0	1957
6-8961.5	Grand River at Blockton	207	116	2.0	1.4	0.87	1957
6-8962	E.F. Grand R at Mt. Ayr	64.7	39	0.1	0.1	0	1957
6-8962.5	E.F. Grand R South of Mt. Ayr	95.9	56	0.2	0.1	0	1957
6-8977.7	Thompson River nr Hebron	80.0	47	0.4	0.3	0.11	1957
6-8978	Threemile Creek at Afton	54.8	33	0.1	0.1	0	1957
6-8978.2	Thompson River nr Afton	231	128	1.5	1.0	0	1957
6-8978.8	Twelvemile Creek nr Arispe	68.0	41	0.2	0.1	0	1957
6-8979	Thompson River nr Grand River	401	215	3.1	2.1	0.83	1957
6-8979.4	Long Creek nr Van Wert	117	68	0.2	0.1	0	1957
6-8983	Weldon River East of Leon	72.4	43	0.2	0.1	0.06	1957
6-8984.5	Weldon River nr Pleasanton	228	127	1.0	0.6	0	1957
6-8984.7	Little River nr Leon	69.2	41	0.1	0.1	0.15	1963
		Chariton River basin					
6-9033	Chariton River nr Derby	71.0	42	<0.1	<0.1	0	1963
6-9033.5	Wolf Creek nr Chariton	65.0	39	<0.1	<0.1	0	1960, 61, 63
6-9036	S.F. Chariton R nr Cambria	58.0	35	<0.1	<0.1	0	1963
6-9036.5	S.F. Chariton R nr Corydon	68.1	41	<0.1	<0.1	0	1957
6-9038	S.F. Chariton R at Griffinsville	234	130	0.4	0.4	0.06	1957
6-9041.5	Shoal Creek nr Cincinnati	56.6	34	<0.1	<0.1	0	1966

Table 3.— Low-flow discharge measurements at supplemental sites (Nos. 1-14), gaging stations, and partial-record stations in the Thompson River basin

Location number (fig. 1)	Stream and location	Drainage area (mi²)	Discharge measurements, in ft³/s, for date indicated by column headings		
			Oct. 16, 1968	July 27, 1970	Sept. 20, 21, 1971
1	Marvel Creek nr Greenfield	11.0		0.21	0.36
2	Thompson River nr Stanzel	33.2	0.60	0.33	0.12
3	Ninemile Creek at Hebron	37.5	0.05	0.08	0.04
6-8977.7	Thompson River nr Hebron	80.0	0.57	0.17	0.31
4	West Branch Creek nr Macksburg	28.8	0	0.01	0
5	Thompson River nr Lorimer	130	0.38	0.52	0.40
6	Threemile Creek nr Afton	32.6	0.26	0.11	0.12
6-8978	Threemile Creek at Afton	54.8	0.08	0.13	0
6-8978.2	Thompson River nr Afton	231	1.32	1.36	0.88
7	Fourmile Creek nr Thayer	32.8	0.10	0.05	0.02
8	Thompson River nr Hopeville	313	2.25	3.72	1.60
9	Twelvemile Creek at Afton	40.1	0.33	0.15	0.04
6-8978.8	Twelvemile Creek nr Arispe	68.0	0.35	0.21	0
10	Twelvemile Creek nr Hopeville	77.2		0.36	0.06
6-8979	Thompson River nr Grand River	401	4.95	4.87	2.41
11	Sand Creek at Westerville	32.3	0.02	0.08	0
12	Long Creek nr Van Wert	58.4	0.02	0.01	0
6-8979.4	Long Creek nr Van Wert	117	0.27	0.21	0.05
13	Thompson River nr Decatur City	597	7.14	7.51	5.36
14	Elk Creek nr Decatur City	23.7	0.02	0	0
6-8979.5	Elk Creek nr Decatur City	52.5	0.04	0	0
6-8980	Thompson River at Davis City	701	6.26	13	7.25

Table 4.— Low-flow discharge measurements at supplemental sites (Nos. 1-9), gaging stations, and partial-record stations in the Weldon River basin

Location number (fig. 1)	Stream and location	Drainage area (mi²)	Discharge measurements, in ft³/s, for date indicated by column headings		
			Dec. 12, 1967	July 28, 1970	Sept. 20, 21, 1971
1	Weldon River nr LeRoy	20.8	0.47	0.003	0
2	Jonathon Creek nr Leon	24.5	0.43	0.006	0.02
6-8983	Weldon River nr Leon	72.4	1.47	0.05	0.22
3	Brush Creek nr Leon	16	0.08	0	0
6-8984	Weldon River nr Leon	104	2.22	0.03	0.12
4	Steel Creek nr Garden Grove	36.4	1.68	0.006	0.04
5	Steel Creek nr Lineville	56.9	4.00	0.13	0.11
6	Weldon River nr Lineville	174	6.44	0.79	0.36
7	Caleb Creek nr Clio	37.0	3.89	0.08	0.06
8	Caleb Creek nr Lineville	49.0	4.54	0.11	0.15
6-8984.5	Weldon River nr Pleasanton	228	12.5	0.67	1.30
9	Lick Branch nr Pleasanton	11.0	0.16	0	0

STREAMFLOW - HIGHLY VARIABLE

With the exception of the Des Moines River, all the streams in south-central Iowa are fairly small. Most of them originate in the area and flow either into the Des Moines River or south into Missouri. The basins of two of the streams are slightly over 700 square miles (1,810 square kilometers) in area while the remainder are about 500 square miles (1,300 square kilometers) or less in size.

The flow of the streams in the area is highly variable with very low dry-weather flows and high flood flows. This is further discussed in the sections on flow duration and low-flow frequency.

Large variations in flow are also experienced during the different seasons of the year. The amount of runoff in relation to precipitation is usually greatest in late winter or early spring when the ground is often either saturated or frozen. Runoff usually decreases considerably in summer as evapotranspiration losses become significant. Figure 12 illustrates the relationship between the average monthly runoff of the Thompson River at Davis City for the period 1941-70, and the normal monthly precipitation at Creston. Normal monthly precipitation at other locations in the area is very similar to that shown for Creston. Normal precipitation is for the period 1941-70.

Figure 13 illustrates the variation in streamflow for the South River caused by extreme variations in the weather. The 1947 average streamflow was the second highest recorded for the period 1941-75. Total precipitation for that year at Indianola was more than 9 inches (229mm) above normal. Average streamflow for 1956 was the lowest on record, about 8 percent of the long-term mean. Precipitation for the year was about 13 inches (330mm) below normal. The flow on 227 days was less than 2 cubic feet per second (ft³/s), or 0.057 cubic meters per second (m³/s) during the year ending March 31, 1956.

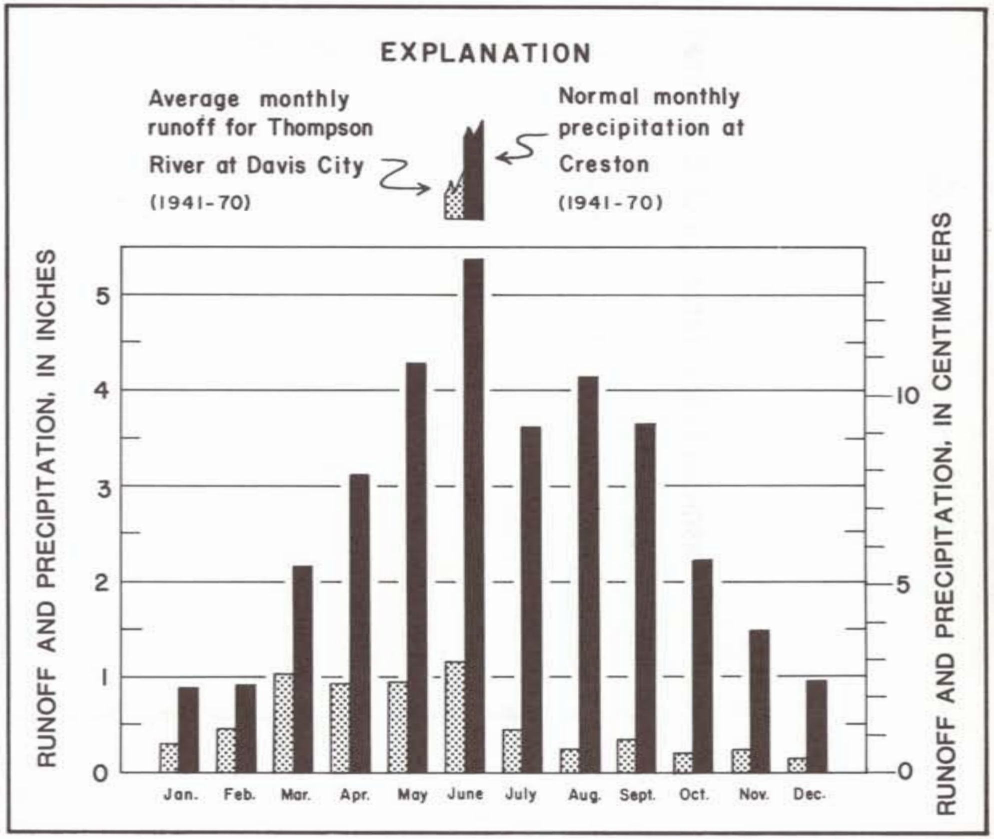
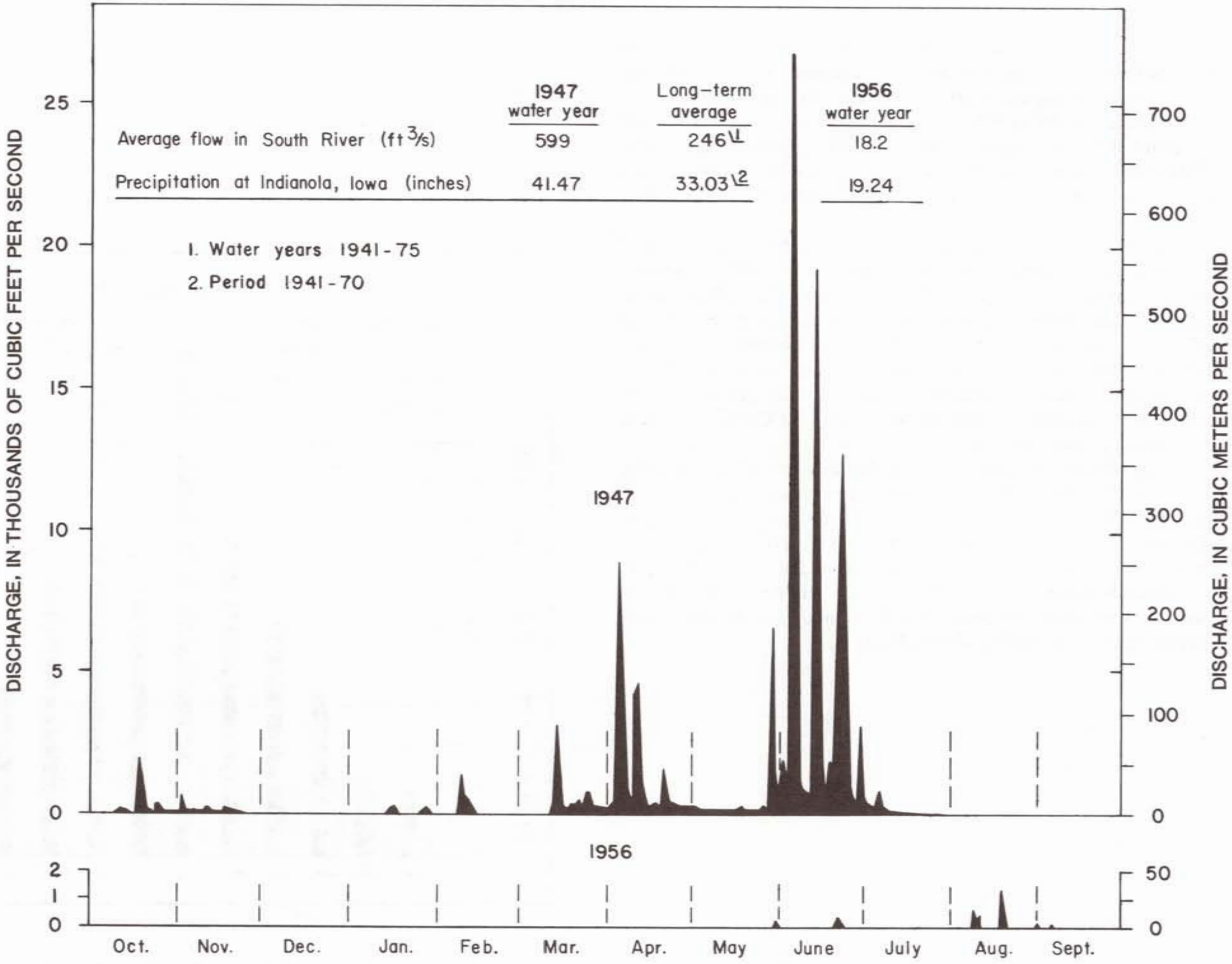


Figure 12.— Average monthly runoff of the Thompson River at Davis City, Iowa, and normal monthly precipitation at Creston, Iowa



	1947 water year	Long-term average	1956 water year
Average flow in South River (ft^3/s)	599	246[1]	18.2
Precipitation at Indianola, Iowa (inches)	41.47	33.03[2]	19.24

1. Water years 1941-75
2. Period 1941-70

Figure 13.— Daily streamflow in South River near Ackworth, Iowa in 1947 and 1956

AVERAGE DISCHARGE

The average discharge at a location on a stream defines the total water available from a stream at that point. The annual mean discharge varies greatly from year to year, but the average discharge derived from a long period of streamflow record is a stable value that is useful in many hydrologic studies. When so derived, it furnishes the theoretical upper limit of usable flow.

Average discharges for the period of operation for the gaging stations are listed in table 1. Those listed for the low-flow partial-record stations in table 2 were computed using a regional equation for the south-central Iowa area. A plot of average discharge in relation to drainage area size for south-central Iowa gaging stations is shown in figure 14.

The regional equation for computing average discharge in south-central Iowa is $Qa = 0.77A^{.94}$, where Qa is the average discharge, in cubic feet per second, and A is the drainage area, in square miles. This equation can be used to compute average discharge on unregulated streams at points where gaging-station records are not available. The graph of the equation is shown in figure 14. Standard error of the equation is about 8 percent. This means that the chances are 2 out of 3 that the true average discharge is within about 8 percent of the average defined from the regional equation.

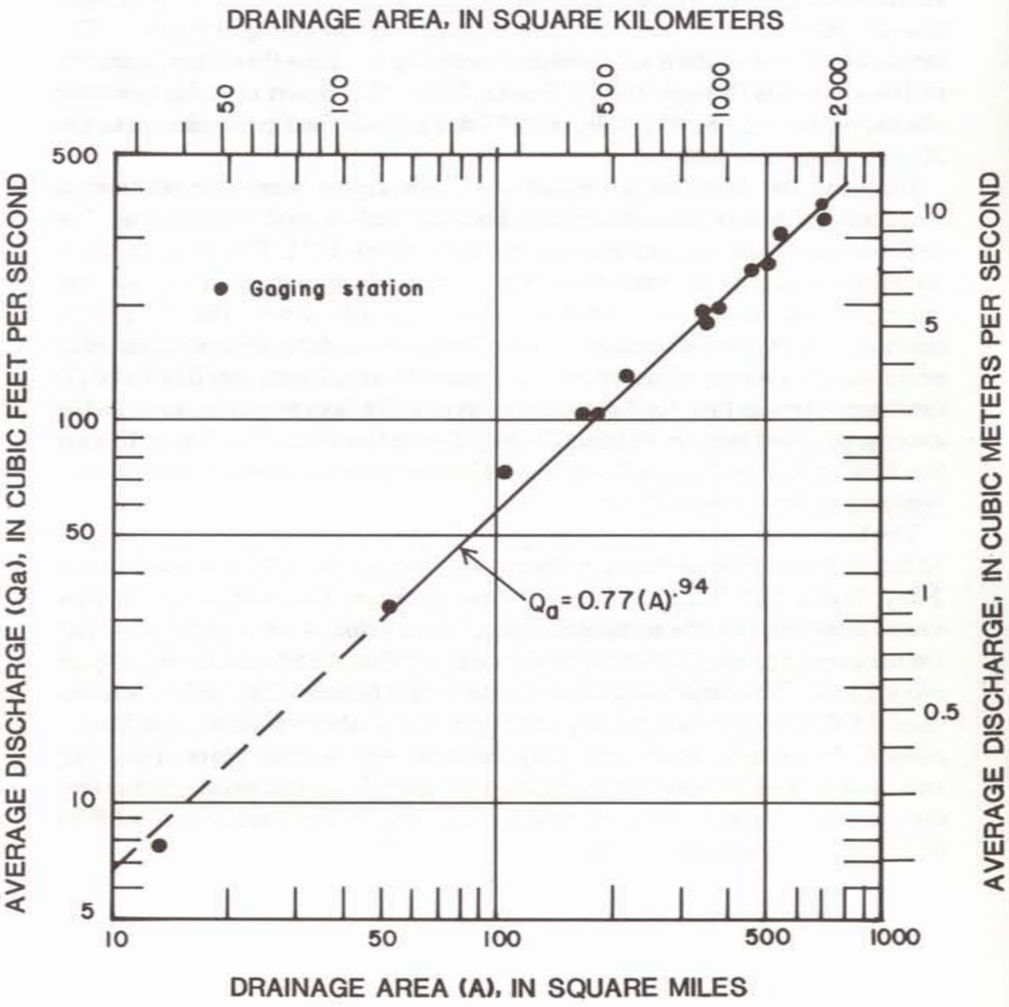


Figure 14.— Average discharge in relation to drainage area for selected south-central Iowa streams

LOW-FLOW FREQUENCY

Surface water may be the only usable source of water for domestic and industrial supplies in areas with insufficient or poor-quality ground-water sources. Analyses of recorded streamflow data for periods of low flow are used to assess the amount of water available from streamflow during dry periods. The results of such an analysis are published in the report "Low-flow Characteristics of Iowa Streams through 1966" (Heinitz, 1970). This report contains low-flow discharges for 7-, 30-, 60-, 120-, and 183-day periods for frequencies up to the 20-year recurrence interval.

Data for the low-flow presentation in this report were derived from a frequency analysis of annual minimum flows of south-central Iowa streams. The analysis was based on data updated through March 1975. The lowest average discharge for seven consecutive days was extracted from each year of streamflow record. Two low-flow statistics were derived from the frequency analysis: (1) the lowest average flow for 7 consecutive days which is expected to occur on the average of about once in 2 years (7-day, 2-year low flow) and (2) the lowest average flow for 7 consecutive days which is expected to occur on the average of about once in 10 years (7-day, 10-year low flow). The 7-day, 10-year low flow is the flow that the Iowa Department of Environmental quality uses in applying water-quality criteria.

The lowest annual average discharge for 7 consecutive days is shown in figure 15 for each year of record for the Thompson River at Davis City to illustrate the 7-day, 2-year and 7-day, 10-year low-flow statistics. One-half of the 38 flow events were less than the computed 7-day, 2-year value of 9.6 ft^3/s (0.272 m^3/s). On the average, then, the 7-day low flow was less than 9.6 ft^3/s (0.272 m^3/s) once every 2 years. This value should not be interpreted to mean that the flow was less than 9.6 ft^3/s (0.272 m^3/s) every other year since above-normal, and below-normal, hydrologic conditions may continue for several years. However, assuming that past record is an indication of future flows, one would predict that there is a fifty percent chance that the annual 7-day flow will be less than 9.6 ft^3/s (0.272 m^3/s) in any future year.

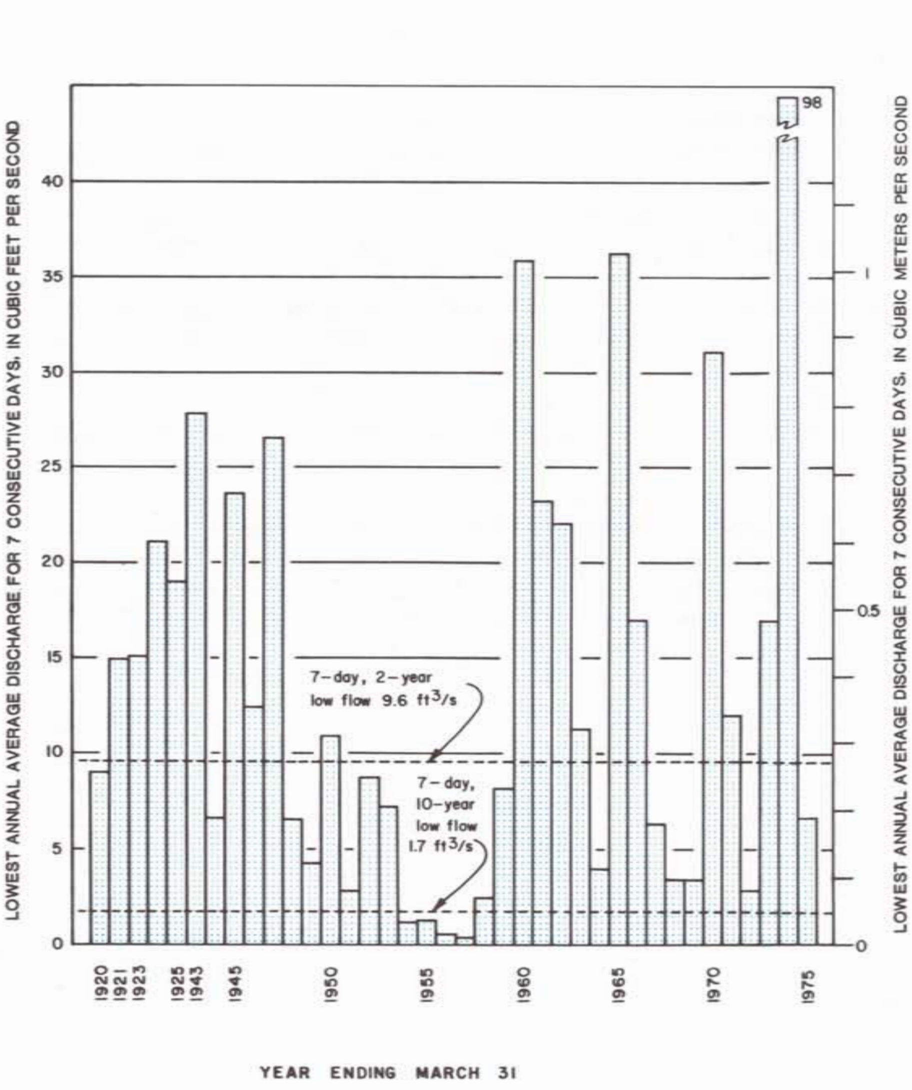


Figure 15.— Annual 7-day minimum flows for Thompson River at Davis City

Four of the 38 low-flow events were less than the 7-day, 10-year computed low flow of 1.7 ft³/s (0.048 m³/s). The record shows that the annual minimum 7-day low flow was less than 1.7 ft³/s (0.048 m³/s) on the average of once every 9.5 years, close to the computed recurrence of once every 10 years. The occurrence of the deficient flows in four consecutive years, 1954-57 inclusive, is a striking illustration that these flows do not occur in regular periodicity as pointed out in the preceding paragraph. Over a long period of time, and assuming that future flows will reflect the historical record, one could expect the annual minimum 7-day low flow to be less than 1.7 ft³/s (0.048 m³/s) on the average of once every 10 years.

The 7-day, 2-year and 7-day, 10-year low-flow discharges for the gaging stations in the report area are listed in table 5. The 7-day, 2-year discharges for the low-flow partial-record stations are listed in table 2. Areal distribution of the 7-day, 2-year discharges for all the stations is shown in figure 16. Streams with drainage areas less than about 50 square miles (130 square kilometers) can be expected to have 7-day, 2-year low flows of less than 0.1 ft³/s (2.83 dm³/s). The band shown in figure 17 shows the range in which the 7-day, 2-year discharges will generally occur. The band was defined by including within its limits about 68 percent of the data points. The Chariton River is at least one stream where the discharges are considerably lower than those indicated by the band. For sites on a stream where the 7-day, 2-year discharge is not known, an estimate can be made from figure 17 if the drainage area of the site is known. Estimated discharges from within the band might be used for preliminary design purposes.

The 7-day, 10-year discharges for the low-flow partial-record stations cannot be determined because of the poor correlations with gaging stations at the very low discharges encountered. However, 7-day, 10-year low-flows probably would be less than 0.1 ft³/s (2.83 dm³/s) at sites with drainage areas less than 100 square miles (259 square kilometers) and zero for most sites with drainage areas less than 50 square miles (130 square kilometers).

Table 5.— 7-day, low-flow discharges for selected frequencies, and discharges for selected duration percentages at south-central Iowa gaging stations for period of record

Station number	Stream and location	Discharge, in cubic feet per second						
		Average 7-day low-flow for recurrence interval shown		Discharge equaled or exceeded for percent of time shown				
		2 years	10 years	5	50	70	90	95
		Des Moines River basin						
5-4860	North River near Norwalk	2.1	0.2	750	37	13	1.4	0.55
5-4864.9	Middle River near Indianola	7.6	1.5	1,070	63	26	7.0	4.2
5-4874.7	South River near Ackworth	3.2	1.0	1,070	32	9.1	2.6	1.6
5-4879.8	White Breast Creek near Dallas	1.3	0.2	880	31	9.3	1.8	1.1
5-4880	White Breast Creek near Knoxville	1.6	0.5	950	21	4.8	1.5	1.1
5-4885	Des Moines River near Tracy**	366	133	18,000	2,100	980	400	270
5-4890	Cedar Creek near Bussey	2.0	0.3	860	30	8.5	1.9	0.8
		Platte River basin						
6-8187.5	Platte River near Diagonal	1.8*	—	450	26	11	3.5	2.6
		Grand River basin						
6-8979.5	Elk Creek near Decatur	<0.1*	—	100	4.0	.8	<.1	—
6-8980	Thompson River at Davis City	9.6	1.7	1,600	72	30	8.9	4.6
6-8984	Weldon River near Leon	0.1	—	270	7.8	2.3	.52	.27
		Chariton River basin						
6-9034	Chariton River near Chariton	0.3*	—	550	11	3.4	.76	.46
6-9035	Honey Creek near Russell	0	0	28	0.36	—	—	—
6-9037	South Fork Chariton River near Promise City	0.3*	—	390	13	5.3	1.0	.64
6-9039	Chariton River near Rathbun**	1.8	0.3	1,450	38	12	3.8	1.7
6-9040	Chariton River near Centerville**	1.7	0.3	1,850	39	9.5	1.8	1.1

*Computed by correlation with nearby stream-gaging stations.

**Flow statistics are for natural flow conditions prior to regulation by reservoirs.

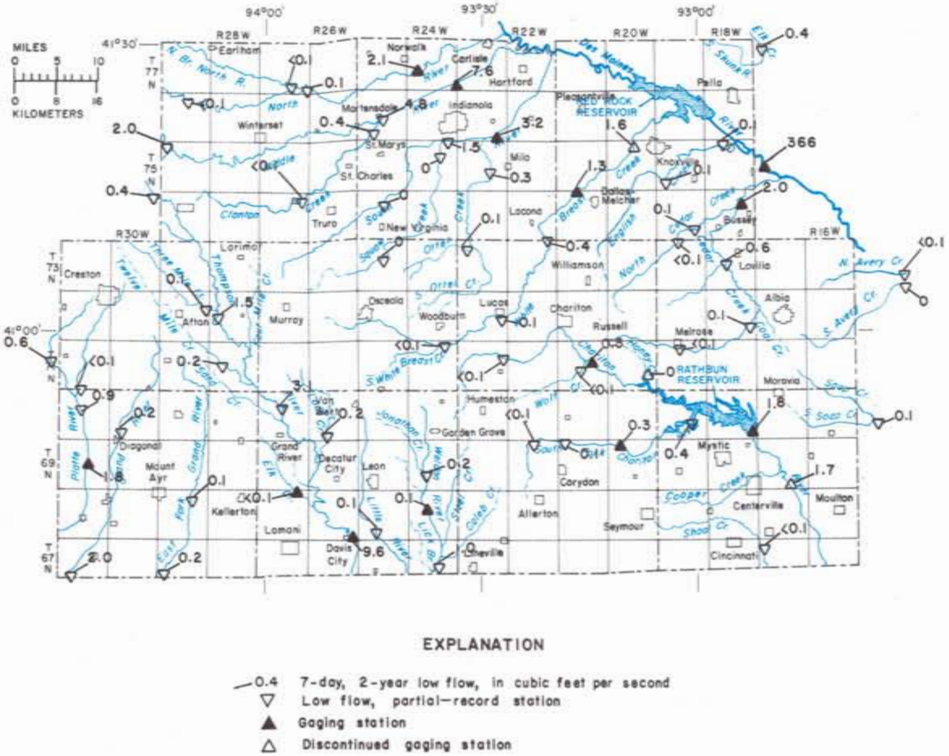


Figure 16.— 7-day, 2-year low flow at all gaging stations in south-central Iowa

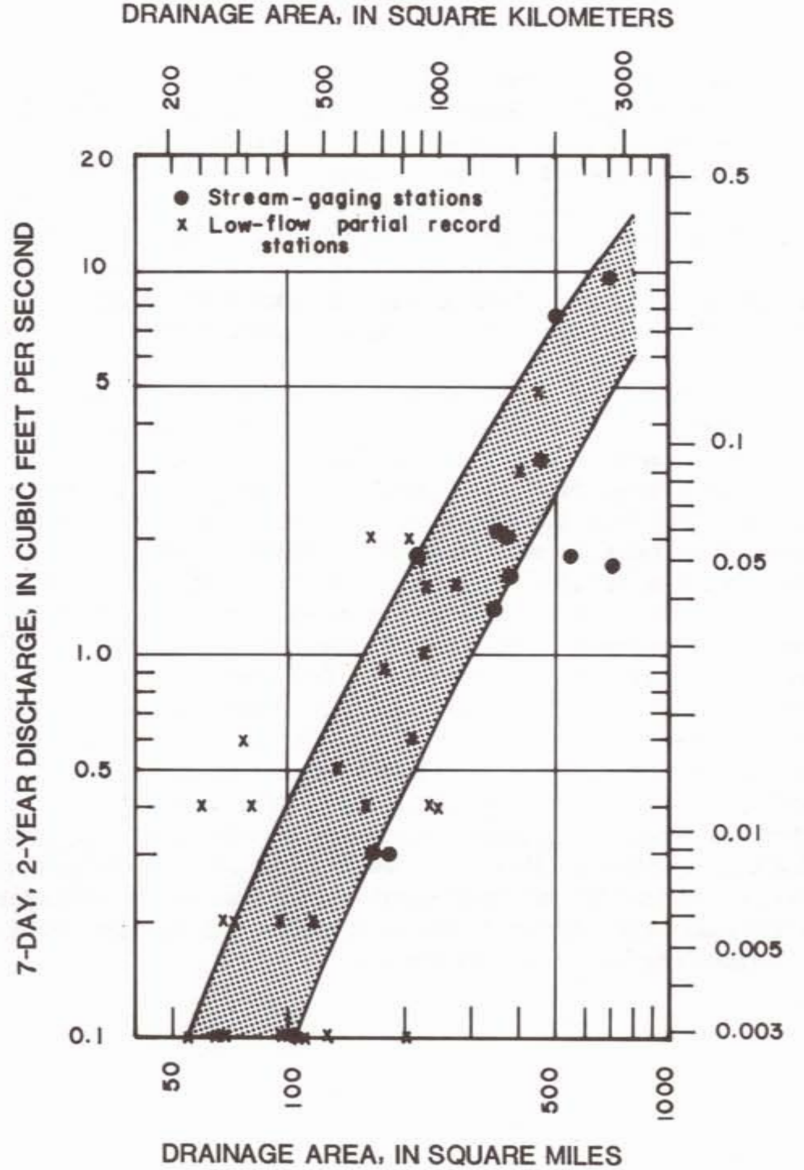


Figure 17.— Variability of 7-day, 2-year low-flow discharges in relation to drainage area for south-central Iowa streams

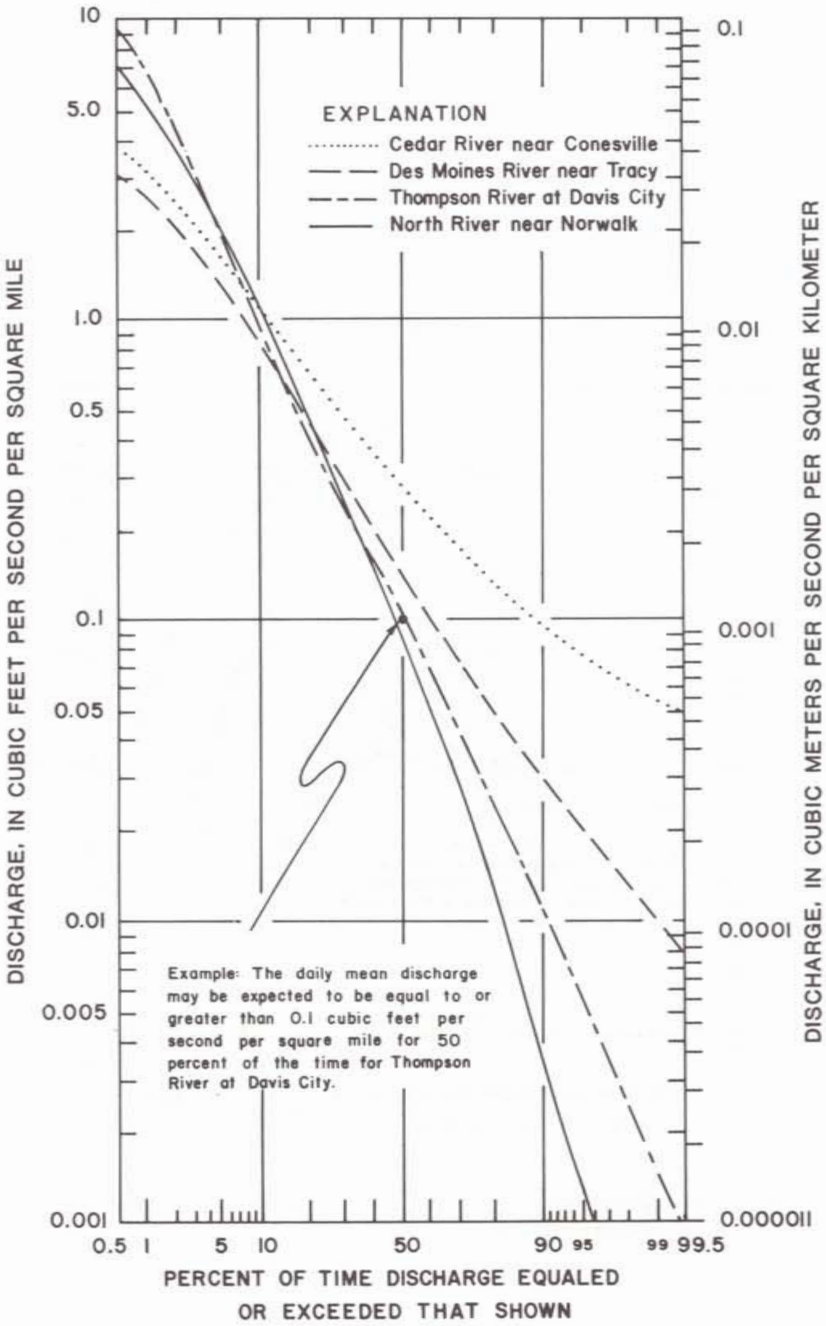


Figure 18.— Flow-duration curves for selected gaging stations

FLOW DURATION

Flow-duration curves show, for a particular period of time, the percentage of time that given flows were equaled or exceeded. These data are valuable for water-resources planners and water users who need to know how much water is available from streams and how often a given amount of water is available for use.

