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Iowa Geological Survey Water Atlas No. 4

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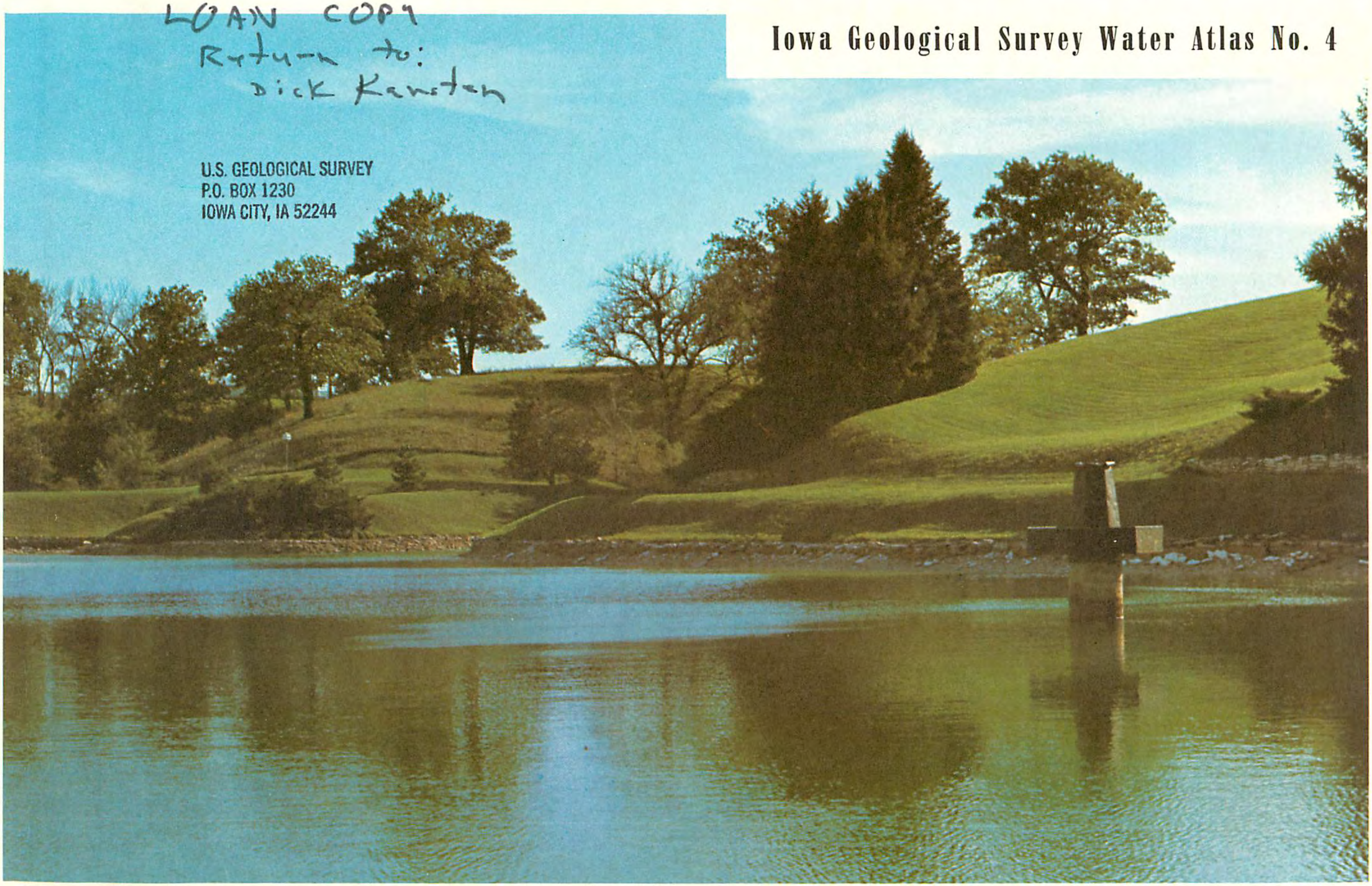

WATER RESOURCES OF SOUTHEAST IOWA

Iowa Geological Survey Water Atlas Number 4

THE WATER RESOURCES OF SOUTHEAST IOWA

by

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with a section on

SURFACE WATER RESOURCES

by

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This atlas presents information on the occurrence, availability, quality, and utilization of water in southeast Iowa

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

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FOREWORD

Water resources are one of the most fundamental elements of the environment of man. All of society's attempts to live in a rational state of balance with nature depend upon an understanding of the limits imposed upon its existence by the quality and quantity of water available to it. In southeastern Iowa there are several alternatives available to those seeking to secure a reliable source of water for themselves or their community. This report summarizes the alternatives in a manner that makes truly long-range planning possible.

The way in which man uses the land has a protracted impact upon the quality and quantity of water available to him. The places he chooses to establish solid and liquid waste disposal sites, the closeness with which he spaces water-using industries, the manner in which he manages his agriculture all relate to the water resources upon which he must rely. This report will have significant usefulness to him in his attempts to deal wisely with these types of problems.

This report contains the presently known information available through the United States and Iowa Geological Surveys. These two agencies are continually gathering hydrologic and geologic data. Those persons requiring water resources and geologic information will find this report to be a thorough, concise summary of the information at the date of publication. Direct inquiry of the Surveys for more recently acquired information is welcomed.

Samuel J. Tuthill
Director & State Geologist
Iowa Geological Survey

Iowa City, Iowa
September 1971

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.

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.

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

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

Aquitard - Rocks that retard the flow of water through them so as to restrict the amount of water which can reach an underlying aquifer or restrict circulation between aquifers.

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 dominantly 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.

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

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 piezometric surface.

Dissolved solids - The total dissolved mineral content of 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.

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 mobile 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 arithmetic average of air temperature values for a 30-year period ending with an even 10-year. In this report, the period is 1931-1960.

Normal annual precipitation - The arithmetic average of annual quantities of precipitation for a 30-year period ending with an even 10-year. In this report, the period is 1931-1960.

Normal pool altitude - The level of a flat-water pool of a controlled stream is maintained at this altitude or at higher altitudes during the navigation season (March 16 to December 9 on the Mississippi River adjacent to southeast Iowa).

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 difference ordinarily found in ground water systems.

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

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 beneath and forming 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

Appreciation is expressed to the water superintendents of all the communities in southeast Iowa and to the plant engineers of many industries who willingly provided water-use data. Many individual farmers and homeowners furnished information about their water supplies and permitted the sampling of water from their wells.

Special thanks are due to the personnel of the Iowa Geological Survey who, through the past years, have analyzed many samples of drill cuttings and have accumulated and stored a wealth of geologic and ground-water data. Their work was the basis upon which the aquifers in this study were defined.

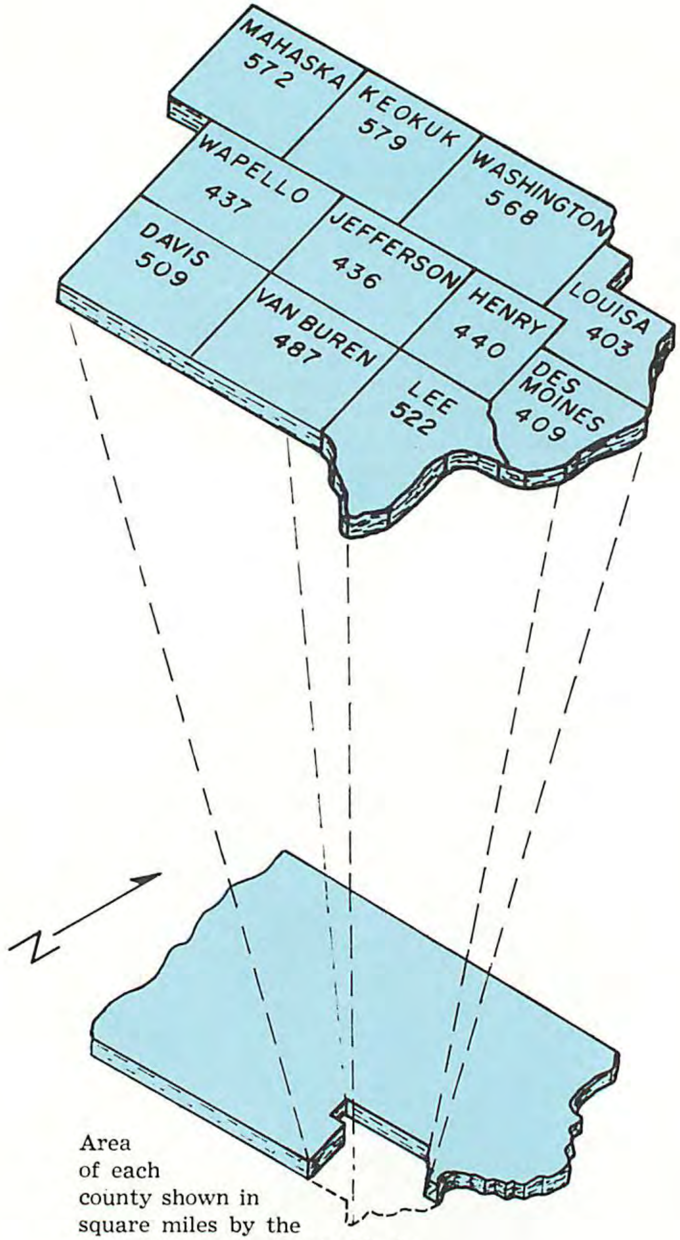
The cooperation of the well drillers who work in southeast Iowa is acknowledged. Their efforts in carefully collecting drill cuttings and recording water data have resulted in a good understanding of the water resources of this area.

All the chemical analyses used in this study were performed by personnel of the State Hygienic Laboratory. Special thanks are due them for their extra efforts in handling the many water samples collected especially for this study.

Besides writing the surface-water section of this report, J. V. Roberts made a study of the geologic and water-yield data pertaining to the Cambrian-Ordovician aquifer. Some of the data presented in this report on that particular aquifer are based on his work.

INTRODUCTION

Water is vital in the lives of the people and the economy of any area. In order to utilize this natural resource in the most efficient and beneficial manner, a basic knowledge and understanding of its sources and the occurrence and potential of each source must be gained. To provide this knowledge, the Water Resources Division of the U.S. Geological Survey in cooperation with the Iowa Geological Survey compiled this atlas describing the water resources available for development in an 11-county area in southeast Iowa. The report contains information on the availability, quality, and utilization of water from all known sources and the future demands upon the water resources in southeast Iowa. The information is presented to aid water users and other persons searching for and evaluating sources of water in a particular place, and planners and water managers who must consider water resources on a regional basis.



Area of each county shown in square miles by the number in each county block.

Figure 1.—The 11 counties in southeast Iowa

SOUTHEAST IOWA

The southeast Iowa area consists of 11 counties in the southeastern corner of the State. These 11 counties cover 5,362 square miles—about 9.6 percent of the land area of Iowa.

Southeast Iowa includes parts of three large drainage basins—the Des Moines, Skunk, and Iowa—and several smaller ones. Except for a few square miles in the southwestern corner of the area, all these basins drain into the Mississippi River which forms the eastern boundary of the area.

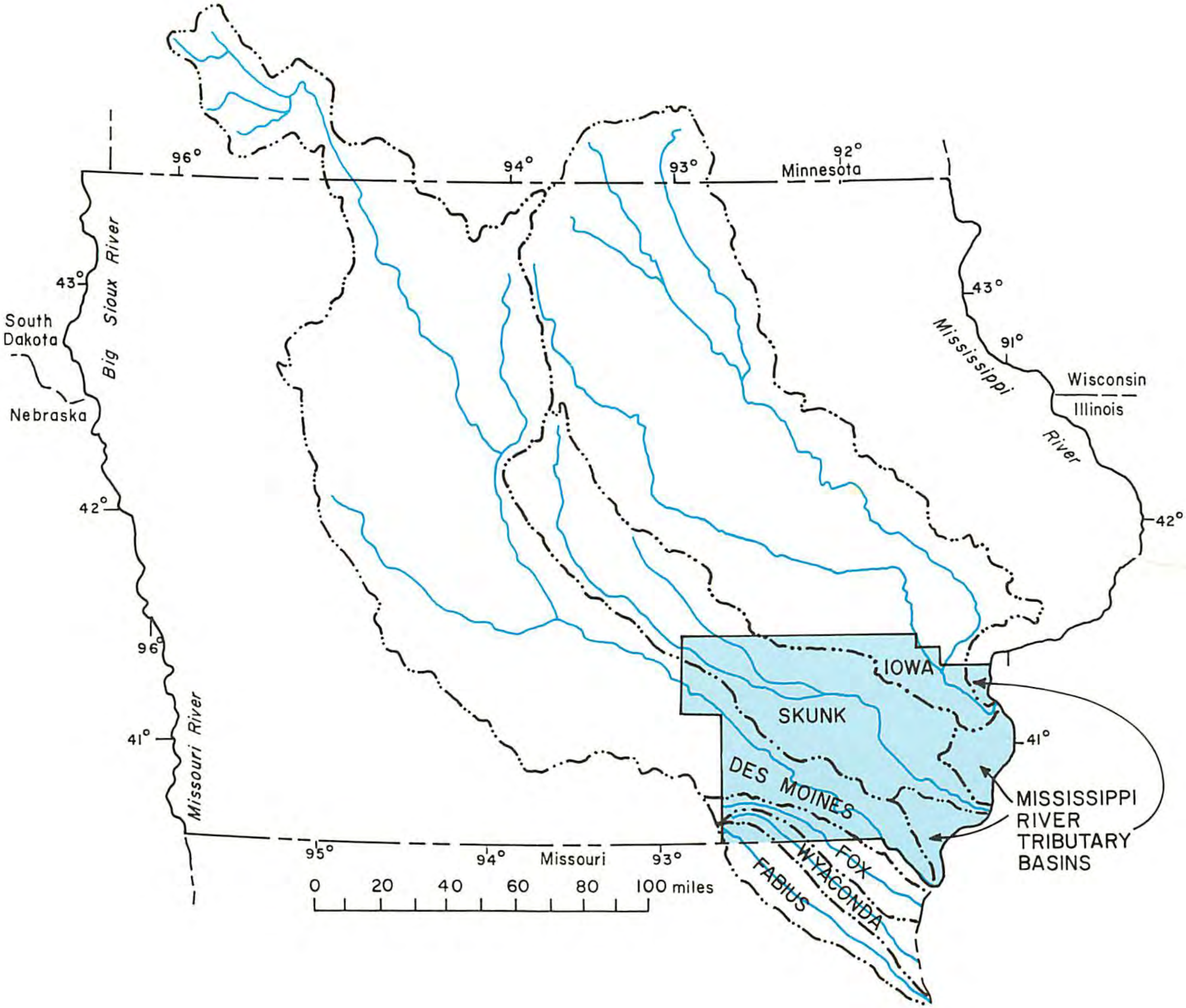


Figure 2.—Drainage basins in southeast Iowa

THE LAND SURFACE

The horizon in southeast Iowa gives the impression of a flat, level land surface, but for the most part the land is hilly and rolling. The topographic development of the basins has reached the stage of late youth or early maturity. The region has a well integrated stream system, and flat divides are fairly narrow. In only a few areas are the flat divides more than 5 miles wide, and in most places their widths are less than 2 miles. The flat upland divides are less than a mile wide or non-existent in extensive areas southwest of the Des Moines River. No natural lakes are found on the uplands.

The valleys of the Mississippi and Iowa Rivers are 5 miles wide in some places, but those of the other major streams are seldom more than 1 mile wide. The streams are free to shift their positions in most parts of the major valleys, and meander development is common although greatest in the Iowa and Mississippi valleys, especially the former. Oxbow lakes and sloughs are evident in at least parts of all the major valleys and are most common along the Iowa and Mississippi Rivers. Tributary valleys are often narrow and steep sided and contain numerous potential dam sites for reservoirs.

Dissected upland surface south of the Des Moines River in Van Buren County

Wide floodplain of the Iowa River near Wapello, Louisa County

The total topographic relief in the area is a little more than 500 feet. As shown on the topographic map (fig. 3), the altitude is lowest, 480 feet above mean sea level, along the banks of the Des Moines and Mississippi Rivers at their junction near Keokuk and is highest, slightly more than 1,000 feet above mean sea level, in the southwestern corner of the area. The local topographic relief, that between the major stream valleys and the adjacent flat drainage divides, is highest near the Mississippi River where it ranges from 160 to 260 feet, and it is lowest in the English River basin where the relief is from 100 to 140 feet.

The altitude of the land surface is needed to estimate drilling depths and water-level depths in wells, 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. More detailed topographic maps are available and can be purchased through the agencies listed in the back of this report.

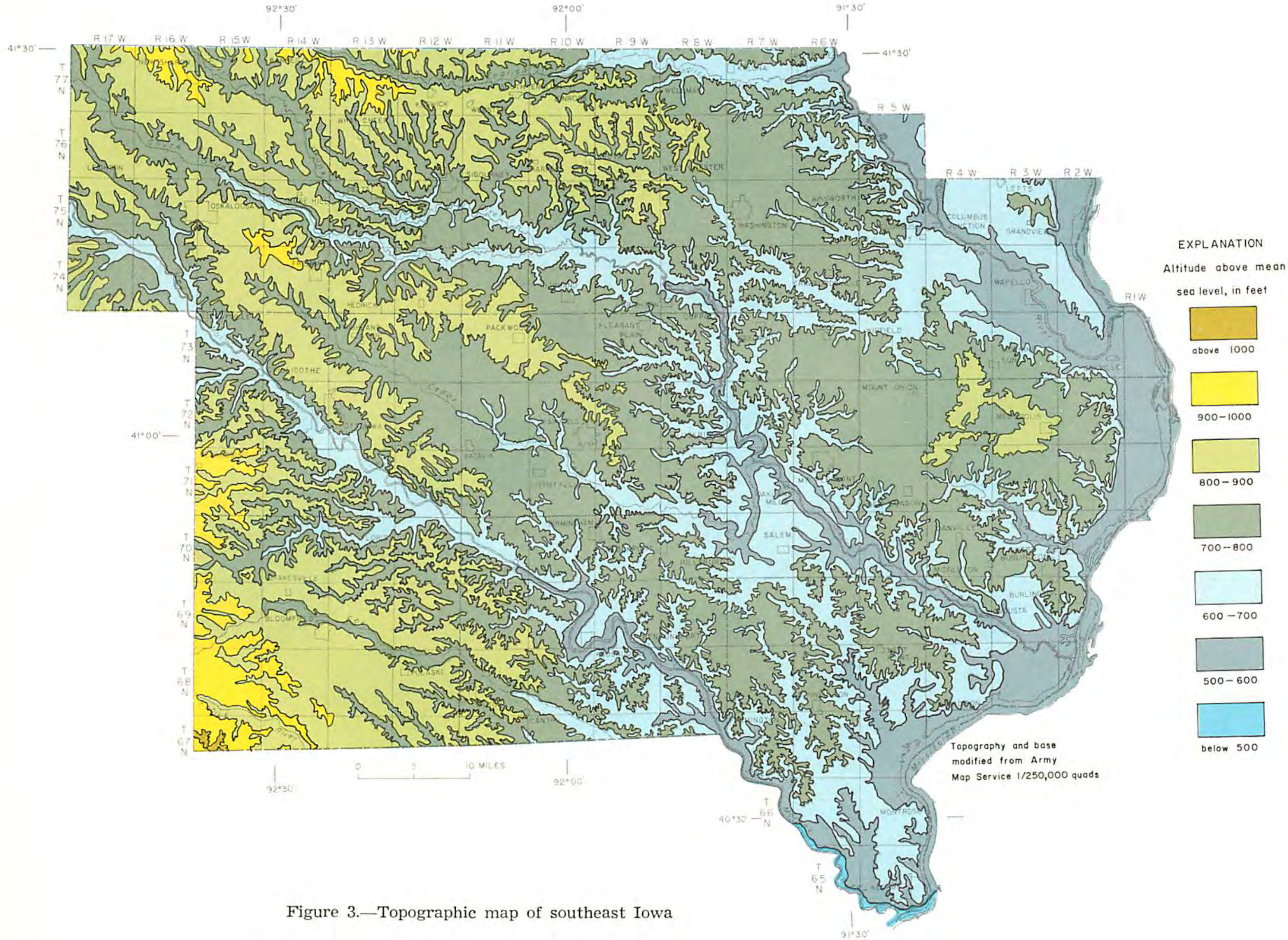


Figure 3.—Topographic map of southeast Iowa

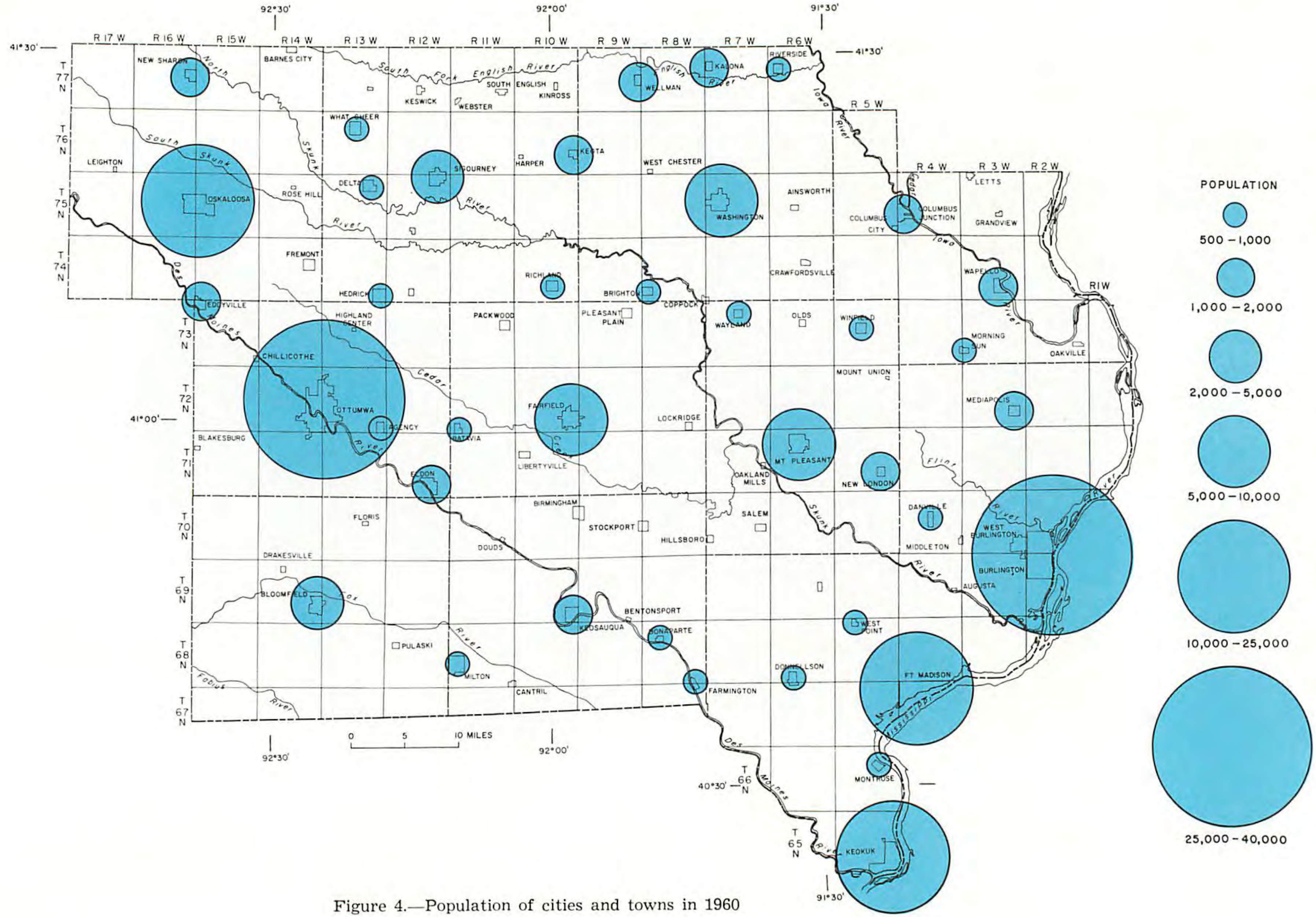


Figure 4.—Population of cities and towns in 1960

POPULATION

In 1960, there were 256,226 people residing in the 11 counties in southeastern Iowa. This was about 9.4 percent of the population of Iowa. Fifty-three percent of these people lived in urban areas (places with more than 2,500 persons). Figure 4 shows the relative sizes of the cities and towns. Ottumwa was the largest city with a population of 33,871. Burlington's population was 32,430; and the adjacent community of West Burlington had a population of 2,470 for a total of 34,900 in that urban area.

Three other communities had populations greater than 10,000; these were Keokuk with 16,316, Fort Madison with 15,247 and Oskaloosa with 11,053.

The total population in southeastern Iowa has been relatively stable since 1910. See figure 5. The predictions of future population illustrated on the adjacent graph show the population remaining about the same or experiencing a modest increase of about 0.25 percent per year. Although this increase is conservative, it is commensurate with the trend during the past few decades. This prediction would indicate a population of from 260,000 to 300,000 in southeastern Iowa by the year 2000.

A steady change from a rural to an urban population has taken place in the past. In 1900 the urban population in southeastern Iowa was 32 percent of the total; by 1960 it had climbed to nearly 53 percent. By the year 2000, twice as many people probably will be living in the urban areas as in the rural parts of southeast Iowa.

This shift in population is significant with respect to the area's water resources. It means that water demands for domestic needs, as well as for industries, will be concentrated even more in and around urban areas.

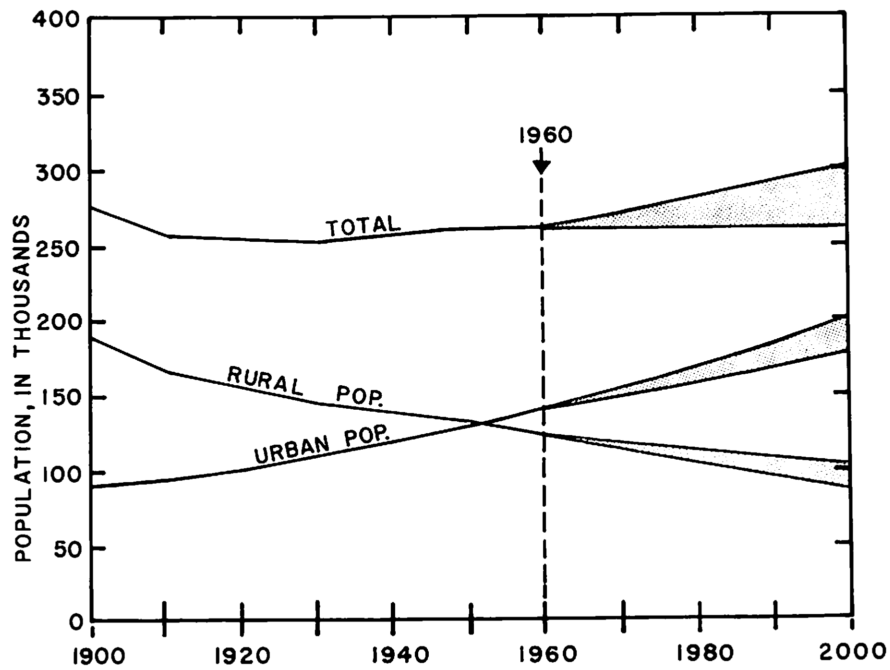


Figure 5.—Population trends is southeast Iowa

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 southeast 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 (see 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. Here 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 southeastern Iowa is slightly more than 33.6 inches per year. Over the entire southeast Iowa area, this amounts to an average of 9 billion gallons of water per day in the form of rain, snow, and sleet.

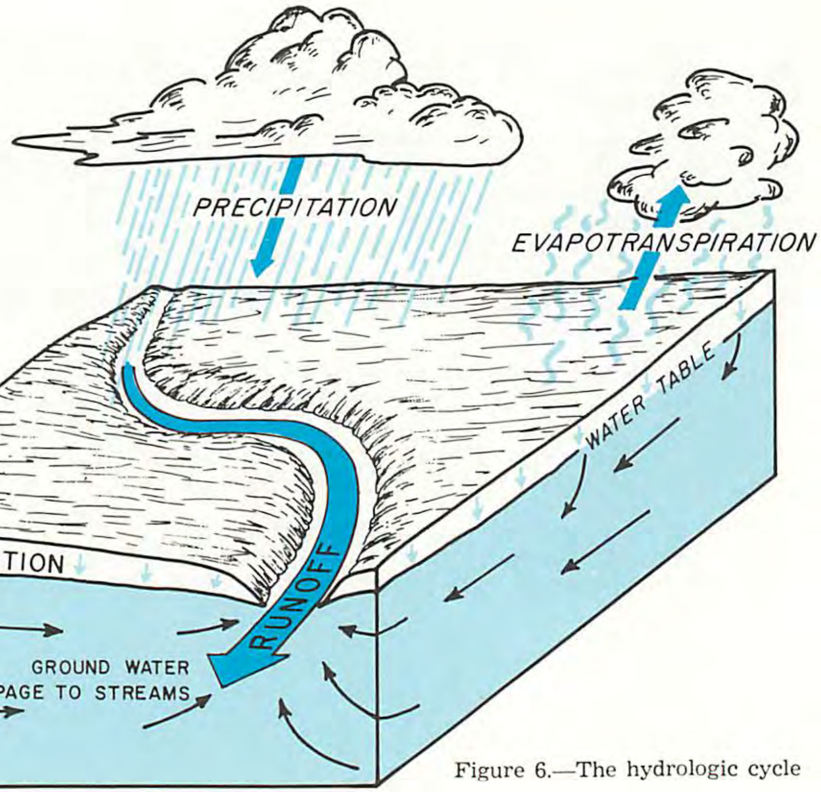


Figure 6.—The hydrologic cycle

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 7.5 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 moves through the open spaces in granular materials and through 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 water in storage. Most of the ground water eventually reappears at the surface to contribute to the streamflow. During dry years, the ground-water discharge makes up a high proportion of the streamflow. Discharge from the ground-water reservoir is a continuous although not a constant process, and depletion of storage from the reservoir results from a decrease in recharge.

Southeast Iowa is not entirely dependent for its water supply on the precipitation that falls within the area. The volume of water carried into southeast Iowa from other parts of Iowa and the upper Midwest by the Mississippi, Iowa, Skunk, and Des Moines Rivers is more than 20 times the runoff contributed by the southeast Iowa area. Also much of the ground water beneath southeast Iowa is derived from recharge outside the area.

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

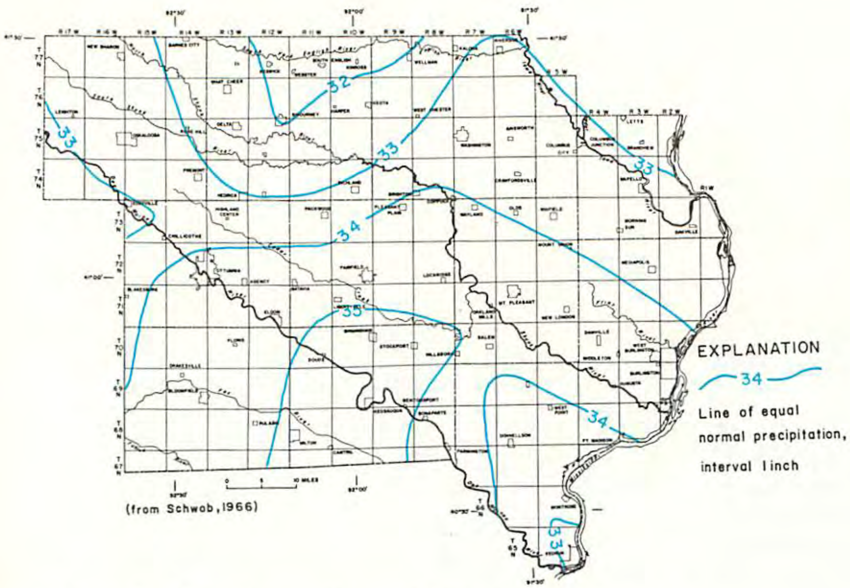


Figure 7.—Normal annual precipitation in southeast Iowa

CLIMATE

The normal annual precipitation for the southeast Iowa area is 33.61 inches, but at various stations within the area it ranges from about 32 to more than 35 inches.

Although the amount of precipitation varies from year to year, the departure from the normal usually is less than 10 inches. An example, shown in figure 8, is offered by the record from the station at Mount Pleasant where the normal annual precipitation is 34.66 inches. The record for 95 years shows a departure of more than 5 inches from the normal occurred during 56 percent of the years, and a departure of more than 10 inches only about 17 percent of the years. Records at other stations in the area exhibit similar departures.

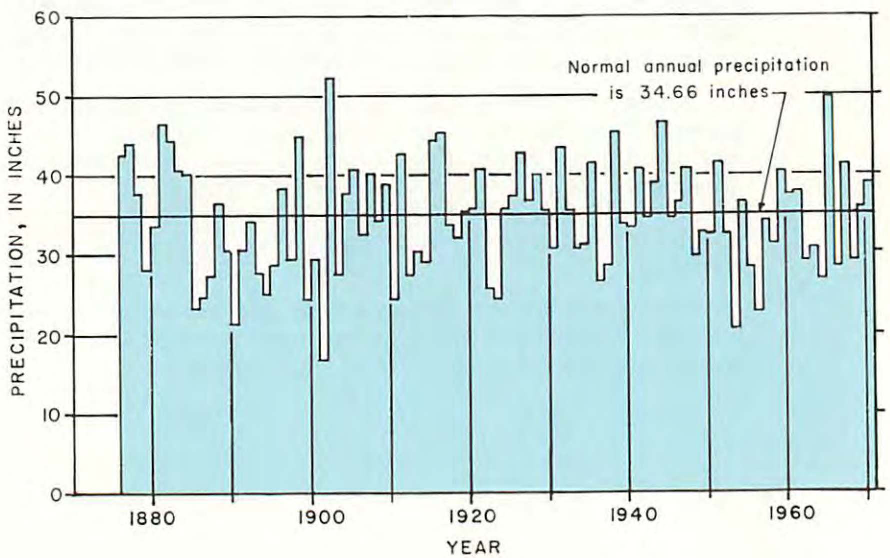


Figure 8.—Annual precipitation at Mount Pleasant, Iowa

Precipitation is greatest during the growing season in the spring and summer months when it is most needed by vegetation. Sixty-seven 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 station in southeastern Iowa during the period of record. March through June are the only months when a measureable amount has always fallen at each station in the area. Maximum recorded rainfall during any month has been almost six times the normal monthly amount, and in some months nearly one-half of the normal annual amount has fallen.

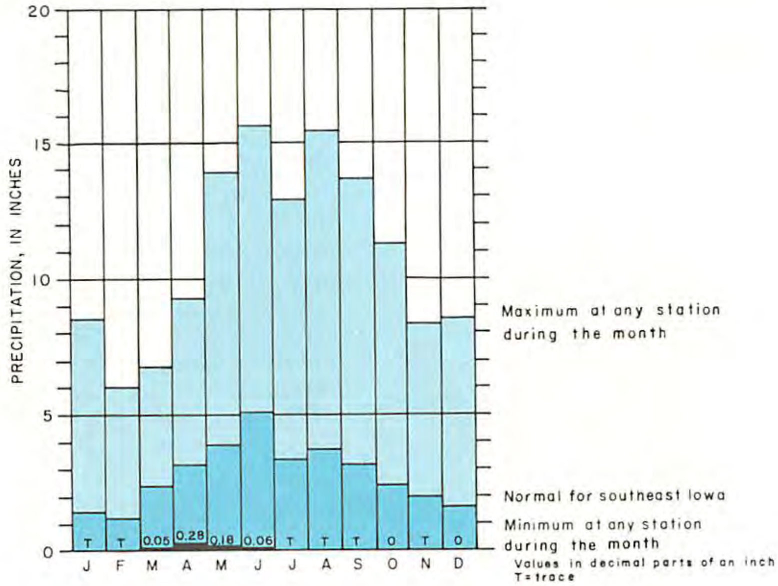


Figure 9.—Monthly extremes and normal precipitation

The normal air temperature in southeastern Iowa is 51.6°F (10.9°C). Monthly mean temperatures throughout the area range from about 25°F (-4°C) to nearly 78°F (25°C). Figure 10 shows extreme temperatures of more than 100°F (38°C) have occurred someplace in southeast Iowa during the 5 months from May through September, and temperatures have dropped below freezing at least once during every month except June, July, and August.

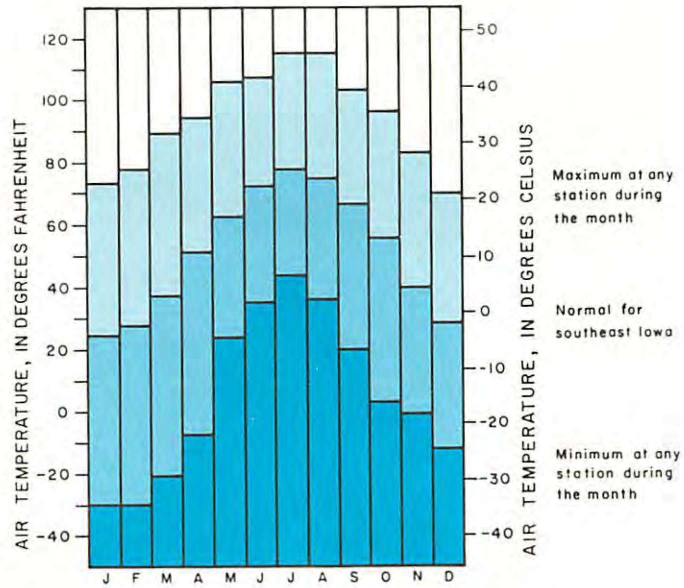


Figure 10.—Monthly extremes and normal air temperatures

SURFACE-WATER RESOURCES

by J. V. Roberts

Water drains from the land into streams that vary in size from small rills, which are dry most of the time, to large rivers. The area drained by a stream is called the drainage basin. Stream-gaging stations maintained by the U.S. Geological Survey (shown on fig. 11) are located in all the major and in some of the minor drainage basins of southeast Iowa. Records of flow at gaging stations provide basic data which are a chronological record of the flow regime. They are analyzed to determine several streamflow characteristics, such as average discharge, flood frequencies, low-flow frequency and duration, and storage requirements on these streams.

Des Moines River at Bentonsport, Van Buren County

In order to obtain additional low-flow information without establishing permanent stations, 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 southeast Iowa are listed in table 2. The discharges at each partial-record station can be correlated with concurrent discharges at gaging stations which have similar drainage basin characteristics. When a satisfactory hydrologic relationship between a gaged and ungaged site is confirmed, streamflow statistics may be estimated for the ungaged site. Estimated streamflow characteristics are less accurate than those based on analysis of long-term streamflow records and are subject to an unknown error. From a practical standpoint, however, these estimates add useful information to a regional study.

Regulation of streamflow by a reservoir alters the natural characteristics of a stream. The Iowa River below Iowa City has been regulated by the Coralville Dam and Reservoir since 1958, and the Des Moines River below Knoxville has been regulated by Red Rock Dam and Reservoir since 1969. Except as noted, streamflow characteristics shown in the ensuing pages for these two streams represent the natural streamflow prior to regulation.

