INTRODUCTION

Groundwater in Iowa is a priceless natural resource: About 75 percent of the population rely on groundwater. The climate, terrain, and geology of the state contribute to the storage of immense quantities of water in five major bedrock aquifers, as well as in porous sand and gravel deposits found along stream valleys, in buried channels, and within the surficial materials sequence. (figure 1).

The rock formations that make up the Iowa groundwater reservoir are primarily Paleozoic sandstones, dolostones, and limestones, but include younger Cretaceous sandstones in northwest Iowa. From the early Paleozoic, and continuing through the Pennsylvanian, these strata were deposited in several structural basins. The East-Central Iowa Basin formed during Silurian time, the Iowa Basin (central and southwest Iowa) during Devonian, and the Forest City Basin in northwest Missouri and adjacent parts of Iowa, Kansas, and Nebraska during Pennsylvanian time (figure 2). The Paleozoic rocks have been tilted and broken by earth stresses. Erosion beveled the surface of the tilted rocks so that the older formations are exposed in the northeast and northwest parts of the state and the younger rocks in central and southwestern Iowa. Shales and sandstones deposited on the beveled Paleozoic surface in northwestern Iowa during the Cretaceous Period remain essentially flat-lying. The surface of the Paleozoic and Cretaceous rocks was severely eroded before glaciers advanced across Iowa during the Pleistocene Epoch. A mantle of glacial drift and loess, generally between 100 and 200 feet thick but ranging up to 600 feet, now covers the bedrock across most of the state.

The five major bedrock aquifer systems are: the Cretaceous (Dakota), Mississippian, Silurian-Devonian, Cambrian-Ordovician (Jordan), and Dresbach (Mt. Simon). These units comprised of porous, permeable sandstones and fractured carbonate rocks are productive water-yielding beds. They are usually separated by confining beds (aquicludes) that retard the movement of water between the aquifers.

Iowa's water withdrawals increased at a rate of approximately 4.0 percent per year between 1975 and 1980, based on estimates issued by the U.S. Water Resources Council and the U.S. Geological Survey. This is somewhat lower than earlier state projections which predicted an increase of 4.6 percent through the year 2020 (Barnard and Dent, 1976). Still, the increased water withdrawal of the past five years was substantial for major categories of use (table 1).