The slope of a duration curve indicates the variability of discharge of the stream, and the natural storage within the basin. A curve with a steep slope throughout denotes a highly variable stream whose flow is largely from surface runoff whereas a curve with a flat slope indicates a well sustained flow from surface or underground storage.

The duration curves shown in figure 18 for the Thompson and North Rivers are representative of duration curves for all the gaging stations in south-central Iowa except for that on the Des Moines River. The steep slope indicates highly variable flow. The near-vertical attitude at the lower end is typical of streams which have very low sustained flow and often go to zero flow during late summer and winter dry periods.

Shown for comparative purposes is the duration curve for the Cedar River near Conesville. The Conesville gaging station is located in southeastern Iowa about 75 miles east of this study area. The moderate slope indicates relatively low variability of daily flows. A flattening trend towards the lower end of the curve together with high discharges at the 90 percent duration indicates that the Cedar River has a fairly high flow during dry periods.

The duration curve for the Des Moines River, which derives most of its flow from central and north-central Iowa, shows characteristics intermediate between those of south-central Iowa and those for regions of relatively low variability like the Cedar River basin.

Data from flow-duration curves have been tabulated in table 5 to show flow characteristics for the period of record for each gaging station. Estimates of the 90-percent duration flow for partial-record stations are listed in table 2. The flow that occurs at the 90-percent duration level is generally about the same as the 7-day, 2-year low flow. This discharge is sometimes referred to as the "normal" low flow.

The duration data disclose that south-central Iowa streams, except the Des Moines River, have highly variable flow with insufficient ground-water inflow during dry periods to maintain significant flows.

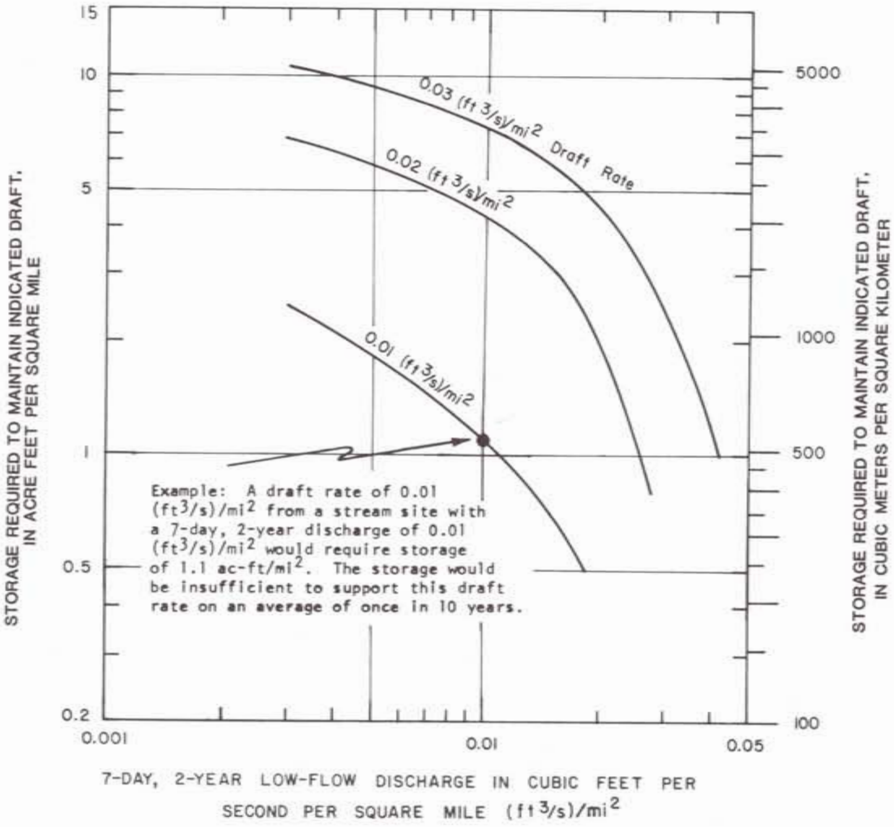
STORAGE REQUIRED

Surface-water storage may be the most economical means of providing adequate and potable water supplies for some areas of south-central Iowa. Water stored during high flows can be used to supplement water requirements when streamflow is inadequate during dry periods. The net storage required to meet specific draft rates can be estimated from analysis of low-flow records (Heinitz, 1970).

Regionalizing data is a means by which draft-storage requirements can be estimated for stream sites other than those where gaging stations are located. The regional curves shown in figure 19 were developed from draft-storage data computed for the gaging stations. These curves were developed by plotting the annual average minimum flows for 7 consecutive days having a recurrence interval of 2 years (7-day, 2-year) versus storage requirements for selected draft rates. The regional draft-storage analysis was made only for the 10-year recurrence interval. To remove the effect of drainage-area size, all parameters were converted to per-square-mile basis.

To estimate required storage for an ungaged site, a 7-day, 2-year low flow can be determined for most locations by making a few low-flow discharge measurements, preferably over a period of several years. These discharge measurements are correlated with concurrent discharges for a nearby gaging station for which a 7-day, 2-year low flow can be determined. The 7-day, 2-year value for the gaging station is transferred through the line of relation to obtain the 7-day, 2-year discharge for the ungaged site. An estimate of required storage can then be made by dividing the 7-day, 2-year discharge by the drainage area at the site and entering the appropriate regional draft-storage curve. For preliminary planning purposes, a 7-day, 2-year discharge can be estimated from figure 17.

The regional draft-storage relations should be useful for preliminary studies of storage requirements. For within-year storage analysis, maximum draft rates must not exceed the minimum annual discharge. Final design of a storage project would also consider the particular stream discharges, the characteristics of the storage site, the pattern of draft, the economic consequences of a temporary deficiency in draft, the amount of evaporation and seepage losses from the reservoir, the probable reduction in reservoir capacity because of sedimentation, and possible constraints upon use of storage because of flood-control or recreation requirements.



Example: A draft rate of 0.01 $(ft^3/s)/mi^2$ from a stream site with a 7-day, 2-year discharge of 0.01 $(ft^3/s)/mi^2$ would require storage of 1.1 $ac\text{-}ft/mi^2$. The storage would be insufficient to support this draft rate on an average of once in 10 years.

Figure 19.— Regional draft-storage curves for south-central Iowa; 10-year recurrence interval

STORAGE RESERVOIRS AND PONDS

Lake Red Rock and Rathbun Lake on the Des Moines and Chariton Rivers, respectively, are regulated by the Corps of Engineers, U.S. Army, for purposes of flood control, low-flow augmentations, conservation, and recreation. These reservoirs could provide water for domestic and industrial uses. A brief description of the two reservoirs follows:

Lake Red Rock: Red Rock Dam was completed in 1969 and storage began in March of that year. Conservation pool elevation is 725 feet (221.0 meters) above mean sea level with storage contents of 90,000 acre-feet (111 hm^3). Flood storage at the uncontrolled spillway elevation, 780 feet (237.7 meters), is 1,830,000 acre-feet (2256 hm^3). Normal operation will maintain an elevation of 725 feet (221 meters), minimum release of 300 ft^3/s (8.5 m^3/s), and maximum release of 30,000 ft^3/s (850 m^3/s) during the non-growing season, providing discharges at Ottumwa and Keosauqua do not exceed 30,000 and 35,000 ft^3/s (850 and 991 m^3/s), respectively.

Rathbun Lake: Rathbun Dam was completed in 1969 and storage began in November of that year. Conservation pool elevation is 904 feet (275.5 meters) above mean sea level with storage contents of 205,000 acre-feet (253 hm^3). Flood storage at the uncontrolled spillway elevation, 926 feet (282.2 meters), is 552,000 acre-feet (681 hm^3). Normal operation will maintain an elevation of 904 feet (275.5 meters), minimum release of 11 ft^3/s (0.31 m^3/s), and maximum release of 1,500 ft^3/s (42,5 m^3/s) providing downstream design discharges are not exceeded. Storage at maximum flood pool elevation is equivalent to 18.7 inches of runoff from the basin, more than twice the average annual runoff. Storage in the conservation pool is equivalent to 7 inches of runoff from the basin. With such abundant storage, Rathbun Lake is well suited for multiple-purpose operation.

Corydon City Reservior, Wayne County

There were a total of 16,440 farm ponds in the eleven counties of south-central Iowa as of June 30, 1973. These ponds have permanent pools which range from 0.5 to 3.5 acres (0.20 to 1.42 ha) in surface area. The average surface area of the permanent pools is about 1.5 acres (0.61 ha).

The number of ponds by county is as follows:

Madison	1,110	Monroe	1,530
Warren	1,179	Ringgold	1,582
Marion	909	Decatur	2,773
Union	956	Wayne	1,622
Clarke	1,559	Appanoose	1,466
Lucas	1,754	Total	16,440

All of the ponds probably have a capability of supplying water for livestock and limited irrigation. Ponds in close proximity to the farmstead could provide water for fire protection and possible farm domestic use if proper treatment were applied. They also provide recreation opportunities and wildlife habitat and improve the general environmental and aesthetic values of the area.

In many places in this area, surface storage may be the only source for a water supply that is adequate in quantity and quality. Fortunately, the relatively rugged topography is conducive to storage development. Extrapolating from figure 19, discussed in the previous section, a draft rate of 1 ft^3/s from a stream draining 100 mi^2 would require about 270 acre-feet, and a draft rate of 3 ft^3/s would require about 1,200 acre-feet of net storage. Water lost to seepage and evaporation from the impoundment would have to be added to determine total required storage. Obviously, detailed site surveys and economic analyses would be needed for a comprehensive evaluation of storage at any location.

Farm pond in Monroe County

REGULATED STREAMS

Regulated streams in south-central Iowa include the Des Moines River below Red Rock Dam and the Chariton River below Rathbun Dam.

Figure 20 illustrates how the natural streamflow hydrographs for water years 1947 and 1956 for the Des Moines River near Tracy might have been changed by the operation of Red Rock Lake. Mean discharge for the 1947 water year was the second highest on record - 9,660 ft^3/s (273.6 m^3/s). The maximum known flood occurred in June 1947. Streamflow for the 1956 water year was the lowest on record - the mean was 496 ft^3/s (14.1 m^3/s) which was less than 11 percent of the long-term average discharge of 4,660 ft^3/s (132.0 m^3/s). The hydrographs of regulated flow are based upon preliminary studies by the Corps of Engineers on a rule of operation for the Red Rock Dam. Actual experience in operating the dam may suggest somewhat different patterns of regulation than those shown if conditions similar to 1947 and 1956 were to occur.

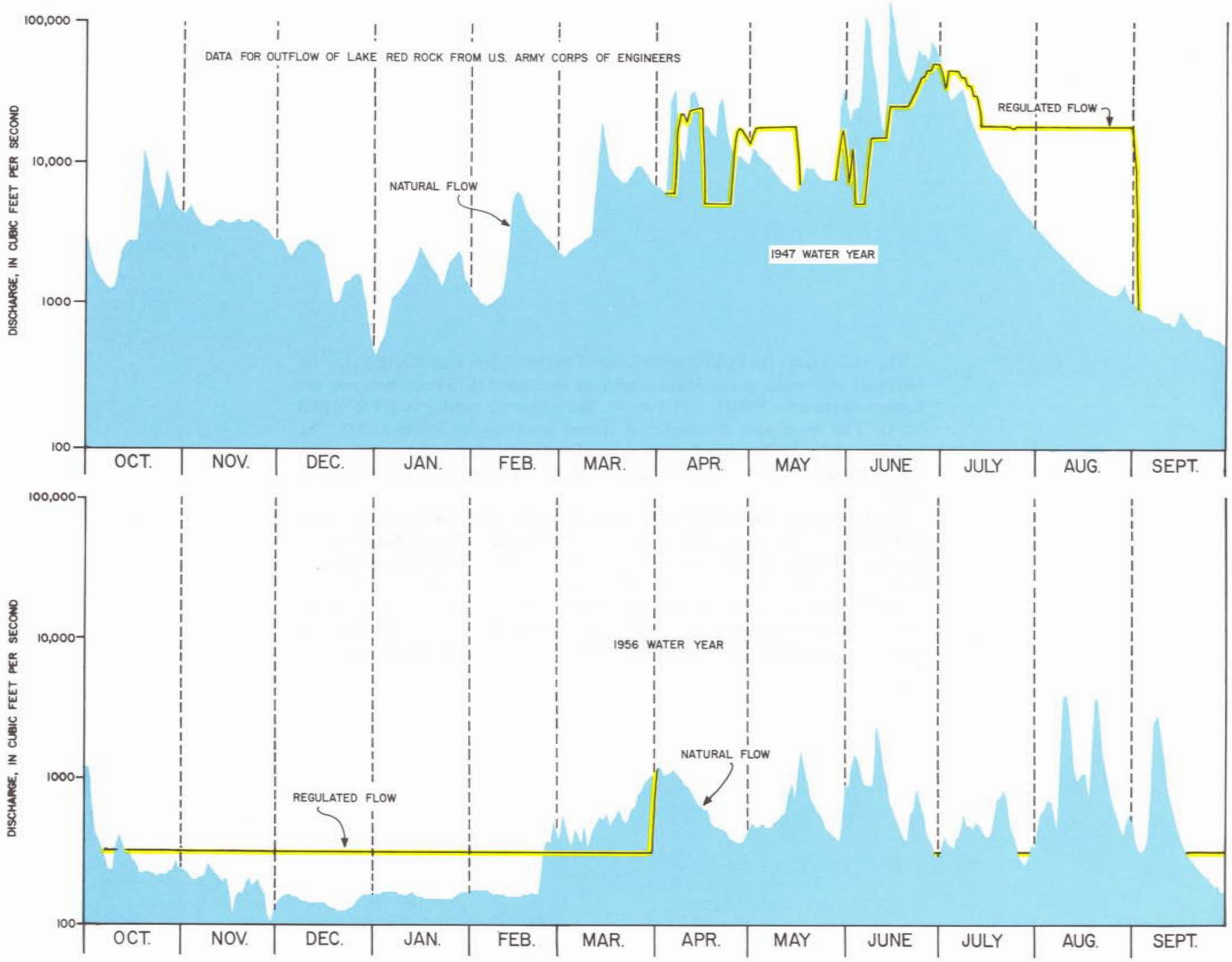


Figure 20.— Hydrographs showing how the natural flow of the Des Moines River at Tracy could be modified by operation of Lake Red Rock

Figure 21 shows the hydrographs for the Chariton River near Rathbun for the 1957 and 1973 water years. Mean discharge during the 1973 water year was the highest on record - 750 ft^3/s (21.2 m^3/s). The long-term average is 309 ft^3/s (8.8 m^3/s). The maximum discharge of record occurred in March 1960. The hydrograph for 1973 shows the flow as regulated by the Rathbun Lake. Data for the inflow and outflow are from the records of the Corps of Engineers, U.S. Army.

The hydrograph for the 1957 water year shows how the flow might have been altered by the opertion of Rathbun Lake. The regulated flow is based on the assumption that a minimum flow of 11 ft^3/s (0.31 m^3/s) would be released from the reservoir. Streamflow for the 1957 water year was the lowest on record - about 25 percent of the long-term average of 309 ft^3/s (8.8 m^3/s). Streamflow records for the Chariton River near Centerville gaging station indicate that the mean discharge for the 1956 water year was considerably less than that for 1957.

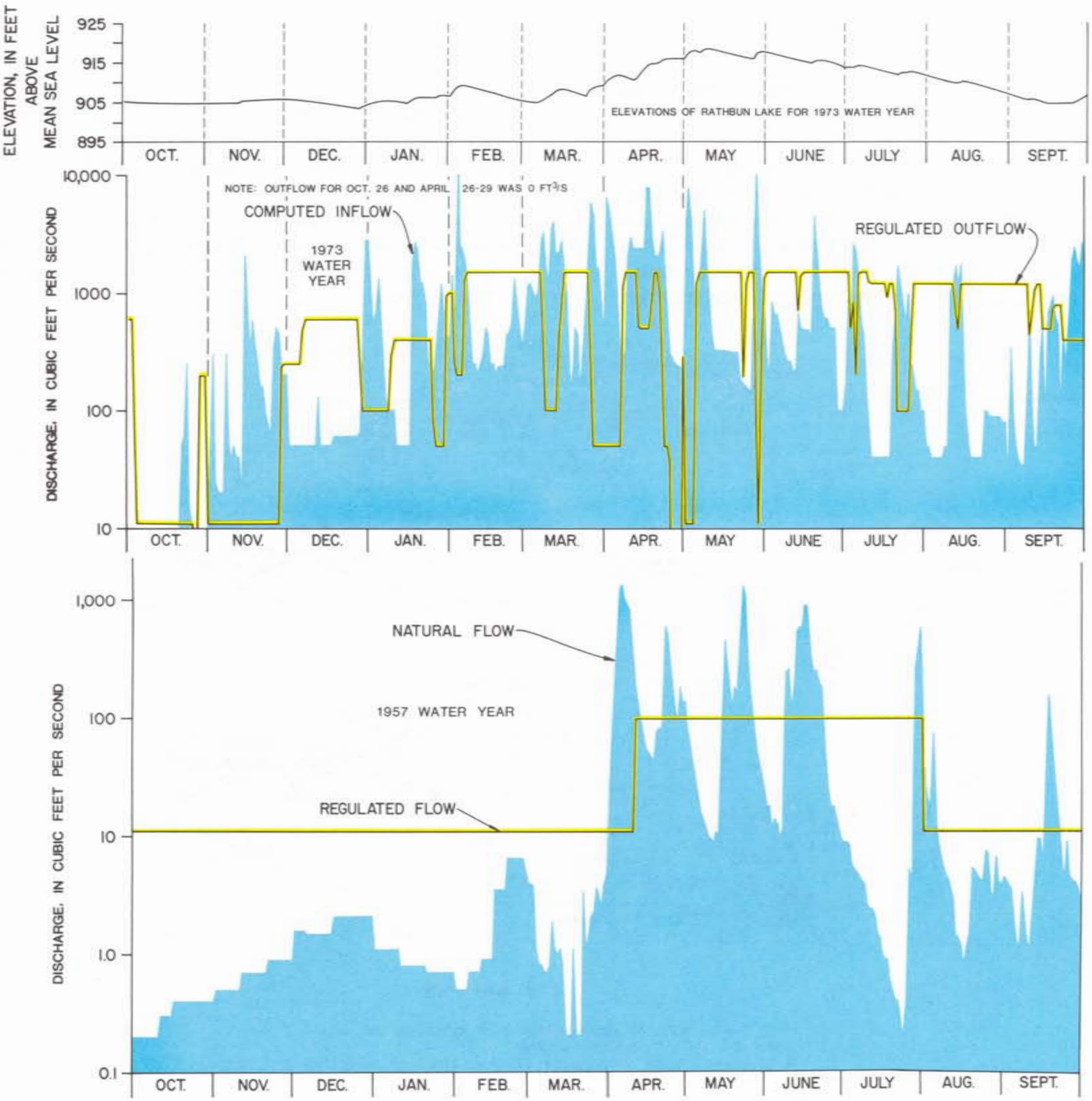


Figure 21.— Hydrographs for Chariton River and Rathbun Lake near Rathbun. Lower: showing regulated discharges for 1957 water year which could have occurred from operation of the Rathbun dam. Middle: showing computed inflow and regulated outflow of Rathbun Lake for 1973 water year. Upper: Rathbun Lake elevation for 1973 water year.

FLOODS

Floods occur when runoff from excessive precipitation and (or) snowmelt overtaxes the carrying capacity of the stream channel causing flood waters to flow out of the channel. Ice or debris jams in the stream channels can cause an increase in the height of the flood waters. The maximum flood discharges for the period of record for gaging stations in south-central Iowa are listed in table 1 and are shown in figure 22. Also shown in figure 22 are the computed 50-year flood discharges for comparison of flood magnitudes. A 50-year flood is one that can be expected to be equaled or exceeded on the average of once in 50 years or one that has a 2 percent chance of occuring in any year. The 50-year flood discharges were obtained from a flood-frequency study of Iowa streams prepared by the U.S. Geological Survey (Lara, 1973). Also included in the report by Lara (1973) are regional methods for estimating the magnitude and frequency of floods. Curves based on the regional method which relates flood discharges to the size of the drainage area of a stream are shown in figure 23. These curves can be used to estimate the magnitude of a flood of selected recurrence interval at any point on unregulated streams in south-central Iowa. For example, the 100-year flood discharge at a point on a stream where the drainage area is 200 mi² would be about 16,700 ft³/s.

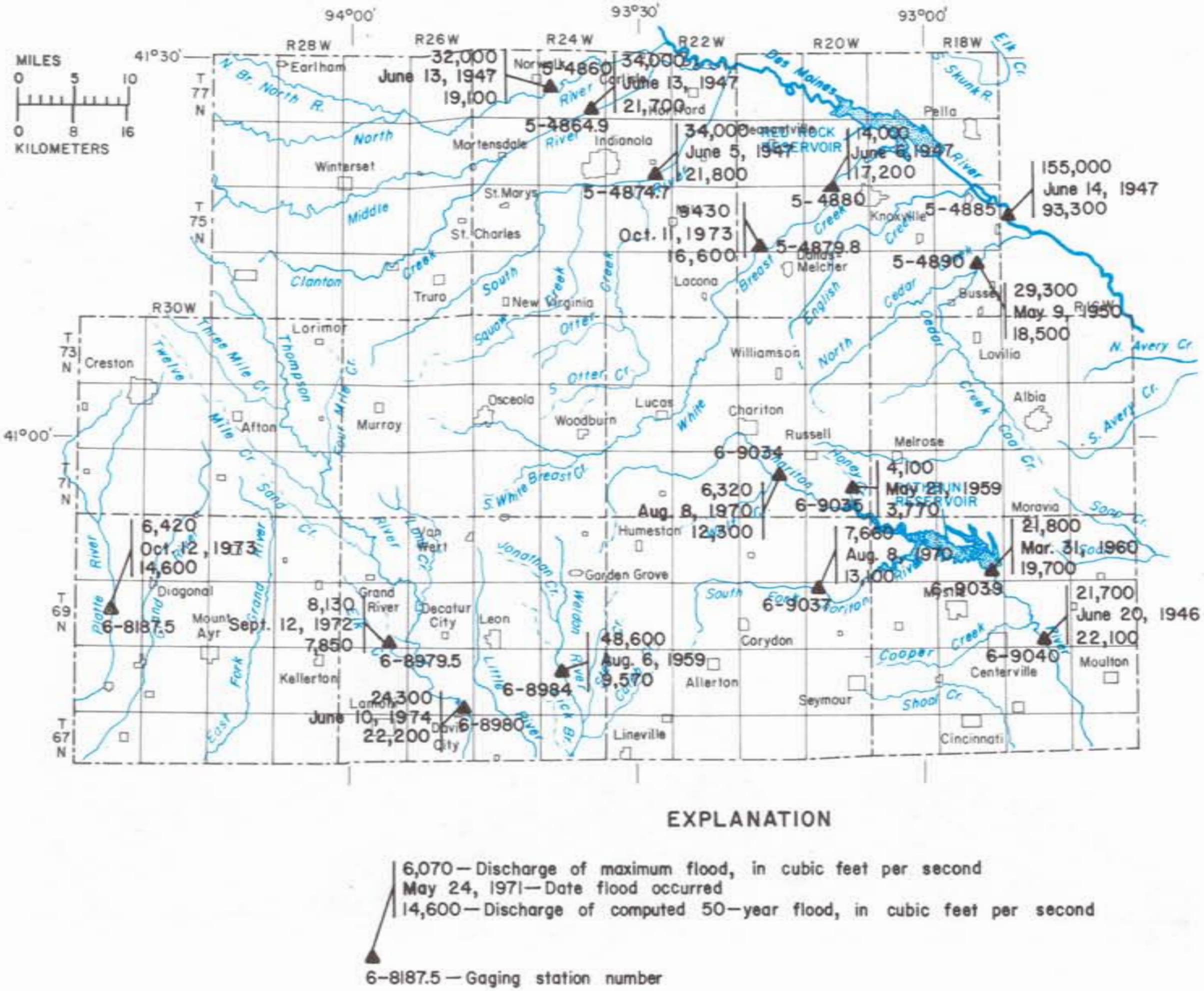


Figure 22.— Floods at south-central Iowa gaging stations

The frequency or recurrence interval of a known flood peak discharge can also be determined by use of the curves. For example, a flood discharge of 10,000 ft³/s at a point where the drainage area is 200 mi² would be determined by plotting the discharges shown for 200 mi² on log-probability paper and fitting a smooth curve through the plotted points as shown in figure 24. From this graph, the probability of occurance of a 10,000 ft³/s peak is 6.5 percent. The recurrence interval of this peak is computed by taking the reciprocal of 6.5 and multiplying by 100, as 1/6.5 x 100 = 15 years.

A federal flood-prone area mapping program is aimed at reducing the risk of flood losses by alerting the public to the possible dangers of development on the flood plains. Maps produced in this program show the areas that are subject to inundation by a 100-year flood. The base maps used are generally the U.S. Geological Survey 7 1/2-minute topographic maps.

Eleven flood-prone area maps are available (1975) for south-central Iowa. Listed by counties, they are:

Warren County:	Hartford, Milo
Lucas County:	Russell
Decatur County:	Leon, Woodland, Lineville
Wayne County:	Confidence
Appanoose County:	Plano, Mystic, Hiattsville, Unionville

The areas covered by these maps are shown in figure 25.

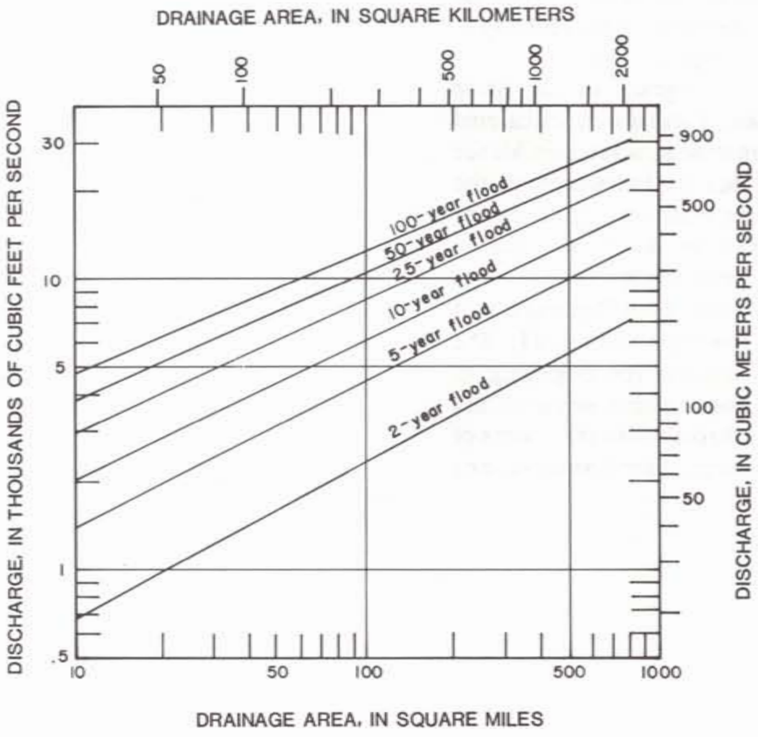


Figure 23.— Relation between discharge and drainage area for indicated recurrence interval floods for streams in south-central Iowa

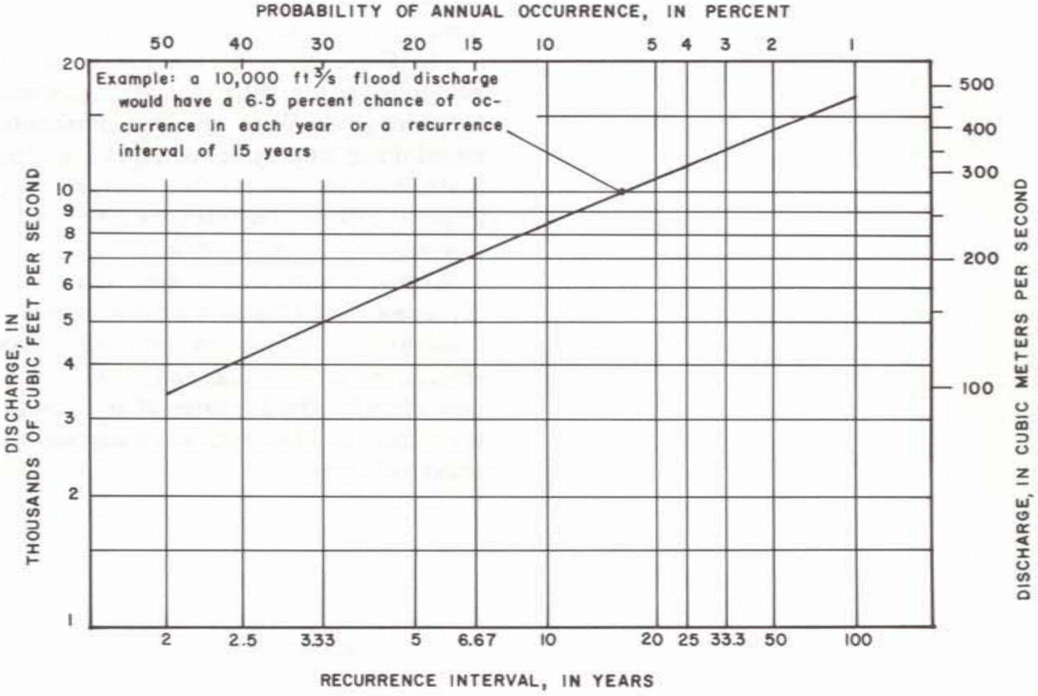


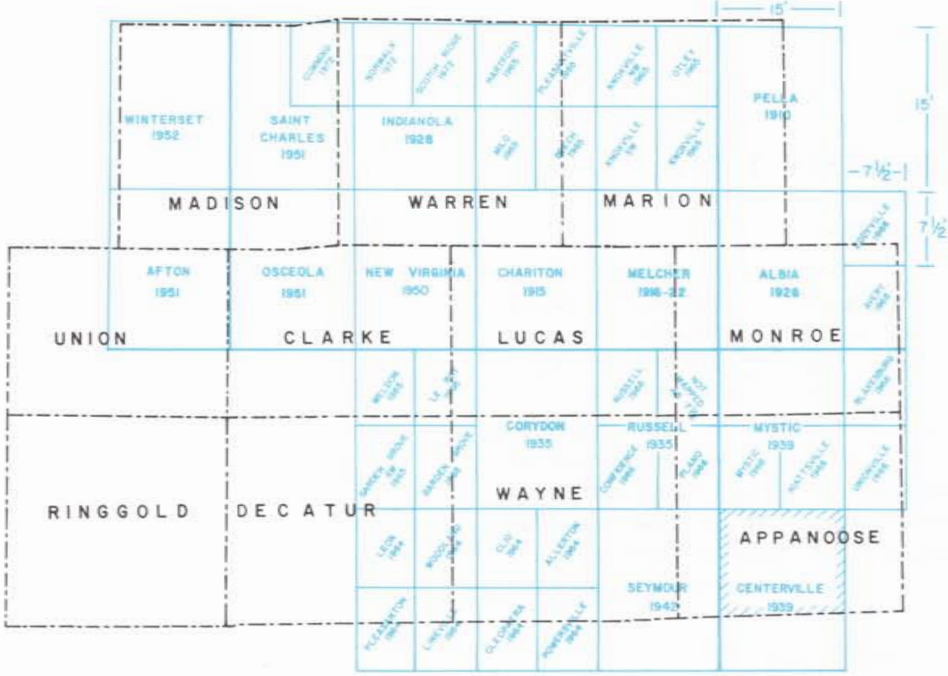
Figure 24.— Flood-frequency curve for 200 square mile drainage area in south-central Iowa

REGULATIONS PERTAINING TO FLOOD-PLAIN DEVELOPMENT AND WATER QUALITY

The Iowa Natural Resources Council is the regulatory agency in the State for administering the water laws relating to flood-plain management. Flood-plain regulation is practiced in Iowa in an attempt to reduce flood hazards and damage. The Iowa Natural Resources Council has the authority to establish floodways along rivers and streams. A floodway is the channel of a river or stream and those portions of the flood plain adjoining the channel which are reasonably required to carry and discharge the flood water or flood flow of any river or stream. It is unlawful to erect any structure, dam, obstruction, deposit or excavation in any floodway which will adversely affect the efficiency or unduly restrict the capacity of the floodway. Written application must be made to the Iowa Natural Resources Council for a permit to erect any of the aforementioned structures on a flood plain. The Iowa Natural Resources Council has the power to remove or eliminate any structure which affects the efficiency or restricts the capacity of a floodway. The procedures for obtaining permission to erect any of these structures are set forth in The Code of Iowa, Chapter 455A.

The Department of Environmental Quality is the agency of the State authorized to prevent, abate, or control water pollution. These duties are carried out through the Water Quality Commission. The commission is responsible for establishing, modifying, or repealing quality standards for the waters of the State, and for establishing, modifying, or repealing effluent standards for disposal systems. Instructions outlining the operation of the Water Quality Commission are set forth in The Code of Iowa, Chapter 455B.

Written permits are required from the executive director of the Department of Environmental Quality to carry on any of the following activities: (1) The construction, installation, or modification of any system for disposing of sewage, industrial waste, and other wastes. (2) The construction or use of any new outlet for the discharge of any sewage or wastes directly into the waters of the State. (3) The operation of any waste disposal system other than sewage or industrial waste.



EXPLANATION

Eddyville — Name of quadrangle
1968 — Year of map preparation

Note: These maps are for sale by the Iowa Geological Survey, 123 N. Capitol St., Iowa City, Iowa

Figure 25.— Available topographic maps for south-central Iowa

TOPOGRAPHIC MAPS

Published topographic maps, prepared by the U.S. Geological Survey, are available for areas in south-central Iowa shown in figure 25. The 1:24,000-scale maps (1 inch on the map equals 24,000 inches on the ground) and the 1:62,500-scale maps (1 inch on the map equals approximately 1 mile on the ground) can be used to determine land-surface elevations. The 1:24,000-scale maps cover 7-1/2 minutes of latitude and longitude and have a contour interval of 10 feet; the 1:62,500-scale maps cover 15 minutes of latitude and longitude and have a contour interval of 20 feet.

Also available are the following 1:250,000-scale (1 inch on map equals approximately 4 miles on ground) NK series maps, which cover all of the south-central Iowa report area:

Name of Map	Map Series	Contour Interval (feet)
Centerville, IA; MO	NK 15-11	All have 50-foot contours with supplementary 25-foot contours
Des Moines, IA	NK 15- 8	
Nebraska City, IA; MO; NB	NK 15-10	
Omaha, IA; NB	NK 15- 7	

Published topographic maps are for sale and may be ordered from governmental agencies at a nominal charge. The map order should include the map name and the map series designation; for example, Clio, Iowa, 7-1/2 minute series; or Centerville, Iowa-Missouri, NK 15-11 series. Maps may be ordered from the following governmental agencies:

Iowa Geological Survey, 123 N. Capitol, Iowa City, IA 52242

and (or) Denver Distribution Center, U.S. Geological Survey, Federal Center, Denver, CO 80225.

An index map of the state showing the topographic maps that have been published is available upon request from the Iowa Geological Survey.

Additional information concerning the progress of mapping in Iowa may be obtained from the Topographic Division, U.S. Geological Survey, Box 133, Rolla, MO 65401.

GROUND WATER RESOURCES

THE AQUIFERS

Permeable rock zones through which water moves freely enough to supply wells are called aquifers. Rocks which are aquifers are sources for about two-thirds of the water withdrawn for urban- and rural-domestic, livestock, and commercial and industrial and irrigation use in south-central Iowa.