REGULATIONS PERTAINING TO NAVIGABLE WATERS

The administration of Federal laws for the protection and preservation of the navigable waters of the United States is the responsibility of the U.S. Army Corps of Engineers. This responsibility includes: granting permits for structures over and in such navigable water; establishing regulations for use of navigable waters, including anchorages, dumping grounds, fishing areas, and harbor lines; and preventing pollution of navigable waters from oil or refuse. Persons planning to utilize the surface-water resources by constructing or erecting any structures over or in any of the principal waterways should obtain information about the regulations concerning these activities from the Corps of Engineers.

Table 1.—Gaging stations

Station Number	Stream Name and Location	Drainage Area (sq. mi.)	Average Discharge (cfs)	Lowest Daily Mean Discharge (cfs)	Maximum Discharge (cfs)	Records Used
	Iowa River Basin					
5-4555	English River at Kalona	573	320	1.1	20,000	1940-68
5-4557	Iowa River nr Lone Tree[a]	4,293	2,249	75	31,200	1957-68
5-4650	Cedar River nr Conesville	7,785	3,985	250	70,800	1940-68
5-4655	Iowa River at Wapello[a]	12,499	6,184	300	94,000	1915-68
	Skunk River Basin					
5-4715	South Skunk River nr Oskaloosa	1,635	750	1.8	37,000[b]	1946-68
5-4725	North Skunk River nr Sigourney	730	380	.1	27,500	1946-68
5-4730	Skunk River at Coppock	2,916	1,350	8	41,500	1914-44
5-4735	Big Creek nr Mt. Pleasant	106	56.0	0	6,150	1956-68
5-4740	Skunk River at Augusta	4,303	2,187	7	51,000	1915-68
	Mississippi River Main Stem					
5-4745	Mississippi River at Keokuk	119,000	60,970	5,000	360,000[c]	1879-1968
	Des Moines River Basin					
5-4885	Des Moines River nr Tracy	12,479	4,230	40	155,000	1921-68
5-4890	Cedar Creek nr Bussey	374	182	0	31,500[d]	1948-68
5-4895	Des Moines River at Ottumwa	13,374	4,669	30	135,000	1918-68
5-4905	Des Moines River at Keosauqua	14,038	5,158	40	146,000	1904-05 1912-68
5-4910	Sugar Creek nr Keokuk	105	64.4	0	Unknown[e]	1922-31 1959-68
	Fox River Basin					
5-4943	Fox River at Bloomfield	87.7	43.8	0	8,600	1958-68
5-4945	Fox River at Cantril	161	97.7	0	16,500	1941-51

a. Regulated by Coralville Reservoir since September 1958.
b. Flood of May 1944.
c. Flood of June 6, 1851.
d. Flood of June 1946.
e. Occurred on November 17, 1928.

Table 2.—Low-flow, partial-record stations

Station Number	Stream and Location	Drainage Area (sq. mi.)	Estimated Average Discharge[a] (cfs)
	Iowa River Basin		
5-4554	South English River nr Keswick	66.2	36
5-4554.5	South Fork English River nr Kinross	125	65
5-4652	Long Creek nr Ainsworth	68.4	42
5-4653	Long Creek nr Wapello	146	90
5-4656	Otter Creek nr Wapello	64.7	40
	Flint River Basin		
5-4697	Flint River nr Burlington	107	70
	Skunk River Basin		
5-4714	Elk Creek nr Taintor	59.9	36
5-4724	Middle Creek nr Rose Hill	58.5	34
5-4724.5	Cedar Creek nr Sigourney	92.5	50
5-4730.2	East Fork Crooked Creek nr Winfield	65.3	42
5-4730.5	Crooked Creek nr Coppock	259	163
5-4731	Walnut Creek at Germanville	66.3	44
5-4732	Cedar Creek nr Highland Center	73.6	43
5-4732.5	Competine Creek below Forks nr Batavia	68.8	45
5-4733	Cedar Creek nr Batavia	252	167
5-4733.5	Little Cedar Creek nr Salem	55.0	38
5-4734	Cedar Creek nr Oakland Mills	522	360
5-4734.5	Big Creek at Mt. Pleasant	58.0	38
	Devils Creek Basin		
5-4741.9	Devils Creek nr Viele	20.0	13
5-4742	Sugar Creek nr Franklin	75.6	51
5-4743	Sugar Creek nr Viele	109	73
	Des Moines River Basin		
5-4893	North Avery Creek nr Chillicothe	60.1	37
5-4894	South Avery Creek at Chillicothe	51.6	32
5-4899	Soap Creek nr Ash Grove	97.3	61
5-4901	Soap Creek nr Floris	243	161
5-4902	Lick Creek at Kilbourn	82.7	61
5-4903	Chequest Creek nr Troy	85.0	60
5-4904	Chequest Creek nr Pittsburg	123	90
5-4907	Sugar Creek nr Charleston	62.3	41

a. Standard error of estimate of average discharge is approximately ± 11 percent.

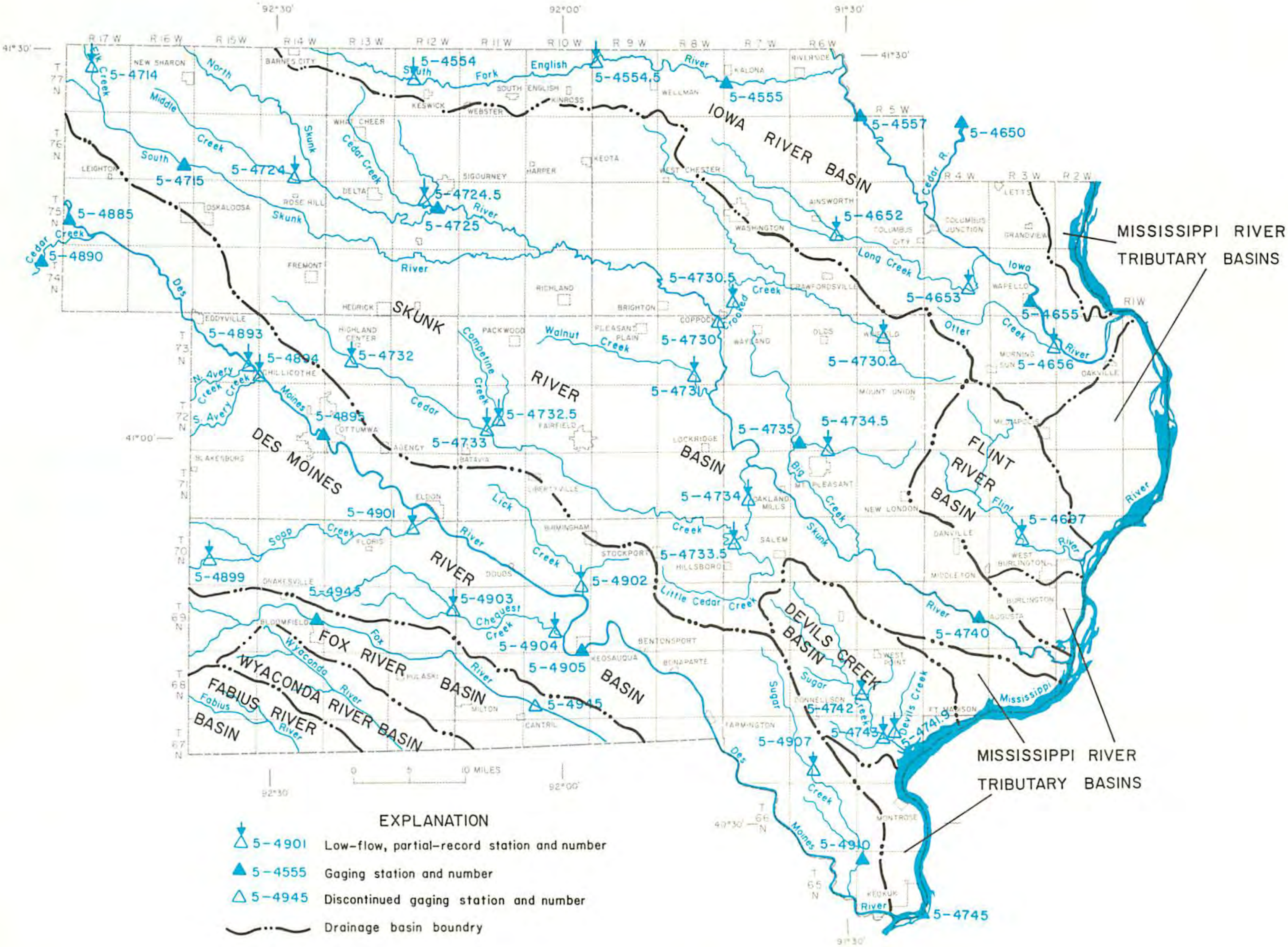


Figure 11.—Gaging stations and low-flow, partial-record stations in southeast Iowa

STREAMFLOW—SOMETIMES HIGH, SOMETIMES LOW

Fluctuations in streamflow are caused by many factors. During the winter precipitation, often as snow, is less than during other seasons. Because temperatures generally fall below freezing at night and frequently remain below freezing during the day, the snow accumulates on the ground and dissipates slowly. Small amounts of water from precipitation and low temperatures yield little runoff; thus streamflow during the winter season is low. See figure 12. In early spring, however, as temperatures rise the snow and ice that have accumulated during the winter months melt. Because the soil just below land surface may either be saturated with water or frozen, much of the water from melting snow and ice runs directly to the streams with a resultant increase in streamflow. In midspring evapotranspiration losses become significant and streamflow decreases slightly. In late spring, evapotranspiration losses may be offset by precipitation which is maximum at this time of year. In the summer precipitation is still relatively high, but streamflow decreases sharply because of increased evapotranspiration.

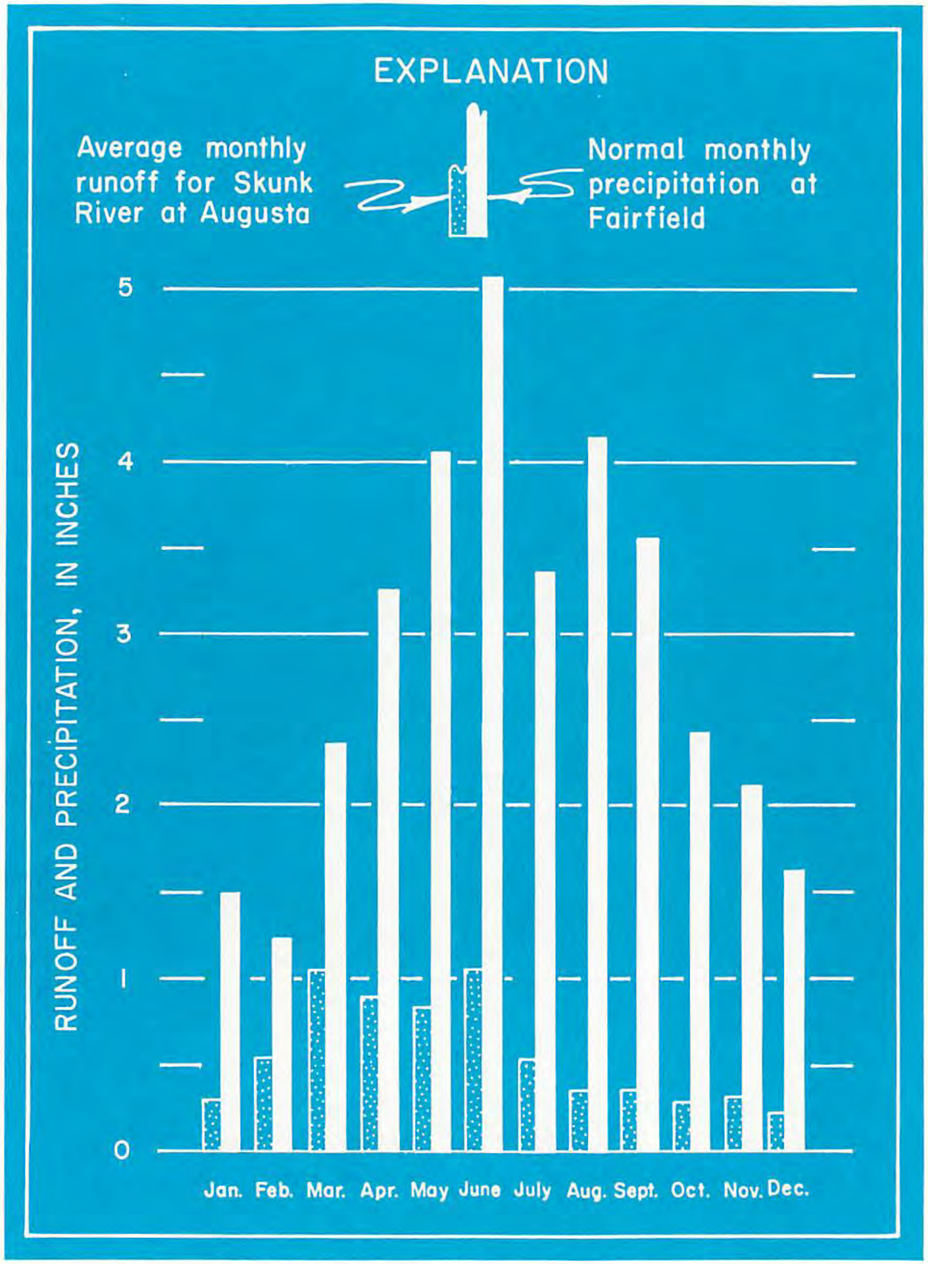


Figure 12.—Average monthly runoff of the Skunk River at Augusta, Iowa and normal monthly precipitation at Fairfield, Iowa

Streamflow in Big Creek for two different water years illustrates how the stream responds to variations in weather. (See figure 13). The 1965 average streamflow for Big Creek was the highest on record. Total precipitation for that water year at Mount Pleasant was more than 12 inches above normal, the highest in at least 35 years.

Average streamflow during 1957 was the lowest on record, less than 7 percent of the long-term mean. There were 215 days of zero flow during the year and rainfall was nearly 7 inches below normal. The preceding year was also extremely dry. In fact, the average flows of most larger streams in the region were substantially lower in the 1956 water year than in 1957.

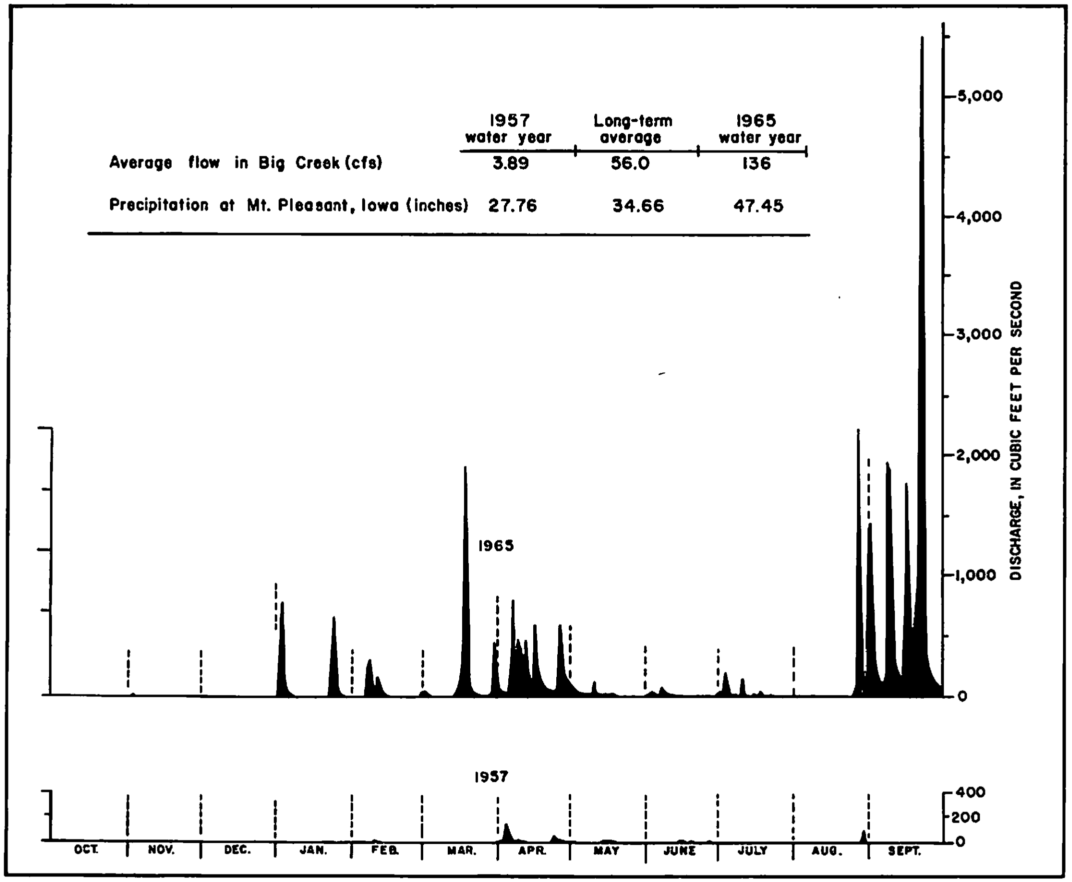


Figure 13.—Streamflow in Big Creek near Mt. Pleasant, Iowa in 1957 and 1965

AVERAGE DISCHARGE

The total quantity of water discharged by a stream over a long period of time can be expressed as an average discharge for that period. The average discharge is, therefore, the upper limit of water available for long-term use. Differences in the average discharge of different streams are related principally to the size of the upstream drainage basin and the amount and distribution of precipitation in the upstream drainage basin.

Using multiple-regression analysis, engineers of the U.S. Geological Survey have determined a relationship between normal annual precipitation, drainage area, and average discharge for interior Iowa streams. This relationship is expressed in the regression equation, $Qa = 0.0000007063\ A^{1.013}\ P^{3.88}$, where Qa is the average discharge, in cubic feet per second, A is the drainage area, in square miles, and P is the average annual precipitation, in inches, over the basin (based on the 1931-60 period). The standard error of the relationship is approximately 11 percent. This means that the chances are 2 out of 3 that the true average discharge is within about 11 percent of the average defined from the regression equation. The average discharges for the low-flow, partial-record stations shown in table 2 and figure 14 were computed from the regression equation. Those shown for the gaging stations in table 1 and figure 14 are observed values.

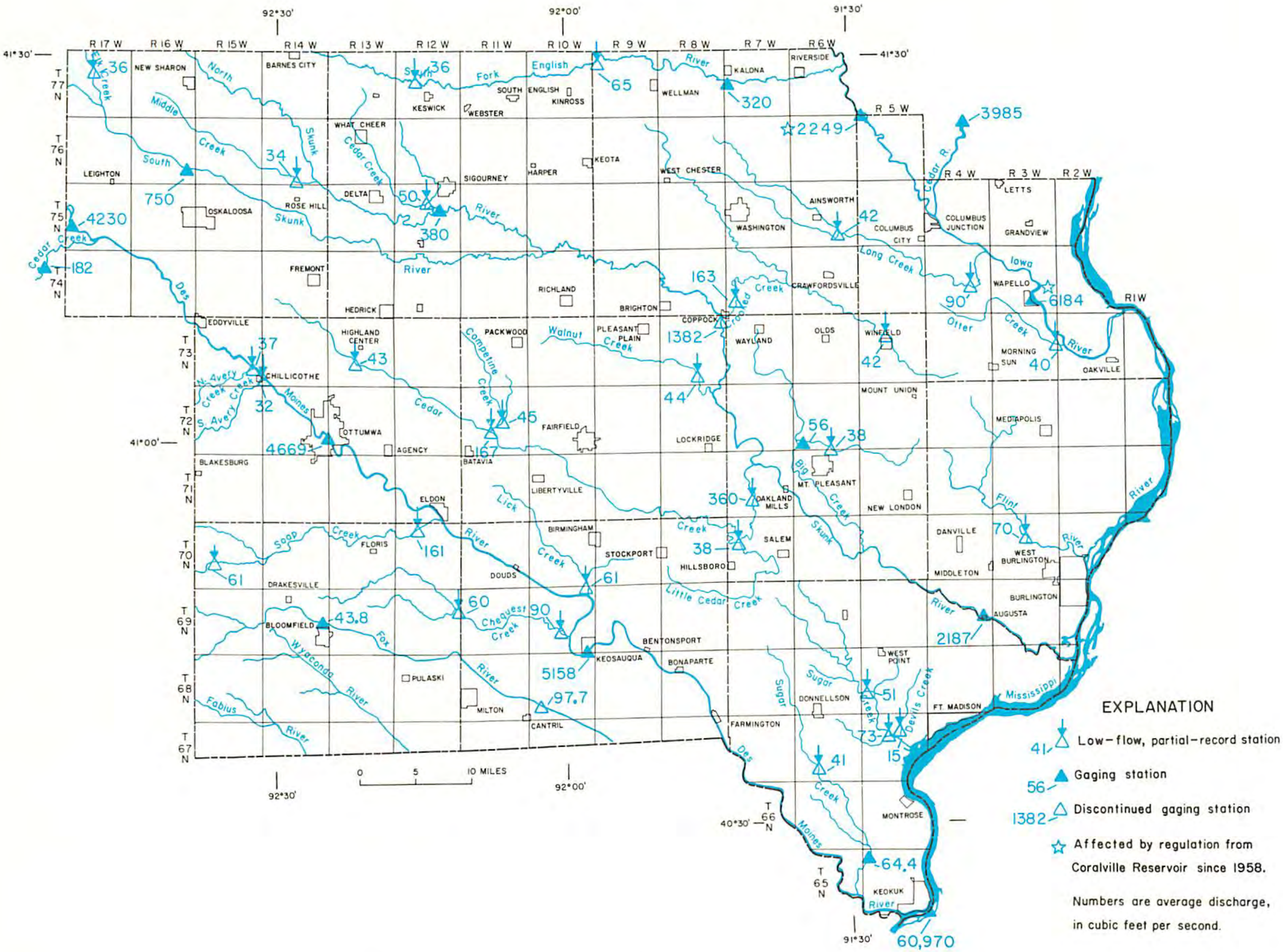


Figure 14.—Average discharge of southeast Iowa streams

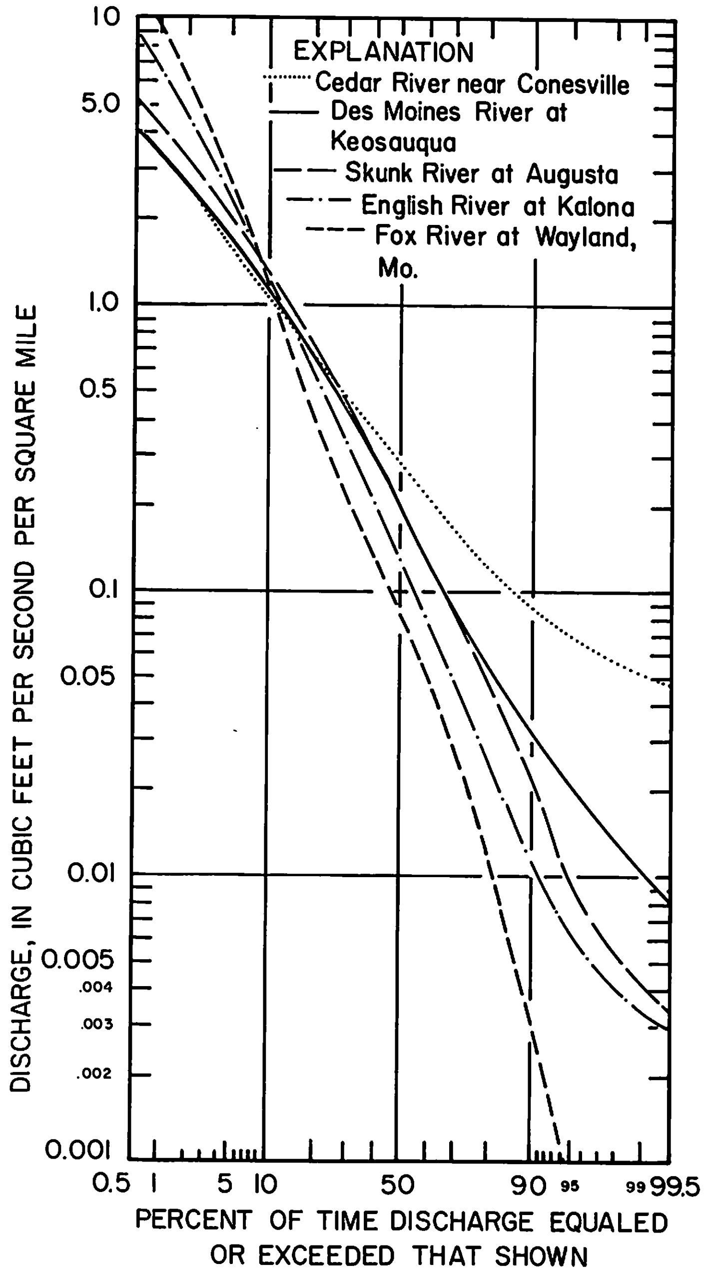


Figure 15.—Flow-duration curves for five southeast Iowa streams

FLOW DURATION

Water resources planners and water users need to know how much water is available from streams and how often a given amount of water is available for use. Answers to these questions are provided by the flow-duration curve, a curve that shows the percent of time specified discharges were equaled or exceeded during a given period. See figure 15.

The slope of the duration curve indicates the variability of discharge during the period of record. The steeper the slope the more variation in the discharge, and conversely, the flatter the slope the less variation in discharge. The slope of the lower end of the duration curve, say between 80 and 100 percent, is an index of ground-water storage within the drainage basin. Flat slopes usually indicate a basin containing sufficient ground-water storage to maintain a relatively high flow during dry periods.

Duration curves illustrated are based on data for the years 1941-60. Hydrologic conditions during this 20-year period include several years of above-normal precipitation and runoff during the 1940's, and several years of deficient precipitation and runoff during the middle 1950's. The moderate slope of the duration curve for the Cedar River indicates 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 high flow during dry periods. On the other hand, the steep slope for the Fox River indicates a highly variable stream. The near-vertical attitude at the lower end is typical of streams which cease to flow during late fall and winter dry periods. Duration curves for the Skunk, English, and Des Moines Rivers show characteristics intermediate between those of the Cedar and Fox Rivers. Even though the Skunk, English, and Des Moines Rivers do not go to zero flow, ground-water inflow during dry periods is insufficient to maintain high flows.

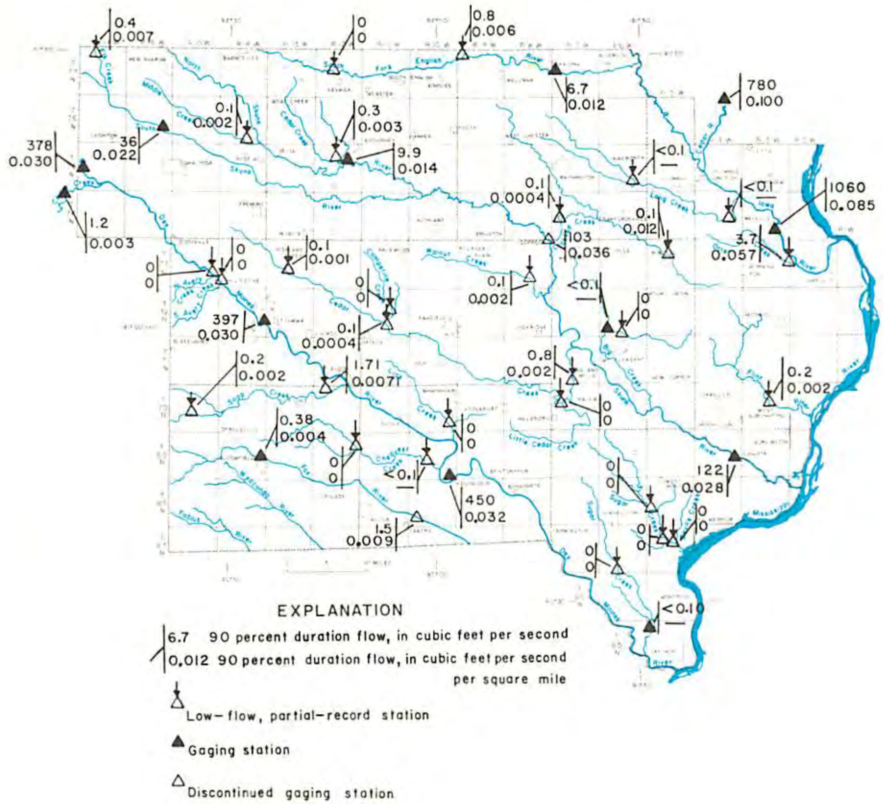
Data from flow-duration curves have been tabulated in table 3 and on figure 16 to show flow characteristics for the period of record of each gaging station, and estimates of the 90-percent duration flow are shown for partial-record stations on figure 16. The duration data disclose that southeast Iowa streams, except the Iowa and Cedar Rivers, are moderately to highly variable with insufficient ground-water inflow during dry periods to maintain high flows. Records for stream gages in the Fabius and Wyaconda River drainage basins in the state of Missouri reveal characteristics similar to those of the Fox River.

Table 3.—Discharge for selected duration percentages for southeast Iowa streams at gaging stations

Discharge, in cubic feet per second, and cubic feet per second per square mile (underscored)

Station Number	Stream and Location	Discharge Equaled or Exceeded for Percent of Time Shown					Records Used
		5	50	70	90	95	
				Iowa River Basin			
5-4555	English River at Kalona	1440 2.51	83 0.145	30 0.052	6.7 0.012	3.9 0.007	1940-66
5-4650	Cedar River nr Conesville	12800 1.64	2410 0.310	1420 0.182	780 0.100	620 0.080	1940-66
5-4655	Iowa River at Wapello	19300 1.54	3520 0.282	2500 0.200	1060 0.085	840 0.067	1915-58
				Skunk River Basin			
5-4715	South Skunk River nr Oskaloosa	3150 1.93	313 0.191	131 0.080	36 0.022	20 0.012	1946-66
5-4725	North Skunk River nr Sigourney	1730 2.37	118 0.162	46 0.063	9.9 0.014	4.5 0.006	1946-66
5-4730	Skunk River at Coppock	5200 1.80	600 0.208	300 0.104	103 0.036	63 0.022	1914-44
5-4735	Big Creek nr Mt. Pleasant	270 2.55	6.8 0.064	1.0 0.009	0.10 --------	------- -------	1956-66
5-4740	Skunk River at Augusta	9400 2.18	880 0.204	407 0.095	122 0.028	66 0.015	1915-66
				Des Moines River Basin			
5-4885	Des Moines River nr Tracy	15000 1.20	2000 0.160	940 0.075	378 0.030	250 0.020	1921-66
5-4890	Cedar Creek nr Bussey	820 2.36	23 0.066	5.8 0.017	1.2 0.003	0.53 0.002	1948-66
5-4895	Des Moines River at Ottumwa	18200 1.36	2170 0.162	1060 0.079	397 0.030	250 0.019	1918-66
5-4905	Des Moines River at Keosauqua	19900 1.42	2380 0.170	1150 0.082	450 0.032	300 0.021	1904-05 1912-66
5-4910	Sugar Creek nr Keokuk	265 2.52	11 0.105	2.4 0.023	0.10 --------	------- -------	1923-31 1959-66
				Fox River Basin			
5-4943	Fox River at Bloomfield	188 2.14	3.7 0.042	1.2 0.014	0.38 0.004	0.21 0.002	1958-66
5-4945	Fox River at Cantril	390 2.42	14 0.087	4.8 0.030	1.5 0.009	0.96 0.006	1941-51

Figure 16.—90 percent duration flow



LOW-FLOW FREQUENCY

Utilization of surface water requires a knowledge of the amount of water available during dry periods. Minimum flows may be insufficient for municipal and industrial supplies, supplemental irrigation, maintenance of suitable conditions for fish and wildlife, and dilution of wastes. A low-flow frequency analysis is used to assess the amount of water available for use without storage reservoirs and can be used to estimate the net amount of storage required to maintain streamflow during critical periods.

Data for this low-flow presentation were derived from a frequency analysis of annual minimum flows of southeast Iowa streams. The lowest average discharge for seven consecutive days was extracted from each year of streamflow record. Two low-flow statistics were derived from the data: (1) the lowest average flow for 7 consecutive days which occurred 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 occurred on the average of about once in 10 years (7-day, 10-year low flow).

The lowest annual average discharge for 7 consecutive days is shown on figure 17 for each year of record for the English River at Kalona to illustrate the 7-day, 2-year and 7-day, 10-year low-flow statistics. One half of the 26 flow events were less than the computed 7-day, 2-year value of 8.6 cfs. On the average then, the 7-day low flow was less than 8.6 cfs once every 2 years. This value should not be interpreted to mean that the flow was less than 8.6 cfs 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 low flow will be less than 8.6 cfs in any future year.

Two of the 26 low-flow events were less than the 7-day, 10-year computed low flow of 1.8 cfs. The record shows that the annual minimum 7-day low flow was less than 1.8 cfs on the average of once every 13 years, close to the predicted recurrence of once every 10 years. 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 1.8 cfs on the average of once every 10 years.

The average 7-day minimum flows expected to be reached on an average of once every other year and once every 10 years at gaging stations are shown in table 4. The areal distribution of the former is shown in figure 18. The values for the low-flow, partial-record stations were determined by correlation with data for nearby gaging stations.

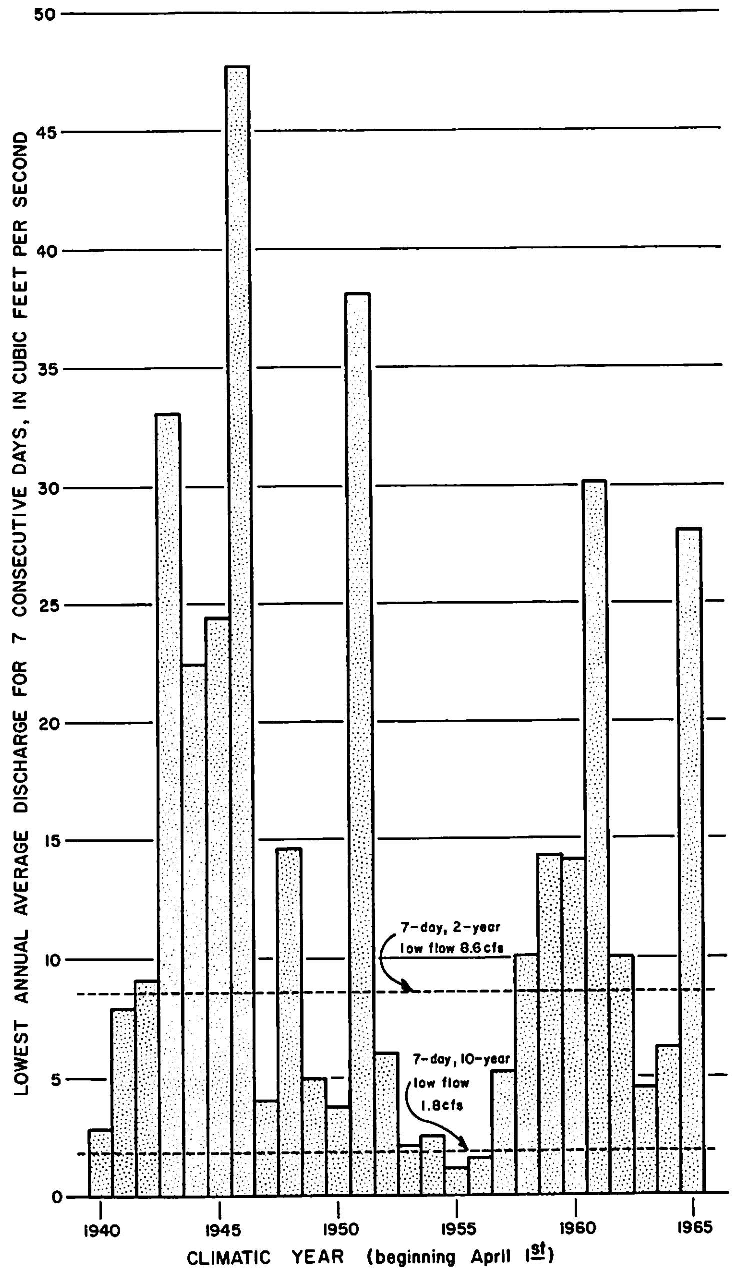


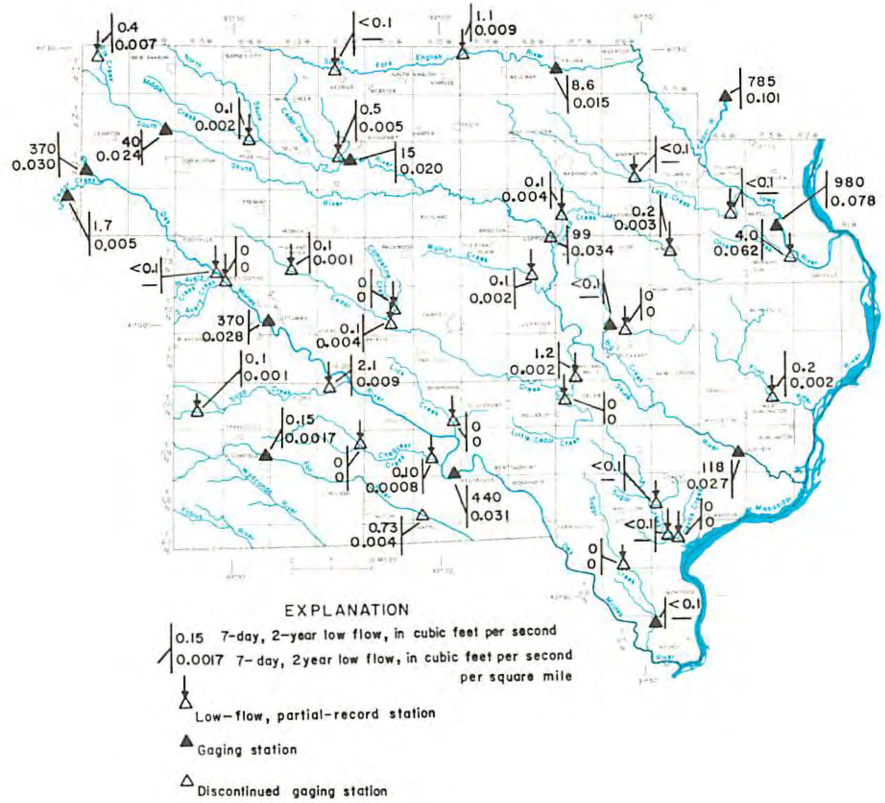
Figure 17.—Annual 7-day minimum flows for the English River at Kalona

Table 4.—Low-flow discharge at 2 and 10-year intervals at southeast Iowa gaging stations

Discharge, in cubic feet per second, and cubic feet per second per square mile (underscored)

Station Number	Stream and Location	Average 7-day Low Flow for the Recurrence Interval Shown: 2 yrs.	10 yrs.	Records Used
	Iowa River Basin			
5-4555	English River at Kalona	8.6 0.015	1.8 0.003	1940-65
5-4650	Cedar River nr Conesville	785 0.101	390 0.050	1940-65
5-4655	Iowa River at Wapello	980 0.078	507 0.041	1915-57
	Skunk River Basin			
5-4715	South Skunk River nr Oskaloosa	40 0.024	4.8 0.003	1946-65
5-4725	North Skunk River nr Sigourney	15 0.020	0.98 0.001	1946-65
5-4730	Skunk River at Coppock	99 0.034	20 0.007	1914-43
5-4735	Big Creek nr Mt. Pleasant	0 -------	------- -------	1956-65
5-4740	Skunk River at Augusta	118 0.027	20 0.005	1915-65
	Des Moines River Basin			
5-4885	Des Moines River nr Tracy	370 0.030	112 0.009	1920-65
5-4890	Cedar Creek nr Bussey	1.7 0.005	0.10 -------	1948-65
5-4895	Des Moines River at Ottumwa	370 0.028	100 0.007	1917-65
5-4905	Des Moines River at Keosauqua	440 0.031	126 0.009	1904-05 1912-65
5-4910	Sugar Creek nr Keokuk	0.10 -------	------- -------	1923-30 1959-65
	Fox River Basin			
5-4943	Fox River at Bloomfield	0.15 0.002	0 0	1958-68
5-4945	Fox River at Cantril	0.73 0.005	0.10 -------	1941-50

Figure 18.—Average 7-day, 2-year low flow



FLOODS

Flooding occurs when a river channel becomes filled and water spills out over the surrounding lowlands. The height to which water will rise depends on the amount and rate at which water is supplied to the channel system and the capacity of the channel system to remove the water. Floods which inundate small areas occur more frequently than floods which inundate large areas. Statistical studies of floods indicate that, on the average, streams fill or overflow their channels about once every 1½ years.

