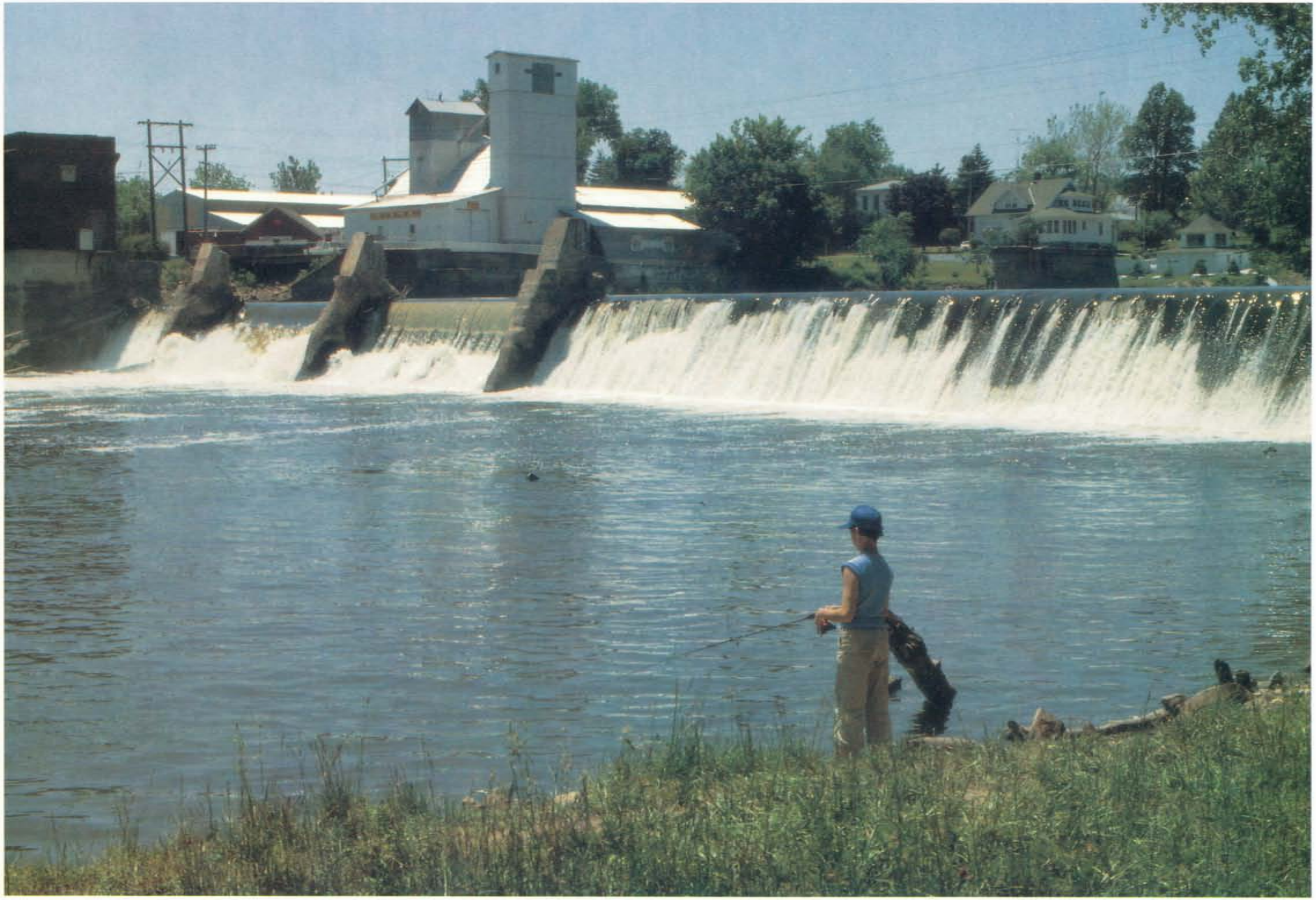
Iowa Department of Natural Resources Water Atlas No. 8



WATER RESOURCES OF NORTHEAST IOWA

Iowa Department of Natural Resources
Water Atlas Number 8

Water Resources of Northeast Iowa

by
Paul J. Horick

with a section on
Surface-Water Resources
by Phillip J. Soenksen
U.S. Geological Survey

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COVER PHOTO:
Pictured is one of northeast Iowa's scenic low-head dams. This concrete structure, owned by Iowa Public Service Company, Sioux City, is located on the Cedar River at Nashua, Chickasaw County. Built in 1916, the dam impounds a 700-acre lake used primarily for general recreation and fishing purposes. The drainage area above the dam is 1,113 square miles. Photo by P. J. Horick.

CONTENTS

CONTENTS

Illustrations

CONTENTS
Illustrations

CONTENTS

Tables

Appendices

GLOSSARY

Abbreviations

ac-ft - acre-feet; one acre-foot is equivalent to water 1-foot deep covering an area of 1 acre; it equals 325,843 gallons or 43,560 cubic feet.

bgd - billion gallons per day.

cfs - cubic feet per second; one cfs is equivalent to 646,315 gallons per day.

cfsm - cubic feet per second per square mile of drainage-basin area.

DNR - Iowa Department of Natural Resources.

gpm - gallons per minute.

mgd - million gallons per day.

mgpy - million gallons per year.

mg/l - milligrams per liter or parts per million.

μg/l - micrograms per liter or parts per billion.

μmhos - micromhos.

Alluvium - Stream deposits of stratified sand, gravel, silt, or clay.

Anticline - A convex upward fold in which the oldest stratigraphic units are in the core.

Aquifers - Saturated rocks or sediments that readily yield water to wells.

Artesian wells - Wells in which groundwater is under sufficient pressure to rise above the top of the producing aquifer, although not necessarily above the land surface.

Average discharge - The long-term average of streamflow at a given location.

Baseflow - That part of stream discharge derived from groundwater seeping into a stream.

Basement complex - An assemblage of igneous and metamorphic rocks that lie beneath sedimentary rocks in Iowa.

Bedding plane - The planar surfaces between adjacent layers of sedimentary rocks.

Carbonate rock - A sedimentary rock, such as limestone or dolostone, consisting chiefly of carbonate minerals; specifically, a sedimentary rock composed of more than 50 percent by weight of carbonate minerals.

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-flow studies.

Confined aquifer - An aquifer that is overlain by a confining bed and contains water under artesian pressure.

Confining bed - Rock or sediment, such as shale, glacial till, and clay, that retards or restricts groundwater flow.

Consumptive water-use - Water that is no longer available because it was evaporated, transpired, incorporated into products or crops, consumed by people or animals, or otherwise removed from the water environment.

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

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

Conversion factors -

Multiply *English unit*	*by*	*To obtain metric unit*
Inches	2.54	(cm) centimeters
Feet	3.048×10^{-1}	(m) meters
Yards	9.144×10^{-1}	(m) meters
Miles	1.6093	(km) kilometers
Square feet	9.29×10^{-2}	(m^2) square meters
Acres	4.047×10^{-3}	(km^2) square kilometers
Square miles	2.590	(km^2) square kilometers
Cubic feet	4.047×10^{-3}	(m^3) cubic meters
Cubic feet per second	2.832×10^{-2}	(m^3/sec) cubic meters per second
Acre-feet per day	1.233×10^{3}	(m^3/d) cubic meters per day
Gallons	3.7854	(l) liters
Gallons per minute	6.309×10^{-2}	(l/s) liters per second
Gallons per day per foot	2.07×10^{-1}	(l/s)/m liters per second per meter

Gallons per day	3.785×10^{-3}	(m^3/d) cubic meters per day
Million gallons per day	3.785×10^{3}	(m^3/d) cubic meters per day
Million gallons per year	3.785×10^{3}	(m^3/y) cubic meters per year
Billion gallons per year	3.785×10^{6}	(m^3/y) cubic meters per year

Discharge - The volume of water passing a given point within a given time. Groundwater discharge is the volume of water flowing from an aquifer.

Dissolution - The chemical process through which groundwater dissolves rock materials and forms voids or cavities in the rock.

Dissolved solids - The total concentration of dissolved minerals in water.

Drawdown - The lowering of the water table or potentiometric surface of an aquifer by pumping a well or wells.

Evapotranspiration - Loss of water as vapor from the land surface, surface water, and plant transpiration and evaporation.

Fault - A rock fracture or series of fractures along which there has been relative movement.

Floodplain - That part of a valley bottom that becomes inundated during the stream's flood stage. The deposits underlying the floodplain consist of alluvium.

Gaging station - A measuring station on a stream where a record of stage and discharge is obtained.

Glacial drift - Sediment transported by glaciers and deposited by or from the melting ice.

Glacial till - Unsorted and unstratified drift deposited directly beneath a glacier without reworking by water from the glacier.

Groundwater - Water contained below the water table in saturated rock and sediment.

Igneous rock - A rock that has solidified from a molten magma or partially molten rock material.

Infiltration - The movement of water from the land surface through soil and rock to the water table.

Joint - A fracture in rock along which no movement has occurred.

Karst - The solution enlargement of openings in carbonate rocks by which sinkholes, caverns, tunnels, and other karst features are formed; an important source of secondary permeability in carbonate aquifers.

Mean annual air temperature - The arithmetic average of annual air-temperature values. The period of record in this report is 1896-1974.

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

Metamorphic rock - A rock transformed from pre-existing rocks by mineralogical, chemical, and structural changes in response to marked changes in temperature and pressure, or to deformation.

Normal annual precipitation - The arithmetic average of annual precipitation. In this report the period of record is 1900-81.

Potentiometric surface - The water-pressure surface of a confined aquifer. It represents the levels to which water will rise in wells completed in the aquifer.

Recharge - The various processes that deliver water to the water table or to an aquifer.

Runoff - As used in this report, precipitation discharged overland through surface streams.

Sea level - Elevations referenced to the National Geodetic Vertical Datum (NGVD) of 1929, a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

Sedimentary rock - A rock formed by the cementation of loose sediment that was deposited as layered strata.

Specific capacity - The rate of discharge of water from a well per unit of drawdown. It is usually expressed in gallons per minute per foot of drawdown.

Static-water level - The non-pumping water level in a well.

Structural deformation - The folding and faulting of rock strata by natural forces.

Syncline - A concave upward fold in which the youngest stratigraphic units are in the core.

Synthetic organic compounds - Man-made organic chemical compounds including petroleum products, industrial solvents, and pesticides.

Terraces - Those parts of the valley above the present floodplain. Individual terraces may be nearly level, composed predominantly of alluvium deposited when the stream was at a higher level, and separated from the floodplain and adjacent terraces by steep slopes.

Transmissivity - The rate at which water moves through a unit width of earth material under a unit hydraulic gradient.

Unconfined aquifer - An aquifer in which the water table forms the upper boundary; i.e., the water is not confined under pressure beneath a confining bed.

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

Water table - The surface of the zone of saturation in an unconfined aquifer.

Water year - In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period from 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 rocks and soils are filled with water.

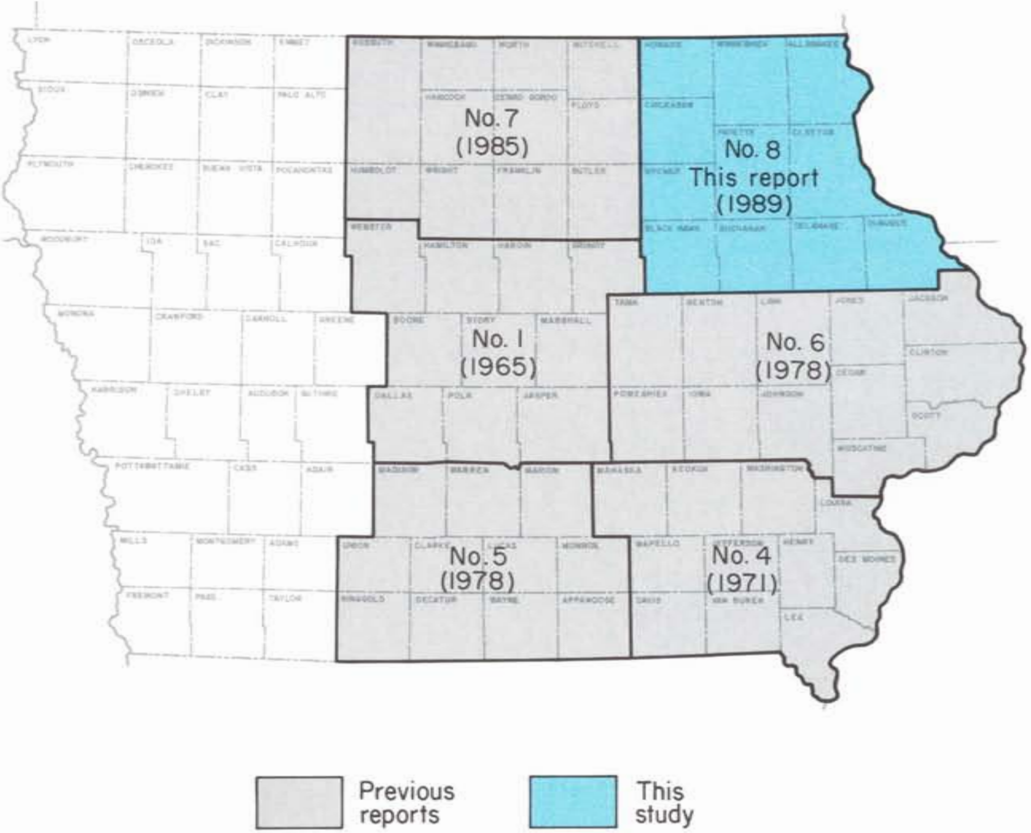
ACKNOWLEDGEMENTS

A report of this magnitude and diversity could not be completed without the cooperation and assistance of several colleagues and others. Many people must be credited, beginning with several Iowa well drilling contractors for their well logs, drill cuttings, and water-level and pumping-test data. Notable are Gary and George Shawver, Fredericksburg; Willard Holthaus, Decorah; and Curtis Nuehring, Farmersburg; as well as the Layne-Western Company, Winslow Well Drilling, Ogden Well Service, and Thorpe Well Company. Paul Waite, former State Climatologist, supplied valuable precipitation and temperature records. Phillip Soenksen of the U.S. Geological Survey did the surface-water report, while Richard Karsten and Robert Buchmiller of that agency supplied water-use statistics. Other water-use data were obtained through James Wiegand (deceased) of the Iowa Department of Water, Air and Waste Management (now the Iowa DNR). I drew on the expertise of Michael Schendel, Richard A. Bishop, and Arnold Van der Valk for information on wetlands. The section on Iowa's water resources laws and regulations was updated by the Surface/Groundwater Protection Bureau of the Department of Natural Resources' Environmental Protection Division. Numerous consultations on identification of stratigraphic units and terminology were held with coworkers Brian Witzke, Bill Bunker, and Robert McKay. Lawrence Mitchell provided information on flowing wells in Allamakee County. Patricia Ring and Richard L. Talcott assisted by retrieving computerized water-quality data, and Paul VanDorpe, using a computer, reformatted the manuscript tables. Donivan Gordon, general supervisor of the project, was always available for consultation. Kay Irelan and Patricia Lohmann are to be thanked for drafting the illustrations and assisting with the report format. Mary Pat Heitman and Lois Bair were responsible for typing much of the manuscript. Greg Ludvigson and Tim Kemmis had the major responsibility for coordination of the technical review of the manuscript and maps. Mention should also be made of the ongoing and arduous work and research on the hydrogeology and water quality of the region conducted by George Hallberg, Bernard Hoyer, and their co-researchers who brought to light much valuable data. Previous investigations by A.J. Heinitz, O.G. Lara, and H.H. Schwob of the U.S. Geological Survey provided useful background for the surface-water study. Finally, I would be remiss if I did not mention my wife, Claudia Horick, who assisted in the field several weekends on visits to dam sites and wetlands. I am grateful to all these people for their assistance and patience while the data were synthesized and the final report composed, edited, and published.

P. J. H.

FOREWORD

In 1965 a cooperative investigation with the U.S. Geological Survey produced Water Atlas No. 1 (Twenter and Coble, 1965). It presented information on the occurrence, availability, use, quality, and future demand of water in 10 counties in the central part of the state. Subsequent investigations produced Water Atlases No. 4 (Coble and Roberts, 1971) for southeast Iowa, No. 5 (Cagle and Heinitz, 1978) for south-central Iowa, No. 6 (Wahl et al., 1978) for east-central Iowa, and No. 7 (Buchmiller et al., 1985) for north-central Iowa. The present study, Water Atlas No. 8 (1989), describes the surface-water and groundwater resources of 11 counties in extreme northeast Iowa. With the publication of this report, water atlases are now available for the eastern two-thirds of the state.



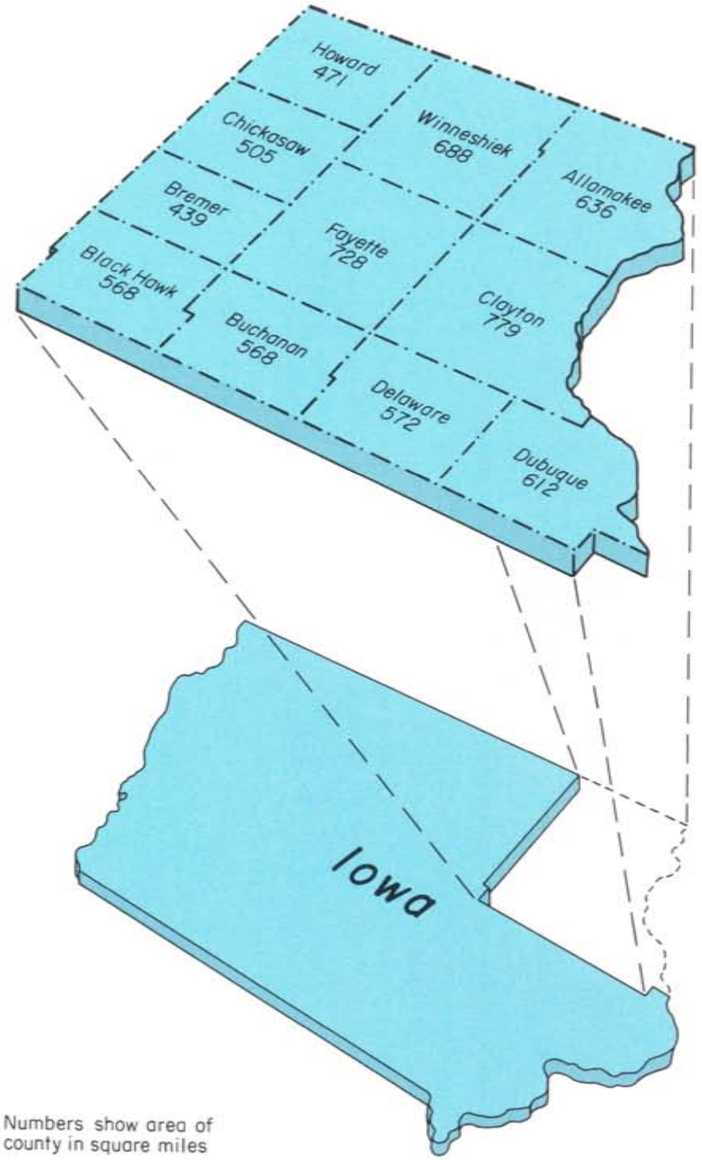


Figure 1. The 11 counties of northeast Iowa

INTRODUCTION

NORTHEAST IOWA

The 11 counties of northeast Iowa (figure 1) include 11.7 percent of the state's total land area. Part of five large drainage basins are located within the area, including the Cedar, Wapsipinicon, Maquoketa, Turkey, and Upper Iowa basins, as well as three small Mississippi River tributaries (figure 2). All are tributaries of the Mississippi River which borders the eastern edge of the study area.

Northeast Iowa differs from most other parts of the state because extensive bedrock areas are at or near the surface. The upper aquifers are often poorly protected from surface contamination. The information presented here will be useful to those looking for dependable sources of water and for water managers who must develop the available water resources on a regional basis.

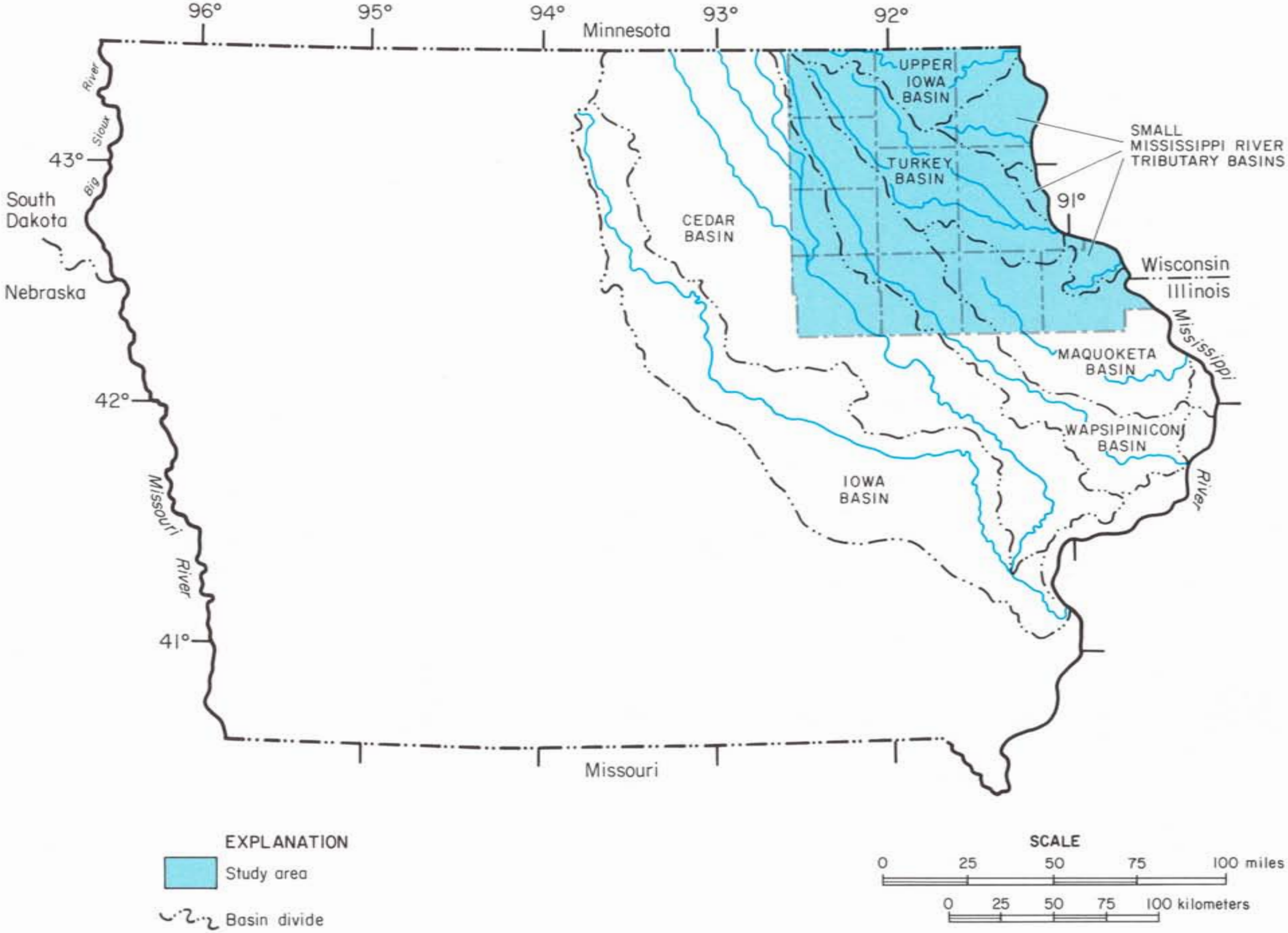


Figure 2. Drainage basins of northeast Iowa

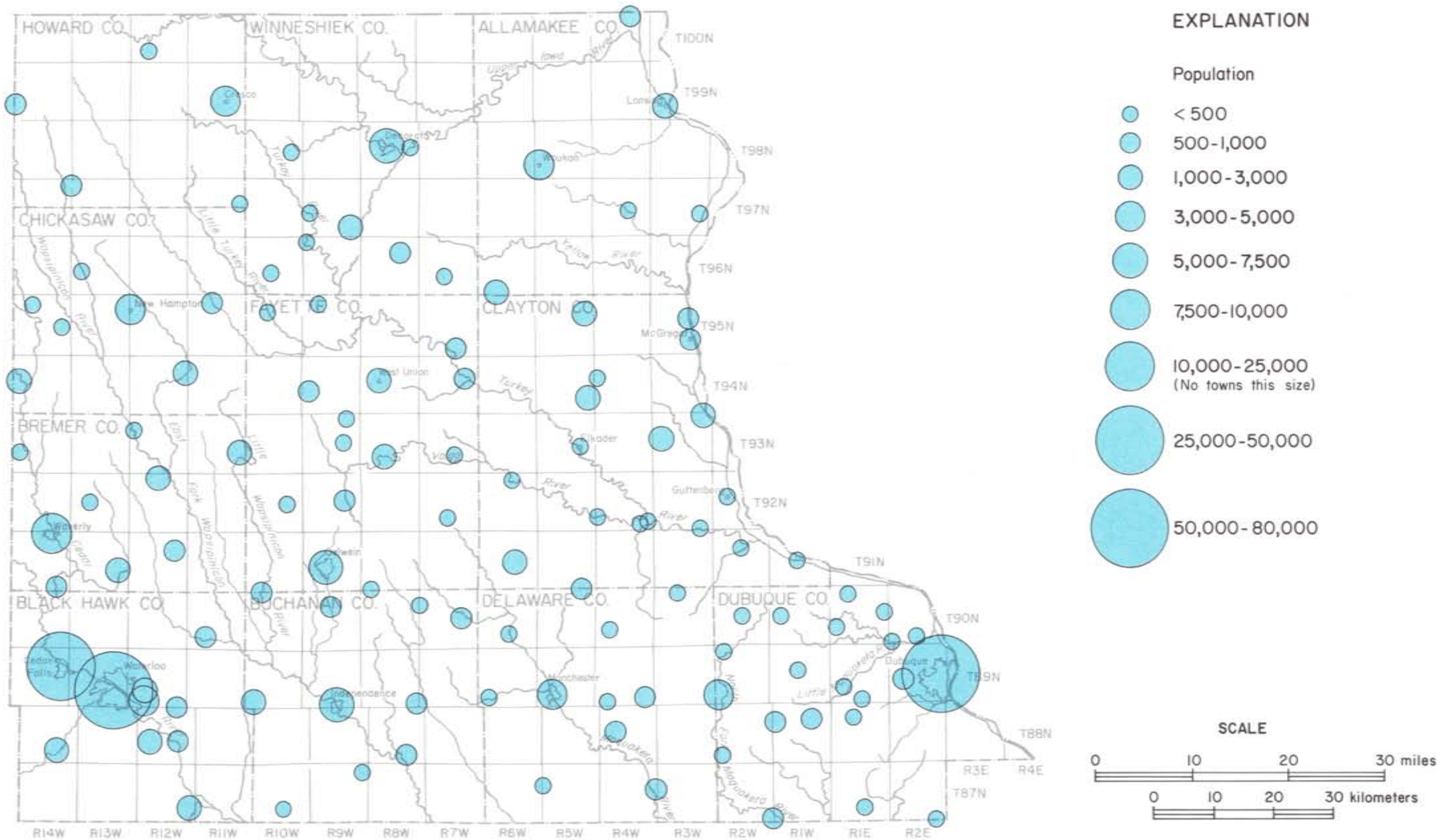


Figure 3. Population of cities and towns in 1980

POPULATION

The 11 counties comprising northeast Iowa have a population of 408,480 according to the 1980 census. This is about 14 percent of the state's population. Approximately 59 percent of the population is classed as urban (living in communities with more than 2,500 persons) and 41 percent as rural. However, 15 percent of the population live in incorporated towns each having less than 2,500 population so that about 74 percent (299,412) live in incorporated communities.

There are 121 incorporated cities and towns in this area. The location and size of these communities are shown in figure 3. Waterloo is the largest city, having a population of 75,535. Dubuque with 61,932 and Cedar Falls with 36,134 are the next largest cities. There are no cities with populations between 10,000 and 25,000. Decorah, Waverly, Oelwein, and Independence are in the range of 6,000 to 8,500. No other cities have populations of more than 5,000, but there are seven towns with populations between 2,500 and 5,000.

The total population of the area has increased since 1900 at an average rate of about 5 percent each decade or 0.5 percent annually. The urban population increased from 27 percent of the total in 1900 to 59 percent in 1980, while the rural population declined from 73 percent to 41 percent. The actual number of rural residents has declined only 19.6 percent (an average of 0.24 percent per year). However, urban growth has been significant, increasing 217 percent over this 80-year period (an average of 2.7 percent per year), exceeding the rural population shortly after 1950. These trends are expected to continue for the next few decades, as shown in figure 4. Figure 4 also shows that the rate of rural population growth has declined somewhat since 1960, with an annual growth averaging only about 0.36 percent. The projected population for the year 2000 is about 435,000 at which time an estimated 100,000 more people will be living in urban areas than rural areas.

With the major concentration of northeast Iowa population now located in and around cities and towns, the communities are forced to continually upgrade and expand their water systems to meet increased demand for municipal, industrial, and domestic uses. In contrast, many rural wells may have been abandoned. If left open or improperly plugged, the abandoned wells are potential avenues of pollution to local aquifers.

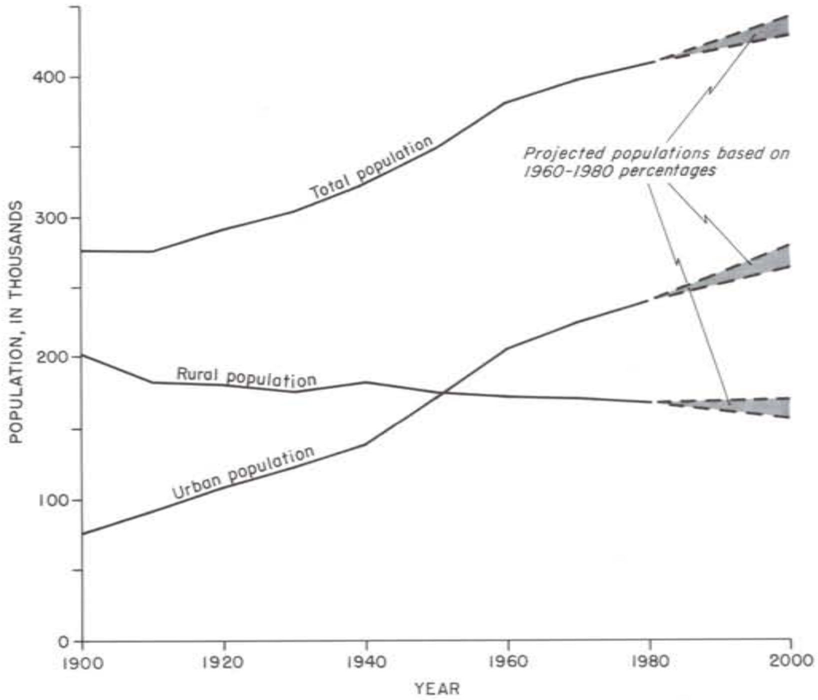


Figure 4. Population trends in northeast Iowa, 1900-2000

THE LAND SURFACE

Northeast Iowa is located in the upper Mississippi River basin and in the Central Lowlands physiographic province of North America. The area includes parts of three distinct physiographic regions—the Paleozoic Plateau, the Iowan Surface, and the Southern Iowa Drift Plain (figure 5). The character and areal distribution of these regions are described in Prior (1976).

Paleozoic Plateau

The Paleozoic Plateau covers 40 percent of this 11-county study area. Although this region is called a plateau, it includes some of the roughest topography in the state (figure 6) and has been referred to as the "Switzerland of Iowa." The region includes all of Allamakee, most of Clayton, most of Winneshiek, and parts of Fayette and Dubuque counties. Only thin, isolated remnants of the loess and glacial-drift deposits remain in the Paleozoic Plateau, and the underlying bedrock is near the land surface in this area. Early geologists described this area as part of the "Driftless Area" that included southeastern Minnesota, southwestern Wisconsin, and northeastern Illinois. This term is now

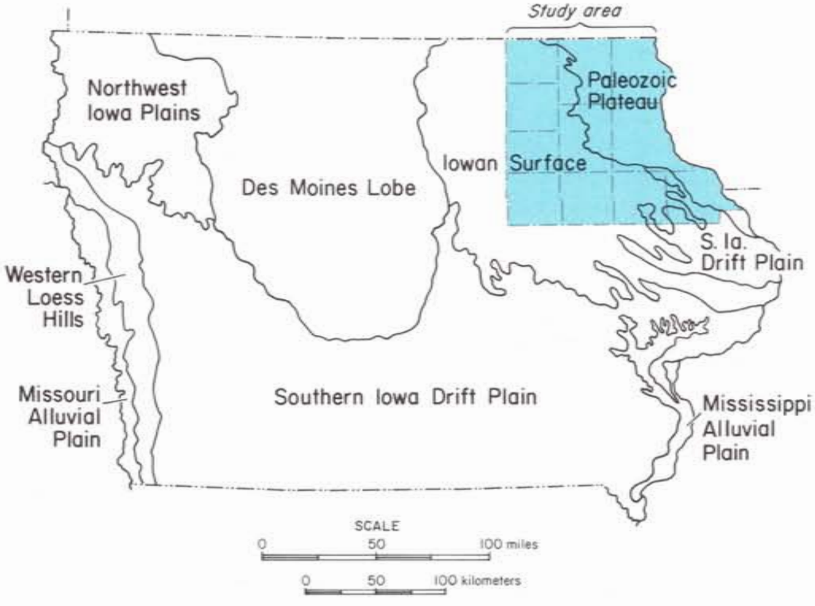


Figure 5. Landform regions of Iowa

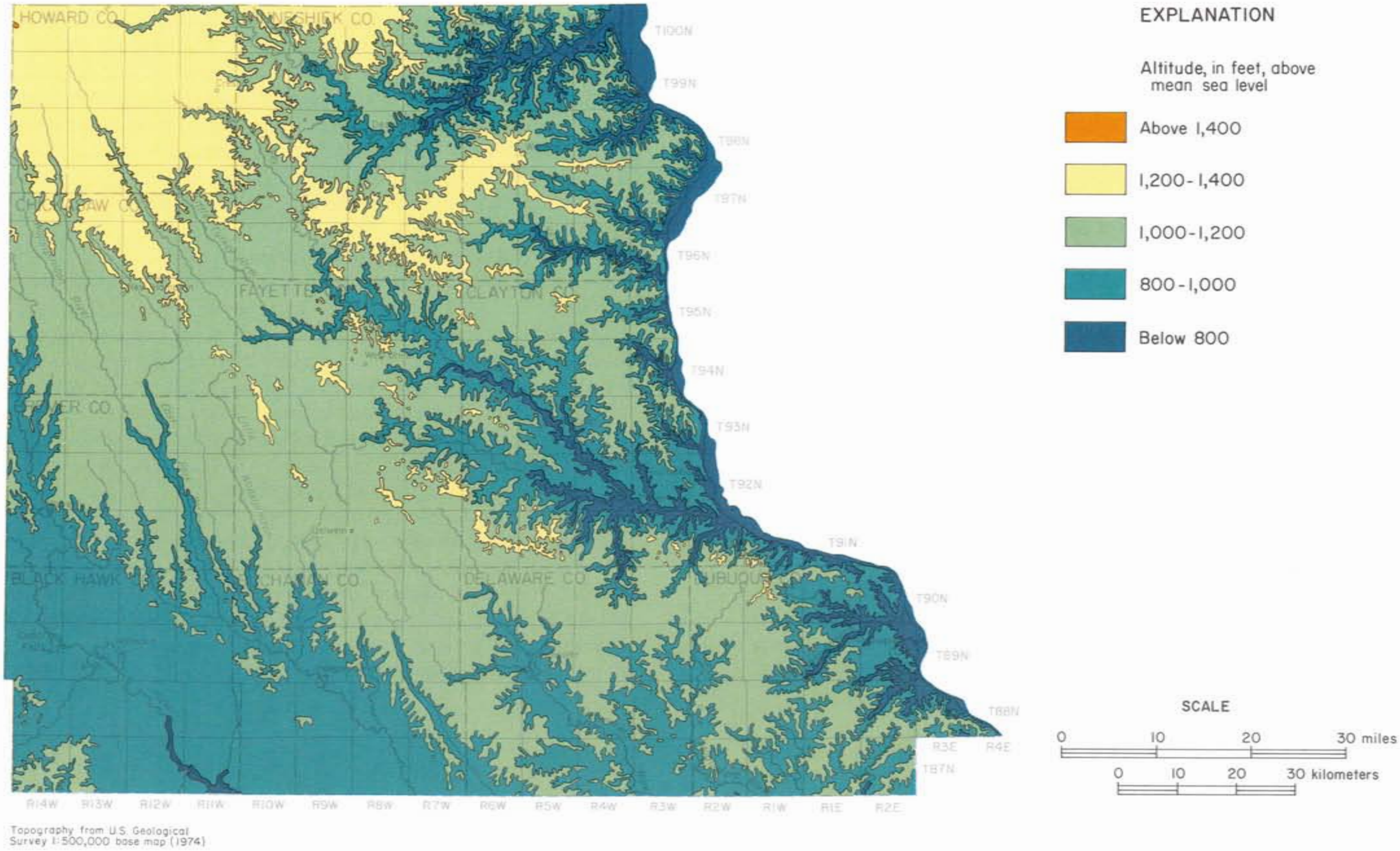


Figure 6. Topography of northeast Iowa

known to be incorrect. The Mississippi, Upper Iowa, Yellow, Turkey, and Volga rivers have eroded trenches 500 to 600+ feet below the uplands, forming the most prominent topographic features of the region. However, when viewed from a high elevation, the accordant summits of the uplands dominate the landscape and indicate that the present topography is that of a deeply eroded plateau. These summits have a gradual slope to the south and southeast. The maximum topographic relief in northeast Iowa is 710 feet, the highest altitude being just over 1,300 feet above sea level in northern Winneshiek County, and the lowest altitude at about 600 feet along the Mississippi River in southeastern Dubuque County.

The broad Mississippi Valley is generally 2 to 3 miles wide, and contains numerous sloughs, oxbow lakes, and islands. The valley floors of the principal tributaries are usually less than one-half mile wide, with the exception of the Upper Iowa River where erosionally less-resistant shales comprise the bedrock upstream from its mouth for several miles.

The upland surface has less relief and becomes more rolling away from the larger streams. In the western portion of the Paleozoic Plateau region, 10 to 30 feet of loess and as much as 80 feet of glacial drift mantle the bedrock, and surface relief is more subdued.

Outcrops of erosionally resistant limestone and dolostone and of more easily eroded sandstone of Cambrian and Ordovician age form steep bluffs along the Mississippi River and for several miles up the tributary valleys. The western margin of the Paleozoic Plateau in Dubuque, Clayton, and Fayette counties is marked by a prominent escarpment 100 to 200 feet high formed by resistant Silurian dolostone that is underlain and accentuated by a long, low slope on underlying, easily eroded shale of the Brainard Member of the Maquoketa Formation. The scarp slope is not as steep in southwestern Winneshiek County where both the Silurian dolostone and Brainard Member are completely eroded. The scarp in western Winneshiek County is harder to define, but Devonian bedrock makes a low ridge 20 to 25 feet high that can be identified in the field as a continuation of the Silurian escarpment.

Karst topography occurs where carbonate rocks occur at depths of less than 50 feet beneath the surface. Dissolution of limestone and dolostone by groundwater enlarges crevices and forms surface depressions, sinkholes, and caves. Sinkholes are abundant along the Silurian escarpment in southern Clayton and eastern Fayette counties, and in the Galena Group rocks in southwestern Allamakee and portions of Clayton and Winneshiek counties. Hallberg and Hoyer (1982) presented a detailed map of sinkhole distribution in northeast Iowa.

Iowan Surface

The Iowan Surface is a low-relief plain. The valleys have extremely long slopes that gradually merge with the interstream divides. Although the stream network is well established, stream gradients are low. Overall, the Iowan Surface slopes southeasterly with an inclination similar to the Paleozoic Plateau. The highest altitude is about 1,340 feet above sea level in northern Howard County, and the lowest is about 785 feet above sea level in the Cedar River valley at the southwestern corner of Buchanan County. The Iowan Surface is an extensive erosion surface formed during the Wisconsinan Stage.

The Iowan Surface is also noteworthy in places for the glacial boulders scattered on the surface. Another unusual feature of the southern part of the Iowan Surface is the occurrence of isolated paha. These northwest-southeast oriented ridges are wind-aligned dunes of loess and sand 30 to 100 feet high. Several are located in Bremer County near Waverly and in Delaware and Buchanan counties. Paha are more abundant in Benton, Linn, and Cedar counties just to the south of the study area.

Southern Iowa Drift Plain

The Southern Iowa Drift Plain comprises only 3 percent of northeast Iowa, primarily in western and southern Dubuque County west of the Silurian escarpment, and in northeastern and northwestern Delaware County (figure 5). The topography consists of steeply rolling hills with small areas of narrow, low-relief uplands, and relatively low-relief valley bottoms.

The surficial materials usually consist of thin loess and glacial drift mantling the bedrock, but in buried bedrock channels the loess and glacial drift are as much as 175 to 200 feet thick. A well developed dendritic drainage system has given the land a distinctive rolling appearance. Exposures of dolostone occur along some of the larger stream valleys.

SOURCES OF FRESH WATER

THE HYDROLOGIC CYCLE

The continuous process through which water is drawn from the oceans to the atmosphere, distributed over the land surface, then returned to the oceans is known as the hydrologic cycle (figure 7). Precipitation is the fundamental source of our useable water. Once precipitation reaches the land surface it may evaporate, infiltrate the soil, or run off. Most of the precipitation received by northeast Iowa is returned to the atmosphere by evaporation and plant transpiration (evapotranspiration). The quantity not lost to evapotranspiration flows overland to streams or infiltrates to become groundwater. A large proportion of this groundwater is taken up by plants and returned to the atmosphere. Only a small percentage percolates deeper to the zone of saturation and becomes groundwater in storage. During periods of low rainfall, groundwater discharging from storage is primarily responsible for sustaining streamflow.

Normal annual precipitation for northeast Iowa is between 32 and 34 inches. This amounts to about 9.5 million gallons for each person in the area, although only a fraction is actually available for use. About 2 inches of the annual amount never reaches the ground because it is intercepted by trees and other plants. About 4 to 6 inches of water reaching the ground drains overland to creeks and rivers. The rest infiltrates the soil and bedrock. Most of this, about 24 inches, is taken by roots of growing plants and transpired. Generally, 2 inches or less moves to the zone of saturation. In humid regions like Iowa, the surface of streams and lakes marks the intersection of the land surface and the water table (the surface of the zone of saturation). In some situations groundwater may be suspended above the water table by impermeable materials. Such conditions create "perched" water tables. Infrequently, lakes are attributable to perched groundwater.

Groundwater flows through openings in the granular materials and in creviced and porous bedrock. It flows to points of discharge, such as springs, streambeds, or lakes. The groundwater contribution to rivers and streams is called baseflow. In northeast Iowa, 60 or more percent of total streamflow is groundwater discharge. Groundwater discharge to streams is continuous, although discharge rates vary in response to rainfall. During dry periods, groundwater discharges are high and may even completely sustain streamflow.

Large quantities of water are transported into the area by the Mississippi, Upper Iowa, Wapsipinicon, and Cedar rivers. The volume of water carried through the area by the Mississippi River is about 6.5 times the runoff for the area. The volume of water carried into the area by streams from other parts of Iowa and Minnesota is about one-third of the area's runoff.

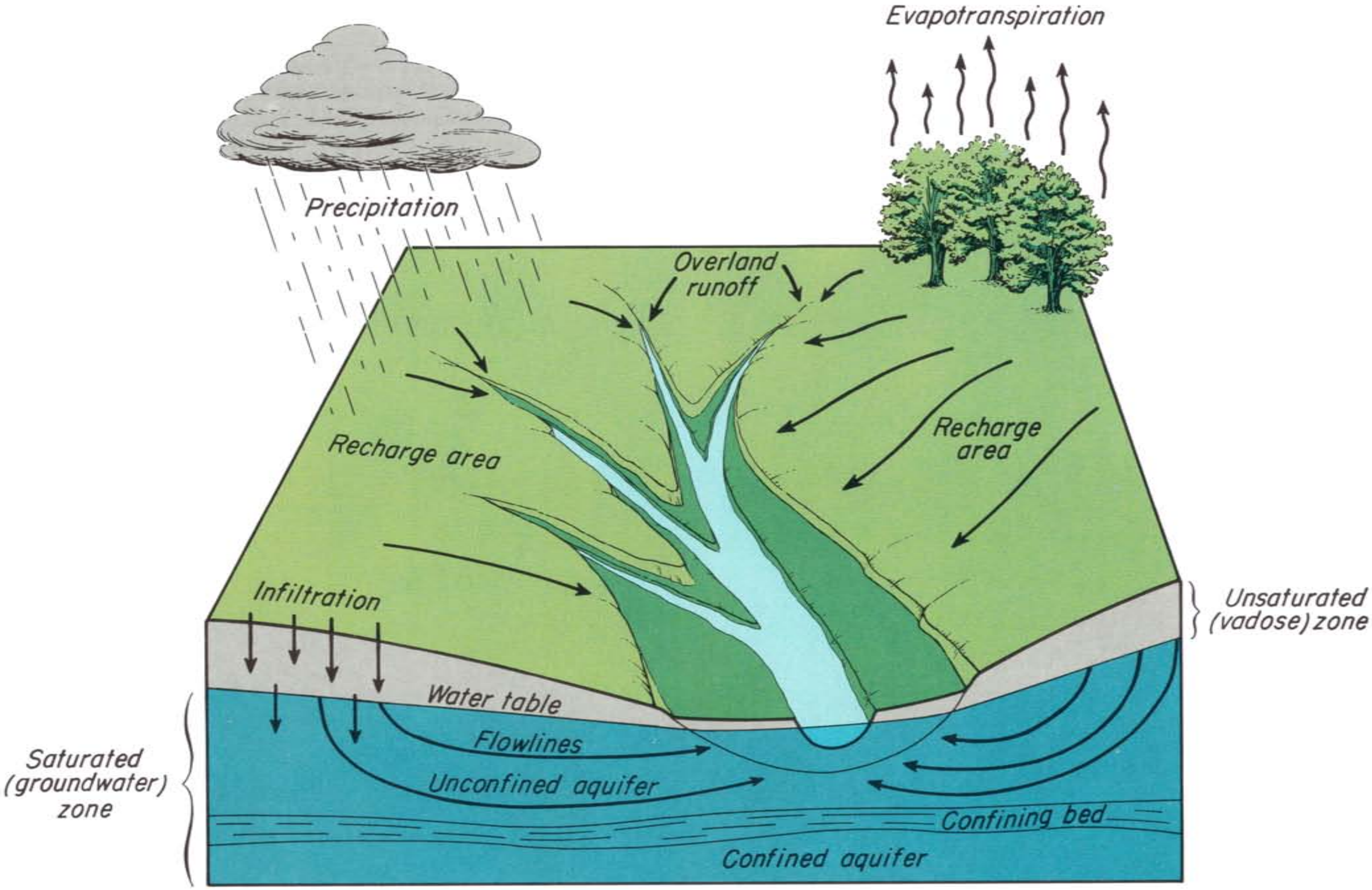


Figure 7. Schematic representation of the hydrologic cycle

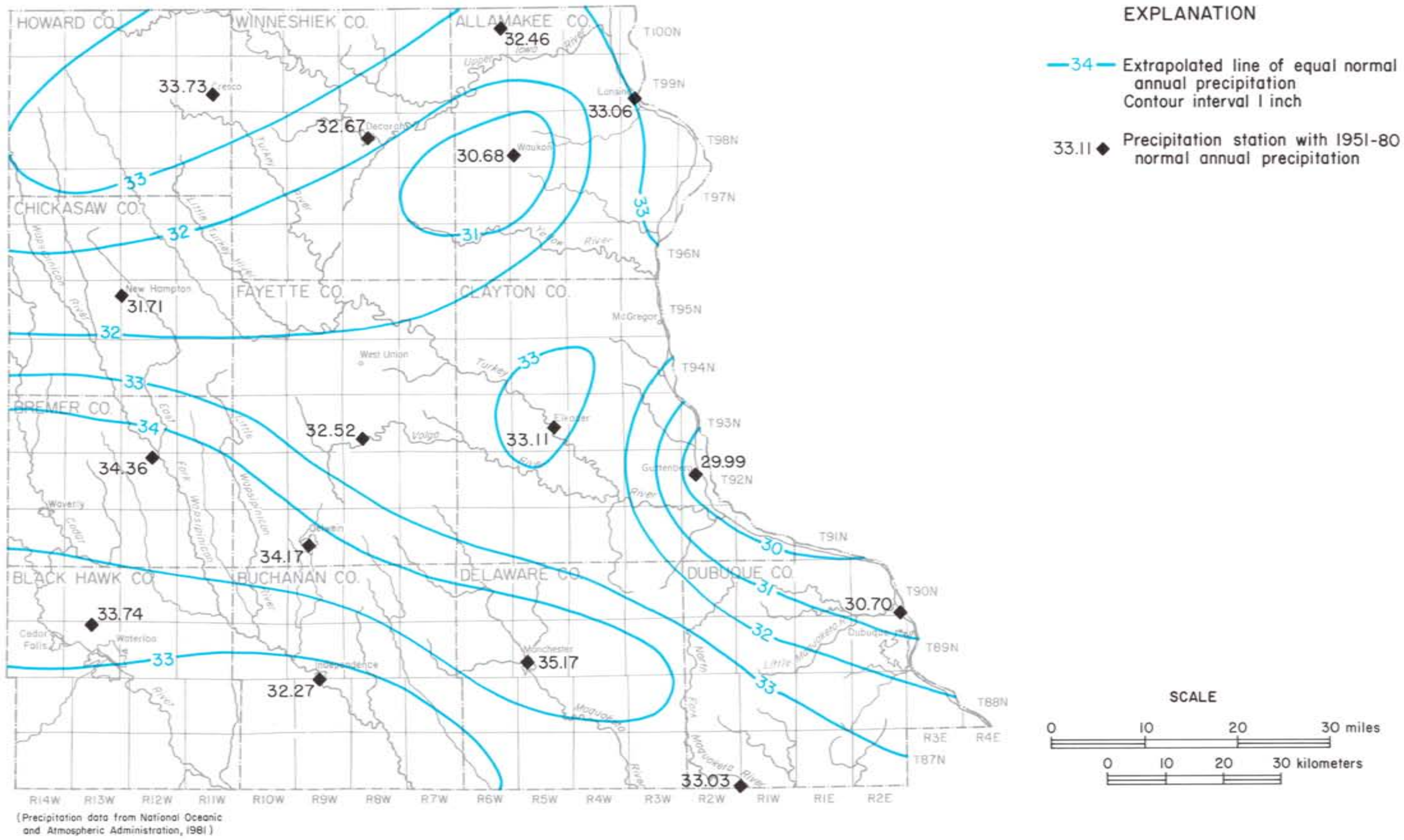


Figure 8. Normal annual precipitation for northeast Iowa, 1951-80

CLIMATE

The normal annual precipitation for the study area is about 32 inches and varies from 29 to 35 inches across the area (figure 8). Although precipitation varies from year to year, the annual departure from normal between 1900 and 1981 was less than ten inches 89 percent of the time. The normal annual precipitation at Fayette, Iowa, for the period 1951 to 1981 is about 32 inches (figure 9). Normal monthly precipitation is greatest from April through September, and least from October through March. About 70 percent of the precipitation falls during the April-to-September growing period. However, from year to year the variations from the monthly norm can be quite large (figure 10).

The mean annual air temperature at Fayette, Iowa, located near the center of the area, is 45°F. The monthly mean temperature ranges from about 16°F to about 72°F. Extreme temperatures of more than 100°F have been recorded during the months of May through September, and historically, temperatures below freezing have been recorded at least once in every month except July and August (figure 11).