All of south-central Iowa is underlain by several aquifers. The uppermost aquifer, the surficial aquifer, is composed of unconsolidated deposits that at most places lie at or near the land surface. Underlying the surficial aquifer is a sequence of consolidated sedimentary rocks, collectively called bedrock, that extend downward for at least three thousand feet. Some of these rocks are aquifers and yield water to wells; some are confining beds and do not yield water to wells (fig. 26).

The major bedrock aquifers underlying all or part of the region are the Mississippian aquifer, the Devonian aquifer, and the Cambrian-Ordovician aquifer. Sandstone and limestone aquifers of subregional and local extent occur also in the thick Pennsylvanian rocks. In the following sections, the geologic and hydrologic aspects of the aquifers will be described with regard to the distribution and spatial relationships of the aquifers, the occurrence and movement of water in the aquifers and the yield to be expected from them, and the water quality.

Beneath the combined surficial and sedimentary sequences lie igneous and metamorphic crystalline rocks often called the "basement complex." These rocks are not believed to contain water in south-central Iowa and are considered to be the base of the ground-water reservoir.

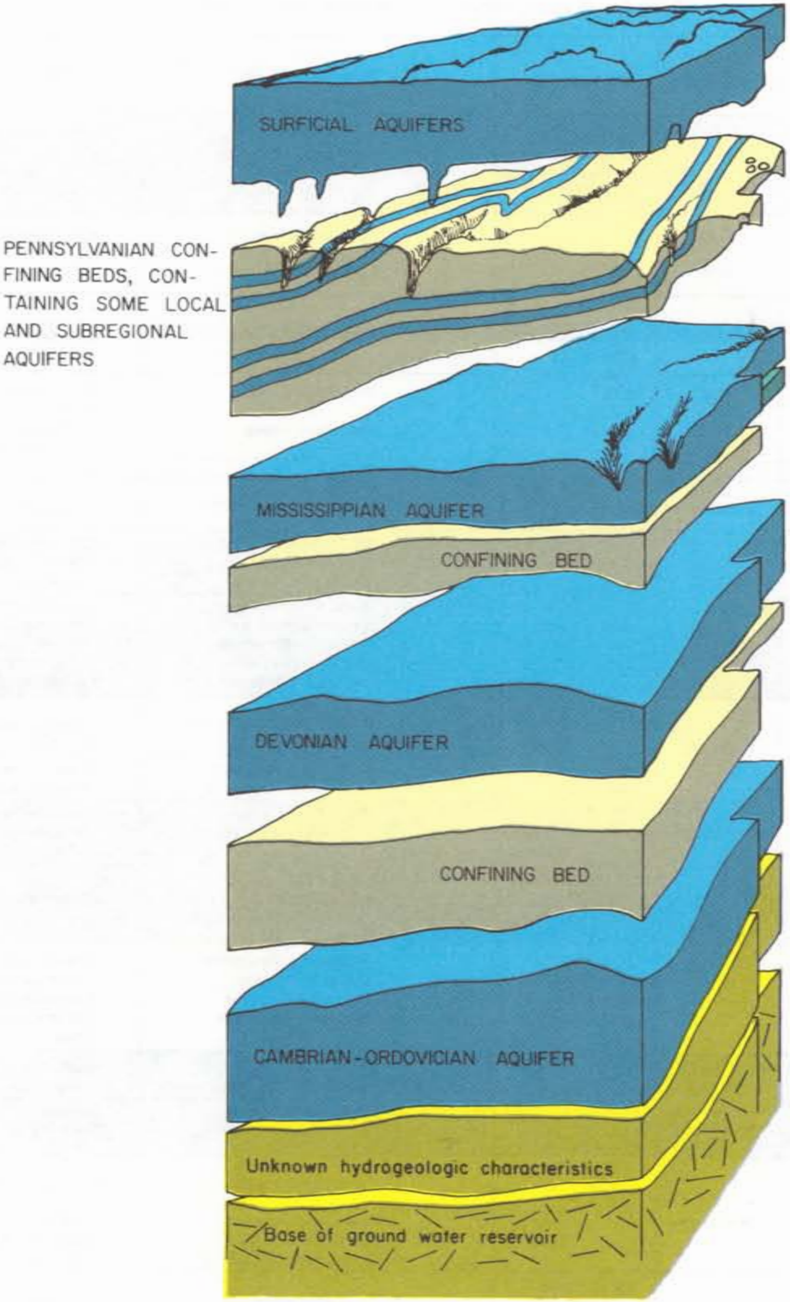


Figure 26.— The aquifers in south-central Iowa

Table 6.— Hydrogeologic units in south-central Iowa

Hydrogeologic Unit	General Thickness (feet)	Age of Rocks	Name of Rock Unit*	Type of Rock
Surficial aquifers alluvial buried channel drift	0-430	Quaternary (0-1 million years old)	Quaternary deposits, undifferentiated	Sand, gravel, silt, and clay Sand, gravel, silt, and clay Till (sandy, pebbly clay), sand, and silt
Confining beds	0-40	Pennsylvanian (280 to 320 million years old)	Shawnee Group	Shale, siltstone, and minor thin limestone beds
	0-125		Douglas Group	
	0-60		Lansing Group	
Principally confining beds, containing local subregional aquifers	0-225		Kansas City Group	Alternating shale and limestone units
Confining beds	0-45		Pleasanton Group	Shale, sandstone, thin limestone beds
	0-140		Marmaton Group	Alternating shale and limestone; thin coal and sandstone
Principally confining beds, containing subregional aquifers	0-510		Cherokee Group	Shale, clay, siltstone, sandstone and coal beds; minor limestone beds
Mississippian aquifer Upper	150-600	Mississippian (320 to 345 million years old)	St. Genevieve Limestone	Limestone and sandstone
			St. Louis Limestone	Limestone and sandstone
			Spergen Formation	Limestone
Mississippian aquifer Lower			Warsaw Formation	Shale and dolomite
			Keokuk Limestone	Dolomite, limestone and shale
			Burlington Limestone	Dolomite and limestone
			Hampton Formation	Limestone and dolomite
			Starrs Cave Formation	Limestone
Confining bed	40-335		Prospect Hill Formation	Siltstone, limestone and dolomite
		Devonian (345 to 395 million years old)	Yellow Springs Group	Shale, dolomite and siltstone
			Lime Creek Formation	Dolomite and shale
Devonian aquifer 220-640	220-615		Cedar Valley Limestone	Limestone and dolomite
			Wapsipinicon Formation	Dolomite, limestone, shale and gypsum
	0-85	Silurian (395 to 430 million years old)	Undifferentiated	Dolomite
Confining bed	190-535	Ordovician (430 to 500 million years old)	Maquoketa Formation	Dolomite and shale
			Galena Formation	Dolomite and chert
			Decorah Formation	Limestone and shale
			Platteville Formation	Limestone, shale and sandstone
Cambrian-Ordovician aquifer	435-615 (thickness of St. Lawrence not included)		St. Peter Sandstone	Sandstone
			Prairie du Chien Formation	Dolomite and sandstone
		Cambrian (500 to 570 million years old)	Jordan Sandstone	Sandstone
			St. Lawrence Formation	Dolomite
Unknown hydrogeologic characteristics	Not known		Franconia Sandstone	Shale, siltstone, and sandstone
			Galesville Sandstone	Sandstone
			Eau Claire Sandstone	Sandstone, shale and dolomite
			Mount Simon Sandstone	Sandstone
Base of ground-water reservoir		Precambrian (570 million to more than 2 billion years old)	Crystalline rocks, undifferentiated	Sandstone, igneous and metamorphic rocks

*The nomenclature and classification of rock units in this report are those of the Iowa Geological Survey and do not necessarily coincide with those accepted by the U.S. Geological Survey.

The rock layers that underlie south-central Iowa are listed in the stratigraphic chart (table 6). The stratigraphic sequence contains many rock units which are distinguishable from one another because of numerous physical, mineralogical and paleontological characteristics. However, for the purpose of describing the general availability of water, these units have been grouped into aquifers and confining beds on the basis of their water-yielding characteristics.

The surficial aquifers are closest to the land surface. They are composed of unconsolidated material deposited by glaciers and by streams. Sand and gravel beds in the surficial deposits are aquifers and the clay and glacial till beds are confining beds. The surficial aquifers are subdivided into three aquifers — the alluvial aquifer, the drift aquifer, and the buried-channel aquifer — on the basis of areal and vertical distribution and water-bearing characteristics.

Pennsylvanian rocks comprise the upper bedrock in south-central Iowa, except in relatively small, scattered areas in Marion and Monroe counties. The Pennsylvanian bedrock crops out in some localities, but at most places it is covered by varying thicknesses of the surficial deposits. The predominantly impermeable shale beds of the Pennsylvanian are a regional confining bed that separates the surficial aquifer from the underlying aquifers. However, the permeable limestone and sandstone beds in the Kansas City and Cherokee Groups are aquifers of local and subregional extent. Because definitive data are not available, these aquifers are discussed only in a generalized way in the report.

The Mississippian aquifer is composed principally of carbonate rocks (limestones and dolomites) and underlies all of the south-central area. The aquifer is at the bedrock surface and beneath the surficial aquifer at places in Marion and Monroe Counties; elsewhere in the region the aquifer is overlain by Pennsylvanian rocks. The aquifer can be divided into upper and lower parts, which will be discussed separately whenever possible; otherwise, they are treated as a single unit. The upper unit contains some gypsum and anhydrite beds that greatly influence the chemical quality of water.

The Devonian aquifer, which is composed principally of carbonate rocks, is present throughout the subsurface and is everywhere separated from the Mississippian aquifer by predominantly shale confining beds. Some Silurian age rocks are included with the Devonian aquifer. The Silurian is of limited extent in south-central Iowa and is known to occur only in parts of Madison, Marion, Union and Warren Counties. The aquifer characteristics of the Devonian in south-central Iowa are not well known; however, based on its apparent low-to-moderate yield potential, poor chemical quality of the water, and relatively great depth, the Devonian is of less importance as a source of water than are the other bedrock aquifers.

The Cambrian-Ordovician aquifer is separated from the overlying Devonian aquifer by a thick shale and dolomite interval. The aquifer is predominantly dolomite; however, two sandstone units occur within the sequence. The lower one, the Jordan Sandstone, is the principal water-bearing unit in the aquifer, and it usually accounts for the high yields afforded by the aquifer.

Underlying the Cambrian-Ordovician aquifer are the Galesville and Mount Simon Sandstones, which are known to be excellent aquifers in eastern-most east-central Iowa. However, hydrologic data on these units are lacking in this region.

Mississippian aquifer exposure in Monroe County

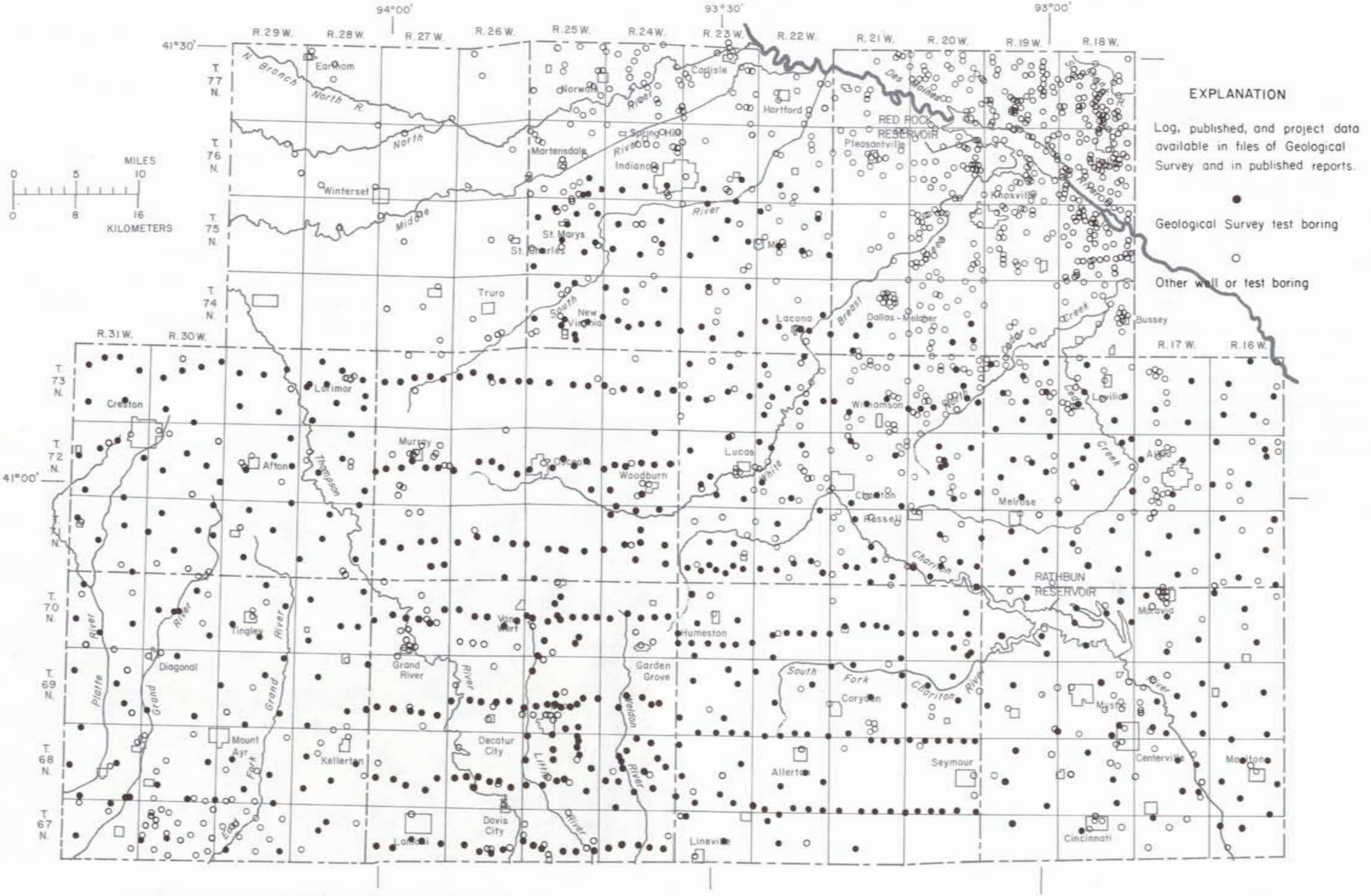


Figure 27.— Availability of well data

WELL DATA

The ground-water information contained in this report is based on geologic and hydrologic data from more than 1700 wells and test holes, and from numerous rock outcrops and quarries. Information on wells and test holes, collected over a period of many years by the Iowa Geological Survey shows well depths, well construction, water levels and yields, and source of supply. A cooperative Iowa-U.S. Geological Survey test-drilling program resulted in the drilling of 713 test holes in 10 of 11 counties in the report area. In addition, an intensive inventory of rural-water supplies was made in conjunction with the test-drilling operations, and information was collected on hundreds of farm wells and water supplies. Figure 27 indicates the density and distribution of the aforementioned data. Although the illustration shows a fairly uniform distribution of data points, many of these points represent shallow wells in the surficial aquifer and these data could not be used to construct maps depicting features of bedrock aquifers.

The surficial aquifers are the principal source of ground-water supplies in the region. Most wells tapping the surficial aquifers are relatively shallow, bored or dug farm wells constructed with brick or cement-tile casing 12 to 48 inches in diameter. A few shallow farm wells, the deeper wells in the glacial drift, and municipal and industrial wells tapping the shallow alluvial and drift aquifers usually have steel casing, 4 to 8 inches in diameter; but some large-capacity wells have 16 to 40 inch steel casing. Most of these wells have screens set in the sand and gravel formation, or they are gravel packed opposite the screen. The small-capacity wells commonly are equipped with cylinder type (lift or force) pumps that are operated by hand, by a windmill, or by electric- or gasoline-driven pump jacks; some wells have electric-powered jet or submersible pumps.

Wells tapping aquifers in the Pennsylvanian, Mississippian, and Devonian strata generally have steel casing, 5 to 8 inches in diameter; but some of the deeper, large-capacity wells have 10 to 16 inch diameter casing. The most common method of construction is to set the bottom of the casing at or near the top of the aquifer and to leave the hole open opposite the water-bearing zones; but a few wells are cased to the bottom and are perforated opposite water-bearing zones or are left "open end" at the bottom.

Because of the relatively great depth and production capability of the Cambrian-Ordovician aquifer, telescoping casing of various sizes is often used. Wells that develop water from the aquifer have steel casing with diameters ranging from about 8 to 24 inches, and the wells are constructed by setting the bottom of the casing at or near the top of the aquifer and leaving the lower part of the well open opposite the water-bearing horizons. The casing in most of these wells is grouted to prevent intermingling of highly mineralized water from the overlying aquifers.

Windmill-powered pump in Warren County

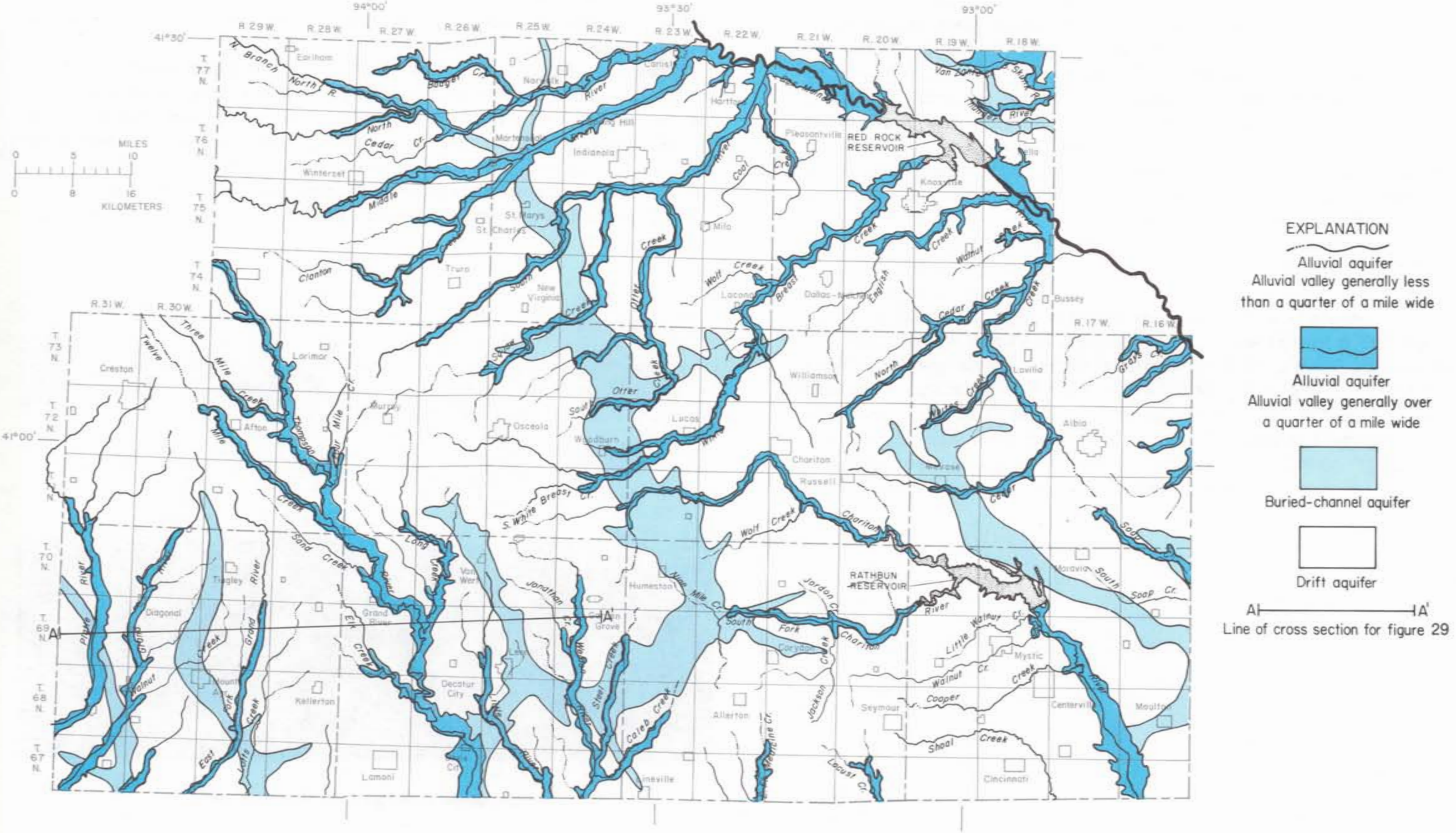


Figure 28.— Areal distribution of surficial aquifers in south-central Iowa

SURFICIAL AQUIFERS

The surficial aquifers are water-bearing sand and gravel deposits that lie between the land and the bedrock surface in south-central Iowa, except at a relatively few places where the bedrock is exposed at the land surface. The surficial aquifers are subdivided into three types, depending on their mode of occurrence and distribution: alluvial aquifers, drift aquifers, and buried-channel aquifers (fig. 28). The alluvial aquifer is composed of materials deposited in the valleys of the present-day streams, and consists of floodplain and terrace deposits. The buried-channel aquifer consists of material deposited in the valleys of preglacial streams which were overridden by glaciers and are now buried under glacial or younger alluvial deposits. The drift aquifer is made up of water-bearing zones of limited extent in the deposits of drift that blanket most of the upland. The cross section (fig. 29) shows the relationships of the three surficial aquifers, the present land surface, and the underlying bedrock surface.

The alluvial aquifer occurs in present-day stream valleys, and its general areal extent is identified by the flood plains and terraces of the streams. The alluvial aquifers are composed primarily of sand and gravel, but layers and irregular bodies of clay and silt are also found within the alluvium. The thickness of the water-bearing sand and gravel in the major stream valleys is about 10 to 25 feet. The alluvial aquifer receives recharge from precipitation, seepage from nearby streams, and in some instances from the underlying bedrock.

The glacial drift, which is exposed along upland surfaces in the report area, attains a maximum thickness of about 430 feet. It is composed predominantly of sandy, pebbly clay (till) and sand and gravel deposits of varying thickness and extent. Of the more than 700 test holes drilled in south-central Iowa about 70 percent penetrated one or more beds of sand and gravel. Individual beds of sand and gravel that comprise the drift aquifer usually are from 1 to 3 feet thick and seldom exceed 5 feet. These beds most commonly occur at relatively shallow depths (less than 50 feet) in the glacial drift. However, they also occur at intermediate depths and in the basal part of the drift, particularly where the drift is thickest over bedrock channels. Thus, the probability of penetrating any sand and gravel in the drift increases over buried-channel areas. The shallower sand and gravel deposits usually are lenticular in shape, erratic and local in occurrence, and can be traced only short distances in the subsurface; whereas, the deeper deposits appear to have greater extent. The drift aquifer will yield only small supplies at most places, but moderate yields are sometimes obtainable. The drift aquifer is important as a source of small water supplies for rural-domestic and livestock use, because it often is the only source of readily available water in the interstream areas. The occurrence of sand and gravel in the drift is covered in more detail in two prior reports on water availability in south-central Iowa (Cagle and Steinhilber 1967, and Cagle 1969).

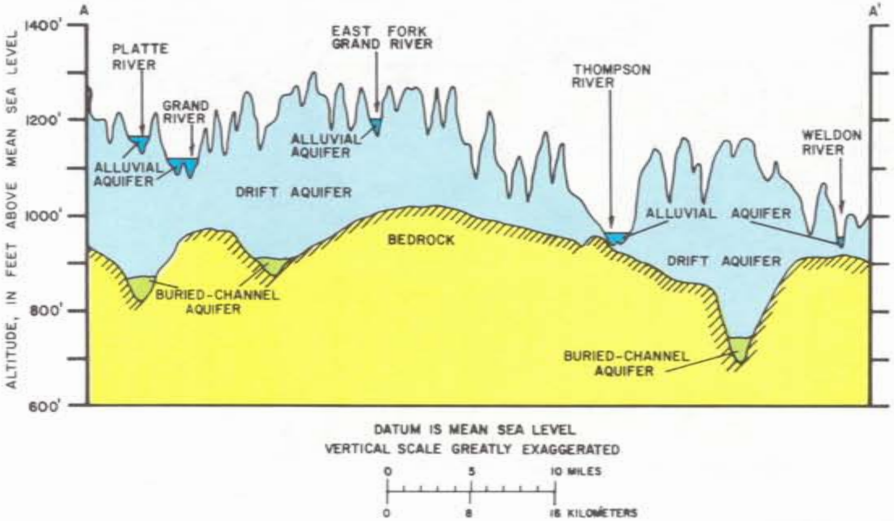
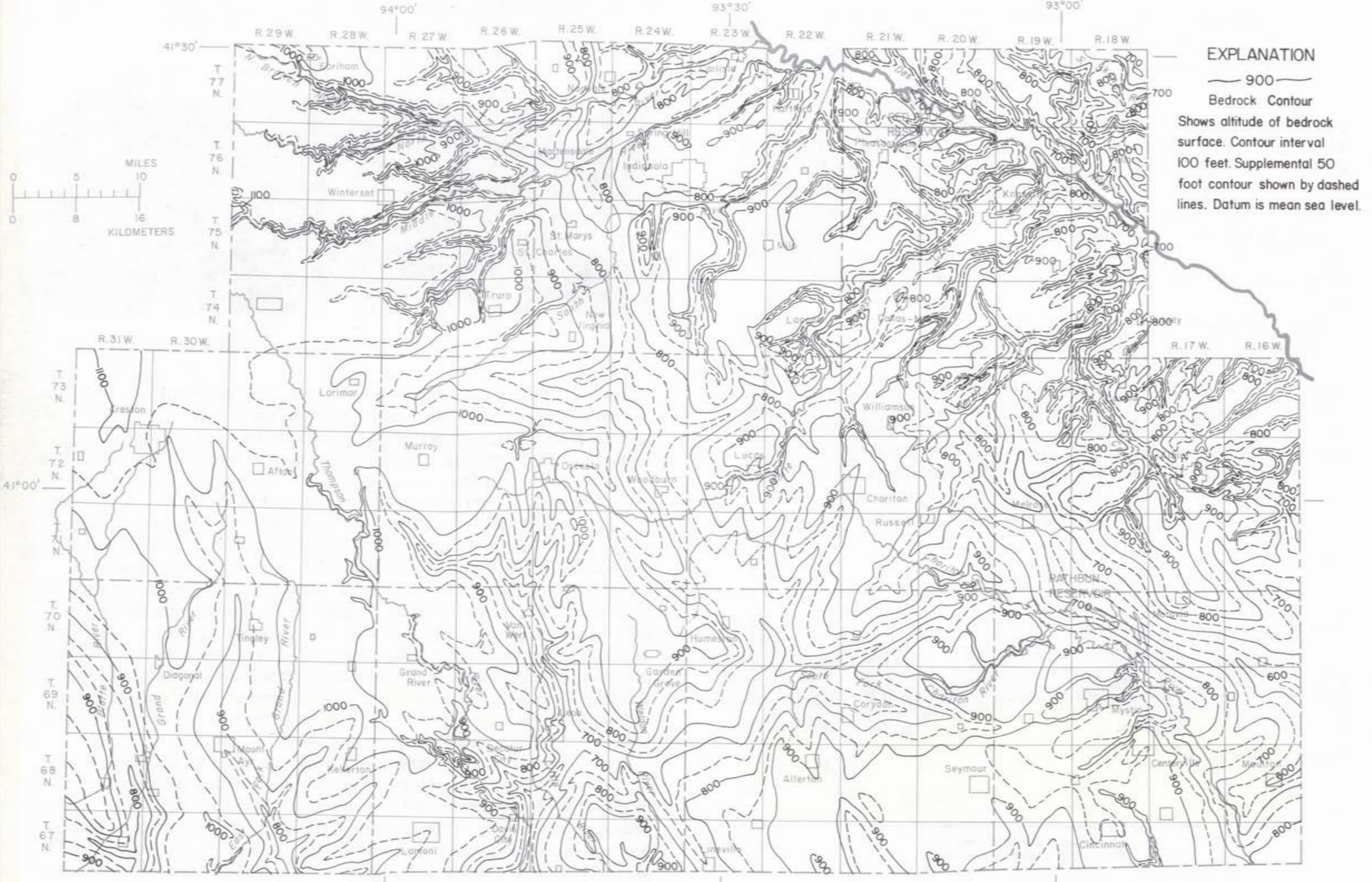


Figure 29.— Generalized hydrogeologic cross section of the surficial aquifers

Alluvial aquifer underlying wide flood plain of Thompson River, Decatur County

Buried-channel aquifers consist of stream deposits that filled portions of bedrock channels before and between glacial periods. The aquifer is not present in all parts of buried channels, but where present, the individual water-bearing beds seem to have wider distribution and are thicker than are the drift aquifers. Small-to-moderate yields are available from the aquifer; the most favorable areas for moderate yields probably are in Appanoose, Marion, and Warren Counties.



Modified from Cagle, 1973

Figure 30.— Bedrock topographic map

BEDROCK SURFACE

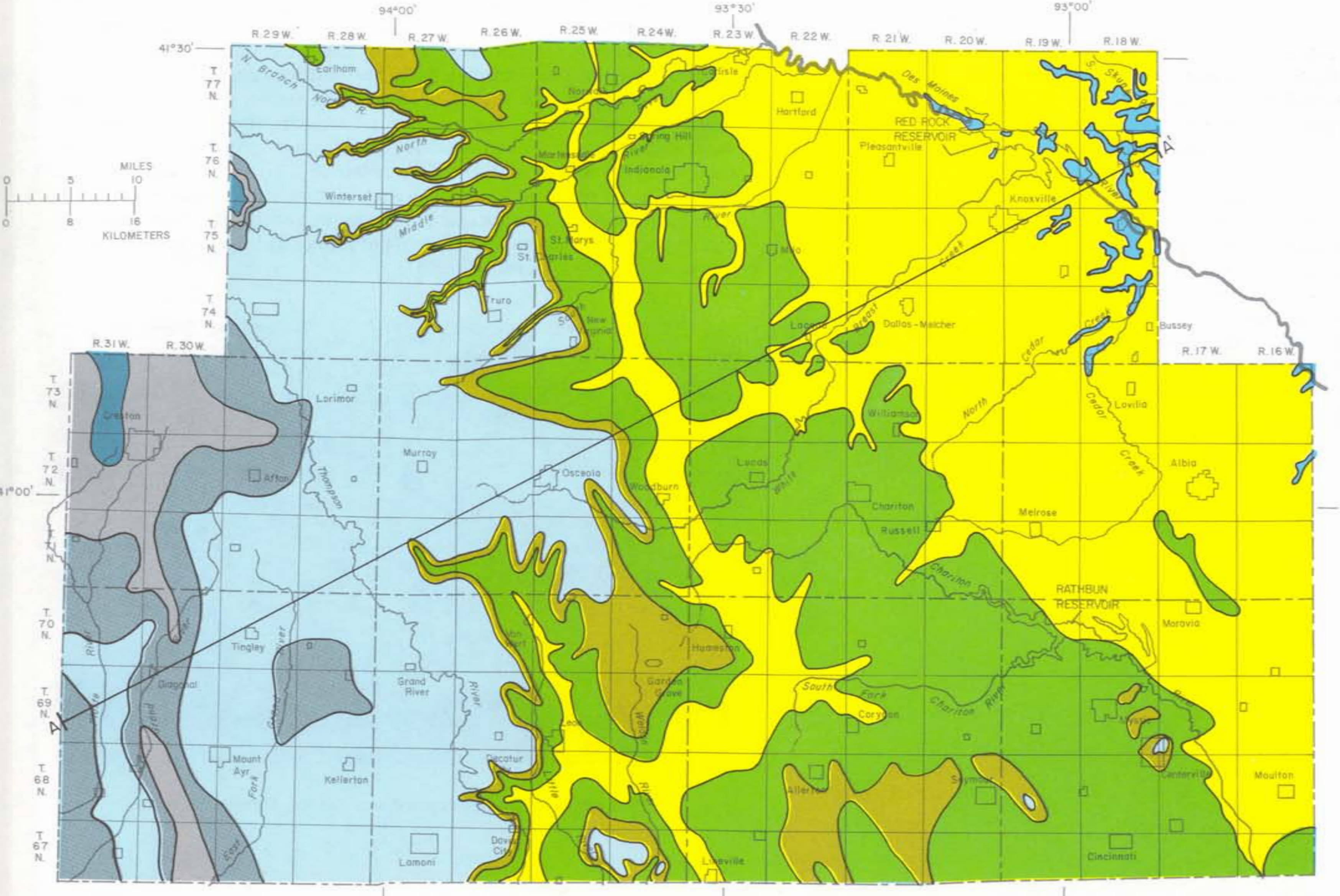
The bedrock surface in the south-central area is on consolidated rocks of Pennsylvanian and Mississippian age and is nearly everywhere beneath unconsolidated deposits of glacial drift and alluvium. The bedrock surface is the result of a complex system of drainage courses, which were developed during the long period of preglacial erosion and during shorter, more intense periods of interglacial erosion. Figure 30 shows the topography of the bedrock surface as it would appear if the surficial deposits were removed. The map shows the elevation and configuration of the bedrock surface and indicates the position of topographic features such as buried-bedrock channels and buried-bedrock uplands.

In approximately the southern one-half of the map area, deeply buried bedrock channels are the most conspicuous physical features. The channels are cut into bedrock that is dominantly shale and are characteristically relatively wide with gently sloping walls. Northward, the buried channels terminate or become less conspicuous. In most of this area the bedrock surface has been sculptured by present-day streams. Many of these streams have deeply incised the bedrock, and, generally, the valleys are narrow and steep walled. This present-day drainage pattern in the north is in marked contrast to the southern area, where most present-day stream valleys are cut into the drift.

The physical features of the bedrock surface have a special significance in most glaciated regions. In south-central Iowa the test-hole and other data indicate a relationship between the bedrock topography and ground-water occurrence in the overlying glacial deposits. Areas underlain by buried-bedrock channels generally are more favorable for the development of ground-water supplies than are areas underlain by buried-bedrock uplands.

The depth below land surface of the bedrock surface at a given site in the south-central area is important in planning the construction and development of water wells. The approximate depth to bedrock at a proposed site is obtained by subtracting the altitude of the bedrock surface (fig. 30) from the altitude of the land surface (determined from topographic maps and other sources). Another useful purpose of the bedrock map is in preparing a bedrock hydrogeologic map and for indicating the altitude of the tops of various hydrogeologic units, as can be done by relating figures 30 and 31.

Pennsylvanian bedrock exposed near Lovilia, Monroe County



EXPLANATION

PENNSYLVANIAN ROCKS

Shawnee Group
Cyclic deposits with limestone and shale beds. Most individual units are confining beds.

Douglas Group
Cyclic deposits with shale, siltstone, and minor thin limestone beds. Most individual units are confining beds.

Lansing Group
Cyclic deposits with thin-bedded limestones and interbedded shales. Most individual units are confining beds.

Kansas City Group
Alternating limestone and shale beds. In this area, one or more water-bearing limestone units generally can be found within 35 feet of the bedrock surface. The shale confining beds are not differentiated on the map.

Pleasanton Group
Shale with some sandstone, thin limestone beds and minor amounts of coal. Most individual units are confining beds.

Marmaton Group
Alternating shale and limestone with some sandstone and coal. Most individual units are confining beds.

Cherokee Group
Shale, clay, siltstone, coal, and minor limestones are mostly confining beds. Sandstone beds are water-bearing units and the probability of their occurrence within the Cherokee at any given site is more than 50 percent.