The map on the opposite page (fig. 19) shows the magnitude of maximum known floods and the magnitude expected to be equaled or exceeded on the average of once in 50 years at southeast Iowa gaging stations. The data were obtained from a flood-frequency study of Iowa streams prepared by the U.S. Geological Survey (Schwob, 1966).

Record floods on the Skunk River occurred in the spring months of 1944 and 1960. Excessive precipitation in the upper Skunk basin in May 1944 caused record discharges at Oskaloosa and Coppock. Rapid melting of snow and light rains in southern Iowa during the last few days of March and early April 1960 produced record discharges at Sigourney and Augusta.

Flood of 1944 peak discharges, in cfs	Station	Flood of 1960 peak discharges, in cfs
14,500	N. Skunk R. near Sigourney, 5-4725	a27,500
a37,000	S. Skunk R. near Oskaloosa, 5-4715	14,800
a41,500	Skunk R. at Coppock, 5-4730	———
44,800	Skunk R. at Augusta, 5-4740	a51,000

a. Maximum recorded flood.

Record floods on the Des Moines River occurred in the late spring months of 1903 and 1947. Discharge increased downstream during the 1903 flood, but decreased downstream during the 1947 flood.

Flood of 1903 peak discharges, in cfs	Station	Flood of 1947 peak discharges, in cfs
b130,000	Des Moines R. near Tracy, 5-4885	a155,000
ab140,000	Des Moines R. at Ottumwa, 5-4895	130,700
a146,000	Des Moines R. at Keosauqua, 5-4905	124,000

a. Maximum flood. b. About

FLOOD-PLAIN REGULATION

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 on 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 does affect 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. Regulations pertaining to the construction of mill dams are in Chapter 469.

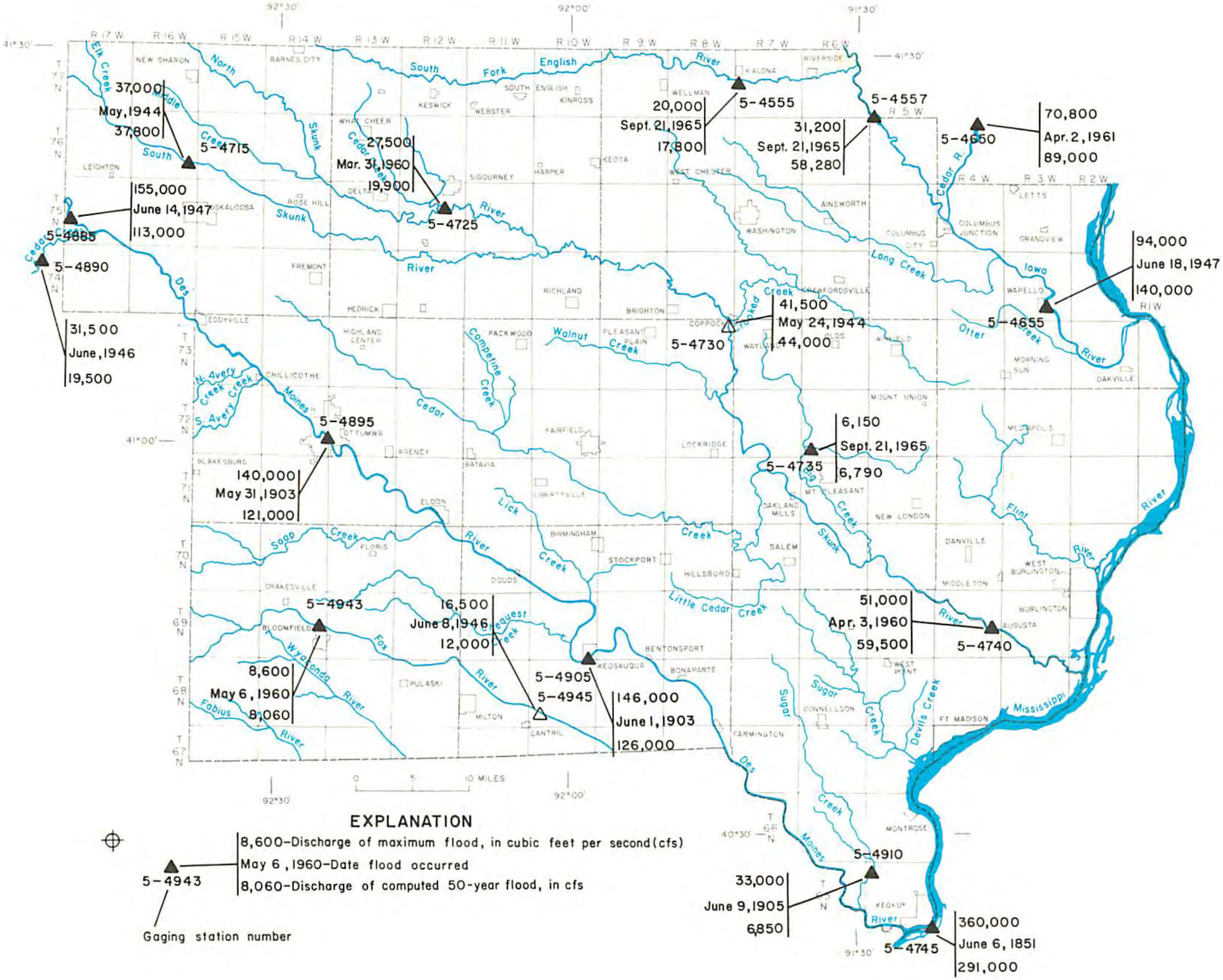


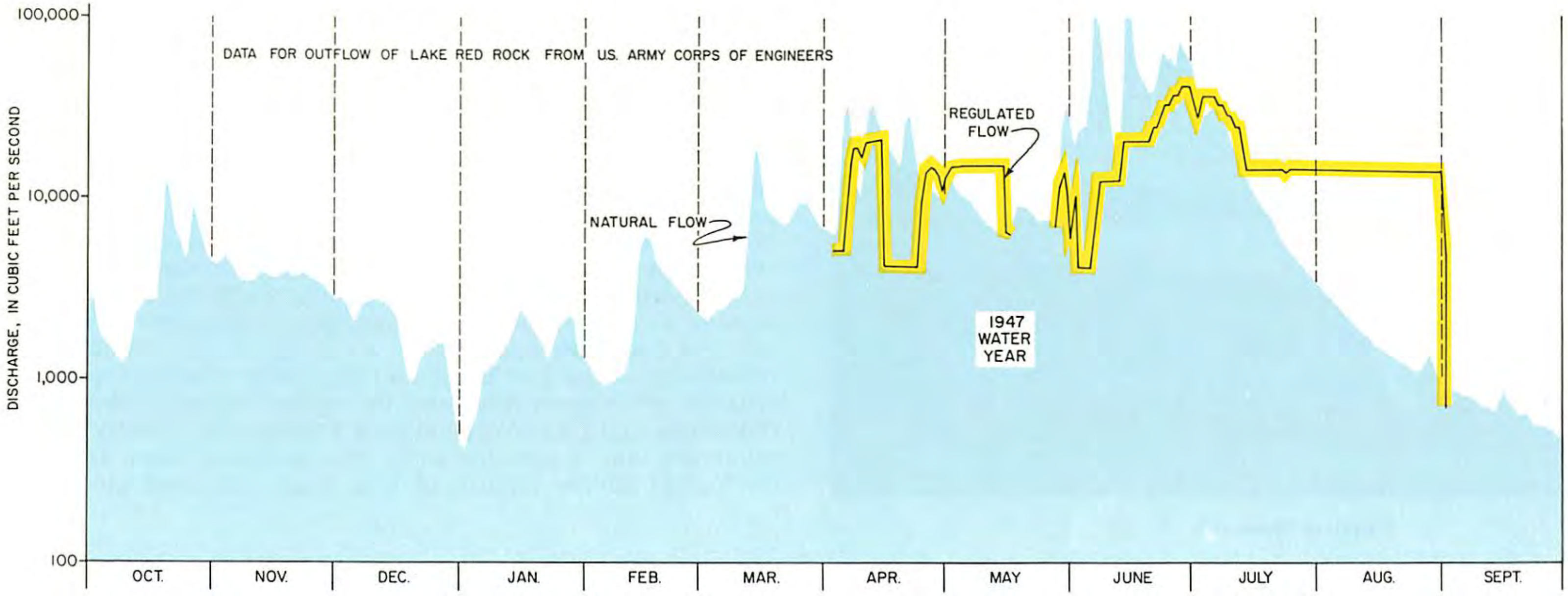
Fig. 19—Floods at southeast Iowa gaging stations

REGULATED STREAMS

Regulated streams in southeast Iowa include the Iowa River below Coralville Dam and the Des Moines River below Red Rock Dam. Records of natural streamflow for the Des Moines and Iowa Rivers collected prior to regulation have been included in this report. When sufficient record of regulated streamflow becomes available, a comparison between regulated and natural flow will be possible.

Anticipated changes in streamflow due to regulation are illustrated by hydrographs for the water years 1947 and 1956 for the Des Moines River near Tracy. Mean discharge during the 1947 water year was the highest on record—9,660 cfs—with the maximum known flood occurring in June. Streamflow during the 1956 water year was the lowest on record—the mean was 496 cfs—which was less than 12 percent of the long-term average discharge of 4,330 cfs. See figure 20.

The hydrographs on the opposite page (fig. 20) show how in 1947 and 1956 the flow of the Des Moines River at Tracy might have been altered by the operation of Red Rock Dam. 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 recur.



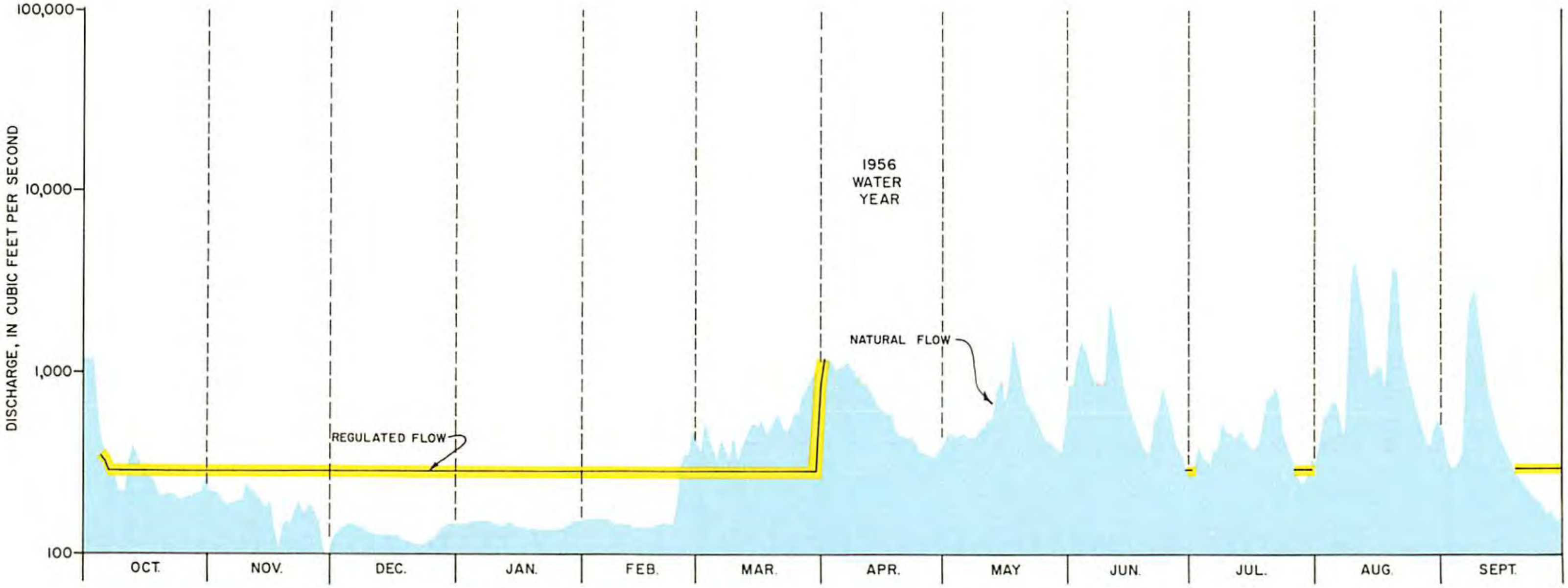


Figure 20.—Changes in streamflow of the Des Moines River at Tracy which would result from the operation of the Red Rock Reservoir

Fairfield Reservoir

LAKES AND RESERVOIRS

Natural lakes in abandoned river channels abound on the lowlands adjacent to the Mississippi River and along the lower reaches of the Iowa River. Lowlands along other streams contain few lakes. Lake levels are normally within a few feet of the water-surface altitude of the adjacent stream with inundation during floods a frequent occurrence. Lake levels respond to precipitation, changing river stage, lake evaporation, and evapotranspiration by bordering vegetation.

Numerous stock ponds and several artificial lakes provide water storage in southeast Iowa. Municipal water systems for Bloomfield and Fairfield are supplied in whole or in part from reservoirs on tributaries of the Fox River and Big Cedar Creek, respectively. Lakes created for conservation and recreation include Lake Keomah near Oskaloosa and Lake Wapello near Drakesville. Yearly maximum and minimum lake stages for these two artificial lakes, taken from U.S. Geological Survey records of lake stage, are illustrated on figure 21.

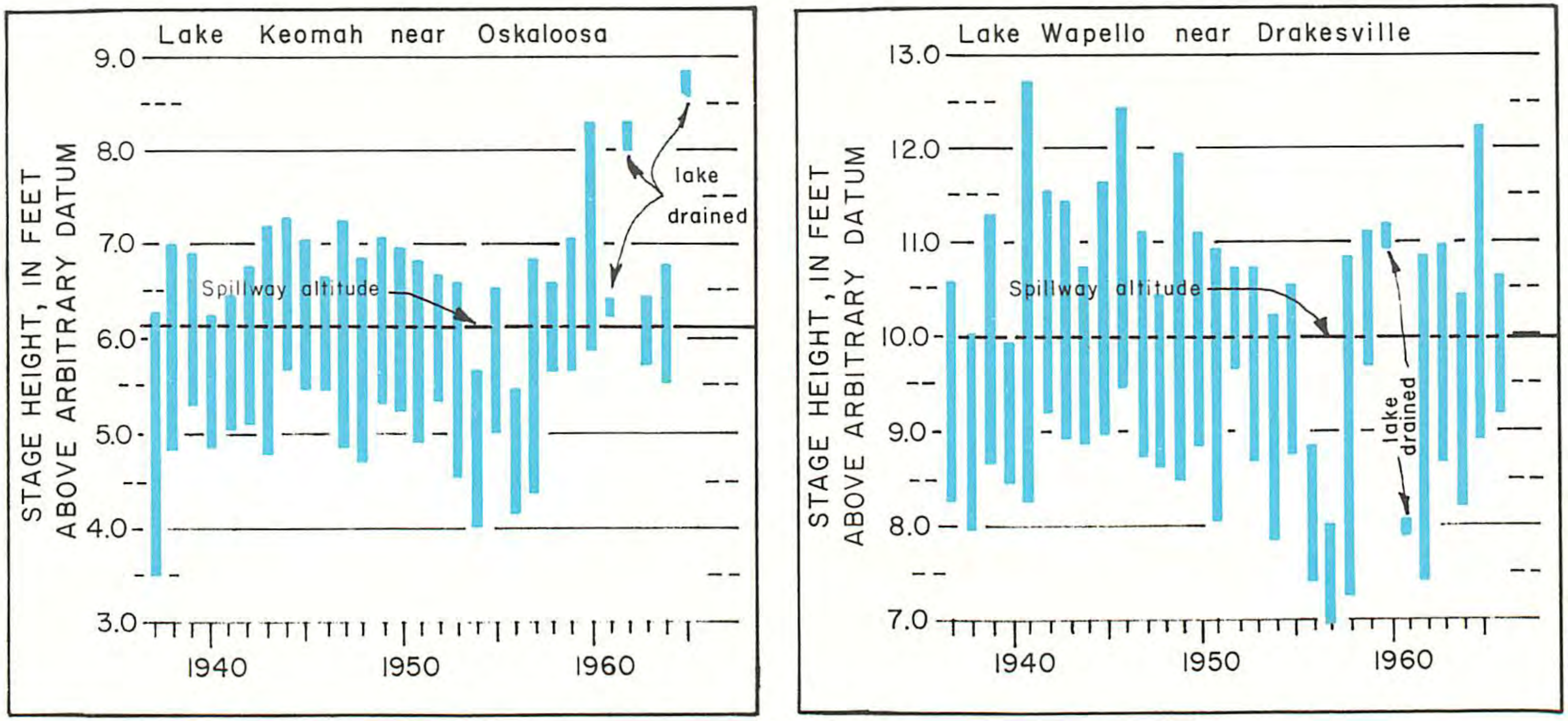


Figure 21.—Maximum and minimum stages of Lakes Keomah and Wapello

WATER IN THE MISSISSIPPI RIVER

Large quantities of water are available for use from the Mississippi River. Maximum, minimum, and average daily flows at Keokuk for each water year since 1879 illustrate the magnitude and range of the discharge. See figure 22.

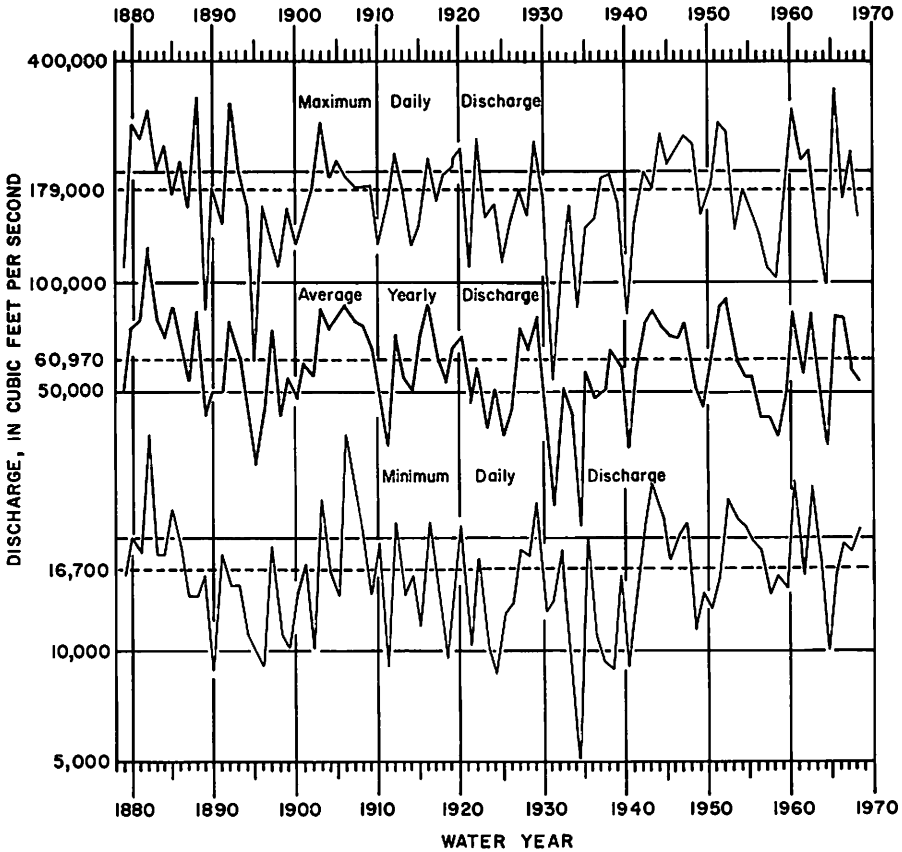


Figure 22.—
Magnitude and range of discharge of the Mississippi River at Keokuk

The annual maximum daily discharges vary about an average of 179,000 cfs. The maximum daily discharge of 327,000 cfs occurred during the flood of 1965.

The upper limit of water available for long-term use is the long-term average discharge of 60,970 cfs. Variations in annual average discharge are shown.

The annual minimum daily discharges vary about an average of 16,700 cfs. The lowest daily discharge of 5,000 cfs occurred during the drought of 1934.

GROUND-WATER RESOURCES

THE AQUIFERS

Wells supply water for many communities, farms, and industries in southeastern Iowa. The water from these wells comes from deposits of earth materials and layered rocks whose characteristics and locations are constant enough to allow fairly reliable predictions as to their location and water-yielding potential. These predictions are based on the analysis of records from about 2,000 wells in southeastern Iowa and adjacent counties.

Rocks that store and transmit water are called aquifers. In this report, only those aquifers that yield appreciable amounts of water to wells will be considered. The first part of this discussion concentrates on the spatial relationships of the aquifers, and the second part will be devoted to the water contained in and yielded by these aquifers.

All parts of southeastern Iowa are underlain by three of four aquifers (fig. 23). The unconsolidated deposits near the land surface comprise the surficial aquifer. Underlying the surficial aquifers are several layers of consolidated sedimentary rock collectively called bedrock. Some of these layers are aquifers and others will yield little or no water to wells—these are aquicludes. The layers that do yield water to wells have been grouped together into three major bedrock aquifers—the Mississippian aquifer, the Devonian aquifer and the Cambrian-Ordovician aquifer. The aquifers are separated by intervening aquicludes.

Beneath the combined surficial and sedimentary sequences lie igneous and metamorphic crystalline rocks often called the "basement complex." These rocks are not thought to contain much water in southeastern Iowa.

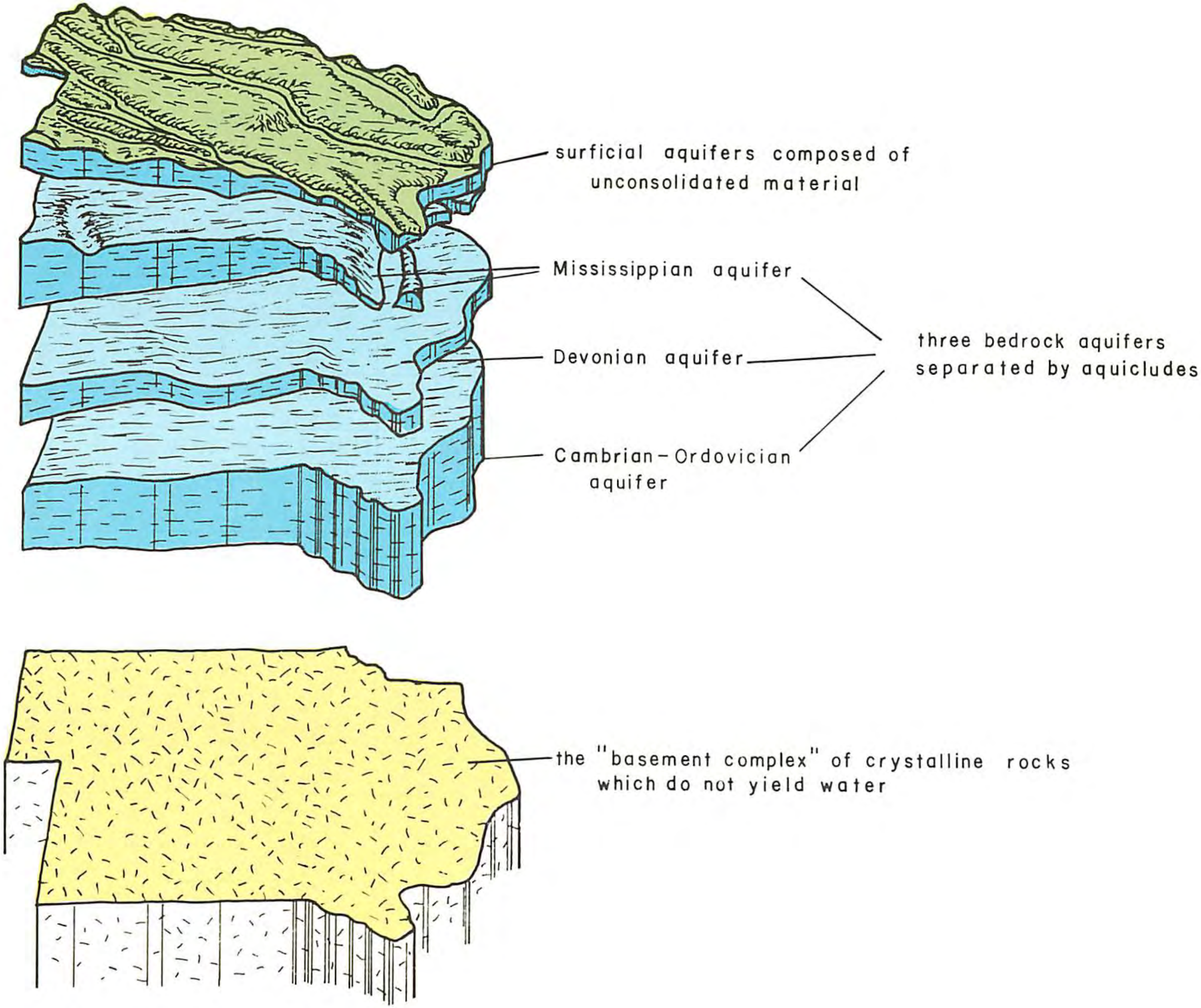


Figure 23.—The aquifers in southeast Iowa

Table 5.—Hydrogeologic units in southeast Iowa

Hydrogeologic Unit	General Thickness (feet)	Age of Rocks	Name of Rock Unit*	Type of Rock
Surficial aquifers alluvial buried-channel drift	0 to 320	Quaternary (0-1 million years old)	Undifferentiated	Sand, gravel, silt, and clay Sand, gravel, silt, and clay Till (sandy, pebbly clay), sand, and silt
Aquiclude	0 to 370	Pennsylvanian (180 to 310 million years old)	Undifferentiated	Shale, sandstone, limestone, and coal
Mississippian aquifer upper	0 to 600	Mississippian (310 to 345 million years old)	St. Louis Spergen	Limestone and sandstone Limestone
lower			Warsaw Keokuk Burlington Hampton Starrs Cave	Shale and dolomite Dolomite, limestone, and shale Dolomite and limestone Limestone and dolomite Limestone
Aquiclude	0-425		Prospect Hill McCraney	Siltstone Limestone
		Devonian (345 to 400 million years old)	Yellow Spring Lime Creek	Shale, dolomite and siltstone Dolomite and shale
Devonian aquifer	110 to 420		Cedar Valley Wapsipinicon	Limestone and dolomite Dolomite, limestone, shale, and gypsum
	0 to 105	Silurian (400 to 425 million years old)	Undifferentiated	Dolomite
Aquiclude	150 to 600	Ordovician (425 to 500 million years old)	Maquoketa Galena Decorah Platteville	Dolomite and shale Dolomite and chert Limestone and shale Limestone, shale, and sandstone
Cambrian-Ordovician aquifer	750 to 1110		St. Peter Prairie du Chien	Sandstone Dolomite and sandstone
		Cambrian (500 to 600 million years old)	Jordan St. Lawrence	Sandstone Dolomite
Not considered an aquifer in southeast Iowa	450 to 750+		Franconia Galesville Eau Claire Mt. Simon	Shale, siltstone, and sandstone Sandstone Sandstone, shale, and dolomite Sandstone
		Precambrian (600 million to more than 2 billion years old)		Sandstone, igneous rocks, 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 southeastern Iowa are listed in the stratigraphic table (table 5) on the opposite page. 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 aquicludes 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 aquicludes. The surficial aquifers are subdivided into three aquifers—the alluvial aquifer, the buried-channel aquifer, and the drift aquifer—on the basis of areal and vertical distribution and water-bearing characteristics.

The Mississippian aquifer is the shallowest bedrock aquifer in most of southeastern Iowa. It is separated from the surficial deposits in most places by an aquiclude of Pennsylvanian shales. However, the Mississippian aquifer is often found directly beneath the surficial aquifer or at the land surface. This aquifer is composed mainly of carbonate rocks (limestone and dolomite) which are the major water-yielding material. The Warsaw Formation which contains shale often acts as an aquiclude or aquitard within the aquifer and does affect the quantity and quality of the water from the Mississippian aquifer in some places.

The Devonian aquifer is found below the Mississippian aquifer and is separated from the Mississippian aquifer by a thick predominantly shale interval. The rocks of the Devonian aquifer are mostly carbonates. Evaporite minerals, gypsum and anhydrite, are minor rock types; but in areas where these minerals are present, they are major factors influencing the chemical quality of the water from the aquifer. Some Silurian aged rocks are included in the Devonian aquifer. They are of limited extent in southeastern Iowa, being found only in the northeast corner, but where present they are hydrologically similar to and a part of the Devonian aquifer.

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 accounts for the high yields afforded by this aquifer.

Underlying the Cambrian-Ordovician aquifer are the Galesville and Mt. Simon Sandstones, which are excellent aquifers in easternmost east-central Iowa. However, data concerning these rock units in this area are lacking.

The information on the next 14 pages is concerned with the areal distribution, depth, and thickness of the aquifers listed in this table.

Exposure of rocks of the Mississippian aquifer in the Mississippi River bluffs, Des Moines County

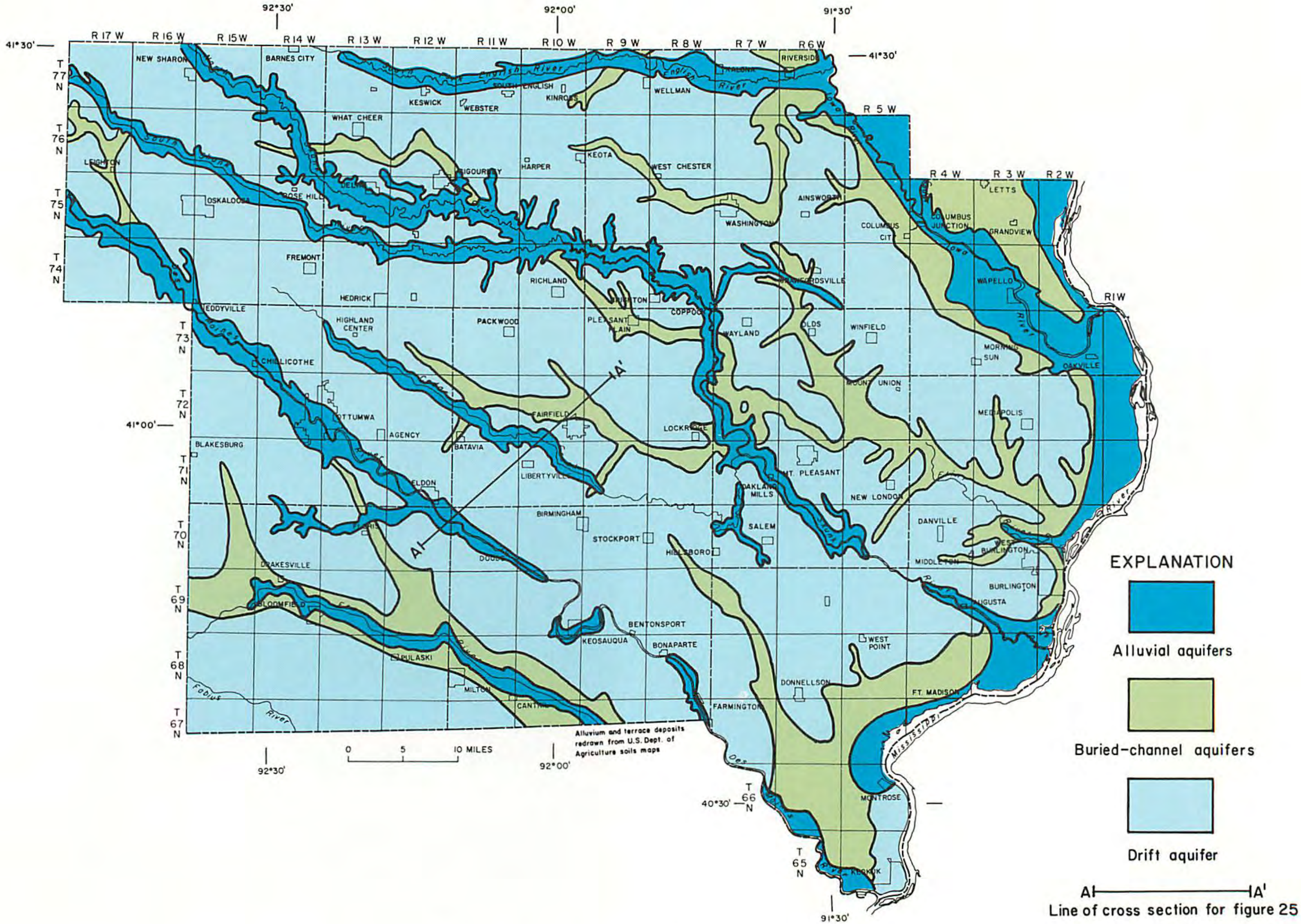


Figure 24.—Areal distribution of surficial aquifers

SURFICIAL AQUIFERS

The surficial aquifers lie between the land surface and the bedrock surface. They cover nearly all of the southern Iowa area with the exception of places where the bedrock is exposed at the land surface. The surficial aquifers are of three types: alluvial aquifers, buried-channel aquifers, and drift aquifers (fig. 24). The alluvial aquifer is composed of materials deposited in the valleys of the present 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 glacial drift that blanket most of the upland. The cross secion (fig. 25) shows the relationships of the three surficial aquifers, the present land surface, and the underlying bedrock surface.

The alluvial aquifer is confined to stream valleys. Its width ranges from several miles, as in the Mississippi Valley, to a few feet in places where streams like the Skunk and Des Moines Rivers have cut narrow gorges. The alluvial aquifer is composed primarily of sand and gravel, but layers and irregular bodies of clay are often found within these deposits. The sands and gravels will yield large amounts of water, and they are readily recharged by precipitation and infiltration from nearby streams. The aquifer is an excellent source of water in many valleys.

Water well being drilled into the alluvial aquifer of the Mississippi River Valley

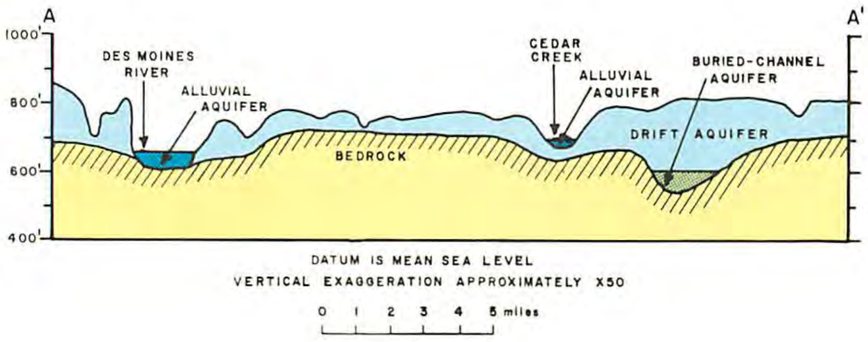


Figure 25.—Generalized hydrogeologic cross section of surficial aquifers

Buried-channel aquifers consist of stream alluvium that filled valleys before or between the glacial periods. Although buried beneath glacial deposits in many places, the ancient stream channels often coincide with the present stream valleys. Some buried channels contain as much as 50 feet of sand and gravel while others contain none. The buried-channel aquifers will yield moderate supplies of water at some localities.

Glacial drift covers vast expanses of southeastern Iowa. Nearly all of the area, with the exception of the stream valleys, is underlain by glacial till (pebbly and sandy clay) and silt deposits. Parts of the drift contain thin sand and gravel beds which have a limited areal extent, and these beds are the drift aquifers. They are the source of small supplies of water and sometimes yield enough water for a farmstead and rarely enough for a small community. Loess (windblown silt) covers the glacial till over most of the area, and will yield small amounts of water to wells. Dug or bored wells on many farms receive water from these silts at rates of a few gallons per hour.