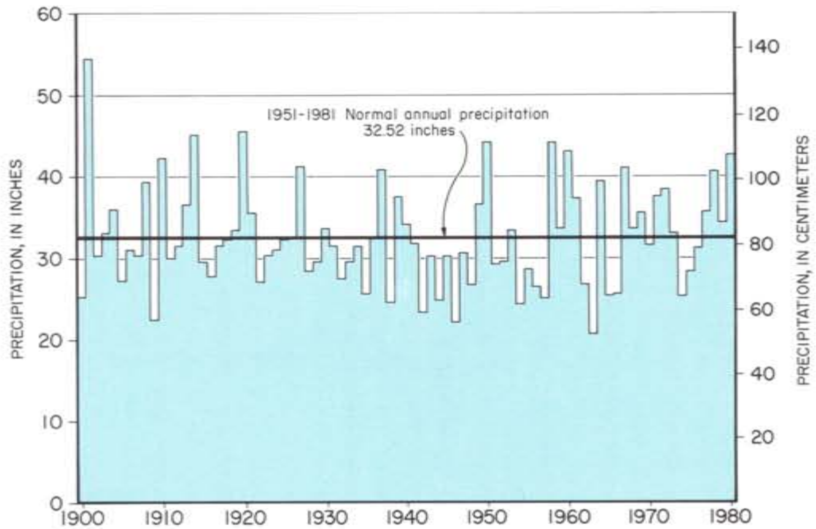


Figure 9. Annual precipitation at Fayette, Iowa, 1951-81

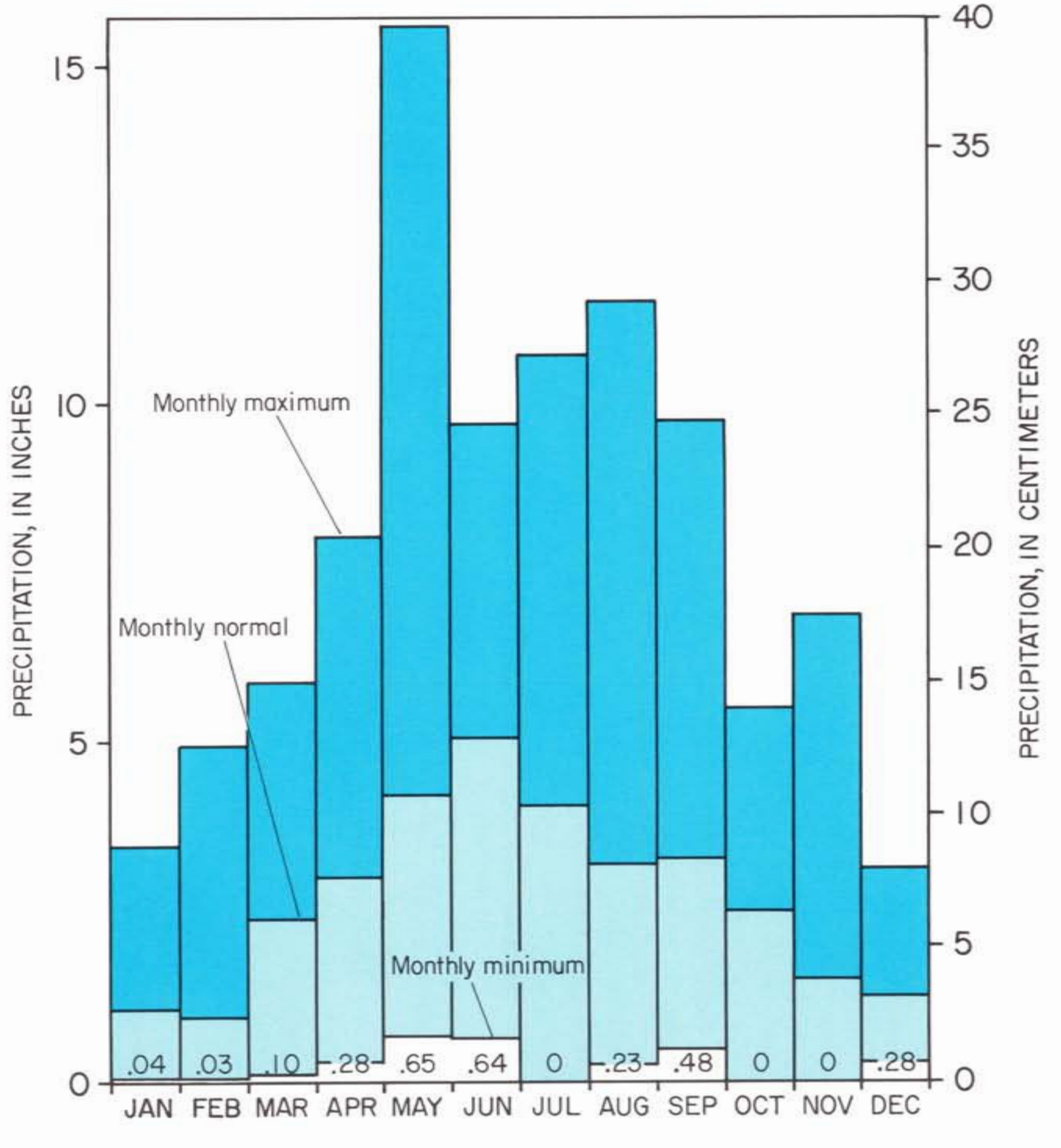


Figure 10. Monthly normal and extreme precipitation at Fayette, Iowa, 1900-80

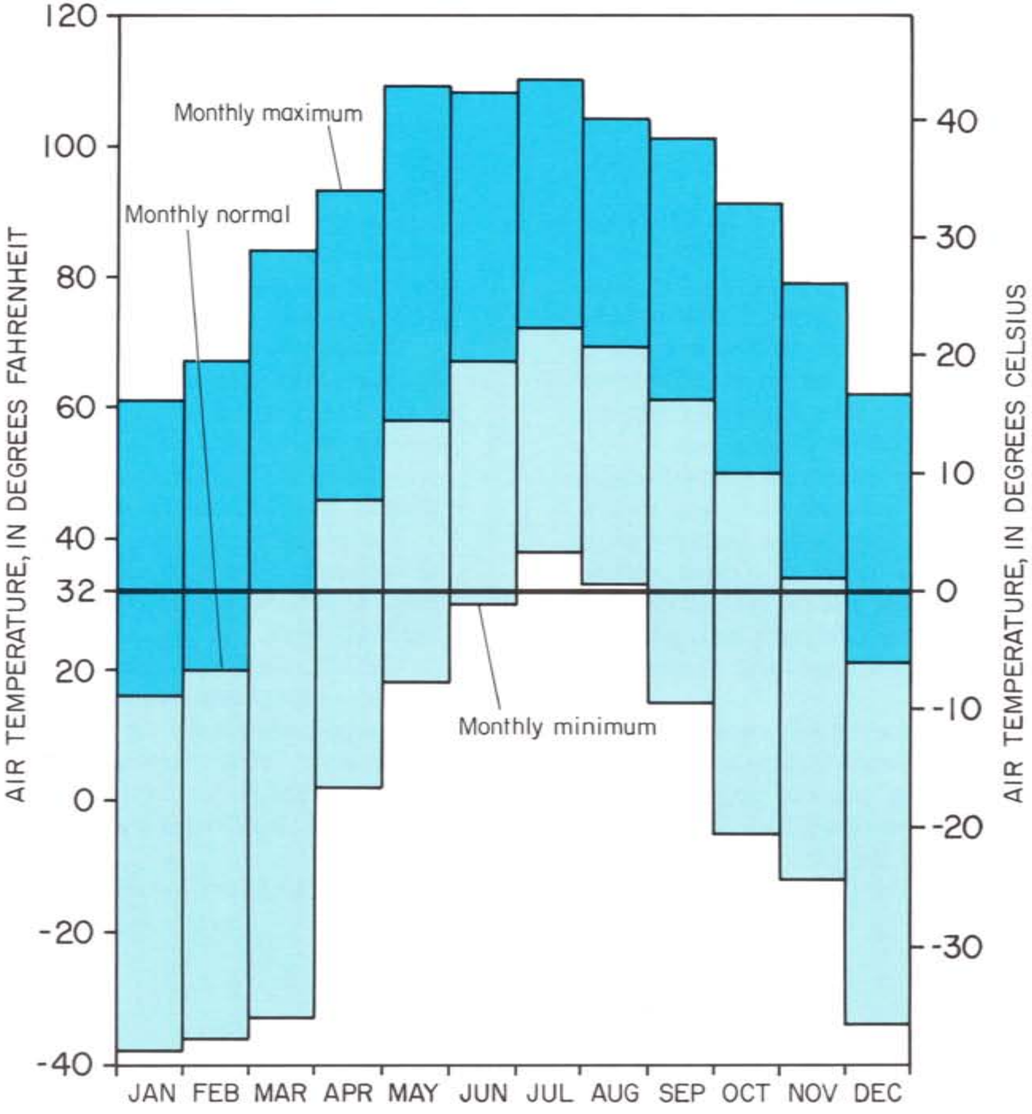


Figure 11. Monthly normal and extreme air temperatures at Fayette, Iowa, 1896-1974

SURFACE-WATER RESOURCES

The surface-water resources of northeast Iowa include a large number of rivers and streams, but relatively few inland-wetland areas (lakes, ponds, marshes).

The Mississippi River along the eastern boundary of the study area is the largest and economically most important river. Three dams with navigation locks are located along this reach, some of which have transformed the river into a series of giant pools with many side channels and backwater areas. The lock-and-dam system, built to maintain a channel for barge navigation, also provides for an abundance of recreational opportunities. Sedimentation in the channel is a continual problem that affects recreational and commercial river use.

All the streams in northeast Iowa are tributaries of the Mississippi River. Most that head in the area flow east and southeast through the increasingly steep terrain of the Paleozoic Plateau before joining the Mississippi River along Iowa's eastern border. The upper reaches of the Maquoketa and Wapsipinicon rivers, and the middle reach of the Cedar River, flow southeast through the more gently rolling terrain of the Iowan Surface. They join the Mississippi River south of the study area.

The scenic, free-flowing, natural qualities of many northeast Iowa streams have made them popular for activities such as canoeing and fishing. Several have been identified for possible inclusion in the state's Protected Water Areas (PWA) system (Iowa Conservation Commission, 1981), including 3 miles of the Little Turkey River in northeast Delaware County and most of the Upper Iowa and Wapsipinicon rivers (Iowa Conservation Commission, 1981). During 1971, most of the Upper Iowa River was recommended for inclusion in the National Wild and Scenic Rivers System (Bureau of Outdoor Recreation, 1971). Most of the Turkey and Yellow rivers, and the Wapsipinicon River downstream from Frederika, have been listed in the national inventory of significant free-flowing rivers (National Park Service, 1982).

The study area contains 225 of the 258 miles of cold-water streams in Iowa—the remainder are adjacent in Mitchell and Jackson counties (Iowa Conservation Commission, Planning and Coordination, written communication, 1979). The majority of these small spring-fed streams are located in the Paleozoic Plateau region and many are routinely stocked with trout by the Iowa Department of Natural Resources.

The overall quality of surface water is probably better in northeast Iowa than in other parts of the state. Of the 17 surface-water sites listed as requiring above-standard water-quality protection, 13 are in northeast Iowa.

The U.S. Geological Survey operates a network of stream-gaging stations which provide current and historical data on the surface-water resources in northeast Iowa. This network is composed of three types of stations: continuous-record stations; low-flow, partial-record stations; and high-flow, partial-record stations. The network includes information on all major and many minor streams as shown in figure 12.

Continuous-record stations provide daily gage height and discharge

P. J. Horick

This view of the Mississippi River valley is seen from Pikes Peak State Park near McGregor, Clayton County. In the foreground are numerous islands and river meanders of the Upper Mississippi Wildlife and Fish Refuge.

data. The discharge data are published in the U.S. Geological Survey's annual state water-resources data reports, and are periodically analyzed to determine average discharge, flow duration, low-flow frequencies, and flood frequencies. Selected streamflow statistics for continuous-record stations are presented in table 1.

Low-flow, partial-record stations provide additional flow information when streams are being sustained by groundwater inflow. Selected streamflow statistics from Lara (1979) for low-flow, partial-record stations are presented in table 2. The average discharge values are from regional equations; the remaining streamflow values are based on correlations between discharge measurements made at partial-record stations and concurrent flows at continuous-record stations.

High-flow, partial-record stations are generally located on streams that drain less than 100 square miles, and provide supplemental gage height and discharge data on flood peaks. Selected streamflow statistics for high-flow, partial-record stations were computed and are presented in table 3.

All the stations in this network have an assigned number that places them in downstream order with all other stations in the country. The leading numerals, "05" (see tables 1, 2, and 3), refer to the Upper Mississippi River basin which includes all of northeast Iowa. For brevity, these numerals are omitted from some of the illustrations.

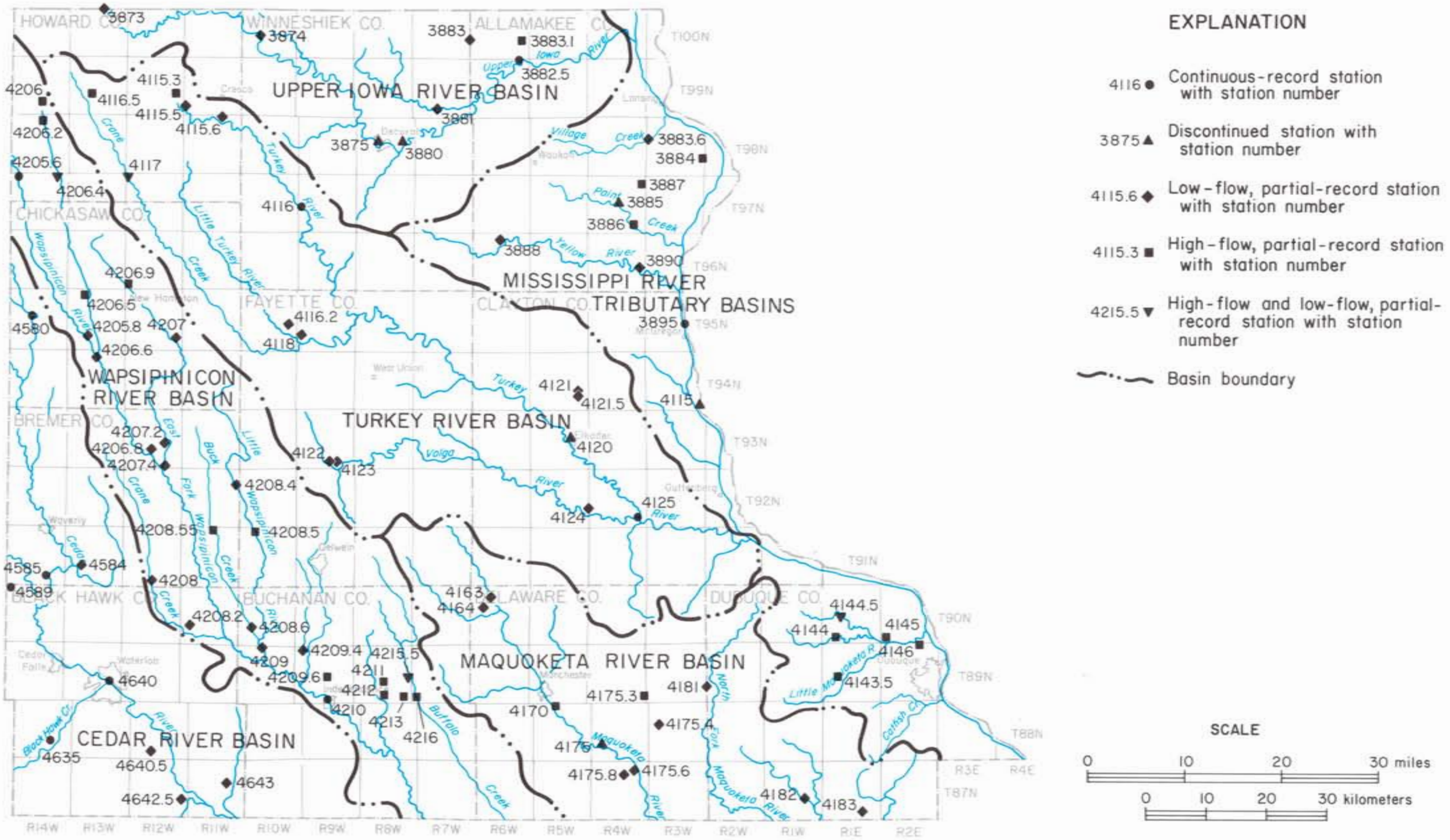


Figure 12. Surface-water data sites in northeast Iowa

Table 1. Streamflow statistics for continuous-record stations in northeast Iowa

Station number	Station name	Period of record	Drainage area (mi^2)	Average discharge	Minimum daily mean discharge	Year occurred	7-day low-flow for given recurrence interval 2-year	10-year
	UPPER IOWA RIVER BASIN							
05387500	Upper Iowa River at Decorah	1951-83	511	327	22	1959	61	34
05388000	Upper Iowa River near Decorah	1913-14, 1919-27, 1933-51	568, 584[a]	331	10[b]	1933, 1934	61[c]	30[c]
05388250	Upper Iowa River near Dorchester	1975-84[d]	770	616	79	1976	---	---
	PAINT CREEK BASIN							
05388500	Paint Creek at Waterville	1952-73	42.8	15.9	1.1	1958	2.7[c]	1.5[c]
	YELLOW RIVER BASIN							
05389000	Yellow River at Ion	1934-51	221	140	14	1939	29[c]	19[c]
	MISSISSIPPI RIVER MAIN STEM							
05389500	Mississippi River at McGregor	1936-84	67,500[e]	34,810	6,200	1936	12,500	8,950
05411500	Mississippi River at Clayton	1930-36	79,200[e]	25,620	5,540	1933	---	---
	TURKEY RIVER BASIN							
05411600	Turkey River at Spillville	1956-73, 1977-84	177	126	4.4	1959	21	8.5
05412000	Turkey River at Elkader	1932-42	891	487	21[b]	1940	47[c]	27[c]
05412500	Turkey River at Garber	1913-16, 1919-27[g], 1929-30, 1932-84	1,545	956	49	1940	167	82
	LITTLE MAQUOKETA RIVER BASIN							
05414500	Little Maquoketa River near Durango	1934-82	130	84.9	5	1936	14	7.4
	MAQUOKETA RIVER BASIN							
05417000	Maquoketa River near Manchester	1933-73	305	208	6	1934	41[c]	21[c]
05417500	Maquoketa River near Delhi	1933-40	347	136	5	1939	---	---
	WAPSIPINICON RIVER BASIN							
05420560	Wapsipinicon River near Elma	1958-84	95.2	69.2	1.9	1959	7.2	4.1
05421000	Wapsipinicon River at Independence	1933-84	1,048	626	7	1934, 1977	53	17
	IOWA RIVER BASIN							
05458000	Little Cedar River near Ionia	1954-84	306	180	3	1959	19	6.2
05458500	Cedar River at Janesville	1904-06, 1914-27, 1932-42, 1945-84	1,661	862	28	1922	146	71
05458900	West Fork Cedar River at Finchford	1945-84	846	518	5.9	1959	48	15
05463500	Black Hawk Creek at Hudson	1952-84	303	173	0.12	1977	16	2.9
05464000	Cedar River at Waterloo	1940-84	5,146	3,055	152	1959	559	285

[a] station located 4 miles downstream [b] regulated [c] from Lara, 1979 [d] September 1936 to June 1975 - gage height and discharge measurements only [e] approximately
[f] from U.S. Army Corps of Engineers, 1979 [g] monthly discharge only for some periods [h] continued as high-flow station only - see Table 3 for flood data
commas denote non-contiguous years --- insufficient data - less than 10 water years of record

Note: Because the discharges for the 7-day low-flow, duration of flow, and flood frequencies are based on analyses of relatively short periods of recorded data, they may, in some cases, not be representative of the actual long-term period.

Duration of daily discharges, equaled or exceeded, for percent of time indicated						Maximum known discharge	Year occurred	Flood discharge for given recurrence interval			
		Oct-Sep			Apr-Sep						
5	50	80	90	95	84			2-year	10-year	50-year	100-year
1,100	156	79	61	49	94	28,500	1941	6,490	14,100	20,900	23,800
1,106[c]	159[c]	79[c]	62[c]	51[c]	88[c]	28,500	1941	8,230	15,200	21,500	24,100
---	---	---	---	---	---	30,400	1941	6,610	12,200	---	---
39[c]	6.4[c]	3.2[c]	2.4[c]	1.9[c]	3.3[c]	9,100	1951	2,240	4,510	6,760	7,770
406[c]	64[c]	36[c]	27[c]	24[c]	42[c]	21,200	1941	8,010	15,600	22,400	25,300
88,600	25,000	15,400	12,800	11,200	17,300	276,000	1965	f	166,000[f]	227,000[f]	256,000[f]
---	---	---	---	---	---	300,000[e]	1965	f	191,000[f]	253,000[f]	277,000[f]
413	60	27	18	14	33	10,000	1947	2,850	7,020	11,000	12,700
1,660[c]	217[c]	93[c]	68[c]	52[c]	94[c]	30,000	1916	12,000	21,300	28,900	31,900
3,280	484	229	159	120	255	32,300	1922	15,700	24,100	30,300	32,700
266	36	18	14	12	18	h	h	h	h	h	h
650[c]	98[c]	50[c]	39[c]	32[c]	52[c]	h	h	h	h	h	h
---	---	---	---	---	---	7,360	1929	4,040	7,780	---	---
257	20	9.2	7.1	5.7	9.6	10,100	1974	2,380	7,450	13,400	16,200
2,540	248	82	49	30	92	26,800	1968	6,680	15,600	23,600	26,900
711	65	28	19	13	34	10,800	1961	3,040	8,240	13,600	15,900
3,110	426	208	154	120	239	37,000	1961	10,500	24,100	36,600	41,900
2,010	203	71	44	28	91	31,900	1951	5,630	17,200	29,100	34,100
648	66	24	15	9.9	28	19,300	1969	2,970	8,440	14,900	18,000
10,600	1,630	735	538	426	659	76,700	1961	24,000	56,800	85,500	97,100

[all discharges in cubic feet per second]

Table 2. Streamflow statistics for low-flow, partial-record stations in northeast Iowa

Station number	Station name	Drainage area (mi^2)	Regional average discharge[a]	Low-flow discharge[a] 7-day, 2-year	Low-flow discharge[a] 7-day, 10-year	Low-flow discharge[a] 84-percent duration Apr-Sep
	UPPER IOWA RIVER BASIN					
05387300	Upper Iowa River at Chester	141	84	7.5	4.3	13
05387400	Upper Iowa River near Kendallville	273	164	22	13	39
05388100	Canoe Creek near Decorah	58.9	35	7	4.3	12
05388300	Bear Creek near Highlandville	53.4	31	15	11	16
	VILLAGE CREEK BASIN					
05388350	Village Creek at Village Creek	58.5	34	19	17	20
	YELLOW RIVER BASIN					
05388800	Yellow River at Myron	59.5	35	4.1	2	7
	TURKEY RIVER BASIN					
05411550	North Branch Turkey River near Vernon Springs	40.1	23	1.6	0.8	3
05411560	Turkey River near Vernon Springs	87	51	2.5	0.9	5
05411620	Little Turkey River near Waucoma	102	60	13	5.2	20
05411700	Crane Creek near Lourdes	75.8	45	2	0.5	4
05411800	Little Turkey River near Alpha	319	193	29	12	46
05412100	Roberts Creek above St. Olaf	70.7	42	b	0	0.1
05412150	Roberts Creek at St. Olaf	101	60	b	0	0.1
05412200	Volga River near Fayette	53	31	2.8	1.6	3.9
05412300	Little Volga River near Fayette	31	18	1.6	0.4	2.4
05412400	Volga River at Littleport	348	211	34	17	52
	LITTLE MAQUOKETA RIVER BASIN					
05414450	North Fork Little Maquoketa River near Rickardsville	21.6	13	0.6	0.3	0.8
	MAQUOKETA RIVER BASIN					
05416300	Maquoketa River at Dundee	61.1	36	11	6.7	13
05416400	South Fork Maquoketa River near Dundee	54.8	32	4.1	2.1	5.6
05417540	Plum Creek near Earlville	65.7	39	9.2	5	12
05417560	Maquoketa River near Hopkinton	454	277	64	34	82
05417580	Buck Creek near Hopkinton	50.7	30	7.3	5.9	3.5
05418100	North Fork Maquoketa River at Dyersville	80.2	47	9.8	5.2	13
05418200	Whitewater Creek at Fillmore	91.9	54	14	7.4	18
05418300	Lytle Creek near Bernard	62.7	37	11	6	13

Table 2. (continued)

Station number	Station name	Drainage area (mi²)	Regional average discharge[a]	Low-flow discharge[a] 7-day, 2-year	7-day, 10-year	84-percent duration Apr-Sep
	WAPSIPINICON RIVER BASIN					
05420580	Wapsipinicon River near Ionia	161	96	9.5	4.7	12
05420640	Little Wapsipinicon River at Elma	37.3	22	3.6	1.4	4.5
05420660	Wapsipinicon River near New Hampton	291	176	13	5	23
05420680	Wapsipinicon River near Tripoli	343	208	13	5	23
05420700	East Fork Wapsipinicon River near Fredericksburg	62.2	36	2.8	1.1	5.1
05420720	East Fork Wapsipinicon River near Tripoli	144	86	6.6	2.6	11
05420740	Wapsipinicon River at Tripoli	498	304	14	4.1	28
05420800	Crane Creek near Denver	63.6	37	b	0	0.4
05420820	Crane Creek at Dunkerton	101	60	b	0	0.7
05420840	Little Wapsipinicon River near Westgate	57.4	34	2.6	0.6	5.2
05420860	Buck Creek near Littleton	57	33	0.6	0.1	1.6
05420900	Little Wapsipinicon River at Littleton	205	123	10	3.9	17
05420940	Otter Creek near Otterville	101	60	9.4	3.1	17
05421550	Buffalo Creek above Winthrop	68.2	40	2.7	1.1	3.7
	CEDAR RIVER BASIN					
05458400	Quarter Section Run near Denver	83.5	44	0	0	0
05464050	Millers Creek near La Porte City	54.8	30	0.9	b	3.7
05464250	Wolf Creek at La Porte City	327	175	16	4.0[c]	37
05464300	Spring Creek near La Porte City	57.5	33	2.9[d]	0.9[d]	4.5[c]

[all discharges in cubic feet per second]

[a] from Lara, 1979   [b] less than 0.1 cubic feet per second   [c] estimated from extrapolated correlation curve   [d] estimated from generalized map

Note: Because the discharges for the 7-day low flow and 84-percent duration of flow are based on analyses of relatively short periods of recorded data, they may, in some cases, not be representative of the actual long-term period.

Table 3. Streamflow statistics for high-flow, partial-record stations in northeast Iowa

Station number	Station name	Period of record	Drainage area (mi²)	Maximum known discharge	Year occurred	Flood discharge for given recurrence interval 2-year	10-year	50-year	100-year
	UPPER IOWA RIVER BASIN								
05388310	Waterloo Creek near Dorchester	1966-84	43.6	9,380	1978	---	---	---	---
	WEXFORD CREEK BASIN								
05388400	Wexford Creek near Harpers Ferry	1953-84	11.9	8,100[a]	1978	---	---	---	---
	PAINT CREEK BASIN								
05388600	Paint Creek near Waterville	1953-84	56	19,000[a]	1974	2,130	5,370	9,440	11,500
05388700	Little Paint Creek tributary near Waterville	1953-84	1.09	480[b]	1959	---	---	---	---
	TURKEY RIVER BASIN								
05411530	North Branch Turkey River near Cresco	1966-84	19.5	4,400	1969	284	1,750	5,000	7,180
05411650	Crane Creek tributary near Saratoga	1953-78	4.06	1,830	1962	632	1,580	2,520	2,930
05411700	Crane Creek near Lourdes	1953-84	75.8	11,900	1962	2,100	6,450	11,400	13,600
	LITTLE MAQUOKETA RIVER BASIN								
05414350	Little Maquoketa River near Graf	1951-84	39.6	7,220	1951	2,280	4,740	7,280	8,450
05414400	Middle Fork Little Maquoketa River near Rickardsville	1951-73, 1976-84	30.2	23,000[a]	1972	957	2,900	5,930	7,700
05414450	North Fork Little Maquoketa River near Rickardsville	1951-84	21.6	7,180	1972	1,300	3,130	5,380	6,530
05414500	Little Maquoketa River near Durango	1934-83	130	40,000	1972	6,580	14,500	23,900	28,600
05414600	Little Maquoketa River tributary at Dubuque	1951-84	1.54	3,000	1919	226	824	1,760	2,290
	MAQUOKETA RIVER BASIN								
05417000	Maquoketa River near Manchester	1928-30, 1933-83	305	25,400	1925	4,670	10,200	15,600	17,900
05417530	Plum Creek near Earlville	1966-84	41.1	4,000	1981	1,350	2,880	4,380	5,050
	WAPSIPINICON RIVER BASIN								
05420600	Little Wapsipinicon River tributary near Riceville	1953-84	0.90	920[a,b]	1984	250	794	1,380	1,640
05420620	Little Wapsipinicon River near Acme	1953-84	7.76	2,380	1962	471	1,300	2,420	3,010
05420640	Little Wapsipinicon River near Elma	1953-84	37.3	5,740	1962	1,200	3,420	5,940	7,120
05420650	Little Wapsipinicon River near New Hampton	1966-84	95	9,200	1969	2,060	4,550	7,220	8,480
05420690	East Fork Wapsipinicon River near New Hampton	1966-84	30.3	11,000	1969	1,800	5,600	10,100	12,300
05420850	Little Wapsipinicon River near Oran	1966-84	94.1	6,200[a]	1979	1,600	3,690	5,840	6,810
05420855	Buck Creek near Oran	1966-84	37.9	1,460	1979	c	c	c	c
05420960	Harter Creek near Independence	1952-63	6.17	2,280	1962	371	1,520	3,220	4,120
05421100	Pine Creek tributary near Winthrop	1952-84	0.334	334	1968	84	238	412	494
05421200	Pine Creek near Winthrop	1950-84	28.3	24,200	1968	1,180	3,570	7,150	9,180
05421300	Pine Creek tributary no. 2 at Winthrop	1953-84	0.704	570	1968	69	411	1,030	1,380
05421550	Buffalo Creek above Winthrop	1957-84	68.2	14,100	1968	1,590	5,980	13,300	17,700
05421600	Buffalo Creek near Winthrop	1953-55	71.4	14,800[a]	1968	1,510	6,720	16,000	21,700

[a] estimated [b] revised [c] regional outlier - data not used

[all discharges in cubic feet per second]

--- insufficient data - less than 75% of years during periods of record had peaks above bottom of gage

Note: Because the flood-frequency discharges are based on analyses of relatively short periods of recorded data, they may, in come cases, not be representative of the actual long-term period.

STREAMFLOW VARIABILITY

Streamflow is variable, ranging from relatively short periods of destructive high flows (floods) to long periods of low or no flow. This variability occurs because such influencing factors as precipitation, temperature, soil moisture and type, basin cover, basin size, and geology are commonly quite variable. Streamflow (discharge) responds most directly and quickly to intense and/or frequent precipitation as shown in figure 13.

Typical seasonal variation in runoff is shown in figure 14. It shows, for the period 1951-80, the average monthly precipitation on the Turkey River basin upstream of Garber and the resulting average monthly runoff. Runoff is greatest during March although precipitation is greater during each of the next six months, and precipitation during July is about twice that of March. Generally, the percentage of runoff to precipitation is greatest during March; during late winter the ground is still frozen or saturated so little water infiltrates, plant growth is minimal so evapotranspiration is small, and warmer temperatures release any stored winter precipitation. From March to September, runoff and the percentage of runoff to precipitation decrease each month as infiltration and evapotranspiration take a greater share of the available moisture. After July, precipitation continues to decrease until January, but runoff remains fairly steady as infiltration and evapotranspiration decrease.

Streamflow variability for water years 1934 and 1983 for the Turkey River at Garber is shown in figure 15. The lowest average annual discharge recorded was 249 cubic feet per second (2.20 inches runoff) in 1934 when total basin precipitation was about 25 inches. By contrast, the highest average annual discharge recorded was 2,234 cubic feet per second (19.63 inches runoff) in 1983 when total basin precipitation was about 43 inches. Based on the entire period of record for the Turkey River at Garber (table 1), the average annual discharge is 956 cubic feet per second, and is equivalent to 8.4 inches of runoff from the entire drainage area. Based on the standard period 1951-80 for three climatological stations, the average annual precipitation for the Turkey River basin upstream from Garber is about 33 inches.

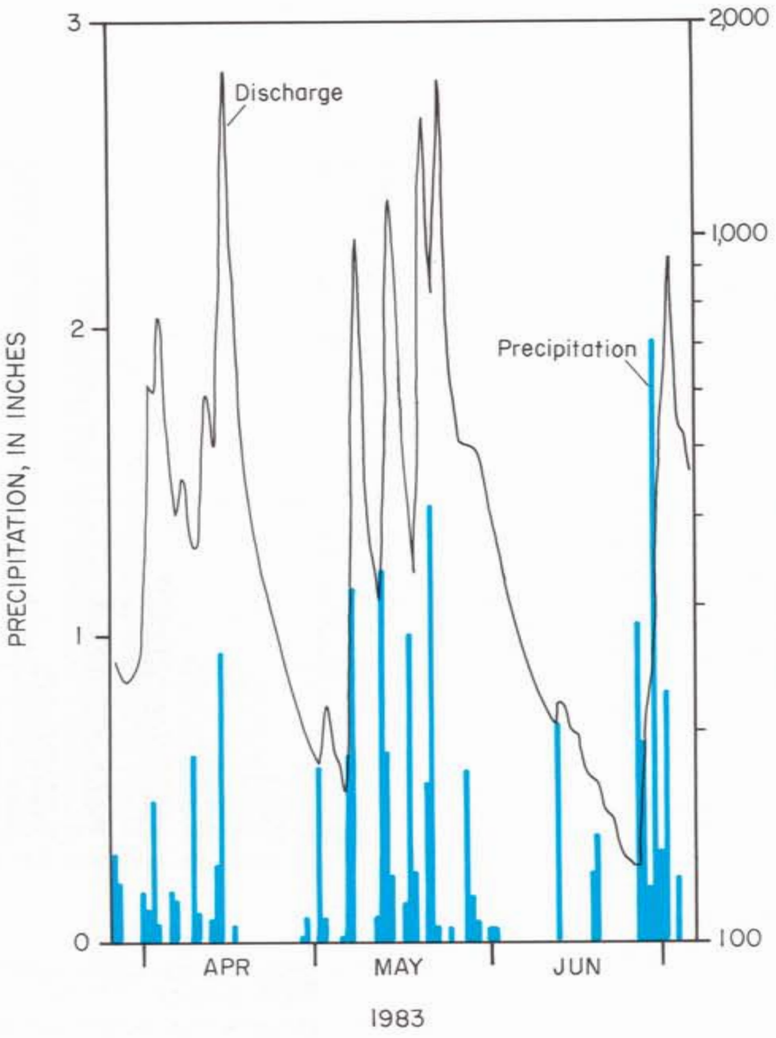


Figure 13. Total daily precipitation and average daily discharge at Spillville, Iowa, (April - June, 1983)

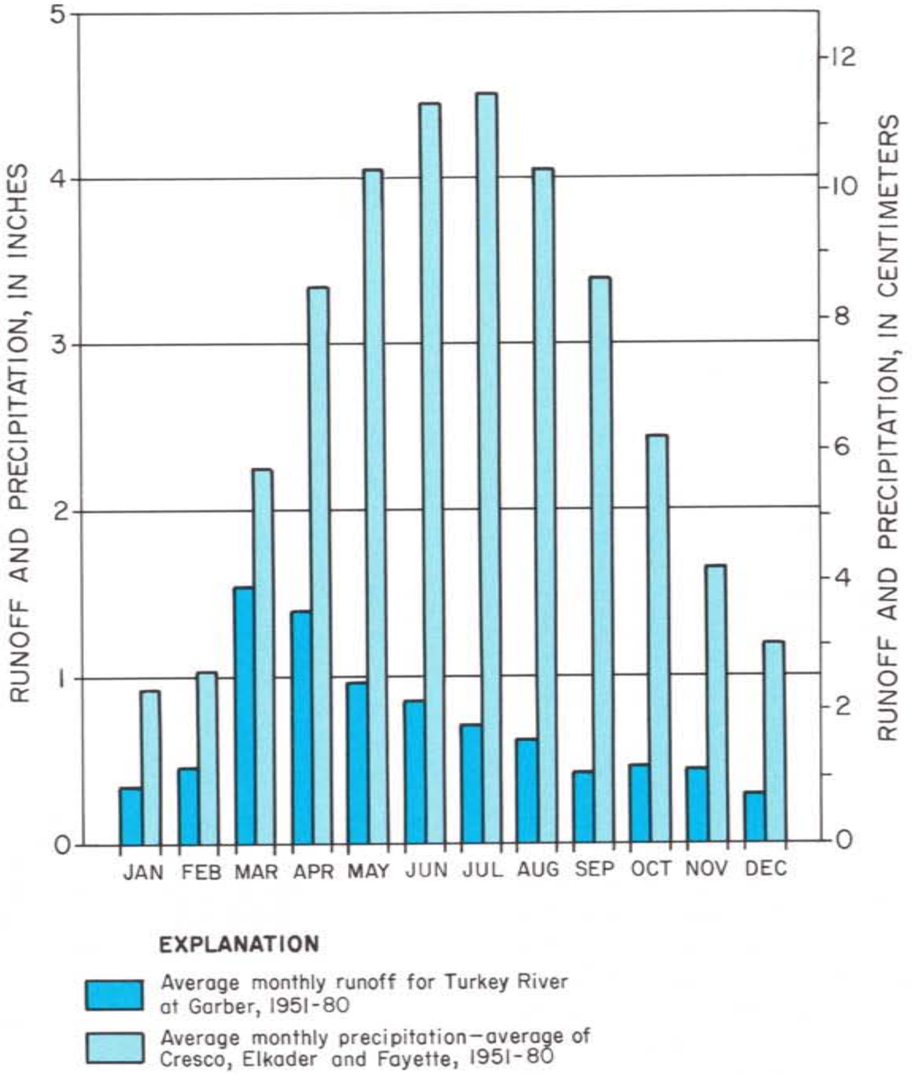


Figure 14. Average monthly precipitation in the Turkey River basin and average monthly runoff for Turkey River at Garber, Iowa, 1951-80

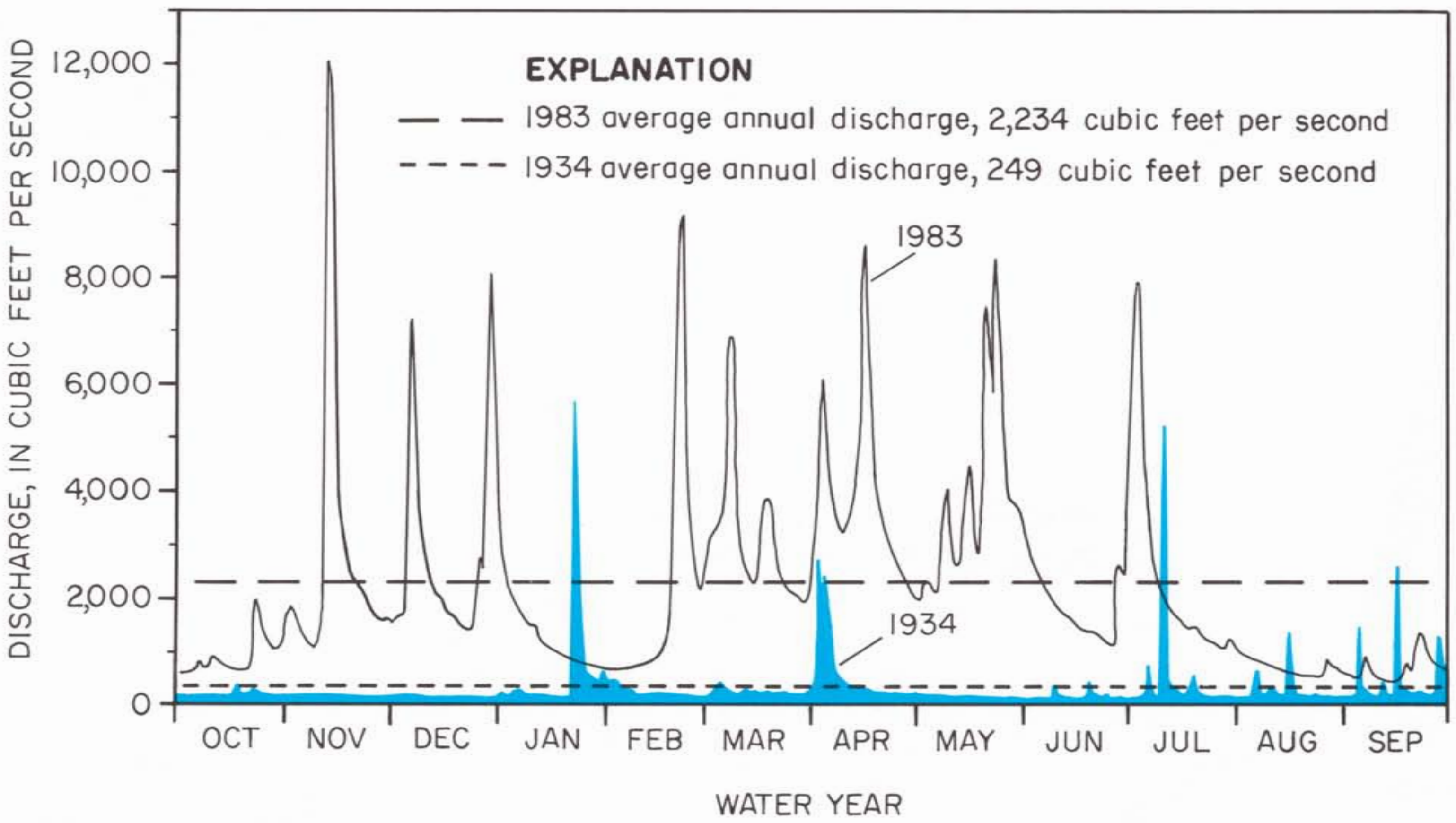


Figure 15. Average daily streamflow (discharge) in Turkey River at Garber, Iowa, in 1934 and 1983

Figure 16. Regional average-discharge areas and equations (from Lara, 1979)

AVERAGE DISCHARGE

The average discharge or streamflow for a given stream location theoretically represents the total amount of water which is available for long-term use from that stream. When related to drainage area, the average discharge also provides information for making hydrologic comparisons between different drainage basins and geographic regions.

Because streamflow information is often required at ungaged or partially gaged stream locations, equations have been developed to estimate average discharge for any stream location in the state (Lara, 1979). Three regional equations were developed using available streamflow records through the 1976 water year. Average discharge values for low-flow, partial-record stations (table 2) were computed from these equations. All of northeast Iowa is included in Region I except for the Cedar River basin which is in Region II (figure 16); Region III is for northwestern Iowa and is not shown in figure 16. For Regions I and III, drainage area (A, in square miles) is the only parameter needed to compute average discharge (Qa, in cubic feet per second), but in Region II average annual precipitation (P, in inches) also must be used. A graph of the equations that apply to the study area and the individual station's data are shown in figure 17. Note that these are generalized equations based on more information than shown. The equations have a standard error of about 17 percent.

Northeast Iowa has higher average streamflow than most other areas of Iowa. This is indicated by a regional comparison of average discharge values for 100-square-mile drainage areas in different parts of the state: northwestern (region III), 22 cfs; central and southwestern (region II), 50 cfs; southeastern (region II), 61 cfs; and northeastern (region I), 59 cfs. Some of the regional variation in average streamflow is caused by increasing precipitation from northwest to southeast, but some is also caused by differences in physical basin characteristics across the state.

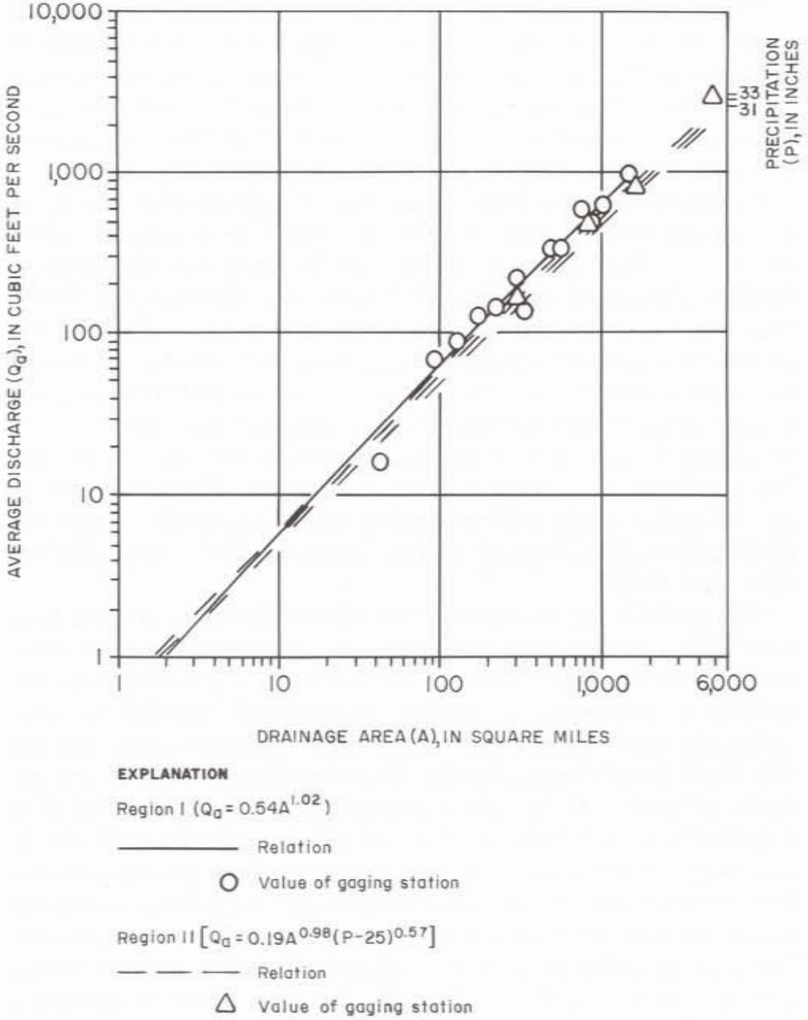


Figure 17. Average discharge in relation to drainage area in northeast Iowa

FLOW DURATION

Flow-duration curves and tables show the percentage of time that certain flows at a particular stream location have been equaled or exceeded during the period of record. For stations that have enough years of record, flow-duration relations can be used for designing river power plants, estimating future water supplies, establishing regulations on water use and withdrawal, and studying basin characteristics.

Summaries of daily discharge duration through the 1984 water year for streams with at least 10 years of continuous record are shown in table 1. More complete summaries, including various seasonal-duration discharges, are available for all Iowa streams (Lara, 1979). They are based on records through the 1976 water year. The 84-percent flow-duration values for April through September are one of the criteria used by the Iowa Department of Natural Resources for determining protected streamflows, regulating stream withdrawals, and regulating alluvial aquifer withdrawals within 1/8 mile of streams. The 84-percent values listed in table 1 were computed for the continuous-record stations using methods developed by Lara (1979). Those for the low-flow, partial-record stations listed in table 2 were obtained from Lara (1979).

When flow-duration values are plotted in discharge-per-unit area, as in figures 18 and 19, the range of values and the shape of the flow-duration curve can be indicators of hydrologic and geologic characteristics of that basin. At the high-discharge end of a flow-duration curve, flat slopes and relatively small values indicate streams that rise and recede slowly during floods. Such moderate reaction to precipitation generally signifies that the basin includes areas of natural or man-made surface storage (wetland areas, wide flood plains or reservoirs), or has a large drainage area or some combination thereof. Flow-duration curves with steep slopes and large initial discharge values are indicative of streams that react quickly to precipitation, discharge relatively large volumes of water for a short period of time, and then recede quickly. Generally, this type of curve signifies a basin with small surface-storage capacity and small total drainage area, or both. The low-discharge end of the flow-duration curve indicates how well a basin can sustain flow during dry periods. Larger discharge values and flat slopes indicate substantial inflow from groundwater sources. Smaller discharge values and steep slopes characterize streams

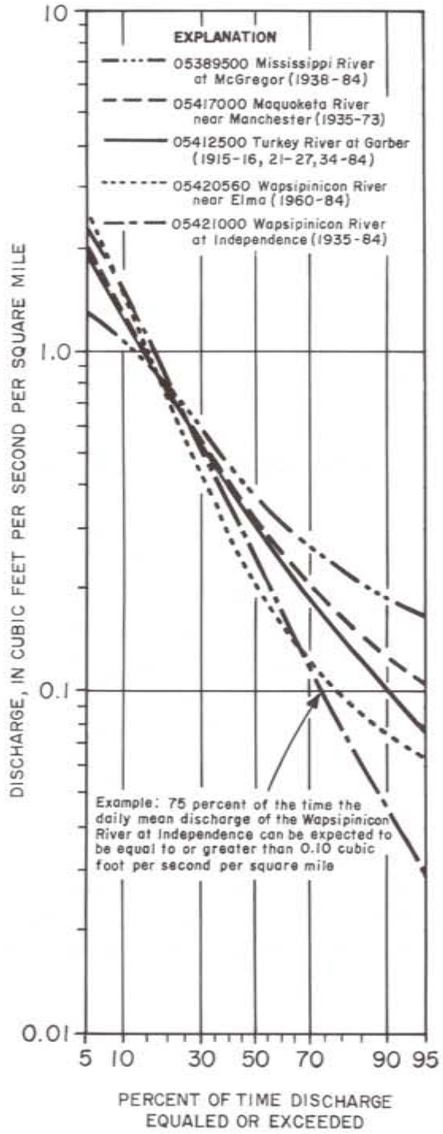


Figure 18. Flow-duration curves for five northeast Iowa rivers

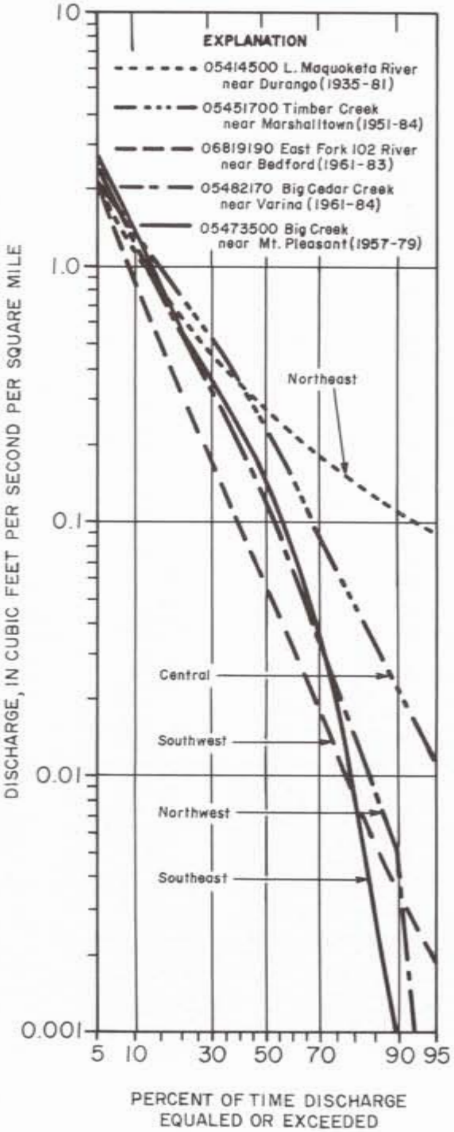


Figure 19. Flow-duration curves for five Iowa streams

that could go dry because groundwater inflow is insufficient or streamflow is lost to the groundwater system.

Flow-duration curves for five streams in northeast Iowa are shown in figure 18. The Mississippi River at McGregor receives most of its drainage from areas outside the study area, but the flow-duration curve is typical of a very large stream with stable flow characteristics. Typical of much of the study area are the flow-duration curves for the Turkey River at Garber and Maquoketa River near Manchester which denote large, sustained low flows. Flow-duration curves for the Wapsipinicon River near Elma and at Independence (downstream of Elma) show an interesting difference. Beyond the 70-percent duration, the discharge per square mile at Independence decreases markedly from that near Elma, possibly indicating that between the two stations there is proportionately very little surface or underground basin storage and/or there is some loss of streamflow.

Flow-duration curves for five streams from different areas of the state with approximately the same size drainage basins are shown in figure 19. The sustained flows in northeast Iowa, as typified by the Little Maquoketa River near Durango, are much higher than the other streams shown in figure 19. Big Creek near Mt. Pleasant, in southeastern Iowa, typifies a stream that is flashy during floods and has little basin storage available to maintain low flows.

LOW-FLOW FREQUENCY

While flow-duration curves provide valuable information about low-flow characteristics of streams, they provide no information about low-flow values for a given number of consecutive days. Low-flow frequency analyses are valuable to those who must manage the available water supply to meet specific needs or design storage structures and to those for whom groundwater supplies are not available.

For this report, the lowest average discharge for 7 consecutive days of flow from each climatic year (April 1 - March 31) was determined for each station that had at least 10 years of daily streamflow record. Using these values, a mathematical frequency analysis was done to determine the 7-day low flow that could be expected to occur on the average of once in 2 years (7-day, 2-year low flow) and once in 10 years (7-day, 10-year low flow). This does not mean that the 7-day 2-year low flow will occur every other year; rather, the 7-day low flow for any one year has a 50-percent chance of being equal to or less than the 7-day, 2-year low-flow value. Likewise, any one year has a 10-percent chance of having the 7-day low flow equal to or less than the 7-day, 10-year low-flow value. Computed low-flow values for continuous-record stations are shown in table 1, and low-flow values from Lara (1979) are shown for low-flow, partial-record stations in table 2. There are some extremely low discharge values in table 2 for two Roberts Creek stations; direct loss of streamflow to groundwater via sinkholes is the apparent reason.