MISSISSIPPIAN AQUIFER

Limestone, dolomite, and shale; sandstone predominant in upper part.

A ——— A'

Line of hydrogeologic cross-section for figure 32.

Figure 31.— Bedrock hydrogeologic map

BEDROCK AQUIFERS

The bedrock hydrogeologic map (fig. 31) shows the areal distribution of the aquifers and confining beds that make up the bedrock surface. The areal pattern shown is the result of both the regional dip of the rocks to the southwest and the effects of erosion. The general pattern of successively younger hydrogeologic units to the southwest is interrupted at places where preglacial streams have deeply incised the bedrock to expose older units.

The shallowest bedrock units in most of the area are Pennsylvanian strata that, in general, are a succession principally of shale confining beds and some thinner, less extensive aquifers. The aquifers in the Pennsylvanian, principally sandstone in the Cherokee Group and limestone in the Kansas City Group, are not differentiated in figure 31. Studies of the Pennsylvanian during this investigation indicated the presence of several separate and potentially definable sandstone aquifers within the Cherokee; however data were insufficient to map the sandstones. Water-bearing limestones within the Kansas City Group are aquifers or potential aquifers of limited extent. These occur in alternating sequence with confining beds and lie at or near the bedrock surface throughout the exposure area of the Kansas City Group (fig. 31). However, these limestone beds have not been studied in sufficient detail to determine their areal extent.

At places in Marion and Monroe Counties erosion has removed Pennsylvanian rocks overlying the Mississippian aquifer. The areas where the Mississippian aquifer is at the bedrock surface are relatively small and disconnected and are overlain by surficial material. Comparison of the accompanying map with figures 30, 33, and 34 suggests that, at most places where the Mississippian occurs at the bedrock surface, the Pennsylvanian deposits were originally thin and the Mississippian surface was relatively high.

The Devonian and Cambrian-Ordovician aquifers, and the confining beds which separate these aquifers from each other and from younger strata, are not at the bedrock surface in the study area. The relative positions of all hydrologic units and the dip (slope) to the southwest is illustrated in the hydrogeologic cross section (fig. 32).

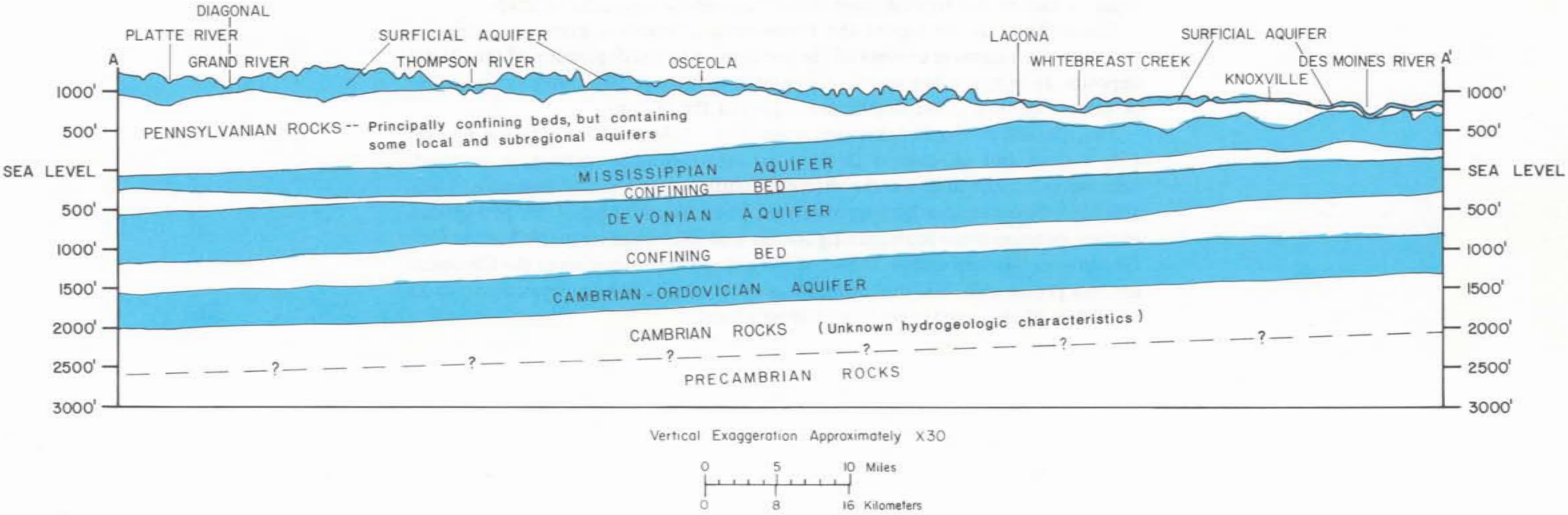


Figure 32.— Hydrogeologic cross section

DEPTHS TO THE BEDROCK AQUIFERS

The depths to the bedrock aquifers vary considerably throughout the region because of the topographic relief of the land surface and the structural attitude of the bedrock units. Because of the great variability, it is convenient to map the upper surface of the aquifers with reference to a common datum—sea-level datum in this report. Such altitude maps are presented on the following three pages (figs. 33 through 37). As is explained on page 4, the depths to the aquifers can be determined from these maps and a topographic map.

The altitude of the top of the Pennsylvanian rocks is extremely variable, owing to the extensive erosion of the rocks prior to the deposition of the glacial deposits. In fact, erosion was severe enough to remove all Pennsylvanian rocks at many localities in the northeastern part of the region.

The altitude of the Pennsylvanian aquifers — the limestones in the Kansas City Group and sandstones in the Cherokee Group — cannot be mapped, because sufficient data on the discrete aquifer units are not available. Their altitudes, however, can be approximated from the altitudes of the two groups in their outcrop areas (compare figures 31 and 33). Aquifers in the Kansas City Group generally are within 35 feet of the group's top. Aquifers in the Cherokee are less predictable, but one or more sandstones will be encountered within 25 to 50 feet of the group's surface at most places.

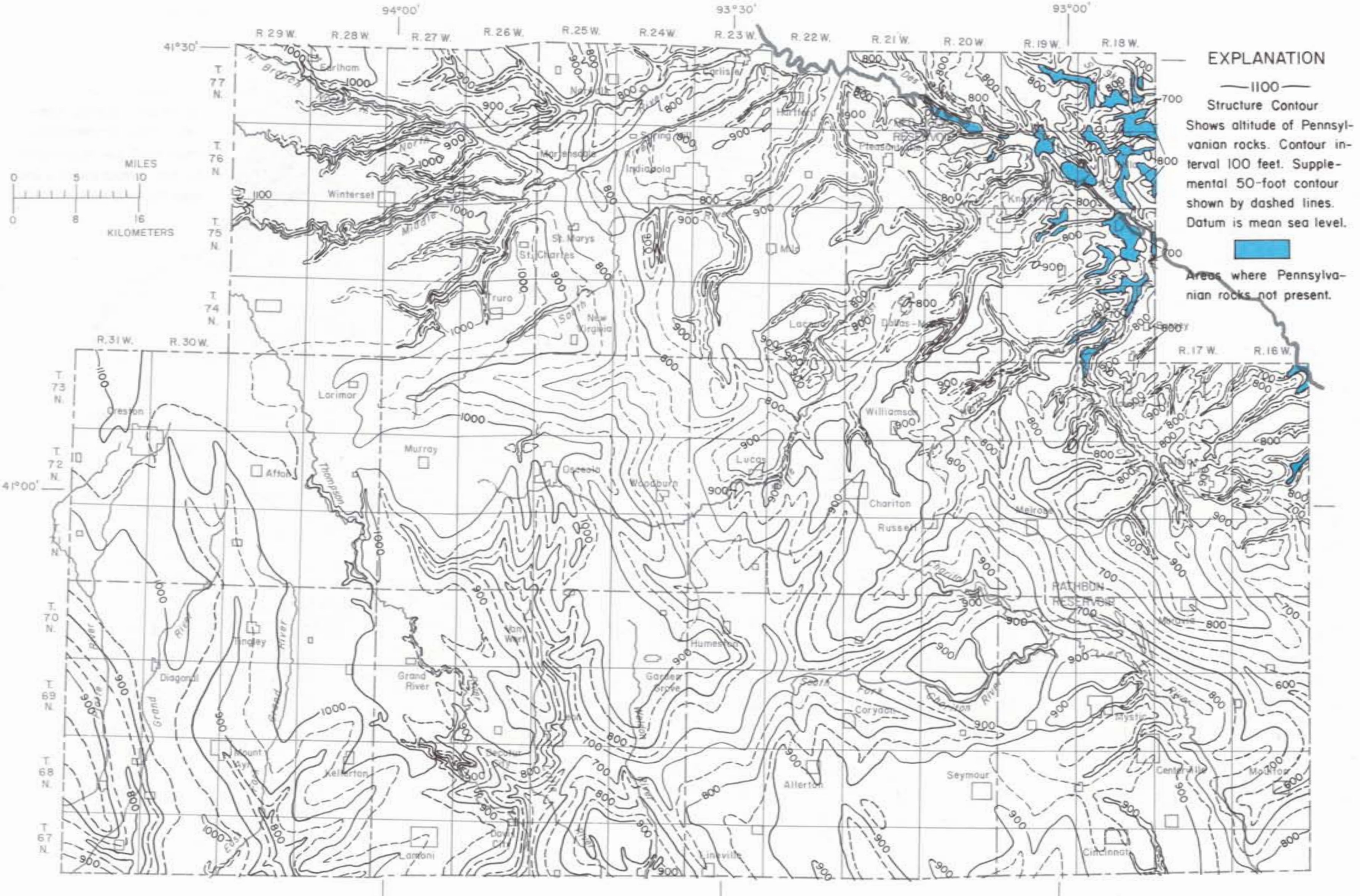


Figure 33.— Altitude of the top of the Pennsylvanian rocks

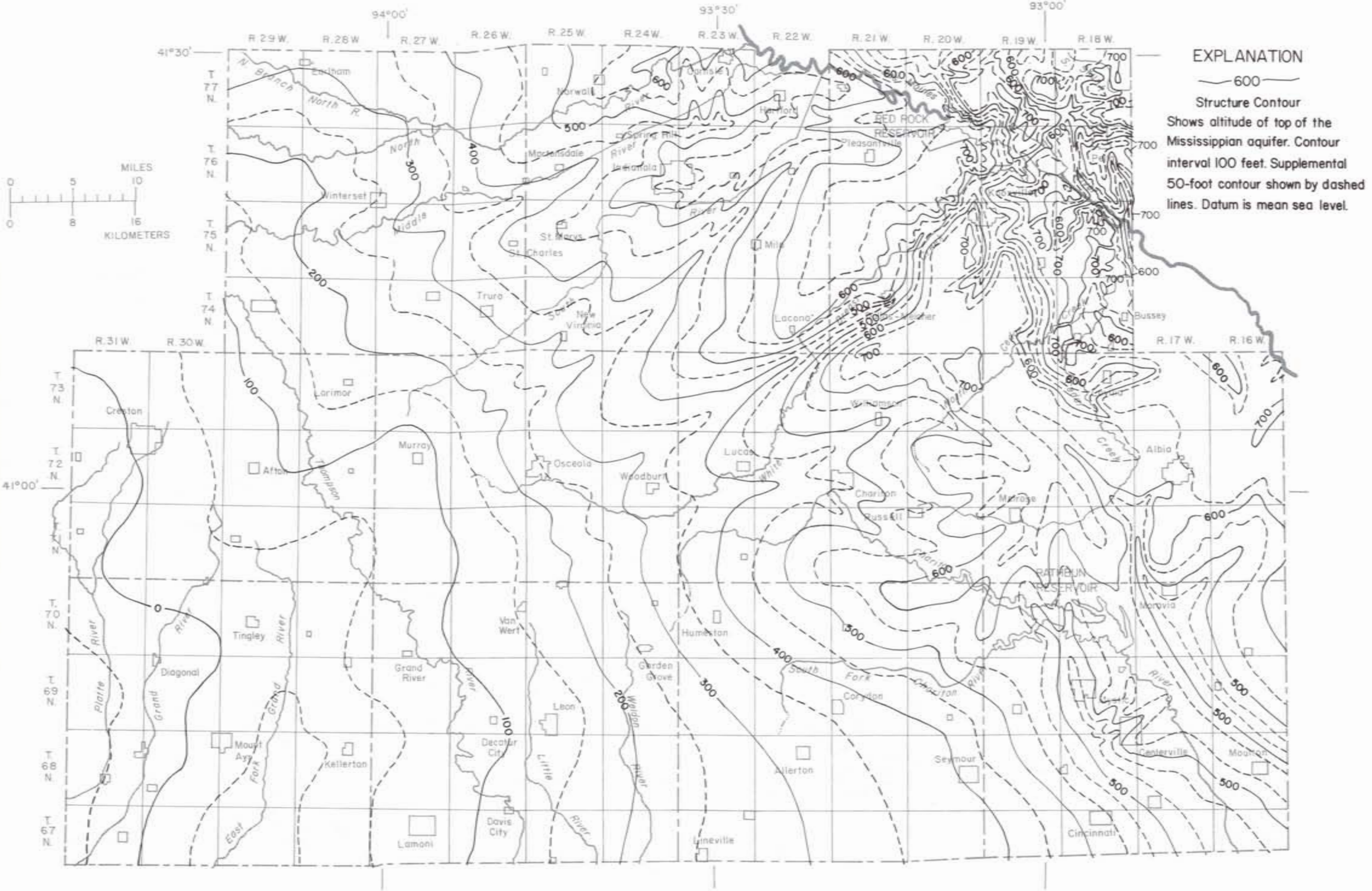


Figure 34.— Altitude of the top of the Mississippian aquifer

The westerly regional dip of the Mississippian and lower aquifers is quite noticeable on the adjacent maps (figs. 34-37). Dissection of the Mississippian aquifer is pronounced in the northeastern part of the region, where numerous steep-walled valleys were cut into the rocks. Marion County, with its highly dissected Mississippian surface, whose relief varies 100 feet or more within a distance of one-half mile, is a good example of the importance of aquifer altitude maps in computing drilling depths. The maps of the Devonian and Cambrian-Ordovician aquifers indicate the presence of a number of local structures caused by structural deformation.

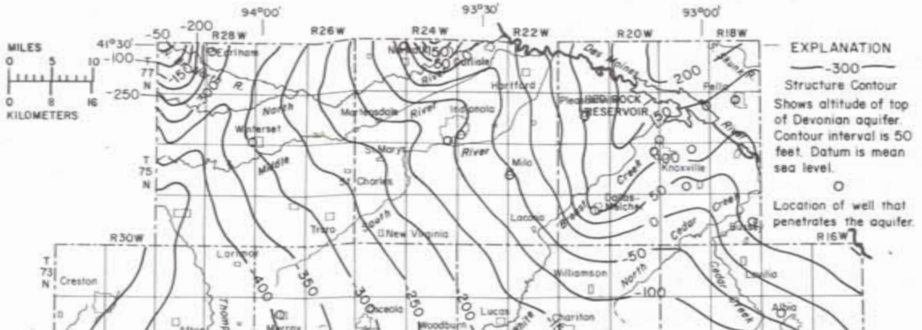


Figure 35.— Altitude of the top of the Devonian aquifer

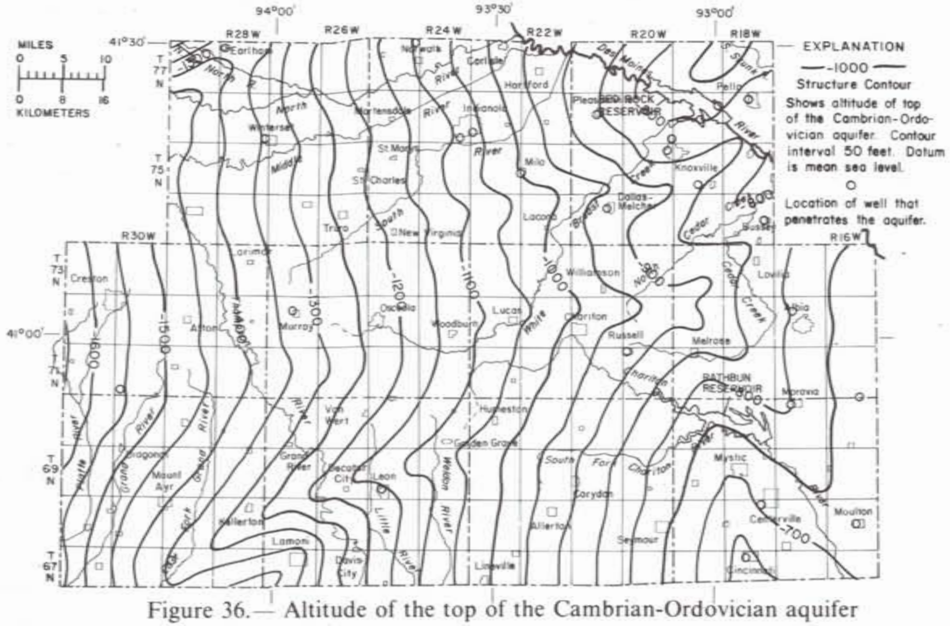


Figure 36.— Altitude of the top of the Cambrian-Ordovician aquifer

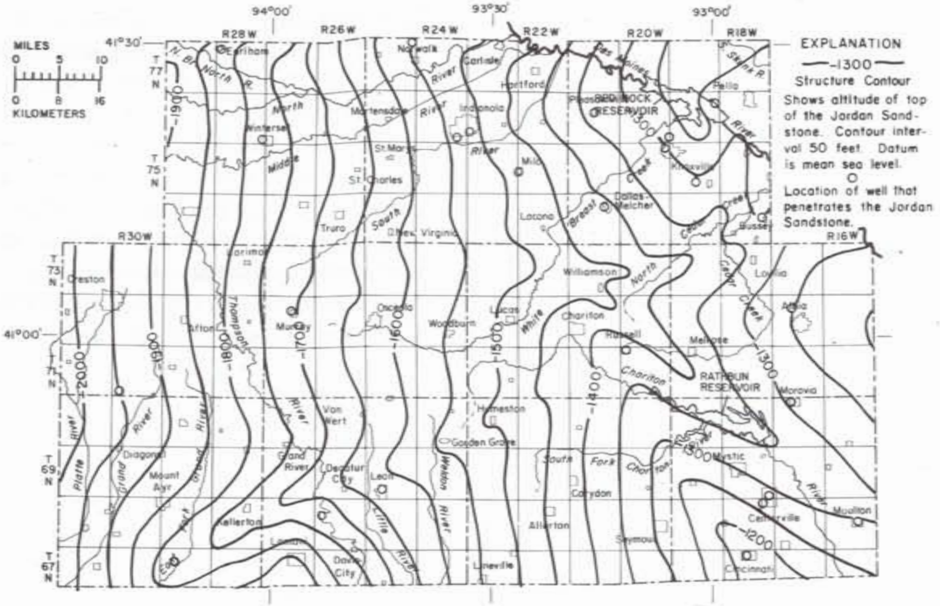


Figure 37.— Altitude of the top of the Jordan Sandstone

THICKNESS OF THE BEDROCK AQUIFERS

An aquifer will usually yield the largest quantity of water to a well where the aquifer is thickest and the well fully penetrates the aquifer. Maps depicting the thickness of the aquifers can be used in conjunction with altitude maps to determine the depth to which wells must be drilled to penetrate the aquifers fully.

The thickness of each bedrock aquifer varies from place to place throughout the entire south-central area. Three factors account for this lack of uniformity. These are (1) that the surface upon which these rocks were deposited was not smooth, and more sediment accumulated over the low places than over the high spots; (2) that more sediment was carried into or precipitated over some places than others; and (3) that erosion which took place after deposition removed a considerable amount of the material from some places.

The thickness of the Pennsylvanian rocks depicted in figure 38 is an aggregate thickness, at any given locality, of confining beds and aquifers that compose this series of rocks. Thicknesses of individual aquifers are not shown for the reasons previously indicated. However, the map is useful, when correlated with the hydrogeologic map (fig. 31) in determining the thickness of the Kansas City and Cherokee Groups in their outcrop areas.

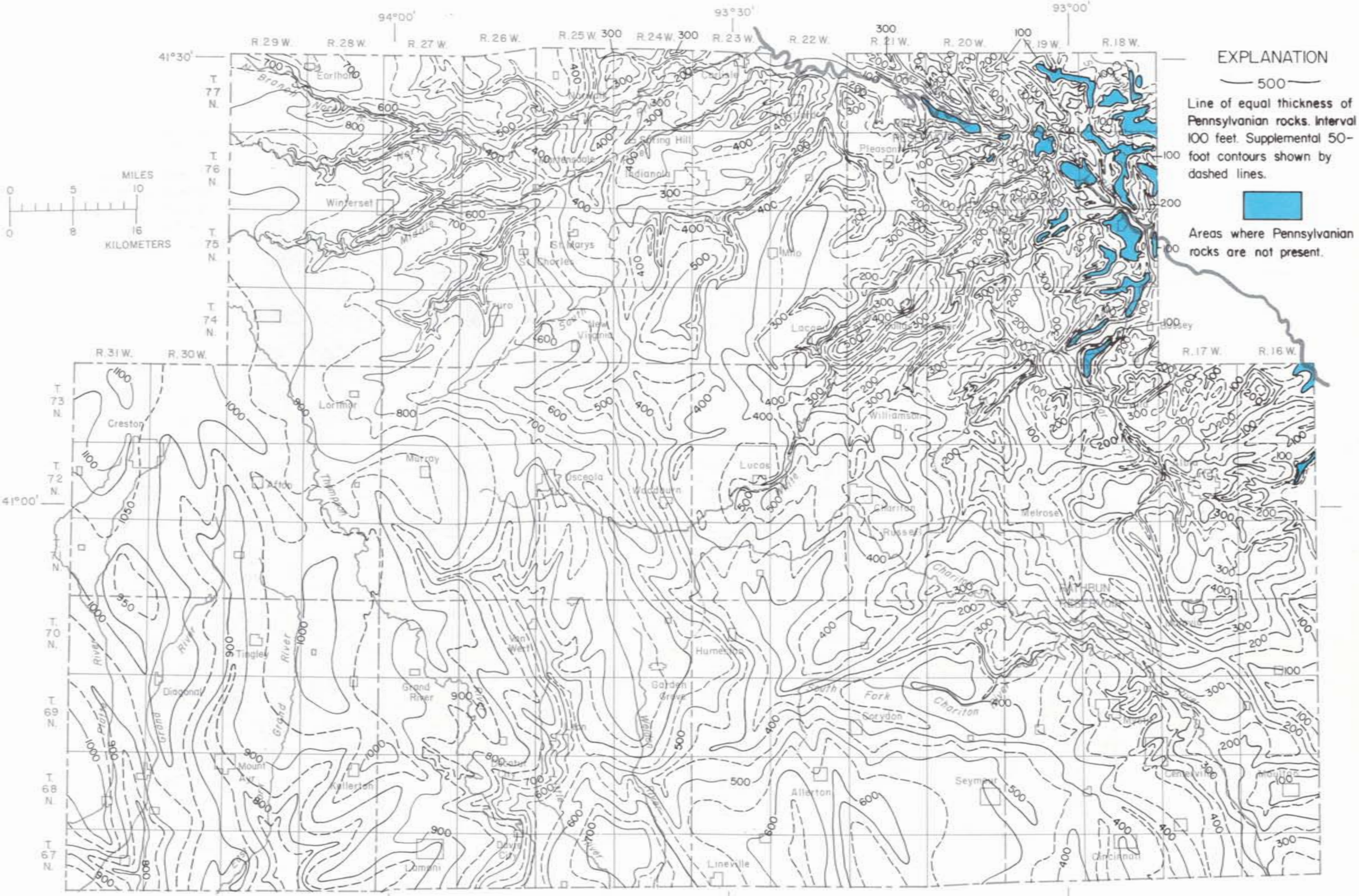


Figure 38.— Thickness of the Pennsylvanian rocks

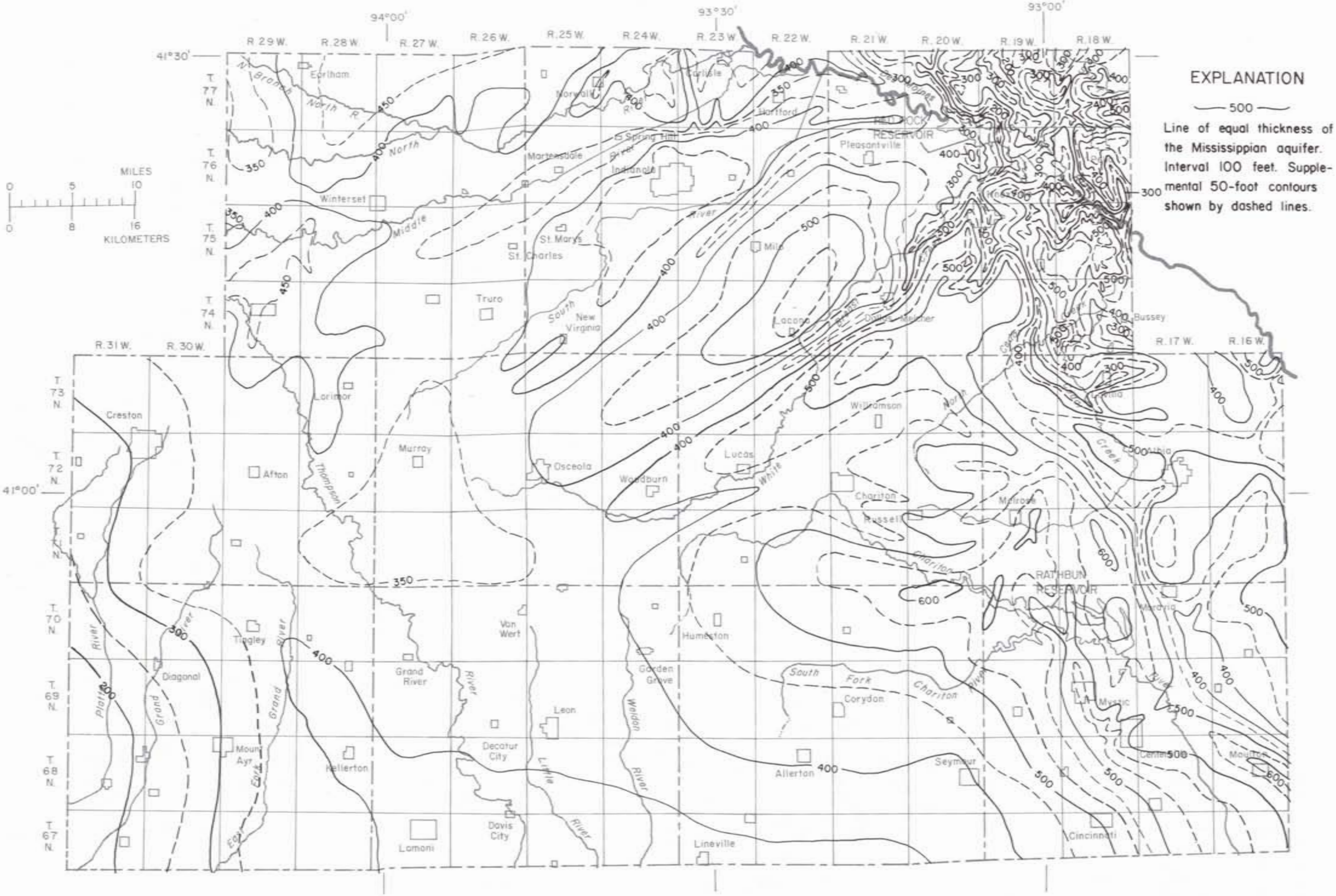


Figure 39.— Thickness of the Mississippian aquifer

The Mississippian is thinnest in north central Marion and western Ringgold Counties where it is, respectively, about 150 and 200 feet thick; it is thickest, about 600 feet, in small areas in Appanoose and Monroe Counties (fig. 39). The aquifer deviates from the regional depositional pattern in that it is thinner down dip in Clarke, Decatur, Madison, Ringgold and Union Counties where it ranges from 200 to 450 feet thick.

In Marion County, sufficient data are available to distinguish the upper part from the lower part of the aquifer. There the maximum known thickness of the upper part of the aquifer is 145 feet; whereas the lower part ranges from 250 to 345 feet in thickness. The total thickness of the Mississippian aquifer in the county ranges from about 150 feet to 575 feet, being in general, thickest in the southern part of the county.

The Devonian aquifer becomes progressively thicker from northeast to southwest in the area and, over relatively large parts of the central and western counties, maintains a thickness of about 525 feet (fig. 40). Regionally, the thickness varies from about 220 feet in the extreme southeast to about 640 feet in western Ringgold and Union Counties.

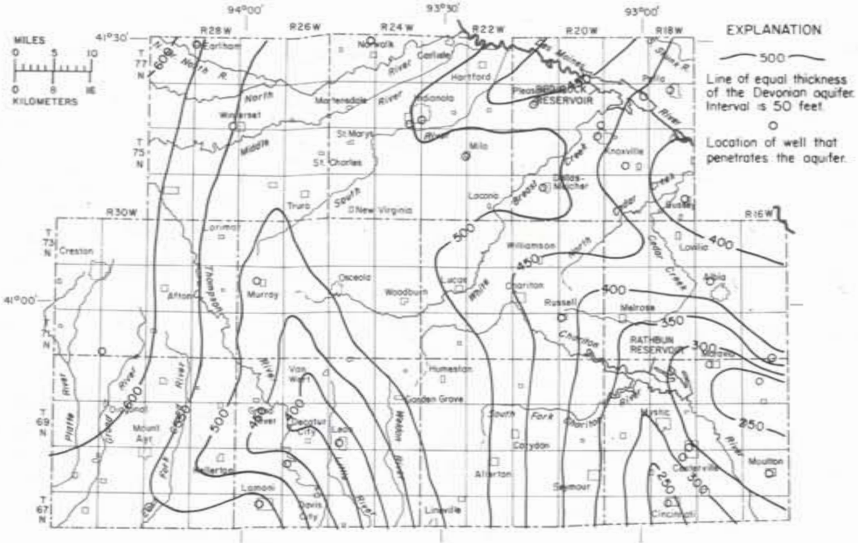


Figure 40.— Thickness of the Devonian aquifer

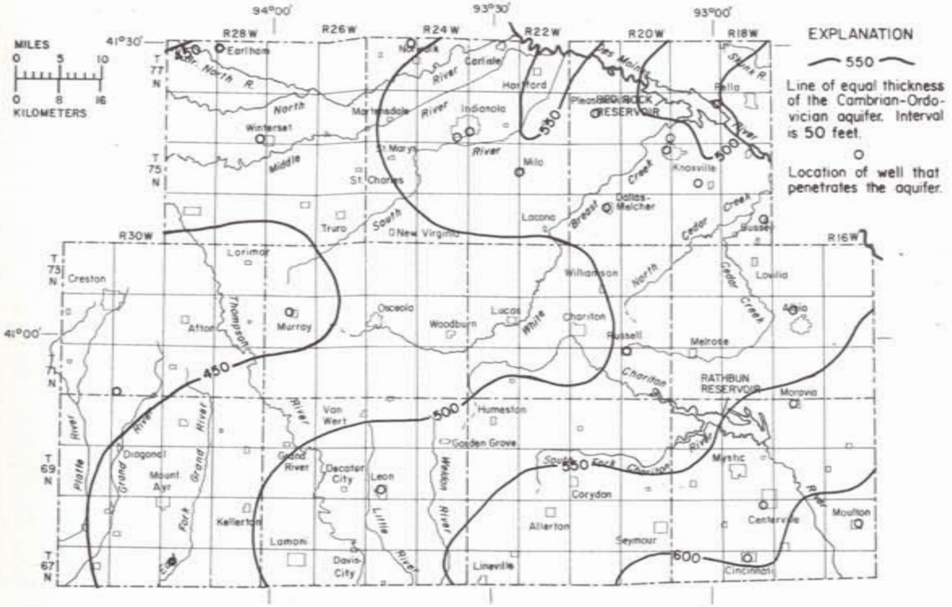


Figure 41.— Thickness of the Cambrian-Ordovician aquifer (does not include thickness of the St. Lawrence Formation)

The Cambrian-Ordovician aquifer ranges in thickness from an estimated 425 feet in the western part of the area to a little more than 600 feet in the extreme southeast. The aquifer maintains a relatively uniform thickness throughout most of the south-central area, and local variations in thickness do not exceed 50 to 100 feet (fig. 41). The lowermost unit in the aquifer, the St. Lawrence Formation, has not been fully penetrated by wells in south-central Iowa; hence, its thickness is not known.

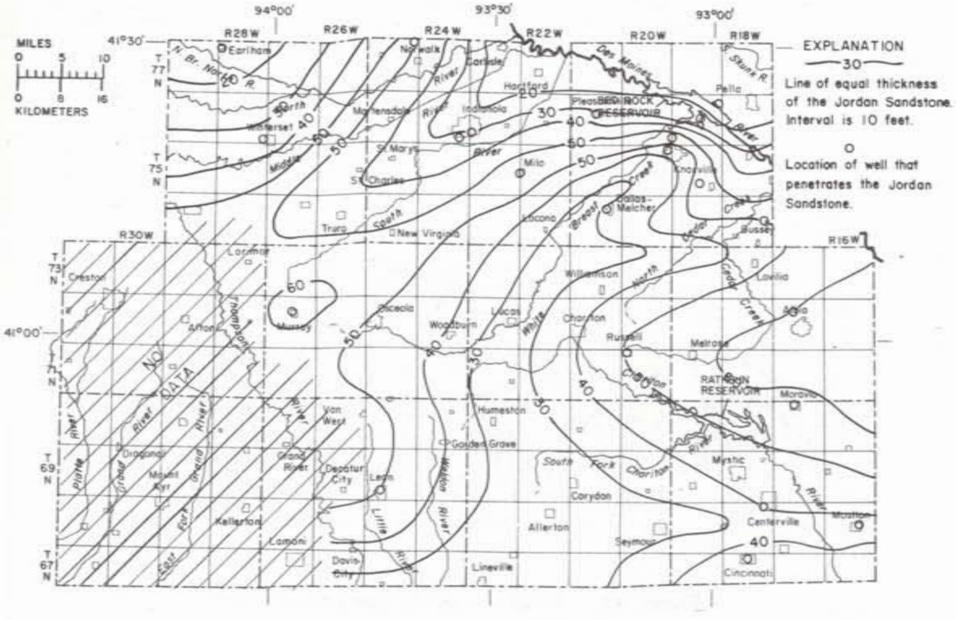


Figure 42.— Thickness of the Jordan Sandstone

The Jordan Sandstone, the principal water-bearing unit within the Cambrian-Ordovician aquifer, exhibits considerable variation in thickness throughout south-central Iowa (fig. 42). The thickness ranges from slightly less than 20 feet to about 60 feet. Well yields from the Cambrian-Ordovician aquifer are influenced principally by the thickness of the Jordan Sandstone; larger yields are available where the Jordan is thickest.

USE OF MAPS
TO PREDICT DEPTH OF DRILLING

The depth to surficial and bedrock aquifers at a given site is very important in planning the construction and development of water wells. In addition to being able to approximate the drilling depth to a particular subsurface horizon, the amount of casing necessary and thus the entire construction costs can also be estimated. The purpose of the altitude of aquifer and thickness maps is to provide a means of making these determinations. Following is a discussion of how these maps, when used in conjunction with land-surface altitudes, can be used to predict drilling and casing depths. It is important to remember, when computing drilling depths, that the depth to any aquifer is equivalent to the individual or combined thickness of all hydrogeologic units that lie between the land surface and the top of a particular aquifer.