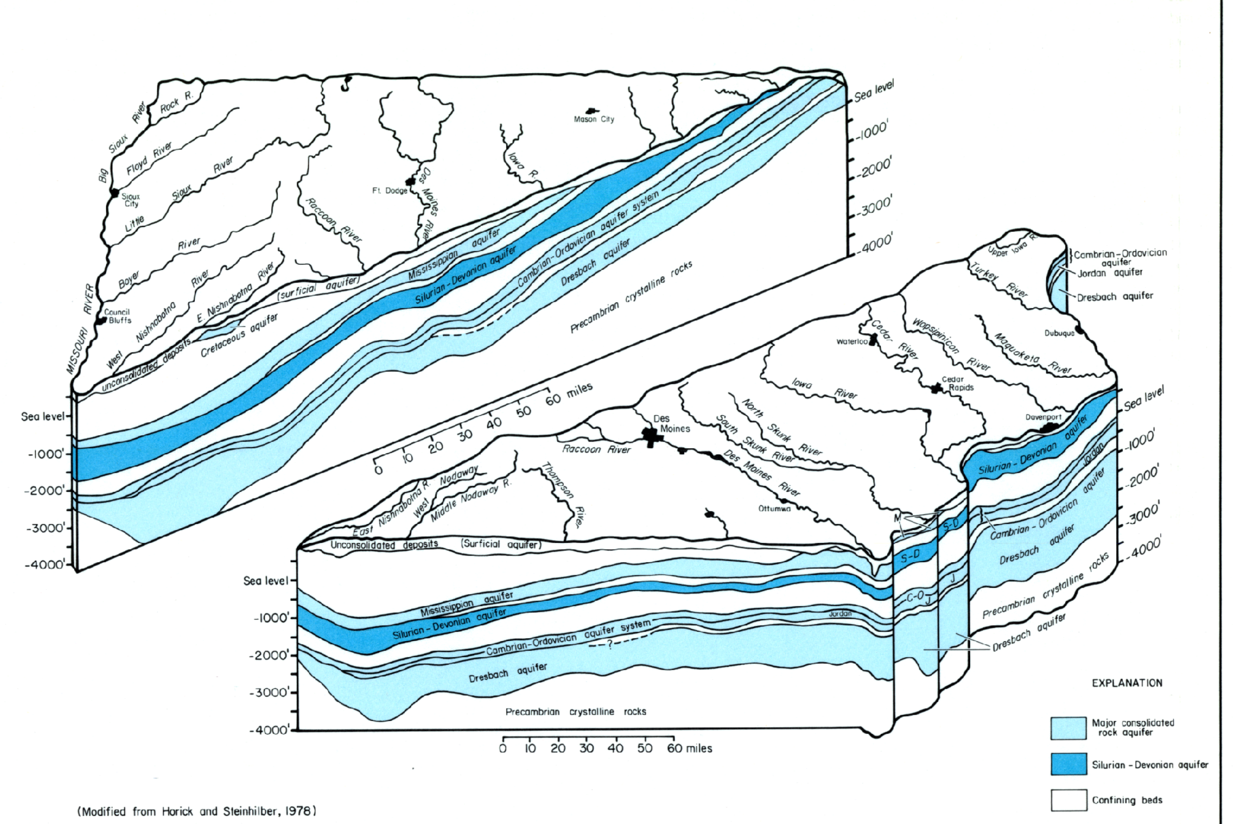
Table 1. Water use in Iowa 1975 and1980. Amounts are in millions of gallons per day.

	1975	1980
Public Supplies	300	311
Rural	170	185
Irrigation	21	56
Industrial	310	551
Thermoelectric	2700	3104
Total	3501	4207

The cumulative increase equals 20 percent in five years. The largest percentage gains occurred in irrigation and industrial uses, while the thermoelectric category is by far the largest user. Energy-associated, industrial, and agricultural uses accounted for about 91.4 percent of the total water withdrawals in 1975 compared with 92.6 percent for 1980. Barnard and Dent have projected that these uses will increase to as high as 98 percent of the total withdrawals by the year 2020.

Data from the Iowa Department of Water, Air and Waste Management (J. F. Wiegand, personal communication) indicate that the number of water permits granted for public supply, industrial, and irrigation use more than doubled during the period 1965-1980, while the number of irrigation permits alone increased by about 200 percent in the last 20 years (a water permit is required in Iowa whenever water use will exceed 25,000 gallons a day). These data imply that both surfacewater and groundwater use will continue to increase in Iowa. Some periods of anomalous increase or leveling off of water use related to economic factors and conservation can be expected, but overall use will increase. Very large water requirements such as for power plants and some municipalities will continue to be met by direct or indirect (from wells adjacent to streams) surfacewater withdrawals. However, groundwater appears to be preferred over surfacewater if available in adequate quantity and quality without impacting on other users and at comparable overall cost.

This report on the Silurian-Devonian aquifer system is a continuation of a series of investigations to define, describe, and evaluate the major regional aquifers of Iowa and follows the general format of preceding reports in the series: *Mississippian Aquifer of Iowa* (Horick and Steinhilber, 1973) and *Jordan (Cambrian-Ordovician) Aquifer of Iowa* (Horick and Steinhilber, 1978).



(Modified from Horick and Steinhilber, 1978)

Figure 1. BLOCK DIAGRAM OF IOWA'S GROUNDWATER RESERVOIR SHOWING THE STRATIGRAPHIC RELATIONS OF THE SILURIAN-DEVONIAN AQUIFER

PURPOSE AND METHOD

This atlas is intended to aid hydrogeologists, water-system consultants and planners, well drillers, industries, farmers, irrigators, and other interested individuals and organizations in gaining a better understanding of the occurrence, movement, availability, use, and quality of water in the Silurian-Devonian aquifer of Iowa. The data and interpretations presented are summarized under headings of geology (two sheets), hydrology, and chemical quality of the water.