The 7-day, 10-year low-flow data is of special importance to the Iowa Department of Natural Resources for at least two regulatory purposes. When streamflow exceeds the 7-day, 10-year low flow, water-quality standards for the various stream classifications are enforced (Iowa Department of Water, Air, and Waste Management, 1983). When streamflows are less than the 7-day, 10-year low flow, consumptive users of water from alluvial aquifers must cease withdrawals within 1/4 mile of streams. Annual 7-day low-flow data for the Wapsipinicon River at Independence are shown in figure 20. Low and high years tend to group together in a roughly cyclical pattern. During 1935-42, only one year had a 7-day low-flow value greater than the 7-day, 2-year low-flow value (53 cfs), and three years had 7-day low-flow values less than the 7-day, 10-year low-flow value (17 cfs). Conversely, during 1979-84, all 7-day low-flow values were

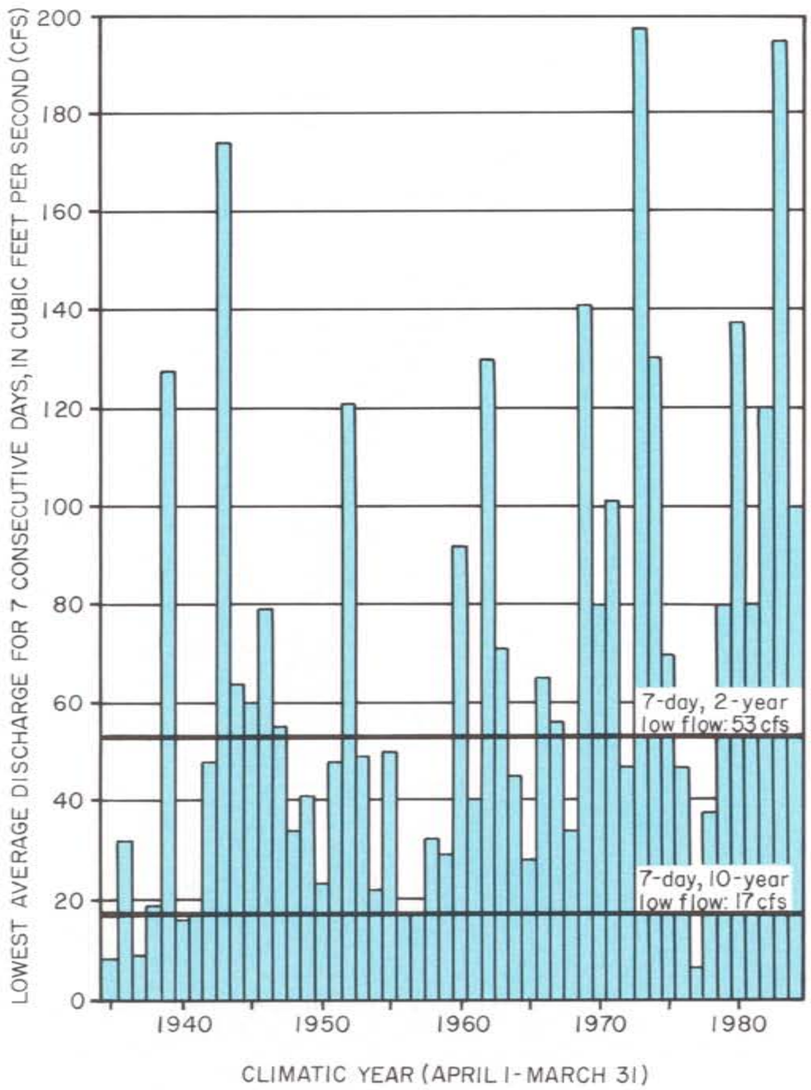


Figure 20. Annual, 7-day low flows for the Wapsipinicon River at Independence, Iowa

greater than the 7-day, 2-year low-flow value.

The 7-day, 2-year and 10-year low-flow values are but two of the many low-flow statistics that can be calculated from frequency analyses. Based on data through 1976, Lara (1979) published low-flow discharges for periods of 3, 7, 14, 30, 60, 120, and 183 consecutive days and recurrence intervals of 1.5, 2, 5, 10, and 20 years, as well as 7-, 14-, and 30-day low-flows within each quarter of a year.

FLOODS

Because floods are costly in terms of damage to property and loss of human lives, it is necessary to know as much as possible about them. Streamflow data from stream-gaging stations are recorded and then accessed by various telephone, radio, and satellite systems for immediate use. They are stored along with any known historical data for future reference. Flood-flow data have a wide range of application: flood mapping; regulation of flood plains; design of flow structures (bridges, culverts, spillways, dam outlets), temporary and permanent containment structures (levees and floodwalls), and storage and detention dams; and other public and private needs within flood-prone areas. Management of these structures and facilities, as well as flood forecasting, rely heavily on current streamflow data.

Frequency analyses of recorded and historic floods are useful to plan for future floods. Using guidelines of the Interagency Advisory Committee on Water Data (1982), relations of flood discharge to recurrence interval have been computed for each continuous-record and each high-flow, partial-record station that has at least 10 years of record, as of the 1984 water year. Values for the 2-, 10-, 50-, and 100-year floods are shown in tables 1 and 3. These floods have a 1 in 2, 1 in 10, 1 in 50, and 1 in 100 chance of occurring in any one year. These values of flood frequency are accurate to the extent that the record from which they are computed represents the long-term flood history.

A flood-frequency curve for the Upper Iowa River at Decorah is shown in figure 21. Also shown is a regional flood-frequency curve for the same size drainage area, as computed from Lara (1973). Using all available flood data, Lara developed equations that can be used to estimate the flood discharge for various frequencies at any stream

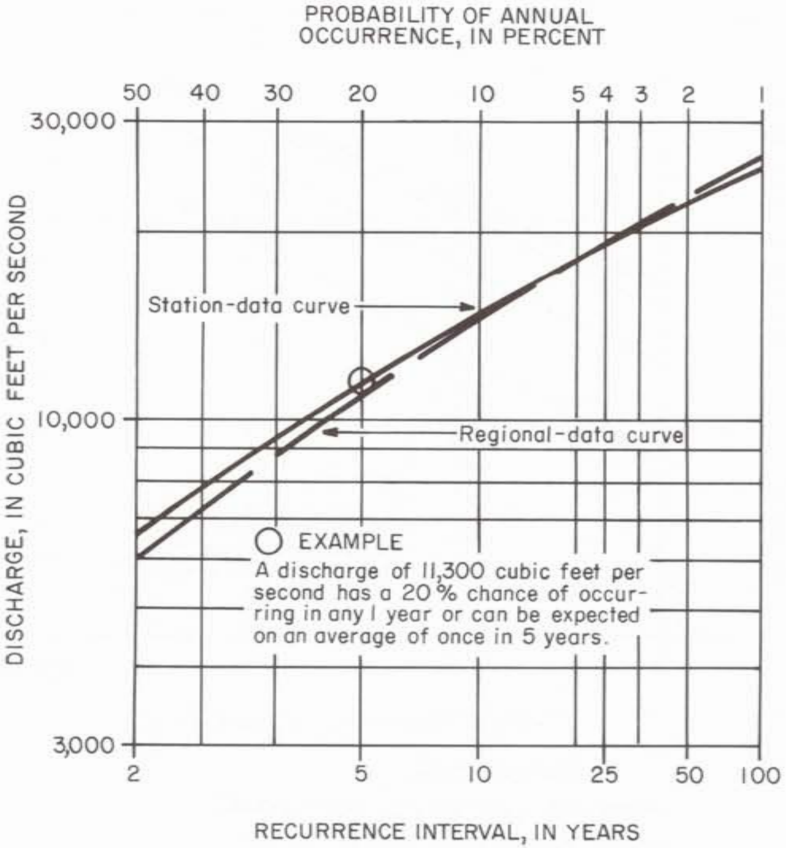


Figure 21. Flood-frequency curve for the Upper Iowa River at Decorah, Iowa

location in the state. Estimates can be made for stream locations that have at least 2 square miles drainage area, provided the channel slope can be determined, or 10 square miles drainage area if only the area and location are known. All of northeast Iowa is included in Region I, except the Cedar River below its confluence with the West Fork Cedar River. Plots of Region I relations of flood discharge to drainage

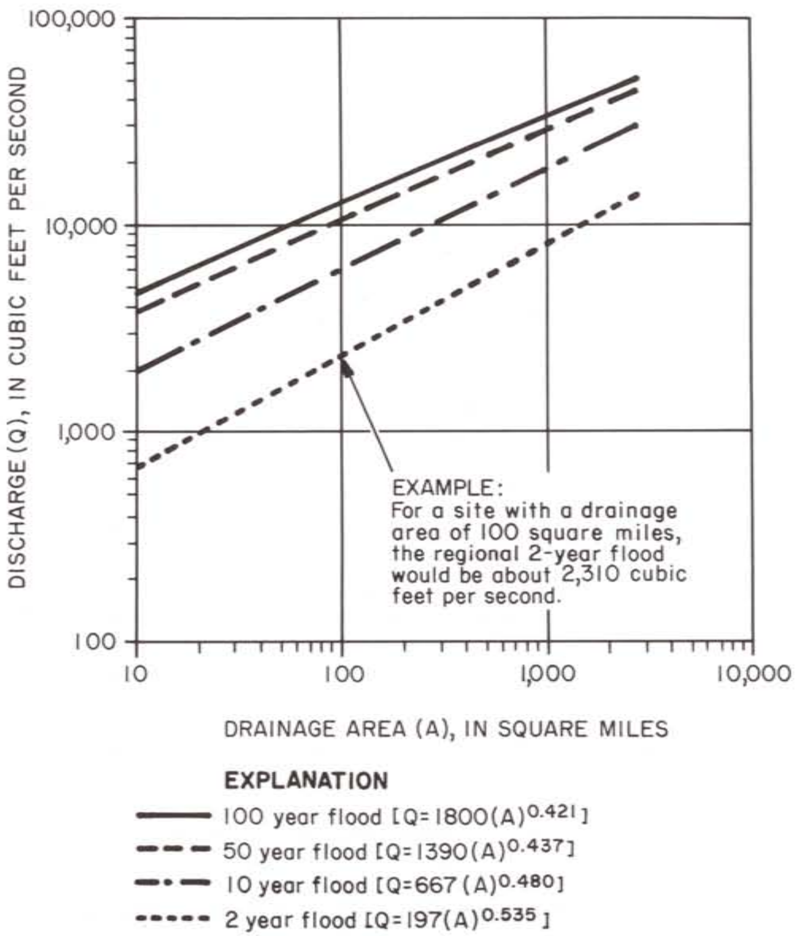


Figure 22. Relation between flood discharge and drainage area for given recurrence intervals

area for several recurrence intervals are shown in figure 22. Flood discharge data for the mainstem of the Cedar River are shown in figure 23.

The largest known flood for each continuous-record, and each high-flow, partial-record station is listed in tables 1 and 3. These values were obtained from the annual State Water Resources Data reports. Special flood-profile reports that provide more detailed flood information are also available for the Cedar River basin (Schwob, 1963), Wapsipinicon River basin (Schwob, 1971), and Little Maquoketa River basin (Heinitz, 1973).

TOPOGRAPHIC AND FLOOD-PRONE MAPS

Published topographic maps prepared by the U.S. Geological Survey are available for all of northeast Iowa. The 7 1/2 minute sheets are shown in figure 24; these maps are at a scale of 1:24,000 (1 inch on the map equals 24,000 inches or 2,000 feet) and provide great detail. Contour intervals are either 10 or 20 feet depending on the area's relief. The 1:24,000-scale maps cover 7 1/2-minutes of latitude and longitude, about 55 square miles.

NK-series topographic maps are available for the region at a scale of 1:250,000 (1 inch equals approximately 4 miles). These maps have 50-foot contour intervals and supplementary 25-foot contours. The four sheets covering the study area are: Mason City, Iowa-Minnesota (NK 15-2); LaCrosse, Wisconsin-Iowa-Minnesota (NK 15-3); Waterloo, Iowa (NK 15-5); and Dubuque, Iowa-Wisconsin-Illinois (NK 15-6).

All maps listed are available from the Iowa Department of Natural Resources, Geological Survey Bureau, 123 N. Capitol Street, Iowa City, Iowa 52242, and the U.S. Geological Survey, Map Distribution Center, Box 25285, Federal Center, Denver, Colorado 80225. An index for the topographic maps of Iowa is available from the Department of Natural Resources, Geological Survey Bureau.

For some streams in northeast Iowa, the 7 1/2-minute topographic maps have been used to produce flood-prone-area maps that outline the approximate limits of the 100-year flood or of a historic flood. Available flood-prone-area maps for northeast Iowa are shown in light blue shading on the 7 1/2-minute topographic map index (figure 24).

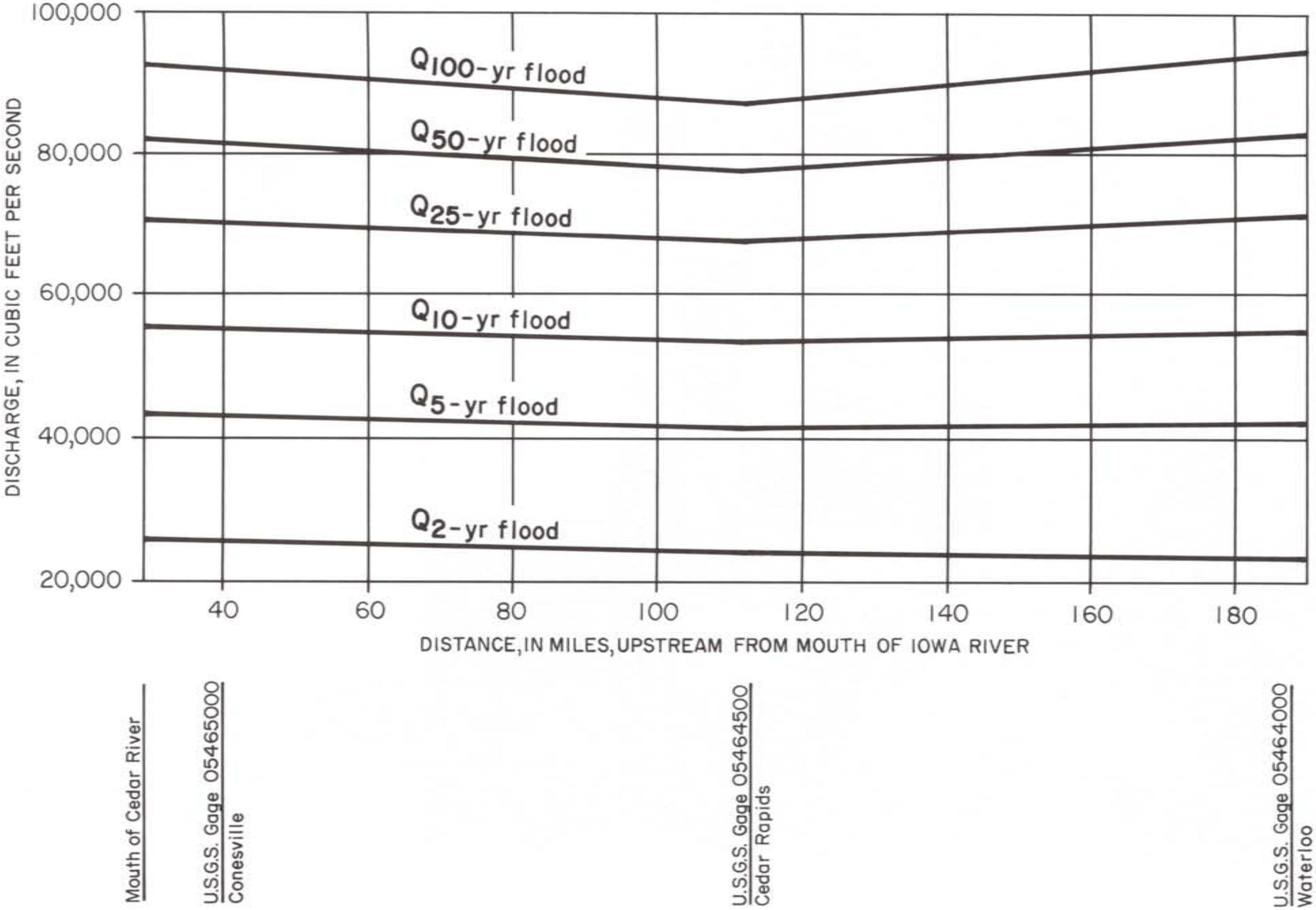


Figure 23. Peak discharges for indicated recurrence intervals for the main stem of the Cedar River (from Lara, 1973)

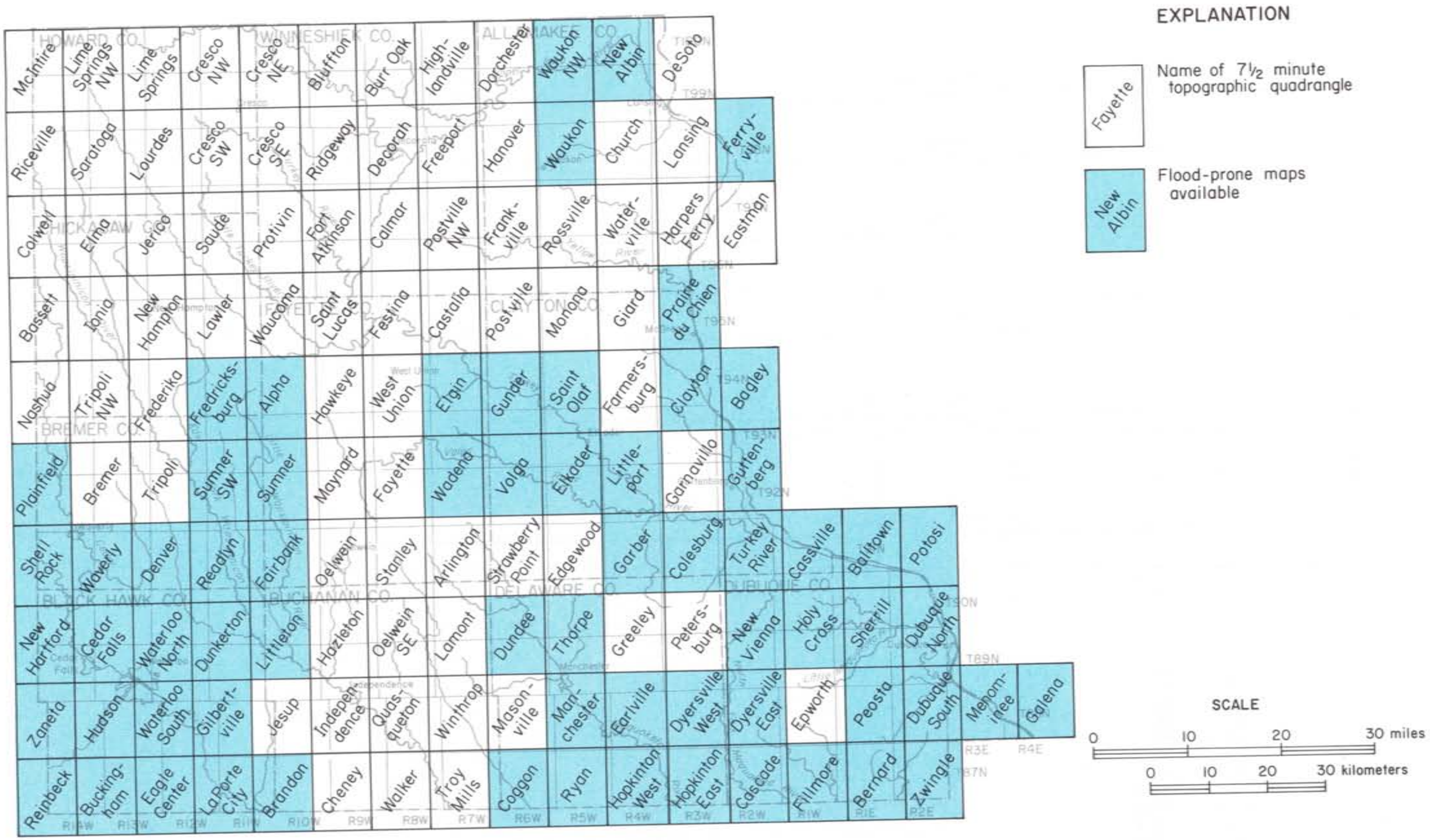


Figure 24. Topographic and flood-prone maps for northeast Iowa

These flood-prone-area maps can be obtained from the U.S. Geological Survey, P.O. Box 1230, Iowa City, Iowa 52244.

The National Flood Insurance Program of the Federal Emergency Management Agency, Federal Insurance Administration has produced a series of flood-insurance-rate maps of cities and unincorporated areas of counties. Those communities that are participating in the program and have maps completed are listed below (Federal Emergency Management Agency, Federal Insurance Administration, 1986). Contact the individual city or county for information or order maps and/ or indices from the Federal Emergency Management Agency, Flood Map Distribution Center, 6930 (A-F) San Tomas Road, Baltimore, Maryland 21227-6227.

MAP TITLE	COUNTY	PUBLICATION
Alta Vista	Chickasaw	Dec. 20, 1974
Black Hawk County		Nov. 17, 1982
Bremer County		May 10, 1977
Cascade	Dubuque	Apr. 2, 1979
Cedar Falls	Black Hawk	Feb. 1, 1985
Clayton County		Jan. 31, 1978
Clayton	Clayton	Aug. 23, 1974
Clermont	Fayette	Mar. 1, 1986
Denver	Bremer	Feb. 27, 1976
Dubuque County		Sep. 1, 1983
Dubuque	Dubuque	Oct. 31, 1975
Dundee	Delaware	Jul. 30, 1976
Dunkerton	Black Hawk	Jan. 16, 1980
Durango	Dubuque	Jul. 16, 1981
Dyersville	Dubuque	Nov. 19, 1980
Elgin	Fayette	Jul. 30, 1976
Elk Run Heights	Black Hawk	Aug. 1, 1983
Elkader	Clayton	Sep. 29, 1975
Elkport	Clayton	Aug. 22, 1975
Elma	Howard	Sep. 19, 1975
Epworth	Dubuque	Jul. 12, 1977
Evansdale	Black Hawk	Nov. 2, 1977
Fairbank	Buchanan/Fayette	Jul. 25, 1975
Farmersburg	Clayton	Nov. 1, 1974
Fayette	Fayette	May 28, 1976
Fredericksburg	Chickasaw	Jul. 23, 1976
Garber	Clayton	Apr. 30, 1976
Gilbertville	Black Hawk	Aug. 1, 1978
Greeley	Delaware	*
Guttenberg	Clayton	Sep. 5, 1984
Hopkinton	Delaware	Oct. 29, 1976
Hudson	Black Hawk	Jan. 15, 1980
Independence	Buchanan	May 16, 1977
Janesville	Black Hawk/Bremer	Oct. 31, 1978
La Porte City	Black Hawk	Jan. 2, 1981
Lawler	Chickasaw	Jun. 28, 1974
Littleport	Clayton	Feb. 6, 1976
Manchester	Delaware	Oct. 15, 1982
Marquette	Clayton	Oct. 3, 1975
Maynard	Fayette	Sep. 19, 1975
McGregor	Clayton	Oct. 17, 1975
Nashua	Chickasaw	Sep. 29, 1978
New Hampton	Chickasaw	May 23, 1978
New Vienna	Dubuque	Oct. 18, 1983
Oelwein	Fayette	Mar. 5, 1976
Osterdock	Clayton	Jul. 18, 1978
Plainfield	Bremer	Mar. 1, 1986
Quasqueton	Buchanan	Aug. 23, 1977
Raymond	Black Hawk	Jul. 11, 1978
Sageville	Dubuque	Jun. 15, 1984
St. Olaf	Clayton	Oct. 31, 1975
Sumner	Bremer	Apr. 30, 1976
Volga	Clayton	Jan. 9, 1976
Waterloo	Black Hawk	Jul. 3, 1985
Waucoma	Fayette	Jul. 30, 1976
Waukon	Allamakee	*
Waverly	Bremer	Mar. 2, 1981
Worthington	Dubuque	Oct. 18, 1983

* - The community has no special flood hazard areas and a flood map for the community has not been published.

WETLANDS

Wetlands are low areas where water stands or flows either continuously or periodically. In popular terms they are called swamps, sloughs, marshes, potholes, lakes, bogs, wet meadows, and seeps, all shallow-water areas. Usually they contain typical plant life such as prairie grasses, sedges, bullrushes, reeds, cattails, and water lilies. The definition of wetlands used here includes man-made lakes, abandoned water-filled gravel pits and quarries, farm ponds, overflow areas, and oxbows (abandoned channels) on river bottomlands.

The U.S. Soil Conservation Service has a wetland classification system with a total of 20 wetland types, but only five types are recognized in Iowa. These are as follows: 1) seasonally flooded basins or flats found in upland depressions and in overflow bottomlands; 2) inland fresh meadows that are usually without standing water, but have water-logged soil to within a few inches of the surface; 3) inland shallow fresh marshes that have water-logged soils and are often covered with six inches or more of water; 4) inland deep fresh marshes in which the soil is covered with 6 inches to more than 3 feet of water during the growing season; and 5) inland open fresh water that includes shallow ponds and reservoirs in which the water is usually less than 10 feet deep and fringed by emergent vegetation.

A description of wetlands in Iowa is also provided by Bishop and Van der Valk (1982). They identified four basic types of wetlands: 1) palustrine wetlands (also known as prairie potholes or prairie glacial marshes) which are typically shallow basins in which the water level fluctuates seasonally or for longer periods due to drought conditions; 2) lacustrine wetlands in shallow protected areas of large lakes; 3) riverine wetlands associated with rivers; and 4) seepage wetlands where the land surface intersects the water table. In this last case, soils are saturated throughout the year but do not have standing water.

Both the Soil Conservation Service and Bishop and Van der Valk (1982) classifications have been used to identify and describe wetlands of northeast Iowa. The majority of wetlands are associated with rivers, such as the backwater areas, sloughs, and lakes of the Mississippi River. Shallow marshes and oxbows occur on the broad floodplains of the Cedar, Wapsipinicon, and Maquoketa rivers, and artificial lakes and deep marshes are found behind dams and levees. Appendix I lists wetlands of northeast Iowa that have surface areas of 5 acres or more. The data were obtained from topographic maps; from the Iowa Department of Environmental Quality, Water Quality Management Plan, Northeast Iowa Basin (1976); from the U.S. Department of Agriculture, Soil Conservation Service; and by field investigation.

It is estimated that since 1850, 95 percent of Iowa's wetlands have vanished. They have been converted to farmland and urban areas by various drainage methods. More than 50 percent of Iowa's existing wetlands are owned by state or county government.

SPRINGS AND SEEPS

Springs and seeps contribute significant streamflow in northeast Iowa. The sources of spring flow can usually be identified; the most common sources are Silurian System and Galena Group limestones and dolostones. Prairie du Chien Group and Jordan Sandstone strata also may be sources for a few springs in Allamakee County. The springs vary in size, abundance, and discharge rate. They may emanate from small fractures in carbonate rock or from large crevices and caves. Their discharge rates range from intermittent to perennial flow; maximum measured discharges of almost 300 cfs have followed intense rainstorms. Big Spring along the Turkey River in northwestern Clayton County reportedly discharges as much as 295 cfs after heavy rains. The minimum discharge of Big Spring is about 32 cfs. Big Spring is fed by a groundwater basin comprising about 103 square miles. Numerous other northeast Iowa springs flow continually. In all cases, rates of discharge reflect seasonal and precipitation variation.

Almost all the springs are associated with the Paleozoic Plateau in Winneshiek, Fayette, Allamakee, Clayton, Delaware, and Dubuque counties. Many occur along stream valleys at the junction of valley walls and valley floors. Other springs occur higher in the valley walls in karst bedrock and create spectacular waterfalls such as Dunnings Spring at Decorah. Many springs are found in the headwaters of small tributary streams along the Silurian escarpment at the contact of the Silurian System dolostones and underlying Maquoketa Shale.

Almost a century ago, Calvin (1895) reported that many large springs were found in northwestern Allamakee County near Quandahl and Dorchester at the contact of the Prairie du Chien Group and Jordan Sandstone. Most of these springs no longer flow, however, because of the considerable decline in water levels. A list of some of the most notable springs of this area is shown in table 4.

Table 4. List of noteworthy springs in northeast Iowa

Spring name	Location	Source
ALLAMAKEE COUNTY		
Unnamed springs	Valley floor, SW, sec. 31, T99N, R6W	Prairie du Chien - Jordan contact
Unnamed spring	Valley floor Paint Creek, SE, NW, sec. 19, T97N, R3W	Prairie du Chien - Jordan contact
CLAYTON COUNTY		
Big Spring (fish hatchery)	Valley floor Turkey River at fish hatchery, SE, NE, SE, sec. 31, T94N, R5W	Galena Group
Unnamed springs	In valley walls in tributaries of Turkey River, secs. 4, 5, 6, T93N, R6W	Silurian
Unnamed spring	At Littleport, supplies Honey Creek, a tributary of the Volga River, SW, SE, SE, sec. 25, T92N, R5W	Galena Group
Bixby State Park Spring	In valley of Bear Creek, SW, SW, SE, sec. 23, T91N, R5W	Silurian
Baron Spring	On a tributary of Kleinlein Creek, 3 miles north of Strawberry Point, SE, NE, sec. 4, T91N, R6W	Silurian
South Spring	In the headwater area of Kleinlein Creek on the valley floor, NE, NE, SW, sec. 10, T91N, R6W	Silurian
Big Spring	Two miles north of Strawberry Point on a small side valley of Kleinlein Creek, NE, NW, NE, sec. 10, T91N, R6W	Silurian
Joy Springs	In the Maquoketa River Valley in Joy Springs County Park, NE, SE, SW, sec. 19, T91N, R6W	Silurian
DELAWARE COUNTY		
Fountain Mill Spring	Several springs in this general area along Branch Creek, Schechtman Branch, and Elk Creek, northeast of Greeley two to four miles, W½, SE, SE, sec. 16, T90N, R4W	Silurian
Richmond Spring	In Backbone State Park on a tributary of the Maquoketa River, SE, SE, NW, sec. 4, T90N, R4W	Silurian
Unnamed spring	In valley of Spring Branch on north side of Highway 20, ½ mile north of fish hatchery, SW, SW, SE, sec. 35, T89N, R5W	Silurian
Unnamed springs	Supplying large ponds on the lower valley slopes of Plum Creek, SW, sec. 22 and SW, NW, sec. 27, T88N, R3W	Silurian
Unnamed springs	In the headwater area of a small valley a mile southwest of Delhi, NW, SE, NE, sec. 19, T88N, R4W	Silurian
Unnamed spring	At Hopkinton at the foot of the valley slope of the Maquoketa River, SW, NW, SE, sec. 13, T87N, R4W	Silurian

Table 4. (continued)

Spring name	Location	Source
DUBUQUE COUNTY		
Black Bridge Spring	On the valley floor of a small tributary of the Mississippi River, SW, SE, SE, sec. 30, T91N, R1E	Galena Group
Unnamed spring	Supplies Durion Creek about 2½ miles northeast of Worthington on valley floor, SW, SE, NE, sec. 17, T88N, R2W	Silurian
FAYETTE COUNTY		
Falling Springs	In the valley wall of a small tributary of the Little Turkey River, SW, SW, SE, sec. 35, T95N, R9W	Silurian
Unnamed springs	On the valley floor of Otter Creek 2½ miles upstream from Elgin, SW, SW, sec. 20 and SE, SE, sec. 21, T94N, R7W	Silurian
Unnamed springs	Along the Volga River tributaries upstream from Volga and Wadena in T92 and 93N, R7 and 8W	Silurian
Blue Spring	In Brush Creek Canyon State Park, SW, SW, NE, sec. 17, T92N, R7W	Silurian
HOWARD COUNTY		
Unnamed spring	At base of valley slope of Bigalk's Creek, NE, SW, SE, sec. 13, T100N, R11W	Galena Group
WINNESHIEK COUNTY		
Mestad Spring	On the valley floor of South Bear Creek, SE, SE, NE, sec. 29, T100N, R7W	Prairie du Chien Formation
Cold Water Spring	On the valley slope of Cold Water Creek, NW, NE, sec. 31, T100N, R9W	Galena Group
Unnamed springs	In the headwaters and valley slopes of small tributaries of Canoe Creek, secs. 28, 32, and 33, T99N, R7W	Prairie du Chien Formation
Unnamed springs	Supply a tributary of Hewitt Creek 2½ miles east of Dyersville Country Club, SE, NW, and NE, SW, sec. 26, T89N, R2W	Silurian
Malanaphy Springs	On the valley slope of the Upper Iowa River, NW, NE, NE, sec. 31, T99N, R8W	Galena Group
Falcon Springs	In the headwater area of a tributary of the Upper Iowa River, NW, SE, NE, sec. 35, T99N, R9W	Galena Group
Cave Spring	On Trout Creek bottoms, NE, SE, SW, sec. 29, T98N, R7W	Galena Group
Dunnings Spring	On the valley wall of a small tributary of the Upper Iowa River, NW, NW, NE, sec. 16, T98N, R8W	Galena Group
Twin Springs	On the floor of a small tributary of the Upper Iowa River, SE, NW, NW, sec. 20, T98N, R8W	Galena Group
Siewers Spring	On the floor of Trout Run at the fish hatchery, E ½, SW, SW, Sec. 27, T98N, R8W	Galena Group
Unnamed spring	Two miles east of Spillville on north side of Highway 325, NE, SW, sec. 21, T97N, R10W	Devonian
Unnamed springs	Three miles north of Ossian in the headwater area of a small stream running north to Trout Creek, SE, NW, SE, sec. 27, T97N, R7W	Fort Atkinson Member

HYDROPOWER POTENTIAL

Because of renewed interest in hydroelectric power as a supplemental energy resource, a brief review of the potential for such development on northeast Iowa streams is included here.

Hydroelectric development began early in this century with the conversion of many old mill dams to produce hydroelectricity. Many small companies developed power for local industrial use. By 1927 there were 48 sites generating hydroelectric power in Iowa. However, low and variable streamflow limits hydroelectric development in Iowa. Currently, there are 38 low-head dams on inland rivers in northeast Iowa (figure 25).

Today, many of the dams have value for purposes other than energy production, such as recreational use or for fish and wildlife propagation. Other applications include historic preservation, tourism, channel-and-bank stabilization, and real-estate enhancement. Waverly has the only active hydroelectric facility in northeast Iowa, with a total installed capacity of 0.495 megawatts, providing 3 percent of the city's electricity requirements.

Further information on the hydroelectric potential of existing dams in Iowa, including northeast Iowa, can be found in Allen (1981).

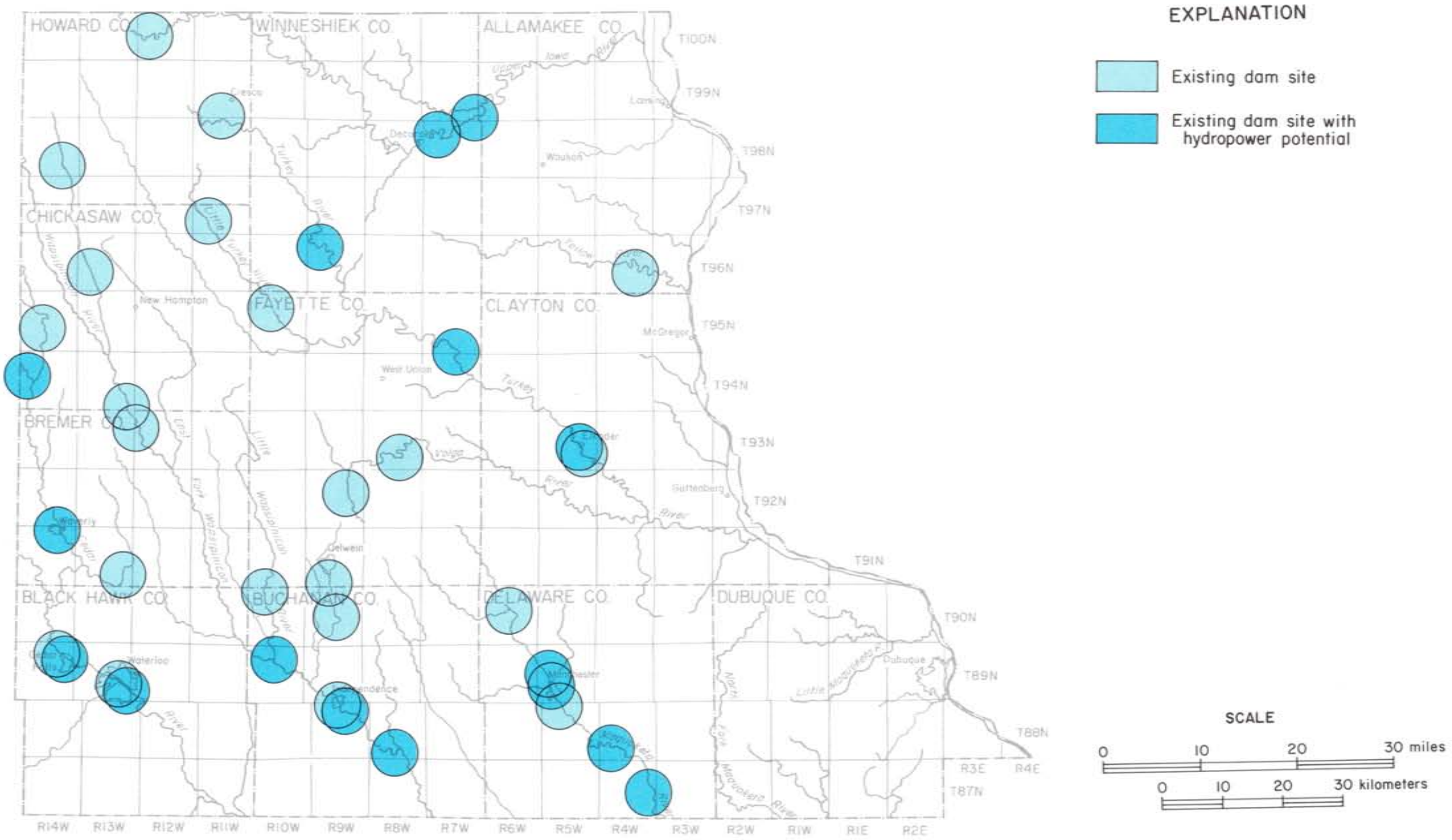


Figure 25. Inland river dams, including dams with hydropower potential

GROUNDWATER RESOURCES

THE AQUIFERS

Nearly all of the water supply for northeast Iowa communities, industries, farms, and rural residences is obtained from groundwater sources. The water is contained in unconsolidated surficial materials and underlying layered limestone, dolostone, and sandstone formations. The characteristics and distribution of these surficial and bedrock units are consistent enough to allow fairly reliable estimates of their location, depth, and water-yielding potential.

Earth materials that contain and yield water to wells are called aquifers. There are three recognizable surficial-aquifer types and four principal bedrock aquifers that supply water to northeast Iowa (figure 26). The unconsolidated, near-surface sand-and-gravel deposits that yield water to wells include alluvium in stream valleys, irregular and lenticular beds within and at the base of the glacial drift, and channel-fill deposits in buried valleys. The bedrock aquifers underlying the unconsolidated materials are the Devonian and Silurian rocks collectively called the Silurian-Devonian aquifer, the Fort Atkinson-Elgin (lower Maquoketa) aquifer, the Galena aquifer, the Cambrian-Ordovician aquifer (including the St. Peter and Jordan aquifers), and the Dresbach aquifer. Other dense sedimentary strata that yield insignificant amounts of water to wells serve as confining layers that separate the major bedrock aquifers.

Igneous and metamorphic rocks of Precambrian age (granite and gneiss) underlie the sedimentary rock formations. These crystalline rocks are commonly referred to as the "basement complex." They have little or no water-yielding potential and are seldom penetrated by wells.

The stratigraphic and hydrogeologic units of northeast Iowa are summarized in table 5. The numerous rock units of the stratigraphic sequence are distinguishable by lithologic, mineralogic, and paleontologic characteristics. The surficial materials are of Quaternary age while the bedrock units range from Devonian to Precambrian in age. As shown in table 5, the principal water-yielding units are grouped as aquifers in blue while the confining beds are white. Aquifers may transgress geologic systems as well as formational boundaries; the Silurian-Devonian and Cambrian-Ordovician aquifers are examples.

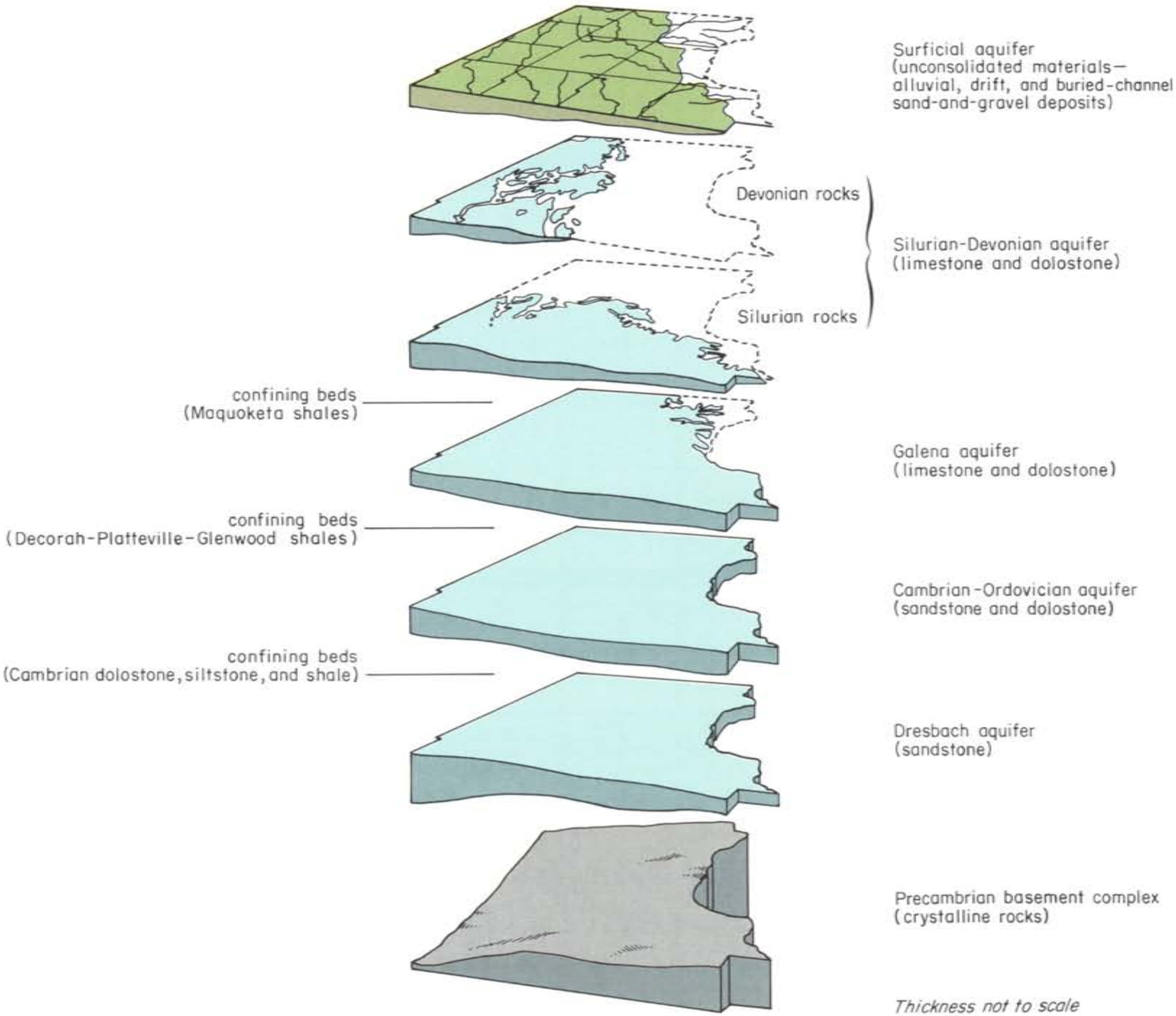


Figure 26. Aquifers in northeast Iowa

Table 5. Stratigraphic and hydrogeologic units in northeast Iowa

Stratigraphic unit			Hydrogeologic units	Type of rock	Hydrologic condition	Thickness range (ft.)	Age of rocks*
Quaternary		Recent and Pleistocene deposits	Surficial aquifers - Alluvium, Drift, Buried-channel	Sand & gravel interbedded with silt and clay	Mostly unconfined local aquifers, some artesian, small-to-large yields	0 - 305	0 - 2.8 million years (m.y.)
Devonian	Yellow Spring Group	Lime Creek Formation (Fm.)	Confining layers	Shale, some dolostone	Non-aquifer	0 - 50	
	Cedar Valley Group	Lithograph City Fm. Coralville Fm. Little Cedar Fm.	Silurian-Devonian aquifer	Limestone and dolostone, thin shales	Major aquifer, mostly artesian, moderate-to-large yields	0 - 400	365 - 405 m.y.
	Wapsipinicon Group	Pinicon Ridge Fm. Spillville Fm.		Dolostone and limestone			
Silurian		Scotch Grove Fm. Hopkinton Fm. Blanding Fm. Tete des Morts Fm.		Dolostone, locally with much chert, local shale as cavern fillings			405 - 425 m.y.
Ordovician	Maquoketa Formation	Brainard Member (Mem.)	Maquoketa Formation confining beds	Shale and dolostone, some chert	Non-aquifer to local aquifer, small-to-moderate yields	0 - 300	425 - 455 m.y.
		Fort Atkinson Mem. Clermont Mem. Elgin Mem.	Fort Atkinson - Elgin aquifer				
	Galena Group	Dubuque Fm. Wise Lake Fm. Dunleith Fm. Decorah Fm.	Galena aquifer	Limestone and dolostone, minor chert, shale at base and locally in upper part	Local aquifer, confined and unconfined, small-to-moderate yields	0 - 240	455 - 460 m.y.
		Platteville Fm. Glenwood Fm.	Decorah-Platteville-Glenwood confining beds	Limestone and shale	Non-aquifer	0 - 50	
		St. Peter Sandstone	Cambrian-Ordovician aquifer	Sandstone	Major aquifer, mostly artesian, large yields	0 - 580	460 - 500 m.y.
		Prairie du Chien Group		Dolostone, minor sandstone and chert			
Cambrian		Jordan Sandstone		Sandstone, dolomitic			500 - 503 m.y.
		St. Lawrence Fm.	Cambrian confining beds	Dolostone, silty	Non-aquifer	0 - 400	503 - 508 m.y.
		Lone Rock (Franconia) Fm.		Fine sandstone, siltstone, shale, and minor dolostone			
		Wenowoc (includes Ironton-Galesville sandstones) Fm.	Dresbach aquifer	Sandstone	Artesian aquifer, large yields	0 - 1,950	508 - 515 m.y.
		Eau Claire Fm.		Fine sandstone, siltstone, and shale			
		Mt. Simon Sandstone		Sandstone			
Pre-C		Undifferentiated crystalline rocks	Unknown	Igneous and metamorphic rocks	Unknown	Unknown	570 m.y. to > 2 billion years

*Age determinations as used on COSUNA charts published by AAPG-USGS

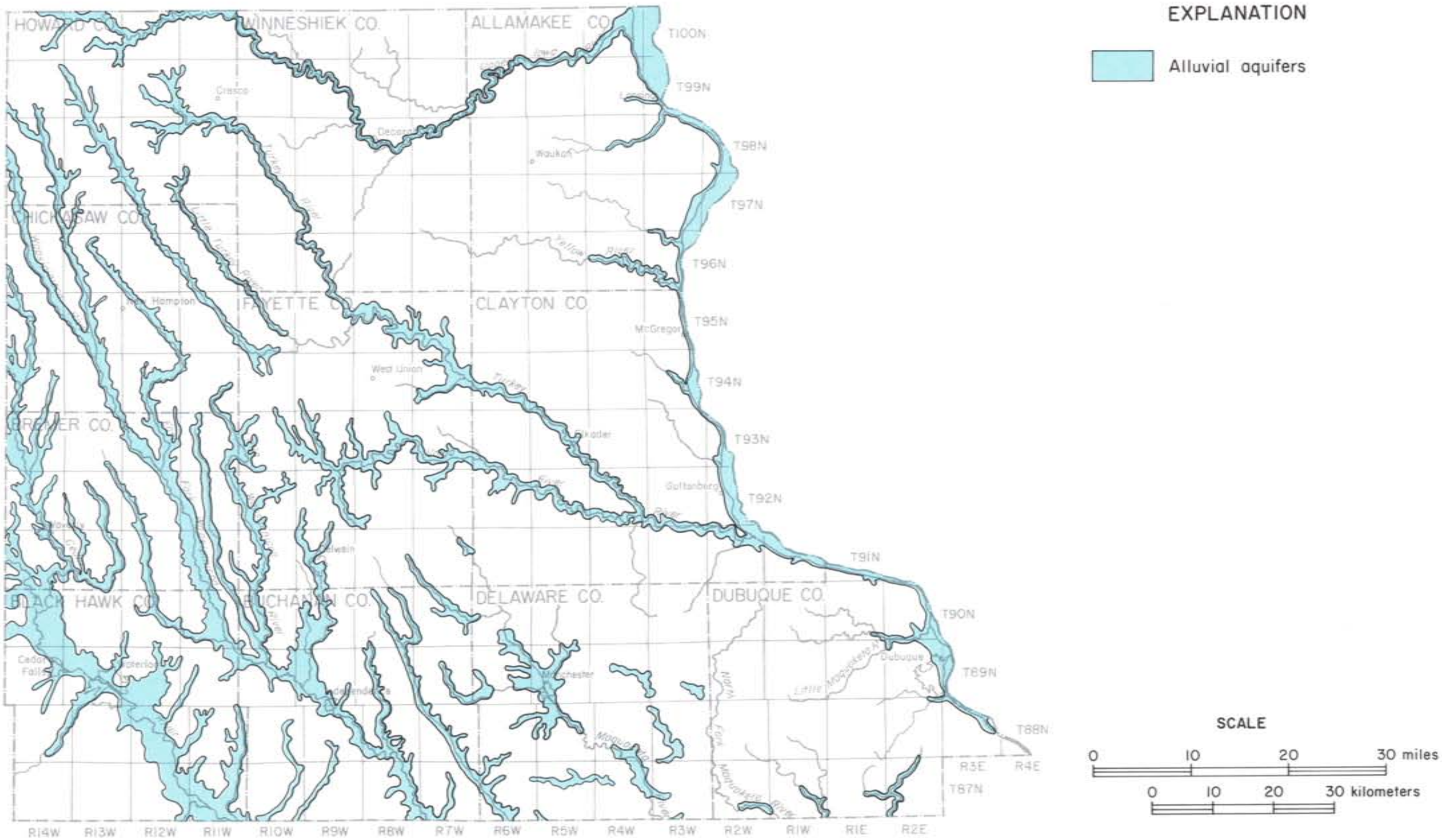


Figure 27. Areal distribution of alluvial aquifers

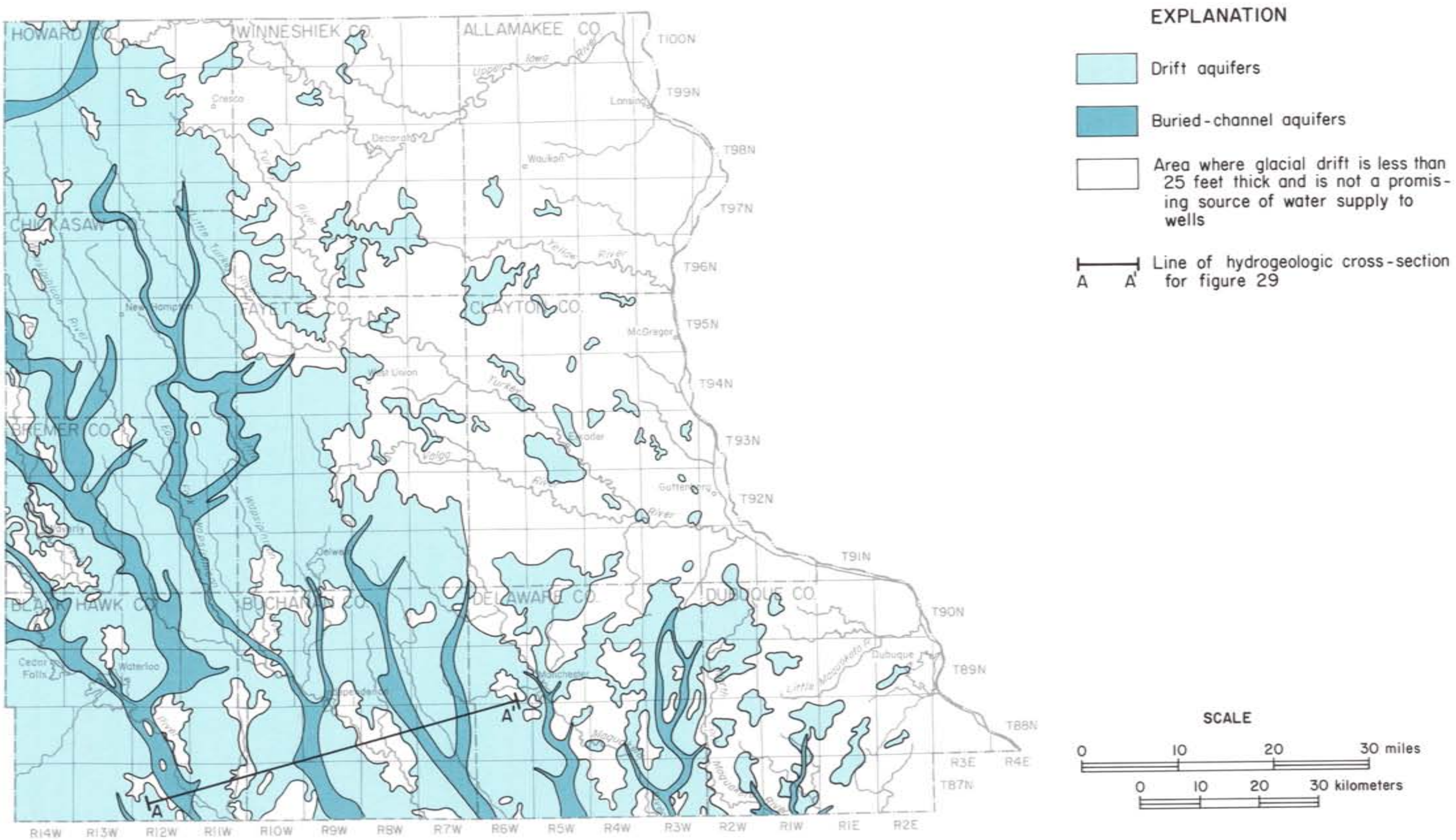


Figure 28. Areal distribution of drift and buried-channel aquifers

Surficial Aquifers

The unconsolidated deposits from the land surface to bedrock in northeast Iowa may include porous sand-and-gravel deposits that comprise three different types of surficial aquifers. Alluvial aquifers are found in the valleys of present-day streams. Alluvium consists of layers of clay, silt, sand, and gravel of varying thickness, extent, and continuity. It is thickest and most extensive beneath the floodplains of larger streams such as the Cedar, Wapsipinicon, Volga, Turkey, and Upper Iowa rivers (figure 27). The sediment was derived from Quaternary materials and older bedrock, and deposited in the stream valleys. The porous sand and gravel within the alluvium form the aquifers. Less permeable layers of clay and silt are commonly interbedded with the sand and gravel, and may comprise most of the alluvial sequence in some valleys. Along small streams, alluvial sediment may be only a few yards wide and less than 5 to 10 feet thick. In contrast, the Cedar River in Black Hawk County has a floodplain 2 to 3 miles wide underlain by alluvium that ranges between 50 and 150 feet in thickness.