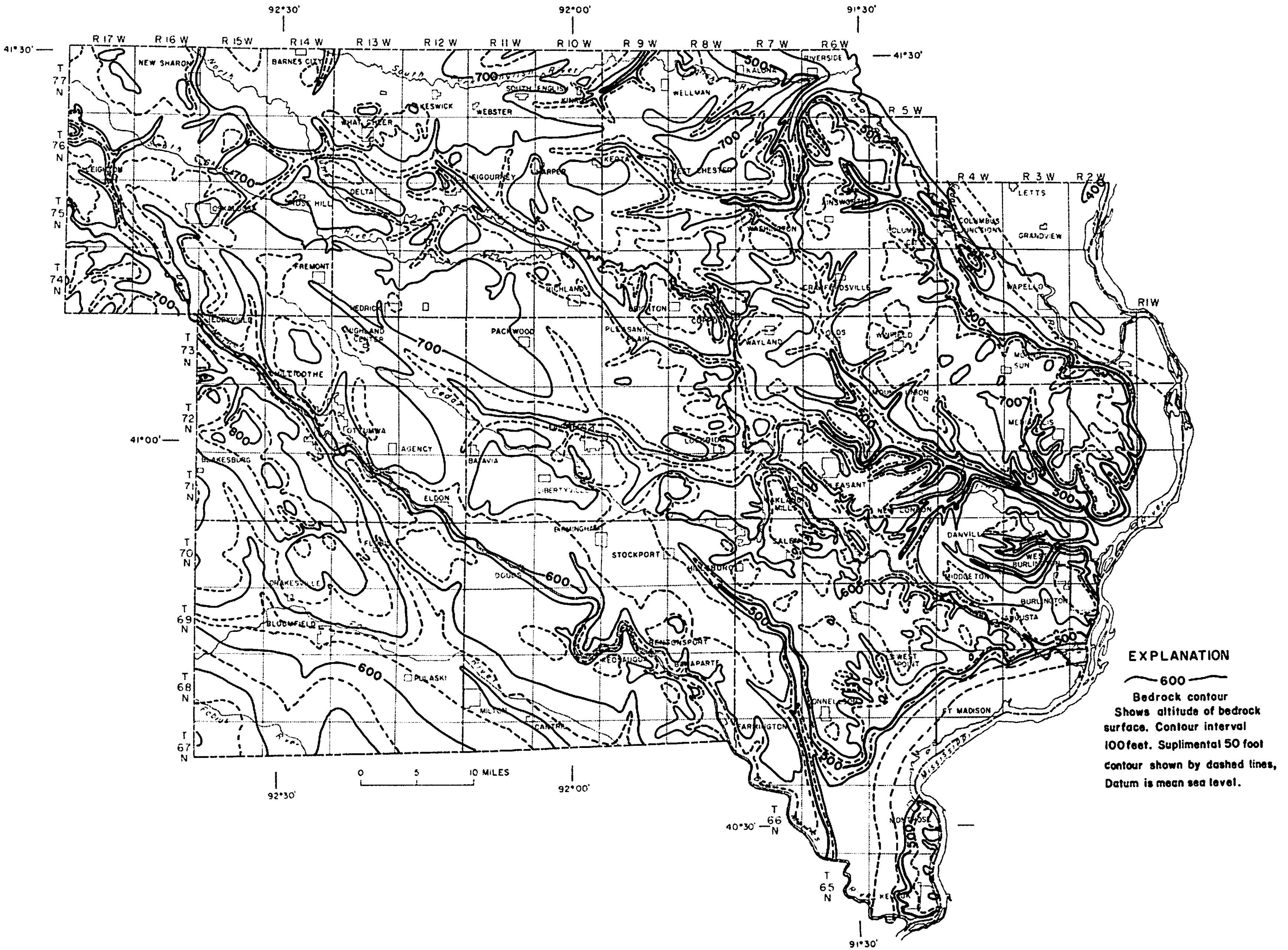


Figure 26.—Bedrock topographic map

THE BEDROCK SURFACE

The bedrock surface is the interface between the surficial deposits and the bedrock aquifers and aquicludes. The altitude and configuration of this surface is shown on the accompanying map (fig. 26). This is a topographic map of what would be the land surface if the surficial deposits were removed.

The map shows the location and depth of the buried channels where ancient streams cut valleys into the bedrock. A comparison of this map and figure 24 shows how a map of this type can be used to find the locations of buried-channel aquifers. Where the altitude of the bedrock surface is high the glacial drift generally is thin, and the chances of finding a source of water in the drift will be slight.

The depth to the bedrock surface can be determined by comparing this bedrock map with the topographic map (fig. 3). Although the bedrock map indicates the position of the bedrock surface, it will not show what type of rock comprises that surface. In some places the bedrock will be an aquifer; in others it will be an aquiclude. In order to predict this, a bedrock hydrogeologic map is needed. Such a map (fig. 27) is shown on the next page.

Bedrock (Pennsylvanian shales) exposed along Cedar Creek in Jefferson County

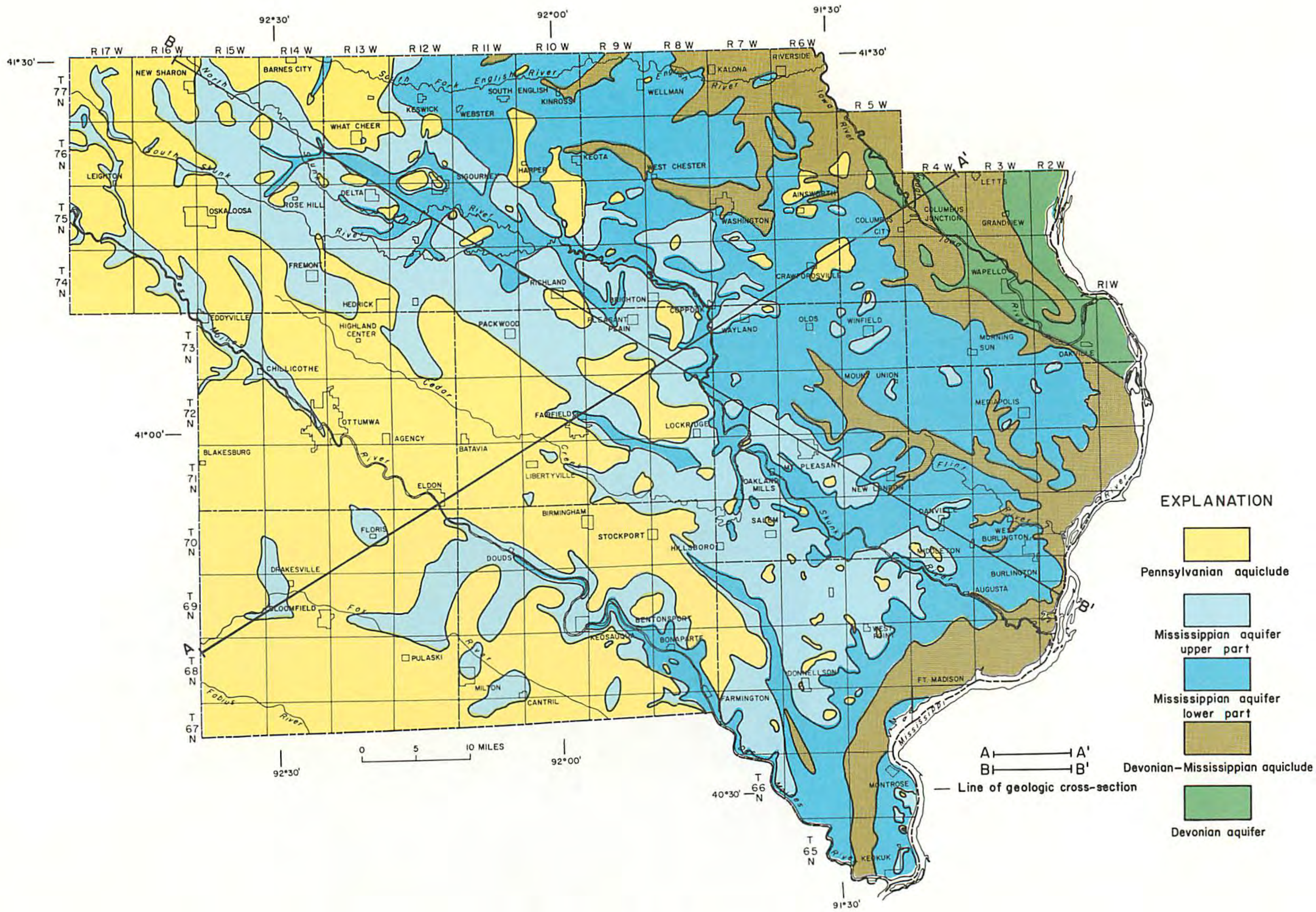


Figure 27.—Bedrock hydrogeologic map

BEDROCK AQUIFERS

The bedrock hydrogeologic map (fig. 27) shows the aquifers and aquicludes that make up the bedrock surface in southeastern Iowa. The Devonian aquifer is the first bedrock encountered in part of the northeastern corner of the area. The Mississippian aquifer lies beneath the surficial deposits in about one-half of the area. An aquiclude consisting of the Upper Devonian and lowest Mississippian rocks occur near the surface in the Mississippi River and Iowa River valleys. Pennsylvanian rocks comprise the bedrock surface in the southwest and west, and outlying patches of Pennsylvanian are encountered over much of the area.

The Cambrian-Ordovician aquifer and the aquiclude which overlies it are not at the bedrock surface anywhere in southeastern Iowa. The Cambrian-Ordovician aquifer is quite deeply buried. Its location with respect to the other units is shown on figure 28. All the units are roughly parallel to each other and dip (slope) toward the southwest (fig. 28).

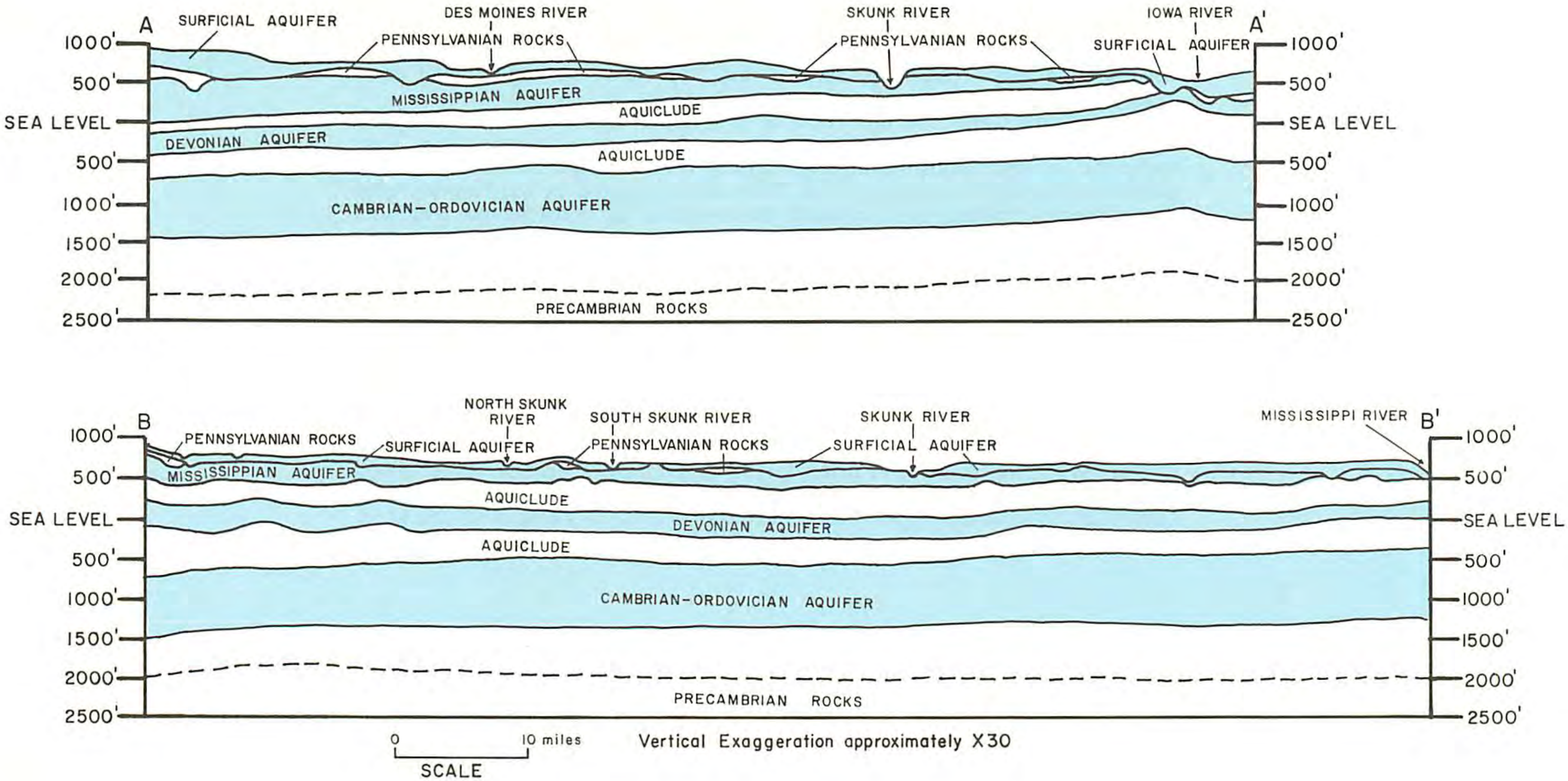


Figure 28.—Hydrogeologic cross sections

DEPTHS TO THE BEDROCK AQUIFERS

The depth to the bedrock aquifers varies considerably throughout the region because of topographic relief of the land surface and structural attitude of the bedrock units. It is convenient to map the upper surface of the aquifers with reference to a common datum—sea-level datum in this report. The depths to each aquifer can be determined by comparing the altitude maps (figs. 29, 30, 31, and 32) with the topographic map (fig. 3).

The altitude and configuration of the upper surfaces of the bedrock aquifers have been influenced by erosion and structural deformation. Various rock layers in southeastern Iowa have been exposed to erosion during different periods of geologic time. This often resulted in the development of extensive drainage systems and the removal of considerable amounts of rock material. All rock layers in the area have been subjected to structural deformation, which caused the regional tilt of the rocks to the southwest (fig. 28) and the localized folds and faults in the strata.

The upper surface of the Mississippian aquifer has many irregularities. The configuration of the upper surface of these rock units was influenced dominantly by erosion which has obscured the regional dip. The patterns of several drainage systems have been etched upon the top of the aquifer. Extensive erosion prior to the deposition of Pennsylvanian rocks is shown by what apparently is a drainage pattern in the southwestern one-half of the area. Two main periods of erosion, the first following the deposition of Pennsylvanian rocks and prior to the deposition of glacial deposits and the second after the latest glacial advance have resulted in valleys being carved into the Mississippian aquifer in the northeastern part of the area.

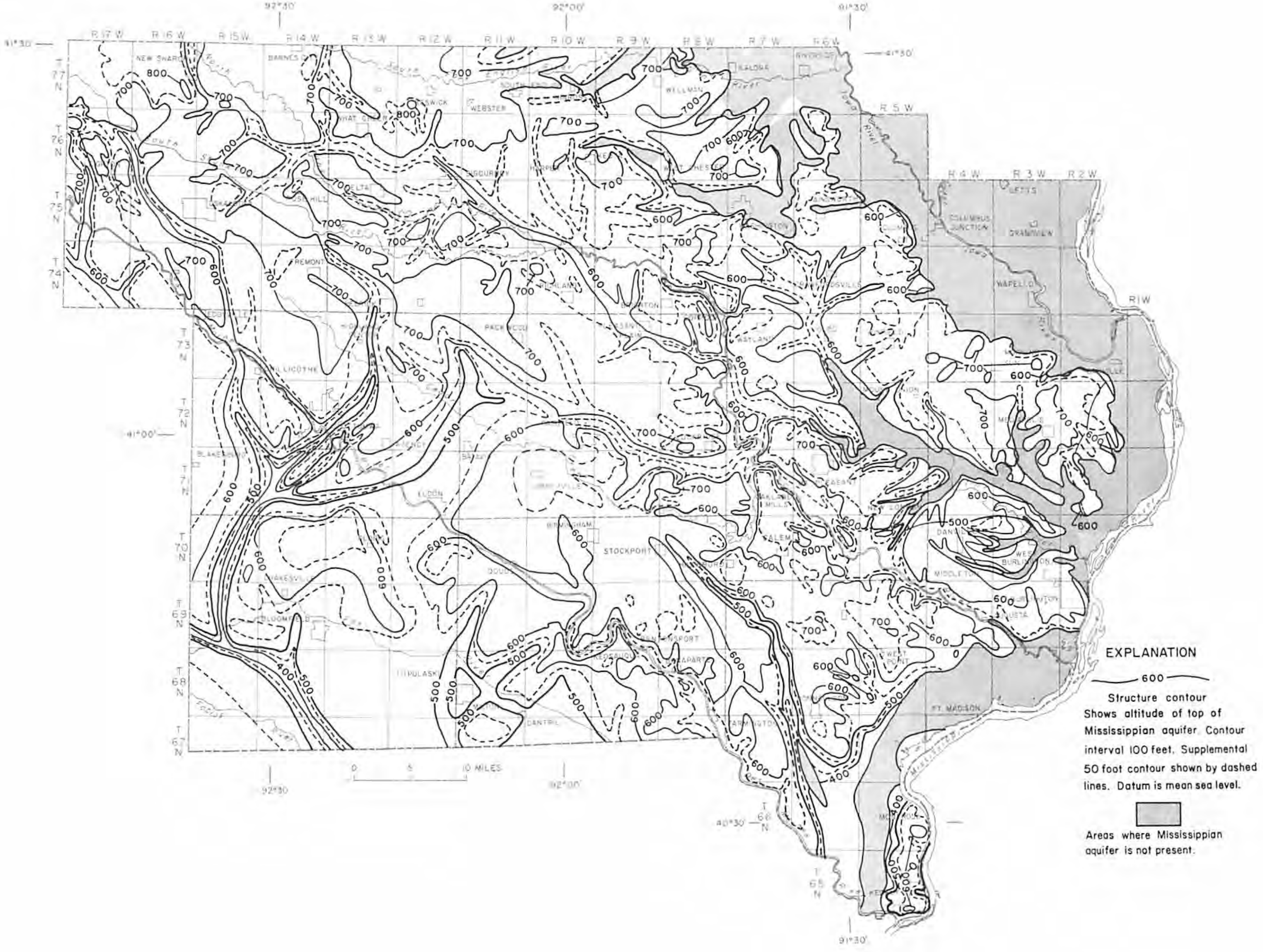


Figure 29.—Altitude of the top of the Mississippian aquifer

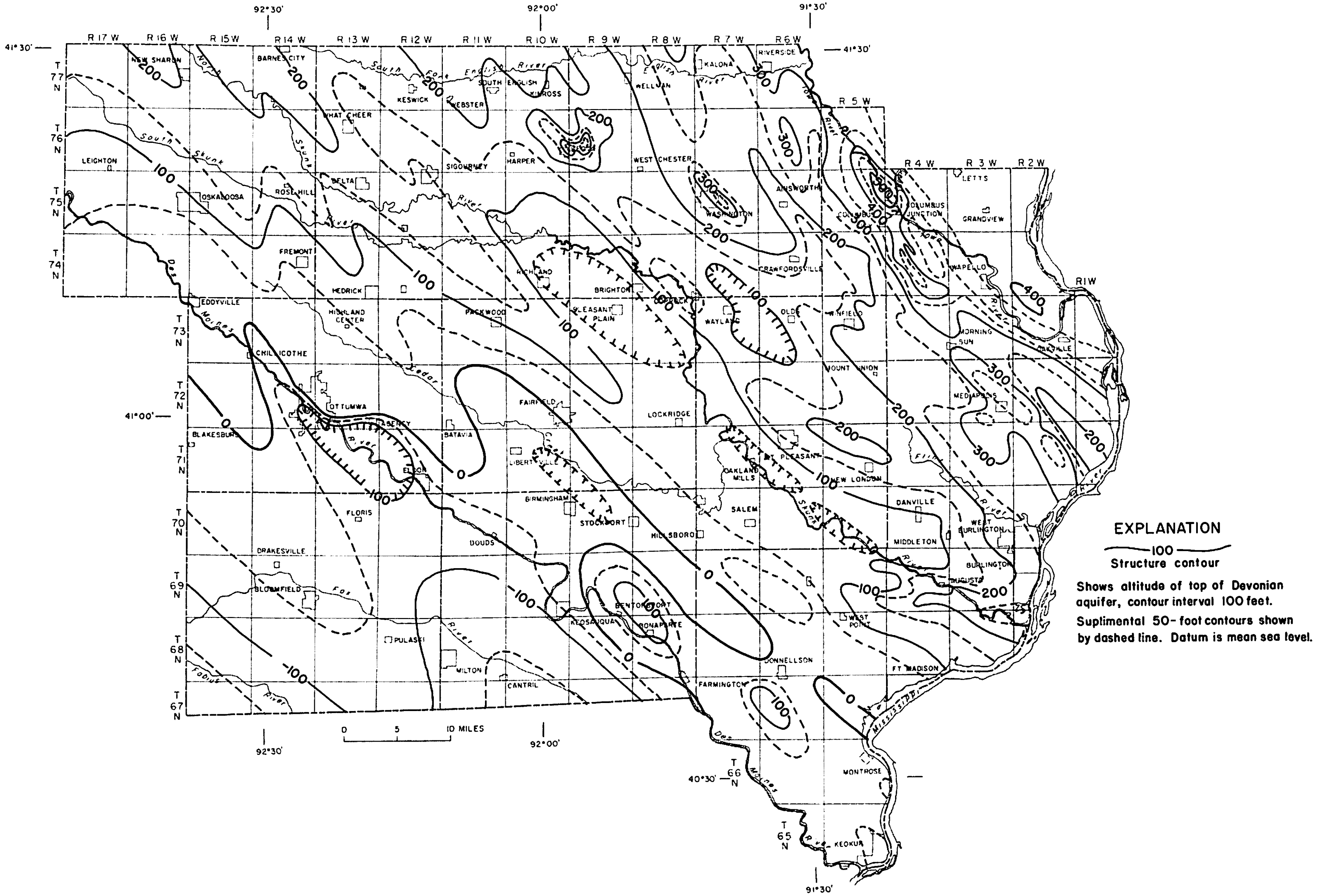


Figure 30.—Altitude of the Devonian aquifer

Structural deformation has been the dominant influence in shaping the upper surfaces of the Devonian and Cambrian-Ordovician aquifers. Down-warping in the southwest or up-warping in the northeast has resulted in these beds dipping generally toward the southwest. Superimposed upon this regional dip are numerous anticlines and synclines (upfolds and downfolds, respectively) whose axes lie in a northwest-southeast direction perpendicular to the southwesterly regional dip. Some of the anticlinal folds are domelike, such as the ones near Bonaparte, Mediapolis, Washington, Keota, and two near Columbus Junction. Evidence of faulting is found only near Washington where as much as 250 feet of displacement may have taken place. The Cambrian-Ordovician aquifer appears to be the only one affected.

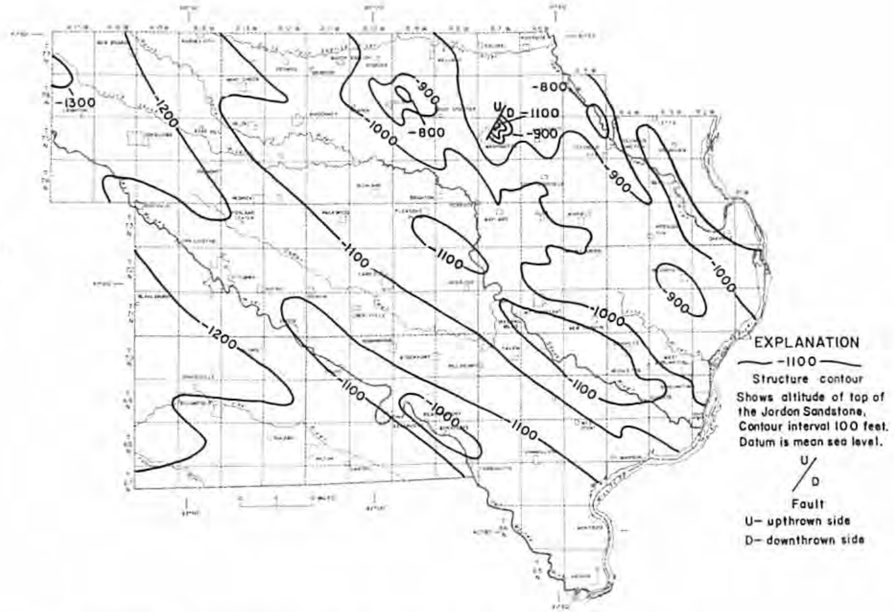


Figure 32.—Altitude of the top of the Jordan Sandstone

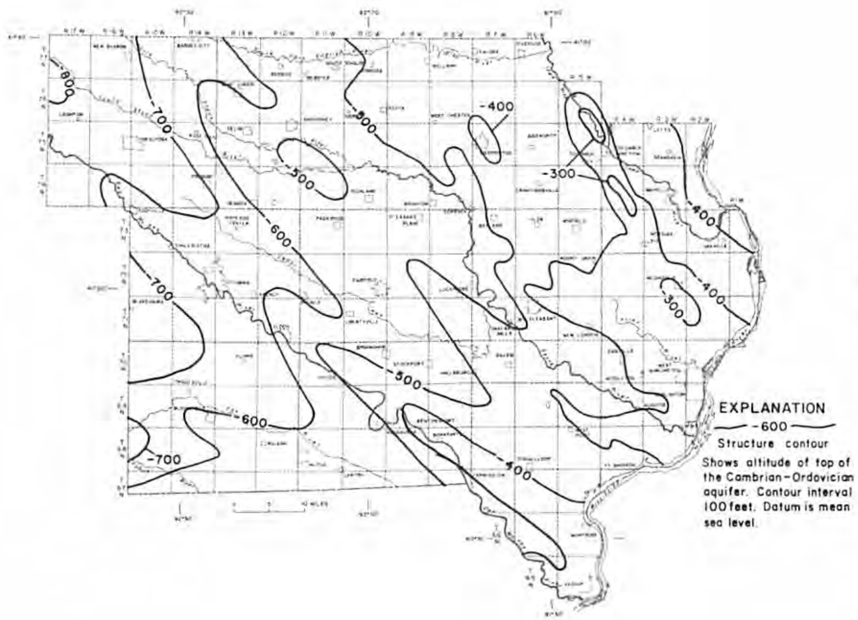


Figure 31.—Altitude of the top of the Cambrian-Ordovician aquifer

The upper surface of the Jordan Sandstone, the principal water-bearing unit in the Cambrian-Ordovician aquifer, is essentially parallel to the top of the aquifer, but lies about 600 feet below it.

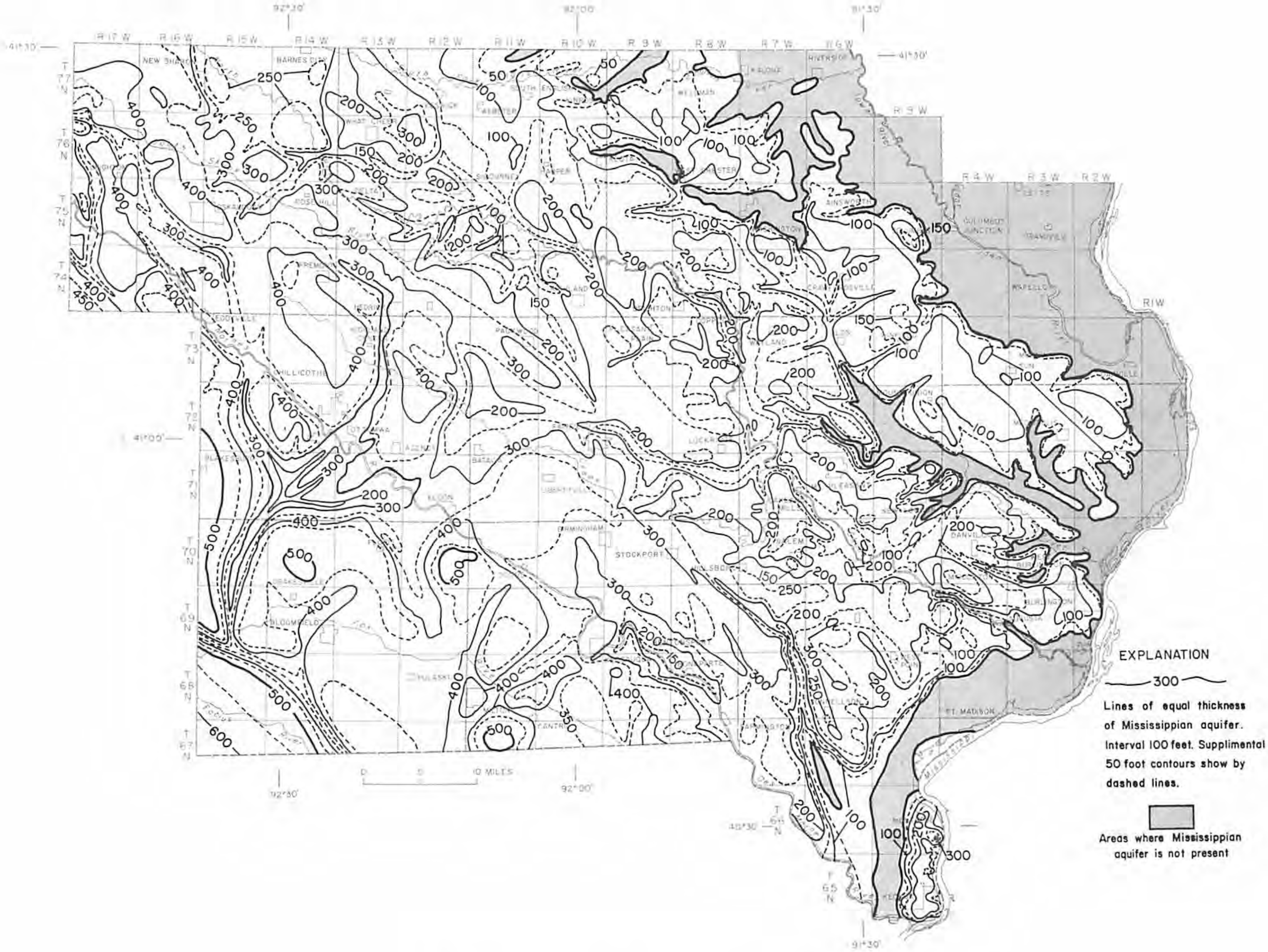


Fig. 33.—Thickness of the Mississippian aquifer

THICKNESS OF THE BEDROCK AQUIFERS

An aquifer will normally 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 the altitude maps to determine the depth to which wells must be drilled to fully penerate the aquifers.

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

The thickness of the Mississippian aquifer ranges from 0 to more than 600 feet. It is thickest in the southwestern part of the area and becomes progressively thinner toward the east and the northeast. Erosion of a considerable amount of rock material accounts for the local variations in thickness and the absence of this aquifer in the eastern and northeastern parts of the area.

The thickness of the Devonian aquifer ranges from more than 400 feet in the western part of the area to less than 150 feet in some places in the east. In the northeast corner the thickness increases somewhat, owing to the presence of the Silurian rocks. These rocks are included as part of the Devonian aquifer wherever they occur.

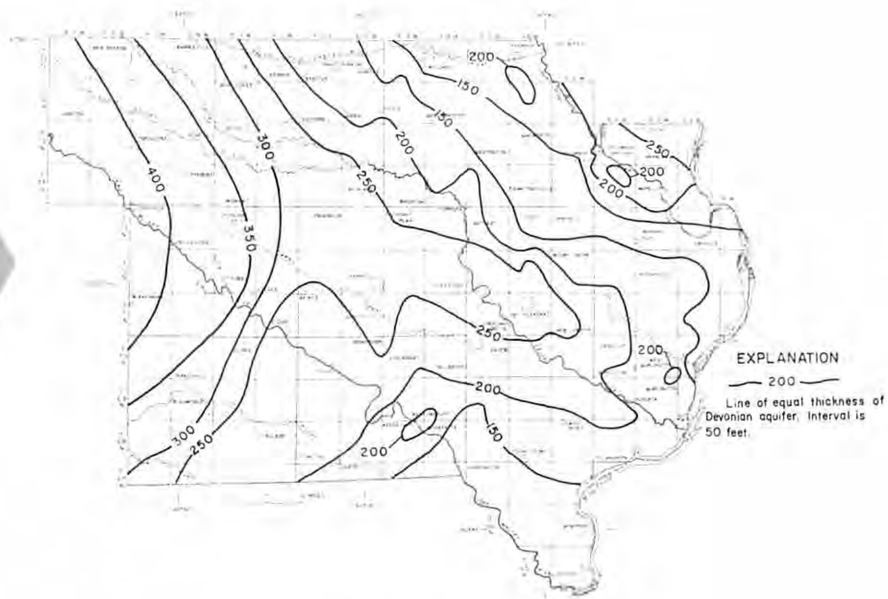


Figure 34.—Thickness of the Devonian aquifer

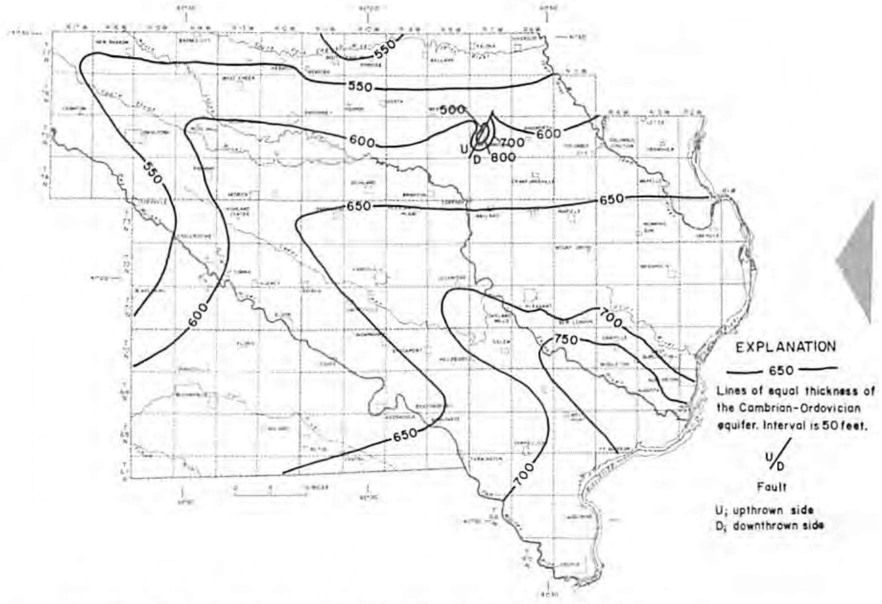


Figure 35.—Thickness of the Cambrian-Ordovician aquifer (does not include the St. Lawrence Dolomite)

Regionally, the Cambrian-Ordovician aquifer ranges from just less than 550 feet to slightly more than 750 feet in thickness. In general the aquifer becomes progressively thicker toward the southeastern corner of the area. What apparently is a fault in the vicinity of the town of Washington has caused localized thinning and thickening of the aquifer; the thickness is less than 500 feet on one side of the fault and a little more than 800 feet on the other side (fig. 35).

This map does not include the thickness of the St. Lawrence Dolomite which is the basal unit of the Cambrian-Ordovician aquifer. Few wells have fully penetrated the aquifer, so information is insufficient to construct an accurate map of its total thickness. Data available from eight wells indicate the St. Lawrence Dolomite is from 120 to 230 feet thick.

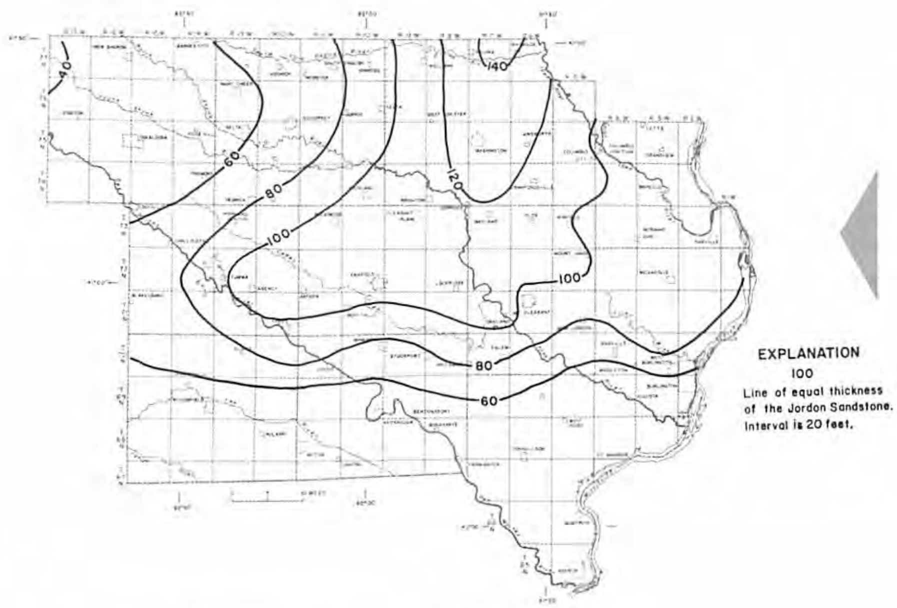


Figure 36.—Thickness of the Jordan Sandstone

The Jordan Sandstone, principal water-bearing unit within the Cambrian-Ordovician aquifer, exhibits considerable variation in thickness throughout southeastern Iowa. 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 DEPTHS OF DRILLING

The preceding maps can be used to predict the depths to the aquifers and their thicknesses throughout southeast Iowa. These determinations will aid in estimating the accessibility of ground water. The depths wells must be drilled in order to obtain water from each aquifer, the amount of casing that must be installed when the well is constructed can be estimated by using the maps, and these depth calculations in turn will help in estimating the cost of constructing the well. For example, assume that one is to drill a well in the western part of Jefferson County at the town of Batavia. Suppose also that it has been decided to obtain a suitable supply from either the Mississippian aquifer or the Cambrian-Ordovician aquifer.

The first step in estimating depths is to check the topographic map (fig. 3) to find the approximate altitude of the town site. This is found to be around 750 feet above sea level. Next, the depth to the top of the Mississippian aquifer, one of the two aquifers to be tested, must be estimated. The map of the top of this aquifer (fig. 29) indicates the top to be at an altitude of 525 feet, or 225 feet below the land surface. The aquifer's thickness (fig. 33) is around 265 feet in this area, so the base of the Mississippian aquifer lies that much more below the land surface, at a depth of 490 feet. A well completely penetrating the Mississippian aquifer would have to be 490 feet deep; and casing for the well, to prevent material from overlying layers from caving into the well and to exclude waters from the higher zones from the well, would have to extend from the land surface to at least the top of the aquifer. This would be to a depth of at least 225 feet.

A well into the Cambrian-Ordovician aquifer will have to be deeper. The top of this aquifer (fig. 31) is a little more than 600 feet below sea level, about 610 feet. A well would have to be 1,360 feet deep to reach the top of this aquifer. Casing in such a well should extend from the land surface to at least this depth. The Jordan Sandstone, the principal water-bearing unit in this aquifer, lies farther down at an altitude of 1,120 feet below sea level (fig. 32). Thus a well must be 1,870 feet deep to reach the top of the sandstone and 105 feet deeper (fig. 36) in order to fully penetrate it. Another unit of the Cambrian-Ordovician aquifer, the St. Lawrence Dolomite, lies below the Jordan Sandstone and is probably about 175 feet thick (see text on page 46); this would require the well to be 2,150 feet deep to fully penetrate the total thickness of the Cambrian-Ordovician aquifer.