Suppose for example, that it is desired to drill a well at Truro in Madison County, with the intention of developing a water supply from either the Mississippian or Cambrian-Ordovician aquifers (fig. 43). To determine drilling depths to these aquifers, the altitude of the land surface must first be obtained, and, at Truro, the altitude is estimated from a topographic map to be 1070 feet above mean sea level (msl). Reference to figure 34 indicates that the altitude of the top of the Mississippian aquifer is about 300 feet (msl). The difference between these two altitudes, 770 feet, is the depth to the top of the aquifer. The thickness of the Mississippian aquifer at Truro from figure 39 is approximately 370 feet. Hence, a well started at land surface and drilled to the bottom of the aquifer would be about 1150 feet deep.

A well drilled to the top of the Cambrian-Ordovician aquifer would be considerably deeper. To compute the depth of drilling to the aquifer surface, refer to figure 36 and find that the altitude of the surface of the aquifer at Truro is about - 1175 feet msl. Here, the altitude of the land surface above sea level (1070 feet) must be added to the altitude of the aquifer below sea level (-1175 feet) for a drilling depth of 2245 feet. To determine the depth of a well penetrating the Cambrian-Ordovician aquifer to the top of the St. Lawrence add the thickness of the aquifer, which is 470 feet from figure 41, to arrive at a total depth of 2715 feet. The lowermost 45 feet of this hydrogeologic unit is the Jordan Sandstone.

To prevent material from overlying layers from coming into the well and to exclude waters from higher zones in the well, it is necessary to install casing, and in most instances this necessitates setting casing into the top of the aquifer to be developed. In the above examples, the bottom of the casing would be set into the tops of the Mississippian and Cambrian-Ordovician aquifers at respective depths of about 770 and 2245 feet.

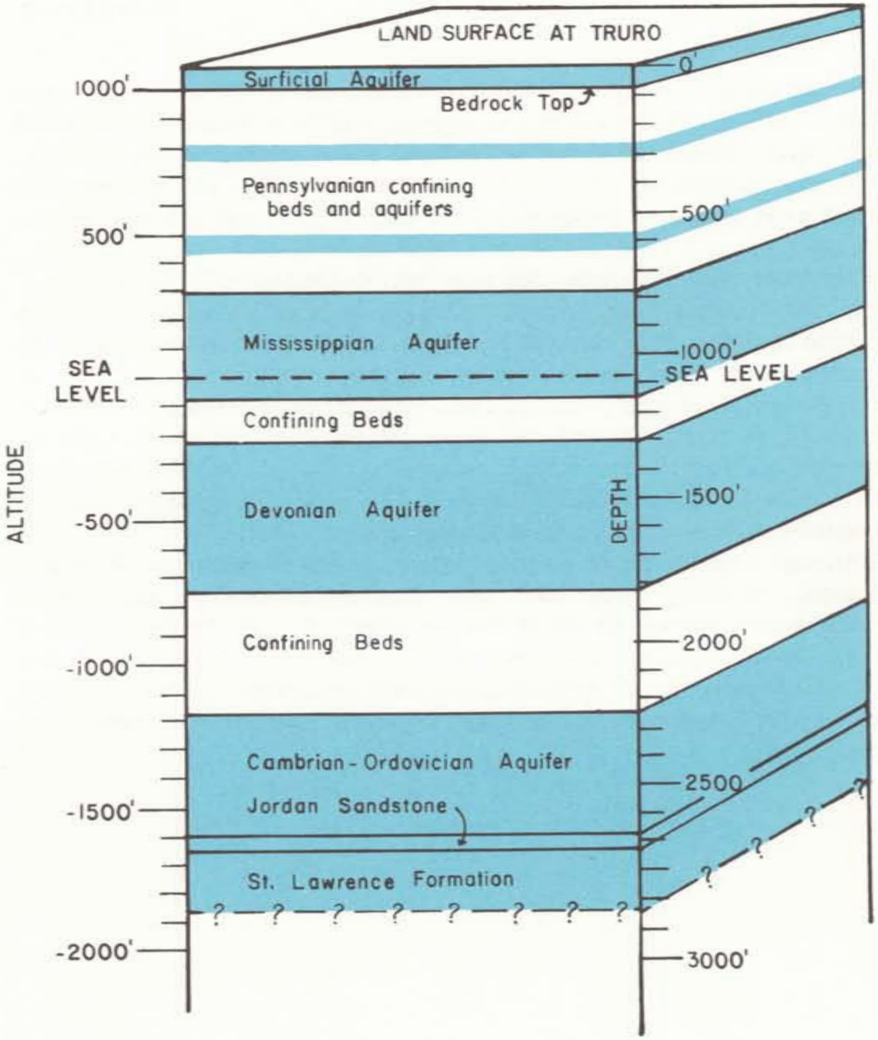


Figure 43.— Example of aquifer depths and thicknesses determined from maps

WATER IN THE AQUIFERS

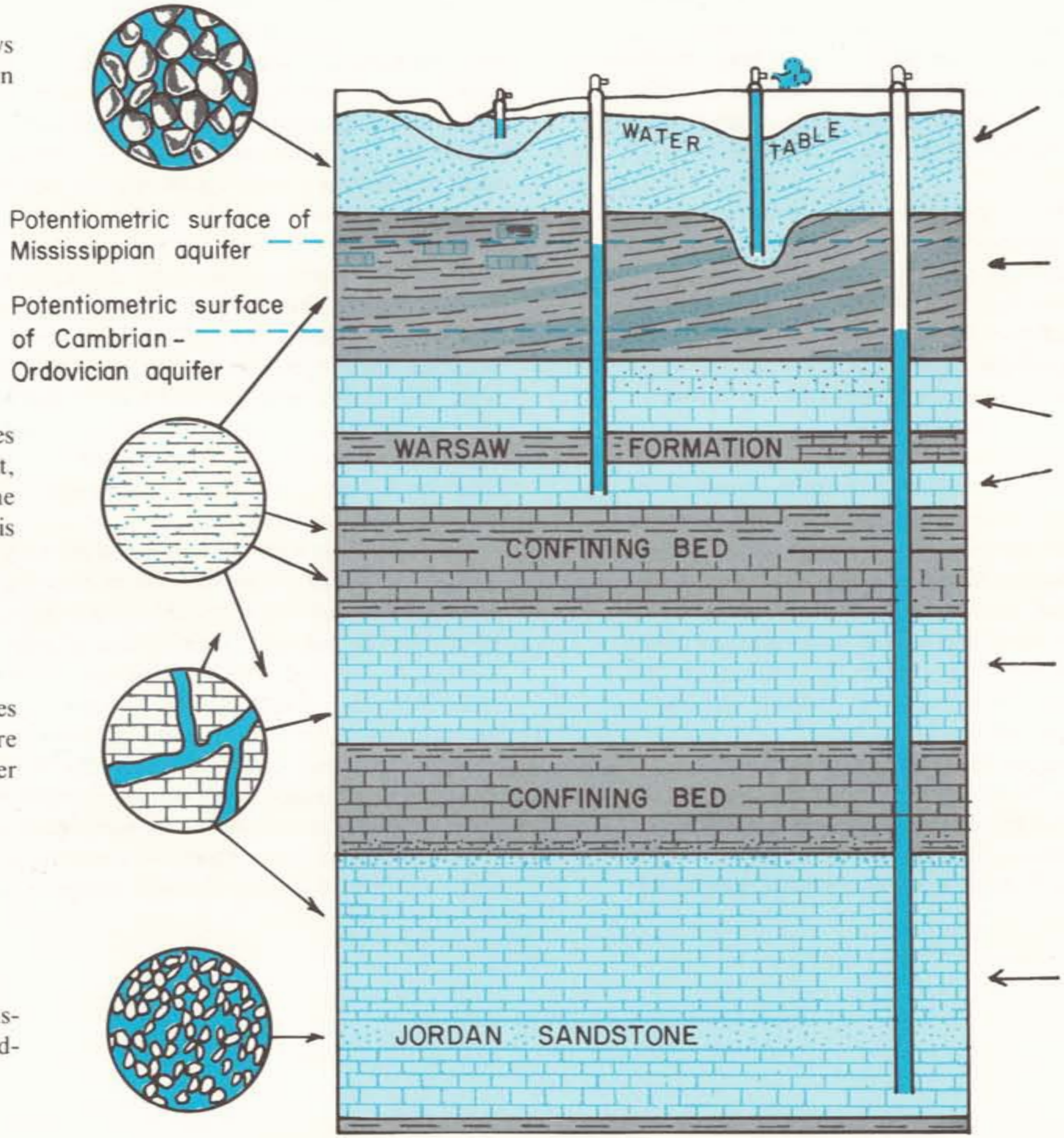
Ground water moves through and is stored in aquifers. The water occurs and moves in fractures, joints, and solution openings in limestone and dolomite, and in the voids between the grains in sand and gravel and sandstone. The size, shape, and distribution of the openings control the storage and movement of ground water and vary considerably from place to place and from rock type to rock type.

Only those rocks with numerous large inter-connected void spaces through which water moves freely enough to supply wells are called aquifers. The principal confining beds, clay and shale, generally are relatively impervious to the movement of water and are not a source of water supply. Clay and shale have a high percentage of void spaces and can store large amounts of water. However, because the rock particles and void spaces are small and the voids are poorly connected, they hold water through molecular attraction rather than allow it to pass to wells. Dense, compact limestones and dolomites and dense fine-grained, cemented sandstones also act as confining beds.

Although aquifers are of primary concern in the discussion of the water resources, confining beds have considerable hydrological significance. Confining beds prevent or retard the movement of water between the land surface and the aquifer and between aquifers. Aquifers overlain by confining beds receive little or no recharge from local precipitation; these aquifers, especially the limestones and dolomites, usually will yield a more mineralized water to wells.

Aquifers that are not overlain by confining beds, such as some of the surficial aquifers and parts of the Pennsylvanian and Mississippian aquifers, contain water that is unconfined. That is, the top of the zone of saturation is free to move up or down and the aquifer can receive recharge from local precipitation. Water in a well tapping an unconfined aquifer will not rise above the level at which it is first encountered. Under this condition the aquifer is referred to as a water-table aquifer and the upper surface of the zone that is saturated with ground water is called the water table (figs. 44 and 45).

In the bedrock aquifers and in some of the surficial aquifers, where they are overlain and underlain by confining beds, the water is confined under pressure. When a well penetrates such a confined aquifer, the hydrostatic pressure causes the water to rise above the top of the aquifer, and the aquifer is referred to as artesian, while the water is referred to as artesian water. The imaginary surface to which water will rise in tightly cased artesian wells is called the potentiometric surface. An artesian well will flow if the altitude of the potentiometric surface is above that of the land surface (fig 45). Each artesian aquifer in south-central Iowa has a separate potentiometric surface.



Water is easily stored and flows freely in the open spaces between grains of sand and gravel.

Water is stored in large quantities in some confining beds but, because the open spaces in the rocks are extremely small, it is not transmitted readily.

Solution channels and fissures in limestone and dolomite are conduits in which ground water can move and be stored.

Water is stored and readily transmitted in the open spaces in sandstone.

SURFICIAL AQUIFERS
Gravels and sands are readily recharged by precipitation.

PENNSYLVANIAN ROCKS
Principally confining beds, containing some local and subregional aquifers. In the study area, sandstone and limestone aquifers are recharged where they are at or near the bedrock surface.

MISSISSIPPIAN AQUIFER
Aquifer recharged where at or near bedrock surface in the study area; also recharged from outside area.

DEVONIAN AQUIFER
Local precipitation has little recharge effect on this aquifer. Recharge occurs outside of this area and water moves laterally through the aquifer.

CAMBRIAN-ORDOVICIAN AQUIFER
Area of potential recharge more than 100 miles from south-central Iowa. Continued long-term withdrawals, both within and outside the area, have resulted in lowered water levels in parts of the area.

Figure 44.— Occurrence of water in the aquifers

WATER LEVELS

The water level in a well represents the position of the water table or potentiometric surface at the site of a well. A number of water-level measurements in many wells throughout an area can be compiled on maps, and the water surface can be represented by contours in much the same way that the land surface and the tops of aquifers are portrayed. Because these maps depict the altitude of the water table or the potentiometric surface of each aquifer, they can be used to predict nonpumping water levels for the proposed wells in an area.

The configuration of the water table or potentiometric surfaces tells an important story about ground-water movement in the area. Water in each aquifer moves from areas of high head (high contour values) to areas of low head (low contour values) and the general direction of flow is perpendicular to these contour lines. That is, unconfined water moves through the rocks in a direction of flow determined by the slope of the water table, and confined water moves in a direction determined by the slope of the potentiometric surface.

Water-level maps for some aquifers indicate that the water is moving directly across south-central Iowa and, except for the Des Moines River and its alluvial valley, local topography and streams have little or no effect on the directions of water movement. These aquifers receive the major portion of their recharge from outside the area, and in some cases the water had moved a long distance through the aquifer before reaching south-central Iowa. Water-level maps for other aquifers indicate that the water movement is influenced by local topography. The higher contour values are in the upland areas and the lower ones are near the streams, indicating that the aquifers are recharged and discharged within the south-central Iowa area. Recharge to these aquifers is from local precipitation; discharge is toward nearby streams.

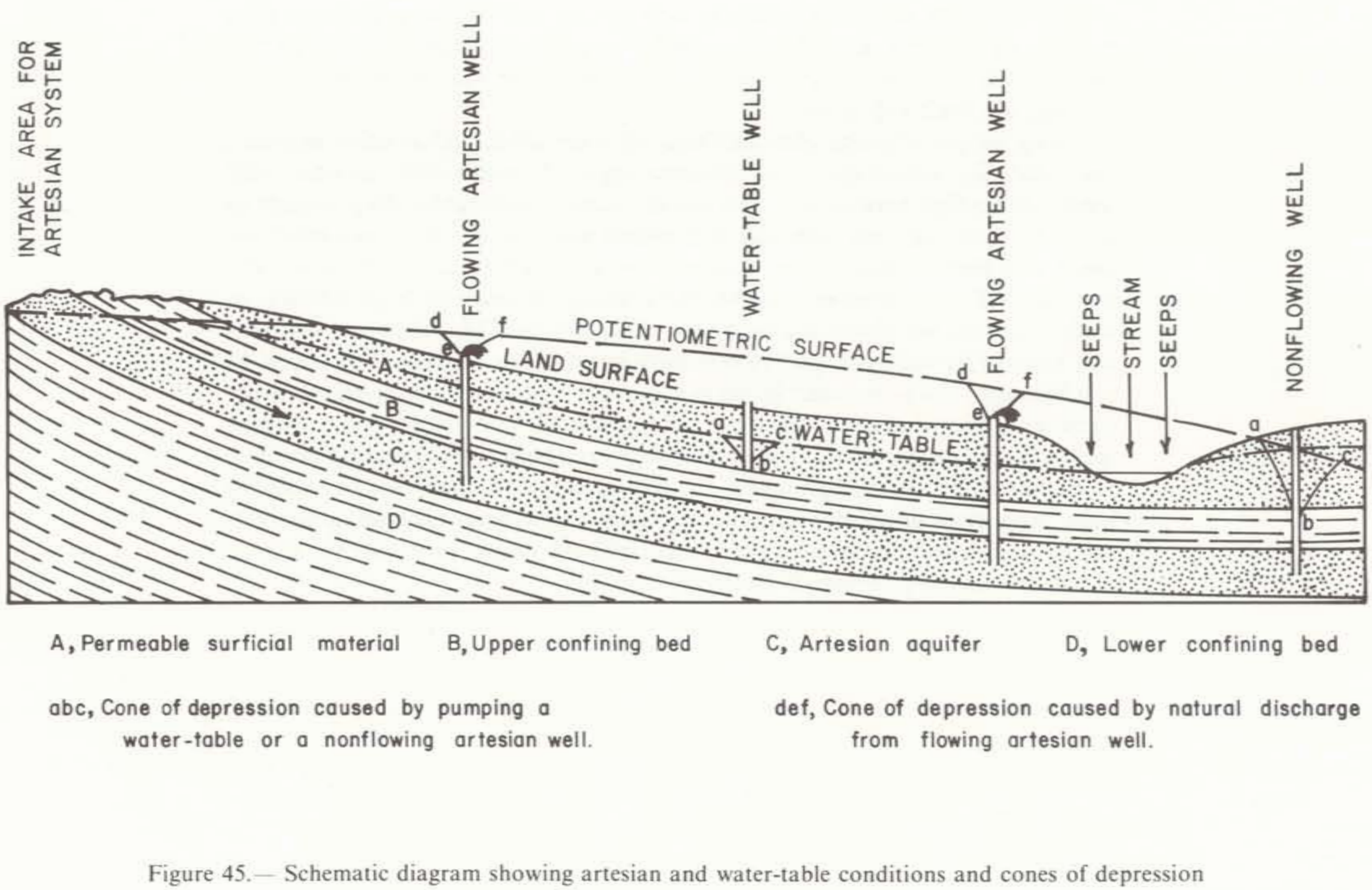
The major part of the recharge reaches the water-table and the shallow artesian aquifers during two periods of the year. One is the time between the spring thaw and the beginning of the growing season. Part of the precipitation can infiltrate the unfrozen soil, and because plant transpiration activity is low during this time of year, the water can move down to the water table. The second period is the interval between the first killing frost in the fall, which heralds the end of the growing season, and before the ground is frozen in the late fall or early winter. During most of the winter when the soil is frozen, very little water infiltrates the soil. During the growing season, vegetation intercepts infiltrating moisture and only excess precipitation or periods of prolonged precipitation will provide enough water to satisfy the demands of plants and still offer an excess that may reach the saturated zone. Hence, water levels in water-table and shallow artesian aquifers generally are highest in late spring and fall, and are lowest in late summer and winter.

When only a small amount of precipitation falls during the recharge periods, such as during times of drought, the water table will continue to fall because discharge from the aquifers is a continuous process. Many shallow wells in water-table aquifers "go dry" in the summer and in some winter periods. The wells are dry simply because the water table is lowered below the bottom of the well. The wells usually contain water again when recharge is sufficient to raise the water table. Because water levels in water-table wells show considerable fluctuations, water-table maps should be based on water-level measurements made on the same day. Water-table maps based on scattered measurements are generalizations at best.

Water levels in artesian aquifers, especially those that are deeply buried, are only slightly affected by short-term changes in recharge. The major areas of recharge for these aquifers are usually tens or hundreds of miles away. The effects on the potentiometric surface of any variations in weather, such as an increase or decrease in recharge during exceptionally wet or dry seasons, will be smoothed out because of the distance to the recharge area. Therefore, the potentiometric surface of deep artesian aquifers that are undisturbed by pumping does not fluctuate seasonally or even annually to any great extent. Potentiometric maps based on water levels made over a period of years have greater validity than have water-table maps made from similar data.

In addition to fluctuations produced by weather, water levels also fluctuate when artificial discharge through pumping wells is imposed on the hydrologic system. When a well is pumped or allowed to flow, the water level or potentiometric surface is lowered around the well, establishing a hydraulic gradient that slopes toward the well in all directions. This depression, in the approximate form of an inverted cone with its apex as the well, is known as the cone of depression. However, as withdrawal continues, the water level declines more slowly as the cone of depression expands and water moves to the well from progressively greater distances. The water level will continue to decline, although at a diminishing rate, and the cone of depression will continue to expand to the limits of the aquifer, unless sufficient natural discharge is salvaged or sufficient recharge is induced to halt its expansion. The diameter of the cone in an artesian aquifer generally is measured in thousands of feet, whereas the diameter of the cone in a water-table aquifer is measured in hundreds of feet.

When two or more pumping wells are located close to each other, their cones of depression are likely to overlap. This interference can result in a decreased yield from each individual well and water levels so low that pumping costs are prohibitive. For this reason, wells pumping large volumes of water from the same aquifer should be spaced some distance apart. A detailed analysis of an aquifer's characteristics often can be conducted to determine the distances needed between wells to avoid interference or keep it within acceptable limits.



A, Permeable surficial material B, Upper confining bed C, Artesian aquifer D, Lower confining bed

abc, Cone of depression caused by pumping a water-table or a nonflowing artesian well.

def, Cone of depression caused by natural discharge from flowing artesian well.

Figure 45.— Schematic diagram showing artesian and water-table conditions and cones of depression

If the pumping rate from an artesian well remains constant, the water level will decline and eventually approach stability with little additional decline. However, any increase in withdrawals from the aquifer will cause the downward trend to accelerate again. If pumping is reduced, the cone of depression will adjust to the lower pumping rate by becoming shallower and smaller. If pumping is stopped entirely, the cone of depression will eventually cease to exist, and the water levels will return essentially to where they were before pumping began.

The same phenomenon, of a much lesser magnitude, is observed in water-table wells. Unless the well is overpumped, the cone of depression in this aquifer reaches dynamic equilibrium much quicker than the cone of an artesian aquifer. The cone in the water-table aquifer will spread until it covers an area large enough to intercept a sufficient amount of infiltrating water to supply the demands of pumping. During wet periods, the cone will shrink, during dry periods, the cone will spread.

Owing to the inherent characteristics of water-table and artesian aquifers, each has its advantages and disadvantages. A water-table aquifer with moderate-to-high permeability can usually yield a moderate-to-large supply of water by receiving local recharge, and several wells can be placed in a relatively small area because their cones of depression are smaller than are those around artesian wells. An artesian well that is pumping moderate-to large amounts of water generally will develop a large cone of depression. Thus, most artesian wells will have to be widely spaced to minimize interference between their cones. In south-central Iowa, the water levels in water-table wells are not excessively deep; therefore, the cost of lifting the water wil not be high. The water levels in artesian wells are often lower than in water-table wells, and because they usually continue to decline with sustained pumping, the cost of lifting the water will be relatively high. A water-table aquifer is responsive to local short-term changes in weather; on the other hand, artesian aquifers, especially the deeper ones, are not greatly affected by short-term trends in the weather.

Water Levels in Surficial Aquifers

Probably most water in the surficial aquifers is unconfined and under water-table conditions, but some is confined and under artesian conditions. Depending upon the relative permeability and the spatial relationships of materials overlying these aquifers, water in a given aquifer may at one place be confined and at another place unconfined. Principally because of these variable conditions of occurrence, and because water-level data were too few and too widely dispersed for mapping purposes, maps were not constructed to show the water surfaces of individual surficial aquifers.

Water levels in the surficial aquifers in the area are affected by the presence or absence of confining beds, precipitation or the lack thereof, evapotranspiration, the interchange of water between the aquifers and streams, and the movement of water between aquifers. Water levels also are artifically affected by pumping and by induced infiltration from streams when pumping causes excessive lowering of the water table in the aquifer.

The alluvial aquifer and the shallower drift aquifers usually are nearest the land surface and usually are unconfined at most places; therefore, water levels in these units respond more quickly to recharge from precipitation than do the other surficial aquifers. Water levels will range from 5 to 20 feet below land surface in the alluvial aquifers and from 10 to 40 feet in the shallow drift aquifers. The deeper drift aquifers and the buried-channel aquifers are confined, and the water is under artesian pressure. For example, in a well completed in one of the deepest buried-bedrock channels, the water level rose as much as 250 feet above the top of the aquifer, which brought the static water level to within 140 feet of land surface. Water levels in these deeper surficial aquifers generally are more than 100 feet below the upland surface.

The hydrologic relationship between streams and the surficial aquifers is varied. The water table in the shallow drift aquifer generally slopes from high topographic areas towards the stream valleys, where water is discharged into the alluvial aquifer. Water in buried-channel aquifers, where under high artesian head, probably moves upward to streams at places where the confining bed permits some upward leakage and the altitude of the stream valley is low. The alluvial aquifer is unique among the surficial aquifers in that there usually is a direct hydrologic connection between the aquifer and the adjacent stream. Normally, water moves from the vicinity of the valley wall to the stream; however, when the stage in the stream is higher, there is a reversal and flow is from the stream to the aquifer. The flow is also reversed when pumping lowers the water level in the aquifer below the stream stage and the aquifer is recharged by the stream.

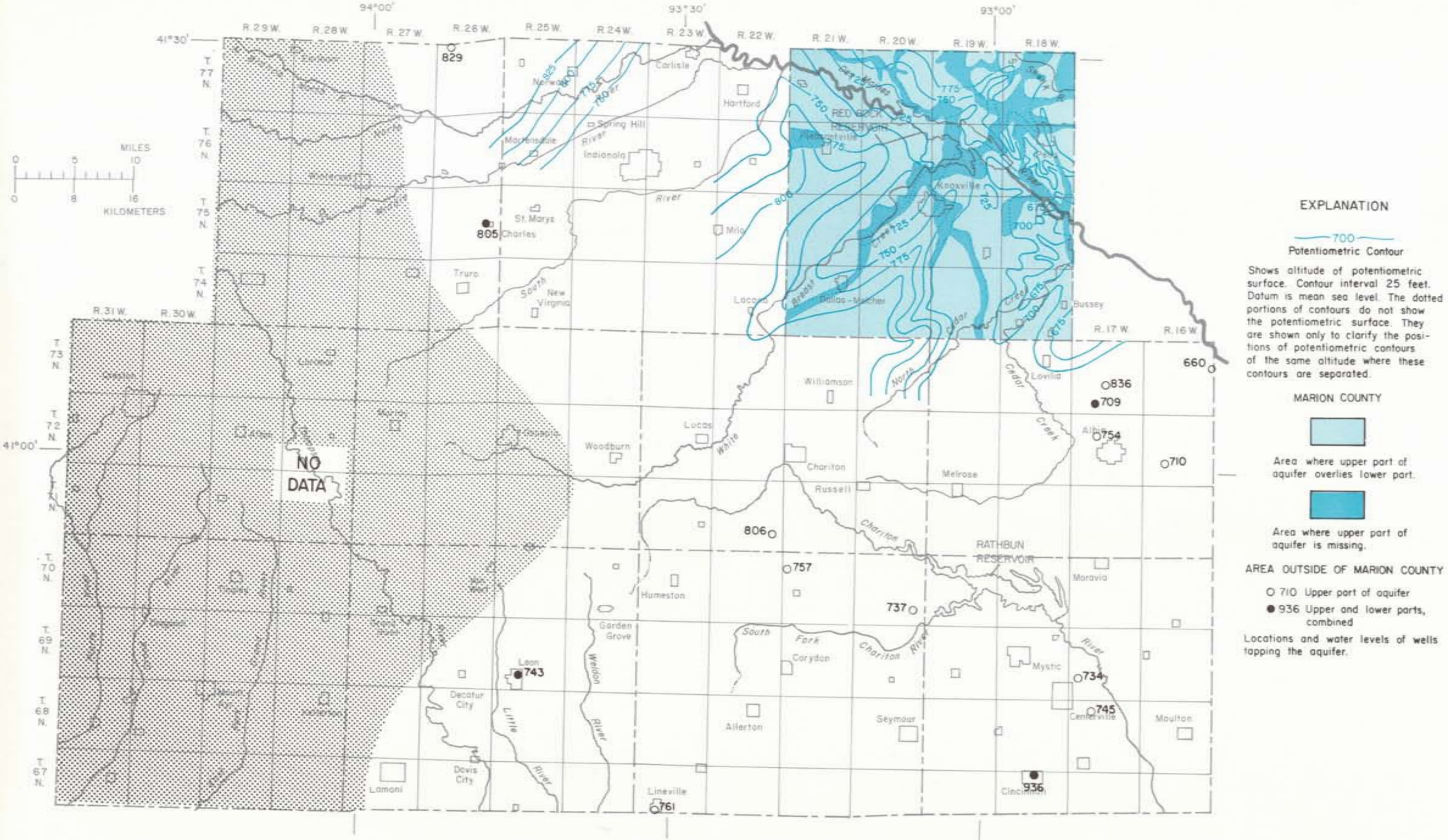


Figure 46.— Altitude of water levels in wells tapping the upper part of the Mississippian aquifer

Water-level maps were not prepared for the Pennsylvanian aquifers, because data are not presently available. However, some general observations can be made with regard to water levels in some of these aquifers. Water in the sandstone aquifers of the Cherokee Group is under both artesian and water-table conditions and, based on scattered data in Decatur, Lucas, Marion, Monroe, and Warren Counties, water levels in these aquifers range in altitude from about 675 to 900 feet above mean sea level. At a few places in these counties, water levels from different water-bearing beds at different depths in the Cherokee could be compared. These comparisons showed that at any given site where two or more aquifers are present, water-level altitudes were progressively higher in aquifers at correspondingly higher altitudes in the Cherokee. Also, water levels in the Cherokee aquifers were higher than were water levels in the Mississippian aquifer, except possibly for those sandstone aquifers near the base of the Cherokee. Too few data were available to make even generalizations about water levels in the limestone aquifers in the Kansas City Group.

Water from the aquifers in the Cherokee Group discharges to the principal present-day valleys and the buried-channel aquifers in parts of Marion, Lucas, Warren, Monroe, and Madison Counties, where the Cherokee has been deeply incised.

In the report area, sufficient data to map the potentiometric surface of the Mississippian aquifer were available only in parts of Lucas, Marion, Monroe, and Warren Counties. In this area, data were available to map the upper and lower parts of the aquifer separately (figs. 46-47). Water in the upper part is under artesian pressure at most places, but where the aquifer is at or near the bedrock surface it is often under water-table conditions. Water in the lower part of the aquifer probably is under artesian conditions everywhere. The potentiometric surface of the upper part of the aquifer in Marion County is about 25 feet higher than that of the lower part. The relationship in the rest of the region is not known. The contours in figures 46 and 47 indicate that water from the upper and lower parts of the aquifer discharges into some of the larger streams and their alluvial valleys at places where the aquifer is at or near the bedrock surface.

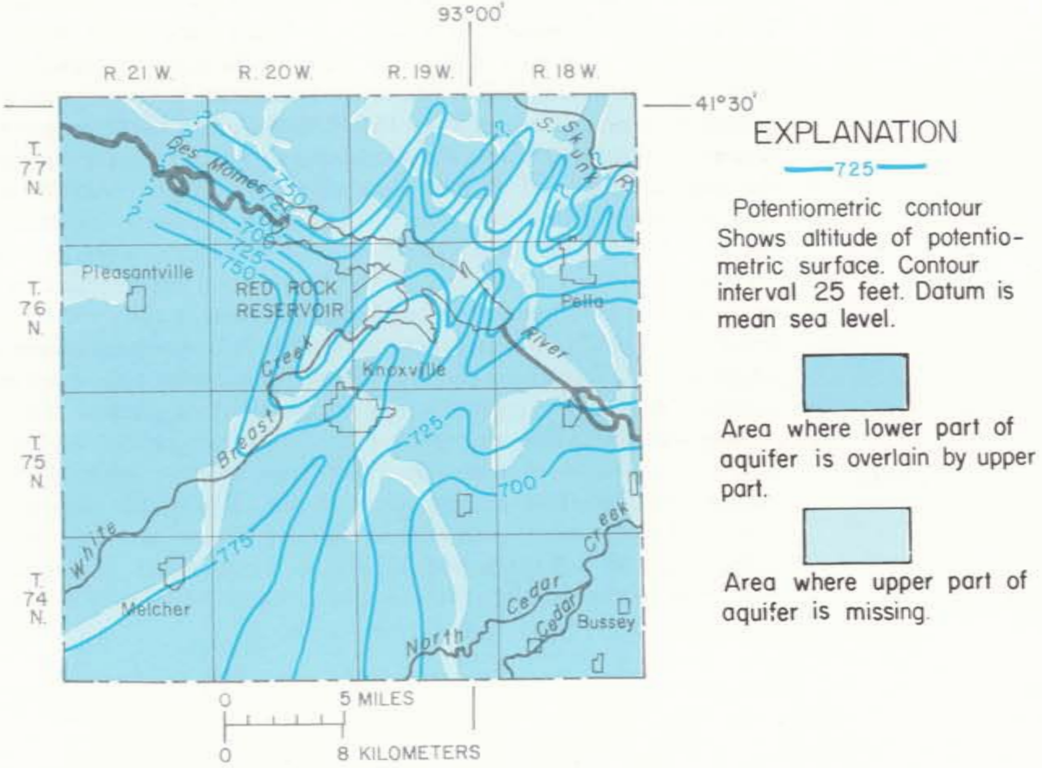


Figure 47.— Altitude of water levels in wells tapping the lower part of the Mississippian aquifer in Marion County

Data were not available to construct a map showing the altitude of water levels in the Devonian aquifer. Only two wells, one of these a former municipal well at Lamoni, are known to have tapped the aquifer for supplies. A comparison of the relative altitude of water levels in the Devonian with other aquifers can be made at Lamoni with only one other aquifer, the Cambrian-Ordovician. The original altitude of the water level in the Lamoni well was about 775 feet and that of the Cambrian-Ordovician aquifer an estimated 725 feet. The 50-foot difference in water levels at Lamoni is reasonable, and a similar difference probably occurs throughout south-central Iowa.

Sustained development of water supplies from the Cambrian-Ordovician aquifer in the region began in 1955, when the town of Indianola instituted pumpage from the aquifer. Prior to 1955, a few wells were drilled to the aquifer during the years 1893 and 1920, but these were soon abandoned and, therefore, had no long-term effect on either regional or local water levels. The pre-1955 water levels, however, were affected to some unknown degree by pumpage adjacent to the region — particularly at Ottumwa, which is about 12 miles east of the regional boundary. (See Coble, 1971, p. 56.) A map of the regional predevelopment potentiometric surface (fig. 48) was constructed using water-level data from the earliest wells (1955-63) drilled in the region. Water-level data from 1965-68 were used if the wells were remote from previously established pumping centers. This predevelopment potentiometric surface of the aquifer ranged from an altitude of more than 725 feet in the northwestern part of the region to less than 625 feet in the southeastern part (fig. 48). The configuration of the potentiometric surface in the eastern part of the region is attributed to large-scale pumpage at Ottumwa. The potentiometric surface as it existed in 1975 is shown in figure 49. Changes which are readily apparent when the two surfaces are compared are (1) the slope of the surface and the direction of the water movement in 1975 was to the north and northeast in the northern part of the report area and (2) the regional water level in 1975 showed a general decline of about 10 to 75 feet of the pre-1955 surface. Maximum decline occurred in the northern part of the region, where the pumpage is greatest. The minimum decline occurred in the easternmost part of the region, where rising water levels, owing to cessation of pumpage at Ottumwa in 1974, mitigated the general decline. The indicated change in the direction of water movement can be attributed to the heavy pumpage in the Des Moines area and the increasing withdrawals at Indianola and Knoxville. Local cones of depression have developed in the vicinity of these towns, where declines in water levels are approximately 125 and 50 feet, respectively.