Sheet 1 provides a definition of the aquifer, describes its physical characteristics, including a discussion of karst features, and presents a contour map of the surface of the aquifer and cross sections. Sheet 2, a continuation of the discussion of hydrogeology, details the distribution and thickness of the Devonian and Silurian rocks, as well as overlying and underlying confining beds, and the base of the aquifer. Sheet 3 defines the aquifer's hydrologic characteristics, the potentiometric surface, water levels, a schematic flow system, data on withdrawals, yields, well-development techniques, fracture systems, and a map of known sinkholes. Sheet 4 presents a discussion of water quality in the aquifer, properties and constituents of the water, selected mineral analyses, maps showing concentrations of significant mineral constituents, water temperatures, and an overburden-thickness map outlining areas potentially susceptible to nitrate, bacteria, and other forms of contamination from surface activities.

ACKNOWLEDGEMENTS

The author is grateful to several colleagues on the staff of the Iowa Geological Survey for discussions on various facets of this report, namely Bill J. Bunker, and Brian J. Witzke on the stratigraphic and structural relations of the Devonian and Silurian rocks; M. J. Bounk on joint sets in the Silurian; George R. Hallberg on sinkholes and water quality in northeast Iowa; Peter Kollasch and R. L. Talcott for computer assistance; and Donivan L. Gordon for general supervision of the project. Roger Splinter of the University of Iowa Hygienic Laboratory reviewed the water quality standards. Michael R. Burkhart of the U.S. Geological Survey critically reviewed the report as did Gordon, Hallberg and Bernard Hoyer. Patricia Lohmann produced the graphics, Laurie Comstock typed the manuscript, and Sheila Baker proofread the text. Finally, numerous Iowa well-drilling contractors and engineering consultants provided useful information in the form of well cuttings, data on water levels, and pumping tests.