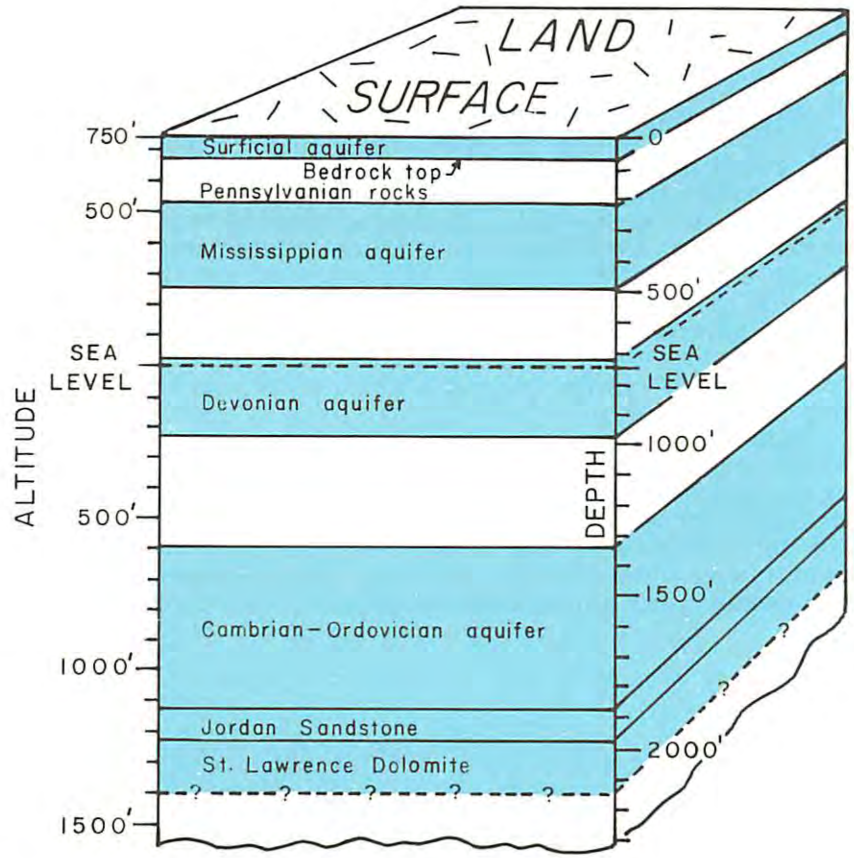


Figure 37.—Example of aquifer depths and thicknesses determined from maps

WATER IN THE AQUIFERS

Ground water moves through and is stored in the aquifers. The water fills void spaces between rock grains of sandstone and sand and gravel and joints, fractures, and solution channels in limestone and dolomite (fig. 38). Only those rocks with numerous large interconnected void spaces will yield large amounts of water to wells. Aquicludes, such as shale and clay, can store a large amount of water in spaces between the very small rock particles; but the molecular attraction between the water and the rock particles and the poor connection between voids tends to retain the water rather than to allow it to pass to a well. Other aquicludes are limestones and dolomites containing few openings through which water can flow; these rocks may be nearly dry.

Although aquifers are of primary concern in the discussion of the water resources, aquicludes have considerable hydrological significance. Aquicludes prevent or retard the movement of water between the land surface and the aquifer and between aquifers. Aquifers overlain by aquicludes do not receive recharge from local precipitation readily; and these aquifers, especially the limestones and dolomites, will usually yield a more mineralized water to wells.

Aquifers that are not overlain by aquicludes, such as some of the surficial aquifers and parts of the Mississippian and Devonian aquifers, contain water that is unconfined; that is, the top of the zone of saturation is free to move up or down. Water in a well tapping an unconfined aquifer will not rise above the level at which it was 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 (fig. 38).

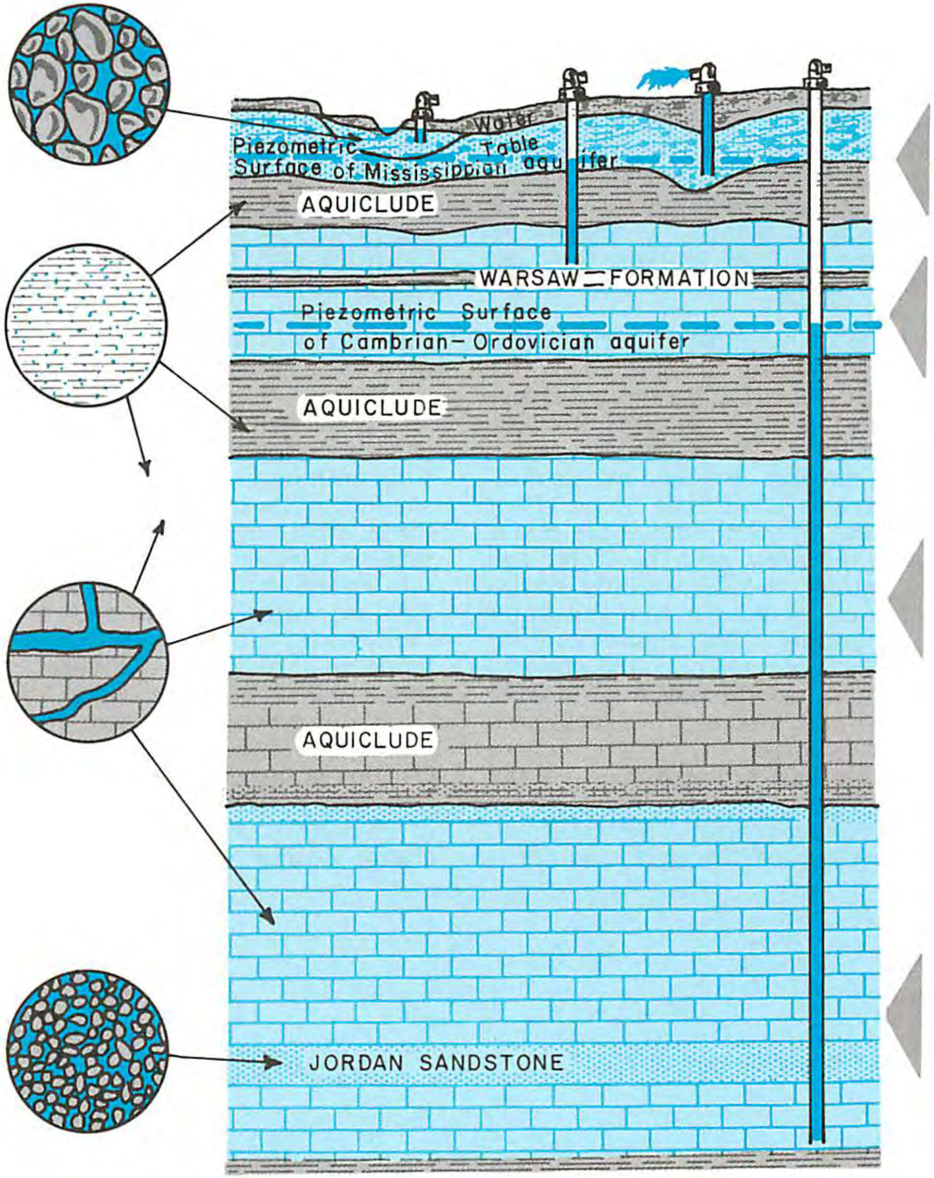
In the bedrock aquifers and in some of the surficial aquifers, where they are overlain and underlain by aquicludes, water is confined under pressure. Water in a well tapping these confined aquifers will rise above the top of the aquifer. The water may rise several feet or it may rise from great depths to the land surface. Under these conditions, the aquifer is called an artesian aquifer and the water is referred to as artesian water. The level to which water from any one artesian aquifer will rise in a well represents a point on an imaginary surface referred to as a piezometric surface. Each artesian aquifer in southeast Iowa has a separate piezometric surface (fig. 38).

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

Water is stored in large quantities in some aquicludes 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.

MISSISSIPPIAN AQUIFER
Water is easily replenished to this aquifer over a large part of southeast Iowa. However, the overlying aquiclude in other parts of the area retards recharge to the aquifer.

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

CAMBRIAN-ORDOVICIAN AQUIFER
Area of potential recharge more than 100 miles from southeast Iowa. Continued long-term withdrawals have resulted in lowered water levels over the entire area.

Figure 38.—Occurrence of water in the aquifers

WATER LEVELS

The water level in a well represents the position of the water table or piezometric surface at the site of the 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 the aquifers are portrayed. Because these maps depict the altitude of the water table or the piezometric surface of each aquifer, they can be used to predict nonpumping water levels for proposed wells in the area.

The configurations of the water table or piezometric surfaces tell 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 the contour lines. Water-level maps for some aquifers indicate that the water is moving directly across southeast Iowa and local topography and streams have little or no effect on the direction of water movement. These aquifers receive the major portion of their recharge from outside the area, and the water has moved a long distance through the aquifer before reaching southeast 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 near the streams indicating that the aquifers are recharged and discharge within the southeast Iowa area. Recharge to these aquifers is from local precipitation; discharge is toward nearby streams.

Most recharge reaches the water-table and near-surface artesian aquifers during two periods each year. One is the time between the spring thaw and the beginning of the growing season. The water can infiltrate into 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 in the 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; only large rainstorms or periods of prolonged precipitation will provide enough water to satisfy the demands of plants and still offer an excess which might infiltrate to the saturated zone. Hence, water levels in water-table and near-surface artesian aquifers are highest in late spring and fall, and are lowest in late summer and winter.

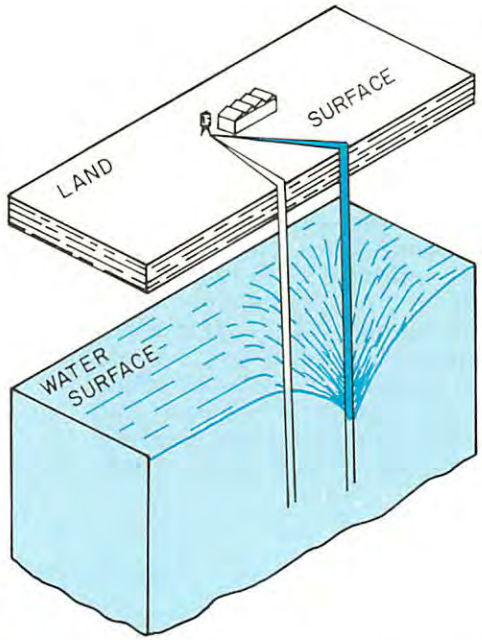
Should only a small amount of precipitation fall during the recharge periods, such as during times of drought, the water table will continue to fall, because discharge is a continuous process. Many shallow wells in water-table aquifers "go dry" in the summer and some winter periods. The wells are dry 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, such as the one in this report, 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; and the effects on the piezometric 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 from the recharge area. Therefore, the piezometric surface of deep artesian aquifers that are undisturbed by pumping does not fluctuate seasonally or even annually to any great extent. Piezometric maps based on water-level measurements made over a period of years has greater validity than water-table maps made from similar data.

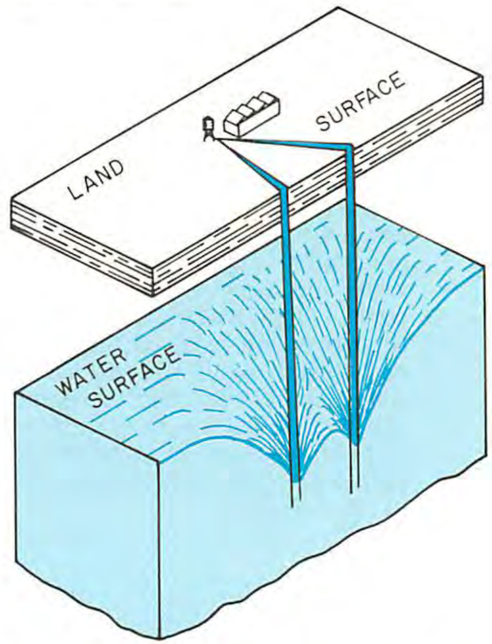
In addition to fluctuations produced by weather, water levels also fluctuate when artificial discharge through pumping wells is imposed on the hydrologic system. When water is removed by a well pumping from an aquifer that is under water-table conditions, the water table at and near the well is lowered quickly. This causes a conical depression, referred to as a cone of depression, in the water table around the pumped well (fig. 39). In aquifers that are under artesian conditions, the withdrawal of water has a similar effect in that it produces a depression in the piezometric surface; although in reality, this cone represents a decrease in the hydrostatic pressure around the well.

The size and shape of a cone of depression depends on the characteristics of the aquifer and the rate of pumping from the well. The higher the rate of pumping, the wider and deeper the cone. Generally speaking, under the same pumping rate, the cone of depression in an artesian aquifer is larger than one in a water-table aquifer. 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 (fig. 39). This interference can result in a decreased yield from each individual well and water levels so low that pumping costs become 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 cone of depression forms around a pumping well.



Cones around closely spaced wells interfere with each other and cause additional lowering of the water level in each well.

Figure 39.—Cones of depression around pumping wells

Records of water levels in a pumping artesian well indicate a continual lowering of the piezometric surface in the vicinity of the well, and the enlarging of the cone of depression. If the pumping regimen remains constant the water level will eventually approach stability. 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 a sensible equilibrium with recharge to the aquifer 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 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 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. The water levels in water-table wells are not excessively deep; therefore, the cost of lifting the water will 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

Water levels in the surficial aquifers are difficult to analyze. Water rises to different levels in wells drilled into each of these aquifers—the alluvial, buried-channel, and drift aquifers. The water table in the drift aquifer generally slopes from the high topographic areas toward the streams. An exception to this is over buried-channel aquifers where levels in the drift aquifer and still lower ones found in the buried-channel aquifer indicated that the buried channels act as subsurface drains through which water from the surficial aquifers, and also water from the shallow bedrock aquifers, move to discharge eventually into surface streams. To show the complex hydrostatic head relationships within the surficial aquifer would require several detailed large-scale maps. This type of analysis is beyond the scope of this report and only a general discussion will be presented.

Water levels in the surficial aquifers change noticeably throughout the year. Levels in drift and buried-channel aquifers respond rapidly to recharge from precipitation. Water levels in the alluvial aquifer fluctuate somewhat in the same way as those in the drift and buried-channel aquifers; however, the main influence on the alluvial aquifer is the stage (level) of the associated streams. Water levels will be high during periods of high stream stage and low during the low-stage periods.

Water levels in the drift aquifers commonly are from 10 to 50 feet below the land surface, and those in the buried-channel aquifer have been reported to be as low as 200 feet below the land surface. The water levels in alluvial wells are from 4 to 20 feet below the flood-plain surface, and the depth to the water surface will be accordingly deeper in wells located on terrace surfaces. Along the Mississippi River and for short distances upstream from the mouths of tributaries, water levels in the alluvial aquifers are sustained at or above the normal pool altitudes behind the navigation dams (fig. 40). Lower water levels will be found only in areas where the aquifer is subjected to heavy pumping or where drainage projects have been constructed.

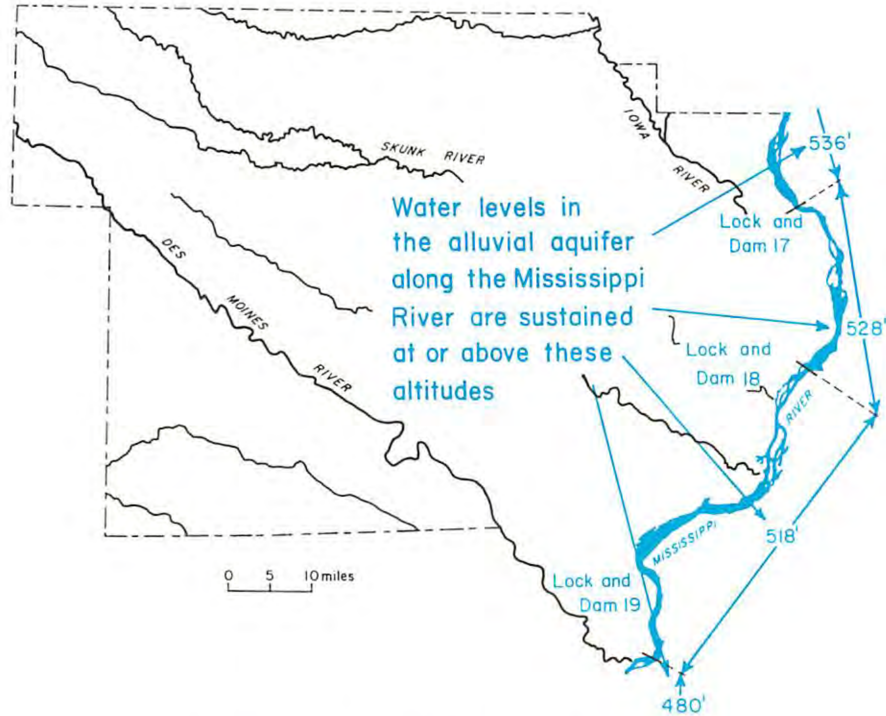


Figure 40.—Normal pool altitudes of navigational lakes on the Mississippi River

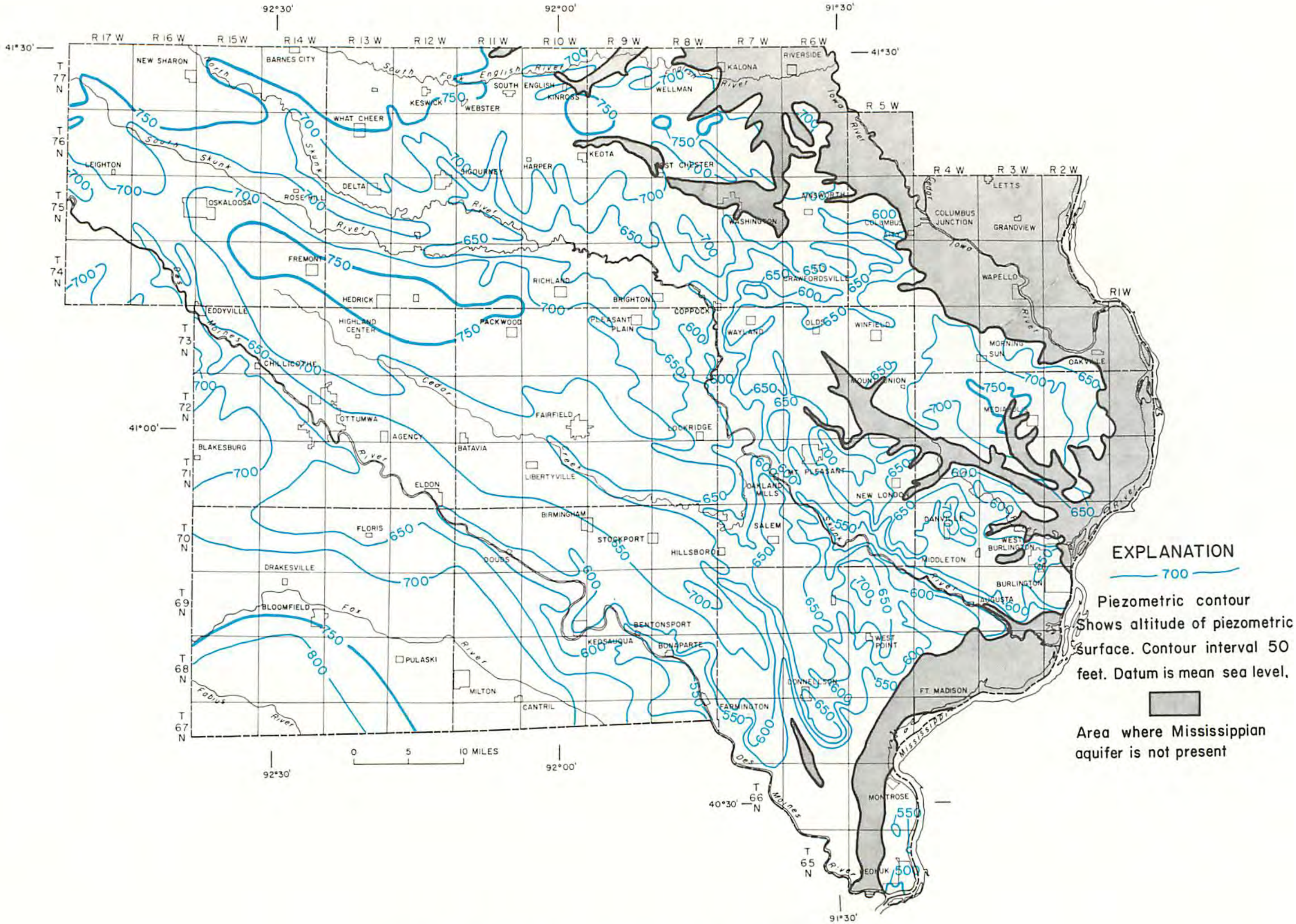


Figure 41.—Altitude of the water levels in wells tapping the Mississippian aquifer

Water Levels in Bedrock Aquifers

Water in the Mississippian aquifer is in part artesian and in part water table and water levels in wells range in altitude from 500 feet to more than 800 feet. The higher altitudes occur in the major divide areas and the lower ones are near the streams. This indicates this aquifer is being discharged into the streams. The regional pattern of flow through the Mississippian aquifer is from the divide areas to the major streams—the Des Moines, Skunk, Iowa, and Mississippi Rivers. The intricate pattern of the contours in the northeastern one-half of the area shows that the water discharges into some small streams which act as drains for the aquifer where the Mississippian aquifer constitutes the bedrock surface (see fig. 27). The buried-channel aquifers act as drains also; the most dramatic example being in western Lee County.

The altitude of the water levels in wells tapping the Devonian aquifer range from more than 800 feet in the northwestern part of the area to less than 550 feet in the southeast. Recharge enters the aquifer somewhere outside the area, probably to the north or northwest, moves in a southeasterly direction and leaves the area as subsurface outflow. The only place where the Devonian aquifer is not covered by an aquiclude in the southeast Iowa area is in the Iowa and Mississippi Valley in Louisa County. This is a potential discharge point for water from the Devonian aquifer to enter the streams or the alluvial aquifers.

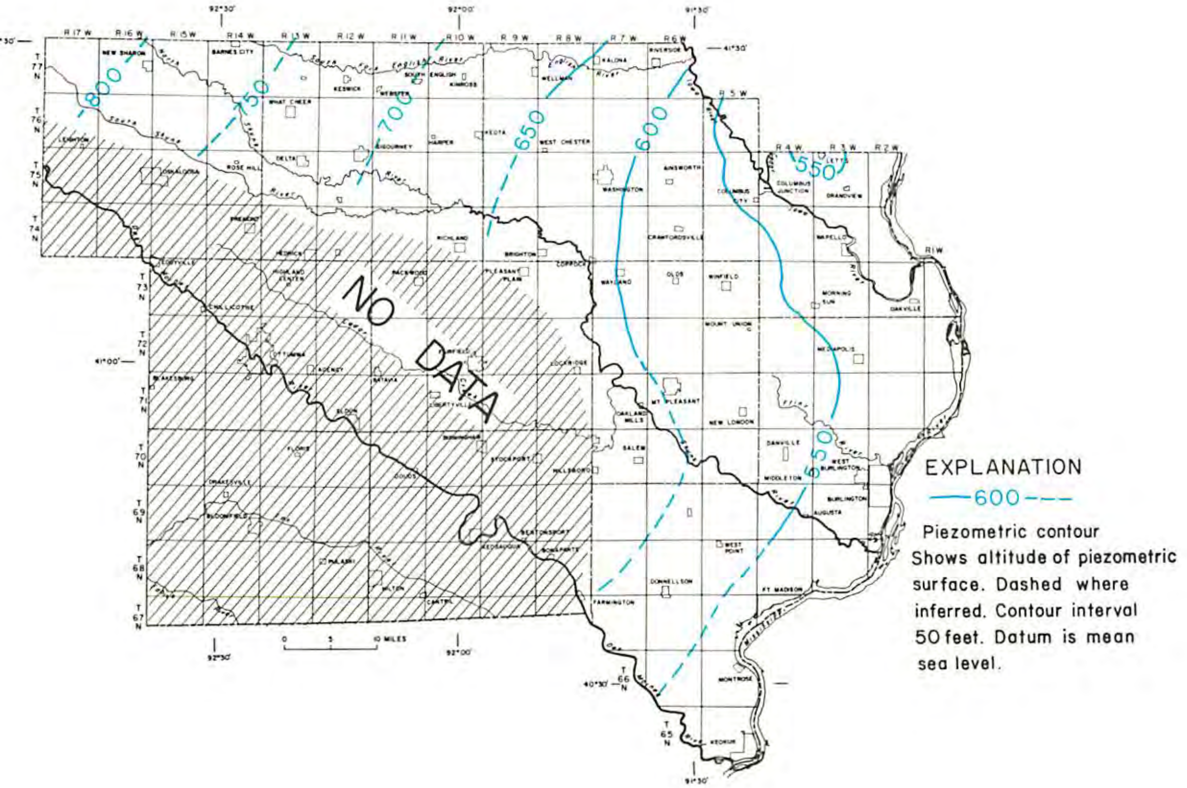


Figure 42.—Piezometric surface of the Devonian aquifer

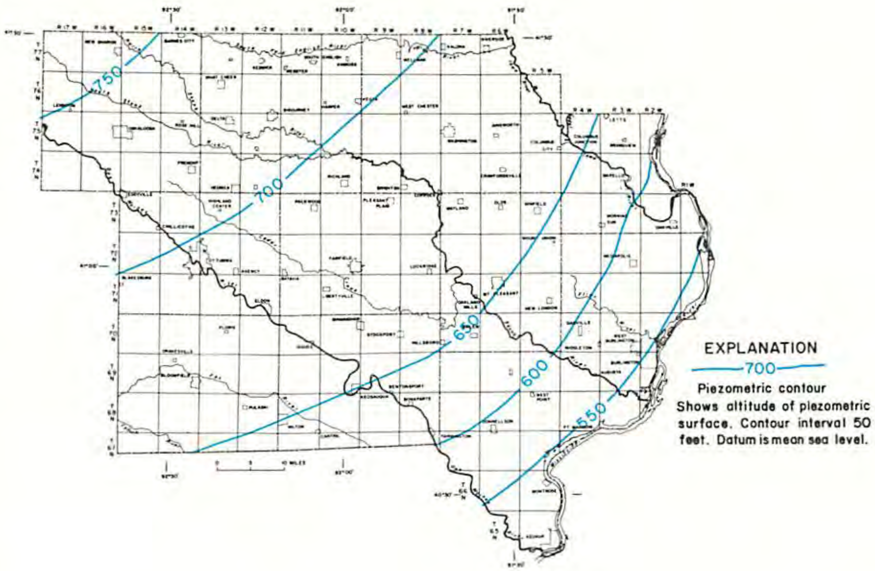


Figure 43.—Generalized piezometric map of the Cambrian-Ordovician aquifer before extensive withdrawals began in the 1940's

The piezometric surface of the Cambrian-Ordovician aquifer has been lowered over the entire southeast Iowa area since pumping from it began shortly after the turn of the century. A map of the undisturbed piezometric surface of that aquifer (fig. 43) was constructed using water-level data from the earliest wells drilled in and adjacent to southeast Iowa. Water-level data prior to the early 1940's were used if the wells were remote from previously establishing pumping centers. During this period, the piezometric surface across the area ranged from an altitude of more than 750 feet in the northwest to less than 550 feet in the east and southeast. Water in this aquifer flowed under the area from the northwest toward the southeast.

Steadily increasing withdrawals from the Cambrian-Ordovician aquifer have resulted in a continued lowering of the piezometric surface. Pumping from this aquifer, and especially the Jordan Sandstone, has taken place for the longest period of time at the cities of Ottumwa, Washington, and Mount Pleasant. At these three cities, water levels have declined about 100 feet. Pumping began at the city of Fairfield in 1957, and the non-pumping water level in that city's well has been lowered 15 feet in 12 years. The present piezometric surface of the Cambrian-Ordovician aquifer and the decline in water levels at major pumping centers are shown on the 1968-69 piezometric map (fig. 44). At the pumping centers, this piezometric surface represents non-pumping levels in individual wells, because measurements are influenced by nearby pumping wells. However, the piezometric surface map does show the altitude of water levels that would be encountered in this area now. Regionally, the surface has been lowered between 25 and 75 feet, and the pumping centers have experienced 100 feet or more of water-level decline. Water levels at the major pumping centers are not approaching stability (fig. 44); thus the piezometric surface in these areas will continue to be lowered.

The piezometric surface across southeast Iowa presently ranges from an altitude of more than 650 feet in the northwest to less than 550 feet in the southeast. Regionally, the water is still flowing through the aquifer from northwest to southeast. However, it is also diverted toward the major pumping centers.

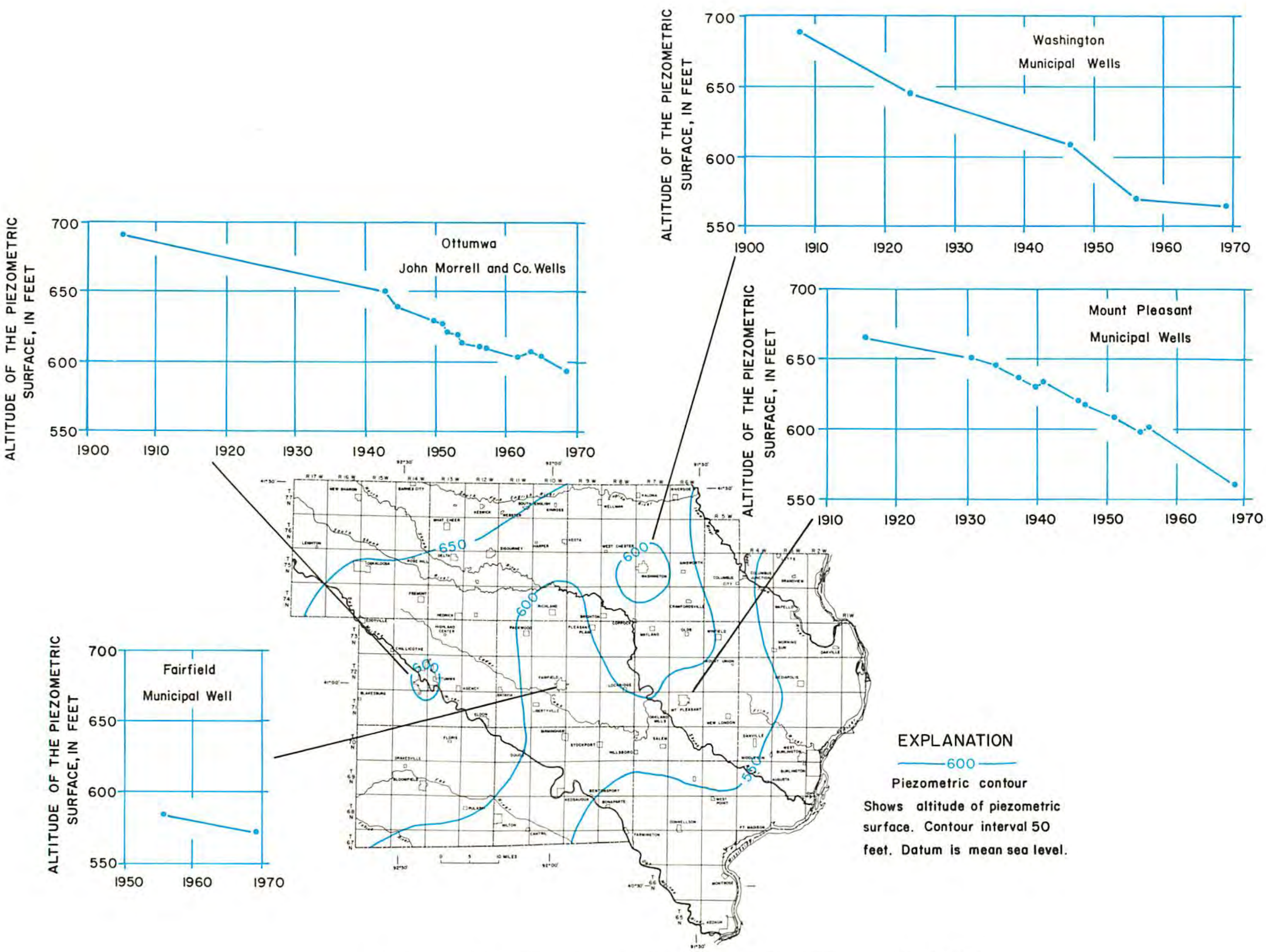


Figure 44.—Piezometric map of the Cambrian-Ordovician aquifer, 1968-69 and hydrographs showing local declines in water level

YIELDS FROM WELLS

The rate at which water can be withdrawn from wells in southeastern Iowa is not only different for the various aquifers, but also for each aquifer from place to place. The maps for each aquifer 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 include the pumping rate of the wells and the drawdown, which is the amount the water level in the well was lowered while the well was pumped at that rate. Using both the pumping rate and drawdown data, it has been possible to estimate a higher probable yield for many wells equipped with small capacity pumps than the amount of water presently being withdrawn from them.

Geologic data indicate the type of rock that comprises each aquifer, the thickness of the rock units, the spatial relationships of the aquifers with respect to land surface and aquicludes, and the characteristics of the rock openings. In areas where limestones and dolomites lie near the land surface and are not covered by aquicludes, 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 exposed at 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 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.

Both water-production data and geologic data were used to make extrapolations of expected yields over broad areas where well records are absent. As new data are made available for the areas where data are now absent, more accurate predictions can be made. The following yield maps are based on information available at the present time and represent known and predicted yields from the several aquifers in southeast 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 three subdivisions of the surficial aquifer—alluvial, buried-channel, and drift aquifers—can be fairly well distinguished on the basis of potential yield. The yield map (fig. 45) indicates highest potential yields are available from the alluvium and associated deposits in the Mississippi River valley. Individual wells in the Fort Madison area often produce more than 1,000 gpm. Only limited data are available concerning the potential yields in the broad flood plain of the Mississippi valley from Burlington north to where the Mississippi River enters the area and for a short distance up the Iowa valley. The type and thickness of alluvial deposits should be the same as those of the prolific aquifer in the Fort Madison area and the same as the high-producing alluvial aquifers just north of the Louisa County line. This part of the Mississippi valley probably is the most promising area for the development of large ground-water supplies. Alluvial aquifers in parts of the other major stream valleys, the Iowa, Skunk, and Des Moines valleys are expected to yield more than 100 gpm to wells.

Buried-channel aquifers yield up to 100 gpm to individual wells in several places. Yields of 200 gpm or more often can be maintained for short periods of time or possibly during one season per year. Because of the slow rate of recharge to these aquifers through the thick overlying material and from rocks which compose the walls of these ancient stream channels, high pumping rates generally cause a continuous lowering of the piezometric surface.

Drift aquifers yield only small amounts of water in this region. An adequate supply for domestic or livestock needs is the best that can be obtained. Yields from the aquifers often are so small that they are measured in units of gallons per hour rather than gallons per minute. Some exceptions do exist, however, and at least one community, Milton, does receive an adequate supply from a drift aquifer.

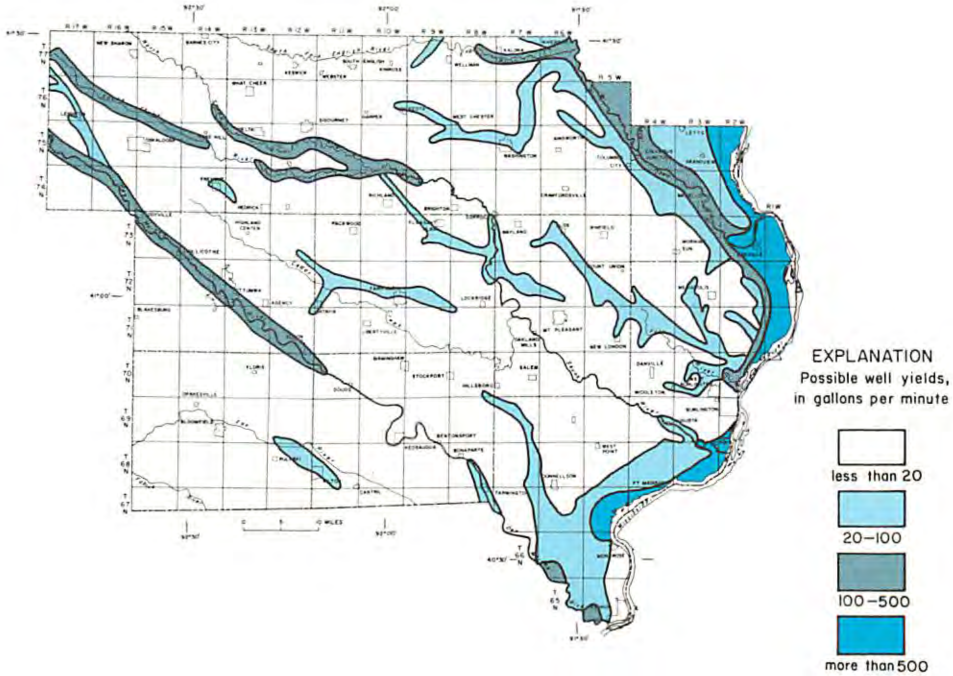


Figure 45.—Yields to individual wells; surficial aquifers

For the purpose of discussing the yield and quality of the water, the Mississippian aquifer can be subdivided into two parts on the basis of lithology. The Warsaw Formation acts as an aquiclude or aquitard (table 5 and fig. 52), which retards circulation of water. Generally, the highest yielding areas for the Mississippian aquifer are in places where that aquifer comprises the bedrock surface. Thus where the upper part of the aquifer (mainly the St. Louis Formation) is present, the highest yields can be expected from that part of the aquifer. When drilling a well in areas where the upper part is present, appreciable increases in yield usually will not be obtained by drilling into and below the Warsaw Formation (figs. 46 and 47).

Yields of over 50 gpm are available at only a few places from the lower part of the Mississippian aquifer in southeast Iowa. Yields of this magnitude have been encountered in only a few scattered areas. Generally, yields of 20 gpm can be obtained in most of the eastern and northeastern parts of the area from either the upper or lower parts of this aquifer.

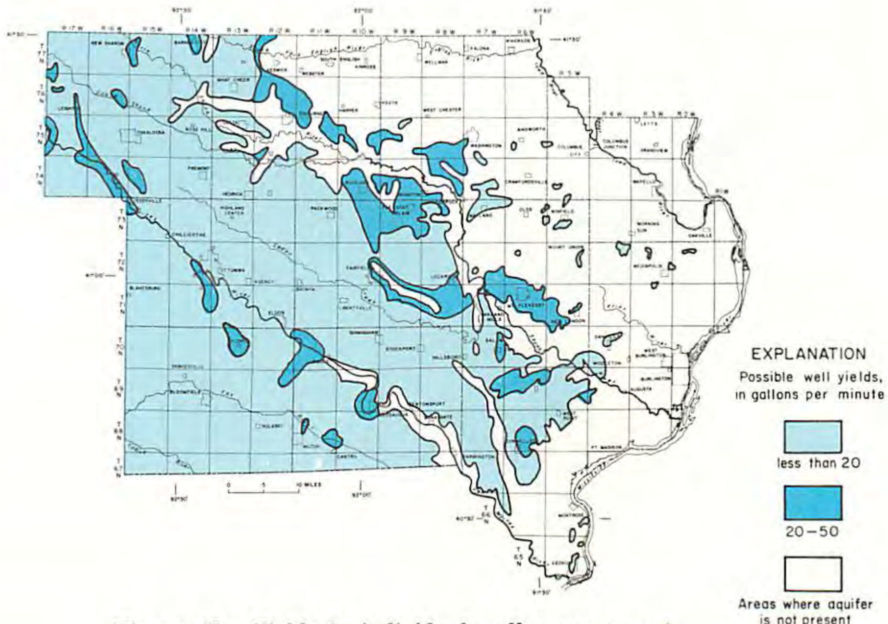


Figure 46.—Yields to individual wells; upper part of the Mississippian aquifer

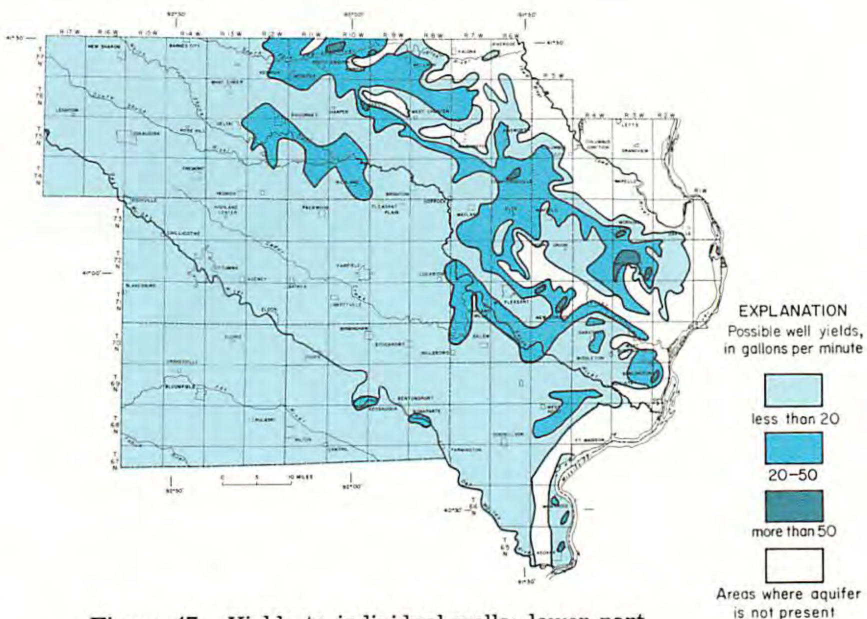


Figure 47.—Yields to individual wells; lower part of the Mississippian aquifer

The Devonian aquifer yields water to wells at a rate of more than 20 gpm in the northeastern and eastern parts of southeast Iowa. Yields exceeding 50 gpm have been developed in very limited areas only, and typical yields in these places normally range from 60 to 75 gpm. A yield of more than 100 gpm was reported from only one well. Data on the production capabilities of the Devonian aquifer are not available in the southwestern part of the area; however, yields of more than 20 gpm are not to be expected.