Large quantities of water can be stored in alluvial deposits. The deposits are generally recharged by precipitation and/or seepage from bedrock aquifers. Alluvial aquifers yield moderate to large quantities of water to shallow wells in portions of the Cedar, Wapsipinicon, and Upper Iowa river valleys.

Drift aquifers (figure 28) consist of lenticular and irregular layers of sand and gravel within unconsolidated glacial deposits. Sand-and-gravel beds that locally occur just above bedrock at the base of the drift are included in the drift aquifer. Because of the irregular distribution of these sand-and-gravel layers, their areal extent and thickness are difficult to predict. The drift aquifers have extremely limited use in the region. Their suitability as a source of water supply varies considerably. Only scattered remnants of glacial drift, usually less than 50 feet thick, occur in the Paleozoic Plateau area. In the area of the Iowan Surface, drift deposits range up to 200 feet thick or more. Here, drift aquifers provide water to farm and domestic wells and a few large-capacity irrigation wells.

Buried-channel aquifers occur where thick sand-and-gravel deposits fill former valleys eroded into the bedrock surface (figure 28). They generally have no surface expression today because they are completely mantled by glacial drift.

Buried channels are common in the Iowan Surface area. They may have widths comparable to or greater than some modern valleys. In general, the trend of the present-day streams is independent of the buried channels, although the Cedar River in Black Hawk County appears to follow an ancient, buried channel. The maximum recorded thickness of the sand and gravel in buried channels is about 80 to 85 feet. Small to moderate yields are available from this source where the sand-and-gravel deposits are at least 10 to 20 feet thick. In places where modern streams intersect buried channels and the alluvial and buried-channel aquifers are in contact, substantial quantities of water may be obtained.

Figure 29 is a hydrogeologic cross-section extending from southern Black Hawk to western Delaware counties (A-A´, figure 28). The figure shows the position and relationships of the various aquifers.

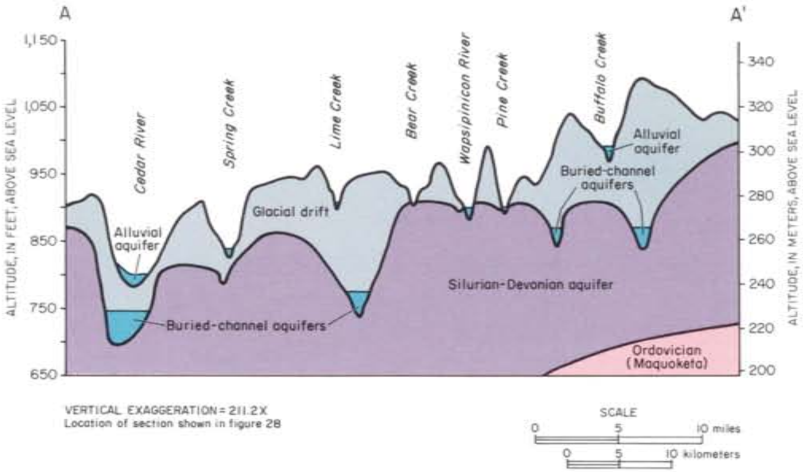


Figure 29. Hydrogeologic cross-section of surficial aquifers and upper bedrock units

The Bedrock Surface

Below the mantle of soil and glacial drift (surficial deposits) are bedrock formations (shale, limestone, dolostone, and sandstone). The altitude and configuration of the bedrock surface is shown in figure 30. The bedrock surface was eroded by ancient streams and further modified by glacial erosion.

Because surficial deposits are thin or absent over the Paleozoic Plateau in the eastern portion of the report area, the bedrock surface and present-day surface are virtually the same. Farther west beneath the Iowan Surface, buried valleys in the bedrock surface range from 100 to more than 200 feet deep.

A prominent physical feature of the bedrock surface is the ridge extending from northeastern Howard County to southeastern Dubuque County. Another bedrock high extends from beneath Ridgeway to Calmar, then easterly through southern Allamakee and northern Clayton counties. The maximum relief of the bedrock surface exceeds 600 feet. The highest point is in northeastern Howard County and the lowest point is in the buried channel at La Porte City in Black Hawk County.

The depth to bedrock can be approximately determined by subtracting the altitude of the bedrock surface (figure 30) from the altitude of the land surface shown on the topographic map (figure 6). More accurate land-surface elevations can be obtained from 7 1/2-minute topographic maps because of their smaller contour intervals (10 or 20 feet) compared to the 200-foot contour interval of figure 6. The bedrock contours, of course, are subject to error as they are drawn from available well data and surface exposures; where control data are sparse or unavailable, accuracy may be poor.

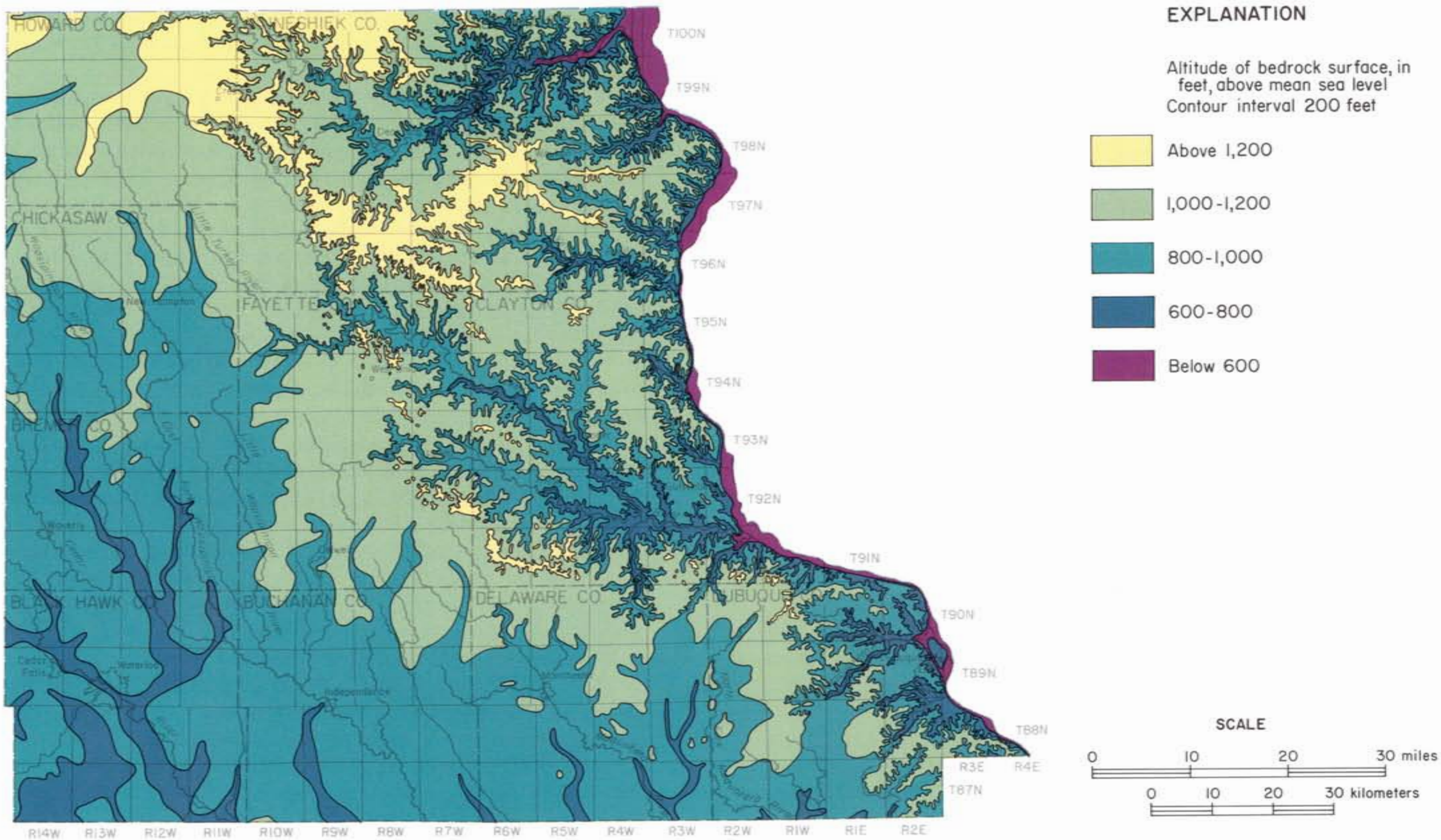


Figure 30. Altitude and configuration of the bedrock surface

Bedrock Aquifers and Confining Beds

The aquifers and confining beds (table 5) at the bedrock surface are shown on the hydrogeologic map (figure 31) and in hydrogeologic cross-sections (figure 32). Progressively younger units occur at the bedrock surface toward the southwest from Allamakee County to Black Hawk County.

The Silurian-Devonian aquifer is the uppermost bedrock in all but the northeast one-third of the report area. Thin Devonian confining shales (Lime Creek Formation) overlie the Devonian Cedar Valley Formation in extreme southwestern Black Hawk County, while thin confining shales (not shown on the maps) occur locally within the upper Cedar Valley Formation in Chickasaw and Howard counties.

The upper Ordovician Maquoketa Formation confining beds (Brainard Member) comprise the first unit below the Silurian rocks. Rocks of the Brainard Member form long gradual slopes below the Silurian escarpment in the outcrop area. This member, along with other underlying members of the formation (Fort Atkinson, Clermont, and Elgin members) form an outcrop belt that ranges up to 19 miles in width east of the Silurian-Devonian boundary.

The Maquoketa Formation confining beds (Brainard Member) outcrop southwesterly across the study area, except in Howard and Chickasaw counties and western Bremer County. The Maquoketa Formation is represented only by Fort Atkinson and Elgin members (carbonate rocks) where the Brainard Member is absent.

The Fort Atkinson-Elgin carbonate rock comprising the lower half of the Maquoketa Formation in some locations constitutes a dependable aquifer in parts of Howard, Winneshiek, Chickasaw, Fayette, Clayton, and Bremer counties.

The Galena aquifer outcrops in most of northern and east-central Winneshiek, southwestern Allamakee, and eastern Clayton counties, and along a narrow band bordering the Mississippi River in Dubuque County. It is present beneath younger rocks across the study area southwest of its outcrop.

The Decorah-Platteville-Glenwood confining beds underlying the Galena aquifer are widespread across the study area southwest of the outcrop. Because these units are thin, they have little surface expression and they are not amenable to mapping, particularly at the scale of the hydrogeologic map.

The Cambrian-Ordovician aquifer (St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone) outcrops in the northeastern half of Allamakee and a portion of northeastern Winneshiek counties, and it extends southward along the Mississippi River as far as Guttenberg. It underlies the Mississippi River valley at Dubuque. This aquifer is present across the entire study area except where it has been erosionally removed by the Mississippi and Upper Iowa rivers.

(NOTE: The Cambrian-Ordovician aquifer as defined in this report consists of three separate water-bearing formations that locally and regionally can have large differences in static-water levels. However, to develop high capacity wells, it is common practice to draw water from more than one of the units in individual wells. Most commonly, "Jordan wells" draw from the Prairie du Chien and Jordan, the Jordan usually providing the greatest yield. Other wells may tap only the St. Peter or may tap the St. Peter and the upper part of the Prairie du Chien. Treated as a single aquifer, the sequence is confined above by Decorah-Platteville-Glenwood confining beds and below by the Cambrian confining units beneath the Jordan. Since the St. Peter and Jordan are the major producing units, it is convenient to subdivide the sequence for discussion purposes. Through this convention, the Jordan is the lower Cambrian-Ordovician aquifer and the St. Peter is the upper Cambrian-Ordovician aquifer.)

The Dresbach aquifer is comprised of rocks of the Elk Mound Group (Wonewoc-Eau Claire-Mt. Simon formations). The principal water-producing units in the sequence are the Wonewoc and Mt. Simon sandstones. This aquifer exists throughout the study area and is only 100 to 150 feet below the land surface at New Albin and Lansing. The lower units of the aquifer rest on Precambrian rocks.

As shown in the hydrogeologic cross-sections, figure 32, the entire sequence of aquifers and confining beds slopes gently to the southwest. Their declination is between 9 and 16 feet per mile.


G.A. Ludvigson

This newly formed sinkhole in the Big Spring basin, Clayton County, developed when the mantling materials collapsed into a solutionally enlarged crevice in the Galena Group rocks.

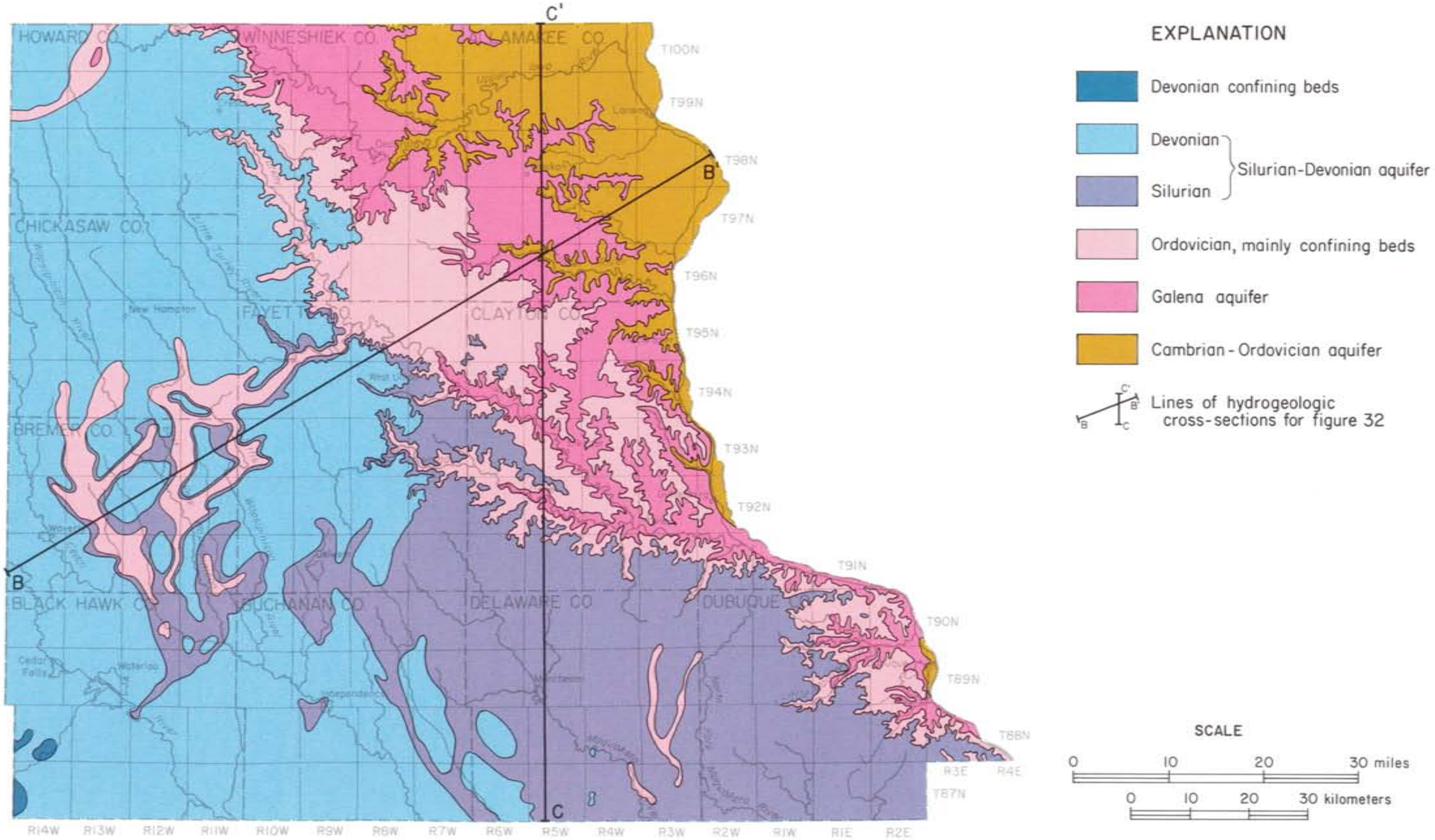


Figure 31. Bedrock hydrogeologic map

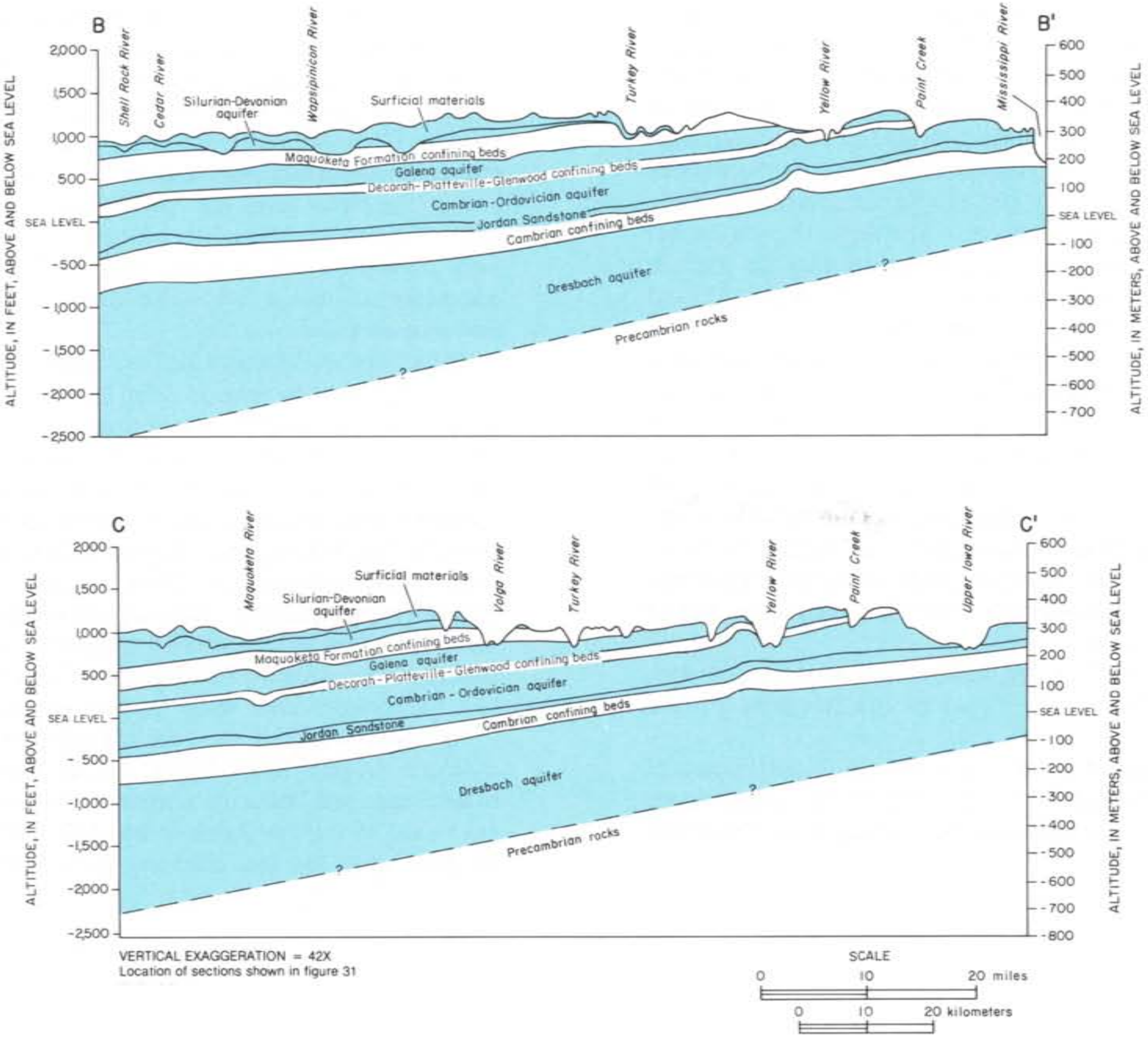


Figure 32. Hydrogeologic cross-sections

Depth and Configuration of the Bedrock Aquifers

The depth to bedrock aquifers varies greatly over the report area. It is controlled by land elevation, thickness of the surficial materials and bedrock formations, and structure and elevation of the bedrock. In the area of the Paleozoic Plateau (figure 5), only thin loess or glacial drift mantles the bedrock. Although the land surface has considerable local relief, bedrock is either at or close to the surface. In the western and southwestern parts of the study area the glacial drift may be more than 250 feet thick over bedrock channels. The depth to each aquifer at any specific point can be determined by subtracting the altitude of the top of each aquifer (shown in figures 33, 35, 36, 38, 39, and 40) from the land-surface altitude at that point.

The configuration of the surface of each bedrock aquifer is the result of erosion and/or local and regional deformation of the strata. During many episodes of geologic history, erosion sculpted the surface of the various aquifers and confining beds. In addition, all rock units in this area have been altered structurally, resulting in a regional tilt of the rocks to the southwest, as well as local folding and faulting.

The altitude of the top of the Silurian-Devonian aquifer is shown in figure 33. The two rock units have been mapped as one unit because the formations are in part hydraulically connected and can be treated regionally as a single aquifer.

Devonian rocks are present in the western half of the report area and their upper surface is eroded. Relief on the Devonian surface is slightly more than 500 feet.

Silurian rocks are uppermost bedrock in the southeastern part of the report area and dip beneath Devonian rocks in the southwestern counties. Local relief on the Silurian surface is between 100 and 200 feet.

The altitude of the top of the Maquoketa Formation is shown in figure 34. The Maquoketa Formation confining beds (Brainard Member) are the most important confining unit in northeast Iowa. Where Silurian rocks have been eroded, the Maquoketa Formation is overlain by younger Devonian rocks and/or surficial materials. The Maquoketa Formation confining beds underlie most of the southern and central part of the report area, but have been eroded from the northwestern part. The outcrop belt of the Maquoketa Formation is up to 19 miles wide in Winneshiek, Fayette, and northwestern Clayton counties, narrowing to only a few miles width in southeastern Clayton and Dubuque counties.

The altitude of the top of the Fort Atkinson-Elgin (lower Maquoketa) aquifer is shown in figure 35. The Fort Atkinson-Elgin aquifer occurs beneath the Maquoketa Formation confining beds. Where these confining beds are absent, this aquifer underlies Devonian rocks. The Fort Atkinson-Elgin (lower Maquoketa) aquifer consists of two carbonate rock units separated by thin shale of the Clermont Member. Both the Fort Atkinson and Elgin members are widespread across the southwestern two-thirds of the study area. The Clermont Member is thick enough to form a confining unit in places, mostly in an irregular band extending from eastern Chickasaw to southwestern Delaware counties. However, the Fort Atkinson-Elgin (lower Maquoketa) aquifer is a fairly dependable water source over a surprisingly broad area.

Carbonate rocks of the Fort Atkinson Member grade to shales in southern Bremer, Black Hawk, and Dubuque counties, and in parts of Buchanan and Delaware counties, while the Elgin Member is mostly composed of shale in Black Hawk, Buchanan, and Dubuque counties. In these areas the two units are considered to be confining beds.

The Galena aquifer as defined in this report includes the dolostones and limestones of the Galena Group (Dubuque, Wise Lake, Dunleith, and Decorah formations). Confining units are the Maquoketa Formation confining beds above, and the first prominent shale in the Decorah Formation below. The altitude of the top of the Galena aquifer is shown in figure 36.

Rocks of the Galena Group are exposed at the surface in parts of Howard, Winneshiek, Allamakee, Clayton, and Dubuque counties. They dip beneath younger formations to the southwest. Structural deformation has been the principal influence in shaping the surface of the Galena aquifer. A belt of anticlines and synclines, at right angles to the regional dip, extends through the center of the area from Chickasaw County southeasterly through Dubuque County. The surface of the Galena aquifer tilts regionally to the southwest.

The altitude of the top of the Decorah-Platteville-Glenwood confining beds is shown in figure 37. The Decorah-Platteville limestones yield minor water supplies to wells in a few places. However, the interval is mainly a confining unit that separates the Galena and St. Peter (upper Cambrian-Ordovician) aquifers. The thickness range of the Decorah-Platteville-Glenwood confining beds is between 77 and 120 feet with total shale thickness comprising about 10 to 35 feet. The shales generally occur as several thin layers between limestone layers. They occur from the middle of the Decorah Formation downward through the Glenwood Formation. This confining interval is present across the study area except in northeastern Winneshiek and Allamakee counties (figure 37). The total shale thickness in this interval generally increases northward in the study area.

The altitude of the top of the St. Peter (upper Cambrian-Ordovician) aquifer is shown in figure 38. The St. Peter (upper Cambrian-Ordovician) aquifer is found at the land surface in numerous places in Allamakee, Clayton, and Winneshiek counties. The aquifer dips southwesterly beneath younger strata at a rate of about 10 to 11 feet per mile. Local rippling and warping of the surface is evident. An apparent fault has been identified in one of Decorah's deep wells based on an approximate 250 foot repeat section of Prairie du Chien rocks.

The altitude of the top of the Jordan (lower Cambrian-Ordovician) aquifer is shown in figure 39. The Jordan (lower Cambrian-Ordovician) aquifer is exposed at the land surface along the Mississippi River valley and its tributary stream valleys. It is difficult to recognize the precise top of the Jordan in some wells. In this report the top is identified where the rock becomes 50 percent or more sandstone, in contrast with overlying Prairie du Chien Group carbonate rocks. The Jordan surface slopes uniformly southwest at about 16 feet per mile. It lies about 300 to 350 feet below the top of the St. Peter (upper Cambrian-Ordovician) aquifer in the eastern part of the report area and 450 to 475 feet below it in the southwestern part. This difference is attributed to thickening of the intervening Prairie du Chien Group.

The altitude of the top of the Dresbach aquifer is shown in figure 40. It has a configuration similar to the top of the Jordan (lower Cambrian-Ordovician) aquifer and lies 300 to 500 feet below the top of the Jordan. The Dresbach aquifer as defined in this report consists of the Wonewoc Formation, Eau Claire Formation, and Mt. Simon Sandstone.

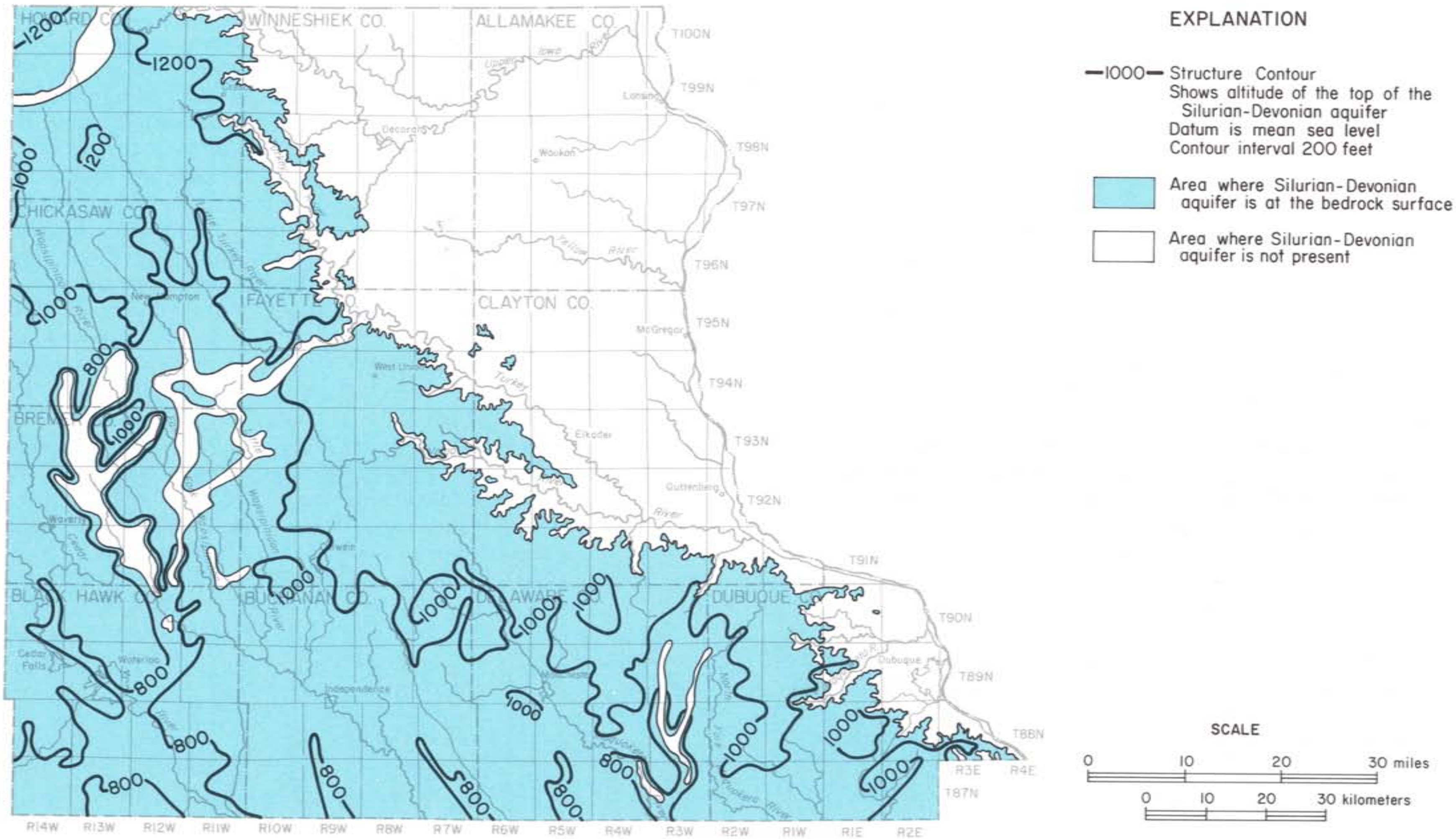


Figure 33. Altitude of the top of the Silurian-Devonian aquifer

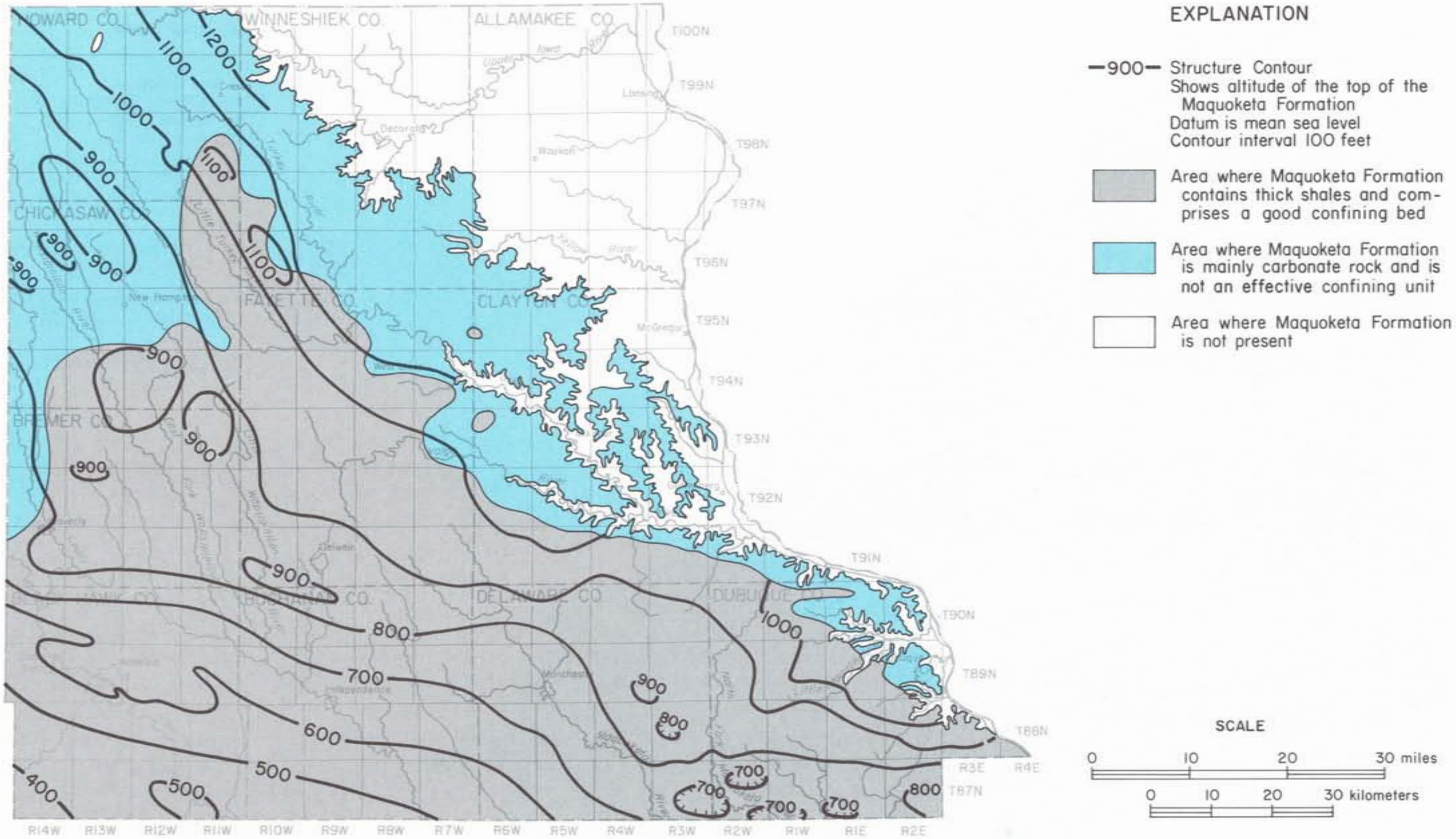


Figure 34. Altitude of the top of the Maquoketa Formation

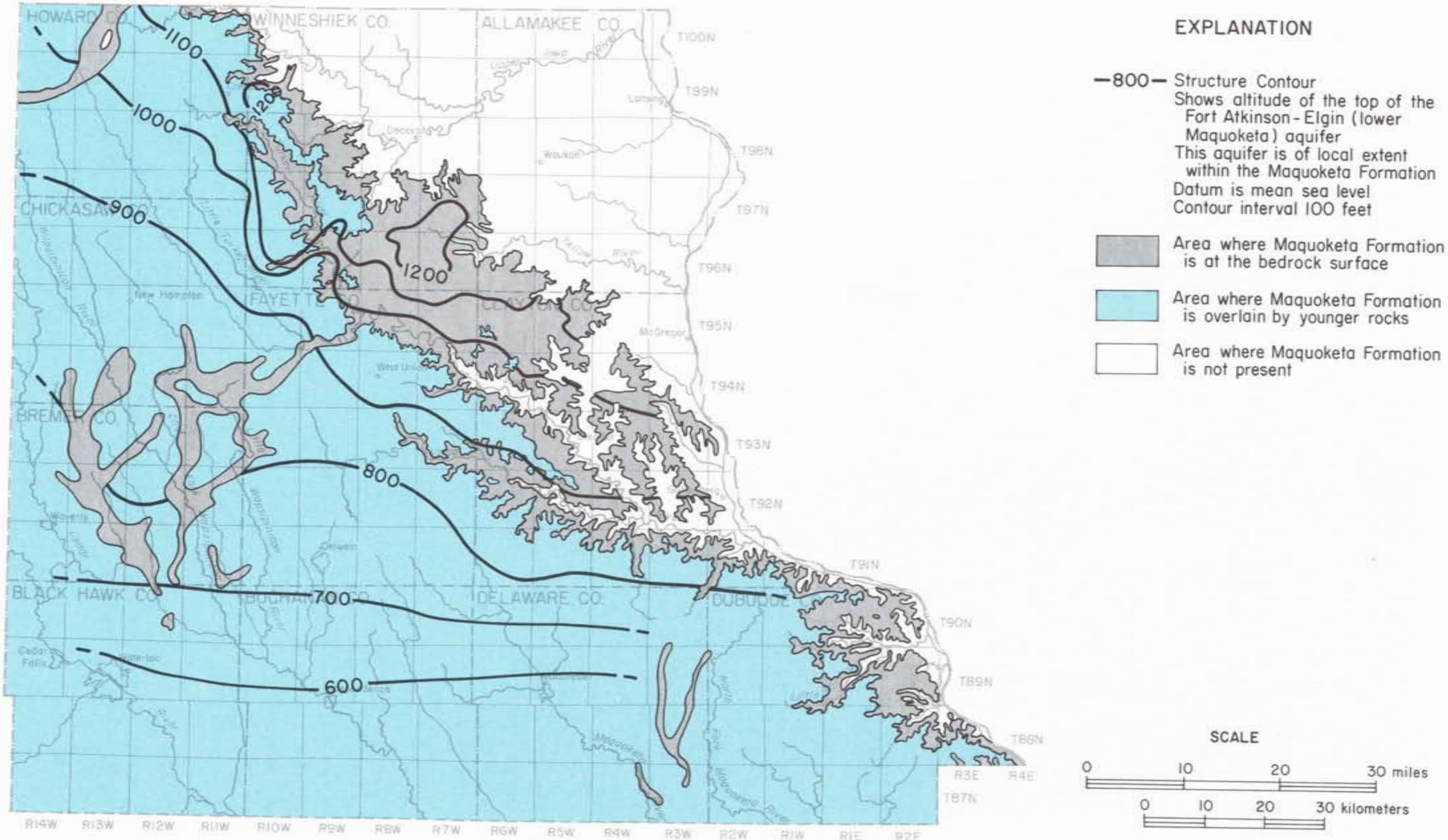


Figure 35. Altitude of the top of the Fort Atkinson-Elgin (lower Maquoketa) aquifer

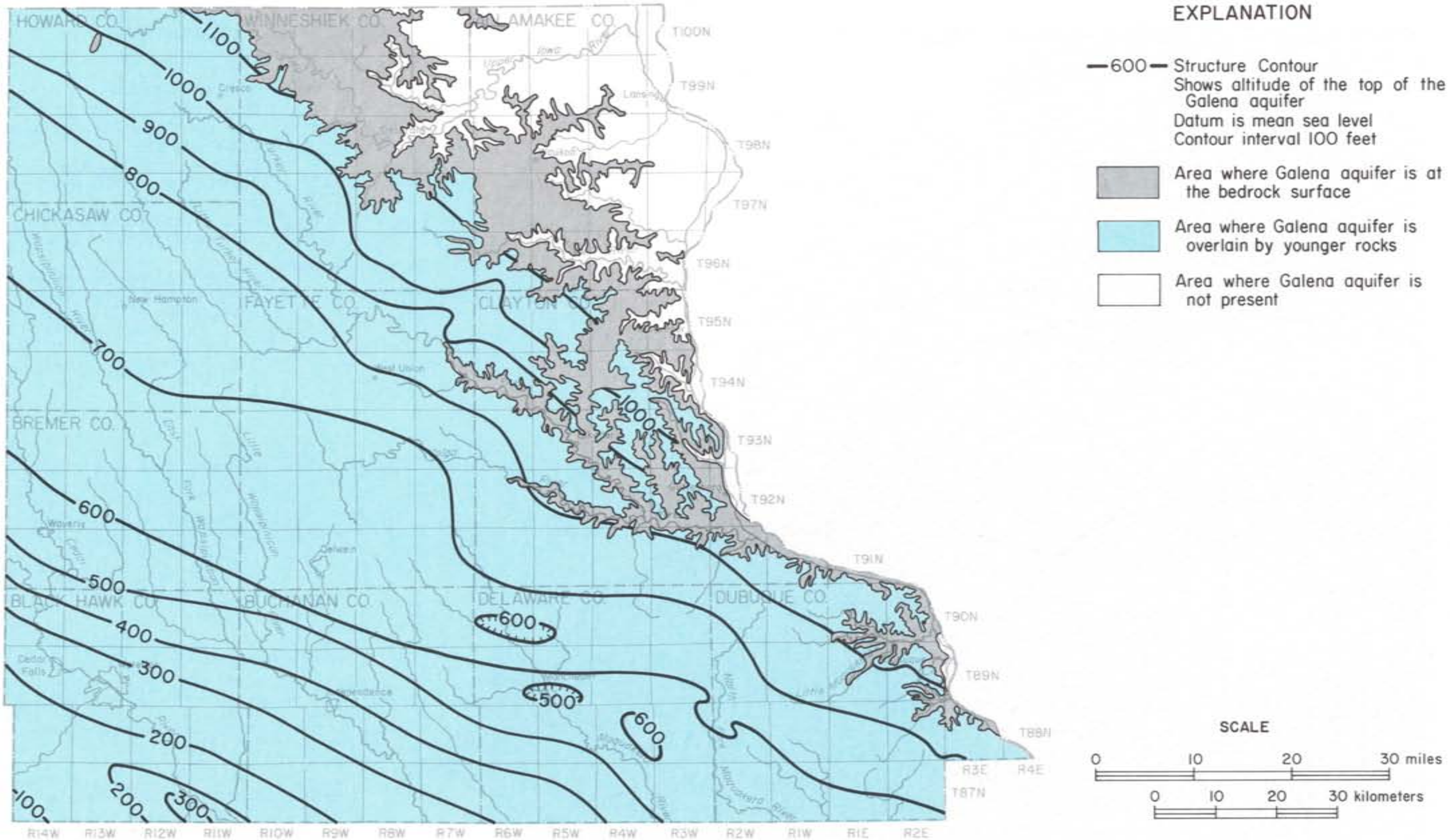


Figure 36. Altitude of the top of the Galena aquifer

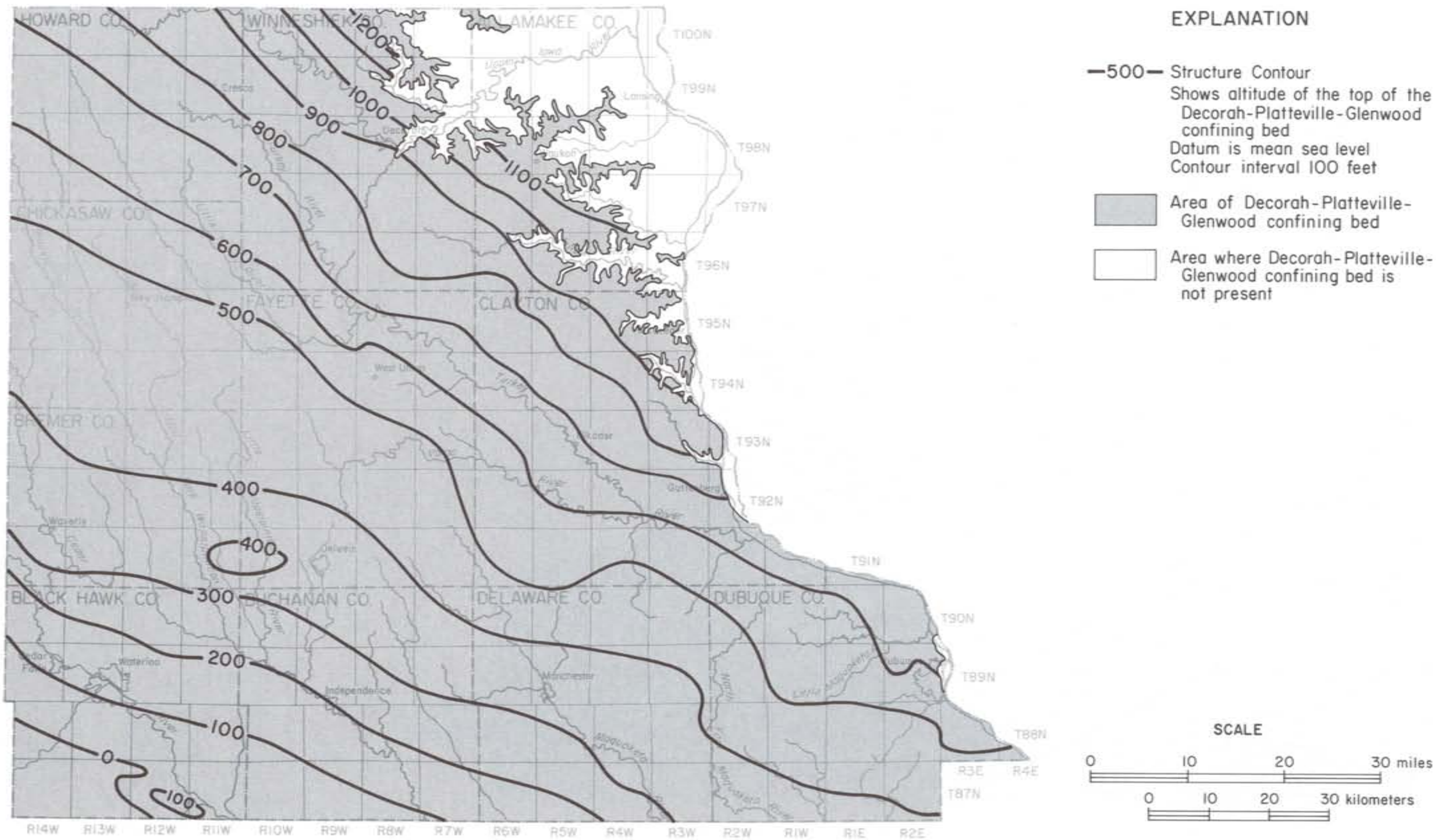


Figure 37. Altitude of the top of the Decorah-Platteville-Glenwood confining bed

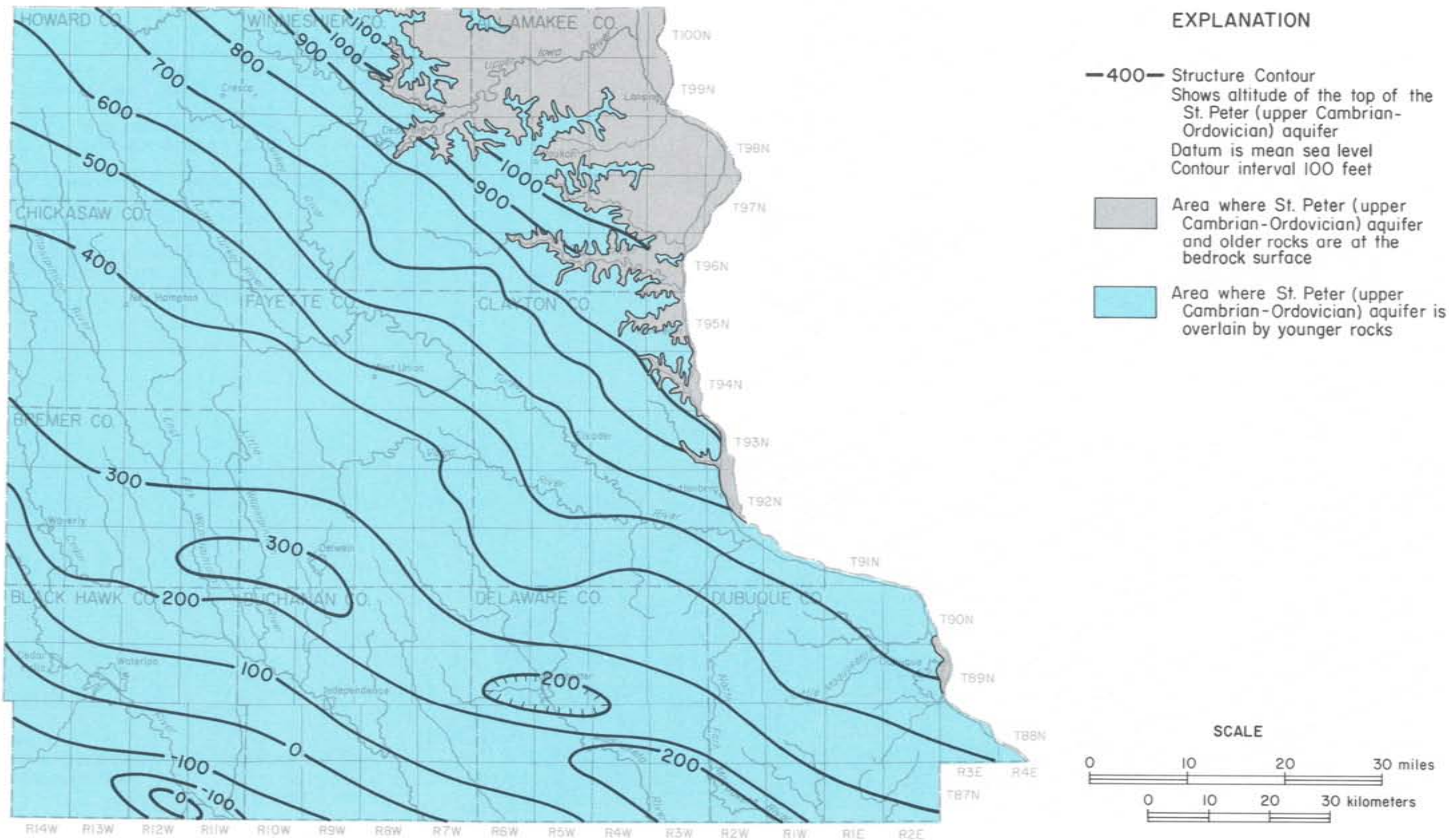
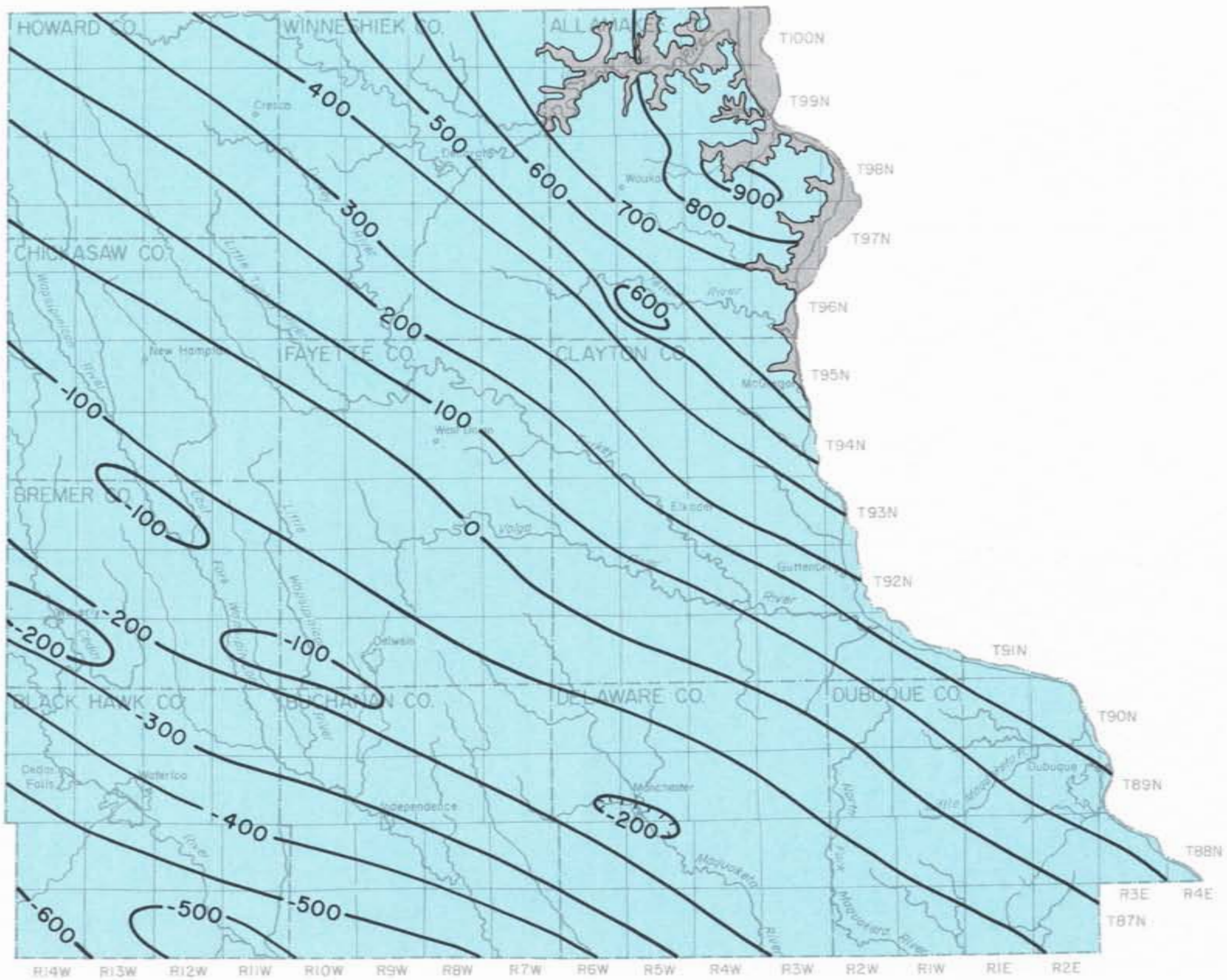


Figure 38. Altitude of the top of the St. Peter (upper Cambrian-Ordovician) aquifer



EXPLANATION

—700— Structure Contour
Shows altitude of the top of the Jordan (lower Cambrian-Ordovician) aquifer
Datum is mean sea level
Contour interval 100 feet

Area where Jordan (lower Cambrian-Ordovician) aquifer and older rocks are at the bedrock surface

Area where Jordan (lower Cambrian-Ordovician) aquifer is overlain by younger rocks

SCALE

0 10 20 30 miles

0 10 20 30 kilometers

Figure 39. Altitude of the top of the Jordan (lower Cambrian-Ordovician) aquifer

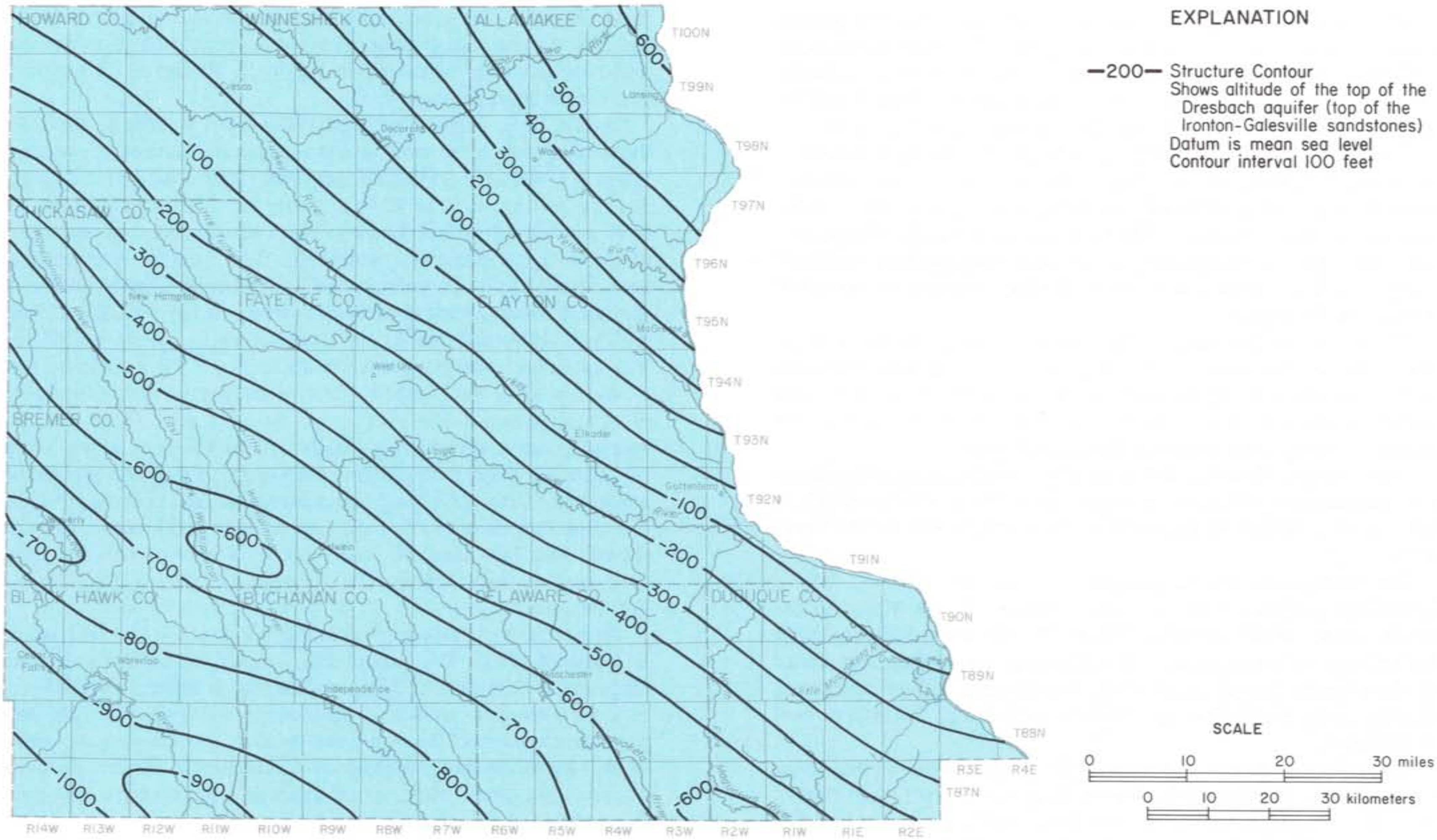


Figure 40. Altitude of the top of the Dresbach aquifer

Thickness of the Bedrock Aquifers

The thickness of an aquifer is significant because it has an important bearing on the amount of water that can potentially be developed from individual wells. An aquifer will generally yield the largest quantity of water to a well where the water-yielding unit is thickest and the well has fully penetrated the aquifer. However, it is possible for a well to produce a higher yield at a location with lesser thickness if the aquifer has a greater hydraulic conductivity (i.e., can transmit water at a faster rate). Hydraulic conductivities of aquifers are variable both locally and regionally. The thickness of an aquifer depends on the following: the topography of the underlying surface, structural changes, and the amount of erosion that has occurred on the upper surface of the aquifer.