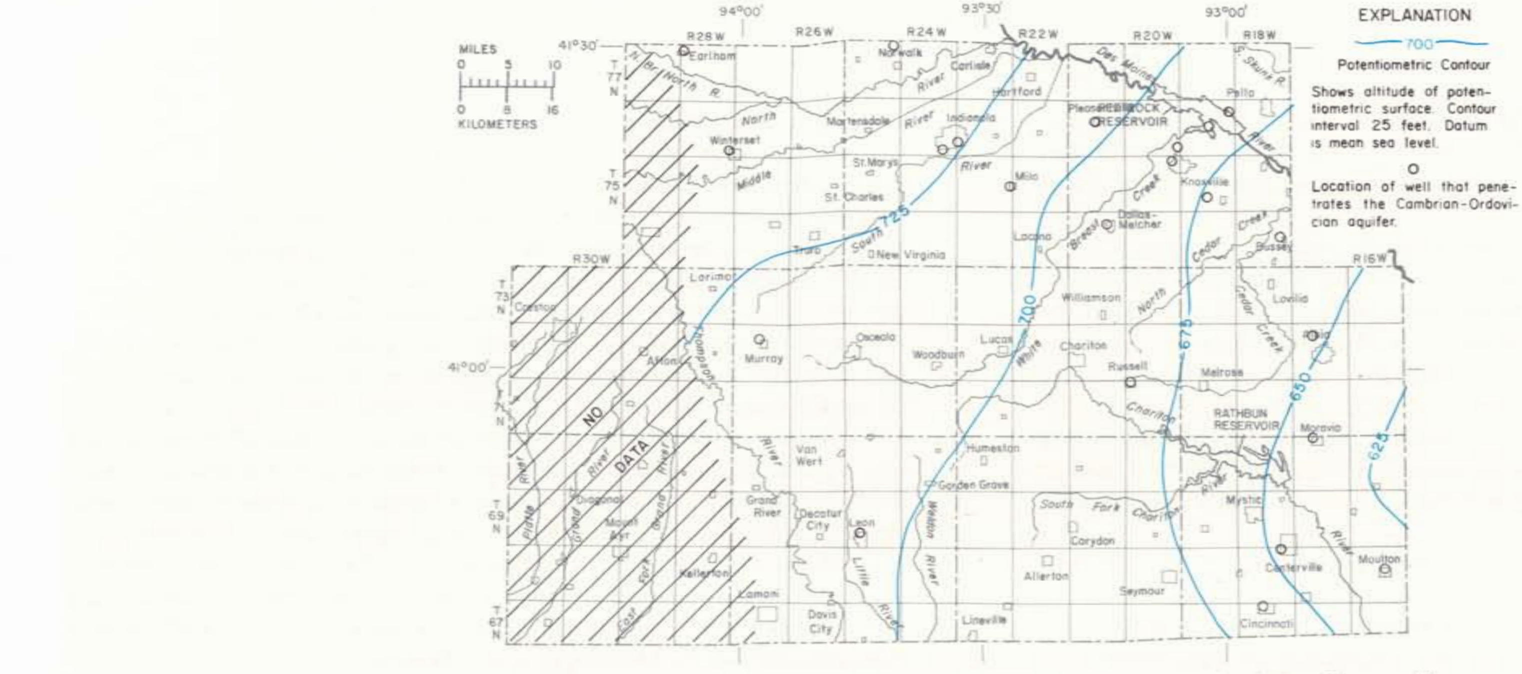


Figure 48.— Predevelopment potentiometric surface of the Cambrian-Ordovician aquifer

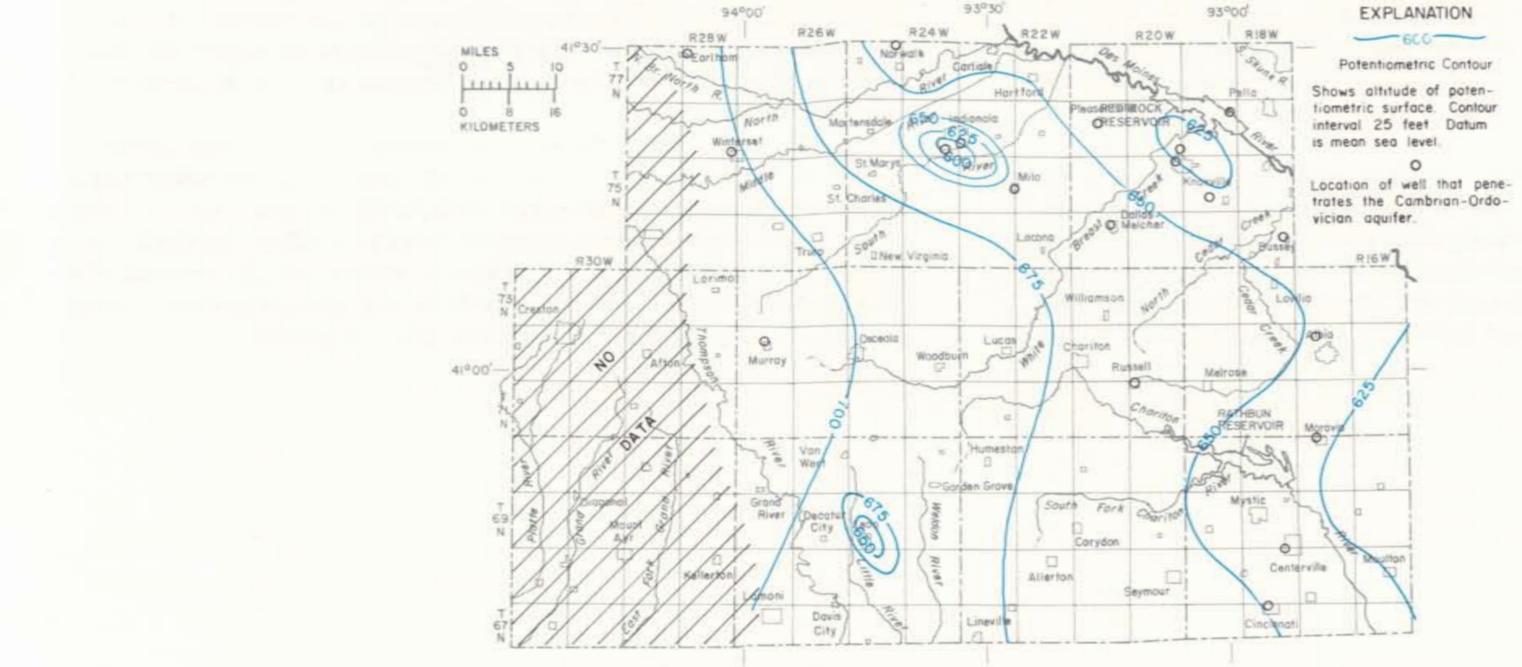


Figure 49.— Potentiometric contour map of the Cambrian-Ordovician aquifer in 1975

YIELDS FROM WELLS

The principal factors affecting well yields are the inherent characteristics of aquifers, which are the aquifers' ability to store and transmit water. Other factors which directly affect yields are the methods and procedures of well design and development.

Aquifer characteristics are quite variable in south-central Iowa; consequently, yields vary both between aquifers and within individual aquifers. The overall range in yields is from 1 gpm or less to more than 1000 gpm and, regionally, the most productive sources are the alluvial and Cambrian-Ordovician aquifers. Generally, the rocks that are the best aquifers are clean, well sorted sand and gravel; coarse-grained, loosely-cemented sandstone; and carbonate rocks that have a high percentage of void space. The maps for some aquifers on the next few pages delineate areas of probable yields to individual wells. The data used in constructing these maps include production records of wells and regional geologic information.

The production records usually indicate the pumping rate of the wells and drawdown, which is the amount the water level in the well was lowered while the well was pumped at that rate. The yield of a well is best expressed in terms of its specific capacity (yield per unit of drawdown) computed from drawdown and pumping rate when the well is test pumped. Because wells are not always test pumped at rates which utilize all of the available drawdown, the test-pumping rates do not necessarily indicate the optimum yield of a well. However, if the specific capacity is known, the potential sustained yield can be determined or estimated. Drawdown, yield, and specific-capacity data were evaluated for wells tapping the various aquifers and this was the main basis for assigning possible yield values to the aquifers.

Geologic data indicating the type of rock that comprises each aquifer, the thickness of the rock units and the spatial relationships of the aquifers with respect to the land surface and to confining beds, and the characteristics of rock openings were also used to predict possible yields. In the areas where limestones and dolomites lie near the land surface and are not covered by confining beds, one can expect the joints, cracks, and fissures to have been enlarged by the solution action. This allows water freer passage through the aquifer than where the rock has only small openings through it. Other factors being equal, the thicker the aquifer the more water it will yield to a well. Sand and gravel deposits will yield more water to individual wells where the deposits are at or near the surface and can be recharged readily by infiltrating precipitation or induced infiltration from streams. Thus, the alluvial aquifers will normally yield more water to wells than will the buried-channel aquifers, which are commonly deeply buried. If the spaces between the grains of a granular aquifer are filled with other materials such as clay or a carbonate type of cement, water cannot move through the material as readily, and a reduction in yields to individual wells will result.

The following yield maps are based on information available at the present time and represent known and predicted yields from the several aquifers in south-central Iowa. An important part of the planning phase for high-production wells should include test-drilling and test-pumping programs in order to determine the water-producing capabilities of the aquifers. This is particularly important when planning to develop any of the surficial aquifers because the water-yielding sands and gravels in these deposits are seldom uniform in thickness, areal extent, or hydrologic characteristics.

The estimated yields from both surficial and bedrock aquifers are those that can be expected from properly constructed and developed wells and are yields that can be sustained over an extended period of time. Anomalous yields which are greater than the normal range of yields indicated for an area do occur, and those are shown on some maps. These anomalous yields, however, probably cannot be sustained.

The alluvial aquifer is the most productive of the surficial aquifers. It is capable of furnishing from about 5 to 500 gpm. Yields are lowest where the aquifer is thin or clayey and highest where sands and gravels are thickest and have relatively wide distribution within the stream valleys. Generally, the best yields can be expected in the largest alluvial valleys. Any development of water from the alluvium should be preceded by drilling several test holes to locate the thickest and most permeable deposits of sand and gravel.

Possible yields from the shallow drift aquifer are, regionally, the lowest available from the surficial aquifer. Yields estimated from this source, generally less than 5 gpm, would apply to the aquifer in most parts of the area, but, locally, yields may be somewhat higher. Most wells that tap the drift aquifer are ended at depths of 50 feet or less in the first water-bearing sand and gravel encountered. However, yields of many of the shallow wells decrease during periods of drought when water levels decline. Higher sustained yields from the drift aquifer often may be found by locating and developing the deeper sands and gravels, because these deposits generally are affected less by variations in local precipitation and usually have a wider distribution than do the shallower sands and gravels.

The buried-channel aquifer is present only in parts of the major buried-bedrock channels, but where present it has the potential to furnish small-to-moderate supplies. Production data generally is lacking for the aquifer; consequently, an estimate of available yields from this source is based on the thickness, distribution, and estimated hydrologic characteristics determined by test-drilling.

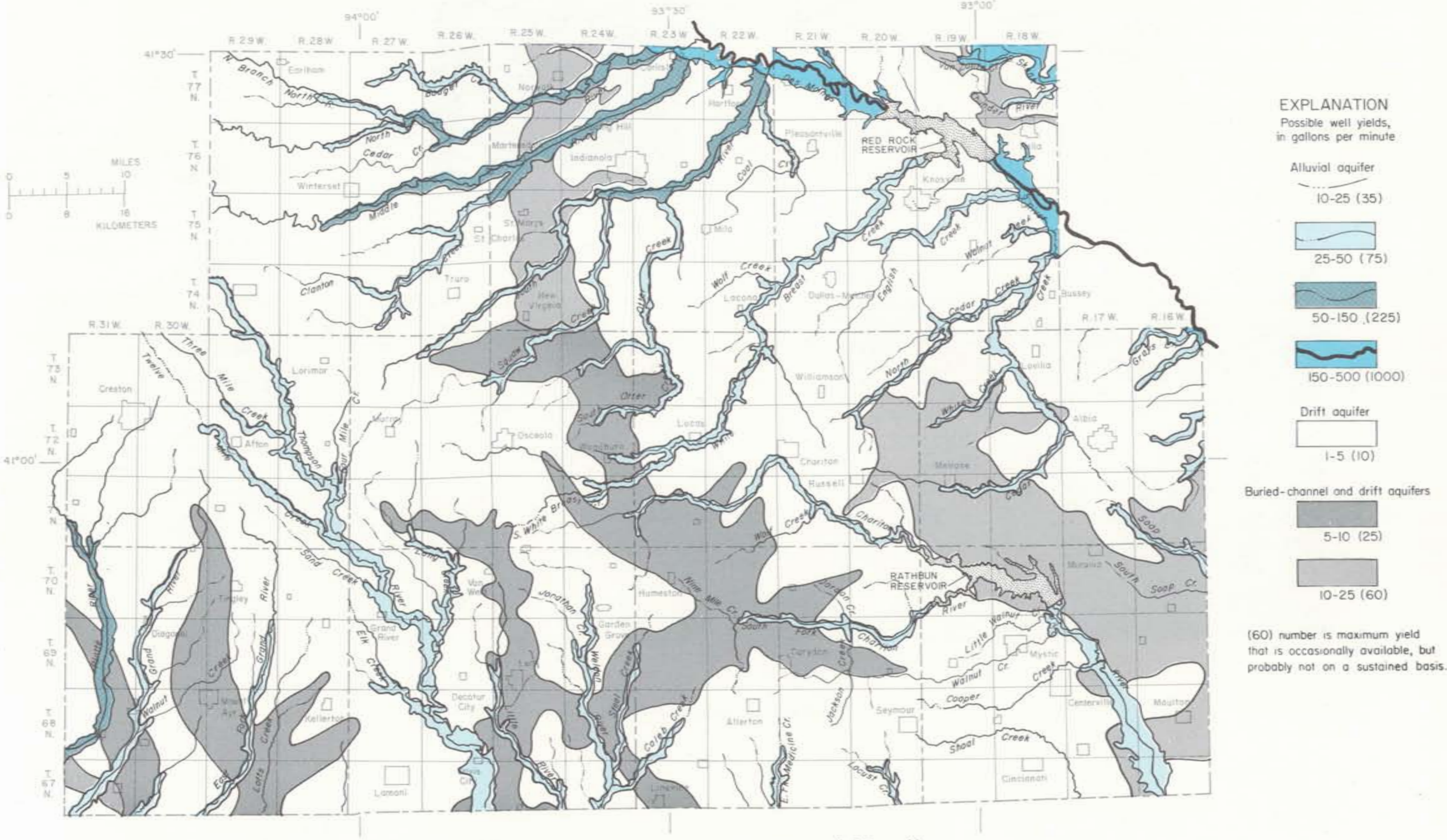


Figure 50.— Yields to individual wells; surficial aquifers

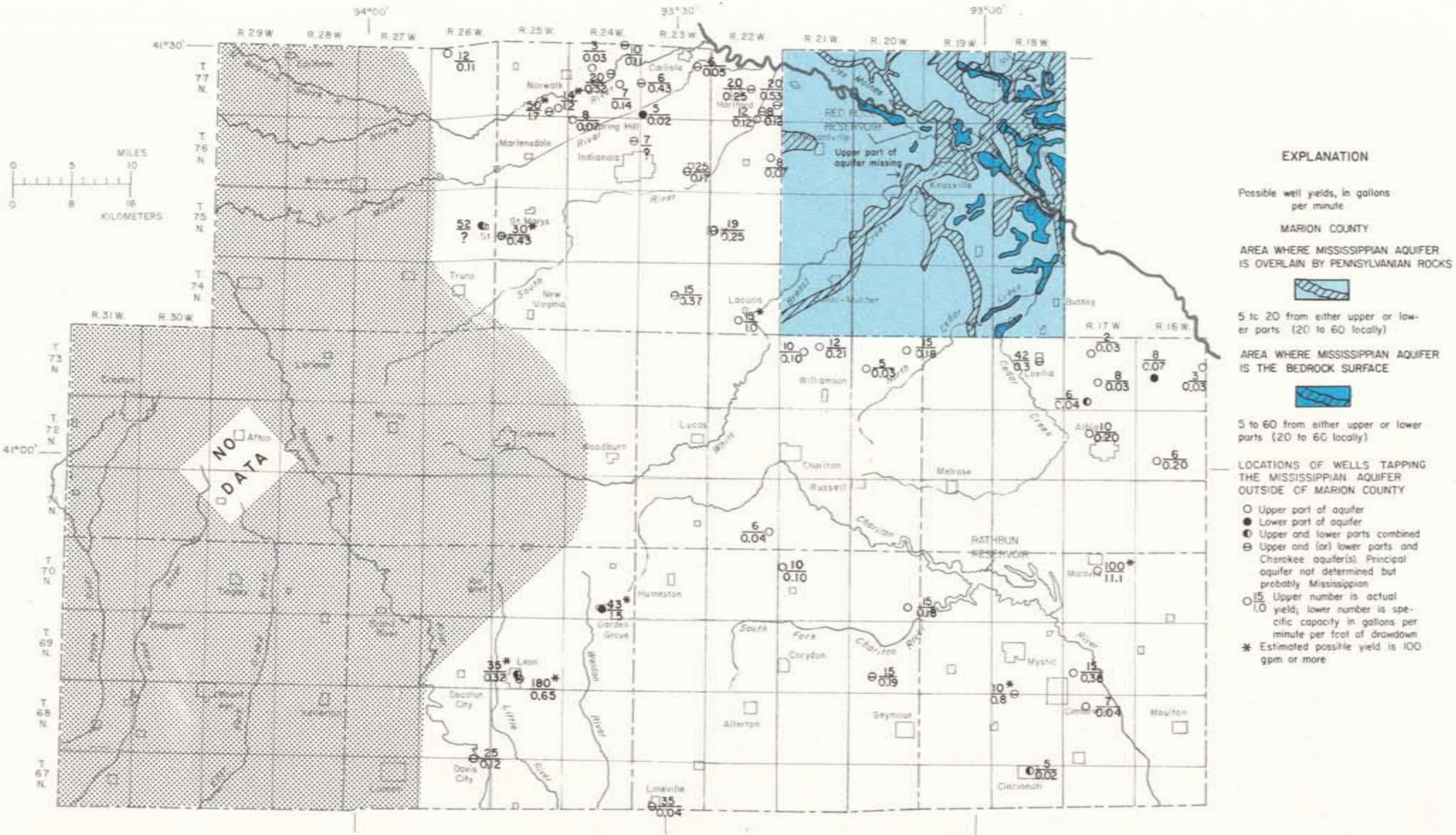


Figure 51.— Yields to individual wells; Mississippian aquifer

The sandstone and limestone beds in the Cherokee and Kansas City Groups of the Pennsylvanian will yield small-to-moderately large quantities of ground water in the report area. The best estimate that can be made of yields from these individual aquifer units in the Pennsylvanian is that at most places production will be less than 25 gpm and usually will be between 3 and 10 gpm. Locally, however, some sandstone aquifers in the Cherokee are capable of furnishing 25 to 100 gpm and occasionally yields will exceed 100 gpm, and some limestone aquifers in the Kansas City Group will yield 25 to 100 gpm where large crevasses or cavities exist. Although no specific relationship was established between individual aquifers and yields in any given area, there is some indication that better yields generally are available where the Cherokee and Kansas City Groups occur at or near the bedrock surface and also are better from the Cherokee where the sandstone aquifers are near pre-glacial channels cut into the bedrock. But, the apparent principal reason for the disparity in yields from the Cherokee sandstones is that for any given bed there are both lateral and vertical changes in the character and composition of the rock that determine its ability to yield water.

Yields from the Mississippian aquifer are variable, which is typical of most carbonate aquifers in Iowa. The highest yields are obtained where the aquifer is the bedrock surface and is overlain by the more permeable surficial materials. The lowest yields are obtained where the aquifer is overlain by the thick Pennsylvanian shales, although exceptions do occur. Data on yields and specific capacities are sparse in the region, except for Marion County. There the data are sufficient in quantity and distribution to depict graphically the yields from the aquifer (fig. 51); elsewhere in the region the data only is presented on the map.

In Marion County possible well-yield values were computed on the premise that a well penetrates and is completed in either the upper or the lower parts of the aquifer. When drilling a well in areas where the upper part of the aquifer is present, appreciable increases in yield usually will not be obtained by drilling into the lower part. In figure 51, within those areas where the areal extent of the two divisions of the aquifer relative to the Mississippian surface and to each other is indicated, there is about an 85 percent probability that the lower estimated yields will be obtained by wells tapping either part of the aquifer. An evaluation of specific capacities of approximately 165 wells indicated a median value of about 0.1 gpm per foot of drawdown for the lower part of the aquifer and 0.15 for the upper part. Within the areas just described, places where higher yields are available locally cannot be accurately delineated because they are of limited extent, rather isolated, and form no particular or obvious areal pattern. The small percentage of sites where higher yields are obtainable almost certainly represent local conditions where relatively large solution channels, cavities or fissures exist in the carbonate rocks.

The Mississippian aquifer in those parts of the report area outside of Marion County appears to have the potential at some places to furnish yields of 100 gpm or more; otherwise yields appear to be comparable to those indicated for Marion County. Also, the probability that the lower range of yields (less than 20 gpm) would be obtained by wells tapping either part of the aquifer outside of Marion County appears to be the same — that is, about 85 percent. Many wells that tap the Mississippian aquifer develop some water from the overlying sandstone aquifers in the Cherokee (fig. 51). Some of these wells are believed capable of yields in excess of 100 gpm.

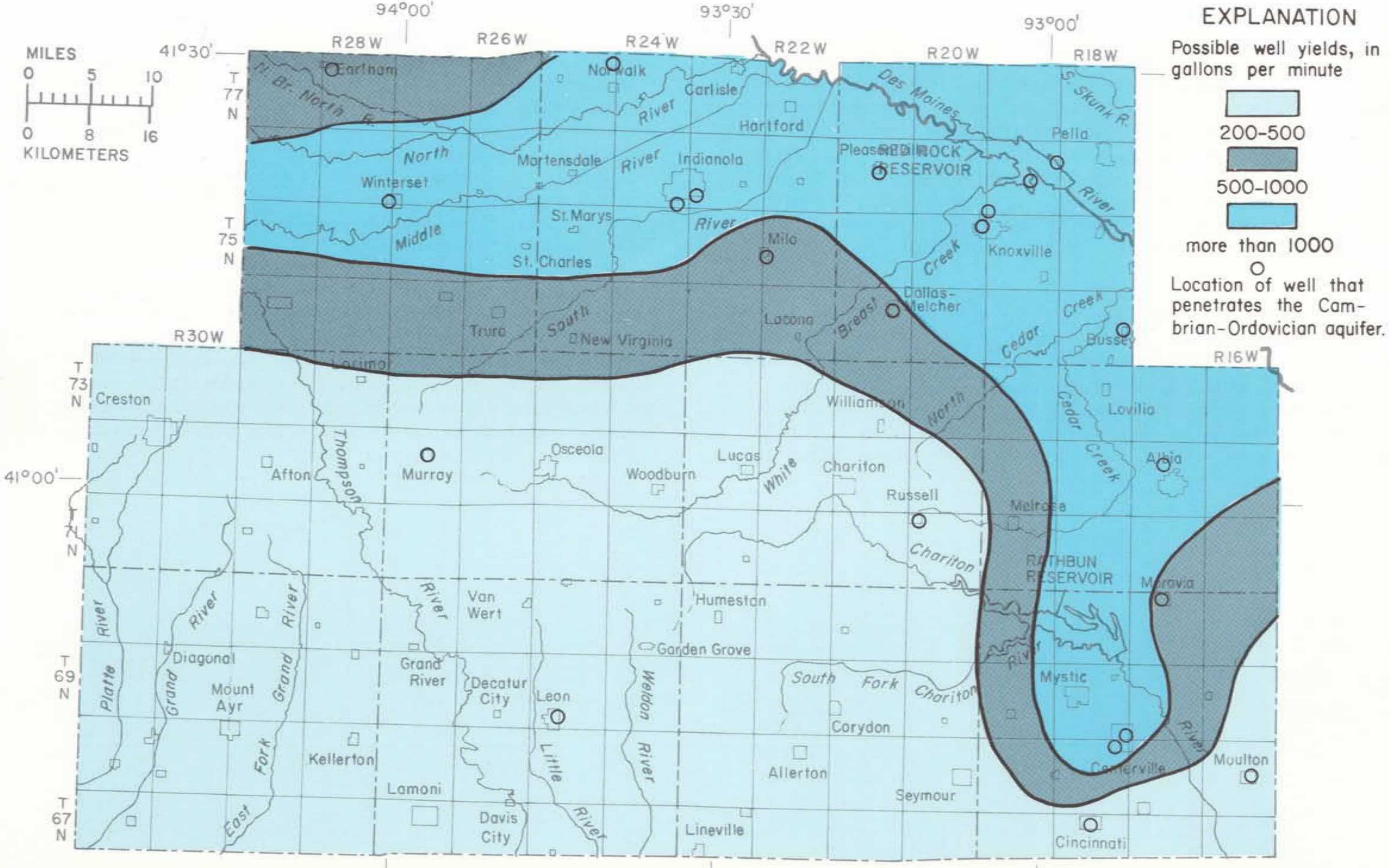


Figure 52.— Yields to individual wells; Cambrian-Ordovcian aquifer

A few wells in south-central Iowa have tapped the Devonian aquifer in combination with other aquifers; however, only two wells are known to have developed water from the aquifer separately. One of these, a municipal well at Lamoni in Decatur County, now abandoned, produced 105 gpm on a pumping test and reportedly produced a sustained yield of 85 gpm. Production data from counties in east-central and southeast Iowa, when projected into the report area and compared with the Lamoni well, indicate a yield range of 20 to 100 gpm for the Devonian in south-central Iowa.

The Cambrian-Ordovician aquifer yields larger quantities of water to individual wells than does any other aquifer in the report area. From 1955 to 1975, 21 wells drilled for public supplies have tapped the aquifer; their yields ranged from 110 to 1529 gpm and their specific capacities ranged from 3.5 to 42 gpm per foot of drawdown. The usual method of well construction and development is to set the bottom of the casing into the top of the Prairie du Chien and to develop the sequence of strata that includes the Prairie du Chien, Jordan, and upper part of the St. Lawrence. The overlying St. Peter Sandstone, almost always is cased off.

The Jordan Sandstone generally is recognized as the most productive individual unit in the Cambrian-Ordovician aquifer in Iowa and this is believed to be so in most parts of south-central Iowa. However, the yield capability of the Jordan decreases in southwesterly and southerly directions in the region, which is attributed to cementation of the pore spaces between the sand grains. In fact, the Jordan was plugged off in a municipal well at Leon in Decatur County owing to an abnormally low yield.

The aquifer probably maintains a fairly uniform permeability within each of the areas defined in figure 52. Locally, however, the rock units are relatively impermeable and acidization has been used to increase yields. Original yields from several wells were approximately doubled or tripled with a corresponding increase in specific capacity.

Because most existing wells that tap the Cambrian-Ordovician aquifer in south-central Iowa are drilled for public supplies, design and yield are based principally on economic and population factors. Estimates of yields given in figure 52 are based on specific capacity and available drawdown data from wells that have been test pumped. Because of the relatively great depth of wells tapping the aquifer, the available drawdown in wells that have been test pumped is great enough that, theoretically, the wells could be pumped at higher rates. But this rate of pumping would drastically lower the water level and would entail setting larger diameter casing and a higher capacity pump to a deeper setting.

WATER QUALITY

The quality of water that is used for any particular purpose is important — just as important as the quantity of water that a source will yield or the cost of obtaining water from that source. The importance of chemical quality is exemplified in south-central Iowa where the shortage of good-quality water has been a factor in inhibiting the economic development of the area.

All natural water contains some dissolved minerals and solid matter. Water flowing over the land surface or through the soil picks up and carries mineral and solid matter to the streams. Some of the stream load is clay, silt, and sand particles, and organic matter obtained by erosion and transport of soil, some is mineral matter dissolved in water. Ground water dissolves minerals from the rocks through which it passes. The amount and character of the dissolved-mineral matter in water depends on the chemical composition and physical characteristics of rocks through which the water passes, the duration of contact, the presence or absence of carbon dioxide, and other factors, such as temperature and pressure. Also, the water may contain domestic, commercial, agricultural chemical, and organic wastes that are often discharged into streams, on the land surface, or into the soil and shallow rock deposits.

The manner in which water is used determines which constituents and properties are desirable or deleterious. Water may be quite suitable for irrigation, but unsatisfactory for a public water supply. Water that is completely satisfactory for industrial cooling might be undesirable in a food-canning operation, and a commercial laundry would need a different type of water than what might be acceptable for watering livestock.

Some of the dissolved-mineral constituents are objectionable in water when they occur in large concentrations; others are objectionable when they occur only in small concentrations. Excessive mineralization of water may restrict its use for human consumption and for many agricultural and industrial purposes.

Exact limits of dissolved minerals that can be tolerated for specific uses are difficult to define; however, standards for drinking water (table 7) for some mineral constituents and properties of water have been established by the Environmental Protection Agency (EPA) and the Iowa Dept. of Environmental Quality (DEQ). The National Interim Primary Drinking Water Regulations promulgated by EPA (Federal Register, Dec. 24, 1975) set maximum contaminant levels for select constituents that are known to affect the health of the populace. Of the inorganic constituents shown in table 7, maximum contaminant levels have been established for nitrate and fluoride. The nitrate level must be adhered to both by community and non-community water systems; the fluoride level must be adhered to by community water systems only. (See Glossary for definition of Public Water Systems, which includes community water systems and noncommunity water systems.) Secondary drinking water regulations, which will set maximum recommended limits for some constituents, currently are being considered by EPA. In the meantime, the Iowa Dept. of Environmental Quality has accepted the recommended limits that were established by the U.S. Public Health Service (1962) as Iowa's esthetic quality standard for public supplies. The recommended limits for some constituents are shown in table 7.

Water-quality limits for industrial and agricultural supplies have been established by other agencies. These are not discussed in this report.

The chemical constituents and properties shown in table 7 form the basis for comparing quality of water from different sources. On the following pages, chemical analyses of surface waters at several sampling points in south-central Iowa are tabulated, and analyses of water from all the aquifers are summarized by showing the range and mean values of some constituents. Where feasible, graphic illustrations of quality data are given. The chemical constituents listed in table 7 are expressed as ions in concentrations of milligrams per liter (mg/L). (See Glossary.)

Table 7.— Significance of chemical constituents and physical properties of water

Constituent or property	Maximum contaminant level (mg/L)	Maximum recommended concentration (mg/L)	Significance
Iron (Fe)		0.3	Objectionable as it causes red and brown staining of clothing and procelain. High concentrations affect the color and taste of beverages. Iron concentrations in excess of 0.3 mg/L were found in 75 to 80 percent of samples from all the aquifers.
Manganese (Mg)		0.05	Objectionable for the same reasons as iron. When both iron and manganese are present, it is recommended that the total concentration not exceed 0.3 mg/L. Manganese was detected in excess of 0.05 mg/L in 50 percent of the samples of ground water.
Calcium (Ca) and Magnesium (Mg)			Principal causes for the hardness and scale-forming properties of water. They reduce the lathering ability of soap.
Sodium (Na) and Potassium (K)	[1]		Impart a salty or brackish taste when combined with chloride. Sodium salts cause foaming in boilers
Sulfate (SO_4)		250	Commonly has a laxative effect when the concentration is 600 to 1,000 mg/L particularly when combined with magnesium or sodium. The effect is much less when combined with calcium. This laxative effect is commonly noted by newcomers, but they become acclimated to the water in a short time. The effect is noticeable in almost all persons when concentrations exceed 750 mg/L. Sulfate combined with calcium forms a hard scale in boilers and water heaters.
Chloride (Cl)		250	Large amounts combined with sodium impart a salty taste.
Fluoride (F)	[2] 2.0	2.0	In south-central Iowa, concentrations of 0.8 to 1.3 mg/L are considered to play a part in the reduction of tooth decay. However, concentrations over 2.0 mg/L will cause the mottling of the enamel of children's teeth.
Nitrate (NO_3)	[3] 45		Waters with high nitrate content should not be used for infant feeding as it may cause methemoglobinemia or cyanosis. High concentrations suggest organic pollution from sewage, decayed organic matter, nitrate in the soil, or chemical fertilizers.
Dissolved Solids		500	This refers to all the material in water that is in solution. It affects the chemical and physical properties of water for many uses. Amounts over 2000 mg/L will have a laxative effect on most persons. Amounts up to 1000 mg/L are generally considered acceptable for drinking purposes if no other water is available.
Hardness (as $CaCO_3$)			This affects the lathering ability of soap. It is generally produced by calcium and magnesium. Hardness is expressed in milligrams per liter equivalent to $CaCO_3$ as if all the hardness were caused by this compound. Water becomes objectionable for domestic use when the hardness is above 100 mg/L; however, it can by treated readily by softening
Phospate (PO_4)			An aquatic plant nutrient which can cause noxious algal growths (blooms) in flowing and standing water. This often results in odor and taste problems. Usually will not cause problems if less than 0.30 mg/L in flowing streams or 0.15 mg/L in water entering ponds or reservoirs. Amounts over 0.30 mg/L can cause difficulties with coagulation processes in water treatment. Common sources are industrial and domestic sewage effluents, plant and animal wastes, fertilizer and sediment from erosion of agricultural areas. Reported here only in analyses of surface waters.
Organic Nitrogen			Nitrogen from plant and animal sources in its unoxidized state. In this report it is listed only in analyses of surface waters.
Chemical Oxygen Demand (COD)			The amount of oxygen needed to oxidize the biological and organic chemical material, such as industrial wastes, in the water. Listed only in analyses of surface waters.
Temperature			Affects the desirability and economy of water use, especially for industrial cooling and air conditioning. Most users want water with a low and constant temperature.

1. A maximum contaminant level for sodium may be established by 1979, when the final primary drinking water regulations go into effect.
2. Applicable to community water systems only.
3. Applicable to both community and noncommunity water systems.

QUALITY OF SURFACE WATERS

CHEMICAL QUALITY

The quality of surface water flowing past a certain point changes continuously. Water which makes up the runoff from a basin comes from two primary sources: (1) the water which flows either over the land or through the soil at shallow depths and (2) the ground-water seepage which is the source of the base flow to the streams. The dissolved-mineral concentration in stream water usually is lowest when the water is principally from recent precipitation. Higher concentrations most often result when the major part of the stream water is ground-water seepage. Although these generalizations are true for the total concentration of dissolved chemicals in the streams, concentrations of some individual constituents and properties may have an opposite relationship. Another factor which influences the chemical quality of some streams is effluent from municipal sewage systems which adds compounds peculiar to man's activities to the water. Municipal sewage effluent also has an effect when ground water from aquifers not normally contributing to the streamflow is used as a source for municipal water systems, and this water is discharged into the streams. In these cases the chemical quality of the stream water often shows the same characteristics as the ground water, especially during times of low stream discharge.

The results of chemical analyses of periodic water samples for five stream-gaging stations are listed in table 8. The locations of these stations are shown in figure 11. Chemical analyses are available for monthly water samples collected at Elk Creek near Decatur City and are published in Part 2 of the annual "Water Resources Data for Iowa" (U.S. Geol. Survey). The only analyses shown for Elk Creek are those for samples which were collected coincident with the samples for the other stations listed in table 8. Many other periodic water samples collected at most of the gaging stations in south-central Iowa were analyzed only for specific conductance and pH. These data with the water temperature of the samples are also published in part 2 of "Water Resources Data for Iowa". Also published are the daily values of temperature and specific conductance for the gaging stations (5-4879.8) White Breast Creek near Dallas, (6-8980) Thompson River at Davis City, and (6-9034) Chariton River near Rathbun for the periods October 1967 to September 1973, April 1968 to September 1973, and October 1969 to September 1973, respectively. The locations of these stations are shown in figure 11. The published chemical-quality data discussed above support the following general statements on the chemical characteristics of surface water in the region:

1. Dissolved-solids concentrations at sites shown in table 8 invariably are less than 500 mg/L and are highest during base-flow periods.
2. Daily specific-conductance measurements during 1972-73 at sites on the Chariton and Grand Rivers and miscellaneous conductance measurements at the low-flow sites on other major streams that indicate the dissolved-solids concentrations of these streams usually are less than 500 mg/L, even during base-flow periods.
3. Water in the streams is hard to very hard and is a calcium-bicarbonate type.
4. Sulfate concentrations do not exceed 100 mg/L and are highest during base-flow periods.
5. Nitrate and organic nitrogen concentrations are generally, but not invariably, highest during spring runoff periods.