Yields from the Jordan Sandstone of the Cambrian-Ordovician aquifer are highest—1,000 gpm or more—in the central and east-central parts of the area where the sandstone is thickest (figs. 36 and 49). However, yields are somewhat lower in the eastern and northwestern parts of the region, because the pore spaces between sand grains are filled with dolomitic cement.

The upper parts of the Cambrian-Ordovician aquifer, the St. Peter Sandstone, and the Prairie du Chien Formation (table 5), also will yield dependable supplies of water throughout southeast Iowa. Wells drilled into the upper part will produce at least 50 gpm, and yields up to 300 gpm are not unusual.

Occasionally wells, such as the Donnellson town well, can be found that produce water at exceptionally high rates—rates much higher than available from other similar wells in the same region. The logical explanation for these anomalies is the wide range of the potential water-producing capabilities of the Prairie du Chien Formation. This formation is a thick sequence of predominantly dolomite rock. Development of an extensive crevice or cavern system in rock of this type would form a water reservoir of considerable size.

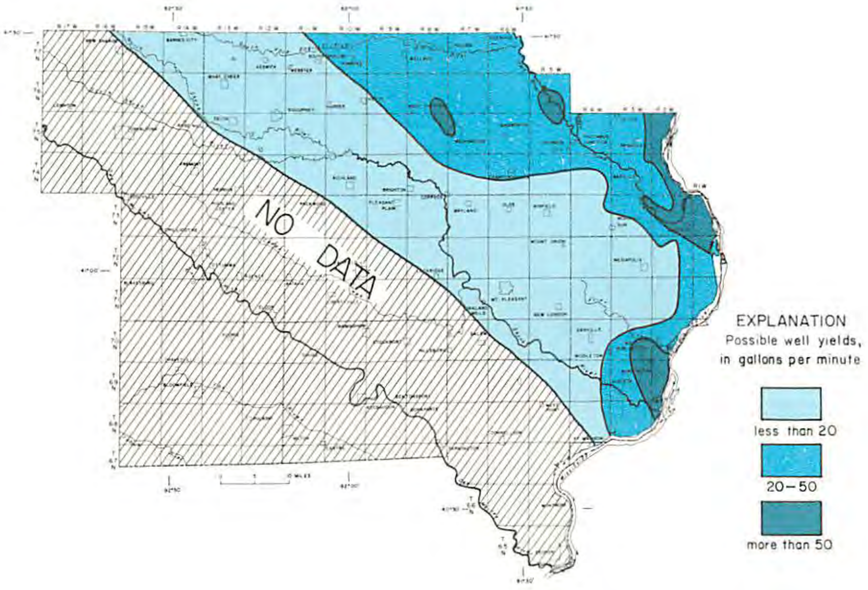


Figure 48.—Yields to individual wells; Devonian aquifer

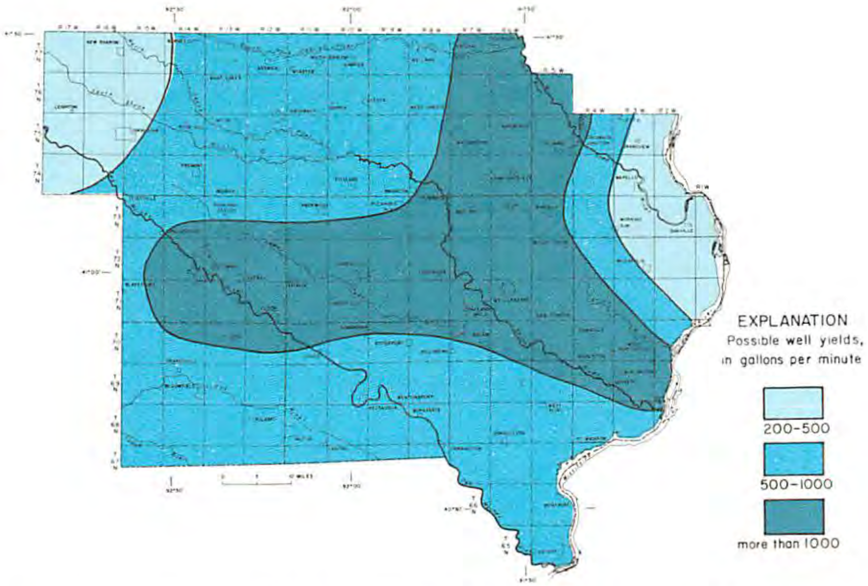


Figure 49.—Yields to individual wells; Cambrian-Ordovician aquifer

WATER QUALITY

The quality of the water that is to be used for any particular purpose is important—just as important as the quantity of water that source will yield or the cost of obtaining the water from that source. Some sources of water are not utilized because the chemical or physical properties of the water make it undesirable for most uses.

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 the water. Ground water moves slowly through the aquifers, and this water can be in contact with several types of earth materials for long periods of time and often dissolves considerable amounts of various minerals. Domestic, industrial, and agricultural chemical and organic wastes are often discharged into streams, or onto the land surface, or into the soil and shallow rock deposits. Water temperature is also an important aspect of water quality. Temperatures of surface water vary throughout the year, and temperatures of the ground water are relatively constant. All of these things result in the water of an area showing a wide variety of characteristics.

The manner in which water is used determines which constituents and properties are desirable or deleterious. Water which might be quite suitable for irrigational purposes could be unsatisfactory for a public-water supply. Water 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.

Any substance in large amounts generally is objectionable. Some are objectionable because they are harmful to the health of humans and animals; acceptable limits have been established for these. Others can be aesthetically offensive in causing odors or color problems—the color of the water itself or staining objects which come in contact with the water. Some constituents are a nuisance that can be alleviated by water-treatment procedures, or users may simply become accustomed to them.

Several mineral constituents and properties of water are listed and explained briefly in the adjacent table (table 6). The maximum recommended concentrations shown are limits established by the U.S. Public Health Service as standards for interstate carriers and are suggested for drinking-water supplies in general. Limits on constituents involving the health of the user are to be adhered to, while some others can be exceeded with no obvious ill effects. Limits for uses other than for drinking water are often different from those listed.

The chemical constituents listed in this report are expressed as ions in concentrations of milligrams per liter (mg/l). One mg/l is 1/1,000ths of a gram (milligrams) of an ion in a volume of 1,000 cubic centimeters (one liter of water). An approximate weight to weight ratio would be 1 gram of the ion in 1,000,000 grams of water.

Table 6.- Significance of mineral constituents and physical properties of water

Constituent or Property	Maximum Recommended Concentration	Significance
Iron (Fe)	0.3 mg/l	Objectionable as it causes red and brown staining of clothing and porcelain. High concentrations affect the color and taste of beverages.
Manganese (Mn)	0.05 mg/l	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.
Calcium (Ca) and Magnesium (Mg)		Principal causes for hardness and scale-forming properties of water. They reduce the lathering ability of soap.
Sodium (Na) and Potassium (K)		Impart a salty or brackish taste when combined with chloride. Sodium salts cause foaming in boilers.
Sulfate (SO_4)	250 mg/l	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 mg/l	Large amounts combined with sodium impart a salty taste.
Fluoride (F)	2.0 mg/l	In southeast 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)	44 mg/l	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 fertilizer.
Dissolved Solids	500 mg/l	This refers to all of 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 1,000 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 be treated readily by softening.
Phosphate (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 waters 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 a water with a low and constant temperature.

See Hem (1959), U.S. Public Health Service (1962), and Federal Water Pollution Control Administration (1968) for further discussion of chemical and physical properties of water.

The principal chemical constituents and properties shown in table 6 form the basis for comparing quality of water from different sources. On the following pages, complete chemical analyses of surface waters are listed for several sampling points in southeast Iowa. Analyses of ground waters are summarized for definitive areas for each aquifer by showing the averages and ranges of values for several constituents.

Summaries of the chemical quality of ground waters do not include iron or manganese. Major differences often exist between the concentrations reported and the actual concentrations in the water at its source. Iron is found in almost all natural water, and special sampling and analytical techniques are needed for an accurate study. In well waters additional iron may be dissolved from well casings, pumps, and pipes. Concentrations may be affected by micro-organisms. Manganese also requires special sampling and analytical techniques for an accurate study, and micro-organisms also can affect concentrations of this ion.

Both iron and manganese are a common local problem in all aquifers in southeast Iowa. Iron concentrations in excess of the recommended limit were found in 75 to 80 percent of the samples from all the aquifers. Manganese was detected in amounts in excess of the recommended limit in nearly one-half of the samples of ground water. Obviously, iron and manganese problems should be considered when planning to develop a ground-water supply. Both iron and manganese problems can be alleviated by water-conditioning equipment.

QUALITY OF SURFACE WATERS

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 content 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 which has been in contact with rocks for long periods and has had time to dissolve minerals from them. 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.

Figure 50.—Surface water sampling sites in southeast Iowa

Since 1956 municipal personnel have collected water samples periodically from the Mississippi River at Keokuk, the South Skunk River near Oskaloosa, and the Des Moines River at Ottumwa (fig. 50). Analyses of those samples show a wide range of concentrations of constituents through several years and under a variety of discharge rates. In order to further define some of the changes in the chemical quality of stream waters, samples for chemical analysis were collected from 12 additional sites in southeast Iowa (fig. 50). Sampling sites were chosen which would offer data from a variety of drainage basin sizes. Collections were made throughout a 1-year period in 1966-67 in order to obtain samples during: (1) low flow in cold weather, (2) the first runoff from the land surface in the spring, (3) high, or flood flows, and (4) low flow during warm weather Only six sites were sampled during a high-flow period in April 1967, but samples were collected from all 12 sites at the other times. Chemical analyses of those samples from the 12 sites are listed in table 7. The following generalizations can be made from these analyses.

1. Concentrations of dissolved solids are highest during periods of low discharge and lowest during high discharge. Highest concentrations are found in water from the Des Moines basin.
2. The predominant type of water in almost all samples was calcium bicarbonate or calcium magnesium bicarbonate. The major exception is Soap Creek (station 5-4901) where the water type is calcium sulfate during periods of low discharge.
3. Concentrations of chloride are mostly less than 50 mg/l. However, the highest are from the Des Moines River where a maximum of 74 mg/l was noted.
4. The nitrate content is highest during periods of high discharge when runoff from the land surface predominates.
5. Concentrations of phosphate are in excess of 0.3 mg/l most of the time.
6. Chemical oxygen demand was highest during high discharge and usually was somewhat higher in samples from the larger streams.

Table 7.—Chemical analyses of stream waters at selected sampling sites

Dissolved constituents and hardness in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa

Sampling Point	Date Collected	Discharge (cfs)	Temperature °F	Temperature °C	Silica (SiO_2)	Iron (Fe) Soluble	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$	Phosphate (PO_4) Soluble	Organic Nitrogen	Chemical Oxygen Demand (C.O.D.)	Specific Conductance (Micromhos at 25°C)	pH
Iowa River Basin																								
5-4555	12-12-66	44	33	0.5	9.2	0.5	0.70	41	16	17	5.1	168	0	40	16	0.2	3.9	252	166	0.36	1.1	32	450	7.7
English River	4-17-67	452	59	15	14	.2	* .05	40	14	10	1.8	139	0	38	6.0	.2	20	238	156	.6	1.6	93	360	7.9
at Kalona	6-12-67	769	70	21	11	.1	* .05	30	9.7	7.1	3.2	84	0	29	6.0	.2	25	195	116	.8	4.7	153	280	7.6
	9-11-67	8.0	59	15	11	.2	1.2	59	18	14	2.7	237	0	45	5.5	.2	.4	387	224	.2	.63	12	450	8.0
5-4653	12-12-66		34	1.0	11	0.9	0.59	42	21	13	9.0	210	0	35	12	0.2	5.8	285	192	2.6	2.5	60	460	7.9
Long Creek	4-17-67	91	62	16	13	.2	* .05	52	23	12	2.3	200	0	46	11	.3	30	316	226	.5	.67	69	490	8.1
near Wapello	6-12-67	247	72	22	12	.1	* .05	45	17	8.2	2.6	127	0	35	9.5	.3	51	284	182	.5	2.3	66	420	7.8
	9-11-67	.16	68	20	3.2	.1	.35	66	29	19	3.6	315	0	56	10	.2	.4	364	284	.2	.63	16	578	8.2
5-4655	12-12-66	1,730	33	0.5	4.0	0.1	*0.05	66	23	24	2.6	267	0	42	28	0.2	8.0	352	258	0.82	1.4	32	610	8.2
Iowa River	4-17-67	7,140	60	16	8.2	.1	* .05	59	16	12	3.3	207	2.4	43	13	.2	11	287	216	.8	2.1	109	470	8.2
at Wapello	6-12-67	18,200	74	23	7.3	.1	* .05	26	8.7	6.5	3.2	85	0	22	7.0	.2	14	160	102	.9	6.5	153	240	7.7
	9-11-67	1,500	69	20	4.0	.1	* .05	56	18	23	3.3	183	22	48	26	.2	.4	312	216	.6	1.5	39	475	8.6
Flint River Basin																								
5-4697	12-12-66		33	0.5	10	0.1	0.59	88	32	26	7.2	326	0	110	18	0.2	7.4	490	350	0.66	0.75	16	800	8.1
Flint River near	4-17-67	126	60	16	11	.2	* .05	52	17	9.7	2.7	190	0	41	7	.2	16	272	200	.5	2.3	69	425	8.1
Burlington	9-11-67	1.0	70	21	7.4	.1	.28	83	28	16	2.6	334	4.8	56	8	.2	.4	389	324	.1	.41	7.8	610	8.2
Skunk River Basin																								
5-4725	12-12-66	42	33	0.5	4.4	0.2	0.32	55	21	16	3.5	233	0	51	8.0	0.3	4.3	292	226	0.24	0.67	10	510	8.0
North Skunk River	4-17-67	230	58	14	13	.3	* .05	46	15	13	5.6	146	0	54	11	.3	14	269	174	.6	1.5	87	425	8.0
near Sigourney	9-11-67	13	60	16	6.4	.4	.31	61	18	26	4.0	254	0	61	8.5	.3	.4	329	228	.3	.77	21	520	8.1
5-4730.5	12-12-66		34	1.0	11	1.0	0.36	48	20	51	9.7	205	0	64	52	0.3	16	398	204	3.0	2.5	68	670	7.9
Crooked Creek	4-17-67		58	14	14	.2	* .05	51	20	11	2.3	176	0	42	11	.3	36	303	212	.7	1.4	93	475	8.0
near Coppock	9-11-67	1.5	69	20	1.2	.2	.33	72	26	56	6.1	310	0	84	43	.4	.4	460	288	.4	1.2	33	700	8.1
5-4734	12-12-66		34	1.0	6.2	0.2	0.22	72	22	40	7.5	238	0	130	28	0.4	4.6	444	272	2.0	0.73	26	750	8.0
Cedar Creek near	4-17-67	436	61	16	13	.2	* .05	46	13	12	4.4	129	0	56	.8	.4	17	269	168	.6	2.2	63	395	8.0
Oakland Mills	9-11-67	4.4	68	20	1.6	.1	.25	82	21	23	6.0	283	4.8	82	13	.2	.4	398	292	.1	.73	21	600	8.2
5-4740	12-12-66	160	33	0.5	5.3	0.1	0.06	72	22	28	4.0	272	0	80	20	0.3	1.6	378	270	0.32	0.53	18	650	8.2
Skunk River	4-17-67	3,200	62	16	11	.1	* .05	39	15	11	4.6	137	0	45	6.0	.3	17	249	160	.9	3.2	93	380	8.0
at Augusta	6-12-67	8,260	74	23	8.4	.1	* .05	28	6.8	5.2	3.7	78	0	25	4.5	.3	20	233	98	.8	11	203	240	7.6
	9-11-67	139	70	21	6.0	.1	.05	74	24	22	2.7	271	12	69	15	.2	.4	371	284	.2	.61	21	540	8.4
Des Moines River Basin																								
5-4885	12-13-66	360	33	0.5	2.1	0.2	0.98	79	37	62	5.4	303	0	140	66	0.4	8.2	579	352	3.1	2.9	7.3	980	8.2
Des Moines River	4-10-67	2,260	62	16	6.3	.2	* .05	73	24	22	5.3	212	7.2	110	22	.4	4.1	430	282	.8	2.2	54	640	8.4
near Tracy	6-12-67	28,700	72	22	9.9	.1	* .05	37	9.2	4.9	3.6	112	0	30	3.5	.4	14	209	130	1.0	6.7	159	300	7.8
	9-12-67	581	62	16	1.6	.1	.05	62	26	31	4.7	171	29	97	31	.3	.4	407	264	1.1	2.3	39	580	8.8
5-4901	12-13-66		33	0.5	7.3	0.7	1.7	100	26	16	3.5	188	0	220	6.5	0.3	0.9	517	356	*0.01	0.20	10	710	7.4
Soap Creek	4-18-67	103	53	12	12	.2	.12	82	20	13	3.9	176	0	150	2.0	.3	1.9	424	288	.1	.56	26	620	8.0
near Floris	9-12-67	2.17	70	21	9.0	.5	1.2	91	20	14	2.8	152	0	210	4.0	.3	.4	476	312	* .1	.20	12	625	7.6
5-4905	12-12-66	216	33	0.5	0.1	0.1	*0.05	69	37	68	5.6	251	1.3	160	74	0.4	8.2	591	326	1.5	2.9	82	975	8.5
Des Moines River	4-17-67	4,930	60	16	10	.2	* .05	51	14	12	4.8	127	0	82	9.0	.4	5.3	289	184	.5	3.3	99	420	8.0
at Keosauqua	6-12-67	30,700	74	23	9.6	.1	* .05	42	9.2	7.4	3.9	121	0	36	4.0	.4	13	226	142	.7	8.7	247	325	7.8
	9-12-67	677	70	21	.6	.1	* .05	62	32	40	5.1	207	13	130	38	.4	.4	452	288	.4	.99	35	690	8.4
Fox River Basin																								
5-4945	12-12-66		33	0.5	11	0.2	1.3	78	19	32	6.0	257	0	110	20	0.2	1.8	410	276	0.16	0.39	14	710	7.8
Fox River	4-17-67		60	16	9.0	.3	* .05	26	7.3	7.4	4.2	80	0	36	2.0	.4	3.2	171	96	.8	7.6	20	239	7.8
near Cantril	9-12-67	0.67	60	16	11	.1	1.6	67	16	30	3.4	193	0	120	8.0	.3	.4	380	236	* .1	.25	14	570	7.9

* Less than value shown.

Chemical analyses of water from the Mississippi River at Keokuk, the South Skunk River at Oskaloosa, and the Des Moines River at Ottumwa are listed on the next three pages (tables 8, 9, and 10). The streams sampled at Keokuk and Ottumwa are the source of the municipal water supplies at these cities. The South Skunk River serves as a standby supply for Oskaloosa.

Chemical analyses of water samples of the Mississippi River at Keokuk show the concentrations of nearly all constituents to be lower and to vary over a narrower range than the constituents in the South Skunk or Des Moines Rivers. Concentrations of nitrates and phosphates usually are higher during periods of higher discharge. Concentrations of the other constituents and properties either remain fairly constant or decrease at higher discharge rates. All available data indicate the water of the Mississippi River at Keokuk to be of the calcium bicarbonate type.

The water in the South Skunk River near Oskaloosa is also of the calcium bicarbonate type. The river has slightly higher concentrations of nitrate, flouride and bicarbonate and lower amounts of iron than the Mississippi or Des Moines Rivers. The chemical-oxygen demand is lower than in the other two rivers. Nitrate content increases with increased discharge and concentrations of sodium and sulfate are definitely lower at higher discharge rates.

Water in the Des Moines River carries higher concentrations of dissolved constituents than either the Skunk or Mississippi Rivers. Concentrations of calcium, magnesium, sodium, potassium, sulfate, chloride, dissolved solids, total phosphate and organic nitrogen are generally higher in this stream than in the other two. Properties such as hardness and chemical-oxygen demand are also higher in the Des Moines River. Concentrations of most constituents are lower at times of high discharge than at low discharge, but concentrations of nitrate and organic nitrogen usually increase during high discharge. Concentrations of phosphate are highest in the winter and spring.

Table 8.—Chemical analyses of Mississippi River water at Keokuk at gage 5-4745

Dissolved constituents and hardness in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa.

Date Collected	Discharge (cfs)	Temperature °F	Temperature °C	Silica (SiO_2)	Iron (Fe) Soluble	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$	Phosphate (PO_4) Total	Organic Nitrogen	Chemical Oxygen Demand (C. O. D.)	Specific Conductance (Micromhos at 25°C)	pH
10-08-56	18,600	63	17	2.4	0.14	*	38	18	8.0	2.7	166	0	31	7	0.15	0.89	198	174	0.66	0.75	24		8.0
2-04-57	20,400			7.6	.28	*	40	17	11	3.6	194	0	40	11	.2	3.1	224	172	.76	1.0	34	378	7.9
4-29-57	59,000	63	17	1.8	.12	*	34	13	7.4	2.8	143	0	33	7	.2	1.3	175	140	.80	1.3	30	306	8.2
7-15-57	106,000	77	25	16	.72	*	40	11	5.8	2.6	148	0	30	2	.2	5.8	218	146	.70	.65	19	311	7.9
10-07-57	30,100	63	17	8.0	.22	*	45	15	8.2	3.2	183	0	35	5	.25	1.8	244	174	.60	.55	25	370	8.2
2-17-58	27,800	34	1.1	10	.22	*	57	20	11	2.8	224	0	43	8	.2	2.7	291	224	.48	.62	23	468	8.0
5-19-58	36,800	70	21	1.3	.26	0.05	40	18	8.3	2.7	160	3.6	43	5	.2	1.8	229	174	.65	.64	20	361	8.2
8-11-58	25,500	82	28	5.2	.24	*	42	16	7.5	2.6	161	2.4	37	5	.2	4.4	219	172	1.4	.51	20	356	8.1
4-06-58	180,400	49	9.4	11	1.4	.12	34	13	4.4	5.6	112	0	33	4	.2	8.9	178	136	1.8	1.3	36	258	7.8
6-22-59	30,400	79	26	3.2	.50	.16	44	15	7.2	2.3	178	0	34	8	.35	4.4	234	172	.69	.64	26	266	7.9
11-23-59	48,400	39	3.9	11	.28	*	49	14	7.4	2.5	176	0	33	9	.25	8.0	247	180	.64	.75	33	372	8.0
2-15-60	46,500	34	1.1	11	.24	.07	55	18	9.0	2.3	198	0	41	8	.2	9.3	286	210	.51	.61	20	430	8.0
4-13-60	132,000	50	10	10	.24	*	43	14	5.1	3.3	142	0	30	6	.2	16	227	164				346	7.9
7-25-60	41,000	82	28	8.8	.12	*	45	21	6.7	2.1	185	4.8	30	8	.2	5.3	251	200	.55	.55	27	393	8.3
2-20-61	23,700	36	2.2	8.8	.26	.70	48	17	9.8	2.0	185	0	35	9	.25	2.7	268	189	.70			375	7.8
6-18-61	46,100	75	24	5.8	.24	*	40	16	5.9	3.3	159	0	32	4	.30	4.4	218	164	.65	.72	32	342	7.8
9-11-61	22,000	81	27	3.0	.20	.25	45	19	8.5	1.9	188	0	35	6.5	.25	.89	230	192	.63	.53	14	377	8.0
12-11-61	51,400	36	2	11	.16	*	58	19	8.6	2.0	221	0	38	7.0	.20	8.4	286	224	.55	.64	17	453	8.1
3-26-62	170,500	42	5.6	9.2	.80	.07	28	10	4.7	3.7	102	0	25	4.0	.20	8.0	176	112	1.4	1.2	36	251	7.8
1-13-64	21,200	37	2.6	1.6	.04	.12	53	20	14	2.8	220	0	34	10	.25	2.8	285	216	.30	.72	32	469	8.0
11-02-64	22,400	59	15	1.8	.18	*	35	16	11	2.2	154	0	31	10	.2	1.1	218	159				345	7.6
5-10-65	246,000	68	20	10	.30	*	34	9.7	5.0	3.3	120	0	28	4.5	.25	5.8	171	124	.60	.79	25	273	7.7
5-10-66	97,900	46	14	.8	.22	*	38	14	5.7	2.1	132	9.6	35	6	.2	1.9	193	152				330	8.7
3-20-67	58,100	41	5	12	.28	.05	39	16	11	3.3	176	0	22	16	.2	.2	219	162	.90	.69	28	370	7.7
7-24-67	40,400	82	28	8.3	.20	*	38	14	8.1	2.1	151	0	34	7	.15	2.3	219	154	.60	.65	24	350	7.9
1-22-68	30,500	37	2.7	3.6	.18	.05	48	25	13	2.2	215	4.8	41	14	.25	2.5	284	224	.7	.99	24	450	8.4
4-20-68	68,500	59	15								149	0		9.5		.4	205		.5	.77	30	330	7.8
2-08-69	58,000			14		.12	48	15	9.9	5.3	185	0	41	12	.4	5.1	252	180				400	7.2
RANGE	High			14	1.4	0.70	58	25	14	5.6	224	9.6	43	16	0.35	16	291	224	1.8	1.3	36	469	8.7
	Low			.8	.04	*	28	9.7	4.4	1.9	102	0	22	2	.15	.2	171	112	.30	.51	14	251	7.2

* Less than 0.05

Table 9.—Chemical analyses of South Skunk River water near Oskaloosa at gage 5-4715

Dissolved constituents and hardness in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa.

Date Collected	Discharge (cfs)	Temperature °F	Temperature °C	Silica (SiO_2)	Iron (Fe) Soluble	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$	Phosphate (PO_4) Total	Organic Nitrogen	Chemical Oxygen Demand (C. O. D.)	Specific Conductance (Micromhos at 25°C)	pH
6-18-56	26	86	30	10	0.11	*	74	26	31	5.4	273	4.8	91	27	0.4	0.88	424	292	1.7	1.6	46	646	8.4
10-29-56	11	55	13	3.4	.16	0.24	79	27	42	6.0	272	2.4	104	39	.3	.88	474	308	1.4	.65	23	759	8.2
2-18-57	140			9.6	.24	*	39	10	13	7.2	134	0	47	13	.2	7.1	240	138	2.2	1.8	30	321	7.8
5-13-57	546	64	18	12	.08	*	58	18	15	6.8	198	0	68	13	.4	12	337	218	1.9	2.2	46	510	8.0
8-26-57	100	72	22	7.2	.10	.08	64	22	20	3.4	232	0	76	19	.4	.88	348	248	1.6	.76	26	554	8.2
9-23-57	87	61	16	9.6	.02	*	77	26	24	4.6	259	17	79	21	.4	4.9	417	302	1.0	.57	29	677	8.2
2-17-58	60	36	2	20	.18	.19	118	33	21	3.6	405	0	103	18	.5	11	557	430	1.4	.51	19	845	7.8
5-19-58	200	67	20	9.0	.08	*	69	28	12	3.5	240	14	67	10	.6	8.0	369	288	.72	.88	20	550	8.4
8-11-58	368	81	27	21	.08	*	95	31	11	2.7	317	17	74	8.5	.45	16	452	364	1.6	.77	24	682	8.4
1-26-59	28	34	1	18	.30	1.3	93	29	28	3.9	346	0	90	26	.5	15	468	352	1.4	1.9	19	754	7.4
4-27-59	1,200	54	12	1.5	.1	*	91	26	8.0	1.6	295	0	71	8	.5	23	462	332	.50	.70	36	568	8.1
6-23-59	485	75	24	18	.06	*	86	27	9.3	1.8	288	12	78	7	.4	16	417	324	.92	.61	19	551	8.3
10-12-59	217			21	.04	*	92	30	14	4.0	327	2.4	77	13	.3	10	353	352	1.3	.43	19	651	8.2
1-04-60	450	37	3	16	.04	*	119	27	9.9	2.1	339	17	70	10	.4	28	507	408	.53	.48	9.6	745	8.2
4-04-60	13,000	45	7	9.4	.14	*	40	12	3.3	3.5	124	4.8	44	5	.2	18	211	152	.80	.86	27	322	8.2
6-27-60	800	77	25	21	.04	*	87	24	8.2	1.6	293	4.8	57	6.5	.5	19	413	316		.76	27	609	8.2
9-26-60	742	70	21	18	.02	*	72	20	9.5	5.2	259	2.4	53	9	.3	8.0	376	264	2.8	1.9	44	490	8.2
1-03-61	110	37	3	18	.08	.44	91	27	15	2.5	325	0	72	12	.35	6.2	427	340	1.0	.39	5.3	655	7.7
6-06-61	440	72	22	15	.08	*	80	26	9.8	2.4	288	7.2	62	6	.4	8.0	370	308		.69		539	8.3
11-27-61	1,670	44	6.5	22	.08	*	94	27	8.2	1.3	327	0	61	6	.3	18	424	348	1.2	.64	8.6	596	8.2
1-19-62	460	43	6	21	.16	.10	86	27	10	1.6	310	0	69	10	.3	12	433	324	.65	.37	6.0	639	7.8
6-03-63	710	75	24	17	.02	*	86	26	9.8	1.9	298	0	54	8	.35	20	435	324	1.3	.88	23	601	7.9
2-04-64	105	37	3	8.6	.24	.33	70	19	25	3.6	251	0	68	19	.3	5.0	343	256	1.4	.16	18	602	7.9
8-31-64	156	75	24	10	.08	*	61	18	17	5.5	217	7.2	65	15	.3	.7	329	228	1.3	.88	24	490	8.4
6-28-65	494	79	26	16	.04	*	77	24	11	1.8	254	7.2	71	10	.3	10	374	290	1.4	.89	22	573	8.4
3-28-66	1,300	45	7	21	.06	*	94	26	8.0	2.0	315	1.2	60	9	.35	7.5	418	344	1.4	1.3	33	663	8.1
4-03-67	178	57	14	13	.24	.15	73	23	22	4.7	268	9.6	70	22	.35	1.9	391	276	1.4	1.1	27	610	8.5
7-17-68	61	72	22	9.2	.08	*	56	28	14	2.1	226	4.8	68	13	.35	5.5	338	254	1.0	.19	22	530	8.3
2-20-68	36			16	.24	1.5	78	29	50	5.2	312	0	92	44	.4	4.3	487	316	3.3	.84	24	790	8.0
5-13-68	160										244	14		23		1.1	395		1.4	1.3	28	600	8.4
5-22-69	2,180±	59	15	16	.28	.09	93	29	10	3.8	298	0	82	17	.3	28	546	352	.6	.76	20	660	8.0
RANGE		High		22	0.30	1.5	119	33	50	7.2	405	17	104	44	0.6	28	557	430	3.3	2.2	46	845	8.5
		Low		1.5	.02	*	39	10	3.3	1.3	124	0	44	5	.2	.7	211	138	.50	.16	5.3	321	7.2

* Less than 0.05

Table 10.—Chemical analyses of Des Moines River water at Ottumwa at gage 5-4895

Dissolved constituents and hardness in milligrams per liter. Analysis by State Hygienic Laboratory of Iowa.

Date Collected	Discharge (cfs)	Temperature °F	Temperature °C	Silica (SiO_2)	Iron (Fe) Soluble	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$	Phosphate (PO_4) Total	Organic Nitrogen	Chemical Oxygen Demand (C. O. D.)	Specific Conductance (Micromhos at 25°C)	pH
6-18-56	609	84	29	9.8	0.08	*	61	20	21	5.4	190	2.4	105	20	0.4	8.0	391	234	1.9	1.6	28	544	8.0
10-08-56	170	63	17	1.2	.20	0.84	52	29	33	6.2	178	0	128	30	.3	.89	393	250	1.1	.93	36		8.0
2-04-57	222	37	2.8	6.0	.30	1.0	99	38	67	7.7	348	0	149	73	.2	3.5	671	402	4.2	1.8	50	1110	8.3
5-27-57	2,860	70	21	6.8	.12	*	50	25	18	4.6	176	0	86	18	.4	13	351	230	.90	2.1	38	529	8.0
9-09-57	650	70	21	.8	.10	*	57	25	25	5.2	178	4.8	111	21	.35	.44	373	246	.96	1.1	25	578	8.3
10-21-57	321	59	15	4.0	.14	.17	67	22	28	6.2	215	2.4	109	27	.25	2.7	387	260	1.0	1.4	26	625	8.2
1-06-58	1,000	30	-1.1	10	.06	*	114	38	27	3.9	359	6.0	146	23	.50	20	601	444	.92	1.0	35	865	8.4
4-21-58	2,120	64	18	.9	.14	.05	66	32	16	3.1	193	9.6	117	14	.40	16	420	296	.83	1.2	24	594	8.4
6-30-58	2,070	79	26	13	.32	*	55	30	15	2.8	161	4.8	106	14	.40	8.9	360	260	.80	1.6	25	546	8.1
3-02-59	6,560	35	1.7	6.8	1.1	*	37	11	5	12	129	0	37	6	.20	4.4	277	148	3.7	3.8	160	320	7.7
6-01-59	37,200	66	19	14	2.0	*	40	13	4.2	4.2	137	0	43	4	.30	12	270	154	3.9	2.4	74	306	7.9
8-24-59	898	88	31	5.2	.02	*	76	16	16	4.4	215	6.0	82	7.5	.40	.44	385	256	.96	.63	29	505	8.3
11-23-59	1,930	33	.6	3.2	.08	*	64	29	18	4.5	193	7.2	111	20	.40	2.2	393	280	.86	.73	29	595	8.5
2-15-60	3,350	32	0	12	.06	.22	84	28	14	3.4	242	0	104	14	.35	13	437	324	.69	.55	8	639	7.8
4-11-60	20,900	44	6.7	16	.10	*	66	19	5.6	3.6	200	0	66	6	.35	19	362	242	1.8	1.8	49	490	8.0
6-27-60	7,000	73	23	22	.06	*	86	24	8.8	2.9	251	7.2	75	8	.55	24	341	312			44	612	8.2
9-26-60	10,000	64	18	10	.14	*	27	11	5.2	5.0	100	0	31	7	.25	7.1	241	112	4.7	2.2	72	253	8.1
1-03-61	700	32	0	10	.10	.34	126	39	30	3.8	388	1.2	169	28	.35	5.8	631	476	13	1.2	26	937	8.1
5-29-61	5,310	66	19	11	.04	*	93	32	11	2.8	259	14	108	9	.55	19	462	364	1.0	1.0	33	664	8.4
11-27-61	6,400	42	5.6	19	.06	*	88	26	11	2.6	273	4.8	85	9	.35	13	438	328	1.3	1.0	17	635	8.1
1-29-62	2,700	32	0	18	.12	.29	97	30	17	2.8	322	0	119	16	.35	11	487	366		.47		729	7.6
6-03-63	4,680	73	23	14	.06	*	91	28	13	2.6	284	4.8	76	11	.35	18	464	344	.80	.85	26	656	8.1
2-03-64	490	32	0	8.2	.08	.45	94	31	39	4.8	273	17	124	38	.35	5.3	527	364	2.3	2.3	48	527	8.4
8-31-64	1,450	77	25	4.8	.12	.12	64	22	19	5.8	205	0	99	19	.35	.9	359	252	1.0	1.1	39	567	7.8
6-07-65	22,600	68	20	16	1.3	.14	61	14	5.6	2.8	178	0	65	6	.35	17	468	208	4.6	6.4	175	427	8.0
3-28-66	5,880	45	7	16	.16	*	85	20	12	3.8	242	0	86	14	.30	7.1	397	296	1.4	1.9	54	621	8.0
4-03-67	2,440	57	14	9.5	.36	.40	53	16	18	7.0	150	0	83	14	.40	3.9	322	196	1.0	1.3	35	470	7.6
7-10-67	5,780			21	.10	*	104	25	12	3.2	300	0	96	16	.45	23	482	364	1.0	.47	28	740	8.2
1-08-68	155	36	2	4.0	.26	1.2	103	36	50	5.8	332	0	170	45	.3	1.9	613	404				910	8.2
5-06-68	1,630										140	0		29		5.0	352		1.0	2.3	9.9	540	8.2
RANGE		High		22	2.0	1.2	126	39	67	12	388	17	170	73	0.55	24	671	476	13	6.4	175	1110	8.5
		Low		.8	.02	*	27	11	4.2	2.6	100	0	31	4	.2	.44	241	112	.80	.47	8	253	7.6

* Less than 0.05.

QUALITY OF GROUND WATERS

Good quality water generally available from the surficial aquifers

The surficial aquifers yield the least mineralized water of all ground water sources in southeast Iowa. The aquifers receive recharge from rainfall, water often percolates through them rapidly, and the amount of time the water has to dissolve mineral matter from the surficial materials is relatively short. The dominant cation in most of the water is calcium and the major anion is bicarbonate. The water is hard, but not so hard as some of the water from bedrock aquifers.

Water from the drift aquifers is generally of good quality. This part of the aquifer seldom yields large quantities of water and its main use is for farmsteads and for livestock drinking water. Many of these farm wells are constructed with porous casing, such as concrete or clay tile, and contamination by pollutants from the land surface is not uncommon. Concentrations of nitrate slightly below or exceeding the recommended limit of 45 mg/l are not unusual in water from drift wells.

Water from alluvial aquifers generally is less mineralized than water from other aquifers in southeast Iowa. Also large yields are often available, making the alluvial aquifers desirable sources of water for many uses. Alluvial aquifers in the Mississippi and lower Des Moines valleys can be expected to yield water containing the lowest concentrations of dissolved solids. The porous soils and sand and gravel deposits which comprise the surface materials at the top of these aquifers facilitate rapid infiltration of precipitation.

Unfortunately, contaminants from the land surface and soil also are transported quite easily into the saturated zone. Nitrates, for example, have been detected in objectionable amounts in some places.