The maximum thickness of the Silurian-Devonian aquifer is more than 300 feet in northeast Iowa (figure 41). Its greatest thickness is in southwestern Black Hawk and southern Buchanan counties. The aquifer is absent in the northeastern part of the report area. It is absent locally in every county except Buchanan County.

The thickness of the Fort Atkinson-Elgin (lower Maquoketa) aquifer was not mapped. However, it is generally 180 to 190 feet thick in its area of principal development in the northern part of the study area.

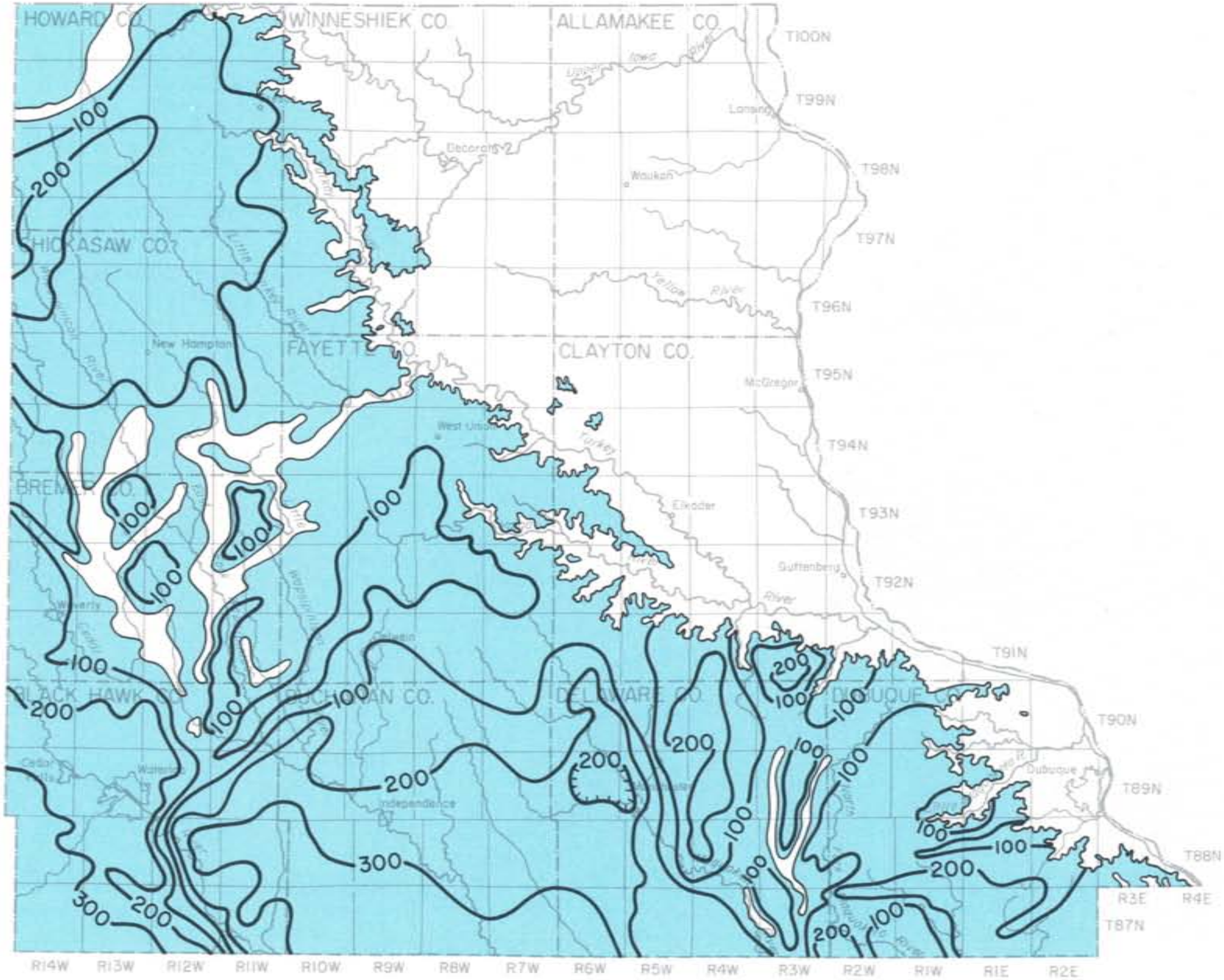
The thickness of the Galena aquifer is extremely variable. Where it outcrops, it ranges from a few feet to about 225 feet thick. Across the remainder of the area it is 200 to 240 feet thick and is overlain by younger rocks (figure 42). It is absent in the northeastern corner of Winneshiek County, most of the northeastern half of Allamakee County, along the Mississippi River as far south as Guttenberg, and at Dubuque.

The Cambrian-Ordovician aquifer (St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone) is up to 575 feet thick (figure 43). It is absent in the Upper Iowa River valley for about 15 miles upstream of New Albin, and in the Mississippi River valley south to McGregor. The greatest thickness of the aquifer is between 525 and 580 feet in the southwestern part of the study area. The increased thickness is attributed to thickening of the Prairie du Chien Group and Jordan Sandstone.

The St. Peter (upper Cambrian-Ordovician) aquifer is thickest in the northern part of the study area in Howard and Winneshiek counties, where it is between 60 and 80 feet thick (figure 44). It is only half as thick, averaging 30 to 40 feet, across the southern part of the area from southeastern Black Hawk to northwestern Dubuque and southeastern Clayton counties. Unusually thick St. Peter sections have been found locally in wells in eastern Dubuque County, where the formation overlies a major erosional surface on the underlying Prairie du Chien Group and, locally, on Cambrian rocks. There the St. Peter fills erosional channels and karst openings on the erosion surface.

The Jordan (lower Cambrian-Ordovician) aquifer ranges from about 50 to more than 120 feet thick across the study area (figure 45). The area of greatest thickness, generally 100 to 120 feet, forms a large "U" opening to the east with one limb in Allamakee and Winneshiek counties and the other in Black Hawk, Buchanan, and Delaware counties. The sandstone is only 50 to 60 feet thick in southeastern Dubuque County and less than 80 feet thick in a narrow belt extending northwesterly from Dubuque through central Clayton and northeastern Fayette counties.

Only a few wells penetrate the full thickness of the Dresbach aquifer in northeast Iowa. The limited data indicate the aquifer's thickness ranges from less than 600 feet at Lansing to more than 2,000 feet in the southwestern corner of the study area (figure 46). The most prominent features of the map are the gradual thickening of the aquifer to the southwest and the distinctive thinning in eastern Buchanan County. The latter might be attributed to a ridge on the underlying Precambrian rock surface.



EXPLANATION

—100— Line of equal thickness of the Silurian-Devonian aquifer
Contour interval 100 feet

Area where Silurian-Devonian aquifer is at the bedrock surface

Area where Silurian-Devonian aquifer is not present

SCALE

0 10 20 30 miles

0 10 20 30 kilometers

Figure 41. Thickness of the Silurian-Devonian aquifer

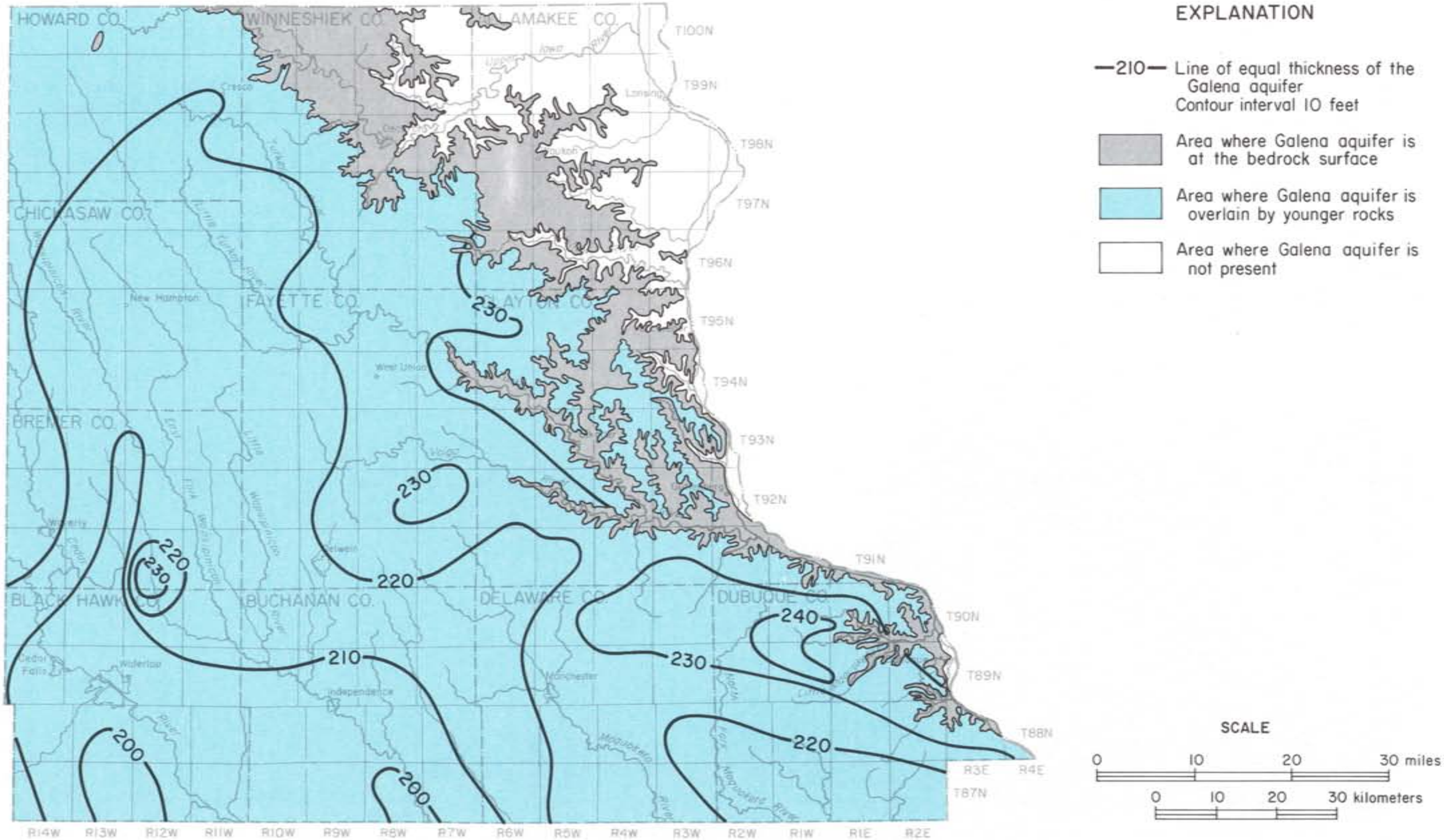


Figure 42. Thickness of the Galena aquifer

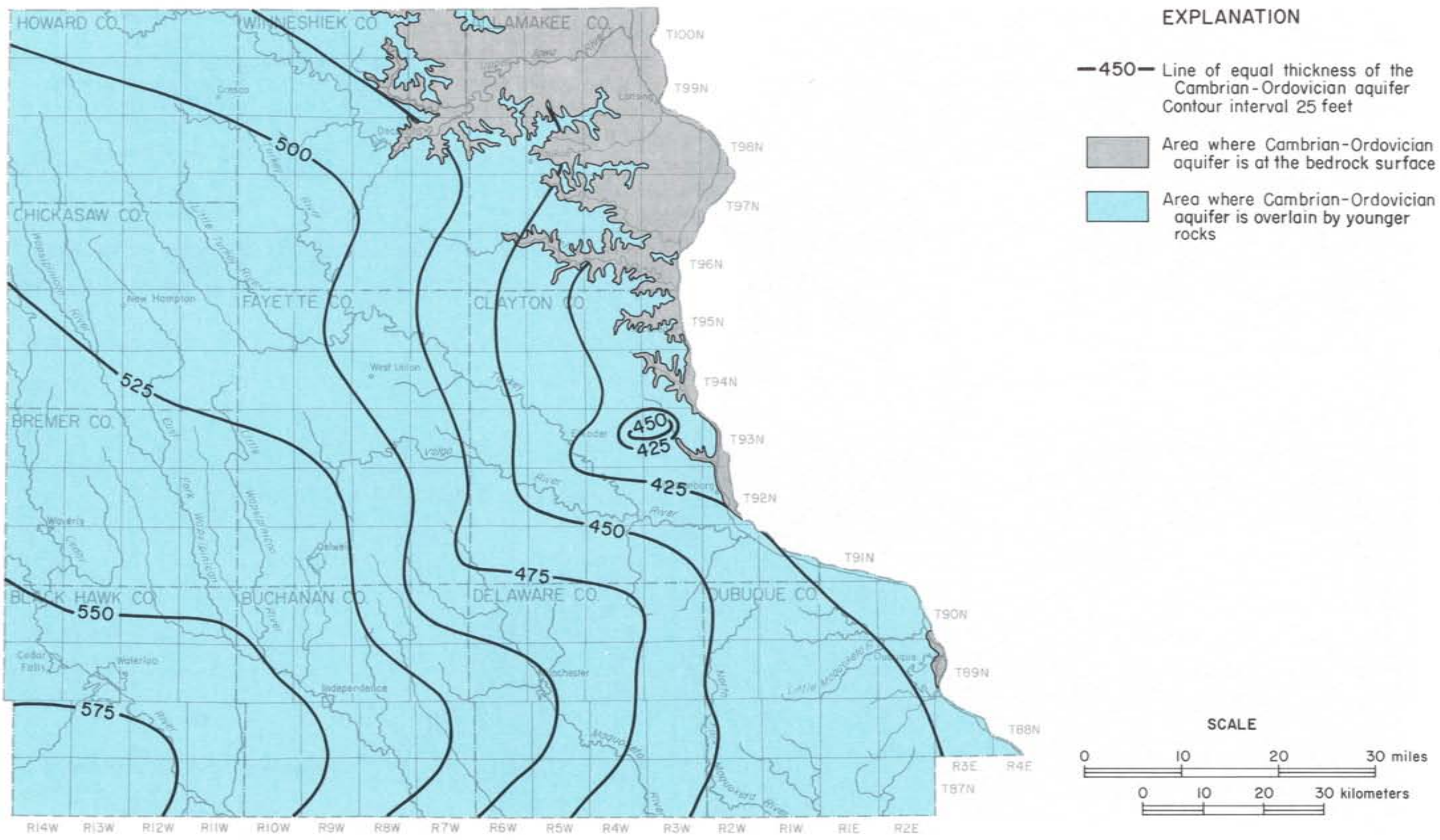


Figure 43. Thickness of the Cambrian-Ordovician aquifer

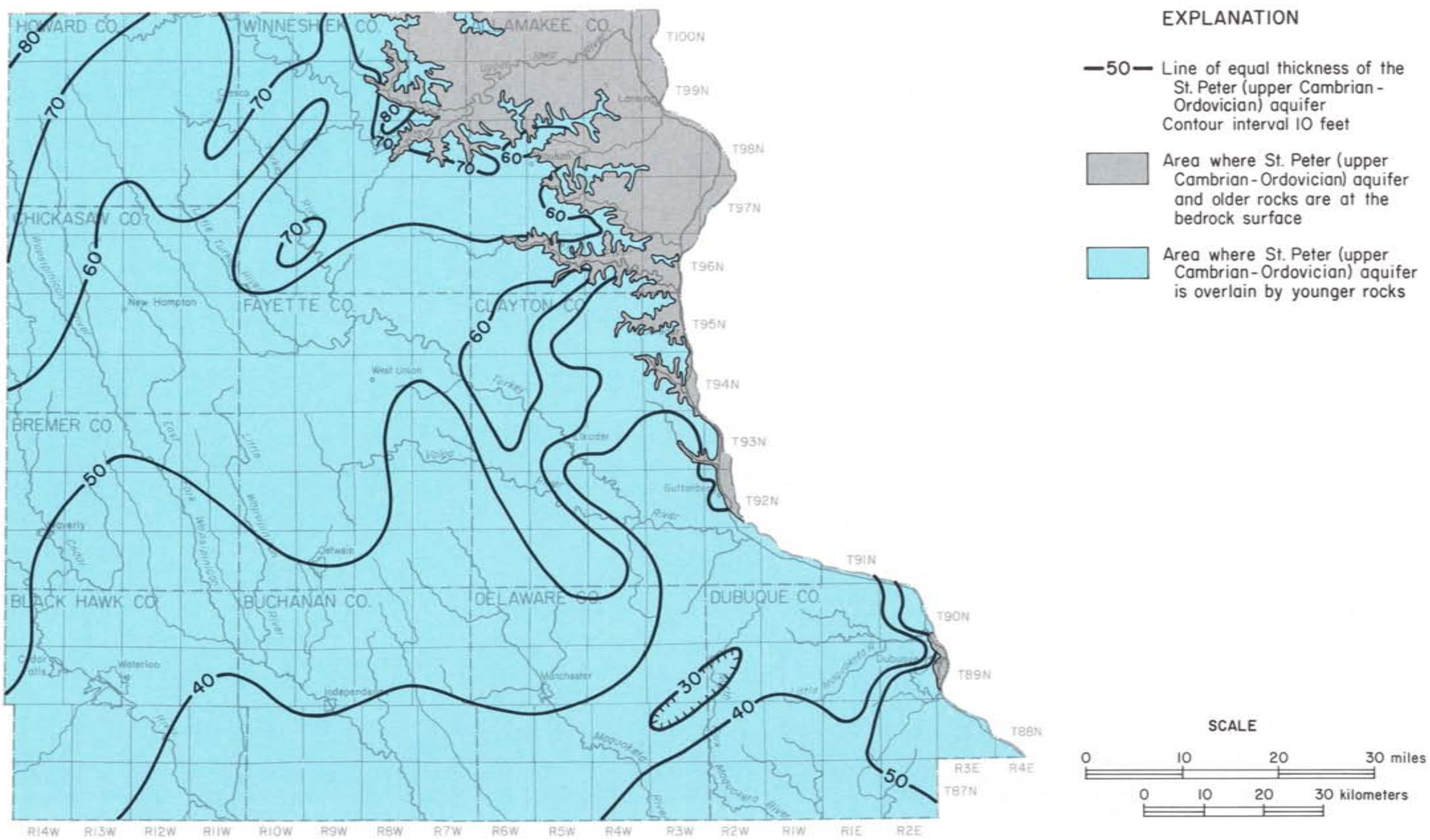


Figure 44. Thickness of the St. Peter (upper Cambrian-Ordovician) aquifer

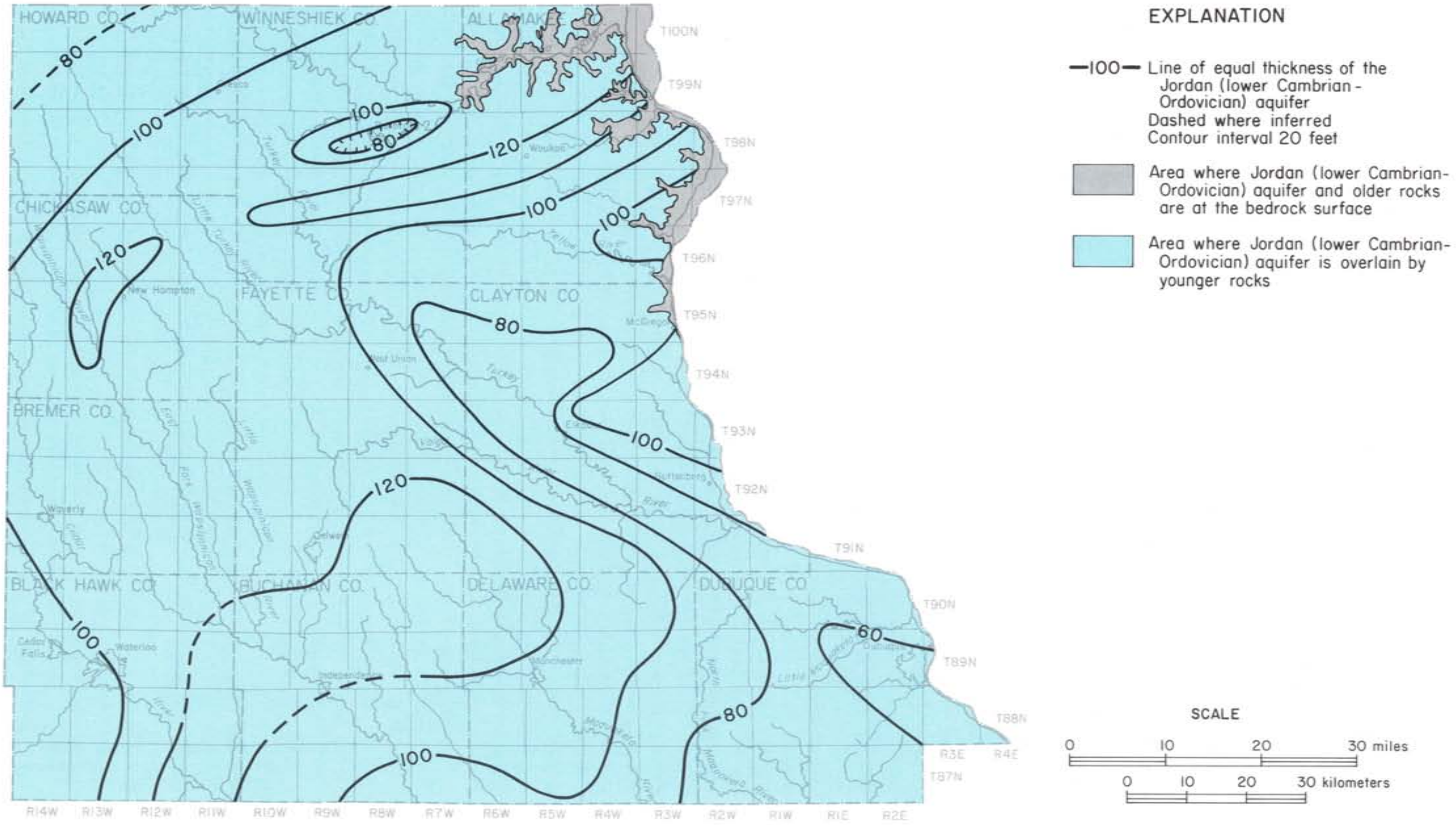


Figure 45. Thickness of the Jordan (lower Cambrian-Ordovician) aquifer

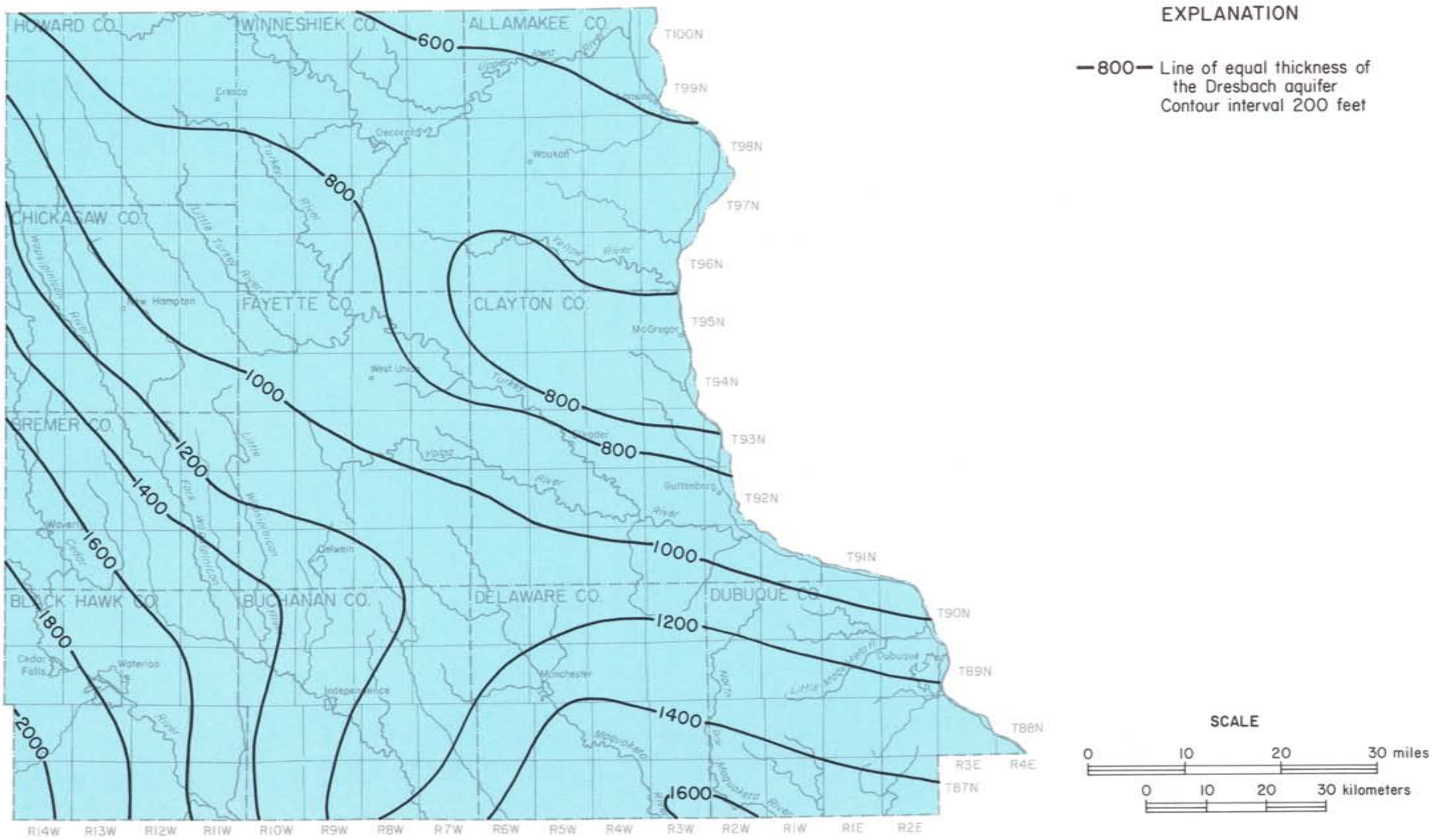


Figure 46. Thickness of the Dresbach aquifer

Use of Maps To Estimate Depths of Drilling

The preceding maps can be used to predict aquifer depths and thicknesses and to aid in estimating the accessibility of groundwater. Well depths and required length of casing can be estimated from the maps as a guide in designing and estimating costs of new wells. The land surface, the bedrock surface, and the tops of the major aquifers are all referenced to sea level to facilitate such planning.

The depth to a given aquifer is the difference between the land-surface altitude (figure 6) and altitude of the aquifer top (figures 33-40). The total depth of a well fully penetrating an aquifer is the sum of the depth to the top of the aquifer and the thickness of the particular aquifer (figures 41-46). Figure 47 compares depth and altitudes for deposits encountered in New Hampton City Well 6. Because the maps used to make the estimates are based on regional information, actual drilling depths may differ.

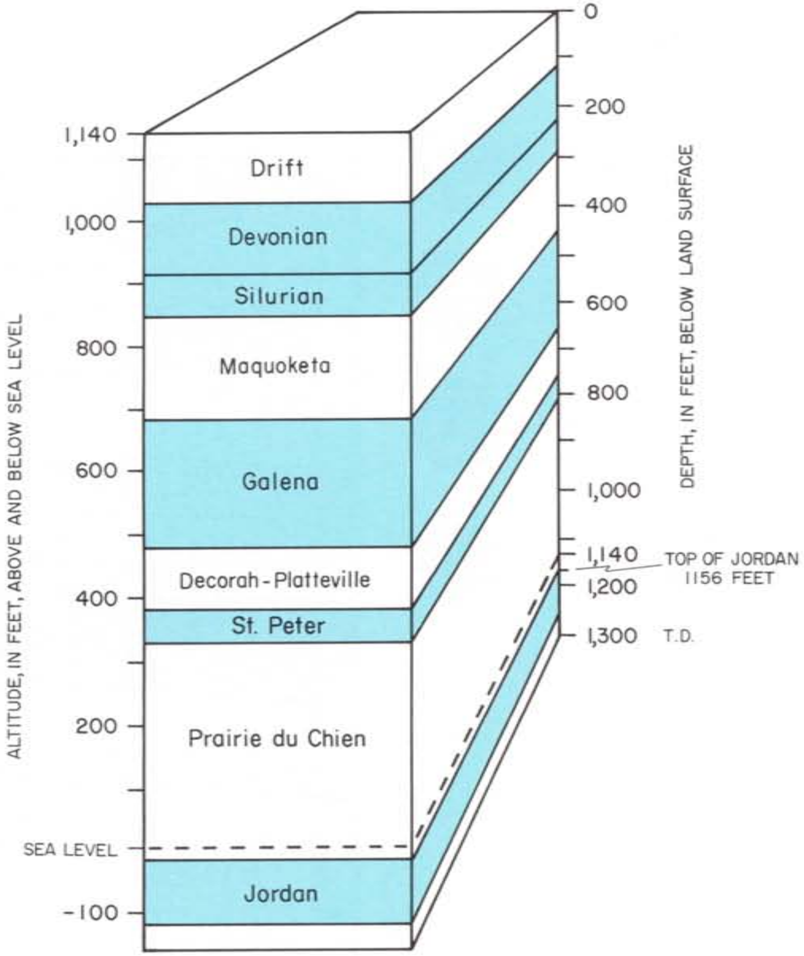


Figure 47. Rock units, depths, and altitudes in the New Hampton, Iowa, City Well 6 (1971)

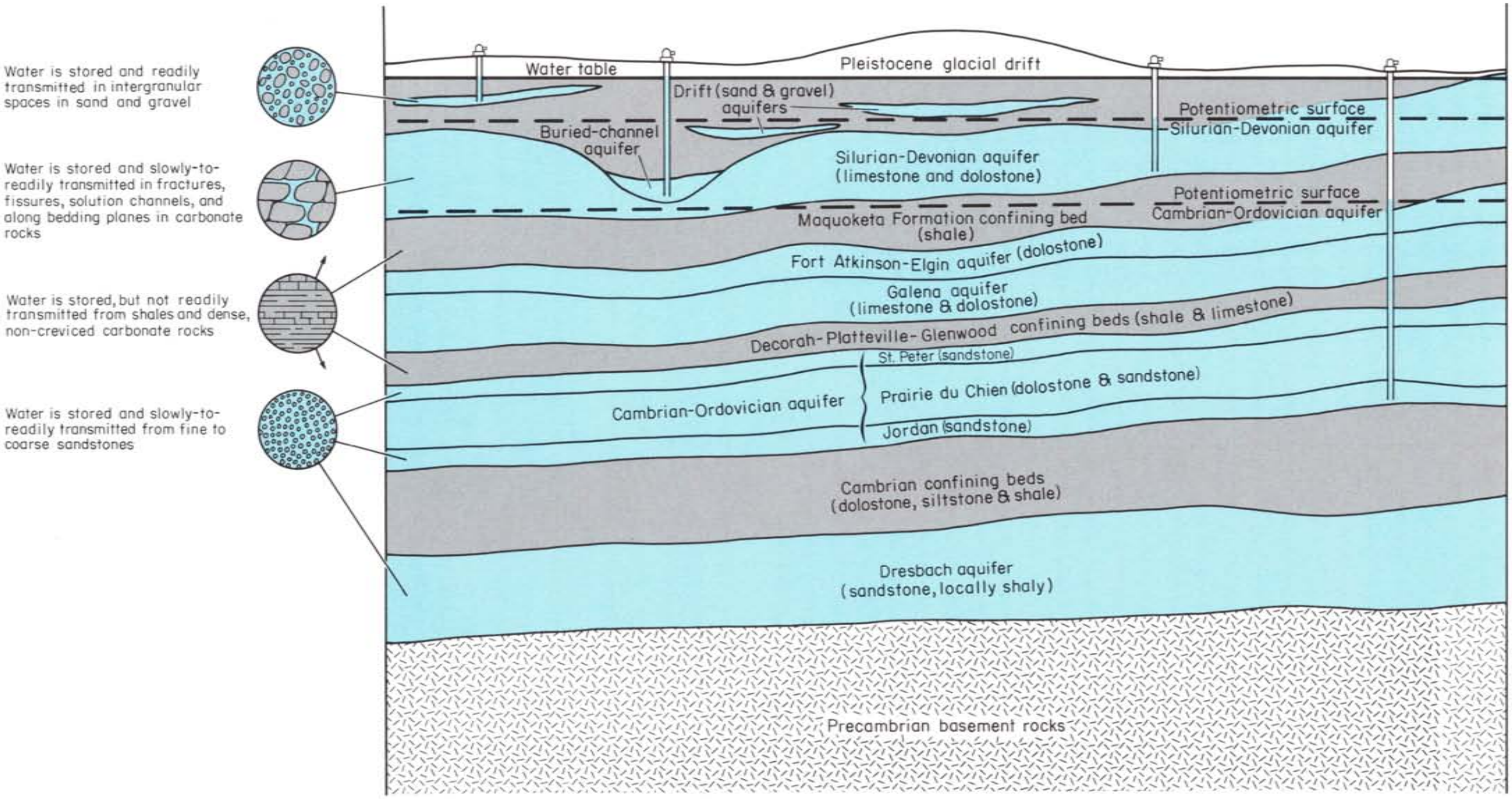


Figure 48. Water in the aquifers

WATER IN AQUIFERS

Water below ground occupies voids between the grains of unconsolidated sediment such as clay, silt, sand, and gravel, and the pore space of consolidated rocks. It may also occupy open spaces along bedding planes, cracks, and solution caverns in limestone and dolostone. Sediment or rock sufficiently permeable to yield appreciable quantities of water to wells is called an aquifer (figure 48). Clays and shales may be porous and sufficiently thick to store considerable amounts of water. However, they do not yield significant quantities of water to wells because individual pores in these materials are very small and poorly interconnected. Units with these characteristics are referred to as confining beds and function to retard the vertical movement of water, maintain water pressure in underlying confined aquifers, and provide natural protection from surface contamination. Limestones and dolostones may also be confining beds if they are extremely dense and have few crevices or solution cavities, or have openings that are filled with clay or mineral deposits.

Water in wells that penetrate confined aquifers will rise a few feet or as much as several hundred feet above the top of the aquifer. In this situation the aquifer is said to be artesian; if the water level rises above the land surface, a flowing artesian well is created. The level to which water will rise in a well completed in a given confined aquifer may be represented as a point on an imaginary surface that is called the potentiometric surface of the aquifer (figure 49). Where the surficial confining beds are thin or absent, as in the Paleozoic Plateau area of northeast Iowa, the top of the zone of saturation, or water table, may be below the top of a particular bedrock aquifer. Aquifer conditions may change from artesian to water table and vice versa over a variable distance in an aquifer depending on the extent of the overlying confining strata. Thus, in some places bedrock aquifers may be under water-table conditions, and may be confined at other locations.

Recharge to deep confined aquifers is mostly by lateral flow from water-table recharge areas long distances away. The water in deeper aquifers commonly has a high dissolved-solids content because it moves so slowly and has been in contact and reacting with the rocks for perhaps hundreds of years.

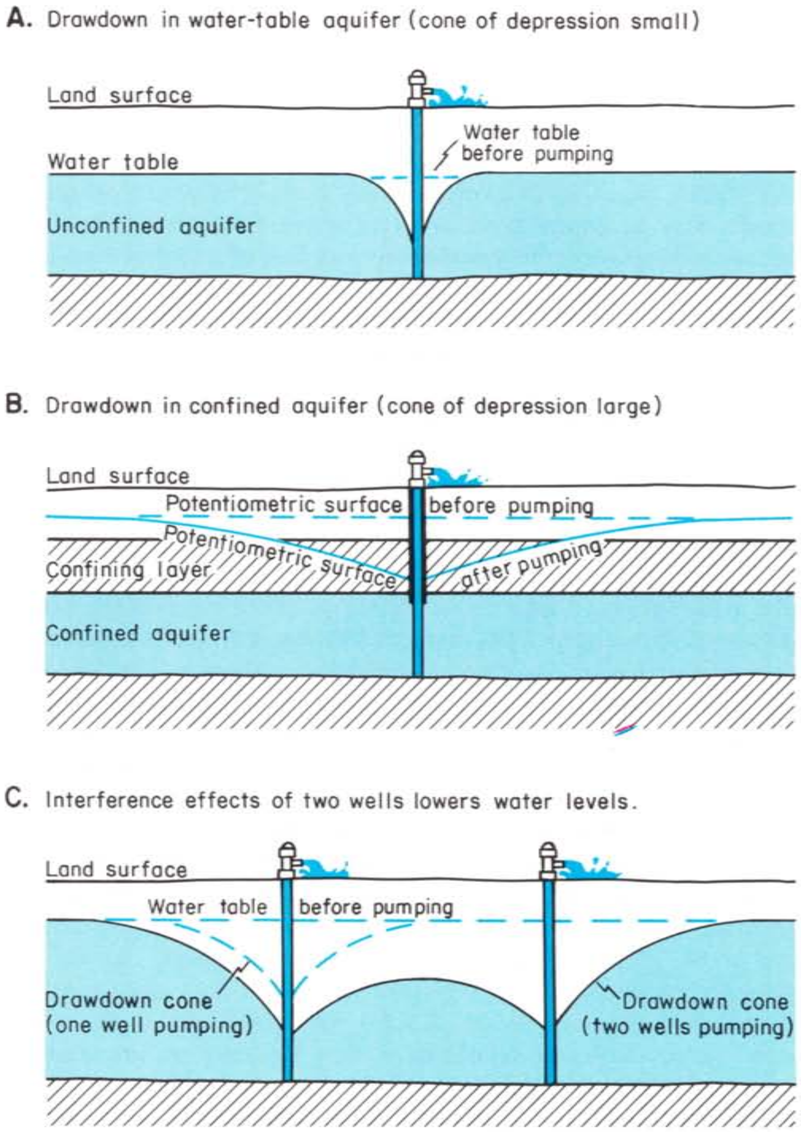


Figure 49. Drawdown cones around pumping wells

WATER LEVELS AND WELL HYDRAULICS

The level of water in a well unaffected by pumping is the static-water level. Static-water levels for many wells finished in a particular aquifer may be compiled on maps to define the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer. These surfaces can be represented by altitude contours in the same way that land-surface topography is mapped. By extrapolation, these maps are useful in estimating static-water levels where data are sparse. These maps also indicate the direction of groundwater movement. Groundwater moves from areas of higher to lower potentiometric elevations, and the general direction of flow is at right angles to contour lines. The dip of rock strata may have little or no effect on the direction of groundwater flow. The potentiometric map for the confined portion of the Jordan (lower Cambrian-Ordovician) aquifer indicates that the water in the aquifer is generally moving from northwest to southeast. The Jordan (lower Cambrian-Ordovician) aquifer receives the major portion of its recharge from southern Minnesota where the formation is at or near the land surface. For shallow portions of the Silurian-Devonian, Galena, and Jordan (lower Cambrian-Ordovician) aquifers, water-level maps indicate groundwater movement is strongly influenced by local topography; recharge to the aquifers from precipitation in upland areas discharges to streams usually only a few miles away.

Water levels in unconfined and semi-confined aquifers are generally highest in the late spring and fall and lowest in the late summer and winter. Most recharge from precipitation reaches these aquifers just after the spring thaw when plant transpiration is low, and from the end of the growing season until the ground is frozen. During the growing season plants and trees take up most of the moisture before it can reach the water table. Excess water infiltrates to the water table during the warm months only when the soils are saturated by heavy or prolonged rainfall.

The water table may fluctuate considerably from year to year and during various seasons of the year in response to local precipitation. During extended dry periods or when plant transpiration consumes most of the available water, water tables decline because of lack of recharge. As a result, shallow wells can go dry if the water level drops below the pump setting or the bottom of the well. These wells usually recover when sufficient recharge raises the water table again.

In contrast to short-term oscillations of water levels in unconfined aquifers, the water levels in deep, confined aquifers fluctuate very little except when stressed by pumping. Weather variations have little effect on the potentiometric surface because the major recharge areas for the deep aquifers are usually very large and distances and travel times are great.

Pumping causes water levels to decline in both unconfined and confined aquifers. Pumping causes a conical depression to develop in the potentiometric surface around the well which is called the drawdown cone or cone of depression (figure 49A). In an unconfined aquifer the drawdown cone is created by actual dewatering of the formation in the vicinity of the well. In a confined aquifer, the drawdown cone represents a reduction of the potentiometric surface caused by depressurization of the aquifer (figure 49B). The physical characteristics of the aquifer and the rate and duration of the pumping determine the size and shape of the drawdown cone. In general, drawdown cones are steeper sided and less extensive in unconfined aquifers than those of confined aquifers. Well interference occurs when drawdown cones overlap. The result is an additional drop in water levels as shown in figure 49C. Prolonged pumping of a well at a constant rate will cause a continual decline of the water level in the vicinity of the well and enlargement of the drawdown cone until equilibrium conditions are met. Equilibrium is reached when the expanded drawdown cone intercepts a sufficient amount of water to supply the pumping demand. Therefore, large-capacity wells finished in the same aquifer should be strategically spaced to prevent serious interference. When the pumps are shut off, water levels eventually will recover to their non-pumping levels.

Wells in unconfined and confined aquifers react differently to pumping and as a result, each has certain advantages and disadvantages. The water level in unconfined aquifer wells may be relatively shallow and large yields may be obtained if the aquifer is thick and highly permeable. Alluvial deposits associated with river floodplains where recharge is rapid are an example. Since drawdown cones in unconfined aquifers are relatively small, several wells may be placed in close proximity. Shallow wells are also less expensive to pump. However, water levels of shallow unconfined aquifers are sensitive to precipitation and wells in such aquifers may be contaminated rather easily. On the other hand, deep, confined aquifers are not responsive to weather changes. Wells in deep, confined aquifers provide a steady source of water supply during the most severe drought, and the quality and temperature of the water are constant. Surface contamination generally will not reach a confined aquifer except through unplugged abandoned wells. Interference is more likely to be a problem because the drawdown cones are large. Deeper water levels increase pumping costs, and these aquifers may yield water that has high concentrations of dissolved solids.

WATER LEVELS IN SURFICIAL AQUIFERS

The main source of recharge in surficial aquifers is precipitation which infiltrates to the water table. Where present, bedrock formations immediately underlying the alluvium or in adjacent valley walls may also recharge alluvial aquifers. Alluvial aquifers, in turn, discharge to nearby streams. Streams receiving groundwater discharge in the study area have greater baseflow, as much as 60 to 70 percent of the total stream discharge, than streams in other parts of the state. Only during periods of heavy precipitation does overland flow contribute more water to streams than groundwater discharge. A schematic streamflow hydrograph illustrating the relative relationships of surface runoff and groundwater discharge during a single rainfall event is shown in figure 50.

Water levels in surficial deposits change noticeably throughout the year and are highest in the late spring and fall. The depth to water in alluvial aquifers averages about six feet below floodplain surfaces, but may range from ground level to 20 feet below the land surface.

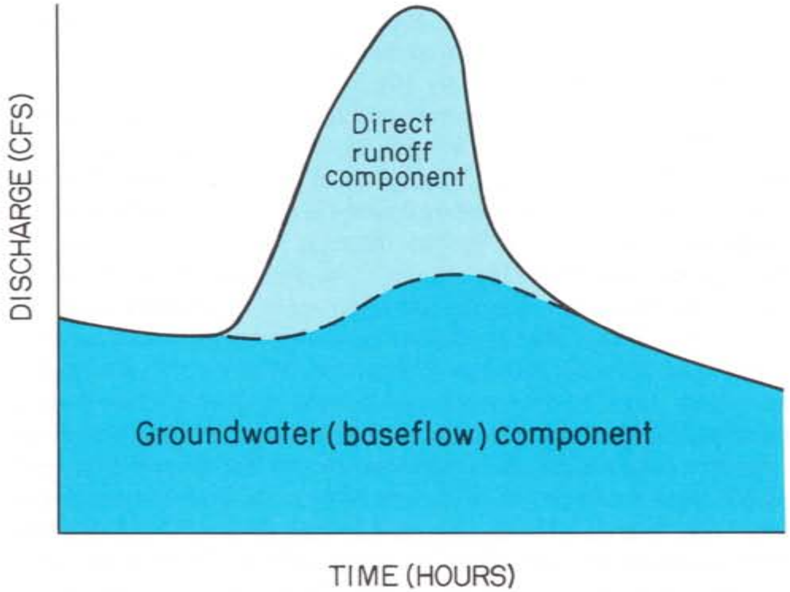


Figure 50. Schematic stream-discharge hydrograph

The navigation pools and lock-and-dam systems along the Mississippi River sustain artificially high water levels in the Mississippi River alluvial aquifer and for short distances up tributary valleys. From Bellevue to Dubuque the normal pool elevation is 592 feet above sea level; from Dubuque to Guttenberg the elevation is 603 feet; from Guttenberg to Harpers Ferry, 611 feet; and from Harpers Ferry to as far as the Minnesota state line, 620 feet.

The contour of the water table is generally a subdued replica of the land-surface topography and is highest under hills and lowest in valleys. Water levels in drift aquifers are usually 10 to 50 feet below the land surface and depend on a site's location within a local flow system.

WATER LEVELS IN BEDROCK AQUIFERS

Silurian-Devonian Aquifer

Water levels in the Silurian-Devonian aquifer range from less than 800 feet above sea level along the Cedar River valley at La Porte City to greater than 1,250 feet along the Iowa-Minnesota state line in northwestern Howard County (figure 51). Both water-table and artesian conditions are represented and merge locally. The direction of groundwater flow in the Silurian-Devonian aquifer is south and southeasterly in the Cedar, Wapsipinicon, and Maquoketa drainage systems. There is also a southwestward-flowing component from the topographic high formed by the Silurian escarpment toward the Wapsipinicon and Maquoketa rivers. Recharge takes place in upland, interstream divides. The aquifer discharges to streams at lower elevations. Water-table conditions generally prevail where surficial materials are absent or less than 50 feet thick. Where surficial materials are greater than 50 feet thick and consist largely of fine-grained sediment, the aquifer is generally confined. No significant drawdown cones are observed on the potentiometric surface (figure 51), even though large quantities of water are withdrawn from the aquifer in places like Waterloo-Cedar Falls, and Independence. This is because these pumping centers occur in large valleys where water-table conditions predominate and the near-surface, fractured, and broken carbonate rock has extremely high transmissivity. A highly communicative hydraulic system is formed by alluvial deposits, fractured carbonate rocks, and the river.

Galena Aquifer

Water levels for the Galena aquifer are shown in figure 52. They range from a minimum of about 600 feet above sea level at Dubuque to more than 1,100 feet above sea level in northwestern Winneshiek County. The flow direction varies locally, but is principally southeastward. In the outcrop area, recharge is in uplands and discharge is to the nearest streams through local flow systems of interconnected joints, crevices, and solution openings. The Mississippi River bordering Clayton and Dubuque counties and the Turkey River in Clayton and Fayette counties are the principal discharge areas. Other important discharge zones are the Upper Iowa River in Winneshiek County, the Volga River in Clayton County, and the Little Maquoketa River in Dubuque County. Practically all the water in the outcrop area of the Galena aquifer is unconfined because of the thin mantle of glacial drift. Where the aquifer occurs beneath the Maquoketa Formation and other younger strata in the southwestern part of the study area, confined conditions exist. Regional flow is from recharge areas in north-central Iowa and southern Minnesota to areas of discharge in the middle and lower reaches of the Turkey River.

Cambrian-Ordovician Aquifer

Of the formations comprising this aquifer, the Jordan (lower Cambrian-Ordovician) aquifer is the main water-yielding unit and the one for which the most reliable water-level data are available. The St. Peter (upper Cambrian-Ordovician) aquifer is less developed and data sources are less abundant. Available data do, however, indicate that the St. Peter has a potentiometric surface that is distinct from that of the Jordan. The Prairie du Chien Group, although water-bearing and hydraulically connected to the Jordan and St. Peter aquifers, comprises a moderately effective confining interval between the two aquifers. This is with the exception of the outcrop area along the Mississippi River and in the valleys of the Upper Iowa River, Village and Paint creeks, and the Yellow River.