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GEOLOGY

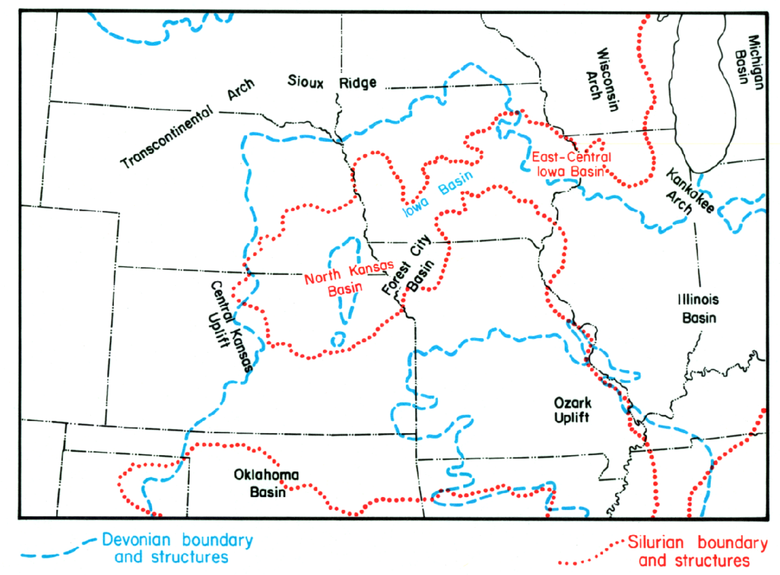


Figure 2. DISTRIBUTION OF THE SILURIAN AND DEVONIAN ROCKS AND STRUCTURAL FEATURES IN THE NORTHERN MIDCONTINENT

The Silurian-Devonian rocks of Iowa are part of an extensive sequence of sedimentary formations covering the upper midwest (figure 3). For the most part these rocks were deposited in shallow epeiric seas that covered the midcontinent. Although the interior of the continent was relatively stable, the seas fluctuated and even withdrew at times. Clastic sediments were washed from the margins of highland areas to mix with the calcareous muds on the sea floors, resulting in varied lithologies. While Silurian deposits apparently covered most of the continental interior, great thicknesses of these and older strata were eroded before the deposition of the Devonian rocks. The greatest thickness of the Silurian rocks were preserved in five large sedimentary basins, the Michigan, Illinois, Oklahoma, North Kansas, and East-Central Iowa basins. The Silurian rocks of Iowa are primarily dolostone, and are more varied in character in the eastern part of the state, i.e., cherty, sandy, and argillaceous in the lower part, and reef-like in the upper part.

The northern midcontinent was exposed as a land area for a long period after the Silurian seas withdrew. No Early Devonian marine rocks appear to have been deposited in Iowa. From Middle Devonian time on however, the seas returned and thick bodies of marine limestone were deposited in the Iowa, Illinois, and Michigan basins. The maximum sediment accumulation in Iowa took place along the axis of the North Kansas and Iowa basins so that the center of the Iowa basin shifted to the central and southwest part of the state. Evaporite-bearing carbonates as well as normal marine fossiliferous limestones dominate the Iowa Middle Devonian. In Late Devonian time the sediments became increasingly clastic when muds derived from the uplifted areas of eastern United States were transported into the midcontinent depositional basins and buried the older structural features. Black carbonaceous shales extend westward from the Appalachian region to Kansas and Texas. However, in Iowa the shales are lighter colored and include carbonate-fixing organisms, so the Lime Creek-Shell Rock sequence contains both shales and limestones, although dark gray, noncalcareous and organic shales occur in the upper Devonian of southeast Iowa. The Saverton-Maple Mill shales, the youngest Devonian clastic rocks, thicken northward from southern Illinois and may have been derived from the north.