Water from the buried-channel aquifer is often more mineralized than water from the other surficial aquifers. Water in the buried channels often takes on some of the characteristics of water from the bedrock aquifers into which these channels have been cut. This may be the reason for the higher values for many constituents in areas 9 and 10. The one water analysis in area 7 is almost the same as many from the Mississippian aquifer in that same vicinity. Water in the buried-channel aquifer in area 6 contains lower concentrations of dissolved constituents than any of the other surficial aquifers. The sand and gravel deposits there are almost completely separated from bedrock aquifers by an aquiclude.

Concentrations of iron in water samples from the surficial aquifers have been found to be as high as 18 mg/l and are in excess of 0.3 mg/l in nearly 80 percent of the samples. Concentrations of manganese were more than 0.05 mg/l in nearly one-half of the samples analyzed, and the maximum concentration found in the surficial aquifers was 2.6 mg/l.

Concentrations of fluoride in water from the surficial aquifers ranges from 0 to 1.0 mg/l, well below the 2.0 mg/l limit recommended. The mean temperature of 60 water samples from all the surficial aquifers is 54°F (12.0°C) and the range of these temperatures was from 48°F to 58°F (9.0°C to 14.5°C).

Table 11.—Chemical characteristics of water in the surficial aquifers

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

Area	Average and Range	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids	Hardness (as $CaCO_3$)	Number of Analyses
						Drift Aquifer					
1	A	103	36	40	506	74	2.7	0.4	547	406	14
	R	77-150	24-61	13-88	304-739	11-393	0.5-7.5	0.2-0.7	357-982	292-625	
						Alluvial Aquifer					
2	A	66	19	15	272	39	8	0.3	306	243	15
	R	41-85	11-29	7.2-56	149-407	8.2-113	.5-31	.2-1.0	221-436	168-330	
3	A	76	28	32	371	49	11	.4	401	308	9
	R	53-91	23-33	13-64	210-478	8.0-130	1.0-39	0-1.0	312-478	243-351	
4	A	78	23	18	248	99	14	.3	415	290	13
	R	59-91	11-31	7.6-37	168-327	58-163	3-25	.2-.4	305-535	216-360	
5	A	108	31	21	295	169	11	.4	552	395	8
	R	84-143	20-41	11-28	218-390	22-287	3.5-17	0-1.0	440-726	304-525	
						Buried Channel Aquifer					
6	A	64	17	7.8	303	10	1.6	0.2	260	244	5
	R	62-69	15-20	0-14	290-309	4.5-24	.5-4.5	0-.4	234-273	218-285	
7	A	228	90	171	273	1000	9.5	.9	1880	942	1
8	A	96	32	45	499	49	7.8	.2	501	374	20
	R	55-135	17-49	3.5-133	305-673	.1-140	.5-36	0-.6	311-676	259-489	
9	A	53	20	153	579	46	12	.4	591	215	12
	R	24-88	3.1-39	87-244	410-803	.2-170	2.5-28	0-1.0	357-715	78-360	
10	A	169	52	95	676	250	2.0	.4	946	616	4
	R	128-175	46-61	42-130	548-775	110-362	.5-4.0	.2-.9	782-1120	510-685	

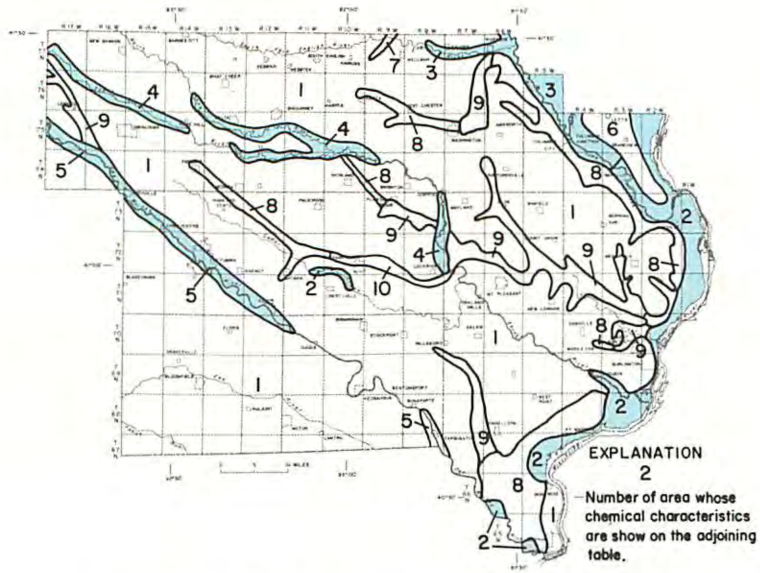


Figure 51.—Water-quality areas of the surficial aquifers

The upper and lower parts of the Mississippian aquifer yield water of unlike quality

The upper and lower parts of the Mississippian aquifer are discussed separately with respect to the quality of the water available from each part of that aquifer. As when considering the yields obtainable from each part, the division is made on the basis of lithology —the dividing bed being the Warsaw Formation (table 5). The Warsaw Formation is an aquiclude, or aquitard, and prevents free circulation of water between the upper and lower parts of the aquifer. Where the upper Mississippian is present, the water in the lower part will be more mineralized than the water in the upper part. Where the upper part of the aquifer and the Warsaw Formation are absent, the water in the lower part of the aquifer usually will have a low mineral content.

An aquiclude—Pennsylvanian rocks—overlying the upper part of the Mississippian aquifer has the same effect on that part of the aquifer as the Warsaw Formation has on the lower part; i.e., an increase in mineralization.

The generalized cross section (fig. 52) illustrates (1) the respective positions of the two parts of the aquifer and the Warsaw Formation and the Pennsylvanian rocks and (2) the effect these two rock units have on the quality of the water in the Mississippian aquifer. The dissolved-solids content of water from both parts of the aquifer generally increases from the northeast toward the southwest. In areas where the Warsaw is not present, dissolved solids are usually less than 500 mg/l. Where the Warsaw is present, dissolved-solids content of water from the upper part of the aquifer ranges from less than 500 mg/l in some areas where the Pennsylvanian rocks do not cover it to more than 2,500 mg/l in areas where the Pennsylvanian rocks form a continuous cover. In the southwestern part of the region, the water in both parts of the aquifer is highly mineralized.

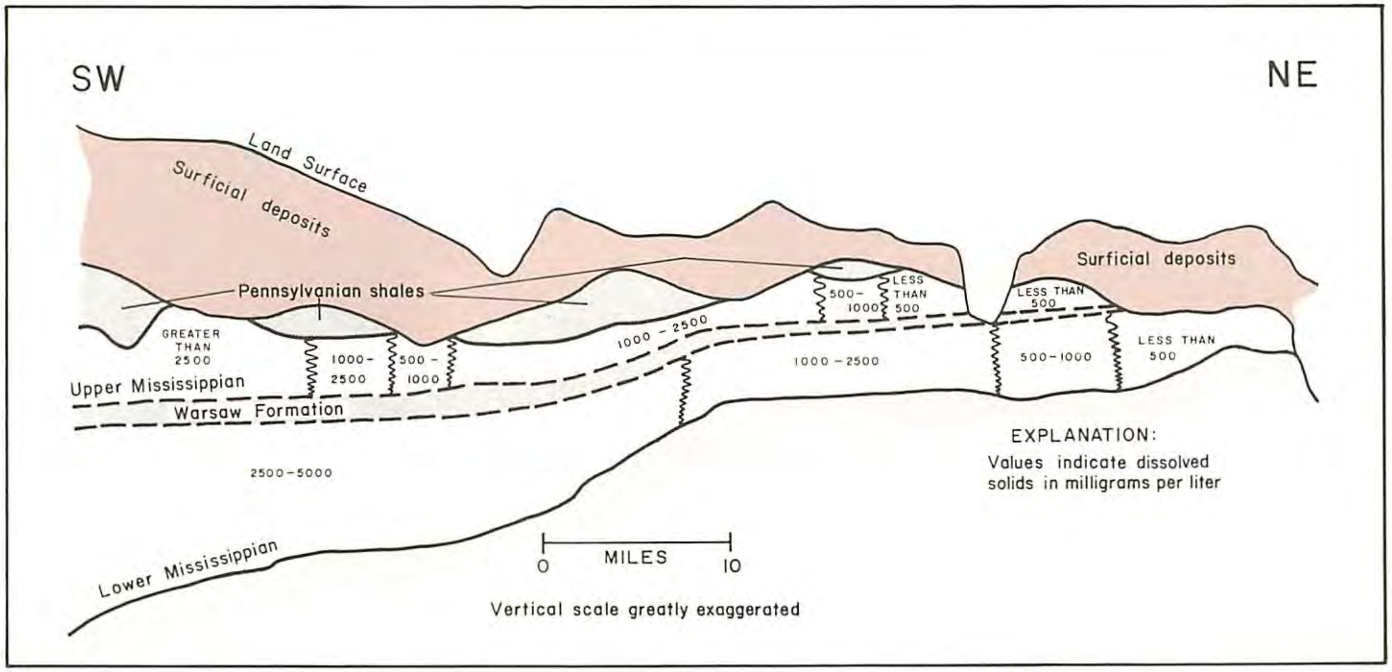


Figure 52.—Generalized cross section of the water-quality zones in the Mississippian aquifer

North of the Des Moines River the upper part of the Mississippian aquifer contains water with less than 1,000 mg/l of dissolved solids over a major part of its areal extent. The dissolved-solids content increases toward the south and west where concentrations of sodium and sulfate rise. Evaporite minerals (gypsum and anhydrite) are present in the Mississippian aquifer in a few places, but their occurrence is more common in the counties immediately west of the southeast Iowa area.

Good to fair quality water is available from the upper part of the Mississippian in area 1 and supplies obtained from area 2 are acceptable for many uses (fig. 54 and table 12). The fluoride content commonly exceeds 2.0 mg/l in parts of areas 4 and 6, and approaches that concentration in areas 1, 2, and 3.

The lower part of the Mississippian aquifer offers good to fair quality water in the eastern part of southeast Iowa. This aquifer is tapped for use by many communities and farms in that area. The dissolved-solids content increases toward the west and south. Exceptions to this trend are found along narrow bands in parts of the Des Moines valley. The best quality water from that aquifer is found in areas 7 and 8 (fig. 56 and table 12). The characteristics of the water in those two areas are very similar; the major difference is an increase in sodium and a decrease in hardness in area 8. Water from area 9 is of fair quality and can be used for most purposes.

Gypsum and anhydrite have been identified in some wells in area 17 and are responsible for the high concentrations of sulfate and dissolved solids in this area and over much of the western portion of southeast Iowa. Fluoride in concentrations over 2.0 mg/l have been found in waters from areas 13, 16, and 17.

Concentrations of iron in both parts of the Mississippian aquifer exceed 0.3 mg/l in a little more than 75 percent of the samples analyzed. The maximum iron content was 28 mg/l. Manganese occurred in concentrations in excess of 0.05 mg/l in about one-half of the samples, and the maximum concentration was 1.3 mg/l from this aquifer.

The mean temperature of the water from both parts of the Mississippian aquifer is 55°F (13°C), and the range found in 124 water samples was from 51°F to 60°F (10.5°C to 15.5°C).

A comparison of the water-quality maps from both parts of the Mississippian aquifer show the relationship that was discussed on the preceding page. In areas where both parts of this aquifer are present, wells drilled only into the upper portion will yield a better quality of water than will those wells which pass through the Warsaw Formation and draw water from the lower portion. Also, wells which tap both parts seldom produce appreciably more water than those drilled only into the upper zone (see figs. 46 and 47).

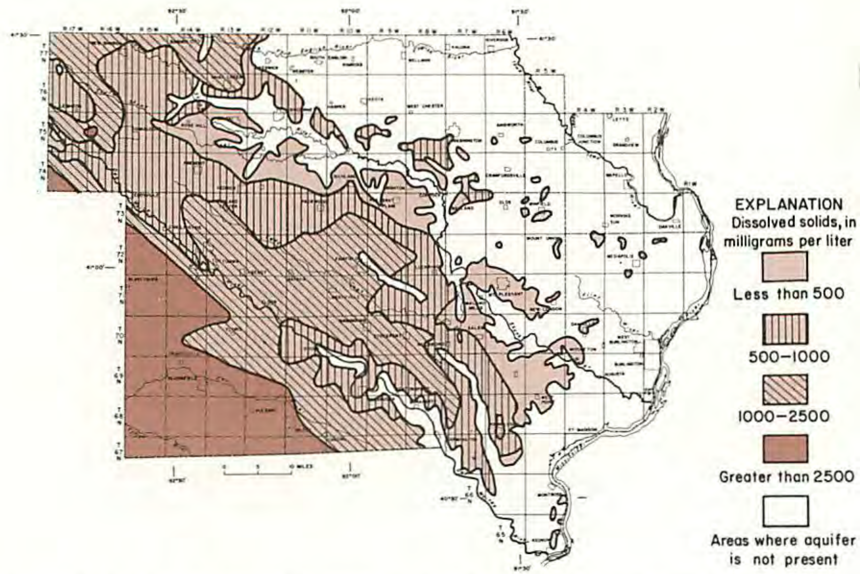


Figure 53.—Dissolved solids content of water in the upper part of the Mississippian aquifer

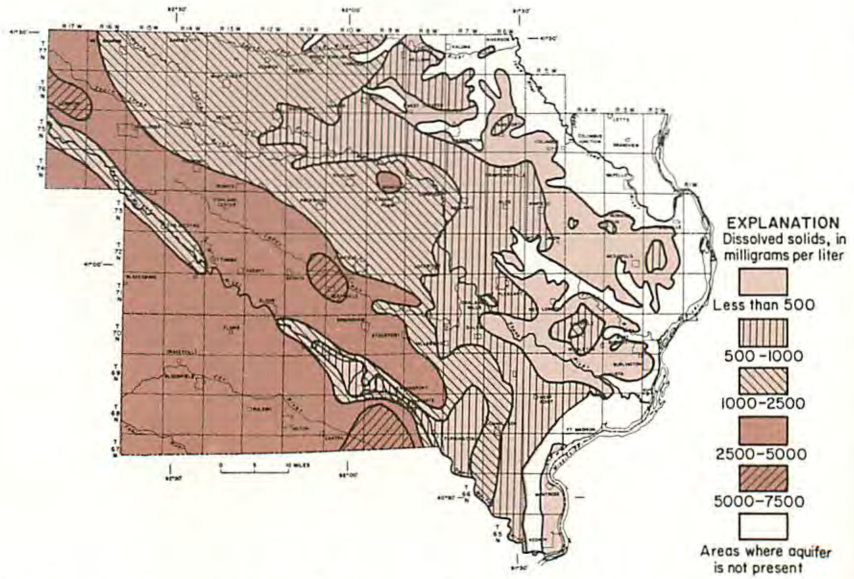
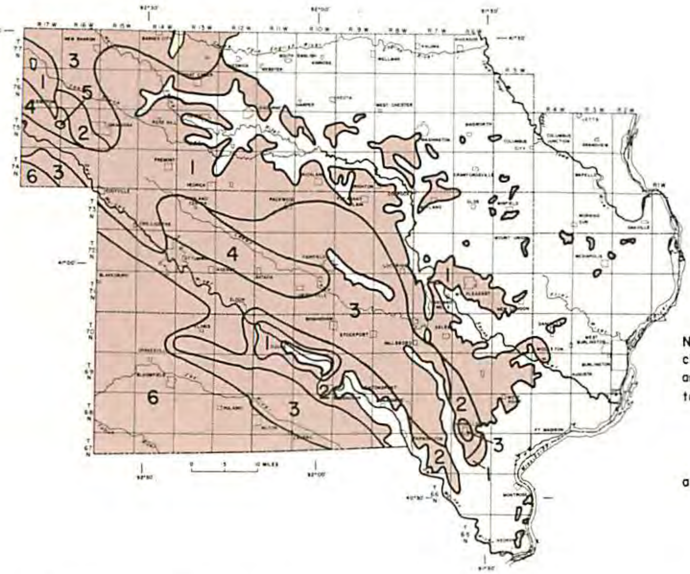


Figure 55.—Dissolved solids content of water in the lower part of the Mississippian aquifer



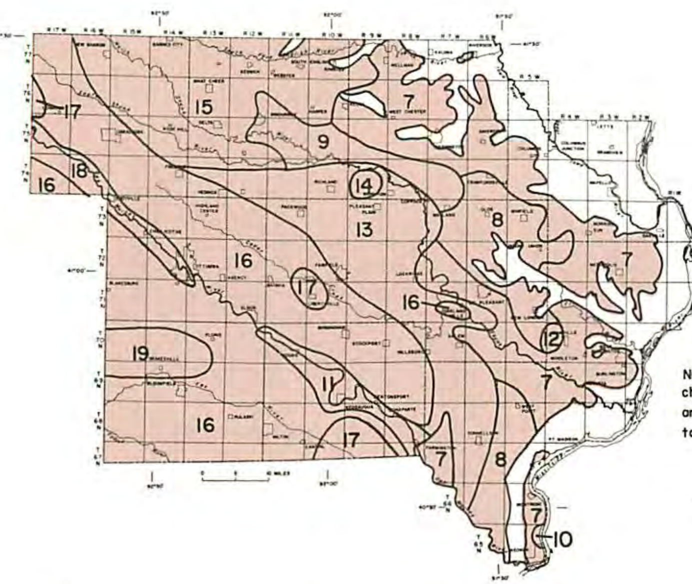
EXPLANATION

4

Number of area whose chemical characteristics are show on the adjoining table.

Areas where the aquifer is not present

Figure 54.—Water-quality areas of the upper part of the Mississippian aquifer



EXPLANATION

7

Number of area whose chemical characteristics are shown on the adjoining table.

Areas where the aquifer is not present

Figure 56.—Water-quality areas of the lower part of the Mississippian aquifer

Table 12.—Chemical characteristics of water in the Mississippian aquifer

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

Area	Average and Range	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids	Hardness (as $CaCO_3$)	Number of Analyses
					Upper Part of the Mississippian Aquifer						
1	A	104	32	43	472	91	4.5	0.4	537	399	32
	R	66-156	19-50	8.8-118	322-802	5.8-240	0.5-24	0-1.8	345-737	315-545	
2	A	155	46	84	423	397	9.9	.6	955	578	5
	R	104-210	21-61	8-177	349-498	321-480	.5-35	0-1.8	793-1050	385-660	
3	A	299	92	125	281	1100	8.5	.8	1950	1130	10[1/]
	R	197-547	47-124	33-214	44-434	750-1590	2-22	.3-1.6	1420-2740	723-1560	
4	A	61	31	404	608	587	22	2.1	1400	281	3
	R	54-69	25-37	275-513	471-736	400-710	20-25	.9-3.5	1060-1490	240-324	
5	A	600	255	344	984	2350	5.0	.1	4450	2550	2
	R	580-620	170-340	295-393	927-1040	1900-2800	1-9		3640-5260	2150-2950	
6	A	327	76	679	284	2160	68	1.4	3620	1130	7
	R	154-490	54-99	474-1080	212-350	1500-2850	27-186	1.2-2.4	2710-4880	605-1520	
					Lower Part of the Mississippian Aquifer						
7	A	90	37	42	504	46	6	0.4	490	380	50
	R	30-160	10-61	9-107	298-710	1-186	0-69	0-1.2	280-800	160-575	
8	A	42	20	117	453	57	14	.9	477	190	8
	R	22-70	12-35	55-195	344-551	1-160	.5-57	0.5-1.5	281-677	102-317	
9	A	122	43	61	344	309	6	.6	794	482	2
	R	92-152	40-46	48-74	336-351	258-360	4.5-7	.4-.7	728-860	394-570	
10	A	194	113	48	462	586	28	.2	1340	946	2
	R	189-198	102-124	33-64	407-517	568-604	20-37		1250-1420	892-1000	
11	A	152	44	79	432	322	45	.4	964	565	5
	R	132-174	28-98	17-162	334-608	84-658	13-93	.2-.7	566-1610	466-840	
12	A	140	68	318	440	850	55	.8	1730	630	1
13	A	78	38	276	592	354	57	1.6	1110	355	10
	R	38-128	19-68	143-489	465-754	260-560	.5-150	.5-2.5	879-1480	176-581	
14	A	102	43	964	408	1020	825		3150	430	3
	R	92-112	38-47	650-1520	378-442	550-1850	600-1180		2140-4800	405-473	
15	A	236	86	148	346	910	21	.8	1740	959	8[2/]
	R	180-317	32-136	61-232	182-479	600-1200	2.5-54	.4-1	1260-2150	729-1300	
16	A	102	52	718	459	1340	169	2.6	2710	469	15[2/]
	R	35-193	15-107	451-994	266-595	920-1660	19-365	.5-6	2220-3250	148-891	
17	A	215	82	1375	956	2520	610	1.8	5260	875	6[2/]
	R	102-452	58-120	1040-1630	378-3640	1800-4020	290-930	1.4-3	4070-7330	497-1620	
18	A	354	36	38	371	295	86		1500	1040	2[1/]
	R	299-410	24-48	28-47	322-420	8-582	9-162		1190-1800	849-1230	
19	A	486	71	203	205	1750	17	0.0	3030	1510	1

1. Includes two analyses just outside the southeast Iowa area.
2. Includes one analysis just outside the southeast Iowa area.

Highly mineralized water occurs in most of the Devonian aquifer

Water of good quality can be obtained from the Devonian aquifer in only a small part of southeast Iowa. Area 1 near the Mississippi River valley in eastern Louisa County is the only place where this aquifer will yield water containing less than 500 mg/l of dissolved solids. The concentration of most constituents increase toward the west and south. The evaporite minerals, gypsum and anhydrite, occur in the Devonian aquifer throughout most of the southeast Iowa area and are responsible for the highly mineralized water. These minerals occur in commercial quantities in some places and are presently being mined near Mediapolis in northern Des Moines County.

Data on the chemical quality of the Devonian water are lacking in the western and southwestern one-half of southeast Iowa. However, it is assumed that the water will be highly mineralized in this region and will be unsuitable for most uses.

The principal constituent in water from the Devonian aquifer outside of area 1 is sulfate. The sulfate content increases toward the west, and is found in excess of 2,500 mg/l over more than one-half of the area where data are available. Sodium becomes the predominant cation toward the west, but calcium and magnesium also increase. Concentrations of fluoride of 2.0 mg/l or more have been found in areas 3, 5, 6, and 7, and are assumed to occur in area 4.

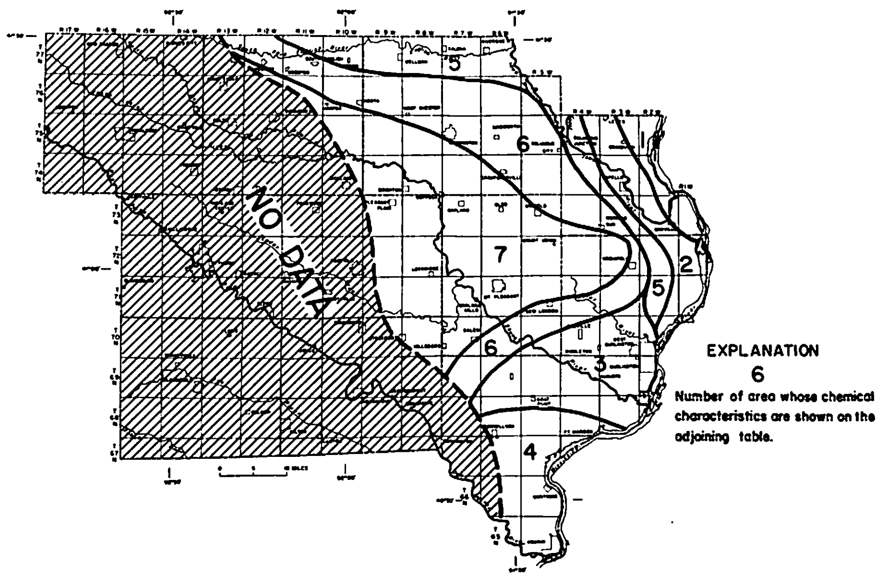


Figure 57.—Water-quality areas of the Devonian aquifer

Table 13.—Chemical characteristics of water in the Devonian aquifer

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

Area	Average and Range	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids	Hardness (as $CaCO_3$)	Number of Analyses
1	A	53	26	83	411	66	10	0.6	433	238	3
	R	32-69	12-35	31-146	281-498	10-180	1-23	0.2-1	368-514	132-316	
2	A	73	36	618	402	910	265	1.6	2120	332	2
	R	68-78	32-41	616-620	379-426	890-930	200-330	1.3-1.9	2070-2170	300-364	
3	A	333	111	485	282	1770	218	2.1	3310	1290	3
	R	246-378	79-145	412-539	244-305	1470-2070	205-235	1.0-3.0	2900-3800	942-1540	
4	A	187	82	813	301	1490	690		3860	810	1
5	A	316	88	993	322	2540	230	1.8	4640	1150	2
	R	201-431	83-94	855-1130	281-364	2480-2600	180-280	1.6-2.0	4450-4840	842-1460	
6	A	359	116	1500	342	3450	516	2.4	6340	1380	7
	R	180-532	75-157	1330-1630	303-388	2200-4000	400-810	1.7-4.2	5050-6900	760-1870	
7	A	492	138	2220	289	4580	1100	2.8	9570	1800	6
	R	441-617	97-155	1850-2700	183-378	4030-5000	550-1740	1.9-5.0	8240-11,100	1580-2180	

The increase in mineral content of the water toward the west can be seen readily on the map of the dissolved-solids content (fig. 58). The area with less than 500 mg/l of dissolved solids is a narrow band in eastern Louisa County. Over a distance of 8 miles or less, the concentrations increase from less than 500 mg/l to more than 2,500 mg/l. Highest known concentrations are found in Jefferson and Washington Counties where they are in excess of 10,000 mg/l. Although data are lacking in the southwestern part of the area, dissolved-solids contents in excess of 10,000 mg/l probably occur in much of this area.

The maximum iron content in water samples from the Devonian aquifer was found to be 18 mg/l, and the recommended limit of 0.3 mg/l was exceeded in slightly more than 75 percent of the samples. Manganese was in excess of 0.05 mg/l in nearly 50 percent of the samples, and the maximum concentration of manganese found was 0.33 mg/l.

The temperature of the water from the Devonian aquifer is higher than that from the surficial or Mississippian aquifers. Water temperatures ranging from 54°F to 64°F (12.0°C to 18.0°C) have been encountered. The mean temperature from 13 water samples was found to be 60°F (15.5°C).

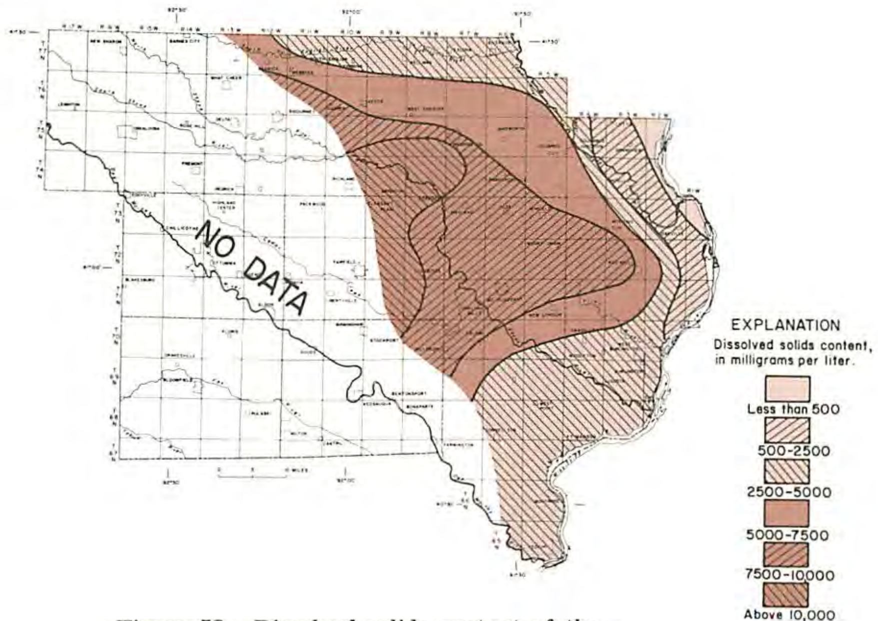


Figure 58.—Dissolved solids content of the water from the Devonian aquifer

The Cambrian-Ordovician aquifer offers water of fair quality

The Cambrian-Ordovician aquifer will yield water of fair quality over most of southeast Iowa. The dissolved-solids content is greater than 500 mg/l throughout the region, ranging from 876 to 1,650 mg/l. However, the water is not as highly mineralized as that from parts of the Mississippian and Devonian aquifers. This absence of highly mineralized water along with the large yields available from the Cambrian-Ordovician aquifer make it a valuable asset over extensive areas of southeastern Iowa where no other suitable water sources are available.

The hardness of the water ranges from about 300 mg/l to slightly more than 500 mg/l. The chloride content progressively increases more than 18 fold from a low of 24 mg/l in area 1 to 440 mg/l in area 6. Concentrations of fluoride in excess of 2.0 mg/l have been found in some samples from area 4 and in all samples from areas 5 and 6, and in those areas the water is likely to be objectionable for public supplies.

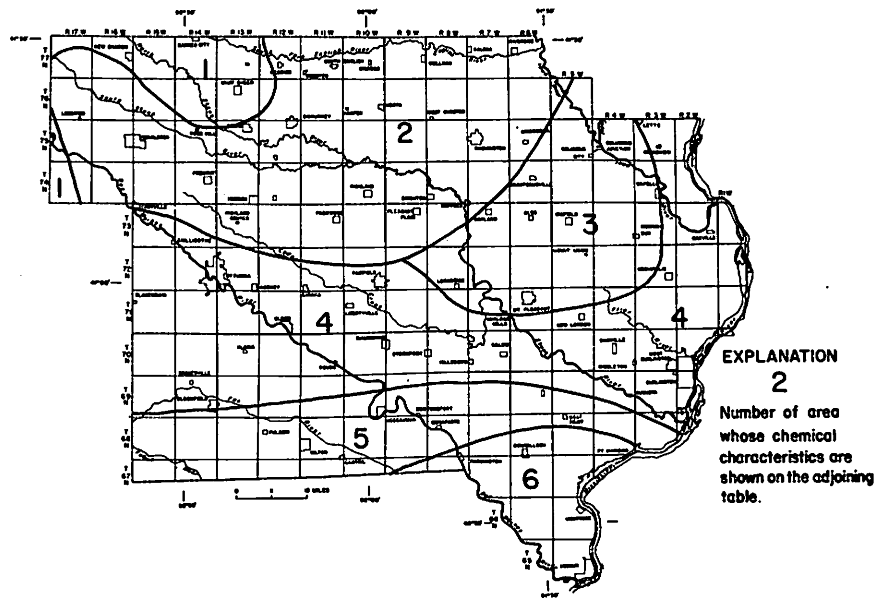


Figure 59.—Water-quality areas of the Cambrian-Ordovician aquifer

Table 14.—Chemical characteristics of water in the Cambrian-Ordovician aquifer

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

Area	Average and Range	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids	Hardness (as $CaCO_3$)	Number of Analyses
1	A	95	49	158	352	402	28	1.2	932	422	4[1]
	R	80-104	39-51	142-176	339-368	363-450	24-33	1.0-1.5	876-980	360-465	
2	A	106	50	202	304	552	52	1.2	1180	470	7[1]
	R	98-116	46-54	192-211	283-337	520-600	38-60	1.0-1.5	1120-1240	452-510	
3	A	93	42	232	295	520	79	1.4	1130	406	4
	R	86-105	37-47	223-249	288-305	489-543	69-85	1.2-1.6	1110-1150	372-455	
4	A	84	34	267	298	476	124	1.7	1160	349	8
	R	78-92	26-41	247-283	283-317	455-500	100-148	1.0-2.2	1100-1220	322-388	
5	A	71	30	322	304	394	216	2.4	1210	300	4[2]
	R	65-76	25-32	310-331	273-326	338-420	209-222	2.0-2.9	1080-1310	290-321	
6	A	97	39	430	300	440	440	3.2	1650	403	1
	R										

1. Includes three analyses outside the southeast Iowa area.
2. Includes one analysis outside the southeast Iowa area.

The dissolved-solids content increases from the northwest to the southeast. See figure 60. The increase is not uniform with the distance, however, in the large 1,000 to 1,500 mg/l area most of the water contains between 1,080 and 1,240 mg/l of dissolved solids (areas 2, 3, and 4). The dissolved-solids content increases rapidly in area 5 and 6 to a maximum known concentration of 1,650 mg/l.

A little more than 75 percent of the water samples from the Cambrian-Ordovician aquifer had an iron content of more than 0.3 mg/l. The highest concentration was 4.8 mg/l. The highest concentration of manganese in samples from this aquifer was 0.30 mg/l, and nearly one-half of the samples contained more than 0.05 mg/l of manganese.

The temperature of the water from the Cambrian-Ordovician aquifer is higher than in the other aquifers. Water temperatures range from 68°F to 76°F (20.0°C to 24.5°C), and the mean of 19 samples is 72°F (22.0°C).

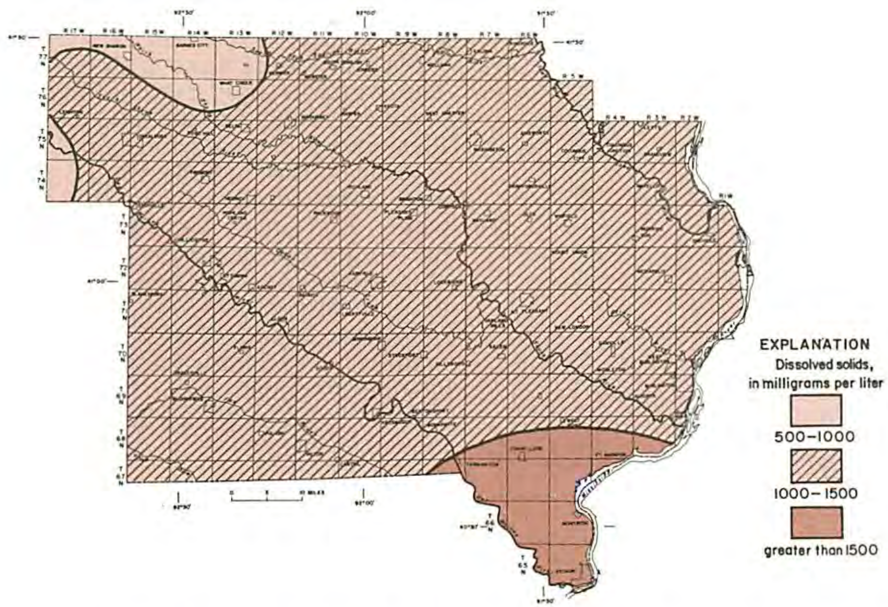


Figure 60.—Dissolved-solids content of water in the Cambrian-Ordovician aquifer

WATER USE

The major categories of water use in southeast Iowa are (1) urban domestic, (2) industrial and commercial, (3) rural, and (4) the water used in the generation of fuel-electric power. Minor uses include irrigation, water used in quarrying, and sand and gravel operations.

Urban domestic uses, in this report, include all water withdrawn for public supplies excluding only that water purchased by industrial and commercial concerns that used large amounts of water. Therefore, the water attributed to urban domestic use encompasses not only water used for drinking and sanitary purposes in homes and for lawn and garden watering, but also transmission losses from water-distribution systems and water used for fire fighting, street cleaning, and municipal swimming pools. Water used in small offices and stores is also considered domestic.

Industrial and commercial uses include the water purchased from public-supply systems, and the water withdrawn from company-owned wells and river-intake systems. Industrial and commercial uses are varied. The water is used for making steam, condensing steam, cooling various products, refrigeration and air conditioning, washing products and facilities, and processing food products.

Rural uses include the domestic uses of drinking and sanitation and also water for livestock. 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 50 gallons a day. Livestock use was also determined by applying an average per capita consumption for each animal. Animal population figures were taken from the 1964 agriculture census.

Water withdrawn for the generation of fuel-electric power is used mainly for cooling steam condensers. The amount used to produce steam is small in comparison. This category includes only public utilities. Water used for power generation by private firms for their own use is listed as industrial use.

The term "water use" can have several meanings. Water can be used in the sense that it is utilized in the navigation of the Mississippi River. The water is passed through locks and is used to either raise or lower tow boats and barges. A similar type of use is at the hydroelectric plant at Keokuk. The water passes from the lake formed by the dam, drops about 34 feet, turns turbines, reaches the lower level, and flows on downstream. This 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 may be less 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. Water is evaporated in many ways, as described before. 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 is described and tabulated in three ways on the following pages. First are water withdrawals. This refers to water taken from where it occurs as a natural resource. In some industrial plants, water is used several times; it is recirculated one or more times through the company's water system until it is discarded or evaporated. This water is counted as a withdrawal only once. Tabulations of water withdrawals have been made for each drainage basin and each county according to the type of water use and the source of the water supply.

The second tabulation is termed resource depletion. This refers to the amount of water returned to the atmosphere by evaporation and transpiration and is tabulated for each type of use in each drainage basin. Once water is lost in this way, it can no longer be managed by man.

The third is called source depletion. This is a calculation of the net amount of water either lost or gained by each of the sources of water —surface waters and individual aquifers.

WATER WITHDRAWALS

More than 246 million gallons of water were withdrawn each day for various uses during 1967-68 in southeastern Iowa. These withdrawals are categorized by use in tables 15 and 16 and in figure 61. Nearly one-half of the total was withdrawn for use in producing fuel-electric power. Industrial and commercial uses accounted for more than 35 percent of the withdrawals, while urban-domestic and rural uses amounted to about 7 percent each. Water used for livestock was estimated to be nearly 75 percent of rural withdrawals.

Most of the water withdrawals occur in the Mississippi River valley where fuel-electric, industrial, and urban-domestic uses exceed those in all other parts of southeast Iowa. Even without considering the water used for fuel-electric power generation, withdrawals in the Mississippi River valley would be at least four times that in any other area. Rural uses are highest in the Skunk River basin. Water withdrawals in Des Moines and Lee Counties, which are bordered by the Mississippi River, far surpass those in any of the other counties.

Table 15.—Water withdrawals in drainage basins

Drainage Basin	Population of Basin 1960	Water withdrawn, in mgd, for type of use indicated								
		Urban Domestic	Industrial-Commercial		Rural Domestic	Electric Power	Livestock	Irrigation	Quarry	Total
			Purchased	Self-Supplied						
Mississippi River Valley and Minor Tributary Basins	82,028	7.98	2.83	75.74	0.61	117.51	1.37	0.09	0.13	206.26
Iowa River	19,720	.62	.03	.50	.59	0	1.85	.02	.43	4.04
Skunk River	84,590	4.32	.52	2.13	1.86	0	5.76	.01	.26	14.86
Des Moines River	61,742	3.79	1.05	5.78	1.01	.91	2.38	.17	4.65	19.74
Fox-Wyaconda Rivers	7,335	.27	0	0	.21	0	.51	0	0	.99
Fabius River	1,241	0	0	0	.06	0	.19	0	0	.25
Chariton River	54	0	0	0	*	0	.01	0	0	.01
TOTAL	256,710	16.98	4.43	84.15	4.34	118.42	12.07	0.29	5.47	246.15

*Less than 5,000 gallons per day.