The potentiometric map for the St. Peter (upper Cambrian-Ordovician) aquifer (figure 53) indicates that regional flow in the aquifer is southeasterly and discharge is to the Mississippi River. The potentiometric surface of the St. Peter (upper Cambrian-Ordovician) aquifer ranges from being the same as, to as much as 200 feet higher than that of the Jordan (lower Cambrian-Ordovician) aquifer. The greatest difference is in Howard and Chickasaw counties where it differs by 100 to 200 feet. For the remainder of the study area the difference between the potentiometric surfaces of the two aquifers is generally 50 feet. In Winneshiek and Allamakee counties the two surfaces are the same. Where the St. Peter (upper Cambrian-Ordovician) aquifer is exposed in stream valleys, natural discharge dewaters the exposed edges of the aquifer creating steep declines in the potentiometric surface. At these locations the Jordan (lower Cambrian-Ordovician) aquifer potentiometric surface may be above that of the St. Peter (upper Cambrian-Ordovician) aquifer.

The predevelopment potentiometric map for the Jordan aquifer (figure 54) indicates that the altitude of this surface ranged from more than 1,050 feet above sea level in Howard County to less than 650 feet along the Mississippi River in Clayton and Dubuque counties. As withdrawals from the Jordan increased, the potentiometric surface experienced a regional decline, as well as showing local drawdown cones created by pumping stress. Municipal and industrial wells at Postville, Waukon, Waverly, Oelwein, New Hampton, and Cresco are major pumping centers of the Jordan aquifer. These and other Jordan wells in northeast Iowa have lowered the potentiometric surface by as much as 50 to 100 feet regionally, and 150 feet or more at pumping centers, notably at Postville. The potentiometric-change map (figure 55) indicates the regional recession of the Jordan potentiometric surface from the original predevelopment surface to present. These declines in the potentiometric surface will continue as long as pumping rates increase. If pumping slows or stops, water levels will recover locally to higher, more stable levels.

The present potentiometric surface of the Jordan aquifer (figure 56) ranges from an altitude of over 1,000 feet above sea level in the northwestern corner of the report area to less than 650 feet in the southeastern corner. The general flow direction in the aquifer is southeasterly. In the outcrop area in Allamakee, in parts of northeastern Winneshiek, and northeastern Clayton counties, the groundwater moves through local flow systems with discharge into the Upper Iowa and Mississippi rivers. Across the remainder of the area, the flow is regional, discharging southeasterly to the Illinois Basin. Locally, the regional-flow direction is influenced by major pumping centers.

Dresbach Aquifer

Limited use of, and therefore data on, the Dresbach aquifer in northeast Iowa precluded construction of a potentiometric map for this unit. Available data indicate groundwater flow is to the south and southeast, and may mimic the general flow directions of groundwater within the Cambrian-Ordovician aquifer. The potential for discharge from the aquifer to the Mississippi River exists, as evidenced by flowing wells located on the Mississippi floodplain near Dubuque and New Albin. Potentiometric elevations above 800 feet have been measured at Decorah, with elevations below 650 feet existing along the Mississippi River.

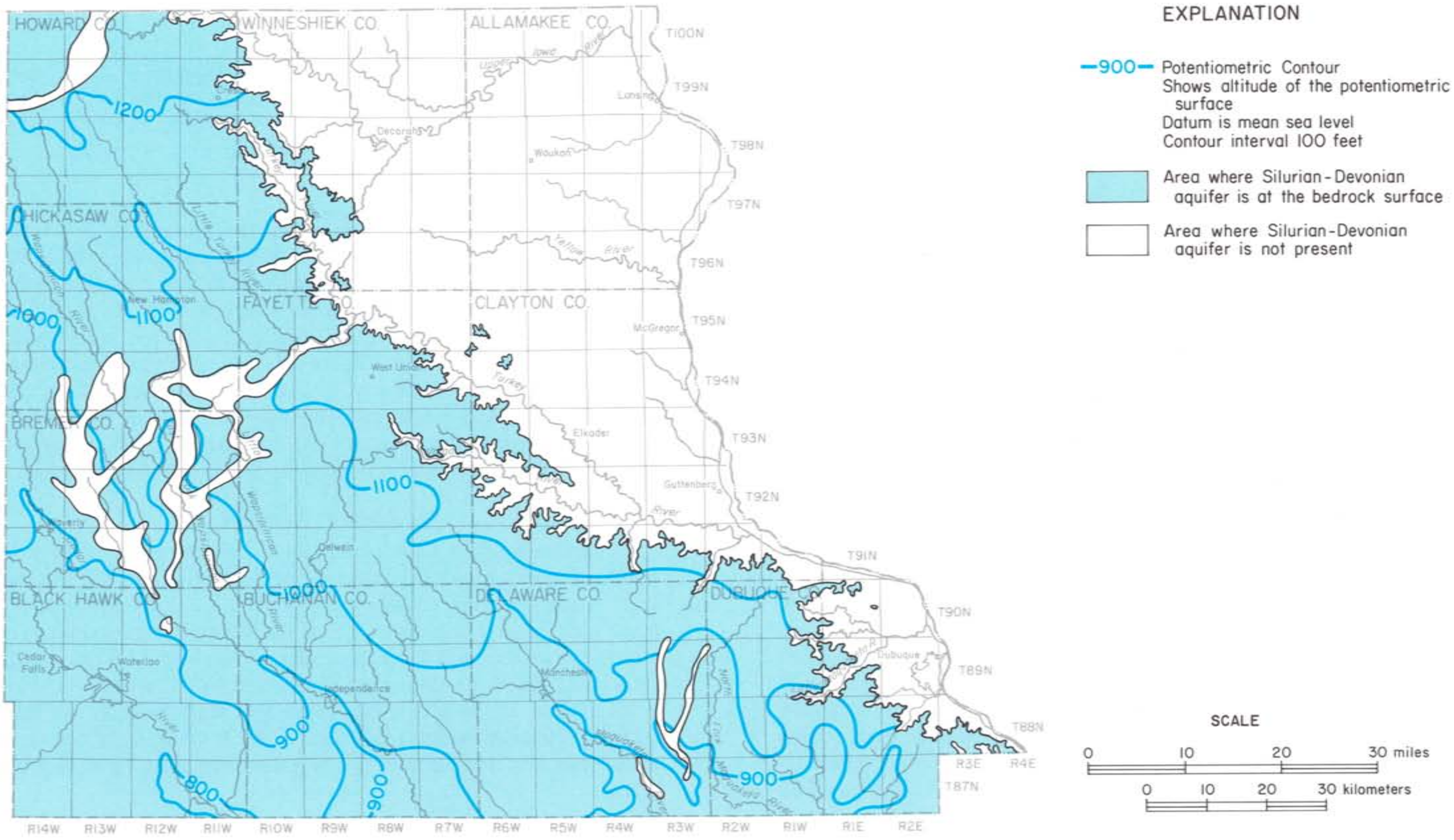


Figure 51. Potentiometric surface of the Silurian-Devonian aquifer

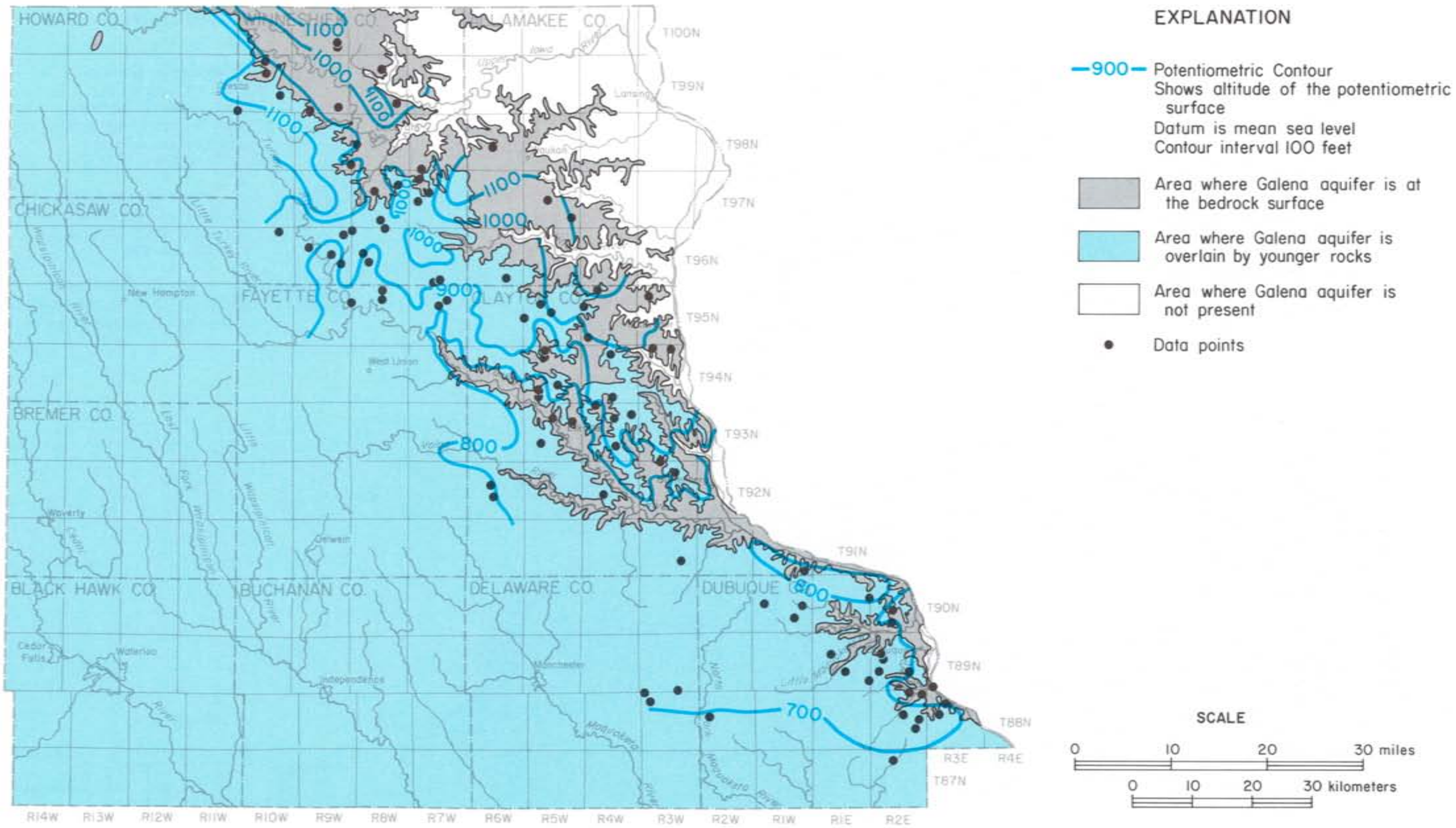


Figure 52. Potentiometric surface of the Galena aquifer

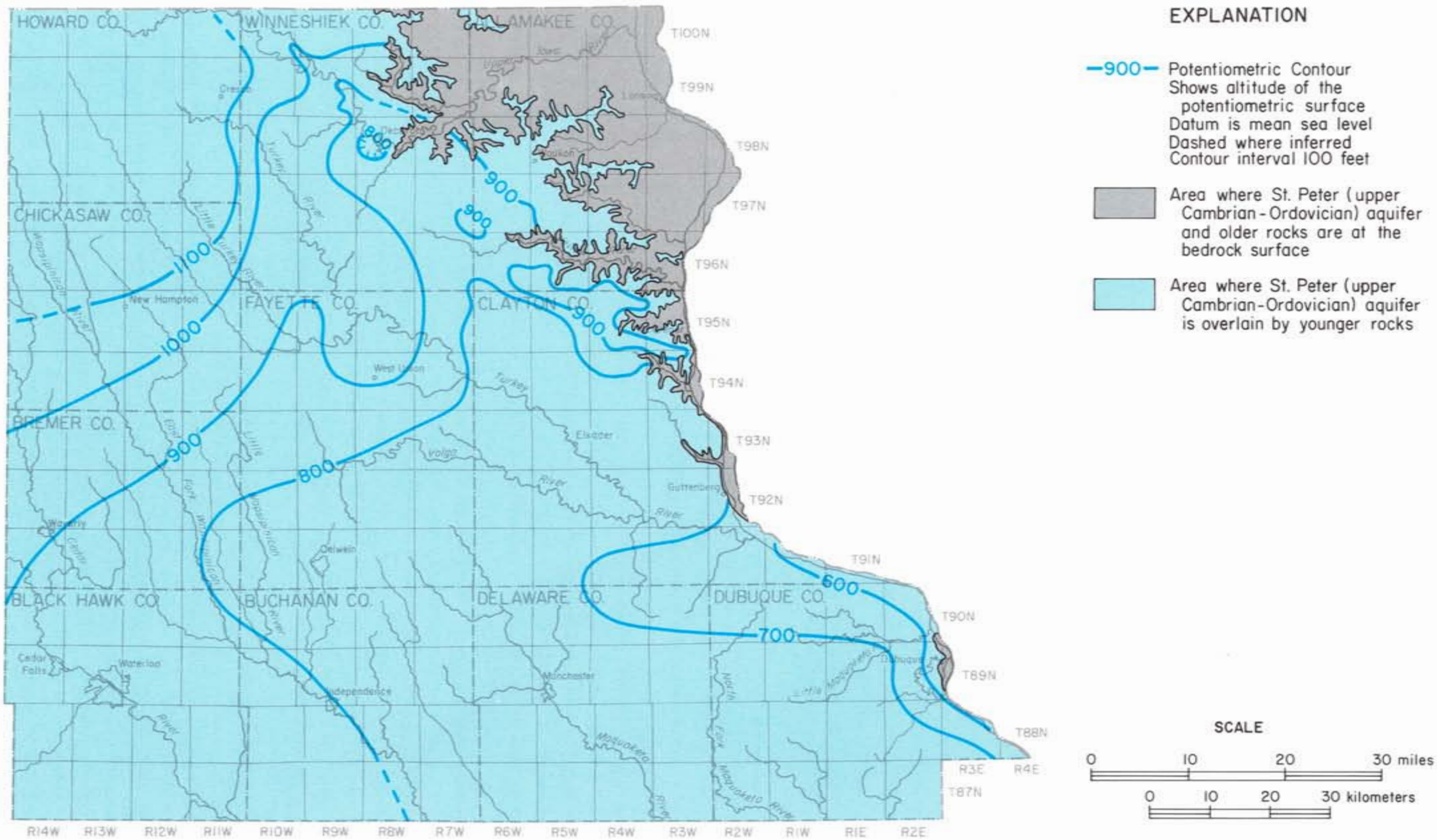


Figure 53. Potentiometric surface of the St. Peter (upper Cambrian-Ordovician) aquifer

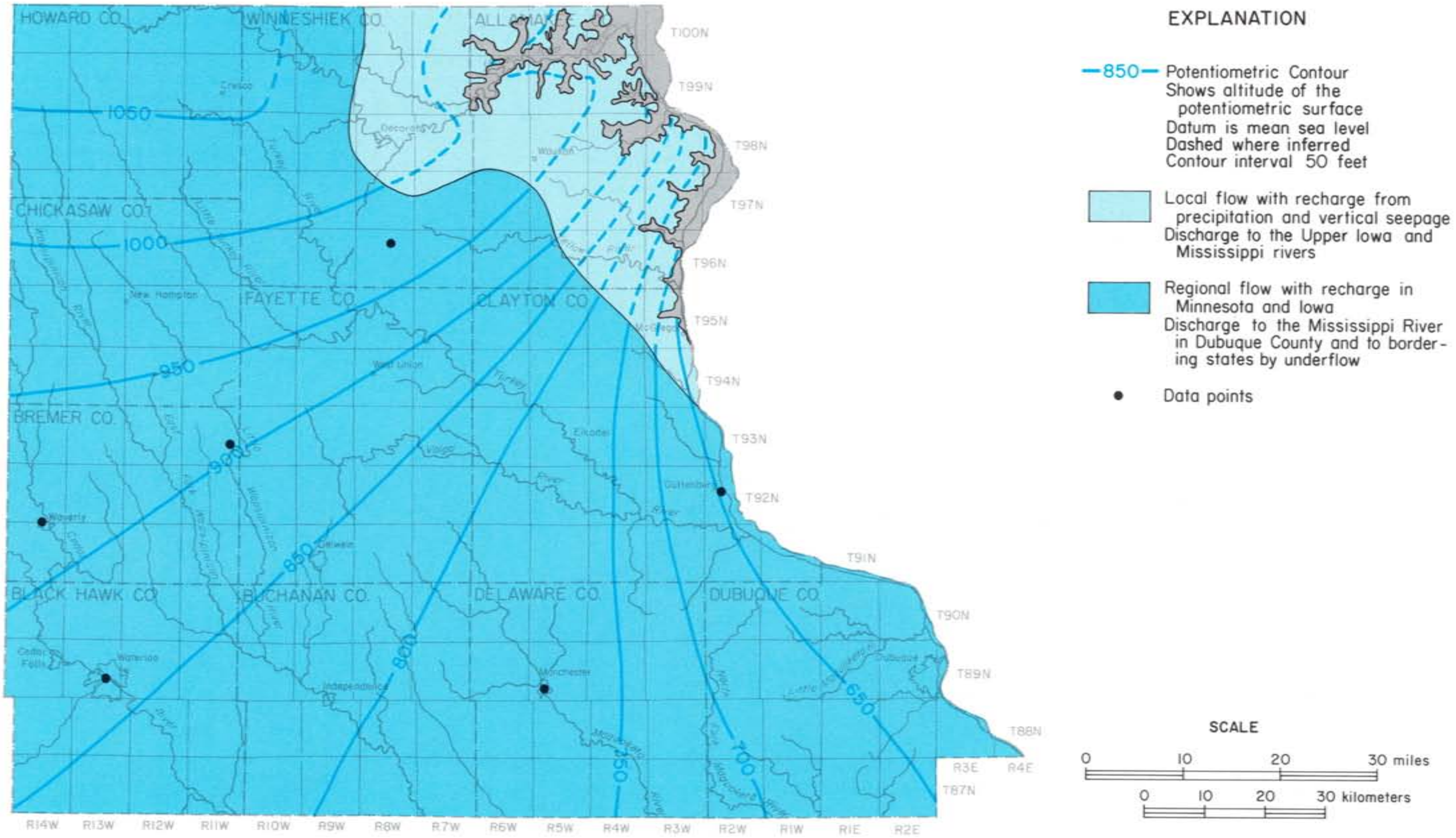


Figure 54. Predevelopment potentiometric surface of the Jordan (lower Cambrian-Ordovician) aquifer

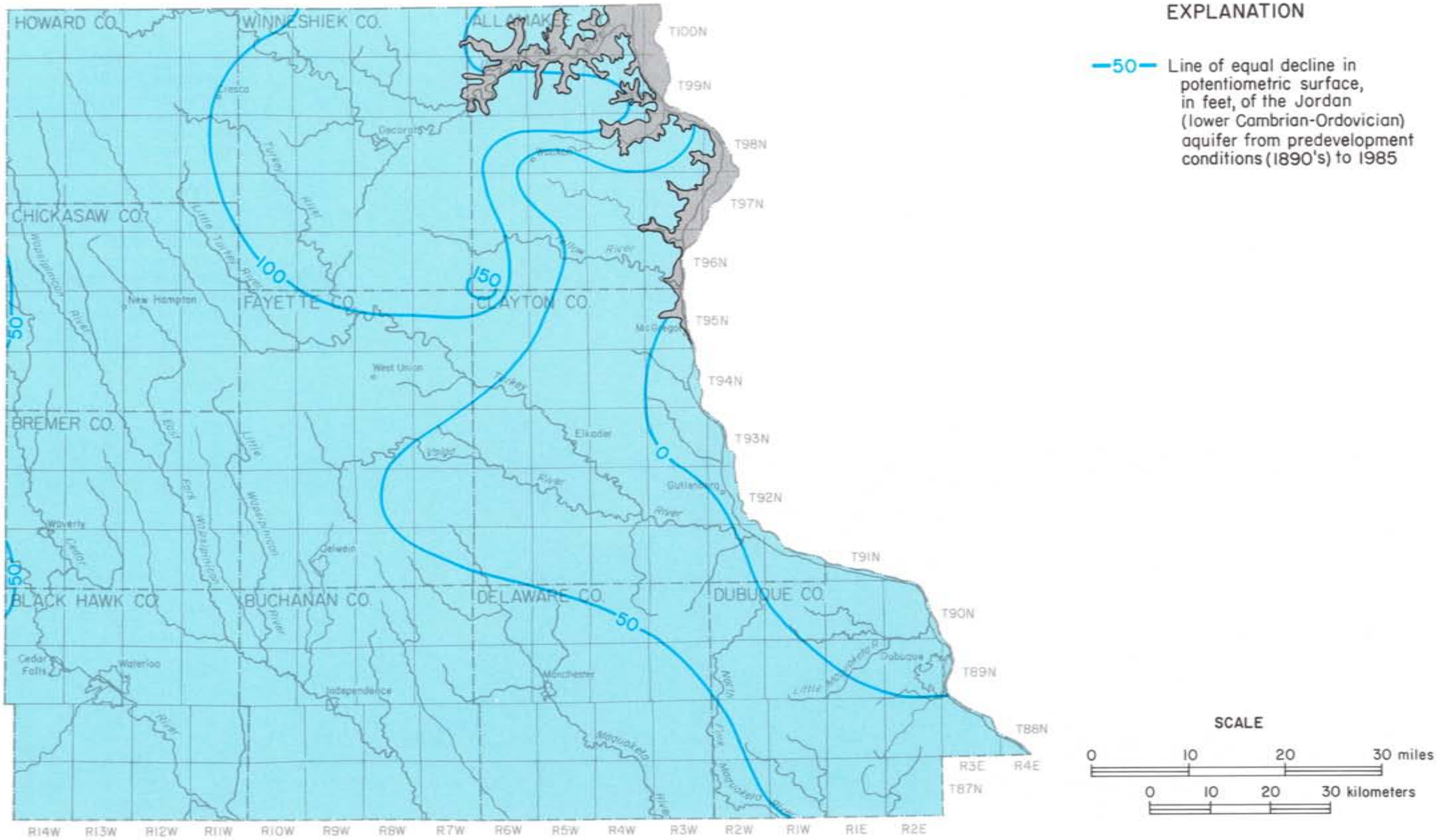


Figure 55. Potentiometric change in the Jordan (lower Cambrian-Ordovician) aquifer

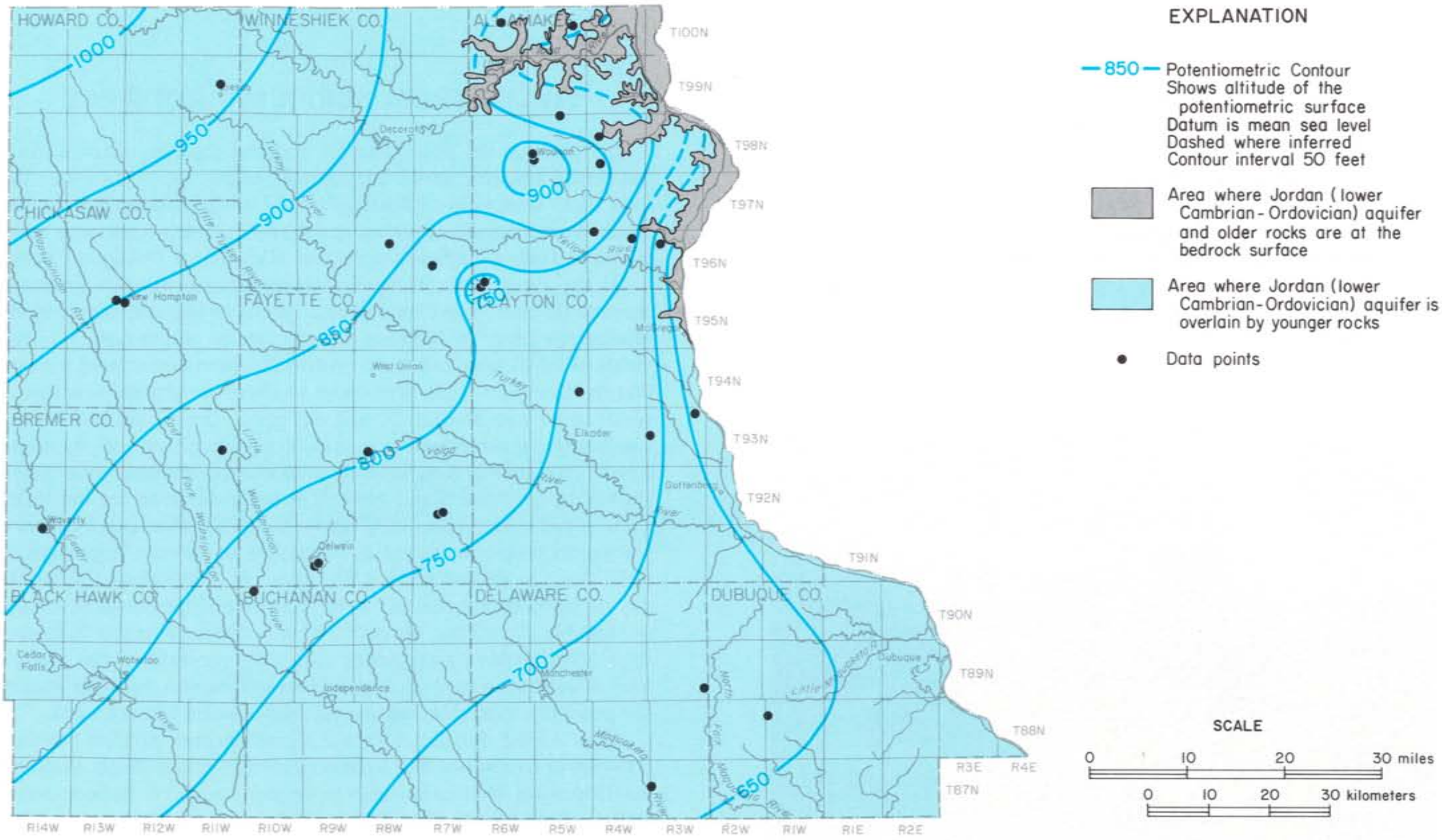


Figure 56. Potentiometric surface of the Jordan (lower Cambrian-Ordovician) aquifer

WELL YIELDS

The rate at which water can be withdrawn from wells differs greatly between various aquifers and from place to place within an individual aquifer. Well yield depends on the hydrologic characteristics of the aquifer, well design, and spatial relationships between wells. Maps depicting possible well yields from the bedrock aquifers are shown on the following pages. The potential-yield maps are based on available information and represent known and predicted yields from the principal bedrock aquifers. The data used in constructing these maps include production statistics from existing wells, drillers' records, and information on file at the Geological Survey Bureau.

P. J. Horick

This photo shows the pumping test of an irrigation well completed in the Silurian-Devonian aquifer at a site northwest of Cedar Falls, Black Hawk County. The well is pumping at a rate of 1,400 gallons per minute with a drawdown of only 2 feet.

YIELDS FROM SURFICIAL AQUIFERS

The yield of the three types of surficial aquifers: alluvial, drift, and buried channel, varies considerably within the study area. Use from these sources is confined primarily to Chickasaw, Bremer, and Black Hawk counties as shown in figure 57. The exception is water produced from the Mississippi River alluvium in Dubuque County.

Of the three surficial-aquifer types, alluvial sources generally produce the most significant yields. Wells in this context along the Mississippi River in Dubuque County can be anticipated to sustain yields of 2,000 gpm and more. Alluvial aquifers associated with the Wapsipinicon and Little Wapsipinicon rivers are probably capable of yields in a range between 50 and 600 gpm. One of the best alluvial aquifers on the interior river system is that associated with the Cedar River. This aquifer is particularly productive in the reach from below Nashua to La Porte City. Here it is not uncommon for individual wells to yield in excess of 1,000 gpm. In the Waterloo area it probably reaches its maximum potential. Waterloo has several large capacity wells that can deliver up to 2,000 gpm. In Winneshiek County the city of Decorah has alluvial wells along the Upper Iowa River that are capable of yielding up to 500 gpm. Throughout the study area there are probably opportunities to develop moderate water supplies from alluvial sources along larger rivers and streams, but other sources are generally available and the alluvial sources are not used.

Wells drilled into the drift and buried-channel aquifers are most common in Chickasaw and Bremer counties. It is difficult, however, to differentiate whether the wells in the area are drift or buried-channel wells with the existing data. The available data were taken from drillers' records that do not distinguish between aquifer types. The only useful data from this source was well depth and yield. Regardless of this problem, the yields from these two sources can be characterized as ranging generally between 6 and 30 gpm. Locally, irrigation wells have produced as much as several hundred gallons per minute.

Figure 57. Principal area of development of the surficial aquifers

YIELDS FROM BEDROCK AQUIFERS

Silurian-Devonian Aquifer

Yields from the Silurian-Devonian aquifer vary because of changes in the distribution of cracks and solution openings, aquifer thickness, and recharge characteristics of overlying rocks. Generally, sufficient water for domestic use and for many moderate-sized communities can be produced wherever the Silurian-Devonian aquifer is present. Domestic wells completed in this aquifer produce between 3 and 60 gpm, and well yields of 10 to 30 gpm are common. The highest specific capacities are found in the Devonian portion of the aquifer in the western tier of counties and in Fayette County, usually 1.5 to 3 gpm per foot drawdown (gpm/ft). The lowest average specific capacities for domestic wells, generally 1 gpm/ft or less, occur in Dubuque, Delaware, and Buchanan counties where the Devonian rocks are absent.

The Silurian-Devonian aquifer is also the most widely used source for large capacity municipal, industrial, and irrigation wells in the study area. At least 42 communities rely on the Silurian-Devonian aquifer entirely or in part, and pump approximately 21 million gallons a day. An area of extraordinarily high yields occurs in a belt 3 to 5 miles wide along the Cedar River in Black Hawk, Bremer, and Chickasaw counties (figure 58). City wells in Waterloo and Cedar Falls, 150 to 300 feet deep, have tested as high as 2,000 to 4,000 gpm at specific capacities of 200 to 300 gpm/ft or more. One irrigation well yielded 1,400 gpm with only 2 feet of drawdown and had a specific capacity of 700 gpm/ft.

Outside of this high-yield area in the Cedar River valley, the Silurian-Devonian aquifer typically yields 100 to 500 gpm to municipal, industrial, and irrigation wells. Specific capacities of 5 to 10 gpm/ft are common.

Fort Atkinson-Elgin (lower Maquoketa) Aquifer

The Fort Atkinson-Elgin (lower Maquoketa) aquifer is used in parts of Howard, Winneshiek, Chickasaw, Bremer, and Fayette counties (figure 59) and is mainly developed for domestic supply. Yields may vary considerably, but the aquifer will generally yield 10 to 30 gpm to individual wells. At Fredericksburg in Chickasaw County, wells tested as high as 180 to 250 gpm at the Fredericksburg Creamery while the nearby city well yielded only 25 gpm.

The communities of Ridgeway and Lime Springs have wells producing from the Fort Atkinson-Elgin (lower Maquoketa) aquifer. The Ridgeway well yields about 65 gpm and the Lime Springs wells yield as much as 200 to 240 gpm. Riceville has two wells open to both the Devonian and lower Maquoketa (Elgin) sequence that yield 200 gpm each.

Galena Aquifer

The Galena aquifer is a very restricted source of water compared to the Silurian-Devonian and Cambrian-Ordovician aquifers. It is a dependable source for domestic wells and a number of municipal and industrial wells in Winneshiek, Clayton, northeastern Fayette, southwestern Allamakee, and central and eastern Dubuque counties. This main area of development occurs just west of the formation outcrop (figure 60) where younger Maquoketa Formation confining beds overlie the Galena aquifer and protect it from surface contamination. Most wells completed in the Galena aquifer in its principal area of use yield between 10 and 30 gpm. A few municipal and industrial wells at Spillville, Luana, Volga, and Holy Cross have produced as much as 150 to 250 gpm. To the east where the Galena aquifer is uppermost bedrock, the overlying mantle of soil and glacial drift is thin, and sinkholes and other karst features are abundant. Because of these factors, the aquifer is significantly contaminated by fertilizers and other agricultural chemicals. In these areas, water from the aquifer commonly has high nitrate concentrations and is unfit for human consumption.

Few wells are completed in the Galena aquifer in the southwestern two-thirds of the study area because adequate yields can be produced from the overlying Silurian-Devonian aquifer. In this area, thick Maquoketa confining beds limit vertical recharge to the Galena aquifer.

Cambrian-Ordovician Aquifer

St. Peter (upper Cambrian-Ordovician) Aquifer

The principal area of development of the St. Peter (upper Cambrian-

Ordovician) aquifer is in Winneshiek, Fayette, Clayton, southwestern Allamakee, and eastern Dubuque counties (figure 61). Domestic wells completed in the St. Peter generally yield between 10 and 20 gpm with little or no drawdown. Industrial and municipal wells have tested as high as 100 to 250 gpm at Ft. Atkinson, Decorah, Elkader, Cresco, Protovin, Waucoma, Maynard, and near Dubuque. In the outcrop area the St. Peter Sandstone may be partly or completely dry, and wells usually extend 100 feet or more into the underlying Prairie du Chien Group before obtaining sufficient water.

In many St. Peter wells the overlying Galena aquifer is left uncased and contributes varying quantities of water. This method of construction is not recommended where the Galena aquifer has a thin soil cover and is subject to contamination by infiltrating surface water.

At some locations there may be problems with wells completed in the St. Peter (lower Cambrian-Ordovician) aquifer because of local geologic conditions. In some wells liner casing is installed in the Decorah-Platteville-Glenwood interval to prevent shale caving into the well. Large drawdowns occur in some St. Peter wells apparently because the sandstone is tightly cemented. In places the aquifer may be weakly cemented, causing sand-pumping problems in wells pumped at rates greater than 100 to 150 gpm.

Jordan (lower Cambrian-Ordovician) Aquifer

The Jordan (lower Cambrian-Ordovician) aquifer is a consistent source for large supplies of water in northeast Iowa. The yield of the aquifer is related to formation thickness, degree of sandstone cementation, and the method of well construction and development. Individual wells are capable of producing more than 1,000 gpm with drawdowns of less than 100 feet over much of the area (figure 62). However, in several areas more than 100 feet of drawdown are required to produce 500 gpm from the Jordan.

Twenty-six communities in the study area use the Jordan aquifer as their principal source of water supply, and it is also used as the principal water supply for large-capacity industrial wells at Postville, Waukon, and Oelwein. In individual wells, yields range from less than 100 gpm to more than 1,200 gpm with specific capacities varying from 2.4 to 26.3 gpm/ft.

Dresbach Aquifer

The Dresbach aquifer is a major water-supply source in parts of Minnesota, Wisconsin, and Illinois adjacent to the study area. Dresbach well yields in these areas average 500 gpm, with a maximum of 1,850 gpm reported. The aquifer is used to a lesser extent in Iowa because its yield potential and water quality deteriorate rapidly west of the Mississippi River corridor. Use of the aquifer in the study area is confined to communities along the Mississippi River.

The aquifer is a dependable source of water supply for New Albin, Lansing, Marquette, and Dubuque (figure 63). The well at New Albin is pumped at 200 gpm; the Lansing well was reported as flowing at 300 gpm when completed in 1943, but it's now pumped at 260 gpm; the Marquette well was flowing in 1950, but is now pumped at about 130 gpm. These data probably do not reflect the true yield potential of the aquifer because all of these communities are small and it is doubtful that their water demands stress the aquifer.

Dresbach wells in Dubuque probably give a better picture of the aquifer's yield potential. The city has four wells completed into the aquifer and they are each capable of pumping 1,500 gpm. One of these wells was test pumped at over 2,000 gpm. Within one mile of the city wells a private concern has a Dresbach well that yields between 1 and 1.5 million gallons per day (around 1,000 gpm).

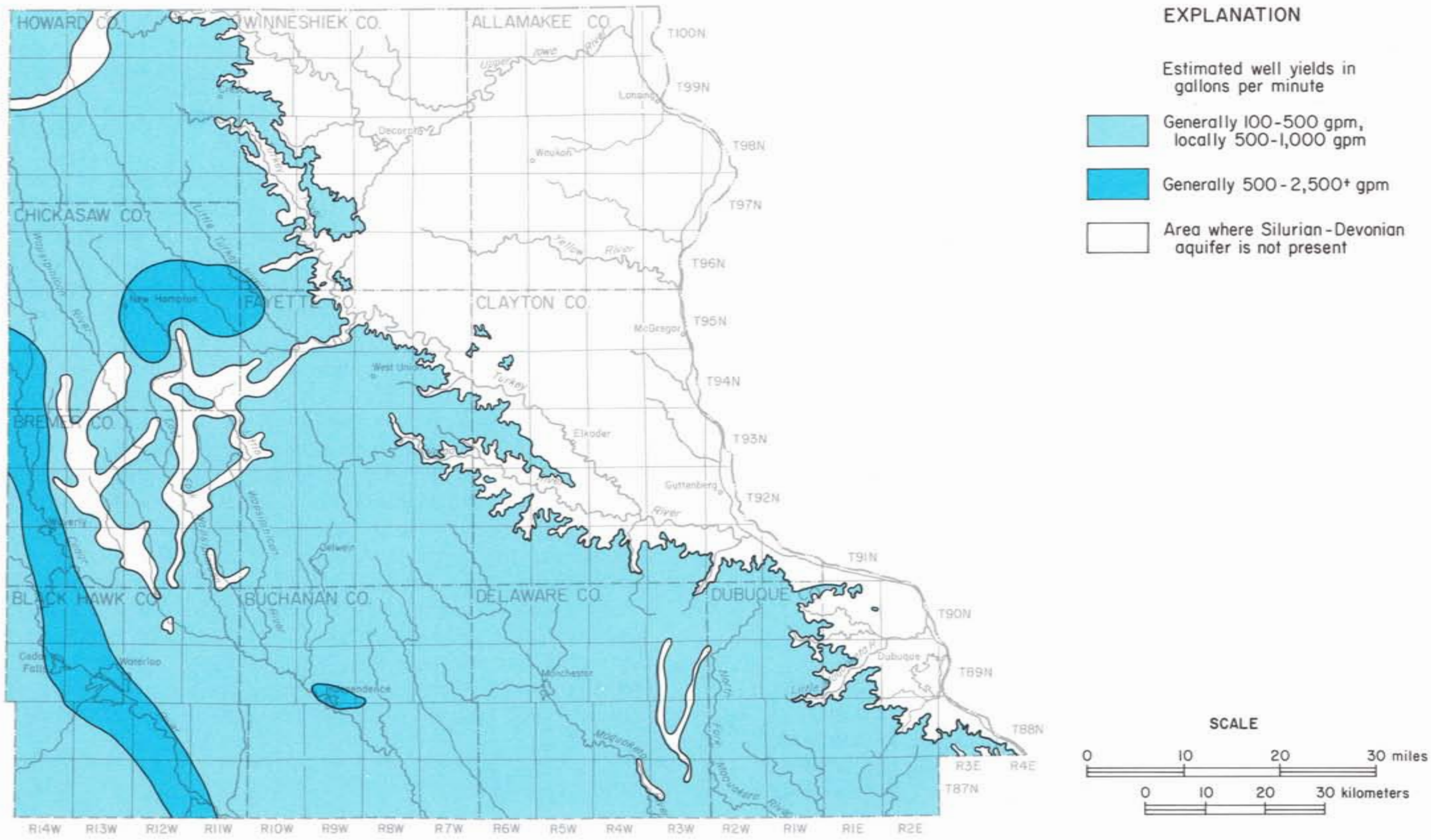


Figure 58. Estimated yields to individual wells from the Silurian-Devonian aquifer

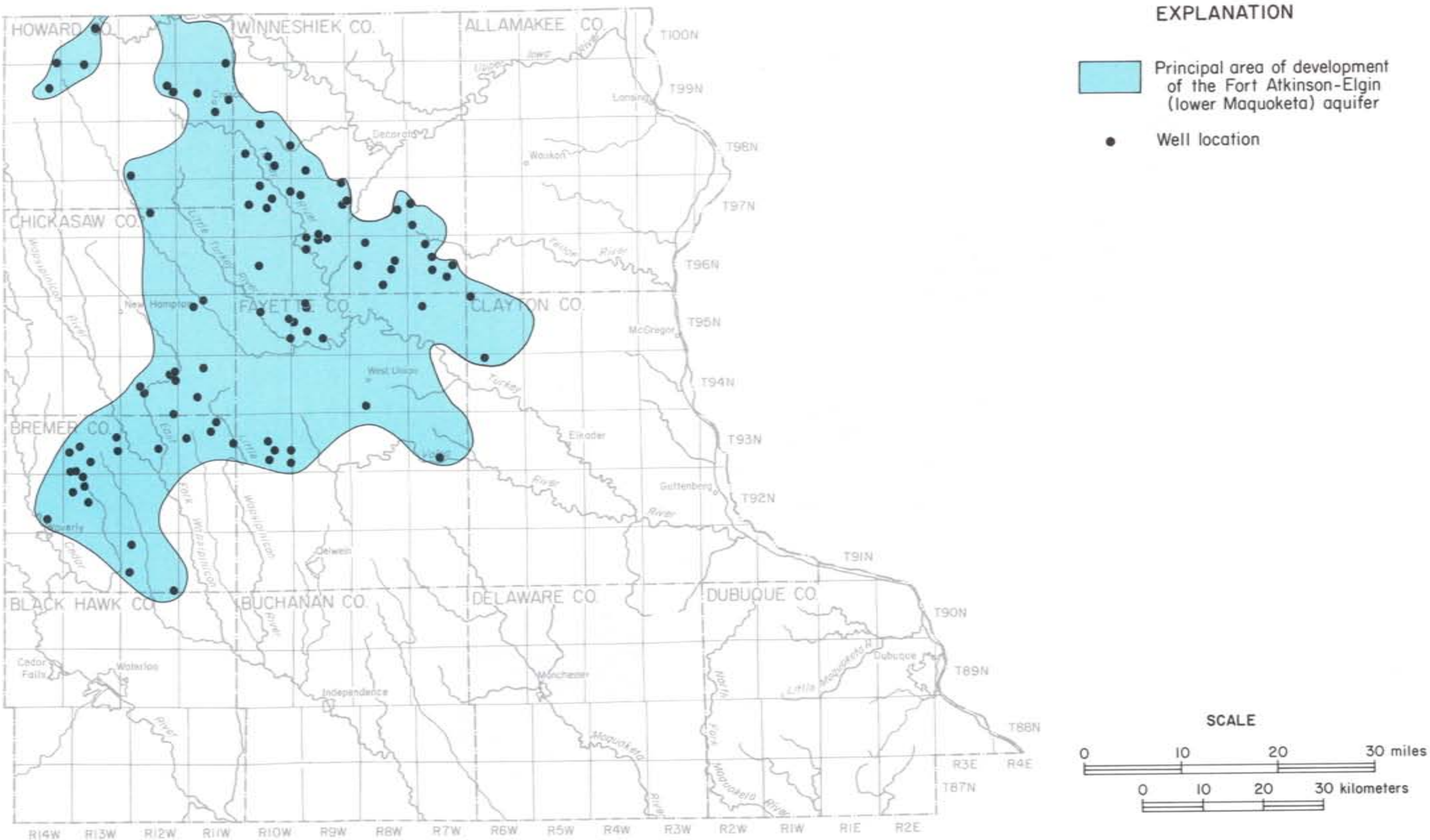


Figure 59. Principal area of development of the Fort Atkinson-Elgin (lower Maquoketa) aquifer

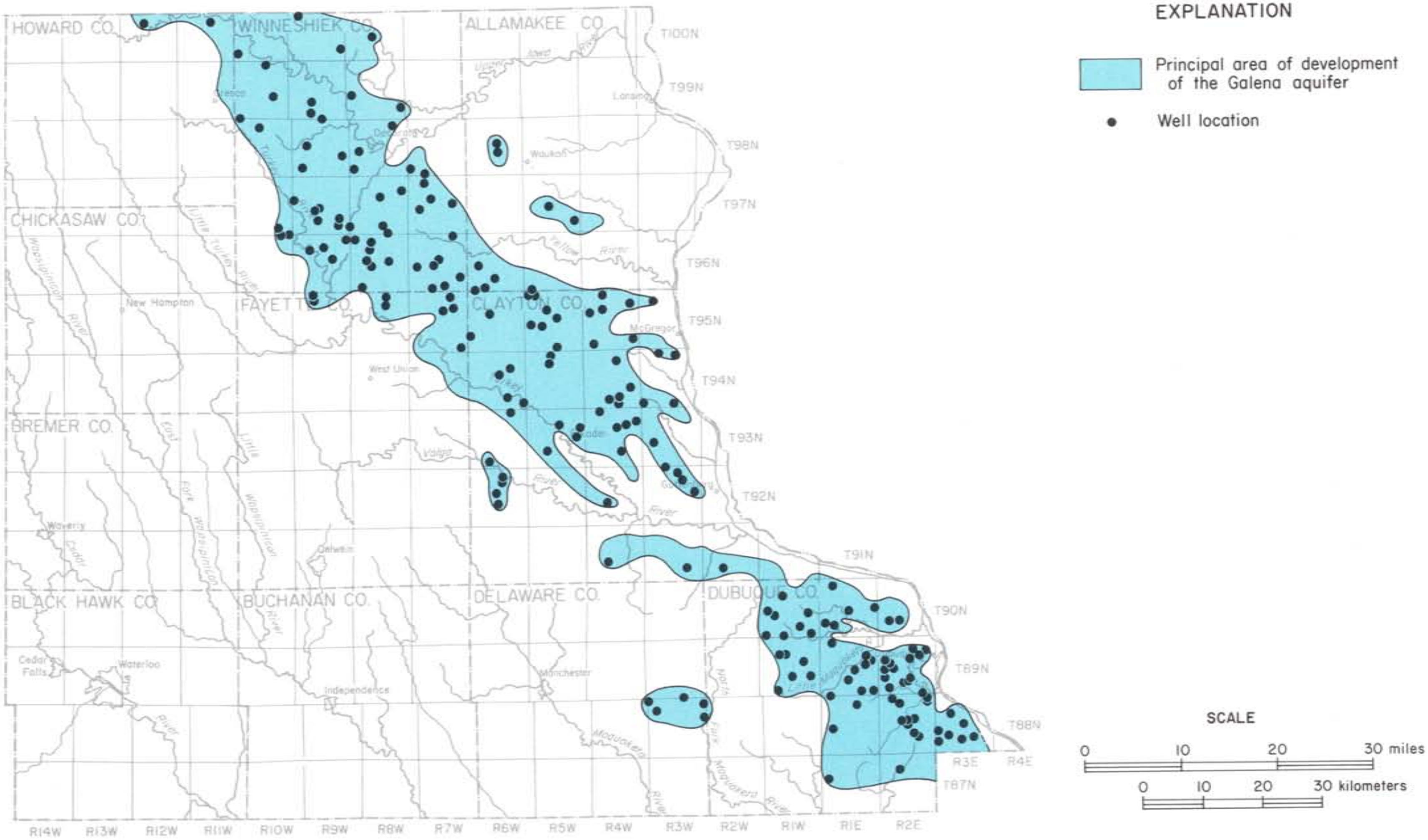


Figure 60. Principal area of development of the Galena aquifer

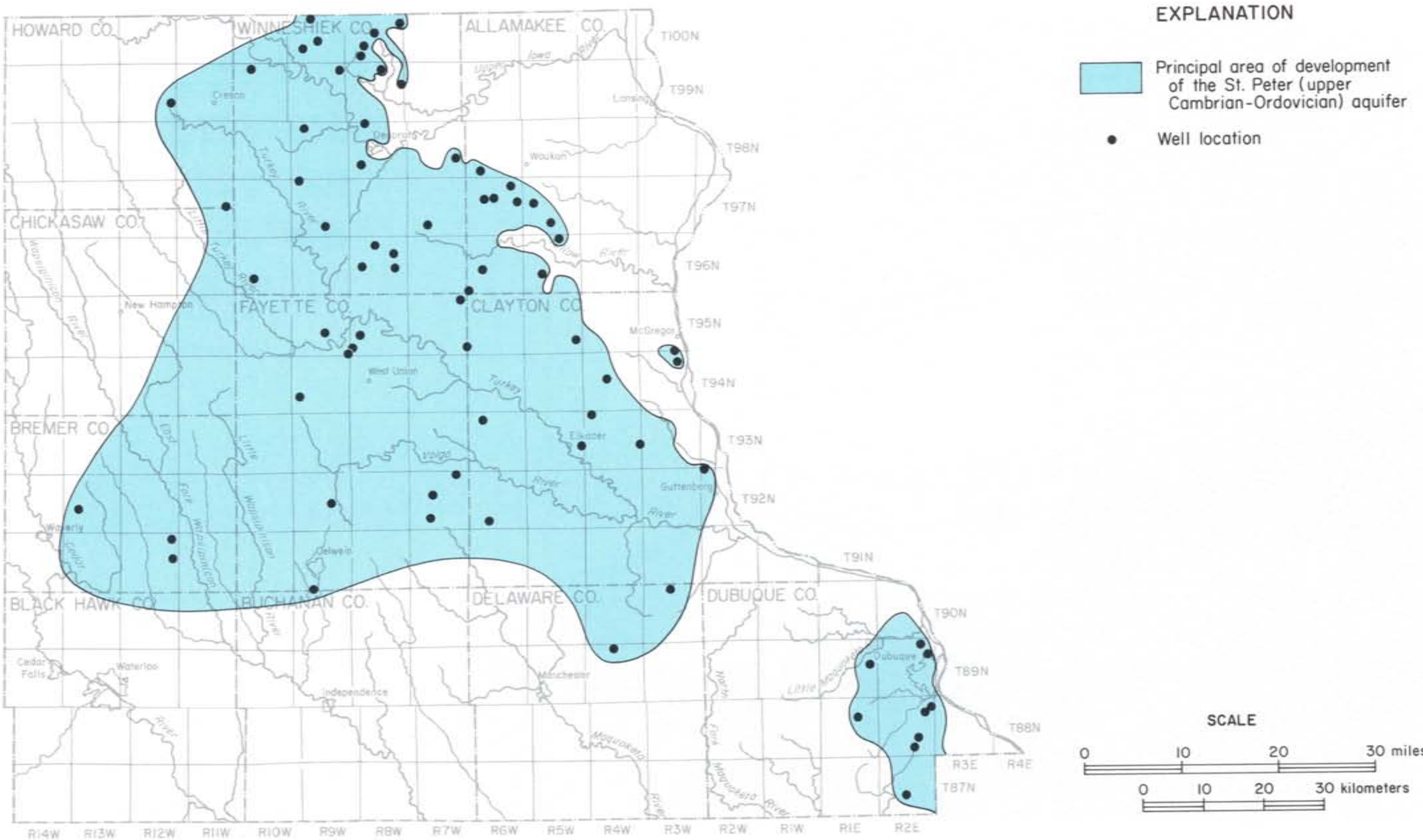


Figure 61. Principal area of development of the St. Peter (upper Cambrian-Ordovician) aquifer

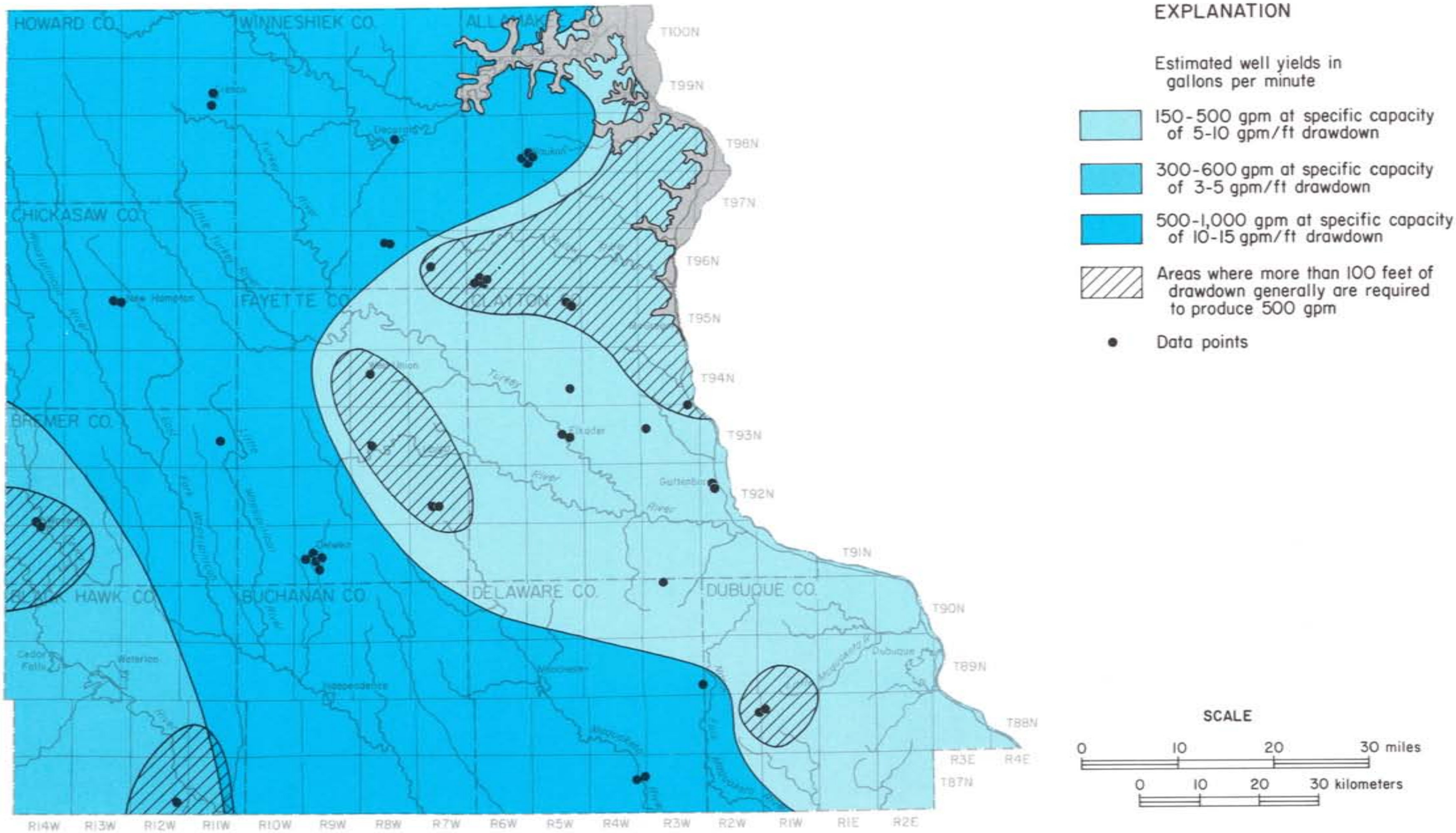


Figure 62. Estimated yields to individual wells from the Jordan (lower Cambrian-Ordovician) aquifer

Figure 63. Estimated yields to individual wells from the Dresbach aquifer

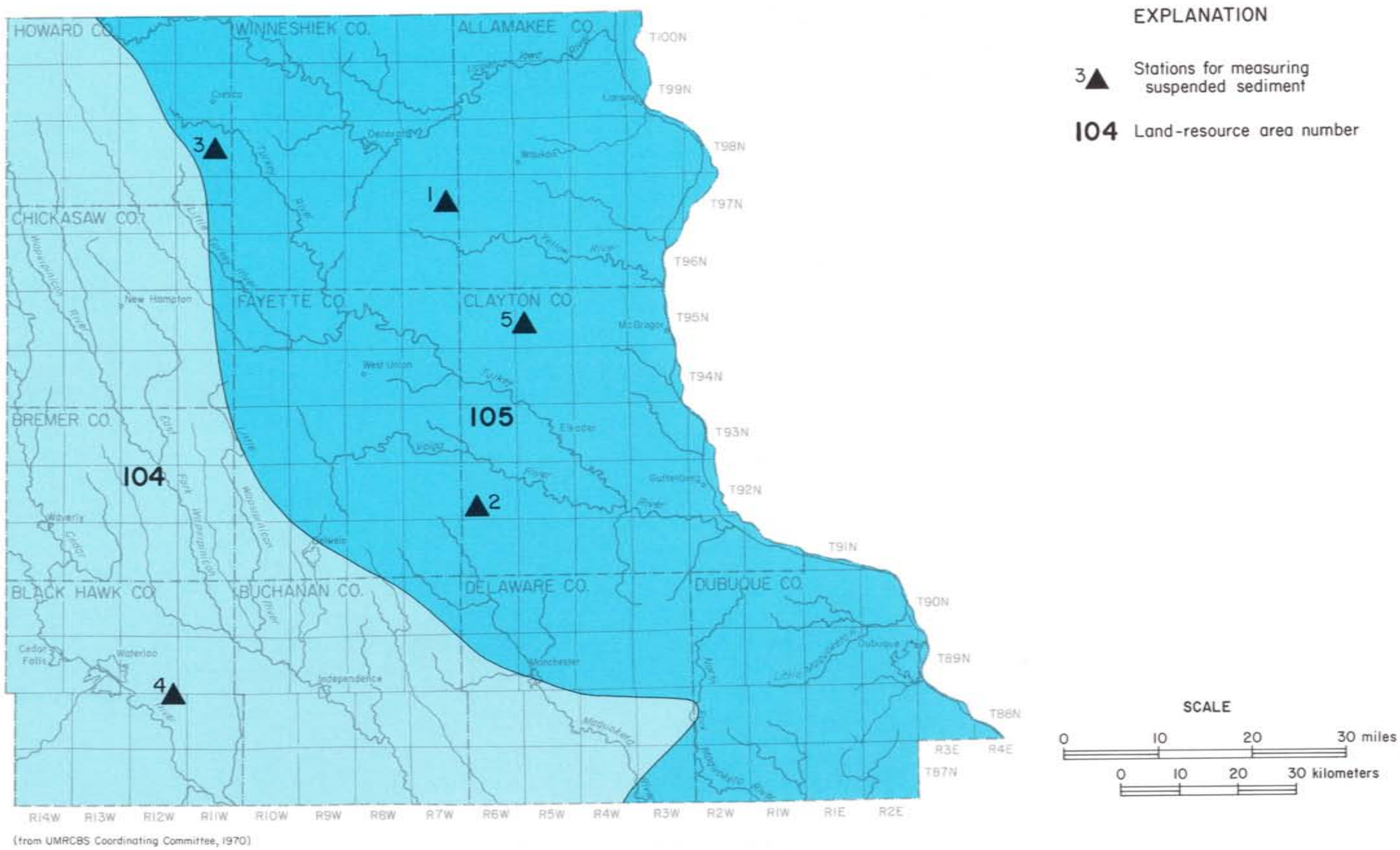


Figure 64a. Land-resource areas

WATER QUALITY

Water quality can be a major factor in the development of any water supply. Water-quality considerations vary depending on the intended use. Water suitable for irrigation may be unsatisfactory for municipal supply, and water suitable for industrial cooling might not meet the needs of a corn-processing plant.