Table 8.— Chemical analyses of stream waters at selected sampling sites (Dissolved constituents and hardness in mg/L)

Station number and name	Date collected	Instantaneous Discharge (ft³/s)	Temperature (C°)	Silica (SiO_2)	Organic Nitrogen (N)	Iron (Fe)	Phosphorus (PO_4) (Total)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity ($CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids (Filterable residue at 180° C)	Hardness (Ca, Mg)	Chemical Oxygen Demand	Specific Conductance (umho/cm at 25° C)	pH	Sodium Adsorption Ratio
5-4879.8	2-26-68	2.8	0	5.7	0.3	0.15	—	1.10	94	19	22	5.8	307	0	252	95	12	0.2	1.4	—	318	14	650	7.8	0.5
White Breast Creek	4-25-68	*1,500	10.0	13	3.2	.72	—	0.11	41	5.3	5.7	3.7	100	0	82	48	1.0	.2	7.8	—	124	117	280	7.6	.2
near Dallas	10-08-68	1.2	13.0	6.8	.6	.20	—	.58	53	14	13	5.2	218	0	179	43	3.5	.2	.2	—	188	8.1	410	7.5	.4
	2-03-69	10	0	12	—	.98	—	.79	46	10	9.2	14	151	0	124	45	13	.2	4.3	259	156	—	370	6.9	.3
	4-08-69	*116	12.0	13	1.3	.10	—	.05	66	13	13	7.6	188	0	154	81	12	.2	4.4	310	216	37	490	7.4	.4
	3-04-70	778	3.5	9.6	3.6	.08	0.10	.17	48	6.8	11	6.2	106	0	87	58	9.0	.2	9.2	296	148	150	340	7.2	.4
	9-08-70	6.8	21.5	13	.75	.13	.20	.34	75	15	13	5.2	266	0	218	66	7.0	.2	.1	324	248	26	520	7.8	.4
	8-10-71	1.4	25.5	7.9	—	.10	—	.32	54	9.7	15	7.4	198	0	162	49	7.0	.3	.4	265	176	—	410	7.7	.5
	4-18-73	3,900	11.0	8.8	—	.51	—	.03	27	6.5	6.0	3.3	90	0	74	36	4.0	.2	—	144	96	—	220	7.8	.3
	9-20-73	92	17.5	10	.25	.12	.10	—	58	15	11	8.1	195	0	160	61	8.0	.2	2.2	269	208	39	440	7.6	.3
6-8187.5	2-04-69	2.5	0	20	—	1.40	—	3.10	56	18	23	20	229	0	188	55	25	.3	4.3	347	212	—	550	6.8	.7
Platte River	4-08-69	73	15.0	16	1.2	.10	—	.06	50	12	16	6.6	161	0	132	59	13	.2	12	248	174	30	410	7.6	.5
near Diagonal	3-04-70	110	6.0	9.4	2.3	.04	.20	.52	43	11	13	6.8	116	0	95	56	23	.3	13	290	152	100	390	7.4	.5
	9-08-70	1.8	24.0	14	.55	.23	.30	.96	56	13	39	6.6	203	0	166	75	38	.9	.5	337	192	22	560	7.6	1.2
	8-10-71	4	28.0	13	—	.08	—	.38	51	12	24	5.3	163	14	158	56	16	.4	.4	291	176	—	440	8.4	.8
	4-18-73	460	12.5	11	—	.06	—	.04	31	9.9	8.8	3.1	93	0	76	36	9.0	.2	19	152	112	—	290	7.7	.4
	9-19-73	29	14.0	15	.87	.16	—	.02	43	14	10	8.8	154	0	126	48	15	.4	7.1	249	172	39	390	7.4	.3
6-8979.5	2-26-68	0.37	0	8.3	—	.48	—	4.00	98	22	12	2.6	346	0	284	63	5.5	.2	1.4	396	336	9.9	630	7.9	.4
Elk Creek near	4-25-68	32	12.0	13	—	.04	—	.05	69	13	10	3.2	190	0	156	84	3.0	.2	4.3	296	224	22	470	8.0	.2
Decatur City	10-09-68	.17	14.0	12	—	.28	.24	2.10	70	17	8.5	4.4	284	0	233	23	4.0	.2	1.8	281	245	—	470	7.7	.2
	2-04-69	.32	0	11	—	.72	.46	.44	43	11	5.8	6.2	142	0	116	41	7.0	.3	5.7	220	152	—	590	8.0	.2
	4-08-69	42	15.0	12	—	.76	—	.24	63	13	9.0	4.4	92	0	75	65	7.0	.3	1.8	284	211	—	330	8.1	.3
	3-04-70	5.0	1.0	9.9	—	.61	.10	.23	59	16	9.9	4.8	184	0	151	58	8.0	.2	15	284	213	—	410	8.2	.3
	9-29-70	5.8	13.5	16	—	.23	.03	.24	74	19	11	5.0	262	0	215	67	5.0	.4	1.6	332	263	—	385	8.1	.3
	7-08-71	.30	35.0	7.7	—	.28	.03	1.10	69	19	13	4.7	291	0	239	33	7.0	.3	1.8	301	250	—	450	8.3	.4
	2-01-73	4,600	—	5.9	—	.23	4.6	.08	19	2.8	1.0	3.7	64	0	52	8.0	4.0	.2	—	76	59	—	—	—	.1
	5-23-73	6.4	—	8.8	—	.06	.14	—	66	25	10	3.3	272	0	223	51	8.4	.2	—	316	270	—	—	—	.3
	8-09-73	191	20.5	7.9	—	.11	10	.35	42	7.6	3.9	4.6	150	0	123	17	3.0	.3	—	165	140	—	—	—	.1
	9-17-74	.002	22.5	11	—	—	—	—	110	24	13	4.0	422	0	436	45	7.7	.4	—	398	370	—	720	7.9	.3
6-8980.0	2-26-68	10	0	5.3	.30	.29	—	1.20	86	18	20	5.2	303	0	248	62	8.5	.2	1.6	340	288	9.9	590	7.9	.5
Thompson River	4-25-68	*997	11.0	11	5.9	.25	—	.05	38	7.3	6.4	3.6	115	0	94	41	2.0	.2	6.0	244	—	192	280	7.8	.2
at Davis City	10-09-68	9.2	13.0	7.6	.60	.08	—	.56	69	9.7	15	4.6	244	0	200	47	5.5	.2	.4	284	212	12	490	7.7	.4
	2-04-69	37	1.0	13	—	.72	—	.54	38	8.7	5.8	17	144	0	118	44	6.0	.2	3.9	221	132	—	320	6.8	.2
	4-08-69	253	13.0	12	1.3	.10	—	.05	62	14	11	7.2	200	0	164	62	9.0	.2	4.9	274	212	38	460	7.5	.3
	3-05-70	2,000	3.5	8.6	.28	.14	.10	.15	35	1.9	3.4	7.5	73	0	60	25	6.5	.2	12	286	96	210	220	7.3	.2
	9-08-70	12	22.5	10	.84	.10	.10	.12	80	14	11	5.2	290	0	238	44	5.0	.2	.1	310	256	26	530	7.8	.3
	8-10-71	20	26.0	5.9	—	.08	—	.09	69	15	14	4.6	249	0	204	41	8.0	.3	.4	302	232	—	480	8.0	.4
	4-18-73	6,350	12.0	7.8	—	.35	—	.01	22	5.0	5.6	3.1	80	0	66	22	2.0	.2	6.9	142	76	—	180	7.8	.3
	9-20-73	257	17.0	11	1.3	.07	.13	—	47	12	8.2	9.3	168	0	138	36	6.0	.2	2.2	210	160	47	350	7.6	.3
6-8984.0	2-26-68	1.0	0	9.8	.20	.15	—	2.50	83	18	23	3.9	299	0	245	76	6.0	.2	1.2	379	284	6.0	600	7.7	.6
Weldon River	4-25-68	*77	10.0	13	.10	.06	—	.05	53	13	10	3.7	156	0	128	57	4.0	.2	12	240	184	32	420	7.9	.3
near Leon	10-09-68	*8.2	13.0	10	1.0	.38	—	.22	45	8.3	13	7.2	165	0	135	35	7.5	.2	.9	236	146	20	350	7.7	.5
	2-04-69	.29	0	17	—	.58	—	3.10	72	16	16	12	271	0	222	62	8.0	.2	3.9	341	246	—	520	6.9	.4
	4-08-69	22	13.0	16	.60	.10	—	.06	70	13	14	7.0	212	0	174	68	8.0	.2	3.5	316	228	22	490	7.6	.4
	3-05-70	24	4.0	11	1.4	.14	.20	.07	66	13	14	6.7	187	0	153	71	14	.2	11	316	216	49	490	7.7	.4
	9-08-70	2.0	17.5	10	.31	.10	.10	.36	74	11	18	4.9	226	0	218	58	6.0	.2	.1	308	228	20	510	7.8	.5
	8-10-71	.05	28.0	13	—	.05	—	.34	62	16	18	5.6	249	0	204	49	5.0	.2	.4	307	224	—	470	8.2	.5
	4-18-73	93	11.0	11	—	.05	—	.04	50	12	8.2	3.7	161	0	132	53	4.0	.2	4.1	200	164	—	220	7.9	.3
	9-19-73	27	18.0	13	.64	—	.09	.01	51	13	10	11	188	0	154	46	5.0	.2	1.2	247	180	30	390	7.6	.3

*Daily mean discharge.

SUSPENDED-SEDIMENT DISCHARGE

The suspended sediment in water is an important consideration of water quality, particularly when the water is used for domestic water supply. Knowledge of the erosion, movement, and deposition of sediment relative to land surface, streams, reservoirs, and other bodies of water is important to those involved directly or indirectly in the development and management of water and land resources. Engineering works associated with these projects are profoundly affected by moving sediments.

The discharge of suspended sediment from different areas of south-central Iowa is dependent mainly on the amount of runoff from the areas and also on the erodibility of the rocks and soils, on the steepness of the land and channel slopes, the temperature, and the intensity and amount of precipitation.

Table 9 summarizes the average annual sediment discharge for selected streams in south-central Iowa. Shown are the stations for which continuous daily suspended-sediment discharges have been computed. The locations of these sites are shown in figure 11. Many periodic samples of suspended-sediment discharge have been collected at other sites throughout south-central Iowa and are too voluminous to include in this report. The analyses of these samples are published in part 2 of the annual series "Water Resources Data for Iowa" (U.S. Geol. Survey). A complete compilation of sediment data can be found in the report "Fluvial Sediment Data for Iowa", (Schuetz and Matthes, 1977).

Table 9.— Average suspended-sediment discharge for selected sites in south-central Iowa

Station number	Stream and location	Drainage area (mi^2)	Period of record	Water discharge ft^3/s-days per year	Suspended-sediment discharge	
					ton per year	acre-feet per year
5-4864.9	Middle River nr Indianola	503	Oct. 1962-Sept. 1967	66,298	822,000	690
5-4879.8	White Breast Creek nr Dallas	342	Oct. 1967-Sept. 1973	73,286	433,000	360
6-8980	Thompson River at Davis City	701	Oct. 1949-Sept. 1953 Oct. 1968-Sept. 1973	168,345	1,231,000	1,030
6-9034	Chariton River nr Chariton	182	Oct. 1969-Sept. 1973	45,232	64,700	54
6-9035	Honey Creek nr Russell	13.2	Oct. 1952-Sept. 1962	2,575	4,440	3.7
6-9037	South Fork Chariton River nr Promise City	168	Oct. 1969-Sept. 1973	42,512	157,000	130
6-9039	Chariton River nr Rathbun	551	Oct. 1962-Sept. 1973	*83,196	*123,000	*100

**Computed for period Oct. 1962 to Sept. 1969 prior to regulation by Rathbun Lake.*

QUALITY OF GROUND WATER

QUALITY OF WATER FROM SURFICIAL AQUIFERS RANGES FROM POOR-TO-GOOD

The alluvial aquifers yield the least mineralized water of all ground-water sources in south-central Iowa. A total of 56 water samples, which are considered representative of the aquifer underlying the principal stream valleys in the area, were collected for chemical analyses (fig. 53). The analyses summarized in table 10 indicate that water from the alluvium is hard to very hard, contains high iron and manganese concentrations at most places, is low-to-moderately low in dissolved-solids, and contains concentrations of fluoride, and nitrate that are well below the maximum contaminant level shown in table 7. The dissolved-solids concentration in 75 percent of the samples was less than 500 mg/L and in the remaining samples the values did not exceed 1000 mg/L (fig. 53). Concentrations of fluoride ranged from 0.1 to 0.45 mg/L and the nitrate content did not exceed 17 mg/L. The mean temperature of water in the aquifer was 55° F and the range of these temperatures was 46° to 60° F. The highest iron concentration recorded from the sampling was 51 mg/L and in 80 percent of the samples iron concentrations were in excess of 0.3 mg/L. The manganese concentration was greater than 0.05 mg/L in about 90 percent of samples from the alluvial aquifer, the largest percentage of any aquifer.

Water at shallow depths (100 ft or less) in the drift aquifer, based on 95 analyses, summarized in table 10, usually is very hard and may often contain undesirable concentrations of iron, sulphate, nitrate, and dissolved solids. Iron concentrations in these samples ranged from 0.02 to 30 mg/L, and in 40 percent of the samples the concentrations exceeded 0.3 mg/L. Sulphate concentrations generally were less than 250 mg/L, but they exceeded the recommended limit in 20 percent of the analyses and for one analysis the value was 1470 mg/L. Nitrate and chloride concentrations were as much as 570 and 200 mg/L, respectively, and, in 45 percent of the samples the nitrate values were higher than the maximum contaminant level shown in table 7. Dissolved-solids concentration varied from 220 to 2840 mg/L; in 25 percent of the samples the values exceeded 1000 mg/L. The mean temperature of water from wells tapping the shallow drift was 53° F and ranged from 50° to 60° F. The fluoride content was below 0.8 mg/L in all analyses.

The higher nitrate, chloride, and dissolved-solids concentrations in some water supplies from shallow depths in the drift aquifer are due to contamination by direct runoff into the well and to infiltration of barnyard wastes. Based on observations at the well sites, the contamination is attributed to poorly constructed and improperly located wells and, hence, is believed to be localized in occurrence. The water samples from these locally contaminated wells, therefore, are not representative of the water under natural conditions in the shallow drift aquifer. Samples that are most representative of the aquifer's natural chemical quality are those that contain less than 10 to 15 mg/L each of nitrate and chloride; the dissolved solids in these samples generally are less than 1000 mg/L.

Based on the above discussion, the following conclusions can be drawn regarding the quality of water in the shallow drift aquifer in the south-central area: (1) Water from the upper 100 feet of drift generally will be acceptable for most purposes if wells are constructed properly and located a suitable distance from sources of contamination. (2) All supplies from existing shallow wells should be analyzed for nitrate and bacterial content; any water supply containing over 45 mg/L should not be used for infant feeding and according to some authorities, water supplies containing nitrate concentrations of several hundred milligrams per liter should not be used for domestic and livestock purposes. (T. L. Willrich, Agricultural Extension Engineer, Iowa State University, Ames, Iowa, oral communication, 1969).

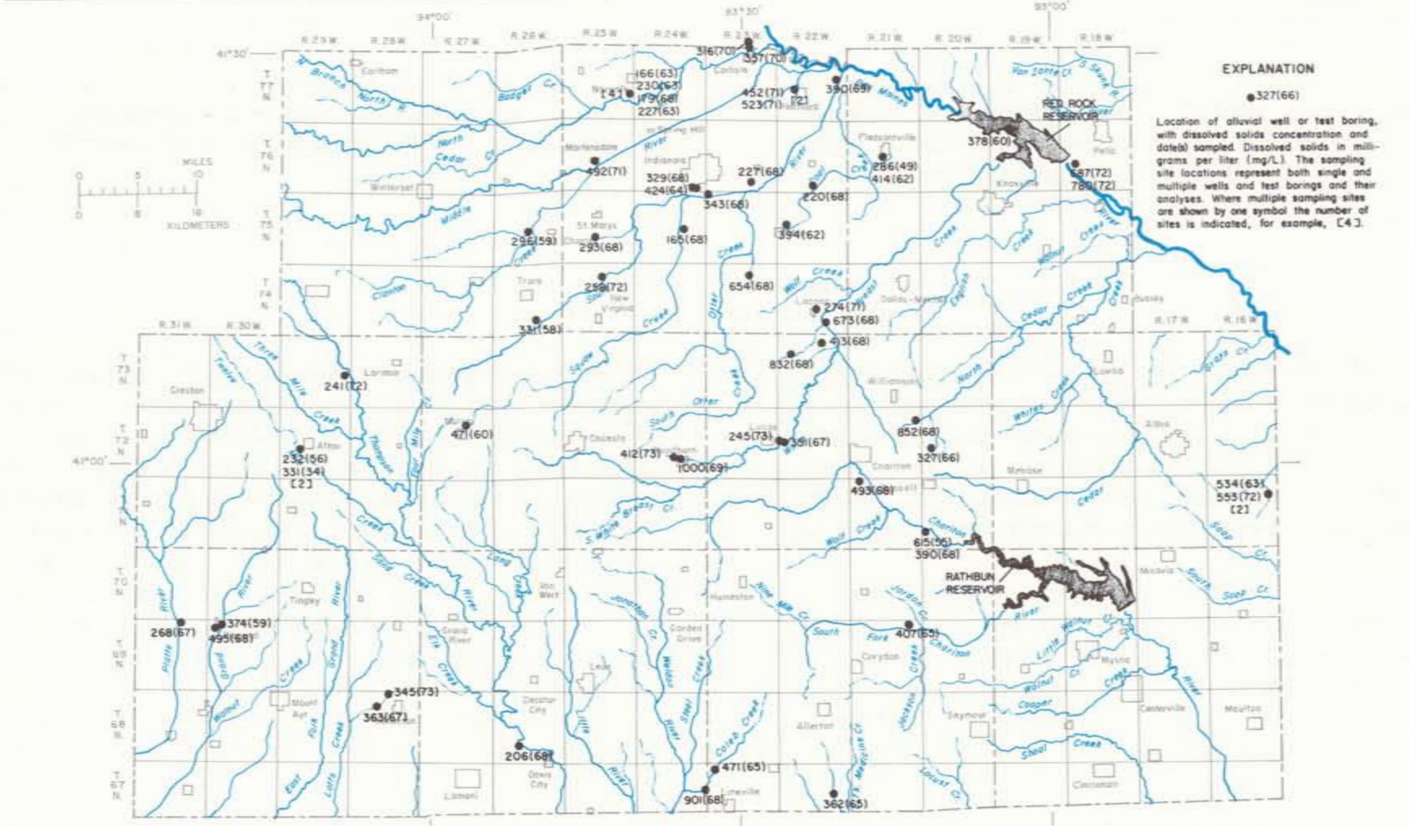
Water from the drift aquifer at intermediate depths (100 to 200 feet) is more mineralized than is that from shallower depths, although the fluoride content, hardness and temperature are similar (table 10). In 23 water samples the dissolved solids ranged from 261 to 2726 mg/L with a mean of 1030 mg/L; the dissolved solids in about 40 percent of the samples exceeded 1000 mg/L. The iron concentrations in about 90 percent of the samples exceeded the recommended limit. Nitrate concentrations were below the maximum contaminant level.

Water from the deep drift and from the buried-channel aquifers, based on 15 analyses, is highly mineralized in most parts of the area (table 10). The water is very hard and contains high concentrations of dissolved solids, sulphate, and iron, although the concentrations of chloride, nitrate and fluoride with two exceptions, are low. Dissolved solids and sulphate values as high as 3657 mg/L and 1990 mg/L, respectively, were recorded in analyses of water from these sources. Water temperatures in the aquifer range generally from 54° to 57° F.

Table 10.— Chemical characteristics of water from the surficial aquifers

Results in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa.

Average (A) and range (R)	Dissolved solids	Hardness (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Number of analyses
Alluvial aquifer										
A	417	288	105	13	0.3	4.2	20.2	9.4	1.5	56
R	165-1000	124-762	3-350	0.5-180	0.1-0.45	0.1-17	4.1-85	0.04-51	0.05-17	
Shallow drift aquifer										
A	736	480	177	37	0.3	81	68	1.1	0.13	95
R	220-2840	153-1710	12-1470	0.5-200	0.2-0.8	0.1-570	7.3-710	0.02-30	0.05-1.9	
Intermediate drift aquifer										
A	1030	569	397	9	0.5	6	108	5	0.09	23
R	261-2726	150-1518	7-1520	0.5-49	0.2-1.0	0-44	17-368	0.04-24	0.05-0.37	
Deep drift and Buried-channel aquifers										
A	2346	868	1254	30	0.6	6.7	334	3.4	0.24	15
R	383-3657	140-1640	42-1990	3-110	0.1-2.0	0-82	54-568	0-18	0-1.4	



EXPLANATION

●327(66)

Location of alluvial well or test boring, with dissolved solids concentration and date(s) sampled. Dissolved solids in milligrams per liter (mg/L). The sampling site locations represent both single and multiple wells and test borings and their analyses. Where multiple sampling sites are shown by one symbol the number of sites is indicated, for example, [4].

Figure 53.— Dissolved-solids concentrations in water from the alluvial aquifer

BEDROCK AQUIFERS

Mineralization limits the use of water from bedrock sources in many parts of south-central Iowa and is a deterrent to a more extensive development of these sources. Without extensive treatment most water from bedrock sources is unsuitable for most domestic and many industrial uses because of high dissolved-solids, sulphate, chloride, fluoride, and sodium concentrations. However, this water can be used without treatment for certain purposes, such as washing, cooling, and fire fighting. The development of a supply of mineralized water solely for these purposes would, for example, allow a municipality or industry to conserve its potable water supplies. A more complete utilization of this mineralized water depends on the development of economical methods of demineralization.

Dissolved-mineral concentrations in water from Pennsylvanian aquifers exceed recommended standards at most places

In most parts of the area, sandstone aquifers in the Cherokee Group of the Pennsylvanian contain water that has a high mineral concentration (table 11). Based on 85 analyses of samples from the Cherokee, the water is less mineralized in the eastern counties (Appanoose, Marion, and Monroe); in this region there is about a 60 percent probability that the dissolved-solids concentration at any given site will be less than 1000 mg/L. In these same counties, however, some dissolved-solids concentrations were as much as 7092 mg/L. West of that area, in the counties of Decatur, Lucas, Madison, Warren, Wayne and Ringgold, dissolved-solids concentrations were, with few exceptions, over 1000 mg/L and ranged up to about 6000 mg/L. The sulphate concentration ranges from 22 to 4139 mg/L, with a mean concentration of 1088 mg/L. Sodium concentrations are noticeably high, ranging from 7 to 2180 mg/L with a mean of 536 mg/L. Water in the Cherokee was found to be soft-to-moderately hard in almost one-half of 24 samples in Warren County but, regionally, the water is moderately hard-to-very hard. In about one-third of all samples the fluoride concentration exceeded 2.0 mg/L; the maximum was 4.0 mg/L. In about 90 percent of the samples the iron concentration was above 0.3 mg/L. Nitrate concentrations, with one exception, were well within acceptable limits. The mean water temperature was 56°F and ranged from 52° to 61°F.

Water in the Mississippian aquifer highly mineralized except in limited areas in Marion County

Regionally, the upper and lower parts of the Mississippian aquifer contain highly mineralized water; however, in limited areas in Marion County, water of relatively good quality is available from both parts of the aquifer (table 11). Only in Marion County were water-quality data sufficient to permit graphic representation of dissolved solids on a map; elsewhere in the region, only the location of a well and the dissolved-solids concentration in the well water are plotted on the map (fig. 54).

In Marion County, the best quality water occurs in areas where the Mississippian aquifer is the bedrock surface (fig. 54). In those areas, the dissolved-solids concentration in water from either the upper or lower parts of the aquifer usually in less than 1000 mg/L and occasionally is less than 500 mg/L. Sulfate concentrations ranged from 27 to 563 mg/L, with about 45 percent of the samples exceeding the recommended limit. In the remainder of Marion County, where the Mississippian is overlain by Pennsylvanian rocks, water from either the upper or lower parts of the aquifer is, with few exceptions, highly mineralized (table 11). The dissolved-solids concentrations in 18 water samples from the upper part of the aquifer ranged from 368 to 6500 mg/L; only one-third of the samples contained less than 1000 mg/L dissolved solids. Water from the lower part of the aquifer invariably contained more than 1000 mg/L dissolved solids; generally the range was between 1200 and 5000 mg/L. The analyses of the water samples from both parts of the aquifer in Marion County also indicated that sulfate concentrations ranged from 49 to 3480 mg/L, iron concentrations were invariably greater than 0.3 mg/L, fluoride concentrations exceed 2 mg/L in about 10 percent of the samples, nitrate concentrations generally were much less than recommended limits, and water temperatures ranged from 52°to 64°F and averaged about 57°F.

In the other counties, limited data summarized in table 11 indicate that the water from the aquifer is highly mineralized and that a discernible trend in mineralization is not apparent (fig. 54). Dissolved solids ranged from 1210 to 8400 mg/L. The analyses also indicate that the sulfate concentrations ranged from 521 to 4500 mg/L, iron concentrations ranged from 0.05 to 23 mg/L, fluoride ranged from 1.0 to 3.6 mg/L, and the mean temperature of the water was 57°F and ranged from 52° to 64°F.

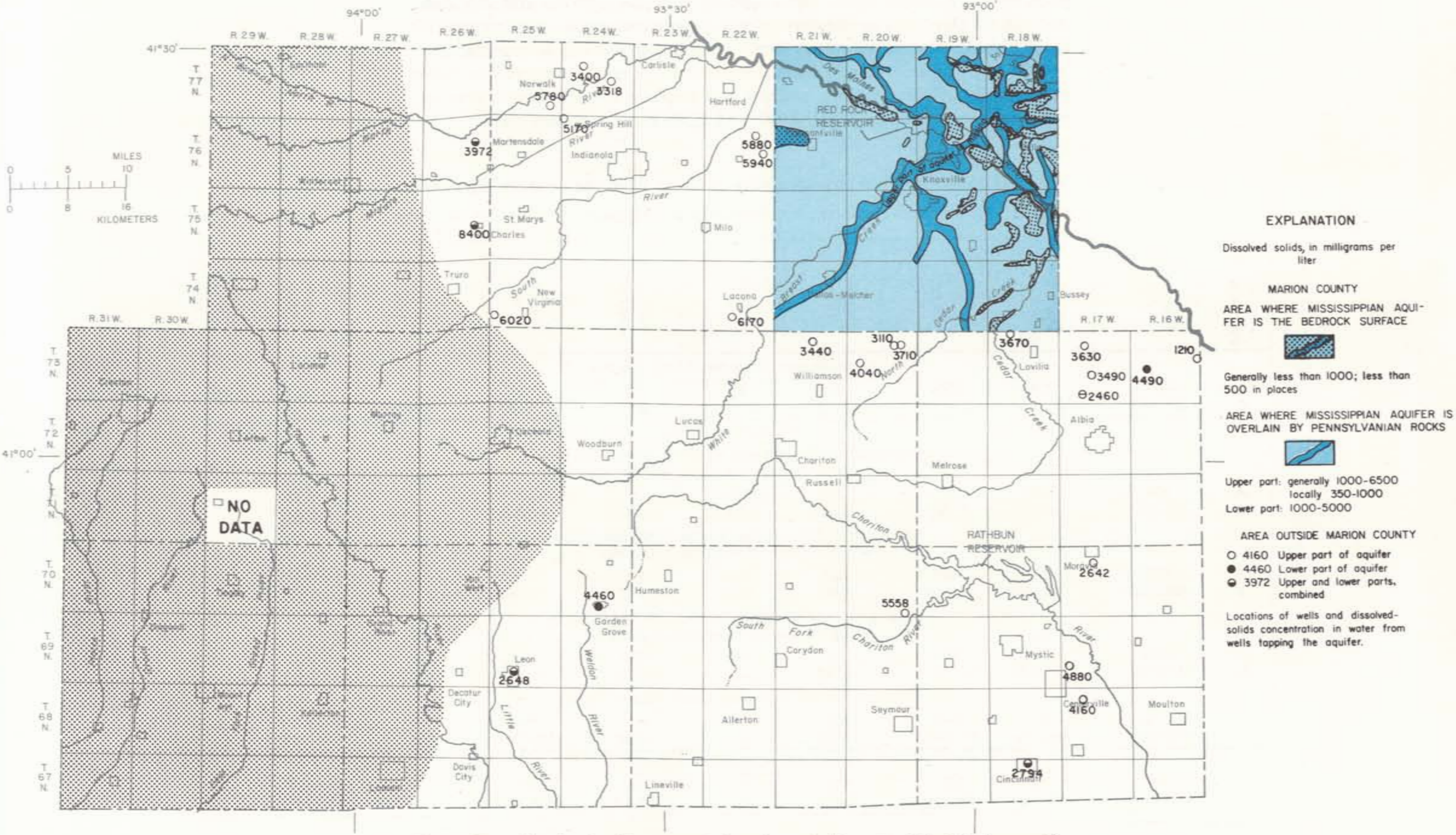


Figure 54.— Dissolved-solids concentrations in water from the Mississippian aquifer

Highly mineralized water indicated to occur everywhere in the Devonian aquifer

Except for analyses from two wells, chemical-quality data were not available to evaluate the chemical characteristics of water in the Devonian aquifer in the report area. Based on analyses from two wells in Decatur and Marion Counties and on quality data from counties adjacent to the report area, it is reasonably certain that the mineral content of water in the aquifer is extremely high in all parts of south-central Iowa. The evaporite minerals, gypsum and anhydrite, occur in the Devonian aquifer throughout the area and probably are responsible for the highly mineralized water. Water from this source can be expected to be very hard, to contain dissolved solids in amounts ranging from 5,000 to 10,000 mg/L, and to have chloride, sodium and sulphate concentrations that are, respectively, as much as 1,000, 2,000, and 2,500 mg/L, or even higher.

Table 11.— Chemical characteristics of water from the bedrock aquifers

Results in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa.

Average (A) and range (R)	Dissolved solids	Hardness (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Number of analyses
Pennsylvanian (Cherokee Group) aquifers										
A	4531	869	1088	97	1.4	3.5	536	3.2	0.15	85
R	251-7092	44-1559	22-4139	0.5-780	0.2-4.0	0-50	7-2180	0.1-22	0-4	
Mississippian aquifer										
Upper part of Mississippian aquifer in Marion County where aquifer is bedrock surface										
A	674	449	217	48	0.24	*	43	2.2	0.12	9
R	422-1380	108-952	27-563	2-32	0.2-0.4	0.1-4.3	8.8-240	0.2-9.8	0.05-0.25	
Upper part of Mississippian aquifer in Marion County where overlain by Pennsylvanian rocks										
A	2826	862	1493	109	1.3	1.6	492	6.6	0.06	18
R	368-6500	124-1660	49-3480	1-492	0-2.4	0.1-7.1	6.8-1480	0.1-45	0-0.12	
Lower part of Mississippian aquifer in Marion County where overlain by upper part of aquifer										
A	3320	1004	1856	89	0.93	15.4	626	4.1	0.23	8
R	1189-4990	731-1159	582-3065	9-230	0-2.8	0.04-32	28-1091	0.18-25	0-1.3	
Mississippian aquifer in area outside Marion County										
A	4274	923	2385	176	1.9	8.4	965	7.6	0.11	29
R	1210-8400	60-1580	521-4500	19-750	1.0-3.6	0-150	270-2100	0.05-23	0-0.34	
Cambrian-Ordovician aquifer										
A	1098	370	397	150	2.3	1.2	226	2.4	0.05	22
R	614-2560	246-1100	190-930	29-620	1.2-3.2	0.08-5.5	100-520	0.04-10	0.01-0.10	

*Only three samples

Water from the Cambrian-Ordovician aquifer on a regional scale is of consistently better quality than water from the overlying bedrock aquifers (table 11); only locally in Marion County is better quality water available from the Mississippian and Pennsylvanian aquifers. Also significant from a planning and management viewpoint, the Cambrian-Ordovician aquifer is the only bedrock aquifer that shows a discernable trend in water-quality characteristics. The aquifer exhibits a progressive increase in dissolved solids from the northeastern part of the region to the southwestern part (fig. 55). Fluoride concentrations and temperature also follow the same trend (figs. 56-57).

Water in the Cambrian-Ordovician aquifer is of poor-to-fair quality

In the eastern one-third of the region the dissolved solids are less than 1000 mg/L. However, the sulfate concentration ranges from 190 to 400 mg/L and averages about 285 mg/L, which is somewhat higher than normally would be expected; the chloride concentration ranges from 29 to 222 mg/L and averages about 88 mg/L. In the rest of the region, where the dissolved solids are above 1000 mg/L, both the sulfate and chloride increase noticeably. Sulfate concentrations range from 360 to 930 mg/L and chloride concentrations from 220 to 620 mg/L. Sodium concentration ranges from 100 to 520 mg/L and follows the chloride trend. The iron concentration with few exceptions exceeds 0.3 mg/L in the region. The nitrate concentration does not exceed 6 mg/L.