Table 2. STRATIGRAPHIC AND HYDROLOGIC RELATIONS OF THE SILURIAN-DEVONIAN AQUIFER

System	Group / Formation	Rock-Stratigraphic Unit	Maximum Thickness (feet)	Physical Description	Hydrologic Unit
MISSISSIPPIAN	NORTH HILL GROUP	Starr s Cave Formation	100	Dolostone	Minor aquifer
		Prospect Hill Formation		Siltstone	
		McCraney Formation		Limestone	
DEVONIAN	YELLOW SPRING GROUP	English River Formation	300	Mostly shale, thin siltstone at top, thin dolostone between Maple Mill and Sheffield in north central Iowa	Confining bed
		Maple Mill Formation			
		Aplington Formation			
		Sheffield Formation			
	LIME CREEK FORMATION	Owen Member	190	Dolostone	Silurian-Devonian aquifer (Western Iowa / Eastern Iowa)
		Cerro Gordo Member		Dolostone and shale	
		Juniper Hill Member		Shale	confining bed (Eastern Iowa)
	SHELL ROCK FORMATION	Nora Member	65	Limestone	
		Rock Grove Member		Limestone	
		Mason City Member		Limestone and dolostone	
	CEDAR VALLEY FORMATION	Coralville Member	500	Limestone	
		Rapid Member		Dolostone and limestone	
		Solon Member		Limestone and dolostone	
	WAPSIPINICON FORMATION	Davenport Member	240	Limestone	
		Spring Grove Member		Dolostone	
		Kenwood Member		Dolostone silty, some shale and sand	local confining bed
		Otis Member		Limestone, lithographic	local confining bed
		Coggon Member		Dolostone	
		Bertram Member		Dolostone and shale	
SILURIAN		Gower Formation	450	Dolostone, chert and limestone	
		Scotch Grove Fm. / La Porte City Fm.			
		Hopkinton Formation / La Porte City Fm.			
		Blanding Formation			
		Tete des Mortes Formation		Dolostone	
		Mosalem Formation		Dolostone, argillaceous	
ORDOVICIAN	MAQUOKETA FORMATION	Neda Member	350	Shale and oolitic ironstone	Confining bed
		Brainard Member		Shale	
		Fort Atkinson Member		Dolostone and shale	Minor aquifer
		Clermont Member		Shale	Confining bed
		Elgin Member		Limestone, some shale	Minor aquifer
	GALENA GROUP	Dubuque Formation	275	Dolostone and limestone, some chert, minor shale in upper and lower parts	Minor aquifer in northeast Iowa. Generally a confining bed.
		Wise Lake Formation			
		Dunleith Formation			
		Decorah Formation			