The chemical quality of groundwater is a reflection of its hydrologic environment. All groundwater contains dissolved minerals. As water moves from point to point in the underground environment it dissolves the more soluble mineral matter it contacts. The mineral content of groundwater is influenced by a number of factors, primarily water temperature, pH, residence time in an aquifer, and chemical composition of an aquifer. Because these influences vary considerably between aquifers and even within aquifers, the quality of groundwater shows commensurate variation. In general, the quality of groundwater decreases as its total-dissolved-solids concentration increases. In addition to its natural inorganic constituents, groundwater may be further degraded by organic substances that are largely the product of human activity.

The Code of Federal Regulations 40, Revised July 1, 1986, summarizes the U.S. Environmental Protection Agency (USEPA) National Interim Primary Drinking-Water Standards for inorganic chemicals (except fluoride), organic chemicals, turbidity, microbiological contaminants (coliform bacteria), and radioactivity. Maximum contaminant levels (MCLs) have been established to protect the health of public-water-supply users. These primary standards are enforced by the Environmental Protection Division of the Iowa Department of Natural Resources.

Secondary Drinking-Water Standards have been established by the U.S. Environmental Protection Agency and are intended to control contaminants that affect the aesthetic quality of drinking water (taste, odor, etc.). These secondary standards are not federally enforceable and are intended as guidelines.

The maximum contaminant levels for the primary and secondary standards are shown in Appendix II. The chemical constituents and properties shown in Appendix II are water-quality characteristics that commonly define water potability. Standards for uses other than drinking water are usually different from those listed.

Generally, the concentration of total dissolved solids can be used as a measure of water quality. In this respect the groundwater and surface water in northeast Iowa are of good quality, usually with a total-dissolved-solids concentration of less than 500 mg/l. This contrasts with other parts of Iowa, particularly the south and northwest, where total-dissolved-solids concentrations in groundwater often exceed 1,500 mg/l. Of course, low dissolved solids does not mean water is safe or desirable. There are substances which can render

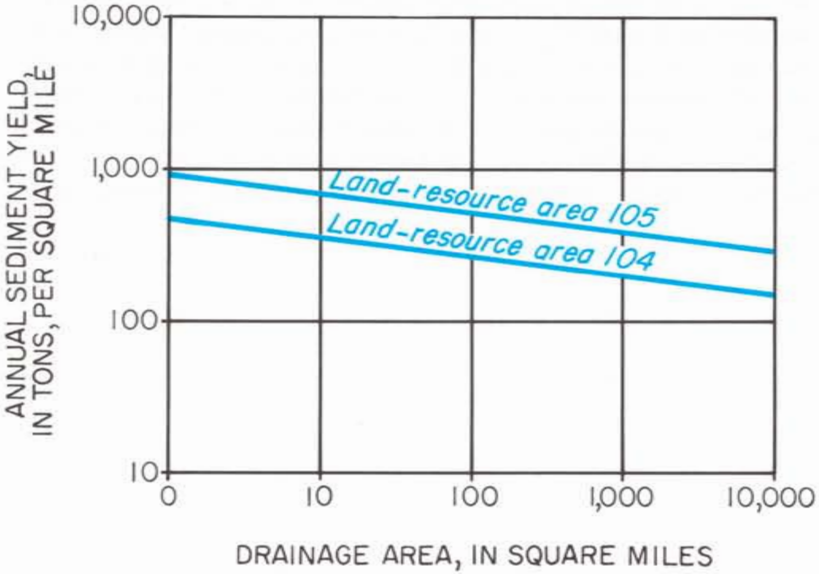


Figure 64b. Annual sediment yields for drainage basins with different areas

water undrinkable at concentrations of only a few mg/l.

Many undesirable constituents found in water are related to human activities. In some areas, these activities primarily affect surface water. However, in northeast Iowa aquifers often lie close to the land surface and are therefore vulnerable to contamination by surface-water infiltration.

SURFACE-WATER QUALITY

One of the most important factors bearing on the quality of surface water is suspended sediment. It is derived from sheet-and-gully erosion of the land surface and from the scouring of stream beds and river banks. Many detrimental effects are created by sediment in streams: reduction of floodplain productivity; obstruction of drainageways; blockage of culvert and bridge openings; destruction of wildlife habitat; siltation of reservoirs and consequent impairment of recreational opportunities.

Two Land Resource Areas (LRAs) comprise the study area (figure 64). LRAs are geographical groupings of land units having common characteristics including: soils, land use, topography, climate, and drainage. LRA 105 includes the area of the Paleozoic Plateau and LRA 104 includes the area of the Iowan Surface. Table 6 gives daily suspended-sediment data for the Mississippi River at McGregor. Figure 64b shows sediment-yield curves for drainage areas of different size for the two areas. As can be seen on the curves, the sediment yield in LRA 105 is about 30 percent greater than LRA 104 for any size drainage area. The principal reasons for the difference are the predominance of loess-derived soils and the greater topographic relief of the Paleozoic Plateau area.

Over time the U.S. Geological Survey (USGS) has operated surface-water sampling stations in the study area. Most of these have been classified as "miscellaneous sites." Data collected by the USGS at miscellaneous sites are used to define water quality in a drainage basin. The miscellaneous sites differ from continuous-record stations in that they are designed for random sampling at varying sampling frequencies. The location of several of these in the study area are shown in figure 65. Water-quality data associated with these stations are listed in table 7. As shown by the specific-conductance values (325 to 630 micromhos), most of the surface water has total-dissolved-solids concentrations less than 500 mg/l. The stations on the Cedar River (I and K) give a more complete picture of surface-water quality in the area. In general, total-dissolved-solids concentrations are low, less than 500 mg/l; calcium and bicarbonate concentrations are moderate; and potassium and nitrate concentrations are high, which is typical for an agricultural area. Water temperature, of course, varies seasonally.

GROUNDWATER QUALITY

Groundwater quality varies regionally within an individual aquifer as well as between different aquifers. In addition, certain chemical constituents in the water of some near-surface aquifers vary seasonally as a result of changing recharge conditions. Appendix III provides the results of typical water-quality analyses from aquifers in the study area although the full range of water-quality conditions is not presented. The following sections discuss typical water-quality variations in the individual aquifers.

Surficial Aquifers

Water-quality analyses for groundwater from alluvial aquifers are shown in Appendix III. The analyses are from the alluvial aquifers of the Upper Iowa River at Decorah, the Cedar River at Waterloo, Black Hawk Creek at Hudson, and the Mississippi River at Dubuque. The highest quality water occurs in thick alluvial deposits along the Mississippi River. Wells at Dubuque are 142 to 200 feet in depth and yield water with total-dissolved-solids concentrations between 179 and 322 mg/l; the average concentration is 287 mg/l. Hardness of the water ranges from 152 to 280 mg/l, and averages 245 mg/l.

In contrast, water from the alluvial aquifers along interior streams has higher total-dissolved-solids concentrations. This is probably because the alluvium of the interior streams receives a higher proportion of recharge from underlying or adjacent bedrock units. Water-quality analyses indicate the water in the alluvial aquifer at Waterloo has an average total-dissolved-solids concentration of 323 mg/l and an average hardness of 271 mg/l. At Decorah the average total-dissolved-solids concentration and hardness are 331 mg/l and 289 mg/l; at Hudson they are about 464 mg/l and 364 mg/l, respectively.

Relatively high iron concentrations, up to 2.5 mg/l, are present in water from the Dubuque city wells. Groundwater from the interior alluvial aquifers generally has low iron concentrations. Reported nitrate concentrations in municipal wells completed in alluvium vary from 5 to 30 mg/l as NO_3.

Water samples from several wells in Chickasaw, Bremer, and Black Hawk counties characterize water quality in the drift aquifers. They indicate the water is generally acceptable for drinking. The deepest wells exhibit the highest total-dissolved-solids concentrations which range between 208 and 628 mg/l. The water is hard, with hardness ranging from 203 to 443 mg/l. Objectionable concentrations of nitrate are mostly limited to wells less than 50 feet deep. Relatively high iron concentrations are present in the water. Many rural residents have iron-filter units to control this problem. Two analyses for buried-channel aquifers have been included with those of drift aquifers in Appendix III. These analyses suggest total-dissolved-solids concentrations in buried-channel aquifers are generally similar to those in the drift aquifers.

Table 6. Daily suspended sediment, Mississippi River, McGregor, Iowa, for water year October, 1984, to September, 1985

Day	Mean Concen-tration (mg/l)[a]	Loads (T/day)[b]	Mean Concen-tration (mg/l)	Loads (T/day)	Mean Concen-tration (mg/l)	Loads (T/day)	Mean Concen-tration (mg/l)	Loads (T/day)	Mean Concen-tration (mg/l)	Loads (T/day)	Mean Concen-tration (mg/l)	Loads (T/day)
	OCTOBER		**NOVEMBER**		**DECEMBER**		**JANUARY**		**FEBRUARY**		**MARCH**	
1	60	5,200	65	13,200	10	1,050	21	2,300	11	671	20	3,420
2	23	1,970	64	13,200	8	866	21	2,270	10	610	19	2,970
3	18	1,520	55	11,400	5	539	22	2,230	9	547	18	2,620
4	17	1,410	50	10,500	5	452	22	2,080	8	486	21	2,780
5	20	1,610	49	10,300	6	455	22	1,990	7	425	56	6,800
6	22	1,690	49	10,000	7	425	24	2,170	5	288	69	7,450
7	30	2,200	49	9,590	7	340	26	2,280	4	230	67	6,870
8	26	1,810	49	9,390	7	327	28	2,460	3	170	50	5,200
9	21	1,330	49	9,090	7	340	30	2,630	3	164	41	4,430
10	21	1,320	48	8,530	7	369	31	2,700	3	157	34	4,130
11	17	1,090	39	6,240	8	540	41	3,430	3	157	37	5,490
12	20	1,350	31	4,540	10	837	51	4,270	3	160	46	7,580
13	24	1,790	26	3,660	12	1,090	53	4,290	5	269	59	11,300
14	26	1,950	44	6,190	14	1,320	53	4,150	11	594	64	13,200
15	29	2,180	74	11,100	14	1,300	54	3,940	17	895	69	15,200
16	32	2,510	86	13,400	11	1,040	50	3,240	24	1,270	82	18,000
17	35	3,030	80	12,300	9	880	38	2,460	27	1,440	110	24,000
18	44	4,020	66	9,940	7	699	28	1,740	30	1,600	108	23,000
19	54	5,340	47	6,500	6	567	28	1,720	34	1,800	90	18,600
20	53	5,540	29	3,600	19	1,850	28	1,700	37	1,950	55	11,100
21	43	4,990	28	3,140	47	4,440	28	1,720	50	2,660	43	8,710
22	30	3,960	31	3,130	59	5,500	27	1,660	108	6,420	37	7,690
23	24	3,530	31	3,060	60	5,670	24	1,470	215	18,000	37	8,020
24	23	3,630	26	2,600	54	5,320	22	1,350	409	47,500	37	8,360
25	26	4,230	22	2,260	45	4,470	18	1,100	356	55,700	36	8,460
26	34	5,750	19	1,940	34	3,470	15	923	207	40,500	37	9,050
27	38	6,590	16	1,560	30	3,100	14	850	90	17,300	46	11,800
28	39	7,060	12	1,120	28	3,010	14	858	31	5,740	57	15,000
29	46	8,580	12	1,100	24	2,660	14	850	---	---	66	17,800
30	56	10,700	13	1,280	22	2,440	13	790	---	---	67	18,100
31	62	12,000	---	---	22	2,440	12	729	---	---	64	17,600
Total	---	119,880	---	203,860	---	57,806	---	66,350	---	207,703	---	324,730

[a] milligrams per liter [b] tons per day Source of data - U.S. Geological Survey Water Resources Data, Iowa Water Year 1985 (1986), p. 60-61

Day	Mean Concentration (mg/l)	Loads (T/day)	Mean Concentration (mg/l)	Loads (T/day)	Mean Concentration (mg/l)	Loads (T/day)	Mean Concentration (mg/l)	Loads (T/day)	Mean Concentration (mg/l)	Loads (T/day)	Mean Concentration (mg/l)	Loads (T/day)
	APRIL		**MAY**		**JUNE**		**JULY**		**AUGUST**		**SEPTEMBER**	
1	55	15,600	36	8,790	57	7,630	30	3,160	19	1,680	23	2,240
2	40	11,700	43	11,000	60	8,310	28	3,020	17	1,420	23	2,090
3	37	10,900	49	12,900	83	11,500	26	2,990	20	1,640	30	2,330
4	35	10,400	47	12,500	98	13,200	23	2,870	38	3,060	43	3,450
5	32	9,500	45	12,100	87	10,900	24	3,210	36	2,750	41	3,810
6	30	8,830	43	11,600	76	9,300	27	3,770	26	1,870	39	4,010
7	28	8,010	49	13,100	66	8,070	27	3,850	23	1,630	37	3,970
8	27	7,580	64	16,800	67	8,450	28	4,020	29	2,090	35	3,870
9	25	6,880	44	11,200	68	9,180	28	3,940	38	2,710	32	3,650
10	23	6,270	37	9,230	69	9,670	28	3,880	40	2,760	30	3,530
11	23	6,190	40	9,680	69	9,950	27	3,650	46	3,180	27	3,280
12	23	6,050	48	11,400	67	9,370	27	3,550	37	2,530	27	3,400
13	26	6,610	53	12,000	64	8,160	26	3,290	24	1,710	25	3,270
14	32	7,820	56	12,100	64	7,590	25	3,020	23	1,860	27	3,790
15	38	8,950	60	12,500	65	7,620	24	2,740	60	5,540	29	4,450
16	42	9,550	63	12,800	67	7,870	23	2,400	48	4,680	30	4,880
17	45	9,910	64	12,700	67	7,960	22	2,080	30	2,970	31	5,030
18	49	10,900	66	12,500	63	7,470	20	1,720	26	2,580	32	5,080
19	48	10,800	67	12,200	58	6,640	19	1,610	27	2,660	30	4,580
20	44	10,100	69	12,200	52	5,770	19	1,630	25	2,400	30	4,370
21	40	9,200	69	12,000	47	5,150	18	1,560	22	1,980	30	4,170
22	37	8,480	68	11,900	42	4,600	18	1,540	17	1,490	29	3,960
23	41	9,220	87	15,400	36	3,940	18	1,460	20	1,730	27	3,740
24	52	11,400	113	20,200	41	4,470	17	1,260	25	2,190	25	3,470
25	61	13,100	120	21,400	53	5,800	23	1,720	29	2,590	25	3,390
26	71	14,900	111	19,800	51	5,550	43	3,530	33	2,930	24	3,250
27	77	16,200	92	16,100	38	4,060	66	5,740	34	2,620	28	3,840
28	60	12,900	73	12,200	29	3,010	69	6,280	20	1,470	44	6,140
29	32	7,130	68	10,600	28	2,910	37	3,480	17	1,320	58	8,600
30	30	7,000	69	10,000	30	3,130	22	2,070	18	1,520	45	7,480
31	---	---	75	10,600	---	---	21	1,920	20	1,870	---	---
Total	---	292,080	---	399,500	---	217,230	---	90,960	---	73,430	---	123,120

Total load for year: 2,176,649 tons

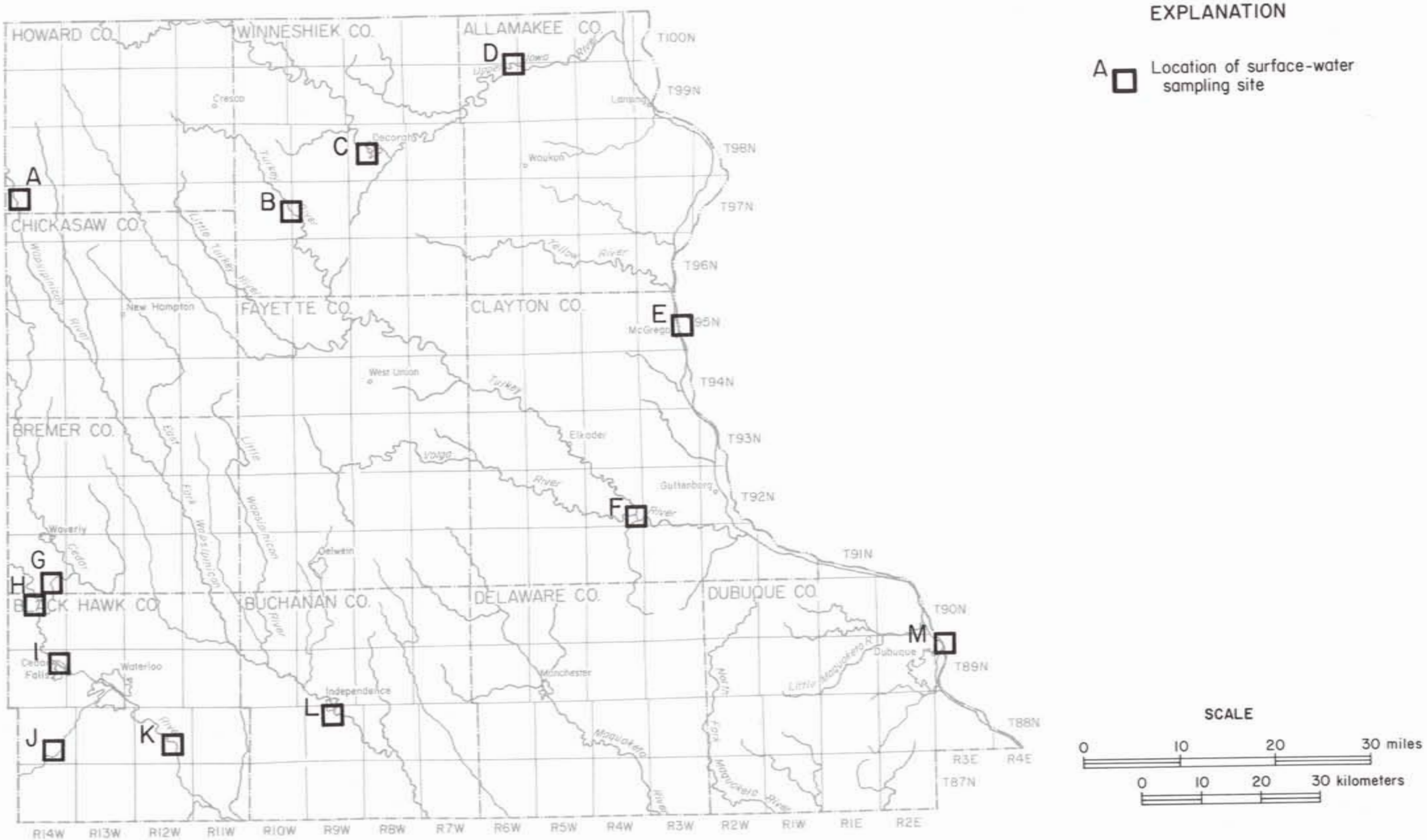


Figure 65. Location of surface-water sampling sites

Table 7. Surface-water analyses of northeast Iowa streams

Station symbol	Station name	Date of collection	Time	Stream-flow (cfs)[a]	Temp. (°C)[b]	pH[c]	Spec. Cond.[d]	Total dissolved solids (mg/l)[e]	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	NO_3 (mg/l)	Hardness (as $CaCO_3$) (mg/l)	Alkalinity (as $CaCO_3$) (mg/l)	Non-carbonate hardness (mg/l)
A□	Wapsipinicon River	11/14/84	15:30	59	6.0		420													
	near Elma, NW, NW,	4/30/85	12:40	55	17.0		440													
	sec. 8, T97N, R14W	7/24/85	12:55	5	25.0		570													
B□	Turkey River near	2/07/85	11:30	27	0.0		560													
	Spillville, NW, NE,	6/10/85	15:50	41	20.0		545													
	sec. 19, T97N, R9W	9/10/85	07:45	123	18.0		480													
C□	Upper Iowa River	10/07/70	14:05	132	15.0	8.1	325													
	at Decorah, NE, SW,	4/26/71	08:15	478	12.0	8.8	480													
	sec. 16, T98N, R8W	7/19/71	17:45	170	24.0	8.1	410													
D□	Upper Iowa River near	11/28/80		280	1.0		350													
	Dorchester, SW, NW,	4/10/81		979	14.0		490													
	sec. 1, T99N, R6W	9/09/81		858	20.0		390													
E□	Mississippi River at	11/02/83	10:30	41,600	11.0		370													
	McGregor, SE, SE,	4/18/84	08:30	105,000	9.0		440													
	sec. 22, T95N, R3W	7/10/84	15:00	82,100	23.5		505													
F□	Turkey River	10/11/84	09:05	339	16.0		575													
	at Garber, SE, NW,	4/30/85	10:20	1,070	15.5		525													
	sec. 36, T92N, R4W	9/09/85	13:40	611	23.5		425													
G□	Cedar River at	11/19/84	16:10	697	3.0		590													
	Janesville, NE, SW,	4/30/85	09:55	1,300	18.0		500													
	sec. 35, T91N, R14W	7/23/85	09:05	252	21.0		450													
H□	W. Fork Cedar River	11/20/84	09:45	237	3.0		600													
	at Finchford, SW, SE,	4/30/85	12:20	693	18.0		580													
	sec. 4, T90N, R14W	7/22/85	15:30	135	28.0		440													
I□	Cedar River at	10/04/77	11:20	1,600	13.5	8.3	556	399	63	23	12	3.3	250	0	42	24	25	252	210	42
	Cedar Falls, NW, NE,	4/27/78	13:30	4,300	15.5	8.5	600	439	84	25	10	2.8	240	3	53	30	44	313	200	113
	sec. 12, T89N, R14W	9/05/78	15:00	1,500	25.0	8.3	460	321	69	20	13	2.5	200	0	45	18	12	255	200	55
J□	Black Hawk Creek	11/20/84	15:05	77	1.0		620													
	at Hudson, SW, NE,	4/29/85	12:10	120	17.0		550													
	sec. 27, T88N, R14W	7/23/85	14:30	39	25.5		610													
K□	Cedar River at	10/13/78	12:00	1,750	11.0	8.7	340	217	28	11	11	2.6	110	1	44	10	20	115	92	23
	Gilbertville, SW, SW,	4/30/79	16:00	6,310	9.0	8.4	600	442	73	23	8.9	1.6	230	0	50	23	44	277	190	87
	sec. 23, T88N, R12W	7/11/79	13:00	2,770	25.0	7.9	630	456	74	20	9.1	4.2			38	22	37	267	210	57
L□	Wapsipinicon River	10/09/84	10:00	89	17.0		420													
	at Independence, SE,	3/21/85	13:40	667	8.0		350													
	sec. 4, T88N, R9W	7/25/85	11:20	61	24.5		400													
M□	Mississippi River	10/25/73		61,000	9.0		330				5.9				19		5.4			
	at Dubuque, NE, NE,	11/22/73		62,000	1.5	8.3	370				6				23		6.8	166	166	12
	sec. 7, T89N, R3E	5/16/74		135,000	13.5	8.4	340				5.6				30		5.9	152	152	12

[a]cubic feet per second [b]degrees Celsius [c]measurements are in standard units [d]specific conductance, measurements are in micromhos (μm) [e]milligrams per liter

Bedrock Aquifers

Silurian-Devonian Aquifer

Water quality of the Silurian-Devonian aquifer in the study area is good. Representative Silurian-Devonian analyses are listed in Appendix III. The total-dissolved-solids concentrations range from less than 300 to greater than 500 mg/l (figure 66) and average 340 mg/l. The highest total-dissolved-solids concentrations are found along the boundary of the aquifer in eastern Howard, eastern Bremer, central Fayette, and Dubuque counties. The lowest concentrations occur in the Cedar River valley in western Bremer and northwestern Black Hawk counties.

The major dissolved constituents in Silurian-Devonian water are calcium, magnesium, and bicarbonate, with sodium and sulfate as lesser constituents. The water is moderately hard, ranging between 206 and 400 mg/l as $CaCO_3$. The average hardness is about 300 mg/l.

Relatively high iron concentrations are common in Silurian-Devonian water. Iron removal or treatment is often necessary. Available analyses indicate the iron concentrations range between 0 and 5.0 mg/l and average about 0.5 mg/l.

Fluoride concentrations are usually low and fluoridation might be considered by municipal supplies.

Nitrate concentrations in the Silurian-Devonian water exceed the 45 mg/l maximum contaminant level (MCL) in numerous wells. Concentrations in municipal wells range from 0 to 56 mg/l. Analyses from shallow, private domestic wells have shown concentrations as high as 150 to 200 mg/l. Wells less than 50 feet deep show the most contamination, but high nitrate concentrations may be found at depths of 150 feet or more if surficial deposits are thin or absent.

The temperature of the water from the Silurian-Devonian aquifer ranges from about 9°C to 13°C (48°F to 55°F) depending on the well depth and location.

Fort Atkinson-Elgin (lower Maquoketa) Aquifer

Only a few chemical analyses are available for water from the Fort Atkinson-Elgin aquifer (Appendix III). However, these analyses indicate the water closely approximates the quality of the water found in overlying Devonian and underlying Galena rocks. The water is acceptable for domestic and public uses. From the few analyses available, hardness ranges between 234 and 358 mg/l with an average of 308 mg/l. Iron concentrations range between 0.56 and 2.9 mg/l. Fluoride is generally less than 0.5 mg/l. Treatment or removal of iron is advisable, and fluoridation to the level of 1.0 mg/l is recommended for municipal supplies.

Galena Aquifer

Seven municipal wells draw from the Galena aquifer in the study region. All of these wells are located in Winneshiek, Fayette, Clayton, and Dubuque counties. Chemical analyses are available from these wells and from a number of domestic wells in northeastern Clayton County. Total-dissolved-solids concentrations range from 245 to 485 mg/l, and hardness ranges between 275 and 350 mg/l. High iron concentrations occur locally, and the fluoride content is usually below the recommended 1.0 mg/l standard. Nitrate concentrations often exceed the 45 mg/l MCL. Depending on well depth and location, the temperature of the water from the aquifer will range between 9°C and 13°C (48°F and 55°F).

St. Peter (upper Cambrian-Ordovician) Aquifer

The St. Peter aquifer is a source of good quality water. Where the St. Peter is overlain and protected by the Decorah-Platteville-Glenwood confining beds, the Maquoketa Formation confining beds, and Galena, Silurian, and Devonian rocks, the total-dissolved-solids concentration of the water ranges between 260 and 595 mg/l and averages 389 mg/l. Iron concentrations are high at some locations, as an average concentration of 0.72 mg/l suggests. Fluoride ranges between 0.2 and 3.0 mg/l with an average of 1.0 mg/l. The water is a calcium-magnesium bicarbonate type, with hardness values ranging from 228 to 522 mg/l and averaging 334 mg/l. The water temperature is generally between 9°C and 12°C (48°F and 54°F), depending on depth and location.

Limited data indicate that the radium concentration of water from the aquifer approaches the maximum contaminant level of 5 picocuries per liter (pCi/l) ^{226}Ra and ^{228}Ra. Concentrations varying between 3 and 5 pCi/l are recorded in St. Peter wells at Elkader, Maynard, and Denver.

The aquifer supplies about 15 municipal systems in the study area, usually in combination with the Galena aquifer or upper part of the underlying Prairie du Chien Group.

Jordan (lower Cambrian-Ordovician) Aquifer

The Jordan aquifer is generally a dependable source of good quality water over the entire study area. The total-dissolved-solids concentration is usually less than 300 mg/l across the northern half of the area (figure 67) and gradually increases to about 600 mg/l at the southwestern corner of Black Hawk County. For the entire region, the total-dissolved-solids concentration ranges from 229 to 560 mg/l with an average of 327 mg/l. Many Jordan wells show significant concentrations of dissolved iron, and treatment for removal may be advisable. The hardness of the water ranges between 210 and 489 mg/l with an average of 277 mg/l. Sulfate, chloride, and fluoride concentrations are well within the maximum contaminant levels (MCL's) proposed for community water supplies. Fluoridation of the water may be considered for municipal supplies in the northern half of the region where the fluoride content is characteristically less than 1.0 mg/l. The temperature of the water ranges from about 10°C (50°F) in the northern part of the region to about 15°C (59°F) in the southern part. A slight hydrogen-sulfide odor may be detected in some Jordan wells, and aeration may be required to remove the odor. Corrosion of metal casing and pump parts may be associated with hydrogen sulfide in some Jordan wells.

Dresbach Aquifer

Water from the Dresbach aquifer in the principal area of use is of generally good quality and is suitable for public and domestic supplies. Available analyses indicate that its total-dissolved-solids concentration generally ranges between 236 and 437 mg/l, and its hardness between 166 and 302 mg/l. The concentrations of other constituents are generally acceptable. Exceptions occur at Dubuque, where radium concentrations approach the 5 pCi/l MCL, and at McGregor, where total-dissolved-solids concentrations of 2,000 to 3,000 mg/l occur. The data from McGregor also suggest that high total-dissolved-solids concentrations are limited to the lower part of the Dresbach aquifer, and that concentrations of less than 650 mg/l are typical in the upper part of the aquifer.

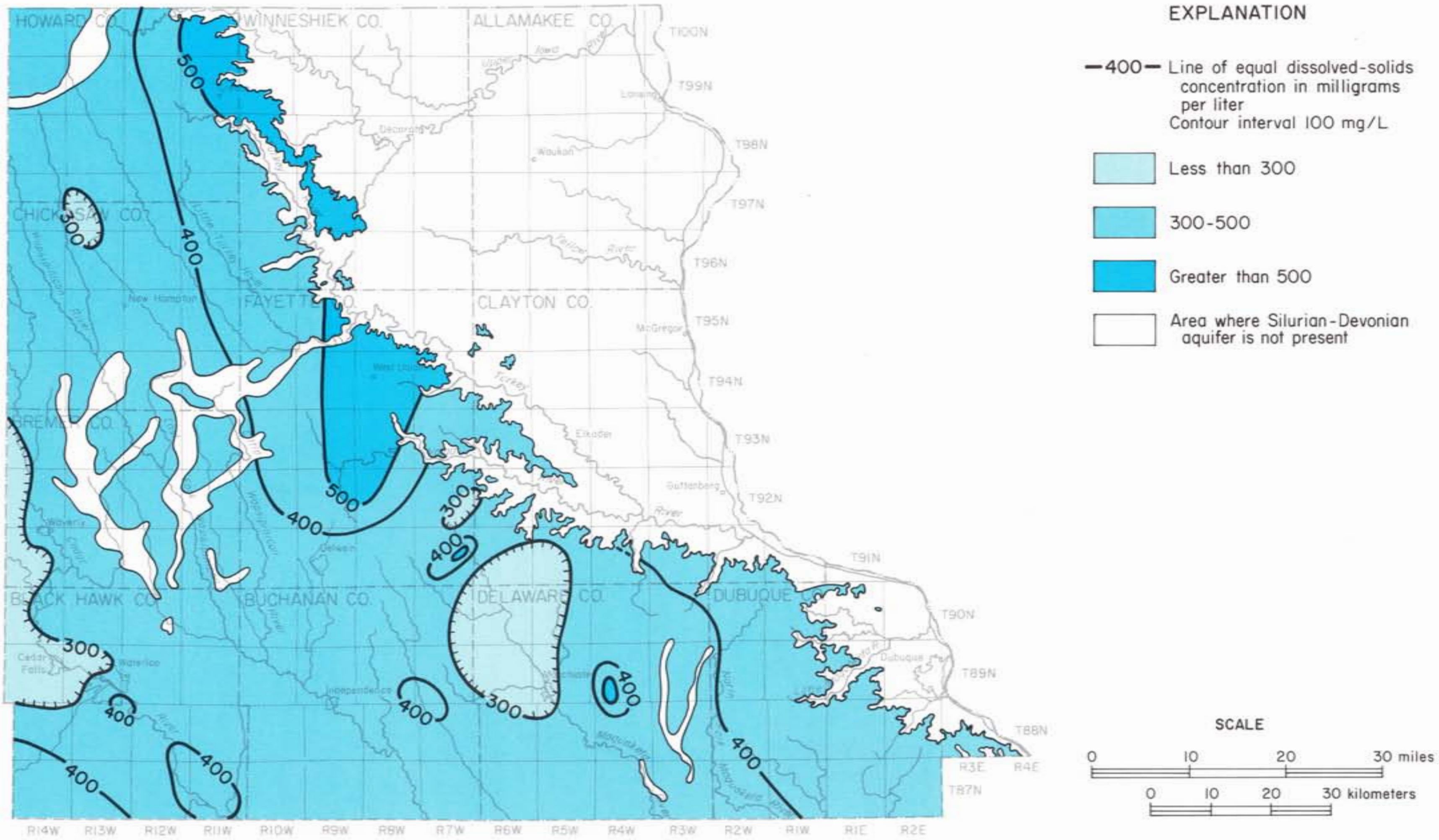


Figure 66. Dissolved-solids concentration of the Silurian-Devonian aquifer

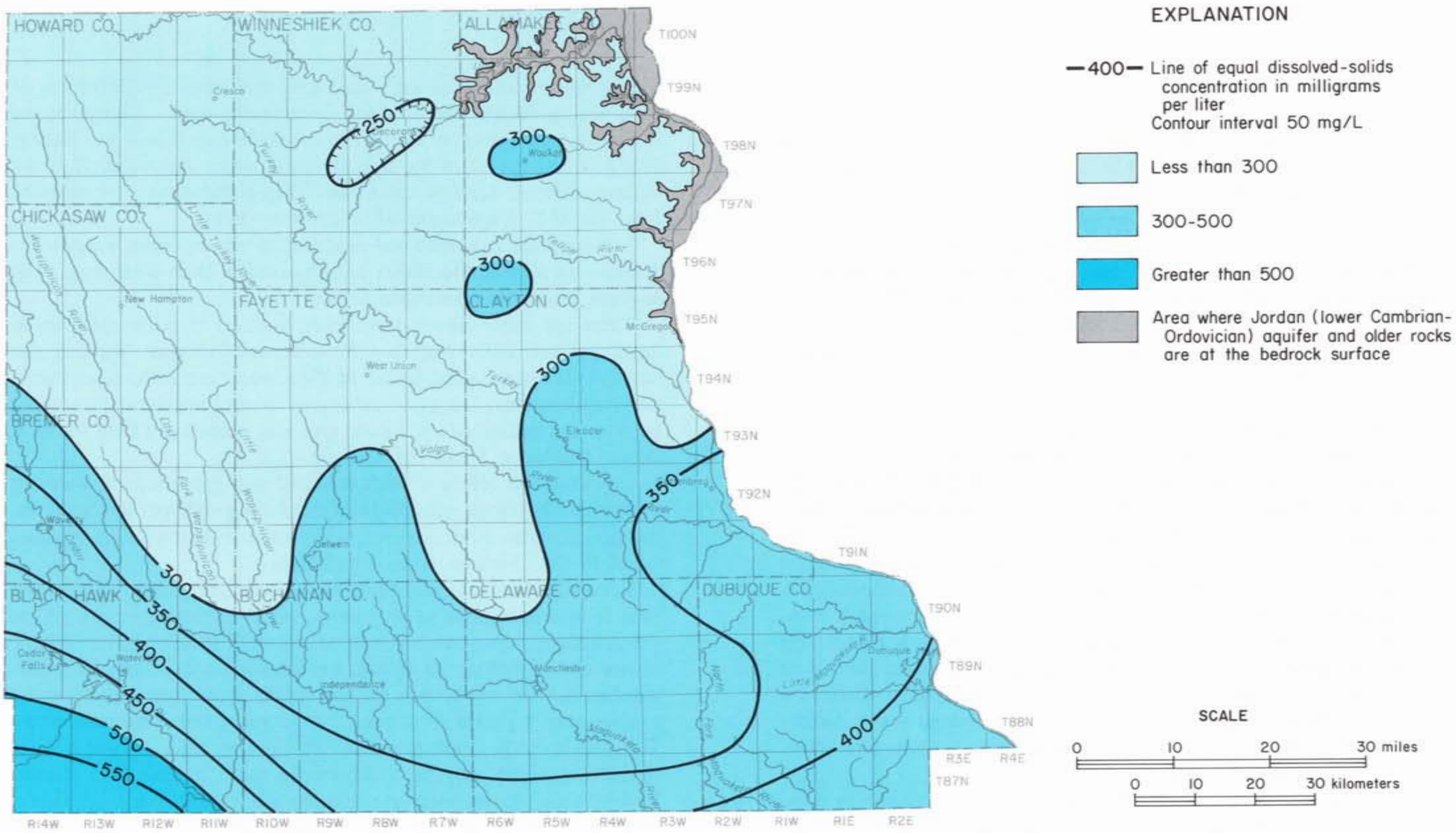


Figure 67. Dissolved-solids concentration of the Jordan (lower Cambrian-Ordovician) aquifer

WATER USE

Water use is defined as the amount of water withdrawn from either surface-water or groundwater sources for human needs. The major categories of water use are: 1) municipal or public supply, including water delivered to domestic, public, commercial, and industrial users from public-supply systems; 2) rural-domestic and livestock use; 3) self-supplied industrial use; 4) irrigation use; and 5) thermoelectric power (electric utility) generation. These various uses are sometimes called offstream uses because they represent water withdrawn or diverted from a surface-water or groundwater source. Most of these uses are consumptive, i.e., water withdrawn is consumed by the user, taken up in the manufacture of a product, or lost through evaporation (cooling water, irrigation water).

A type of water use that is non-consumptive is hydroelectric power generation which is an instream use of water. Hydroelectric plants differ from thermoelectric power plants in that no water is lost or consumed by evaporation and no water is diverted offstream. In hydroelectric plants, water passes from behind a dam, activates turbines, and flows on downstream. In thermoelectric plants, water from a stream or from wells is heated, producing steam that runs turbines to generate electricity, and water is also used to cool the turbines. In the process, a considerable amount of turbine-cooling water is lost by evaporation.

Water used in industrial cooling and refrigeration is heated during the cooling process and is considerably warmer when discharged. Some of this warmer water may evaporate (be consumed). Municipal, domestic, livestock, and industrial uses may change water quality considerably. Some of the water may be returned to the environment, but its quality usually has been degraded.

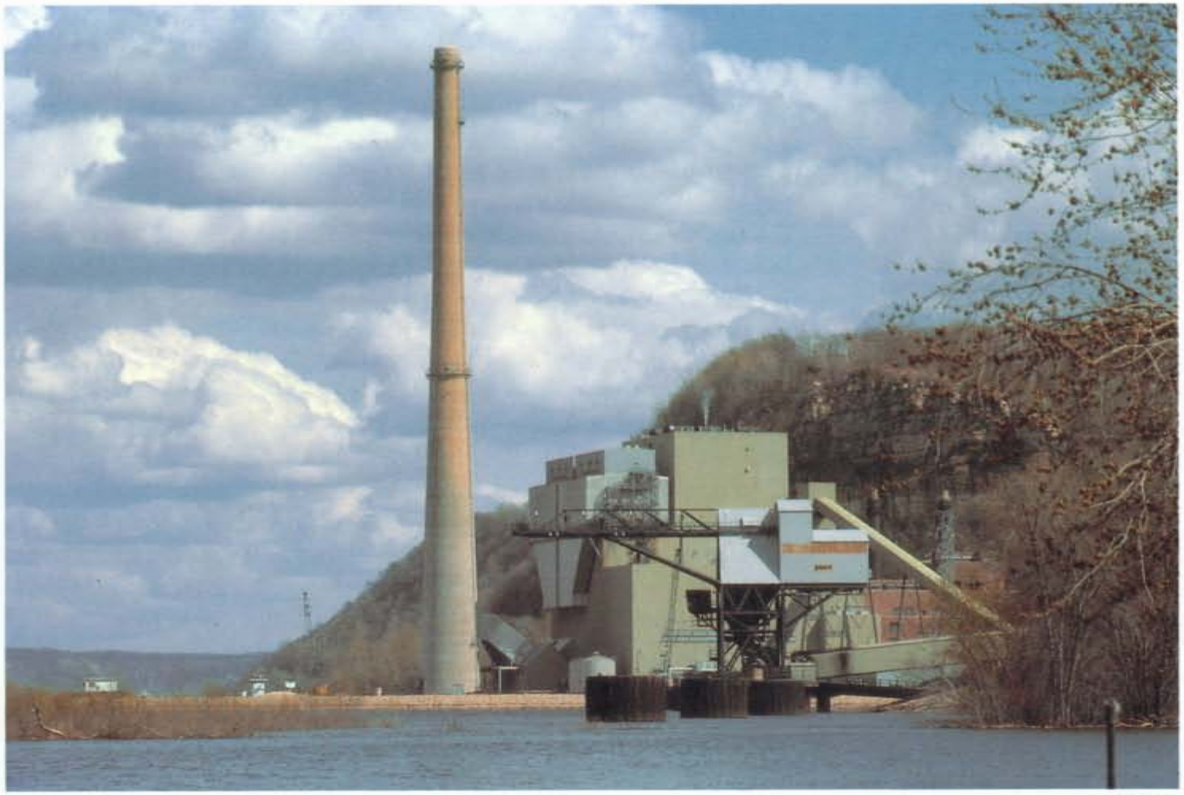
Municipal use in this report represents all water withdrawn by communities for urban-domestic purposes. Rural-domestic and livestock use includes water used on farms and rural homes. Estimates of daily per-capita use can be made from census data. Livestock use is based on the census of animals in the study area (Skow and Halley, 1985) and estimates of the average daily water consumption of the various animals. Data on horse and turkey populations were obtained from the U.S. Department of Commerce (1984).

Self-supplied industrial and commercial use represent water withdrawals by private companies or corporations from their own wells or from stream and reservoir intakes.

There are major power-production facilities in northeast Iowa at Lansing, Cedar Falls, Waterloo, Waverly, and Dubuque. Waverly also has a small hydroelectric plant. In 1985, water use at the Iowa Public Service Company plant in Waterloo was reduced to practically nothing because the electric power for the area was transmitted from the Neal Power Station at Sioux City, Iowa.

Irrigation use refers to both essential and supplemental watering of general farm crops, specialty crops including orchards and nurseries, and golf courses. Presently, irrigation-water withdrawals are reported in all of the counties in northeast Iowa.

Reported water-use quantities for various categories change from year to year in relation to economics, population changes, amount of precipitation, conservation measures, repair of leaking mains, delays, or errors in reporting. Therefore, it is impossible to get precise water-use data for the whole area for any single year. The data collected usually span a period of at least 2 to 3 years and sometimes more. The data given here are primarily for 1983 to 1985. Water use for succeeding years may be substantially more or less than shown. Nevertheless, these water-use records are valuable and provide a perspective on all the various-use categories.



P. J. Horick

Electric generating plants are among the largest users of water. This is the Interstate Power Company plant along the Mississippi River near Lansing, Allamakee County.

WATER WITHDRAWALS

During 1985 about 414 million gallons of water were withdrawn each day (mgd) for various water uses (table 8). The amount is equivalent to about 151 billion gallons a year and about 12.9 percent of the total annual state withdrawal (3,200 million gallons per day or approximately 1.17 trillion gallons per year). Electric power plants at Lansing and Dubuque are the largest users of water in northeast Iowa, consuming almost 68 percent (280 mgd) of the total water used in the study area. This large withdrawal is followed by industrial self-supplied use at 12.2 percent (50 mgd); municipal use, 11.9 percent (49 mgd); livestock use, 5.5 percent (23 mgd); rural-domestic use, 2.4 percent (9.8 mgd); and irrigation use, less than 1 percent (1.4 mgd). The average use for the 11 counties was 282.26 gallons per day per capita for all uses excluding electric-power generation.

About 73 percent (302 mgd) of the withdrawals are from surface-water sources—streams, reservoirs, and ponds, most of it for large power-plant use. The remaining 27 percent is obtained from ground-water sources, principally the Silurian-Devonian aquifer, 16 percent, and alluvial aquifers, about 5.5 percent. The Fort Atkinson-Elgin (lower Maquoketa), Galena, St. Peter (upper Cambrian-Ordovician) and Jordan (lower Cambrian-Ordovician) aquifers produce about 2 percent each. The drift, buried-channel, and Dresbach aquifers, produce less than 1 percent combined. The amount of water withdrawn from each source in the 11-county study area is shown in table 9. Groundwater use is shown in figure 68. Minor amounts withdrawn for industrial use, livestock, and irrigation have been excluded.

Waterloo and Dubuque, the two largest cities in the area, account for 43 percent of the municipal withdrawals. Waterloo withdraws the most, about 27 percent, Dubuque withdraws about 16 percent, Cedar Falls about 8 percent, Oelwein about 4 percent, and Decorah approximately 2 percent. Together these five cities withdraw 57 percent of the municipal water. The quantities of water used by cities varies seasonally. Maximum use is always during the summer months when cooling and air-conditioning needs are highest. The average daily withdrawal is probably 20 to 25 percent greater in summer than during winter.

Industrial self-supplied users are found in every county, with the largest withdrawals concentrated in the vicinity of Waterloo and Dubuque. Black Hawk County accounts for about 61 percent of industrial self-supplied use and Dubuque County about 26 percent. Industrial withdrawals in the remaining 9 counties are much smaller, averaging slightly less than 1.4 percent each. Quarries and sand-and-gravel operations withdraw water mainly to dewater quarries and pits, and to wash aggregate. Water withdrawals for these uses are estimated to be 10 percent or more of the total industrial self-supplied use.

Irrigation withdrawals comprise less than 1 percent of the total water used in northeast Iowa. However, all the counties report some irrigation withdrawal. Chickasaw and Black Hawk counties are the leaders with 63 percent of the total. Allocation data for permitted irrigation (1984) suggests that 3,126 acre-feet of irrigation water could be pumped in Chickasaw County, 2,056 acre-feet in Black Hawk County, and 8,048 acre-feet in all of northeast Iowa. However, available data indicate that only about 18.5 percent of the water allocated was actually used. The low irrigation withdrawal may be attributed to the fact that the early 1980s were relatively wet years. Irrigation use is treated as totally consumptive because of high evaporation losses in addition to water used and transpired by plants.

The fossil-fuel electric plant (321.8 megawatts) at Lansing is the largest off-stream user of water in the study area, withdrawing 225.6 mgd in 1985. The Dubuque plant (78 megawatts) withdraws about

Table 8. Water withdrawals by use in northeast Iowa counties, 1985

County	Population (1980)	Municipal	Rural domestic	Livestock	Industrial self-supplied	Irrigation	Electric power generation	Totals
Allamakee	15,108	1.48	0.67	2.21	0.27		225.73	230.36
Black Hawk	137,961	27.28	1.04	1.12	30.78	0.34	4.00	64.56
Bremer	24,820	1.57	0.76	1.04	0.27	0.09	0.13	3.86
Buchanan	22,900	1.41	0.91	1.61	0.68	0.10		4.71
Chickasaw	15,437	1.20	0.63	1.18	0.48	0.56		4.05
Clayton	21,098	1.07	0.84	3.09	1.09			6.09
Delaware	18,933	1.28	0.92	3.16	1.09			6.45
Dubuque	93,745	8.92	1.85	3.13	13.30	0.12	50.07	77.39
Fayette	25,488	3.03	0.87	2.45	1.60	0.17		8.12
Howard	11,114	0.57	0.39	1.20	0.78	0.02		2.96
Winneshiek	21,876	1.34	0.89	2.82	0.06	0.04		5.15
Totals	408,480	49.15	9.77	23.01	50.40	1.44	279.93	413.70
Percent of total use		11.9	2.4	5.5	12.2	0.3	67.7	100.0

[water withdrawn, in million gallons per day]

50.1 mgd. The plant at Waterloo withdrew about 17.6 mgd as recently as 1980. Minor self-supplied withdrawals for power generation are obtained from groundwater sources at the University of Northern Iowa in Cedar Falls, and at Waverly in Bremer County. About 3 percent of Waverly's requirement for electric power is derived from a hydroelectric dam on the Cedar River.

Although groundwater sources provide only 27 percent of the total water used in the study area, they supply practically all of the municipal and rural-domestic water, 91 percent of the livestock water, 53 percent of the industrial self-supplied water, and 78 percent for irrigation (table 10).

Withdrawals from the Silurian-Devonian aquifer were 68 mgd or 60 percent of the total groundwater used. Withdrawals from the alluvial aquifers comprised about 23 mgd or 21 percent of the groundwater used; the Cambrian-Ordovician aquifer, about 10 mgd or 9 percent; and the Fort Atkinson-Elgin (lower Maquoketa) and Galena aquifers, about 9 mgd or 8 percent. The drift and Dresbach aquifers combined produced about 2.5 mgd, about 2 percent of all groundwater withdrawals.