Table 16.—Water withdrawals in counties

County	Population 1960	Water withdrawn, in mgd, for type of use indicated								
		Urban Domestic	Industrial-Commercial		Electric Power	Rural Domestic	Livestock	Irrigation	Quarry	Total
			Purchased	Self-Supplied						
Davis	9,199	0.25	0	0	0	0.32	0.95	0	0	1.52
Des Moines	44,605	4.82	1.57	2.18	117.51	.34	.84	.01	.13	127.40
Henry	18,187	1.03	.03	.11	0	.36	1.06	.01	0	2.60
Jefferson	15,818	1.28	.27	0	0	.35	.88	*	*	2.78
Keokuk	15,492	.56	0	.01	0	.42	1.53	0	.31	2.83
Lee	44,207	3.25	1.26	75.37	0	.53	1.04	.17	0	81.62
Louisa	10,290	.24	.03	.46	0	.32	.76	.09	.18	2.08
Mahaska	23,602	.89	.16	0	0	.50	1.82	0	3.81	7.18
Van Buren	9,778	.27	*	0	0	.31	.74	.01	0	1.33
Wapello	46,126	3.49	1.05	5.78	.91	.45	.71	0	.86	13.25
Washington	19,406	.90	.06	.24	0	.44	1.74	0	.18	3.56
TOTAL	256,710	16.98	4.43	84.15	118.42	4.34	12.07	0.29	5.47	246.15

* Less than 5,000 gallons per day.

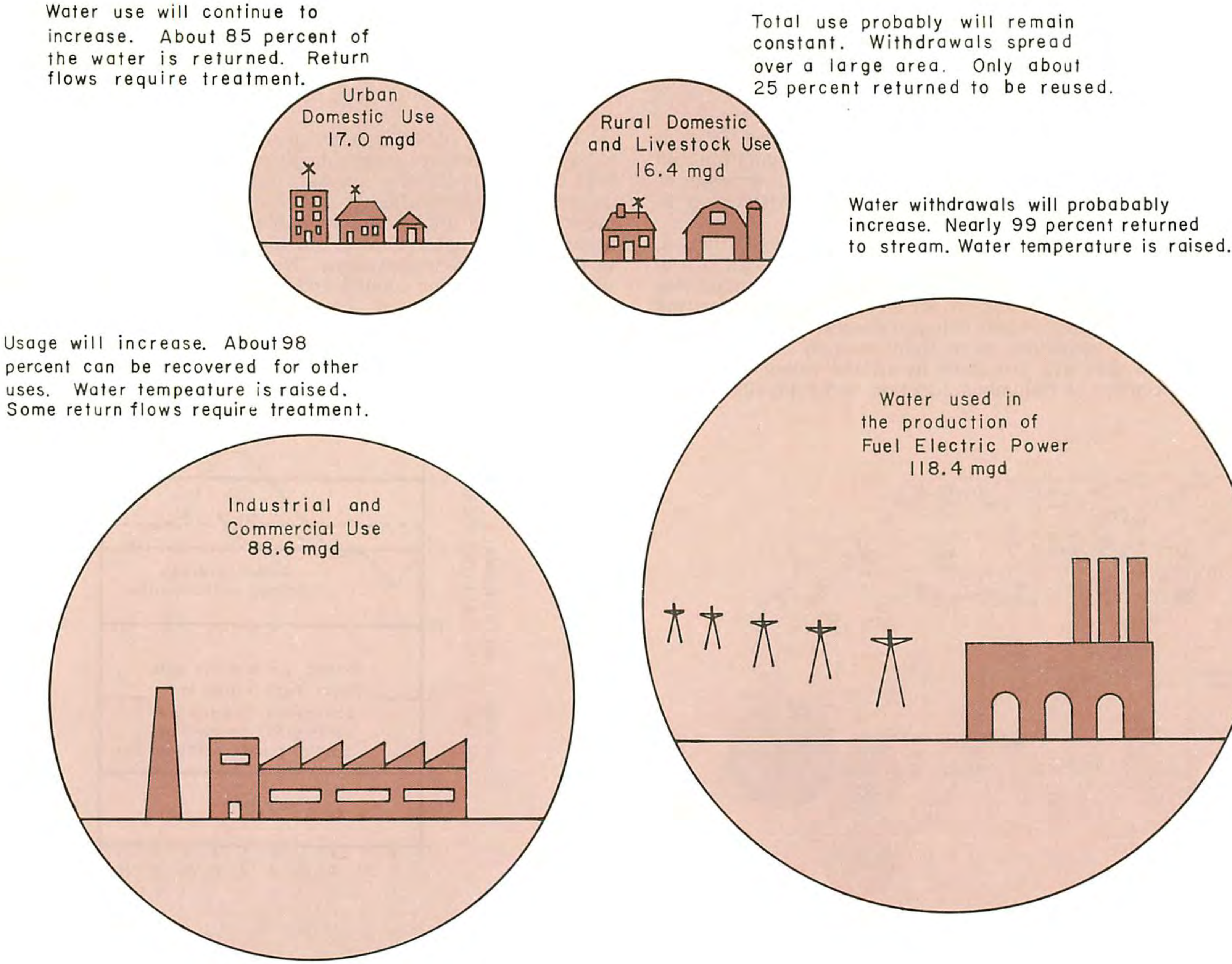


Figure 61.—Average daily water withdrawals by type of use

WATER WITHDRAWALS IN URBAN AREA

The major part of the water withdrawals in southeast Iowa is concentrated in or very near towns and cities. These population and industrial centers account for more than 91 percent—an average of more than 224 mgd—of the total amount of water withdrawn in 1967-68.

Total withdrawals for the four largest cities, Burlington, Ottumwa, Keokuk, and Fort Madison, was 216 mgd. More than one-half of the water withdrawals are in the Burlington area. The predominant use near that city is condenser cooling in an electric-power-generating plant. Industrial uses greatly exceed urban domestic uses at Keokuk and Fort Madison and constitute more than one-half of the use at Ottumwa. Domestic uses are prevalent in all the other cities and towns with the exception of Columbus Junction and Eddyville.

The amount of water withdrawn for distribution through municipal systems varies considerably throughout the year. Data from several cities indicate the average daily use during the hot summer months is 30 percent higher than during the cooler months. The data presented here apply only to public supplies. Accurate data about other uses are not available, but the pattern is probably very similar to that for municipal systems. Nearly all industrial and commercial withdrawals are for cooling and air conditioning and the volumes of water required vary with the weather.

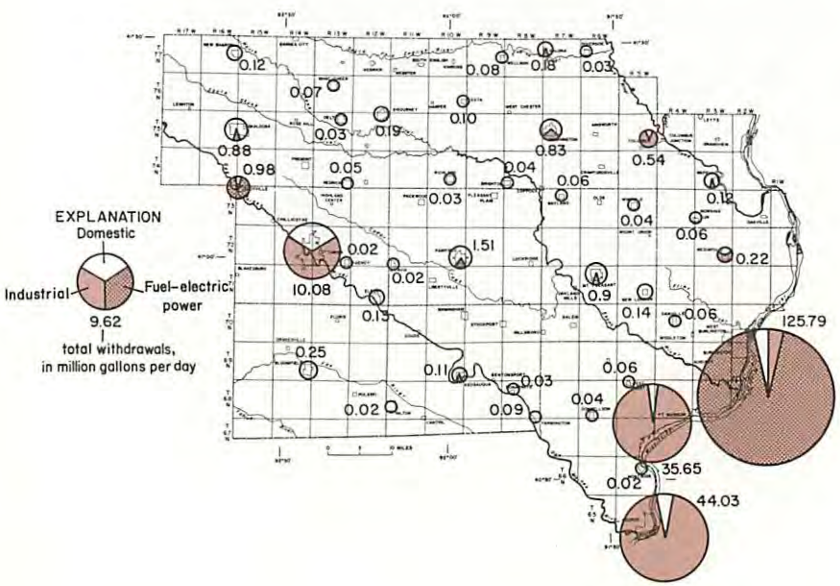


Figure 62.—Average daily water withdrawals and type of use in urban areas—1966-67

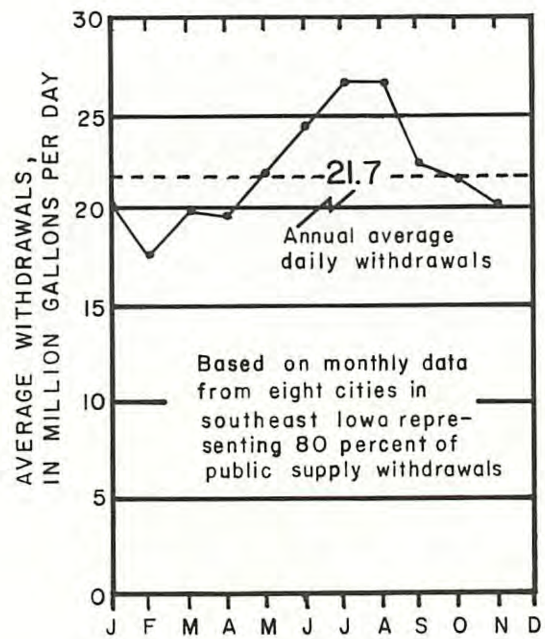


Figure 63.—Monthly variation in public supply water withdrawals

WATER USE BY IRRIGATORS AND THE MINERAL INDUSTRY

Sprinkler irrigation, which is practiced in southeast Iowa, is a highly consumptive use of water; nearly all water is evaporated or transpired by plants. In 1967 permits allowing the use of 936.7 million gallons annually for irrigation in southeast Iowa were on file with the Iowa Natural Resources Council. An average annual amount reportedly used by these permit holders through 1960-67 was only 104.3 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 irrigators 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 their 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 on figure 62, and it probably accounts for a large share of the increased summer use shown on figure 63.

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 quarry 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 1967 the total number of permits on file with the water commissioner allowed the use of about 12.5 billion gallons per year by the mineral industry. Of this total, one-sixth, or an average of 5.5 mgd, was actually reported as being used during 1960-67.

SOURCES OF WITHDRAWALS

The amount of water withdrawn from each source in southeastern Iowa has been tabulated for 1967-68 in tables 17 and 18 and figure 64. Surface-water sources supplied nearly 86 percent of the 240.68 mgd average withdrawals, and ground water was the source for slightly more than 14 percent. In the Mississippi River valley surface water is the major source accounting for 86 percent of the withdrawals. Ground water is the source of 74 percent of the withdrawals in all the other parts of southeast Iowa.

Withdrawals for municipal use and fuel-electric power generation at Burlington in Des Moines County, municipal and industrial use at Keokuk, and industrial use at Fort Madison, both in Lee County, accounted for nearly all the withdrawals from the Mississippi River. The Des Moines River is the source of Ottumwa's (Wapello County) municipal supply. Impoundments on small streams in the Skunk basin supply part of Fairfield's (Jefferson County) municipal needs, and one industry's requirements in Des Moines County. An impoundment in the Fox basin constitutes the source for the municipal system at Bloomfield (Davis County).

Approximately equal amounts of ground water are withdrawn from drift and buried-channel aquifers, alluvial aquifers, shallow bedrock aquifers and the Cambrian-Ordovician aquifer in southeast Iowa. The drift and buried-channel aquifers are the source for many rural supplies. Withdrawals from the alluvial aquifers for municipal and industrial uses are substantial at Fort Madison in the Mississippi River valley (Lee County), and smaller amounts are withdrawn for municipal supplies at Oskaloosa (Mahaska County) and Sigourney (Keokuk County) in the Skunk River basin. Wells drilled into the shallow bedrock aquifers—mainly the Mississippian aquifer—supply water to several small communities and to many farms. The largest withdrawal from the Cambrian-Ordovician aquifer is for industrial use at Ottumwa (Wapello County) in the Des Moines River basin, while smaller amounts supply the cities of Washington and Mount Pleasant (Washington and Henry Counties, respectively) in the Skunk River basin.

Table 17.—Water withdrawals from various sources in drainage basins

Drainage Basin	Population of Basin 1960	Water withdrawn, in mgd, from sources indicated+						
		Surface Water		Ground Water				
		Farm Ponds	Streams	Alluvium	Glacial Drift and Buried Channels	Shallow Bedrock	Cambrian-Ordovician	Total
Mississippi River Valley and Minor Tributary Basins	82,028	0	197.69	5.91	0.83	1.24	0.46	206.13
Iowa River	19,720	0	.01	.49	1.18	1.32	.61	3.61
Skunk River	84,590	.12	2.75	1.24	4.01	4.01	2.47	14.60
Des Moines River	61,742	.48	5.22	.37	1.71	1.27	6.04	15.09
Fox-Wyaconda Rivers	7,335	.17	.25	.01	.37	.19	0	.99
Fabius River	1,241	.06	0	0	.13	.06	0	.25
Chariton River	54	*	0	0	.01	*	0	.01
TOTAL	256,710	0.83	205.92	8.02	8.24	8.09	9.58	240.68

+ Water withdrawn for quarry use not included.
* Less than 5,000 gallons per day.

Table 18.—Water withdrawals from various sources in counties

County	Population 1960	Water withdrawn, in mgd, from sources indicated+						
		Surface Water		Ground Water				
		Farm Ponds	Streams	Alluvium	Glacial Drift and Buried Channels	Shallow Bedrock	Cambrian-Ordovician	Total
Davis	9,199	0.31	0.25	0.03	0.61	0.32	0	1.52
Des Moines	44,605	0	125.39	.12	.47	.87	.42	127.27
Henry	18,187	0	.01	.01	.71	.83	1.04	2.60
Jefferson	15,818	0	.92	.01	.96	.62	.27	2.78
Keokuk	15,492	0	0	.20	.96	1.10	.26	2.52
Lee	44,207	0	74.04	6.02	.67	.79	.10	81.62
Louisa	10,290	0	.08	.30	.48	.52	.52	1.90
Mahaska	23,602	0	0	.99	1.07	1.31	0	3.37
Van Buren	9,778	.25	.01	.01	.65	.30	.11	1.33
Wapello	46,126	.27	5.22	.13	.56	.30	5.91	12.39
Washington	19,406	0	0	.20	1.10	1.13	.95	3.38
TOTAL	256,710	0.83	205.92	8.02	8.24	8.09	9.58	240.68

+ Water withdrawn for quarry use not included.

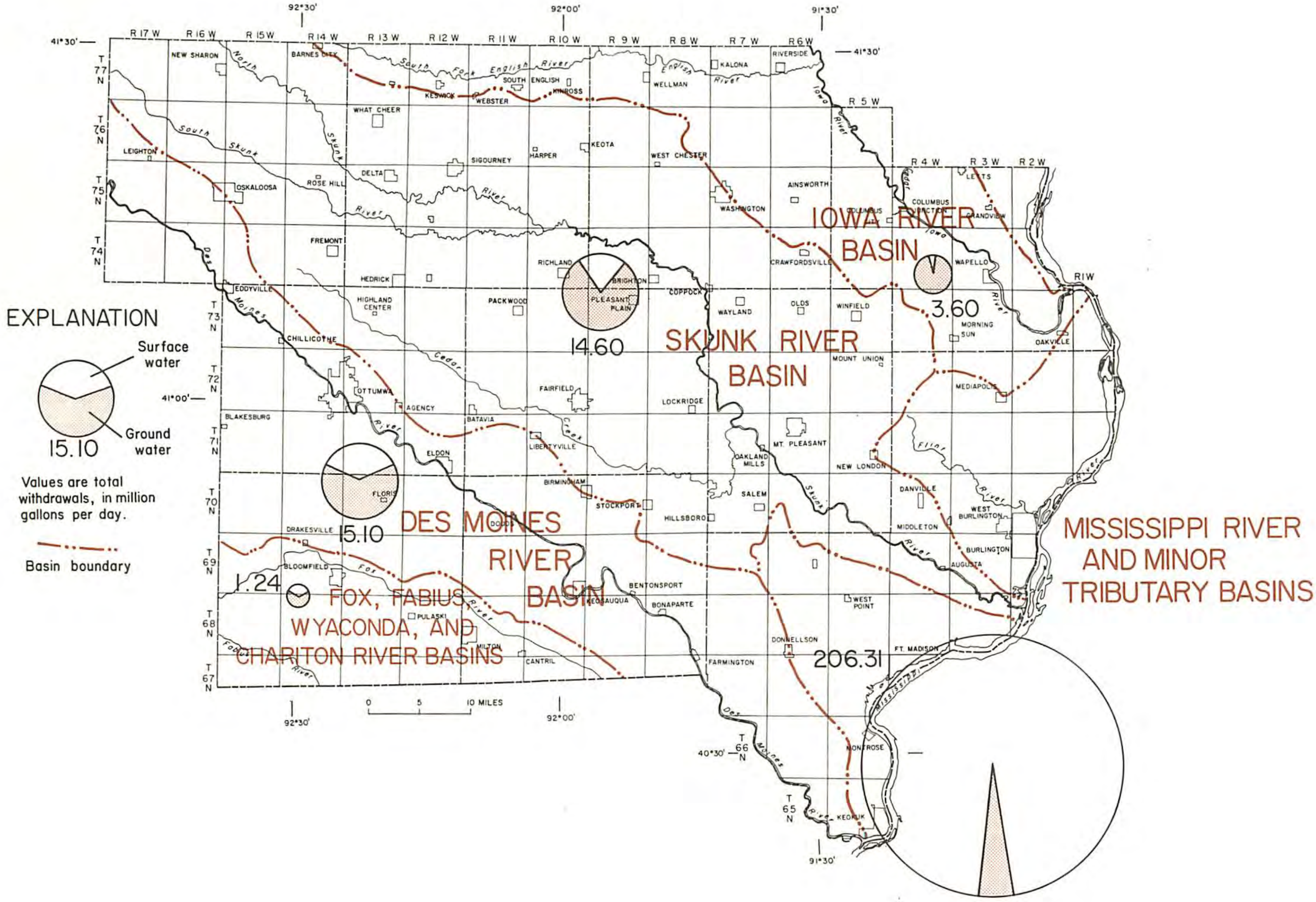


Figure 64.—Sources of water withdrawn from southeast Iowa drainage basins

RESOURCE DEPLETION

One of two things happens to water after it has been used for any particular purpose. Part of the water is returned to the environment in the liquid state and the rest is returned as water vapor. Liquid water is discharged either to a stream or onto or beneath the land surface. Most municipal systems and self-supplied industrial operations return their discarded water to streams. Most private domestic systems, rural domestic in particular, discharge water by way of septic tanks below the ground at shallow depths or discharge it on the land surface. Livestock water is discharged on the land surface, and excess irrigation water usually reaches the saturated zone below the water table.

The rest of the water is consumed, that is, lost to the atmosphere as vapor through evapotranspiration. This constitutes a depletion of the resource. This water cannot be managed or reused in this area again. The amount of water consumed varies with the type of water use. The percentage of loss by each use is given in the table below (table 19). These are estimates of consumptive use taken from data from over the United States. Specific data from southeast Iowa indicate some of these figures to be considerably high for some water users and extremely low for others using water for the same purpose. However, where data were available from several users, the average consumption was very close to those given in the table.

Rural domestic and livestock uses result in the highest rate of loss, mainly because water is discharged on or near the land surface where evaporation and transpiration effect high losses. Irrigation losses are high because of plant transpiration and evaporation from the soil. Consumption of 17 percent for public supplies seems high; but when evaporation losses from car washing, street cleaning, fire fighting, and near-surface leaks from water mains are considered along with evapotranspiration losses from lawn and garden irrigation, the 17 percent figure seems reasonable. Losses from industrial and fuel-electric power generation activities are low, the bulk of the evaporation being boiler steam losses and some from heated cooling water.

The highest depletion in southeastern Iowa occurs through rural uses which account for more than 65 percent of the total consumptive losses (table 20), even though they make up less than 7 percent of the water withdrawals. Consumptive losses from public supplies are about 19 percent of the total losses for southeast Iowa, even though the withdrawals are less than 9 percent. Self-supplied industrial uses make up more than one-third of the total withdrawals, yet they are responsible for less than 9 percent of the water depletion. Fuel-electric power generation withdrawals are overwhelmingly the largest, being more than 48 percent of the total for all of southeast Iowa; but this activity accounts for only slightly more than 6 percent of the total water resource depletion. Depletion losses due to irrigation are less than 1 percent of the total losses.

The large amount of depletion through rural uses is of less concern than some of the other losses because of two factors. First is that this rural depletion is not concentrated in a few areas as are municipal and industrial users, but is spread fairly evenly over the entire southeast Iowa area. Secondly, rural supplies come mainly from shallow ground-water sources which often are recharged readily by precipitation. The effect of water withdrawals and consumption on the total water resources of the area becomes more evident on the next page where the source of the water is considered.

Table 19.—Percent of water consumed by type of use

Type of Withdrawal	Percent of Water Consumed
Public Supply	17
Industrial Self-Supplied	2
Rural Domestic and Stock	77
Electric Power	1
Irrigation	60

Data from MacKichan, K. A., and Kammerer, J. C., 1961.

Table 20.—Resource depletion in drainage basins

Drainage Basin	Population of Basin 1960	Water consumed, in mgd, by use indicated					
		Public Supply	Industrial Self-Supplied	Rural Domestic and Stock	Electric Power	Irrigation	Total
Mississippi River Valley and Minor Tributary Basins	82,028	1.84	1.51	1.52	1.18	0.05	6.10
Iowa River	19,720	.11	.01	1.88	0	.01	2.01
Skunk River	84,590	.82	.04	5.87	0	.01	6.74
Des Moines River	61,742	.83	.12	2.61	.01	.10	3.67
Fox-Wyaconda Rivers	7,335	.04	0	.55	0	0	.59
Fabius River	1,241	0	0	.19	0	0	.19
Charlton River	54	0	0	.01	0	0	.01
TOTAL	256,710	3.64	1.68	12.63	1.19	0.17	19.31

SOURCE DEPLETION

Waste water is not always returned to the same source from where it was withdrawn. An industry may withdraw water from a surface-water source and then return 98 percent of it to the stream. Here the source, the stream, is being depleted 2 percent of the total withdrawals. Another industry withdraws water from deep wells and then discharges 98 percent of the water into a stream. The source of this water, a deep aquifer, has been depleted 100 percent of the withdrawals, but the stream is gaining 98 percent of the withdrawals and yet was not tapped as a source for this particular withdrawal. Thus, man's activities are transfering water from one source to another. There is a net depletion, but some sources are being depleted at the rate of withdrawal while others are getting some water back or even showing a net gain.

The average water-resource depletion in southeast Iowa is 19.31 mgd (table 20). The depletion of ground-water sources is 30.07 mgd while surface-water sources gain 10.76 mgd (table 21). The Cambrian-Ordovician aquifer experiences the largest depletion because of extensive withdrawals and no water being returned to it. All streams in basins where municipalities and/or industries have developed significant ground-water supplies show a gain of water. Only small rivers in the southern part of southeast Iowa experience a net depletion of the surface-water source (table 21).

Table 21.—Source depletion in drainage basins

Drainage Basin	Water depleted, in mgd, from source indicated					
	Surface Water	Ground Water				Total
		Surficial Aquifers		Bedrock Aquifers		
	Streams and Ponds	Alluvium	Drift and Buried Channels	Shallow Bedrock	Cambrian-Ordovician	
Mississippi River Valley and Minor Tributary Basins	+ 1.85	5.84	0.42	1.24	0.45	6.10
Iowa River	+ 1.03	.49	.61	1.32	.62	2.01
Skunk River	+ 3.23	1.19	2.31	4.01	2.46	6.74
Des Moines River	+ 4.90	.30	.96	1.27	6.04	3.67
Fox-Wyaconda Rivers	.19	.01	.21	.18	0	.59
Fabius River	.06	0	.07	.06	0	.19
Chariton River	*	0	.01	*	0	.01
TOTALS		7.83	4.59	8.08	9.57	
	+10.76	30.07				19.31

+ Shows net increase.
* Less than 5,000 gallons per day.

FUTURE DEMANDS

The quantity of water used in southeast Iowa has increased in the past. The amount withdrawn for all purposes except fuel-electric power has increased by nearly 60 percent from 1940 through 1966-67. If this trend continues, water withdrawals will nearly double (from 122 mgd in 1966-67 to 225 mgd) by the year 2000 (fig. 65).

The following assumptions were made in estimating the future water use:

1. The amount withdrawn for rural domestic and for livestock use will remain the same. Most of the water used in rural areas is for livestock. It is assumed that the livestock population will not change significantly. The number of persons living in the rural areas is expected to decrease, but an increase in the number of modern home appliances and conveniences will raise the per capita use.
2. The amount of water distributed through municipal systems will increase. This is water used for domestic purposes and by industrial concerns and commercial establishments which purchase water. Records from municipal water systems, which serve more than 80 percent of the urban population in southeast Iowa, indicate an increase in pumpage of almost 50 percent in 20 years. Urban population has grown moderately, and the per capita water use has increased. If this trend continues, the amount will nearly double in the period from 1967-2000.
3. Industries which supply all or part of their own water needs will continue to increase their withdrawals. Rough estimates of the self-supplied industrial usage indicates a 50 percent increase every 20 years. This means that by 2000 A.D. these water users will more than double their 1966-67 water use.

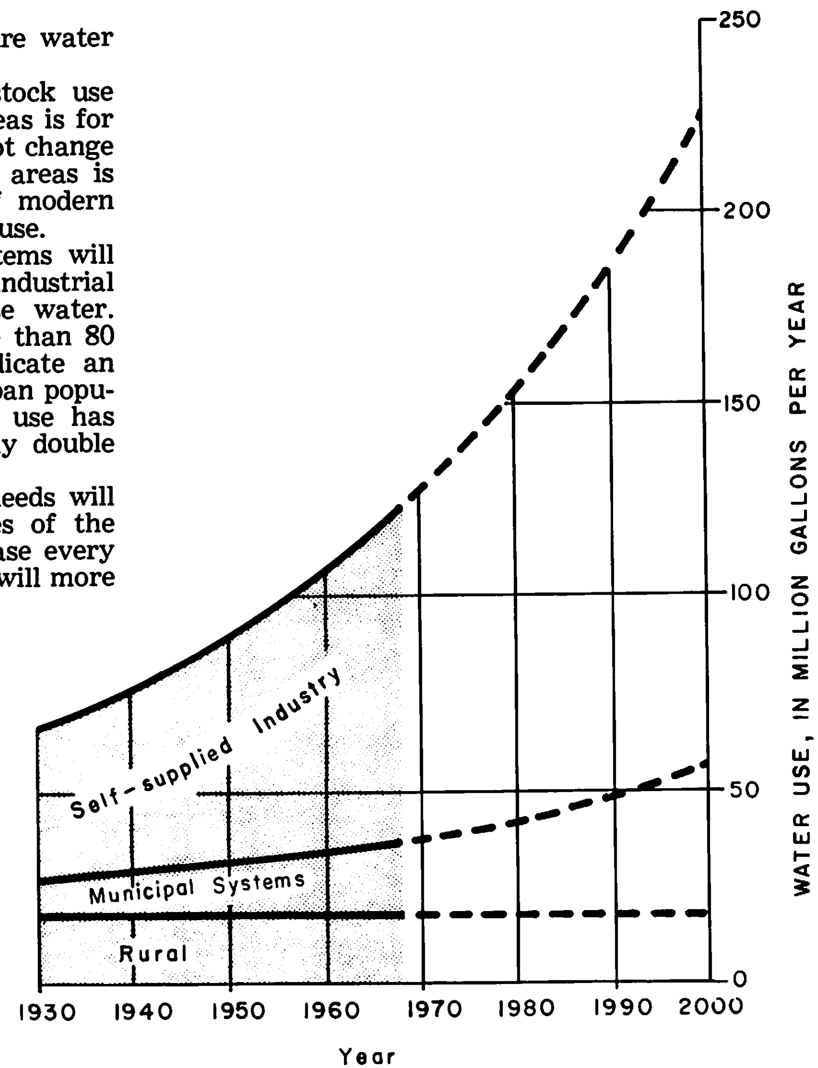


Figure 65.—Projected water use to the year 2000 A.D.

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 nonregulated uses as are any other beneficial use of water by any person which is less 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.

CONCLUSION

Plenty of water is available for the present and the future in southeast Iowa. Although the water resources are adequate for the needs of the total area, the distribution of adequate supplies is not commensurate with the demand in all places. All sites on or near major streams have an accessible source of water that could be developed and would be adequate to supply much more water than is now needed. The alluvial aquifers along these major streams, particularly the Mississippi River, are also capable of producing much more water than is presently demanded of them. Shallow bedrock aquifers in the northeastern part of the area can supply the requirements of farms, small communities, and small industries. The deep-lying Cambrian-Ordovician aquifer yields moderate to large supplies of good to fair quality water throughout most of southeast Iowa. In order to have water in large quantities and of the desired quality for most needs and for future economic growth, water may have to be imported into some areas. These places are generally in the southwestern one-half of the southeast Iowa area, and more specifically in nearly all of the region south of the Des Moines River. It is technically feasible to pipe water into the water-short areas, but this involves economic considerations.

Availability from Streams

Streams in southeast Iowa can furnish enough water to supply demands for all expected withdrawals; however, flows needed for waste dilution and transport will be required over and above the withdrawal quantities taken for off-channel uses. The lowest flows ever recorded on the Mississippi and Iowa Rivers (5,000 cfs and 300 cfs, respectively) are sufficient for all expected withdrawals in these areas for many years. The 5,000 cfs of the Mississippi at Keokuk is more than 10 times the amount of water that will be required for all withdrawals in all of southeast Iowa in the year 2000. The Skunk and Des Moines Rivers could supply all of the water needed in their basins in the year 2000, 95 percent of the time, and the lowest recorded flow of the Des Moines would be sufficient to supply the needs of that basin at use rates predicted for the next 30 years. The low-flow augumentation furnished from the recently completed Red Rock Reservoir will result in minimum discharges of around 300 cfs throughout the Des Moines River valley in southeast Iowa. This flow is more than sufficient for all withdrawals in that basin.

In the basins southwest of the Des Moines Basin (Fox, Wyaconda, Fabius, and Chariton Basins) streamflows are not sufficient to provide dependable supplies of water. The Fox River will be able to supply demands in its basin only about 70 percent of the time by the year 2000, and the other streams in this area have less flow than the Fox River. The lowest average 7-day discharge of the Fox that can be expected once every two years at Cantril is 0.73 cfs (0.5 mgd), and this stream has been known to have no flow several times in the past.

The chemical quality of the water from all streams in southeast Iowa makes them suitable sources of water for most uses. The Mississippi River water is of the best quality, and the Des Moines River generally carries water with the poorest chemical quality. Pollution or contamination of the streams by sediment, municipal and industrial effluents, and runoff from agricultural lands has been noted in the past. An effort must be made to stop or minimize this degradation of the stream waters if they are to be used more fully as a water resource.

Availability from the Surficial Aquifers

The surficial aquifers provide water for a variety of users. The thin and discontinuous sands of the drift aquifer generally yield only small amounts of water and should never be considered when planning for large withdrawals. In only a few instances small communities obtain moderate, but sufficient, amounts for their water systems. Recharge to the drift aquifers is rapid, but the water table often drops below the pump intake in the summer and fall months. Having these wells "go dry" on occasion is not uncommon. The water from the drift aquifer is usually low in dissolved solids; however, nitrates in excessive amounts are common. Contamination of the aquifer by infiltration of agricultural chemicals or from septic tank effluent is always a possibility.

Moderate yields are sometimes available from the buried-channel aquifer. Burial beneath 100 feet or more of clayey glacial material makes recharge to these aquifers slow, and their limited lateral extent restricts the area over which a cone of depression can spread. Large yields are available from these deposits where they are found beneath the valleys of major streams—mainly the Mississippi River. The water from the buried-channel aquifer generally is more highly mineralized than water from the drift or alluvium.

The alluvial aquifer offers the highest yields of any aquifer in southeast Iowa. Wells yielding more than 1,000 gpm are not uncommon in the Mississippi River valley, and yields of several hundreds of gallons per minute are available to wells in parts of the Iowa, Skunk, and Des Moines Valleys. Recharge to the alluvium, through precipitation or by induced infiltration from the rivers, is rapid and can support large withdrawals in many places. Inducing water into the alluvial aquifers will deplete the streamflow. This loss of water must be considered when pumping from alluvium adjacent to small streams or any stream during periods of extreme low flow. The chemical quality of the alluvial water is good and the dissolved-solids content is usually 500 mg/l or less. Concentrations of nitrate in water from the alluvial aquifers are sometimes high, especially in the shallower zones. Although the highly productive parts of the alluvial aquifers are restricted in occurrence to parts of large stream valleys, they have the greatest potential for future development of large quantities of ground water in southeast Iowa.

Availability from the Bedrock Aquifers

The carbonate bedrock aquifers of Mississippian and Devonian rocks can be reached at shallow to moderate depths over about one-half of the southeast Iowa area. Limited yields, usually less than 50 gpm, are available from either the Mississippian or the Devonian aquifers. The Mississippian aquifer is used for numerous rural supplies, public supplies for several small communities, and a few industrial supplies. Recharge to this shallow bedrock aquifer is adequate to maintain present withdrawals. Water of suitable quality for most uses is available from the Mississippian aquifer in most of the Skunk River basin and in parts of the Iowa River basin and the Mississippi River valley. The dissolved-solids content of the water in most of the Des Moines River basin and the other river basins in Davis and Van Buren Counties is in excess of 1,000 mg/l and exceeds 5,000 mg/l in some places.

The Devonian aquifer is not used extensively in southeast Iowa. Only a few rural and industrial supplies have been developed from it in Louisa, Des Moines, and Washington Counties. Yields and the quality of the water obtained have been disappointing. Highly mineralized water is prevalent in the Devonian aquifer throughout most of the area, the only exception being in the Mississippi River valley area in extreme eastern and northeastern Louisa County. Elsewhere, the dissolved-solids content is in excess of 1,000 mg/l, and greater than 10,000 mg/l in several places.

The Cambrian-Ordovician aquifer is an invaluable asset to the water resources of this entire area. It affords a dependable supply of water at rates from a few hundred to 1,000 gpm in places where other adequate sources are non-existent or are several miles away. The Jordan Sandstone, the principal water-bearing unit in this aquifer, can be found at depths ranging from 1,700 feet to about 2,300 feet below the land surface. The long distance and numerous aquicludes between this aquifer and the land surface precludes any significant amount of recharge to the aquifer from precipitation falling in the southeast Iowa area. Water moving laterally through the aquifer into this area is not sufficient to replenish the present withdrawals of 9.6 mgd in southeast Iowa. As a result, as much as two-thirds of the amount withdrawn comes from storage within the aquifer. This has caused the piezometric surface to be depressed from 25 to 75 feet over the entire area. The water levels will be lowered further as withdrawals continue. However, vast amounts of water are still available from the aquifer, and users will be able to pump from it for many years. Pumping costs will increase as the water levels are lowered and the distance the water must be raised becomes greater. Water of fair quality, dissolved solids between 1,000 and 1,500 mg/l, predominates in the Cambrian-Ordovician aquifer throughout nearly all of the area. Water containing more than 1,500 mg/l of dissolved solids have been found only in the southeastern corner of the area—in southern Lee County.

The best chances for a good water supply—A summary

Table 22 is a simplified summary of the possibilities of obtaining a suitable water supply in southeast Iowa. All data used to construct and compile the maps, charts, and graphs in the preceding sections of this report have been considered. To classify a water source as excellent, good, fair, or poor, two criteria were used—yield or quantity of water available and the quality of that water.

Yields for surface-water and ground-water supplies are classified separately. Streams are considered as excellent sources if the 90-percent flow is 100 cfs or greater, the 7-day, 2-year low flow is 100 cfs or greater, and the stream has never reached zero flow. They are considered good sources if the 90-percent flow is from 10 to 100 cfs, the 7-day, 2-year low flow is from 20 to 100 cfs, and the stream has never reached zero flow. Streams are considered fair sources if the 90-percent flow is from 1 to 10 cfs, the 7-day, 2-year low flow is from 5 to 20 cfs, and the stream has never gone to zero flow. They are considered as poor sources if the 90-percent flow is less than 1 cfs, the 7-day, 2-year low flow is less than 5 cfs, or the stream has reached zero flow sometime during the period of record. This classification must be applied only to the main stream in the basin or to only one or two major tributaries, because even the largest streams have small tributaries that are dry a good part of the time.

Yields from ground-water sources are classified as follows: Excellent—those aquifers yielding more than 500 gpm to individual wells; good—those yielding 100 to 500 gpm; fair—aquifers yielding 20 to 100 gpm; and poor—those yielding less than 20 gpm to individual wells.

Water quality suitability is classified by the dissolved-solids content of water from each source. These are broken down as follows: Excellent—less than 500 mg/l; good—500 to 1,000 mg/l; fair—1,000 to 1,500 mg/l; and poor—greater than 1,500 mg/l. If fluoride is present in unacceptable amounts, the source is considered poor even though the dissolved-solids content is less than 1,500 mg/l.

Each source is given one classification for both yield and water quality. The classification is that of the lowest category of either quantity or quality, as this lowest category is the limiting factor of the source's acceptability for most uses. Some ground-water sources, and especially the Cambrian-Ordovician aquifer, have been given a fair or poor rating on the basis of the water quality. The advent of economical demineralization techniques can make these waters desirable for nearly all uses.

Table 22.—Water-supply summary

SOURCE OF WATER \ DRAINAGE BASIN		MISSISSIPPI and TRIBUTARY BASINS	IOWA	SKUNK	DES MOINES	FABIUS, FOX, CHARITON, and WYACONDA
Streams		EXCELLENT	EXCELLENT to FAIR	EXCELLENT to FAIR	EXCELLENT to GOOD	POOR
Surficial aquifers	Alluvial aquifer	EXCELLENT to GOOD	EXCELLENT to GOOD	GOOD	EXCELLENT to GOOD	POOR
	Buried-channel aquifer	GOOD to FAIR	FAIR	FAIR	FAIR	POOR
	Drift aquifer	POOR	POOR	FAIR to POOR	POOR	FAIR to POOR
Mississippian aquifer	upper	FAIR to POOR present only in parts of Lee County	POOR Present only in northwestern Keokuk County	FAIR to POOR	FAIR to POOR	POOR
	lower	FAIR to POOR	FAIR to POOR	FAIR to POOR	FAIR to POOR	POOR
Devonian aquifer		FAIR to POOR	FAIR to POOR	POOR	POOR	POOR
Cambrian-Ordovician aquifer		FAIR to POOR	GOOD to FAIR good only in northwestern Keokuk County	GOOD to FAIR good only in northern Mahaska County	GOOD to POOR	FAIR to POOR

FOR MORE INFORMATION

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UNPUBLISHED DATA AND TOPOGRAPHIC MAPS . . .

Detailed information and data about the hydrology and geology of this area may be obtained by contacting the following agencies:

Iowa Geological Survey
Geological Survey Building, Iowa City, Iowa 52240

U. S. Geological Survey
1041 Arthur Street, Iowa City, Iowa 52240

Topographic maps may be purchased and information about mapped areas may be obtained from the following dealers:

Iowa Geological Survey
Geological Survey Building, Iowa City, Iowa 52240

University Book Store
Iowa State University, Ames, Iowa 50010.