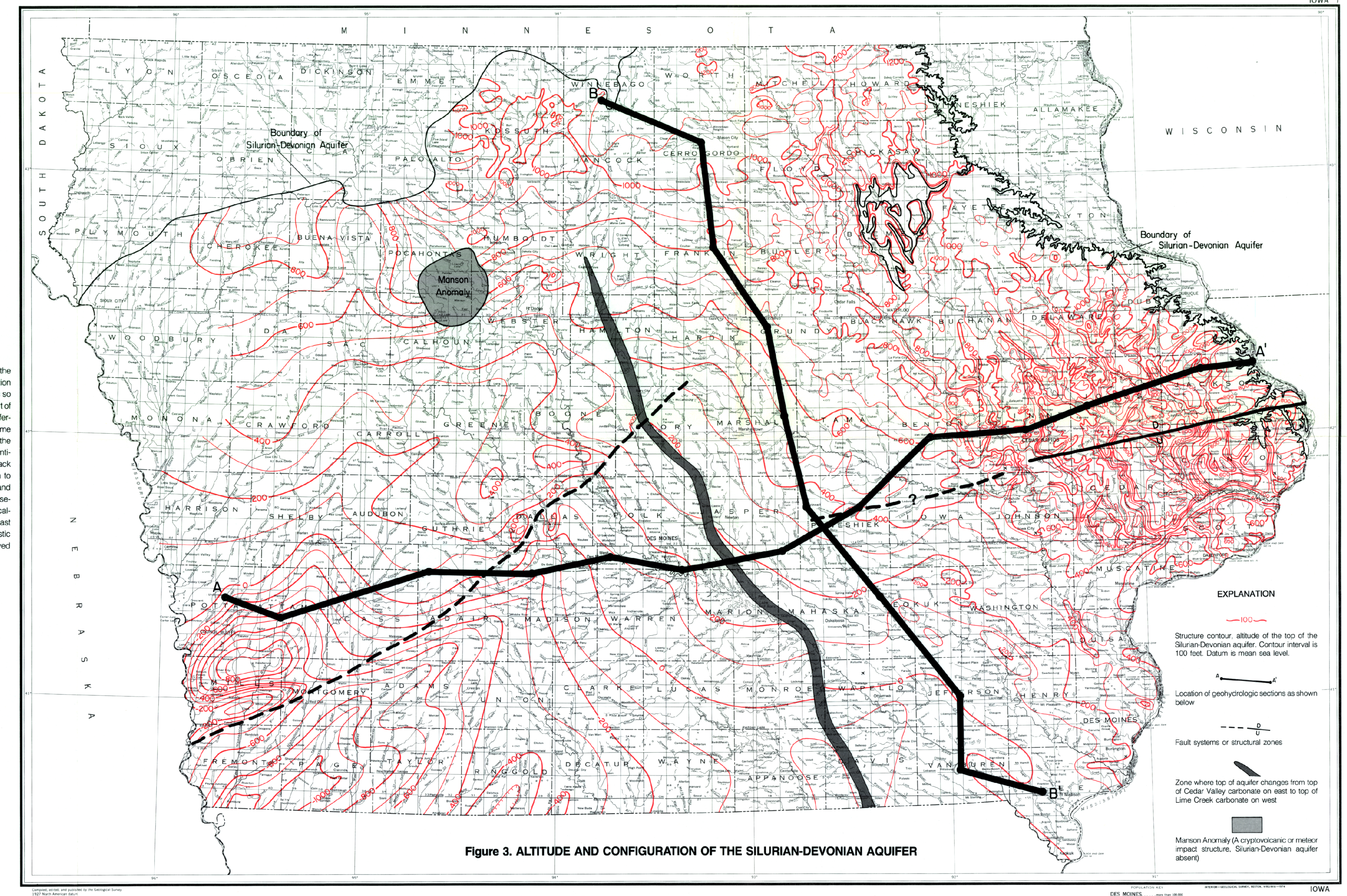
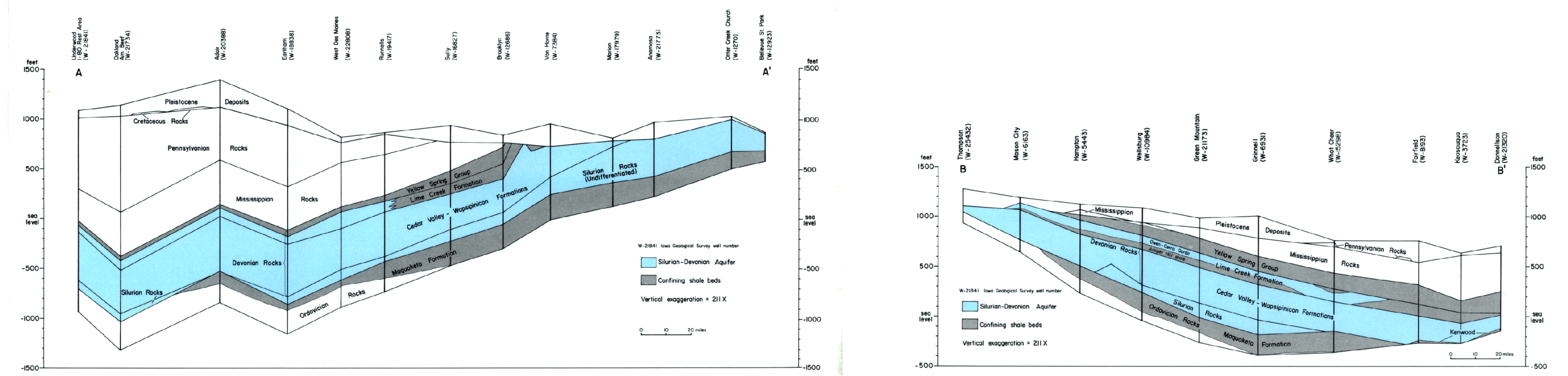