Figure 69 shows the sources and quantities of water withdrawn from

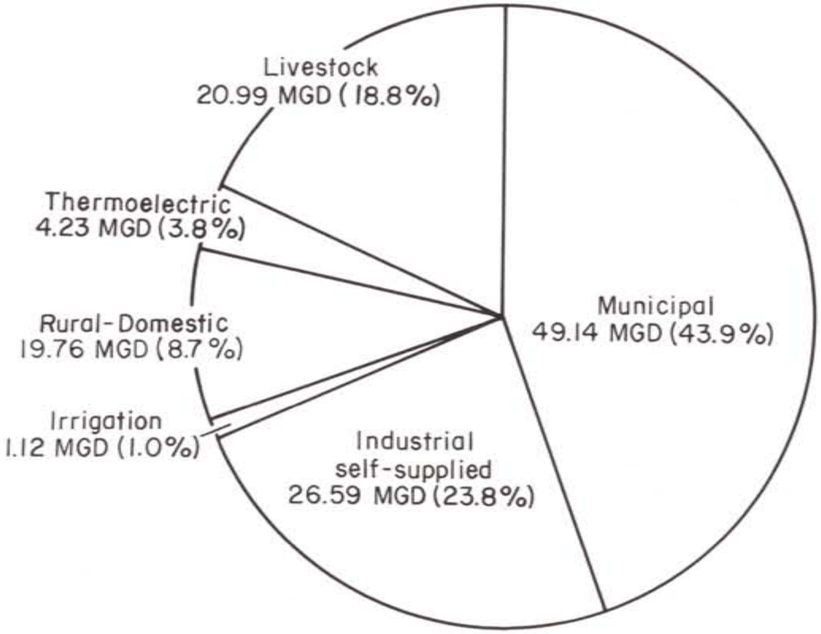


Figure 68. Average daily groundwater withdrawals by use during 1983-85

the major pumping centers in northeast Iowa. Withdrawals are concentrated in or near cities and towns, locations where municipal and industrial use is greatest. A few private quarry operations and housing developments in rural areas sustain substantial withdrawals as well.

It is clear that the Silurian-Devonian aquifer is the major groundwater source in northeast Iowa, mostly in the southwest half of the study area. It provides 64 percent of the rural-domestic water, 59 percent of the municipal water, 54 percent of the livestock water, 45 percent of the irrigation water, and 38 percent of the industrial self-supplied water. Alluvial aquifers are the source of 24 percent of municipal water, 14 percent of industrial self-supplied use, and 10 percent of irrigation use. Next in importance is the Cambrian-Ordovician aquifer which provides 14 percent of municipal use, and about 7 percent of the rural-domestic and livestock uses combined. The Fort Atkinson-Elgin (lower Maquoketa) and Galena aquifers are used primarily for rural-domestic and livestock use, about 27 percent.

Table 9. Water withdrawals by source in northeast Iowa counties, 1985

County	Population (1980)	Surface water	Groundwater						
		Streams	Alluvium	Drift	Silurian - Devonian	Fort Atkinson- Elgin-Galena	Cambrian - Ordovician	Dresbach	Totals
Allamakee	15,108	225.75				1.44	2.78	0.39	230.36
Black Hawk	137,961	13.32	7.88	0.11	43.12		0.13		64.56
Bremer	24,820	0.20	0.02	0.18	2.93			0.53	3.86
Buchanan	22,900	0.64	0.09		3.94		0.04		4.71
Chickasaw	15,437	0.24		0.51	2.33		0.97		4.05
Clayton	21,098	0.98	0.01		0.88	2.90	1.28	0.04	6.09
Delaware	18,933	1.01	0.34		4.87		0.23		6.45
Dubuque	93,745	56.92	13.87	0.10	4.02	1.39	0.29	0.80	77.39
Fayette	25,488	1.61	0.06	0.21	3.84	0.23	2.17		8.12
Howard	11,114	0.88	0.03	0.09	1.48	0.12	0.36		2.96
Winneshiek	21,876	0.32	0.60		0.19	3.07	0.97		5.15
Totals	408,480	301.87	22.90	1.20	67.60	9.15	9.75	1.23	413.70
Percent of total use		73.0	5.5	0.3	16.3	2.2	2.4	0.3	100.0

[water withdrawn, in million gallons per day]

Table 10. Water withdrawals by source for each use in northeast Iowa, 1985

Source	Municipal	Rural domestic	Livestock	Industrial self-supplied	Irrigation	Electric power generation	Totals	Percent of total	Percent of groundwater withdrawal
Surface water:									
Streams, reservoirs, ponds			2.02	23.81	0.32	275.70	301.85	73.0	
Groundwater:									
Alluvial	11.59			7.16	0.15	4.00	22.90	5.5	20.5
Drift and buried-channel	0.05	0.38	0.52		0.25		1.20	0.3	1.1
Silurian-Devonian	29.05	6.26	12.51	19.00	0.66	0.14	67.62	16.3	60.4
Fort Atkinson-Elgin-Galena	0.34	2.47	6.31	0.01	0.02		9.15	2.2	8.2
Cambrian-Ordovician	7.02	0.66	1.65	0.38	0.04		9.75	2.4	8.7
Dresbach	1.10			0.04		0.09	1.23	0.3	1.1
Totals	49.15	9.77	23.01	50.40	1.44	279.93	413.70	100.0	100.0
Percent of total use	11.9	2.4	5.5	12.2	0.3	67.6	100.0		

[water withdrawn, in million gallons per day]

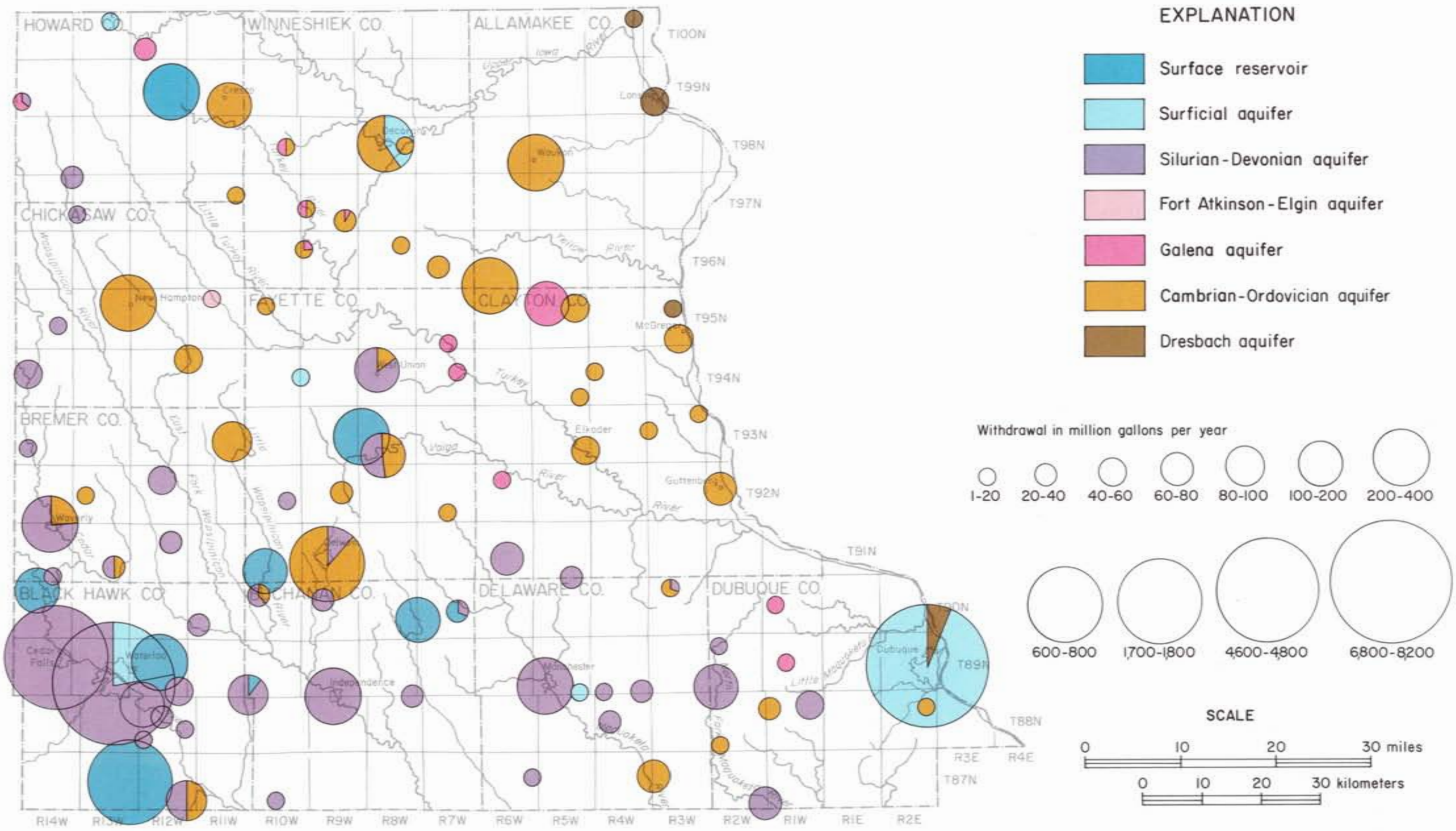


Figure 69. Source and quantity of water withdrawn from major pumping centers, 1984-85

IOWA WATER RESOURCES LAWS AND REGULATIONS

Iowa has a number of laws concerned with the management, protection, control, and use of its water resources. These laws have been created over a period of years often beginning with the establishment of various state and federal water-related agencies, such as the State Department of Health; the Iowa Natural Resources Council; the Department of Environmental Quality; the Department of Water, Air, and Waste Management; the University (State) Hygienic Laboratory; the National Weather Service; the U.S. Army Corps of Engineers; the U.S. Geological Survey; the U.S. Environmental Protection Agency; and most recently, the Department of Natural Resources. There have been many additional agencies involved in water-related activities in Iowa. Authorization for public utilities, cities, and towns to regulate public-water supplies, sewer systems, hydro-power, flood-control works, and recreational areas were also included in the broad field of water laws.

In 1949, the legislature decided the maze of laws authorizing various activities in water management were too confusing, and vested the powers of the State in a single agency, the Iowa Natural Resources Council (INRC). The INRC was given the responsibility and authority to establish and enforce a comprehensive state-wide program for the control, utilization, and protection of surface-water and groundwater resources (Iowa Code, Chapter 455A). Water resources were to be put to beneficial use, to the fullest extent, and waste and unreasonable use of water were to be prevented. INRC was also given authority to establish a state-wide plan for the control of water resources, and from this evolved the Iowa Study Committee on Water Rights and Drainage Laws in 1955. Subsequently, the first Iowa Water Rights Law was adopted in 1957. This law became the foundation upon which most management decisions have been made since its adoption. The Water Rights Law had five basic tenets (Iowa Code, Chapter 455A): 1) waters were declared to be the wealth of the people; 2) a permit system was established for large users (more than 25,000 gpd); 3) small users were not regulated; 4) protected streamflow levels were established; and 5) the policies of beneficial use were described.

In 1972, the Iowa Department of Environmental Quality (DEQ) was created with commissions on air and water quality, chemical technology, and solid-waste disposal (Iowa Code, Chapter 455B). The Water Quality Commission set contamination and discharge limits for surface waters, and reviewed plans for water supply and waste-water treatment plants. Under contract with the DEQ, the State Hygienic Laboratory monitored surface-water quality. A board was appointed to oversee certification of water-treatment-plant operators. All public water suppliers had to submit routine samples of water to the department to assure safety. The department also administered state and federal grants for construction of municipal waste-water treatment facilities. The department became the agency authorized to prevent, abate, and control water pollution, and to establish, modify, or repeal water-quality standards and effluent standards for disposal systems. In 1982, the legislature created the Department of Water, Air, and Waste Management (DWAWM) with primary authority for air, water, solid- and hazardous-waste management, pollution control, drinking water, water rights, and floodplain management (1982 Iowa Acts, Chapter 1199, effective July 1, 1983). This gave authority to DWAWM that had previously resided with INRC, DEQ, and the State Health Department. In effect, DWAWM was created to consolidate the management and regulation of water, air, and waste across the state.

In 1982, the legislature also mandated a State Water Plan and the DWAWM Commission was required to assess the water needs of all water users, and prepare a general plan for water allocation designed to meet the specific needs of all users.

DWAWM proved to be a viable but short-lived agency. The primary objectives of the State Water Plan developed by DWAWM and submitted to the Iowa legislature January 1, 1985, were as follows: 1) to prepare a priority allocation system for water shortage situations; 2) to set up a well-interference system to protect non-regulated users; and 3) to develop a groundwater protection strategy. The allocation and well-interference objectives were enacted into law in 1986 (Iowa Code Chapter 455B.266, amended, and Chapter 455B.281, new section), while the Groundwater Protection Act was passed in April, 1987. In 1987, with the adoption of the State Government Reorganization Plan, the Iowa Department of Natural Resources (DNR) was created. Most of the responsibilities and functions of DWAWM were placed in the Environmental Protection Division of DNR. The DNR Environmental Protection Commission is responsible for the formation of policy, rules, and regulations pertaining to water use, water quality, floodplain management, dams, and waste disposal in Iowa. The commission holds meetings at least quarterly (more often monthly) to take under consideration complaints, violations, appeals, and contested cases.

The DNR's responsibility is defined by five chapters of the Iowa Administrative Code dealing with water use:

1. Scope of Division - Definitions - Forms - Rules of Practice (Chapter 567-50 IAC)
2. Water Permit or Registration - When Required (Chapter 567-51 IAC)
3. Criteria and Conditions for Authorization Withdrawal, Diversion and Storage (Chapter 567-52 IAC)
4. Protected Water Sources (Chapter 567-53 IAC)
5. Criteria and Conditions for Permit Restrictions or Compensation by Permitted Users to Non-regulated Users Due to Well Interference (Chapter 567-54 IAC)

Any person who proposes to impound water in a reservoir in excess of 18 acre-feet, or pump or divert by gravity more than 25,000 gpd of water from any groundwater or surface-water source, is required to obtain a withdrawal permit. The water-permit program authorizes water use, provides streamflow protection, priority allocation between competing uses, water conservation, well-interference compensation, and aquifer protection. Special restrictions for consumptive water uses are imposed on withdrawals from streams or withdrawals from alluvial aquifers. To ensure adequate protection of water supplies for domestic uses, fish and wildlife, recreational use, and protection of aesthetic values, water withdrawals are regulated in relation to instream flow protection. Consumptive withdrawals, except for public drinking-water supplies, are prohibited when the streamflow drops below the protected flow for a particular stream.

Withdrawals for consumptive uses at any point within one-eighth mile of a stream are prohibited if the stream discharge drops below the protected flow. Within one-fourth mile of the stream, withdrawals must cease if the discharge drops below the 7Q10 (seven day, one-in-ten year low flow). There are variances and exceptions to these regulations; if questions arise, advice should be obtained from the DNR, Surface and Groundwater Protection Bureau, Wallace State Office Building, Des Moines, Iowa 50319. The designated protected low flows of streams are provided in Chapter 567-52 and the 7Q10 values can be obtained by contacting the U.S. Geological Survey in Iowa City, Iowa.

The program provides a means to resolve well-interference conflicts between non-regulated (private individual well users) and regulated users when a permitted use causes interference in the pumping or static-water level in the non-regulated well. The complainant and permittee must attempt to negotiate an informal settlement prior to the DNR becoming involved in the verification and settlement procedures. Guidelines for Well Interference Compensation (Bulletin No. 23) are available from the DNR, Surface and Groundwater Protection Bureau.

The current Groundwater Protection Act, adopted by the Iowa Legislature in April, 1987, amended Chapter 455B of the Code of Iowa. Its primary objectives are related to public health and safety by establishing programs relating to the management of agricultural activities, solid-waste disposal, household hazardous wastes, storage tanks, fertilizers, pesticides, landfills, and watersheds. The DNR has initiated several programs to implement provisions of this act and previously existing sections of the Code of Iowa dealing with surface-water and groundwater protection, water-resources management, and safety of water for human consumption as follows:

Registration of Water Well Contractors (Chapter 567-37 IAC)

This provision was enacted in 1986 and requires all water-well construction businesses, and one or more of their employees, to register with the DNR before they can commence construction activities. The law also, in many cases, requires the contractor to submit drilling records and drill-cutting samples to the DNR, Geological Survey Bureau, Oakdale Campus, University of Iowa, Iowa City, Iowa 52242, phone (319)335-4022. Pump installers are exempted from registration. This program complements the programs created by Chapter 467-38 and 567-39 IAC which require private wells to be constructed by a registered well driller and certain types of abandoned wells to be closed by registered well drillers.

Private Water-Well Construction Permits (Chapter 567-38 IAC)

This program began in 1988 and requires that a construction permit be obtained prior to construction. These permits can be obtained from the DNR, directly from the county, if it has been delegated permitting authority by the DNR, or in emergency situations from the county, regardless of whether or not it has received authority from the DNR. A majority of counties have applied, and have been delegated authority to issue these permits for the DNR. The primary purposes of this program are to develop a comprehensive list of all wells, to protect groundwater quality, and to protect health and welfare by assuring that wells are properly constructed. Wells must be drilled by registered well contractors and constructed according to construction standards contained in Chapter 567-49 IAC.

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APPENDICES

Appendix I. Wetlands of northeast Iowa

Lake, impoundment, or wetland	Location	Surface area (acres)	Ownership	Type of water	Description
Unnamed shallow marsh and ponds	SW, sec. 36, T100N, R5W, and center, N½, sec. 1, T99N, R5W, Allamakee Co.	20	Private	OFSI[a]	Located at mouth of old channel of Frenchman's Creek
Waukon Junction Marsh	E½, sec. 10, T96N, R3W, Allamakee Co.	70	State	OFSI	Shallow marsh located at mouth of Paint Creek valley where it empties into the Mississippi River valley
Founders Pond	SE, sec. 33 and SW, sec. 34, T96N, R3W, Allamakee Co.	70±	Federal	OFSI	Open fresh-water pond ½ mile upstream from junction of Yellow River and the Mississippi River
Unnamed shallow marsh	Parts of secs. 19, 20, 21, and 28, T90N, R14W, Black Hawk Co.	100+	Private	OFSI	Shallow marsh on floodplain of Beaver Creek where it joins the Cedar River in northwest Black Hawk County
Frederika Impoundment	SW, sec. 6 and NW, sec. 7, T93N, R12W and NE, sec. 12, T93N, R13W, Bremer Co.	20+	City	ONSI[b]	Palustrine-lacustrine wetland created by a dam on the Wapsipinicon River at Frederika
Sweet Marsh	Secs. 34 and 35, T93N, R12W, and sec. 2, T92N, R12W, Bremer Co.	1,100	State	OFSI	An artificial open-water marsh created by a levee and dam at the junction of the Wapsipinicon River and East Fork Wapsipinicon River floodplains
Unnamed deep marsh	Sec. 18, T92N, R11W, Bremer Co.	200	Private	OFSI	Marsh on the Wapsipinicon River floodplain
Unnamed shallow marshes	E¼, sec. 8 and W¼, secs. 9 and 16, T91N, R11W, Bremer Co.	640	Private	OFSI	Shallow marshes on the Wapsipinicon River floodplain 3 miles east of Readlyn
Fontana Lake	E½, sec. 16, T90N, R9W, Buchanan Co.	60	County	ONSI	Palustrine-lacustrine wetland created by a dam on Otter Creek 1 mile south of Hazleton
Independence Impoundment	Parts of secs. 27, 28, 33, and 34, T89N, R9W, Buchanan Co.	700±	Private	ONSI	Palustrine-lacustrine wetland created by a dam at the Wapsipinicon Mill at Independence
Littleton Impoundment	Sec. 10, T89N, R10W, Buchanan Co.	15	Private	ONSI	Palustrine wetland created by a dam on the Wapsipinicon River at Littleton
Troy Mills Marsh	Secs. 25 and 36, T87N, R8W, Buchanan Co.	75	State	OFSI	Shallow marsh on Wapsipinicon River floodplain 2¼ miles northwest of Troy Mills
Cedar Lake	Secs. 7 and 18, T94N, R14W, Chickasaw Co.	200+	Private	ONSI	Lacustrine wetland created by a dam on the Cedar River at Nashua
Unnamed shallow marsh	Secs. 26 and 35, T94N, R13W, Chickasaw Co.	150	Private	OFSI	Shallow marsh on Wapsipinicon River bottomland 3 miles upstream from Frederika

Lake, impoundment, or wetland	Location	Surface area (acres)	Ownership	Type of water	Description
Split Rock Pond	SW, sec. 35, T94N, R12W, Chickasaw Co.	10	County	OFSI	Small pond with earthen dam and small drainage area
Elkader Impoundment	Secs. 22 and 23, T93N, R5W, Clayton Co.	20	State	ONSI	Palustrine-riverine wetland created by a dam on Turkey River at Elkader
Backbone Lake	Secs. 15 and 16, T90N, R6W, Delaware Co.	100	State	ONSI	Palustrine-lacustrine wetland created by a dual dam on the Maquoketa River 2 miles north of Dundee
Unnamed shallow marsh	Sec. 24, T89N, R6W, Delaware Co.	100	Private	OFSI	Shallow upland marsh 1 mile north of the Manchester municipal airport
Quaker Mill Pond	Parts of secs. 17, 18, 19, 20, T89N, R5W, Delaware Co.	64	Private	ONSI	Palustrine-lacustrine wetland created by a dam on the Maquoketa River 1 mile northwest of Manchester
Hartwick Lake	Parts of secs. 14, 23, 24, 25, 26, T88N, R5W and secs. 19 and 20, T88N, R4W, Delaware Co.	538	Private	ONSI	Palustrine-lacustrine wetland created by a dam on the Maquoketa River 1½ miles south of Delhi
Silver Lake (Delhi)	Secs. 16, 20, and 21, T88N, R4W, Delaware Co.	10	County	OFSI	Lacustrine wetland; an artificial lake at southeast edge of Delhi
Waucoma Impoundment	Sec. 9, T95N, R10W, Fayette Co.	10	City	ONSI	Palustrine-lacustrine wetland on Little Turkey River at Waucoma
Unnamed gravel pit	NW, sec. 29, T93N, R9W, Fayette Co.	20±	Private	OFSI	Large abandoned gravel pit on Volga River bottoms
Volga Lake	Sec. 3, T93N, R8W, Fayette Co.	150	County	ONSI	Lacustrine wetland created by a dam across Frog Hollow 4 miles southeast of West Union
Mare Mard Impoundment	Sec. 14, T92N, R9W, Fayette Co.	5	City	ONSI	Palustrine-lacustrine wetland on Little Volga River at Maynard
Fairbank Impoundment	Sec. 32, T91N, R10W, and sec. 5, T90N, R10W, Fayette Co.	8	Private	ONSI	Palustrine-lacustrine wetland on Little Wapsipinicon River bottoms at Fairbank
Lake Oelwein	Sec. 33, T91N, R9W, Fayette Co.	23	City	ONSI	Palustrine-lacustrine wetland on Otter Creek bottoms south of Oelwein
Lime Springs Impoundment	Secs. 17 and 20, T100N, R12W, Howard Co.	20	County	ONSI	Riverine-palustrine wetland created by a dam on the Upper Iowa River 1 mile north of Lime Springs
Lake Hendricks	S½, sec. 19, T99N, R14W, Howard Co.	50	County	OFSI	Lacustrine wetland created by a dam on Watsons Creek ½ mile northeast of Riceville
Vernon Springs	Secs. 33 and 34, T99N, R11W, Howard Co.	23	County	ONSI	Lacustrine wetland created by a dam on the Turkey River 2 miles southwest of Cresco

Lake, impoundment, or wetland	Location	Surface area (acres)	Ownership	Type of water	Description
Lylahs Marsh	Sec. 23, T98N, R14W, Howard Co.	160±	County	ONSI	Inland marsh wetland created by a dam on the Little Wapsipinicon River 3 miles northwest of Elma
Unnamed shallow marsh	E¼, sec. 23, T98N, R13W, Howard Co.	160±	Private	ONSI	Shallow marsh on bottomland of Crane Creek 2½ miles northwest of Lourdes
Unnamed shallow marsh	E½, SE, sec. 6, T97N, R14W, Howard Co.	80	State	ONSI	Shallow marsh on the bottomland of Wapsipinicon River 4½ miles west of Elma
Hawks Ponds	NW, sec. 22, T100N, R8W, Winneshiek Co.	18±	Private	ONSI	Might be old quarries in Galena bedrock in valley of North Canoe Creek
South Bear Creek Marsh	NE, sec. 33, T100N, R7W, Winneshiek Co.	5	State	ONSI	Shallow marsh on bottomland of South Bear Creek
Cardinal Marsh	SW, sec. 6 and W½, sec. 7, T98N, R10W, Winneshiek Co.	100	State	OFSI	Deep marsh in old meander channel of Turkey River
Lower Dam Impoundment	NW, sec. 2 and NE, sec. 3, T98N, R7W and SW, sec. 35, T99N, R7W, Winneshiek Co.	28	State	ONSI	Riverine and shallow marsh wetland on the Upper Iowa River 3 miles northeast of Freeport
Upper Dam Impoundment	SE, sec. 5 and NE, sec. 8, T98N, R7W, Winneshiek Co.	22	State	ONSI	Riverine wetland on Upper Iowa River 5½ miles northeast of Freeport
Lake Meyers	SE, sec. 33, T97N, R9W, Winneshiek Co.	38	County	OFSI	Artificial lake 2 miles northeast of Fort Atkinson
Mississippi River floodplain complex	Allamakee, Clayton, and Dubuque counties		Federal	ONSI	Three large dams at Harpers Ferry, Guttenberg, and Dubuque used for flood-control and navigation purposes create an almost continuous succession of lakes, sloughs, backwater areas, and emergent marshes
Cedar River floodplain complex	Chickasaw, Bremer, and Black Hawk counties		State and private	ONSI OFSI	Classed as a palustrine-lacustrine wetland because of numerous ponds, marshes, and oxbow lakes found along the bottomlands; sustained in part by dams at Nashua, Waverly, Cedar Falls, and Waterloo
Wapsipinicon River floodplain complex	Howard, Chickasaw, Bremer, Black Hawk, and Buchanan counties		State and private	ONSI OFSI	Classed as a palustrine-lacustrine wetland because of numerous ponds, meander cut-off lakes, and marshes; dams maintain high water levels at Frederika, Tripoli (East Fork), Independence, and Quasqueton

[a] OFSI - Offstream impoundment [b] ONSI - Onstream impoundment

Appendix II. Drinking-water regulations, significance of chemical constituents, and physical properties of water

Constituent or property	MCLs[a] for Community Water Supplies, Primary Regulations	Significance
Inorganic chemicals:		
Arsenic (As)	0.05 mg/l[b]	These elements, exclusive of nitrate, are called trace metals in natural water supplies because they occur in such minute quantity. Some are toxic to people if they occur in significant amounts. When found in excess quantities in Iowa, it is practically always because they were introduced rather than occurring naturally. MCLs have been established for these chemicals; however, a full understanding of the effects on humans has yet to be determined. Nitrate is a chemical that usually has more serious effects on health because it commonly has concentrations exceeding the MCL (10 mg/l as N and 45 mg/l as NO_3) and may cause methemoglobinemia or "blue-baby" syndrome. High concentrations may also indicate the presence of disease-forming organisms in the water supply.
Barium (Ba)	1.0 mg/l	
Cadmium (Cd)	0.01 mg/l	
Chromium (Cr)	0.05 mg/l	
Lead (Pb)	0.05 mg/l	
Mercury (Hg)	0.002 mg/l	
Nitrate (NO_3)	10.0 mg/l	
Selenium (Se)	0.01 mg/l	
Silver (Ag)	0.05 mg/l	
Turbidity	1 T.U.[c]	Turbidity, which is caused by the presence of suspended matter such as clay, silt, organic material, plankton, and other microscopic organisms, is an indicator of potable water quality.
Coliform bacteria	1 organism/100 ml of water	The coliform bacteria are used as the "indicator organism" of microbiological contamination of water. Their presence indicates that fecal contamination from people or animals may be in the water and is cause for rejection of the supply if the arithmetic mean per month exceeds one organism per 100 milliliters of water per sample. The EPA recommends that four organisms per 100 milliliters of water be allowed in 5% of samples when more than 20 samples per month are examined. Disinfection with chlorine is the usual method for control of bacteria.
Radionuclides:		
Gross alpha	15 pCi/l[d]	The effect and significance of low concentrations of radium in public water supplies isn't fully known. However, the EPA believes that any dose of ionizing radiation can be dangerous to health in proportion to the dose received. The MCLs established are based on effects observed at high doses. Monitoring is done through a screening process: when gross alpha exceeds 5 pCi/l, the sample is then analyzed for ^{226}Ra. If the concentration of ^{226}Ra exceeds 3 pCi/l, the sample is then analyzed for ^{228}Ra. The combined ^{226}Ra and ^{228}Ra should not exceed 5 pCi/l. Gross-alpha activity should not exceed 15 pCi/l. None of the northeast Iowa communities appear to have excess radium in their water, with the possible exception of New Albin.
Radium (^{226}Ra)	3 pCi/l	
Radium (^{226}Ra and ^{228}Ra)	5 pCi/l	

Constituent or property	MCLs for Community Water Supplies, Secondary (recommended) Regulations[e]	Significance
Inorganic chemicals:		
Chloride (Cl)	250 mg/l	Chloride concentrations of < 150 mg/l generally are acceptable for most purposes. More than 250 mg/l may combine with other ions to give a noticeably salty taste.
Copper (Cu)	1.0 mg/l	Copper generally is of no significance to community water supplies in northeast Iowa. If present in large amounts, it probably will be obtained from plumbing systems without corrosion control.
Fluoride (F)	2.0 mg/l	Fluoride is desirable in drinking water supplies in concentrations of about 1 mg/l, because it reduces tooth decay. Mottling of tooth enamel of growing children may occur when fluoride exceeds 2 mg/l. However, the EPA has set the MCL for fluoride at 4 mg/l.
Iron (Fe)	0.3 mg/l	Iron concentrations in excess of 0.3 mg/l can be a nuisance by staining laundry and plumbing fixtures a red-rust color and can also plug well screens and water pipes. It also affects the taste and color of beverages.
Manganese (Mn)	0.05 mg/l	Manganese in concentrations as low as 0.01 to 0.02 mg/l is objectionable for the same reasons as iron. It may cause dark brown or black stains on fabrics and porcelain, and impair the taste and color of beverages.
Sulfate (SO_4)	250 mg/l	Sulfate adds a taste to the water in concentrations at 300 to 400 mg/l. Sulfate has a laxative effect when the concentration is above 600 mg/l and magnesium and sodium are present. Users may become acclimated to these high concentrations, but at concentrations above 750 mg/l the effect is noticeable in almost everyone. Sulfate combined with calcium forms a scale in boilers and water heaters.
Zinc (Zn)	5.0 mg/l	Zinc is a heavy metal and an essential trace element in human nutrition. The major concern is not with toxicity, but with deficient zinc intake. It is found in very small concentrations in most water supplies in northeast Iowa.

Constituent or property	MCLs for Community Water Supplies, Secondary (recommended) Regulations	Significance
Other properties:		
Corrosivity	Non-corrosive	Corrosion is a phenomenon associated with metal in a water environment. It is related to the pH, alkalinity, dissolved oxygen, and total dissolved-solids content of the water. It has aesthetic, health, and economic significance. A simple, generally accepted measure of corrosivity hasn't been determined. However, it can be controlled by pH adjustment, chemical stabilization, and other means.
pH	6.5 - 8.5 units	The pH value of water is a measure of hydrogen-ion concentration and indicates whether water is acid or alkaline. A pH less than 7.0 is acid, more than 7.0 is alkaline, and equal to 7.0 is neutral. Most of the surface waters of northeast Iowa have a pH of 7.9 to 8.8, while the pH of groundwater ranges from 7.0 to 8.1.
Total dissolved solids (TDS)	500 mg/l	Dissolved solids refers to minerals in solution in the water. It is a rough measure of the suitability of water for many uses. Both the surface water and groundwater of northeast Iowa have low dissolved-solids concentrations, generally less than 500 mg/l. Concentrations greater than 2,000 mg/l usually imply high sulfate and may have a detectable taste and laxative effect.
Other nonregulated constituents and properties of water:		
Silica (SiO_2)		Silica contributes to the formation of incrusting material or boiler scale and forms deposits on steam-turbine blades. It doesn't have any know physiological significance.
Specific conductance (micromhos @ 25°C)		Specific conductance is a measure of water's ability to conduct an electrical current. It is directly related to the ion concentration in the water. By multiplying the specific conductance by 0.55 to 0.75 micromhos, a fair estimate of the dissolved-solids concentration can be made.
Alkalinity (as $CaCO_3$)		Alkalinity of water refers to its ability to neutralize acid. Calcium carbonate and calcium bicarbonate are the most common compounds that cause water to be alkaline.
Hardness (as $CaCO_3$)		Hardness is a characteristic of water that represents the concentration of calcium and magnesium ions. It is recognized by the amount of soap required to produce a lather. Hard water causes formation of scale in boilers, water heaters, and pipes. The total alkalinity is called carbonate hardness; the amount of hardness in excess of this is called the non-carbonate hardness. There are different definitions for what is hard or soft water, but all northeast Iowa water supplies can be classed as moderately hard to hard water with a range of 200 to 500 mg/l.

Constituent or property	Significance
Potassium (K) and Sodium (Na)	Sodium and potassium in low and moderate quantities have little effect on the usefulness of water. The concentration can be a concern to people on a sodium-restricted diet. When combined with chloride, sodium will give water a salty taste. High concentrations cause foaming in boilers. The waters of northeast Iowa usually have less than 50 mg/l sodium and potassium combined.
Calcium (Ca) and Magnesium (Mg)	Calcium and magnesium ions are the main causes of hardness in water and the formation of boiler scale and deposits in hot-water heaters and pipes. They reduce the lathering and sudsing ability of soaps.
Bicarbonate (HCO_3) and Carbonate (CO_3)	These constituents are formed when carbon dioxide in water reacts with limestone and dolostone. Bicarbonate and carbonate contribute to the alkalinity of water. Bicarbonate is the principal anion in the water of northeast Iowa.
Temperature	Temperature is an important characteristic of water for industrial-cooling and air-conditioning purposes. It is related to location and season for surface-water sources and to location and depth for groundwater sources.
Taste and odor	Undesirable taste and odor that affect the aesthetic quality of water may result from a combination of circumstances. Iron and hydrogen sulfide are common inorganic chemicals that cause taste and odor problems. High iron concentrations will contribute a bitter taste, while hydrogen sulfide will emit a rotten-egg odor. Both are common nuisances in northeast Iowa, and hydrogen sulfide can be lethal if enough is inhaled. Organic constituents such as bacteria and algae are the most frequent cause of bad taste and odor; examples are slimy iron bacteria in wells and water systems, and decayed leaves and vegetation in surface water.

[a] maximum contaminant levels
[b] milligrams per liter
[c] turbidity units
[d] picocuries per liter
[e] Not federally enforceable and mainly affect aesthetic and taste qualities

Appendix III. Representative water-quality analyses from the surficial and bedrock aquifers in northeast Iowa

Well Location	Date of collection	Depth (feet)	Temp. (°C)[a]	pH[b]	Spec. Cond.[c]	Fe (mg/l)[d]	Total dissolved solids (mg/l)	Hardness (as $CaCO_3$) (mg/l)	Alkalinity (mg/l)
ALLUVIAL AQUIFERS									
NE, SW, sec. 16, T98N, R8W	7/22/80	62	11	7.4	570	0.02	342	288	240
NE, SE, sec. 15, T89N, R13W	5/07/79	82	14.5	7.4	580	<0.01	344	265	194
NE, NE, sec. 18, T89N, R3E	3/25/75	200	11.5	7.4	540	1.0	322	280	246
SW, NW, sec. 26, T88N, R14W	5/23/78	50	12	7.1	810	0.01	523	407	282
DRIFT AQUIFERS									
NW, NW, sec. 17, T96N, R12W	5/07/86	158		7.7	870	2.0	492	436	417
SE, SE, sec. 6, T96N, R11W	5/07/86	227		7.7	750	1.7	442	378	287
SE, NE, sec. 11, T95N, R11W	5/07/86	165		7.7	440	5.5	246	203	203
NE, NE, sec. 16, T94N, R13W	12/03/85	158		7.6	580	1.3	309	249	249
SW, NW, sec. 33, T94N, R11W	5/07/86	190		8.0	620	2.1	294	221	221
NW, NE, sec. 30, T94N, R9W	1/23/76	85	11	7.2	640	0.74	405	359	238
NW, SW, sec. 16, T92N, R13W	5/07/86	238		7.8	1,000	4.4	628	359	355
SE, SE, sec. 21, T92N, R11W	5/07/86	146		7.9	680	1.8	370	277	277
SE, SW, sec. 4, T91N, R11W	5/07/86	160		8.1	750	7.5	406	367	354
NW, SE, sec. 29, T90N, R14W	4/19/86	105		7.5	420	1.3	208	211	159
SW, SW, sec. 18, T89N, R11W	12/03/85	105		7.3	910	5.7	558	443	425
SILURIAN - DEVONIAN AQUIFER									
SE, SE, sec. 10, T100N, R13W	4/11/77	176		7.1	570	1.3	336	303	283
SW, SW, sec. 20, T97N, R13W	3/10/76	150		7.7	370	0.97	204	212	162
NE, SW, sec. 3, T91N, R14W	2/24/82	170	11	7.4	580	<0.01	316	297	230
NE, SE, sec. 35, T91N, R14W	8/14/84	150	10	7.7	610	0.02	321	308	218
SE, SW, sec. 22, T91N, R6W	5/09/85	240	10.5	7.4	400	<0.01	229	206	159
SE, SE, sec. 31, T89N, R14W	6/20/77	225	12	7.2	490	0.04	297	260	206
NW, SE, sec. 20, T89N, R5W	4/25/84	270	11.5	7.6	480	<0.01	286	236	176
SW, NE, sec. 4, T88N, R9W	7/25/78	265	12	7.4	470	0.08	276	246	212
NW, SW, sec. 27, T87N, R10W	8/01/79	405	13	7.0	650	0.03	381	337	293
FORT ATKINSON - ELGIN AQUIFER									
NW, SE, sec. 29, T100N, R12W	10/02/74	358		7.5	430	0.56	258	234	216
NE, SW, sec. 30, T99N, R14W	7/09/84	468	12	7.3	640	0.91	374	316	297
NW, NE, sec. 23, T98N, R10W	5/14/80	192		7.5	700	0.92	442	358	269
SW, NW, sec. 27, T95N, R9W	11/05/69	270		7.3	560	2.9	316	324	286

K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Mn (mg/l)	NO_3 (mg/l)	F (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Radioactivity Gross alpha (pCi/l)[e]	^{226}Ra (pCi/l)	^{228}Ra (pCi/l)
1.7	8.8	79	22	0.01	8.7	1.2	16	31	293	0	1.7		
1.6	13	70	22	<0.01	15	0.2	26	50	237	0	2.2		
1.8	6.7	63	30	2.1	2.3	0.15	11	32	300	0	nil		
2.4	14	120	28	0.02	32	0.2	49	55	344	0	0.3		
4.3	26	120	33	0.13	0.3	0.2	1.0	30	509	0			
4.1	18	110	25	0.09	10	0.35	1.5	91	353	0			
1.2	4.5	55	16	0.19	<0.1	0.25	1.5	8.2	267	0			
3.3	23	56	26	0.06	10	0.45	0.5	20	344	0			
4.1	44	62	16	0.08	2.0	0.55	1.0	12	370	0			
0.6	11	110	20	0.29	3.9	0.3	16	88	290	0			
4.7	93	91	32	0.14	<0.1	0.7	3.5	170	433	0			
4.1	44	68	26	0.07	20	0.5	2.5	30	388	0			
4.4	28	81	40	0.31	<0.1	0.5	0.5	44	432	0			
1.2	4.3	58	16	0.2	<0.1	0.45	1.0	10	194	0			
3.0	20	130	28	0.36	<0.1	0.3	16	41	519	0			
3.0	9.1	81	24	0.01	<0.1	0.7	<0.5	27	345	0	0.6		
0.8	3.7	58	16	0.03	<0.1	0.2	3.0	35	198	0	0.1		
1.8	8.9	81	23	<0.01	23	0.2	18	22	281	0	1.4		
1.3	6.0	87	22	<0.01	56	0.6	14	16	266	0	<0.2		
0.6	2.4	51	19	<0.01	27	0.2	5.5	18	194	0	1.3		
2.0	5.7	66	23	0.04	0.6	0.9	5.0	56	251	0	nil		
1.5	8.1	65	18	<0.01	33	0.1	14	21	214	0	0.6		
1.7	6.6	67	19	0.02	0.2	0.2	8	25	259	0	0.6		
3.2	15	87	29	<0.01	24	0.7	8	32	357	0	3.7	1.2	
2.4	5.4	62	20	<0.01	0.3	0.45	0.5	31	263	0	1.9		
4.3	19	73	32	0.02	0.4	0.7	1.0	48	362	0	2.3	2.1	<0.4
2.0	10	100	26	0.06	0.4	0.4	33	62	328	0	4.8	0.5	2.0
2.4	3.6	94	21	0.25	0.5	0.35	3.0	44	349	0			

Well Location	Date of collection	Depth (feet)	Temp. (°C)	pH	Spec. Cond.	Fe (mg/l)	Total dissolved solids (mg/l)	Hardness (as $CaCO_3$) (mg/l)	Alkalinity (mg/l)
GALENA AQUIFER									
NE, SW, sec. 19, T97N, R9W	5/06/80	362	10	7.6	540	0.06	314	294	242
NE, NE, sec. 35, T97N. R9W	7/30/75	350		7.2	1,100	2.4	763	635	404
SW, NE, sec. 34, T95N, R7W	1/29/80	240		7.3	660	0.02	396	344	283
NE, SE, sec. 8, T95N, R5W	9/25/80	347	10	7.3	710	0.26	441	411	287
NW, SW, sec. 13, T94N, R7W	5/18/84	150	12	7.3	670	<0.01	384	328	277
SW, SW, sec. 3, T92N, R6W	12/01/77	225	11	7.4	540	0.03	302	288	231
NE, NE, sec. 19, T90N, R1W	4/24/84	625	13.5	7.3	600	0.10	338	337	307
Big Spring project:									
NW, NW, sec. 34, T95N, R6W	5/05/83	294		7.3	680	0.88	335	374	361
SE, NE, sec. 35, T95N, R6W	5/05/83	260		7.4	600	6.5	323	345	315
NE, NE, sec. 18, T95N, R5W	5/05/83	190		7.3	730	0.03	409	380	305
SE, SW, sec. 22, T95N, R5W	5/05/83	280		7.3	840	7.4	483	453	349
NE, NE, sec. 29, T95N, R5W	5/05/83	225		7.3	900	2.2	482	462	314
SW, SW, sec. 32, T95N, R5W	5/05/83	180		7.4	640	3.4	385	361	280
NE, NE, sec. 19, T95N, R4W	5/05/83	180		7.3	700	3.9	381	381	334
SW, NW, sec. 3, T94N, R5W	5/05/83	300		7.5	700	0.06	407	369	274
NE, SE, sec. 6, T94N, R4W	5/05/83	86		7.3	750	0.05	428	406	305
NW, SW, sec. 17, T94N, R4W	5/05/83	200		7.4	700	7.3	413	351	282
ST. PETER AQUIFER (upper Cambrian-Ordovician aquifer)									
NW, SE, sec. 13, T97N, R11W	7/10/84	699	12	7.2	760	0.17	461	376	272
NW, NW, sec. 16, T97N, R6W	2/19/68	450		7.1	740	0.1	435	416	386
SE, NW, sec. 8, T96N, R9W	4/29/80	545	10	7.2	800	0.53	496	408	298
NE, SW, sec. 9, T95N, R10W	5/18/81	682	10	7.3	800	0.62	531	407	282
NE, NE, sec. 13, T94N, R12W	8/07/84	792	12	7.8	410	0.18	252	226	147
SE, NE, sec. 26, T94N, R5W	1/05/76	378		7.4	490	0.33	279	293	246
NW, NE, sec. 23, T93N, R5W	5/09/85	225	11.5	7.0	570	<0.01	327	289	241
NE, NE, sec. 20, T92N, R13W	9/25/73	815	11	7.2	640	4.0	370	260	260
SE, SW, sec. 14, T92N, R9W	7/02/79	835	15	7.5	480	0.28	276	237	214
NE, NW, sec. 25, T91N, R13W	8/08/84	1,060	12.5	7.6	620	0.35	340	278	276
SE, NE, sec. 4, T90N, R3W	4/10/45	822		7.4		0.8	404	341	257
SW, NW, sec. 26, T88N, R2E	9/02/48	720		7.5	603	0.02	314	292	282

K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Mn (mg/l)	NO_3 (mg/l)	F (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Radioactivity Gross alpha (pCi/l)	^{226}Ra (pCi/l)	^{228}Ra (pCi/l)
1.0	2.9	70	29	0.01	8.3	0.3	10	41	295	0	2.2		
1.9	9.1	160	54	0.18	0.4	0.25	5.5	200	493	0	1.0		
0.8	4.6	85	32	0.01	23	0.2	15	26	345	0	1.5		
<0.01	6.8	92	44	0.01	<0.01	0.3	15	87	350	0	2.5		
2.8	6.1	87	27	<0.01	12	0.3	12	47	338	0	2.3		
2.5	3.4	71	27	0.04	5.1	0.4	8.0	48	282	0	7.3	1.8	
1.9	1.2	79	34	<0.01	0.2	0.2	1.0	25	374	0	0.9		
2.0	8.9	98	31	0.03	0.7	0.3	N.D.	7.5	440				
1.3	6.2	84	30	0.15	N.D.	0.25	N.D.	12	384				
1.0	8.8	91	37	0.02	21	0.2	14	52	372				
0.8	6.4	100	45	0.06	64	0.3	9.0	84	426				
0.9	14	120	41	0.04	62	0.3	34	56	383				
1.7	5.6	89	32	0.57	11	0.4	14	42	342				
N.D.[f]	5.6	84	40	0.02	29	0.1	3.0	15	407				
0.2	10	100	38	N.D.	38	0.2	11	46	372				
N.D.	10	91	40	N.D.	65	0.2	28	27	342				
1.1	12	81	33	0.02	23	0.2	9.0	42	344				
4.9	16	96	33	0.03	14	0.9	8.0	100	332	0	<0.2		
1.4	8.9	98	42	<0.5	0.4	0.3	9.5	28	471	0			
6.4	19	92	43	0.01	1.4	1.6	18	120	364	0	1.0		
11	29	95	41	<0.01	0.2	2.1	1.6	160	344	0	1.8		
5.4	11	51	24	<0.01	0.5	0.6	9.0	32	270	0	3.4	1.5	0.5
2.3	3.7	66	31	0.01	0.3	0.4	1.0	28	300	0	2.4		
4.8	4.6	68	29	<0.01	0.5	0.65	2.0	56	294	0	3.7	2.9	1.2
8.6	34	55	32	0.05	<0.1	2.0	1.0	52	371	0			
7.6	12	52	26	0.01	<0.1	0.6	21	40	261	0	5.9	3.3	
9.2	26	70	25	<0.01	0.5	1.1	1.0	52	337	0	3.9	1.5	3.2
18		84	32	tr.[g]	40	0.2	26	39	314				
9.7		66	31	0	0	0	4.0	46	344				

Well Location	Date of collection	Depth (feet)	Temp. (°C)	pH	Spec. Cond.	Fe (mg/l)	Total dissolved solids (mg/l)	Hardness (as $CaCO_3$) (mg/l)	Alkalinity (mg/l)
JORDAN AQUIFER (lower Cambrian-Ordovician aquifer)									
SW, NW, sec. 23, T99N, R11W	1/27/76	1,145	10	7.5	460	0.21	247	268	235
SW, NE, sec. 30, T98N, R5W	5/16/77	662	10	7.4	500	0.02	293	279	246
SE, SW, sec. 21, T96N, R7W	6/14/79	938		7.5	450	0.48	271	240	210
SE, SW, sec. 10, T96N, R3W	7/28/65	540	11.5	7.5	550	<0.02	323	302	288
NW, SE, sec. 7, T95N, R12W	1/12/77	1,300	10	7.5	470	0.30	261	252	215
NW, NE, sec. 26, T93N, R11W	9/11/79	1,240	15	7.5	500	0.17	270	238	221
NE, SE, sec. 18, T93N, R3W	7/31/80	840	13	7.4	530	0.29	316	283	268
SW, SW, sec. 27, T92N, R7W	4/22/81	1,310	11	7.6	470	0.29	269	228	216
NE, NW, sec. 2, T91N, R14W	3/10/75	1,263		7.4	640	0.25	372	284	284
SW, NE, sec. 21, T91N, R9W	7/30/79	1,328		7.5	520	0.04	298	242	232
NW, SE, sec. 7, T88N, R1W	3/12/80	1,330	16	7.6	700	0.33	399	213	213
NE, SW, sec. 25, T87N, R12W	5/13/80	1,400		7.3	870	1.8	550	347	303
SW, NW, sec. 18, T87N, R3W	2/23/81	1,215	15	7.5	610	0.14	329	213	213
DRESBACH AQUIFER									
NW, NW, sec. 11, T100N, R4W	10/22/79	586	11	7.6	510	0.32	294	285	261
NW, SW, sec. 15, T100N, R4W	4/20/86	?[j]		7.6	550	0.46	294	270	224
NE, SE, sec. 29, T100N, R4W	4/20/86	?[j]		7.6	420	0.46	236	224	158
NE, NW, sec. 29, T99N, R3W	12/10/79	805		7.7	700	0.42	402	166	166
NE, NW, sec. 21, T98N, R8W	2/12/36	1,250		7.1		0.2	320	282	227
" " " " " "	9/06/56	850[h]	10	7.7	486	<0.06	283	274	230
SE, SW, sec. 10, T96N, R3W	7/28/65	540	12	7.5	550	<0.02	323	302	288
SW, NE, sec. 15, T95N, R3W	8/14/80	442		7.5	730	0.54	437	284	248
SW, SE, sec. 22, T95N, R3W	1/18/49	1,006	11	7.5	4,030	1.5	2,664	587	246
SE, SE, sec. 22, T95N, R3W	5/06/49	645	11	7.3	3,060	0.3	2,066	490	246
" " " " " "	4/19/71	479[i]		7.0	1,100	2.0	633	340	264
sec. 36, T89N, R1E	4/10/47	1,230	12.5	7.7	545	0.3	381	270	256
SE, SE, sec. 7, T89N, R3E	2/13/78	1,782	16	7.3	510	0.25	269	298	275

[a] degrees Celsius [b] measurements are in standard units [c] specific conductance, measurements are in micromhos (μm) [d] milligrams per liter

[e] picocuries per liter [f] not detected [g] trace [h] well was plugged back to 850 feet in 1956 [i] well was plugged back in 1951 [j] flowing well

K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Mn (mg/l)	NO_3 (mg/l)	F (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Radioactivity Gross alpha (pCi/l)	^{226}Ra (pCi/l)	^{228}Ra (pCi/l)
0.7	2.0	66	25	0.01	0.2	0.2	1.0	21	287	0	1.1		
1.1	1.0	77	21	<0.01	1.9	0.1	2.0	16	300	0	nil		
1.5	2.7	56	24	0.03	<0.1	0.4	2.0	29	256	0	5.6	1.6	
1.2	2.6	70	31	<0.05	4.6	0.1	2.0	17	351	0			
4.4	4.9	58	26	<0.01	<0.1	0.4	0.5	30	262	0	1.5		
6.9	15	54	25	<0.01	12	1.0	<0.5	38	270	0	2.1		
1.5	3.6	72	25	0.01	0.3	0.3	2.0	18	327	0	1.1		
7.4	11	50	25	0.01	0.1	0.6	1.5	46	263	0	1.7		
10	32	63	32	<0.01	<0.1	1.3	3.0	70	351	0			
9	18	54	26	<0.01	0.2	1.2	2.0	46	283	0	3.1	4.0	
12	67	47	23	0.01	<0.1	0.9	20	78	303	0	3.0	2.1	
13	58	75	38	0.01	<0.1	1.2	5.0	160	370	0		4.4	
11	45	44	25	<0.01	0.5	1.3	6.0	68	294	0	2.1		
<0.1	1.9	38	46	0.01	<0.1	0.2	2.0	22	318	0	9.6	4.3	
4.5	6.4	67	25	<0.02	<0.1	0.2	4.5	25	273	0			
4.7	5.2	60	18	0.06	<0.1	0.35	3.0	24	193	0			
4.9	87	35	19	0.02	0.4	0.3	48	52	278	0	3.0	2.8	
		70	26	0.2	4.4	0	8.0	33	277				
1.8	1.8	70	24	<0.05	1.3	0.1	8.0	29	281				
1.2	2.6	70	31	<0.05	4.6	0.1	2.0	17	351	0			
4.4	50	67	28	0.01	0.4	0.2	60	48	303	0	2.6		
733		138	59	0	0	0.8	1,020	475	300				
511		117	48	0	0	0.7	747	319	300				
8	100	88	29	<0.05	0.5	0.4	140	100	322	0			
42		62	28	0	0	0.2	36	44	312				
3.2	0.8	60	36	<0.01	0.1	0.2	0.5	16	336	0	4.7	5.0	