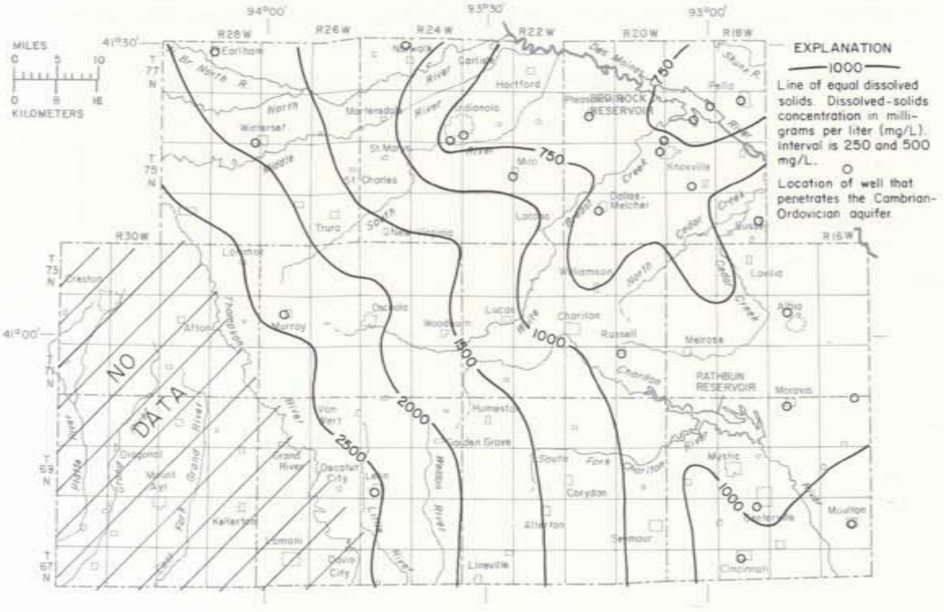


Figure 55.— Dissolved-solids concentrations in water from the Cambrian-Ordovician aquifer

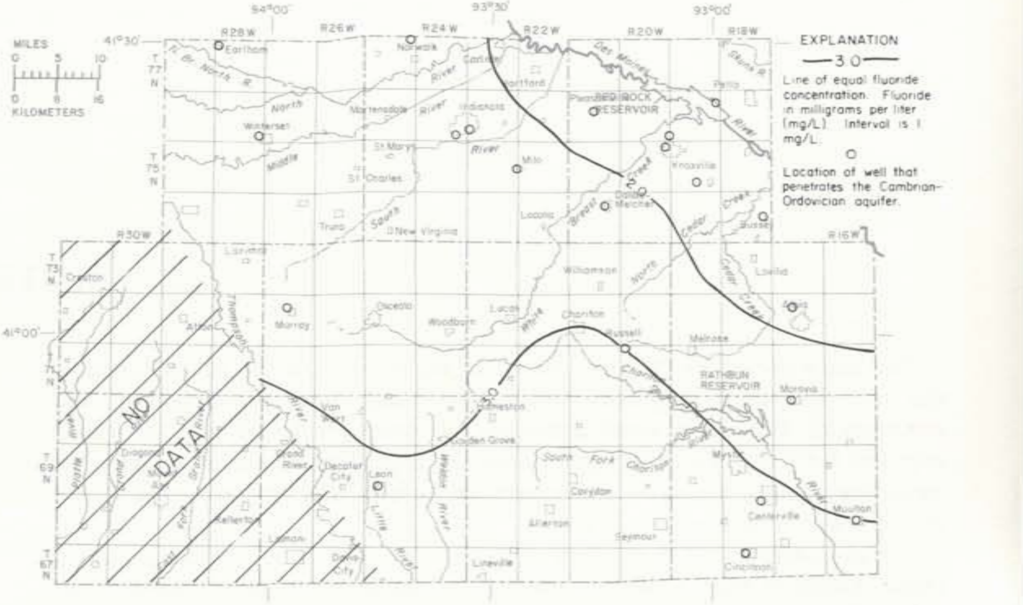


Figure 56.— Fluoride concentrations in water from the Cambrian-Ordovician aquifer

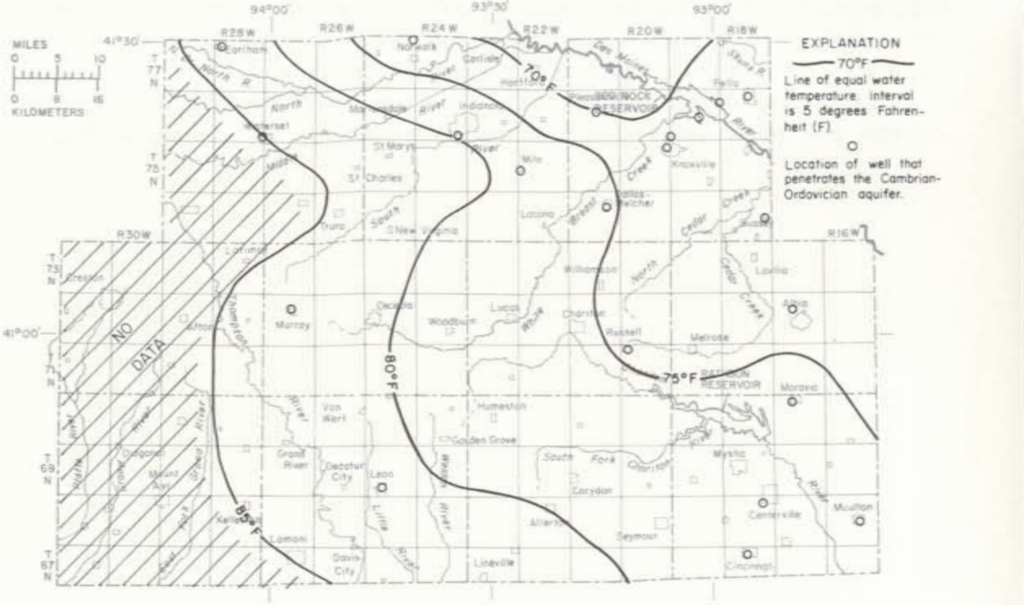


Figure 57.— Temperature of water in the Cambrian-Ordovician aquifer

WATER USE

The main categories of water use in the report area are (1) urban-domestic (2) rural-domestic, livestock, rural-institutional, and (3) industrial and commercial. Relatively small quantities of water are withdrawn for public supplies for purposes other than domestic, and small amounts are used for irrigation, quarrying, sand and gravel operations, and in the generation of electricity in fossil-fuel power plants.

Urban-domestic use, in this report, includes most of the water withdrawn for public supplies; that is, water furnished by municipal systems. Most of the urban-domestic usage is for drinking and sanitary purposes in homes, lawn and garden watering, municipal recreational and institutional supplies, and includes city water furnished to rural residents by direct sales or by city mains which extend outside corporate limits. This category also includes transmission losses from water-distribution systems, water used for fire fighting, street cleaning, and water used in small offices and stores. It does not include water purchased by industrial or commercial concerns that use large amounts of water.

Industrial and commercial uses include water purchased from public-supply systems and water withdrawn from company-owned wells or from surface sources. Industrial and commercial uses are varied. Some of the principal industrial uses of water are for meat processing and in the manufacture of livestock feed and farm equipment, metal and electrical equipment, plastic and chemical, and concrete products. Almost all of the water classified as commercial is for laundromats and car washes.

Rural uses include water for drinking and sanitation, water for livestock, and water for rural-institutional (county farms, rural schools, and highway rest stops) use. The rural-domestic category includes water withdrawn by privately owned and operated systems that supply rural residents in housing developments and in a few unincorporated communities. It would be impossible to accurately meter the water used on each farm. Domestic use was estimated on the basis of a per capita use of 55 gallons a day. Livestock use was determined by applying an average per capita consumption for each animal. Animal population figures were taken from the 1969 agriculture census. Only about 3 percent of the total water use in south-central Iowa during a 12-month period 1972-73 was for irrigation, quarrying and electric power generation.

The term "water use" can have several meanings. Water can be used in the sense that it is utilized in the navigation of large streams, such as the Mississippi River. For navigation on the Mississippi, water is passed through locks and is used either to raise or lower tow boats and barges. A similar type of use is at a hydroelectric plant. The water passes from a lake formed by the dam, drops some distance, turns turbines, reaches the lower level, and flows on downstream. The water has been used, but none was lost or consumed; the water temperature was not changed; and nothing was added to or removed from the water. Its desirability for other uses has not been altered.

Water withdrawn for industrial cooling or air conditioning is used in a different way. The water picks up heat during the cooling process and is considerably warmer when discharged. Because the water is warmer, some will be lost (consumed) through evaporation, and the remainder may not be desirable for many other uses since it is warmer.

Domestic uses change the water considerably. Some used for drinking and for washing is lost to the atmosphere through perspiration and evaporation. Some of the water is heated, and when discharged will be warmer. The chemical quality of the water will be different in that it may undergo softening and disinfection before use, and chemical solid material may be added. A lesser amount is returned to the environment, and the quality of the water will be degraded so as to be less attractive to other users. Livestock and many industrial uses affect the water in the same or similar ways.

The ultimate in water use is its evaporation. When the water is lost to the atmosphere, it is no longer available to be managed or used again. Two uses in which almost all the water is lost to the atmosphere are the production of steam which is eventually released and irrigation where the water is either transpired by plants or evaporated from the soil or land surface.

Water use, in terms of withdrawal, is described and tabulated on the following pages. Withdrawals refer both to water taken from where it occurs as a natural resource and to the purpose for which the water is used. In nearly all industries in the area, water is used only once; however, in at least one industrial plant water is reported to be recirculated one or more times through the company's water system before it is discarded or evaporated. This water is counted as a withdrawal only once.

Tabulations of water withdrawals have been made for each county according to type of use and source of supply. A third tabulation relates source to type of use.

WATER WITHDRAWALS

About 25-3/4 million gallons of water were withdrawn each day for various uses during 1972-73 in south-central Iowa. These withdrawals are categorized in table 12. Water for livestock was the single largest type of use, making up 49 percent of the total water usage and 78 percent of the rural supplies. Water withdrawn for urban-domestic use made up 30 percent of the total usage; rural domestic 13 percent; industrial and commercial about 5 percent; and other categories about 3 percent. In 1973, 57 percent of the population classed as urban domestic (p. 92) used an estimated 69 percent of the total supplies withdrawn for domestic purposes. The daily per capita water use for all purposes was highest for Ringgold County (279 gallons) and lowest for Warren County (128 gallons),and the 11-county average was 177 gallons.

The amount of water withdrawn from each source in the 11 counties of south-central Iowa in 1972-73 has been tabulated in table 13. The amount of water withdrawn from the various sources by municipalities and privately-operated systems that are major pumping centers is shown in figure 58. The municipal supplies are for urban-domestic, industrial and commercial use and the private systems furnish about 7 percent of the rural-domestic supplies and serve 5 percent of the rural population.

Ground-water from the combined aquifers accounted for 17.07 mgd or 66 percent of the total withdrawals, while surface-water sources made up 8.64 mgd or 34 percent. By far the largest sources of supply were the drift and buried-channel aquifers which furnished 42 percent of the total withdrawals; and, when added to the alluvial aquifer percentage gave a total of 54 percent furnished by the surficial aquifers. The Cambrian-Ordovician aquifer, though seldom used as a source prior to 1955 furnished 11 percent of the total withdrawals in 1973. Indications are that the aquifer will supply a larger percentage of the total withdrawals in the future.

As indicated in table 14, urban-domestic requirements during 1973 were met principally by withdrawals from impounding reservoirs (43 percent), from the Cambrian-Ordovician aquifer (34 percent), and from alluvial aquifers (20 percent).

Before 1955 nearly all supplies for municipal use were obtained from the surficial aquifers, the shallow or intermediate bedrock aquifers, and from surface reservoirs. During that period the only supplies from the Cambrian-Ordovician aquifer were from deep wells at Centerville and Pleasantville, which were later abandoned. From 1955 through 1973 the Cambrian-Ordovician aquifer was tapped by 21 wells, mostly for urban-domestic supplies. Rural-domestic requirements are obtained from the drift aquifer and livestock needs from the drift aquifer and farm ponds (table 14). Most of the small industrial requirements were purchased from municipalities (96 percent); the extremely small self-supplied withdrawals (4 percent) were mainly from the alluvial aquifers (table 14).

Table 12.— Water withdrawals by type of use in counties

County	Population 1970	Water withdrawn in million gallons per day, for type of use indicated									
			Industrial-Commercial		Rural						
		Urban Domestic	Purchased	Self-Supplied	Domestic	Institutional	Livestock	Irrigation	Quarrying	Electric Power	Total
Appanoose	15,008	0.83	0.23	*	0.34	*	0.93	—	0.07	—	2.40
Clarke	7,581	.29	.26	—	.21	—	1.01	—	.09	—	1.86
Decatur	9,737	.42	.04	*	.24	.01	1.06	—	—	—	1.77
Lucas	10,163	.57	.03	*	.23	*	.98	—	—	—	1.81
Madison	11,558	.61	.03	*	.33	*	1.44	—	.19	—	2.60
Marion	26,352	1.84	.24	.01	.49	.01	1.50	.12	—	.18	4.39
Monroe	9,357	.26	.06	*	.24	*	.85	—	—	—	1.41
Ringgold	6,373	.20	.01	—	.22	.01	1.34	—	—	—	1.78
Union	13,557	.85	.12	—	.22	.01	1.14	—	—	—	2.34
Warren[1]	27,432	1.47	.04	.03	.70	*	1.27	—	—	—	3.51
Wayne	8,405	.38	.12	.01	.23	.01	1.19	—	—	—	1.94
TOTAL	145,523	7.72	1.18	0.05	3.45	0.05	12.71	0.12	0.35	0.18	25.81
Percent of Total		30	5	<1	13	1	49	<1	1	<1	100

*Less than 5,000 gpd

[1] Includes 0.13 mgd purchased from Des Moines Waterworks.

Table 13.— Water withdrawals from various sources in counties

County	Population 1970	Water withdrawn, in million gallons per day, from sources indicated						
		Surface Water		Ground Water				
		Impounding Reservoirs	Ponds Streams Cisterns	Alluvial[1] aquifer	Drift and Buried-channel aquifers	Pennsylvanian and Mississippian aquifers	Cambrian-Ordovician aquifer	TOTAL
Appanoose	15,008	0.88	0.37	0.07	0.90	*	0.18	2.40
Clarke	7,581	.51	.40	.09	.82	.01	.03	1.86
Decatur	9,737	.25	.30	.14	.85	.06	.17	1.77
Lucas	10,163	.53	.38	.10	.73	.02	.05	1.81
Madison	11,558	.17	.63	.45	1.23	*	.12	2.60
Marion	26,352	0	.54	1.20	1.38	.16	1.11	4.39
Monroe	9,357	.17	.32	.08	.70	.06	.10	1.43
Ringgold	6,373	.17	.42	.16	1.04	*	0	1.79
Union	13,557	.96	.35	.10	.93	*	0	2.34
Warren	27,432	0	.40	.57	1.30	.04	1.07	3.38
Wayne	8,405	.47	.42	.10	.93	.02	0	1.94
TOTAL	145,523	4.11	4.53	3.06	10.81	0.37	2.83	25.71
Percent of total		16	18	12	42	1	11	100

*Less than 5,000 gpd

[1] Includes withdrawals (.003 mgd) by communities outside the region

Table 14.— Water withdrawals by source for each type of use in counties

	Source	Water withdrawn by source, in million gallons per day, for each type of use										
			Industrial and Commercial		Rural							
		Urban Domestic	Purchased	Self-Supplied	Domestic	Institutional	Livestock	Irrigation	Quarrying	Electric Power	Totals	Percent
Surface Water	Impounding Reservoirs	3.28	0.83	—	—	—	—	—	—	—	4.11	16
	Ponds, Streams and Cisterns	—	—	—	.17	—	3.92	.09	.35	—	4.53	18
Ground Water	Alluvial aquifer	1.51	.22	.03	.26	*	.80	.03	—	.18	3.03	12
	Drift and Buried-channel aquifers	.10	*	.01	2.84	.04	7.82	—	—	—	10.81	42
	Pennsylvanian and Mississippian aquifers	.10	.01	.01	.07	.01	.17	—	—	—	.37	1
	Cambrian-Ordovician aquifers	2.60	.12	—	.11	—	—	—	—	—	2.83	11
	TOTALS	7.59	1.18	0.05	3.45	0.05	12.71	0.12	0.35	0.18	25.68	100

* Less than 5,000 gpd

WATER WITHDRAWALS IN URBAN AREAS

A substantial, though not the major part of water withdrawals in south-central Iowa is concentrated in or very near towns and cities. These major pumping centers account for about 34 percent — an average of about 8.8 mgd — of the total amount of water withdrawn in 1972-73. Urban withdrawals include domestic supplies furnished by municipalities, and supplies for commercial and industrial use, that are purchased from municipal systems (fig. 59).

The predominant use of water in urban localities is for domestic purposes, and in only 12 towns and cities that have municipal water systems is the commercial and industrial usage 10 percent or more of the total usage (fig. 59). In only two towns, Allerton and Osceola, did commercial and industrial usage exceed domestic use in 1972-73. A good example of the impact of new industry on a town's water supply is Osceola, where a large meat processing plant operation was begun in 1973. In 1972 the total pumpage reported for Osceola was 100.9 million gallons and in 1973 the total was 185.42 million gallons. For the years 1972 and 1973, respectively, the percentages of the total withdrawals for industrial use at Osceola were 10 percent and 52 percent.

The per capita urban-domestic use of water in south-central Iowa was determined by grouping towns and cities within population ranges and computing the average per capita daily use for each group or range. The population ranges and average per capita daily use for municipalities within each range are: 500 and below (60); 500 to 1000 (70); 1000 to 5000 (85); and 5000 to 9000 (100). The per capita rural-domestic use is estimated to be 55 gallons. Also of interest is the daily per capita use of water by pupils in elementary and secondary schools, which was computed to be about 7 gallons per pupil per school day.

During the inventory of municipal supplies, Water Superintendents in several towns reported unusually high pumpage rates and attributed this to leakage in the city mains. The daily per capita domestic use for these particular towns was calculated to be almost twice as high as was the average for towns in the same population range. Although other factors may be involved, an unusually high per capita use probably indicates some degree of leakage in the water lines, and this should warrant investigation.

The amount of water withdrawn for distribution through municipal systems varies considerably throughout the year. Data from several cities outside the south-central area indicate that the average daily use during the summer months is 30 percent higher than during the cooler months. A similar situation is believed to exist in the municipalities in south-central Iowa.

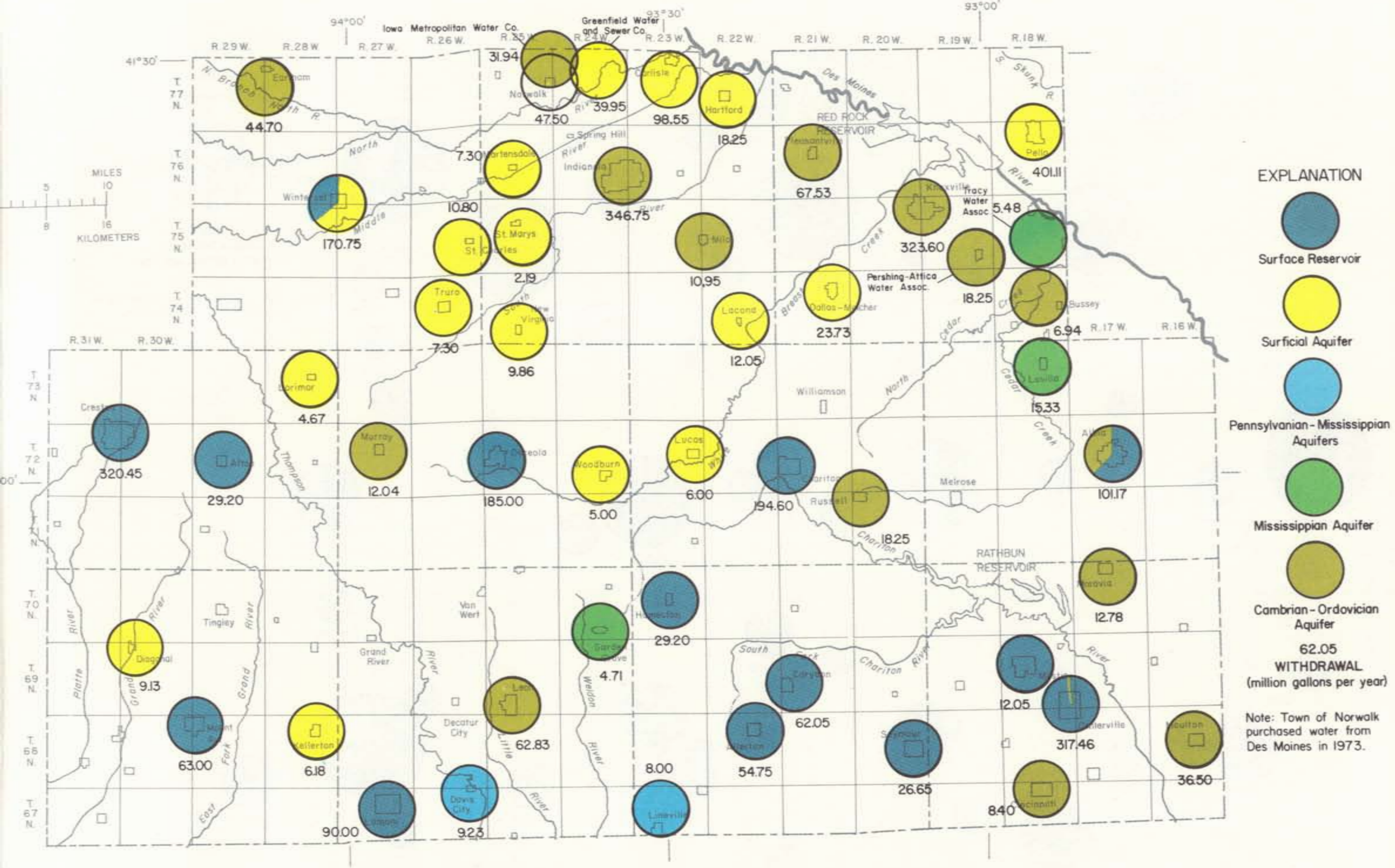


Figure 58.— Sources of water withdrawn from major pumping centers, 1972-73

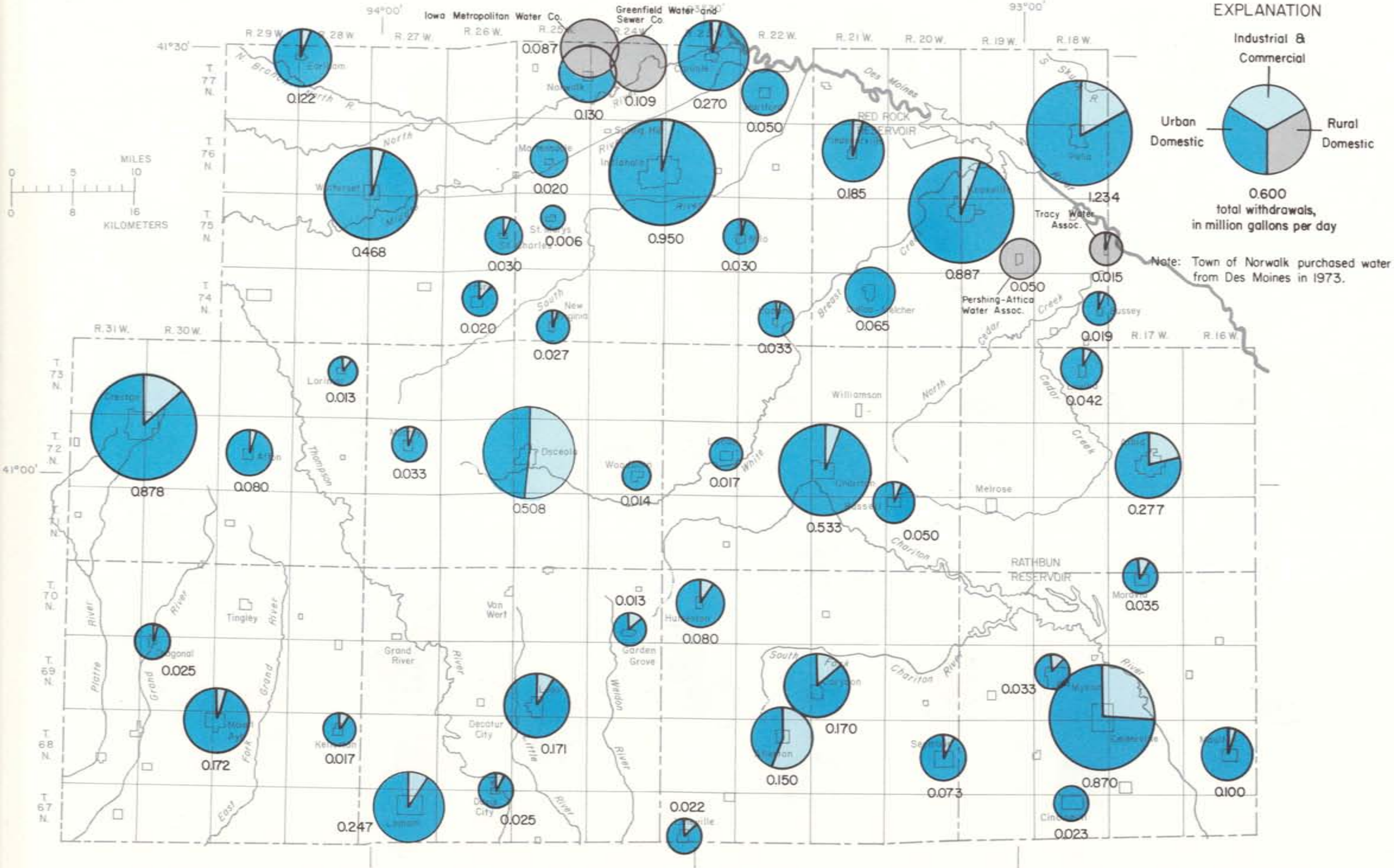


Figure 59.— Average daily water withdrawals from major pumping centers and type of use, 1972-73

WATER USE BY IRRIGATORS AND THE MINERAL INDUSTRY

Sprinkler irrigation, which is practiced in south-central Iowa, is a highly consumptive use of water; nearly all water is evaporated or transpired by plants. In each of the years 1972-74 permits allowing the use of 627.47 million gallons annually for irrigation in south-central Iowa were on file with the Iowa Natural Resources Council. Of this amount, applicants requested permits to withdraw 96 percent of the total from streams and reservoirs, and the remaining 4 percent from wells. The amount of water reportedly used in 1972 — the year in which the most complete records were available — was only 43 million gallons. The amount of water used for irrigation varies considerably from year to year, because irrigation is supplemental and often is not needed. The amount of water used depends a great deal on the type of crop, the interval within the growing season when deficient rainfall might occur, the water-holding capacity of the soil in a particular area, the ease of obtaining large amounts of water, and the market conditions pertaining to a particular irrigated crop. Irrigation is practiced only by farmers who can economically and easily obtain a sufficient amount of water. Most practicing irrigators in the region are located along a stream that can be dammed, along a large stream that can yield large amounts of water without storage facilities, or in areas of extensive flood-plain or terrace deposits where sand and gravel aquifers yield large amounts of water at relatively shallow depths.

An irrigation use that is nearly impossible to measure or estimate is the water used to irrigate urban and suburban lawns and gardens. An average suburban lot is about one-quarter of an acre in size (10,890 square feet). Not counting the area covered by the house, garage, driveway and sidewalks, the lawn and garden area is about 8,000 square feet. It would take 5,000 gallons to apply 1 inch of water to this area. The number of home owners who irrigate these lawns would be difficult to estimate, but the amount of water consumed in this manner must be considerable. It is included with the water shown for domestic use in figure 59; and it probably accounts for a large share of the increased use during summer months.

In addition to the industrial use shown in the preceding tables, there is one other industrial type of water use; that is, water used by the mineral industry in quarrying and gravel pit operations. The water is withdrawn to wash aggregate, drain quarries and pits, and in some sand and gravel operations to transport the material out of the pit. A permit must be secured from the Iowa Natural Resources Council in order to use water for these purposes. Most often, not all the water that an operator is permitted to use is withdrawn. In 1972 the total number of permits on file with the Water Commissioner allowed the use of about 14.5 billion gallons per year by the mineral industry in south-central Iowa. Of this total only 0.35 mgd. was actually reported as being used during 1972.

THE CHANGING WATER PICTURE IN SOUTH-CENTRAL IOWA

The water-use pattern in south-central Iowa has changed significantly in recent years, particularly with regard to the utilization and distribution of public supplies for urban-domestic use. Until about 1960 the percentage of the population in the category of rural-domestic water users was greater than was the percentage of urban-domestic water users. However, beginning in the early 1960's these percentages began to be reversed as indicated below:

Year	Urban-domestic use (percent)	Rural-domestic use (percent)
1930	33	67
1940	37	63
1950	41	59
1960	49	51
1973	57	43

The modern-day needs for additional supplies of good-quality water has been brought about principally by such factors as changing residential patterns, the influx of new industry, and the development of Red Rock and Rathbun reservoirs as recreational areas.

Prior to 1940 only 21 towns had municipal water systems, but by 1960 the number had increased to 39, and in 1973 the total was 46. But in 1973, 41 incorporated towns and communities still did not have water systems.

Until 1966, nearly all public water supplies were obtained from municipal water systems. However, in 1966, the first privately-owned and operated water system was put into operation to furnish public supplies for rural-domestic use. By 1973 there were four companies or associations furnishing water to individuals in rural areas, rural housing developments and unincorporated communities. In 1973 an estimated 3000 rural residents of Marion and Warren Counties were being served by the private systems.

The Rathbun Water Association, which started limited operations in 1977, has been authorized to take up to 438 million gallons of water a year from Rathbun Lake. This water can be withdrawn at a maximum rate of 4,200 gallons per minute. The Association will supply water to over 6,000 users in rural areas and in 13 towns. Ten of these towns have no present water systems. Based on permits issued by the Iowa Natural Resources Council, it is anticipated that public supplies from private systems will increase in coming years.

Four additional private agencies have applied for or have received permits to operate as Water Association or Water Districts and to sell and distribute water supplies. These are Clarke County Rural Water Association, Clearfield Water District, Union County Water District, and Town and Country Water District. These are in various stages of development as of 1977.

REGULATION OF WATER USE

The Iowa Natural Resources Council has the authority to establish and enforce a comprehensive state-wide plan for the control of water and the protection of the water resources of the state. Under this authority, the use of water for many purposes is regulated through a permit system administered by the Water Commissioner.

Regulated uses include: (1) any municipal corporation or person supplying a municipal corporation which increases its water use in excess of 100,000 gallons, or three percent, whichever is greater, per day more than its highest per day beneficial use prior to May 16, 1957; (2) except for non-regulated use, any person using in excess of 5,000 gallons per day, diverted, stored, or withdrawn from any source of supply except a municipal water system or another source specifically exempted (this category includes irrigation); (3) diverting water or any other material from the surface directly into any underground water course or basin (a permit is not needed for this purpose if diversion existed prior to May 16, 1957, and does not create waste or pollution); and (4) industrial water users who have their own water supply, within the territorial boundary of municipal corporations, and whose use exceeds three percent more water than the highest per day beneficial use prior to May 16, 1957.

Many uses do not fall under the control of the Iowa Natural Resources Council. Nonregulated uses include use of water for ordinary household purposes, for poultry, livestock and domestic animals, or the use of surface waters from rivers which border the state or ground water from islands or former islands in these rivers. Beneficial uses of water within the territorial boundaries of cities that do not exceed three percent more than the highest per day beneficial use prior to May 16, 1957, are considered non-regulated uses, as are any other beneficial uses of water by any person using fewer than 5,000 gallons per day.

Persons planning to develop a water supply for any purpose which falls under the category of a regulated use should first make application for a permit. The rules under which the water permit system is administered can be found in The Code of Iowa, Chapter 455A.

SUMMARY

The purpose of this water-resources investigation in south-central Iowa was to obtain water information needed to help solve water-shortage problems in the region. This report provides some information for the eleven counties in the region by evaluating data on the occurrence, general availability, and chemical quality of ground water and surface water in these counties. An evaluation of these data is summarized in the following statements.

Except for the Des Moines River, streams in south-central Iowa can supply very limited amounts of water without storage. The Middle and Thompson Rivers can supply about 7 and 9 cfs 90 percent of the time at sites near Indianola and at Davis City, respectively. During severe drought conditions even these streams recede to very small discharges. In 1955, the average flow for a 60-day period was less than 2 cfs on the Middle River near Indianola and less than 1 cfs on the Thompson River at Davis City. The other smaller streams have lower yields. The normal dry-weather flow (7-day, 2-year low flow) is at or near zero for streams draining 100 square miles or less.

The best sources of surface-water supply in the area are Red Rock and Rathbun Lakes. The water-supply potential of other streams can also be enhanced by the development of storage. The topography of the area is favorable for such development. Site surveys and detailed analyses would be needed to evaluate the possibilities more thoroughly. Stored surface water from thousands of farm ponds that dot the area is being used as a supply for livestock watering.

A few short-term records indicate relatively large yields of suspended sediment, well over 1000 tons per square mile per year, in a large part of the area. This would be an important consideration in the planning and design of storage reservoirs. On the other hand, suspended-sediment yields in the Chariton River basin, in the southeastern part of the area, are substantially lower, on the order of a quarter to a third of those in the Des Moines and Thompson River basins.

Small-to-moderate supplies of water are available for development from the surficial aquifers at most places in south-central Iowa; large supplies can be obtained in some parts of the area. The alluvial aquifers are the best of the surficial aquifers. They yield from 10 to 500 gpm, depending on the size of the valley and the thickness and permeability of the sand and gravel deposits. The source of the largest yields is the alluvial aquifers underlying the Des Moines and Skunk River valleys where a potential of 150 to 500 gpm is estimated to be available from individual wells tapping these aquifers. The deep drift and buried-channel aquifers generally yield 5 to 25 gpm, but occasional yields of as much as 60 gpm can be obtained. The shallow drift aquifers usually yield only 1 to 5 gpm, but occasionally as much as 10 gpm can be obtained.

The most productive of all aquifers in the report area is the deep-lying Cambrian-Ordovician aquifer which invariably will yield 200 to 500 gpm, but is capable of furnishing 1000 gpm or more in more than one-half the region. The other bedrock aquifers, the Pennsylvanian, Mississippian and Devonian aquifers, yield much less water. Yields from these aquifers usually will be less than 25 gpm, but yields of 50 to 100 gpm are obtainable at places where these aquifers are directly overlain by surficial aquifers or where large fractures, crevasses or solution channels exist in the rocks or where these conditions exist simultaneously.

The chemical quality of water from the streams and the alluvial aquifers in south-central Iowa is the best in the region. The dissolved-solids concentration in water from streams and most alluvial aquifers invariably is less than 500 mg/L; very rarely are the concentrations as high as 1000 mg/L in a few alluvial aquifers. The water from both sources is hard to extremely hard, but all constituents except iron and manganese are well below recommended limits. Water from the drift aquifers is quite variable in chemical characteristics. Dissolved solids usually are less than 500 mg/L, but occasionally they range from 500 to 1500 mg/L in water from shallow depths in the drift aquifer. The water is very hard and often the concentrations of iron, manganese, and sulfate exceed recommended limits. Locally, excessive concentrations of nitrate and chloride are attributed to contamination of the well water (the higher dissolved-solids concentrations are found at these sites). Generally, the dissolved solids and sulphate concentrations increase with depth in the drift aquifer while the nitrate concentration decreases. Overall, water in the deep drift aquifer, as well as in the buried-channel aquifer, usually is highly mineralized. Water in the Pennsylvanian and Mississippian aquifers most often will have a high mineral content, but locally and within limited areas, some of which are defined, the quality is acceptable for some uses. The Devonian aquifer contains highly mineralized water and, particularly, has a high chloride concentration. Water in the Cambrian-Ordovician aquifer is of better chemical quality than that from the other bedrock aquifers, containing dissolved-solids concentrations of 1000 mg/L or less in approximately the eastern one-third of the report area. But the quality deteriorates to the southwest, where dissolved solids exceed 2500 mg/L.

CONCLUSIONS

The principal conclusion to be drawn from the information presented in this report is that adequate supplies of good-quality water are available for all purposes only locally or in limited areas, or only after extensive treatment.

Modern rural (farm and small community) needs for readily accessible, good-quality water can be satisfied only locally or in limited areas, where sufficient good-quality water is available from the alluvial aquifer, from shallow depths in the drift aquifer, and from the Pennsylvanian and Mississippian aquifers where they are at the bedrock surface. The rural user can develop sufficient water from Pennsylvanian sandstones and Mississippian limestones at most places and from deeper parts of the glacial drift in some areas, but the water is highly mineralized. The mineralized water generally is satisfactory for a livestock supply and for some domestic purposes, but many rural users may find the water unsuitable for cooking or drinking. Good-quality water is being supplied to some rural users by a small number of rural water districts. This practice is expanding and is expected to solve the quality problems of most rural users.

Industrial needs for large quantities of water can be satisfied in approximately the eastern three-fourths of the area by developing water from the Cambrian-Ordovician aquifer — if the water quality is not an important consideration or if demineralization is economically feasible. Large quantities of relatively good-quality water are also available from the alluvial aquifer in the extreme northeastern part of the area. Light industrial and small-community needs for moderate amounts of water can be satisfied at some places from the surficial aquifers, and from the Pennsylvanian and Mississippian aquifers. Some treatment of the water from these sources may be needed for industrial usage, but this would depend on the water-quality requirements of the industry. Most industrial requirements probably will be best met by purchase from municipal supplies, as they presently are.

Municipal needs for large amounts of moderately good-quality water can be satisfied best by surface-water impoundments, such as Rathbun and Red Rock Lakes. The topography is favorable for additional impoundments. Municipal requirements also can be met by withdrawals from the deep Cambrian-Ordovician aquifer in the eastern one-third of the report area. Elsewhere, it is likely that water from the deeper sources will require extensive quality treatment. The other sources of large municipal supplies are from the alluvial aquifers in the extreme northeastern part of the area.

Another conclusion necessarily follows: the importation of water from outside the region and (or) demineralization of the saline resources in the region may have to be considered to provide sufficient good-quality water that is needed for present and future economic growth. The technology and the sources of water are available to implement either procedure, but economic considerations are involved.

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