Figure 3. ALTITUDE AND CONFIGURATION OF THE SILURIAN-DEVONIAN AQUIFER



GEOHYDROLOGIC CROSS-SECTIONS

DEFINITION AND PHYSICAL CHARACTERISTICS OF THE AQUIFER

The term Silurian-Devonian aquifer was used informally by Iowa Geological Survey geologists for many years prior to its introduction in the literature by Steinhilber and Horick (1970) and Hansen (1970). Although the several carbonate formations that make up the aquifer are distinct geologic entities, it became common practice to treat them as one hydrologic unit because of their hydraulic connection. Since the Silurian usually was the primary source of water for wells, the term Silurian-Devonian aquifer came into general use.

The Silurian-Devonian aquifer of Iowa consists of the thick succession of carbonate rocks, i.e., limestones and dolostones, of Devonian and Silurian age which lie between overlying Maple Mill-Sheffield-Lime Creek shales (Devonian) and the underlying Maquoketa shale and dolostone or Galena limestone and dolostone (Ordovician). The geologic units comprising the aquifer are (from youngest to oldest in descending order) the Lime Creek, Shell Rock, Cedar Valley, and Wapsipinicon Formations of the Devonian System, and the Gower, Scotch Grove, LaPorte City, Hopkinton, Blanding, Tete des Morts, and Mosalem Formations of the Silurian System (table 2). In Cerro Gordo, Hancock, Franklin, Grundy, and Tama counties where the Juniper Hill Shale in the lower part of the Lime Creek Formation is thick enough to form a confining layer, the Owen and Cerro Gordo members in the upper part of the Lime Creek comprise a separate aquifer of local significance. The lower part of the Wapsipinicon Formation (Kenwood-Bertram sequence) also comprises a confining layer within the Silurian-Devonian aquifer in Linn and Benton counties.

Glacial drift, where its permeability is low and it is thick enough, is the upper confining bed for the Silurian-Devonian aquifer in its outcrop area (i.e., where it is the uppermost rock unit). Where the aquifer underlies other rock units (subcrop area), the Devonian Maple Mill-Sheffield-Lime Creek shales are the principal upper confining beds (figures 3 and 4, sheet 2). Cretaceous sandstones and shales cover the narrow belt of Devonian rocks that extend from beneath the Mississippian rocks in northwestern Iowa (figure 1, sheet 2). The Ordovician Maquoketa Shale is the prinicpal lower confining bed for the aquifer. The Kenwood Shale in the lower part of the Wapsipinicon Formation is an aquiclude in a few southeastern counties. There is no confining layer at the base of the Silurian-Devonian aquifer across much of western, northern, and a small part of southeastern Iowa as shown in figure 6, sheet 2.

The aquifer attains its maximum thickness in the southwest quarter of the state where it is generally 500-600 feet thick, reaching a maximum of 700 feet. Over most of eastern and northern Iowa it averages between 200-400 feet in thickness. However, the thickness of the aquifer in the outcrop area often is less than the average because of surface erosion. The thickness of the aquifer at any particular point can be estimated from the maps in figure 2, sheet 1, and figure 5, sheet 2, which provide the elevation of the top and base of the aquifer, or by adding the values on figures 1 and 2, sheet 2.

The depth to the top of the aquifer ranges from 0-400 feet in the outcrop area, but is usually between 50 and 250 feet. In the subcrop area several hundred feet of drilling may be required before the aquifer is reached.

The Silurian-Devonian aquifer underlies approximately 89 percent of the state and is the uppermost bedrock over about 21 percent. Dense limestones and dolostones, with significant secondary porosity (i.e., fractures, joints, bedding planes, and solution cavities) are the principal rock types. Locally, shales and clays fill large cavities in Silurian carbonates. These materials originated from overlying shale formations and glacial drift.

The primary pathways for water movement in the aquifer are the secondary openings in the rock. A few studies suggest there is a general pattern to the fractures in these rocks, but locally they appear to be quite irregular. The fractures are variable in size, extent, depth, and density. The carbonate formations may also be highly broken in places. Both Silurian and Devonian strata have reef facies that are locally very porous and may contribute some primary porosity. However, the porosity and permeability in these rocks is predominantly secondary and related to fracturing and dolomitization (recrystallization and volume reductions of limestone) that formed pores, small voids (vugs), cavities (fossil molds), and shrinkage cracks and fissures.

Recent studies (Hallberg and Hoyer, 1982) show that the land surface above these rocks in the outcrop area is dotted with sinkholes and other karst features where the drift mantle is absent or thin. Karst development is most advanced in northeastern Iowa in Allamakee, Winneshiek, Howard, Mitchell, Worth, Floyd, Fayette, Clayton, Dubuque, Delaware, Jackson, and Clinton counties. The drift in these counties is generally less than 50 feet thick and commonly less than 25 feet thick. The location of thousands of sinkholes in a part of the Iowa Silurian-Devonian outcrop area is shown on the sinkhole map on sheet 3 (figure 6).

Karst topography forms over soluble rocks such as limestone, dolostone, and gypsum, and is characterized by closed surface depressions, sinkholes, caves and larger caverns, and subterranean drainage. Karst features probably are mechanically induced in areas along the Silurian escarpment in northeastern Iowa where the carbonate rocks overlie the Maquoketa Shale (Prior, 1975, and Hansel, 1976). Enlarged fractures near the margin of the scarp have separated huge blocks of dolostone which have moved down the Maquoketa Shale slope into valleys.

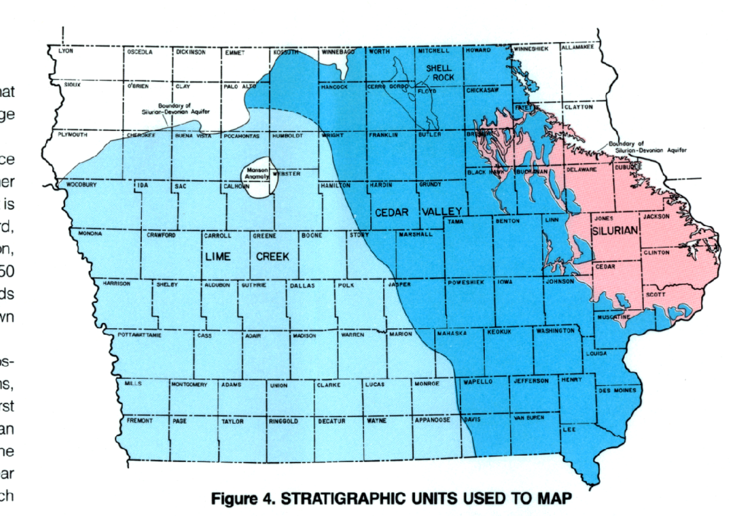


Figure 4. STRATIGRAPHIC UNITS USED TO MAP THE TOP OF THE SILURIAN-DEVONIAN AQUIFER

In drawing the contours on the top of the Silurian-Devonian aquifer (figure 3, above), the author was confronted with the problem of defining the extent of the Juniper Hill Shale aquiclude which is in the lower part of the Lime Creek Formation and extends from Cerro Gordo and Hancock counties in north-central Iowa to Lee and Van Buren counties in the southeastern corner of the state. This unit ranges from 0-150 feet in thickness, but typically is only 50-75 feet in thickness (see figure 4, sheet 2 and hydrologic cross sections A-A' and B-B'). To the west, the Juniper Hill Shale "wedges out" and the Lime Creek Formation is limestone and dolostone and hydraulically connected with the underlying Cedar Valley Formation. For mapping purposes, the top of the aquifer is defined as the top of the Silurian in eastern Iowa, as the top of the Cedar Valley Formation in central Iowa, and as the top of the Lime Creek Formation in western Iowa as shown in figure 4. This results in broken contour lines along the western border of the Juniper Hill Shale where the aquifer surface shifts from the Cedar Valley carbonate to the Lime Creek carbonate (figure 2 and cross section A-A'). The Shell Rock Formation which has a very limited distribution, mostly in eastern Cerro Gordo and western Floyd counties, is used as the top of the aquifer in that area.

SILURIAN-DEVONIAN AQUIFER OF IOWA

by

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Iowa Geological Survey

Published by the
STATE OF IOWA
1984

METRIC CONVERSION TABLE

ft (feet)	X 0.3048	=	m (meters)
mi (mile)	X 1.609	=	km (kilometers)
mi^2 (square mile)	X 2.590	=	km^2 (square kilometers)
acre-feet per day	X 0.504	=	ft^3/sec (cubic feet per second)
gal (gallon)	X 3.785	=	l (liters)
gal/min (gallons per minute)	X 0.06309	=	l/s (liters per second)
(gal/min)/ft (gallons per minute per foot)	X 0.207	=	(l/s)/m (liters per second per meter)
gallons per day per foot	X 0.134	=	(ft^3/ft•d) cubic feet per foot per day
degrees Fahrenheit (° F)	−32 × 0.56	=	degrees Celsius (°C)

GEOLOGY

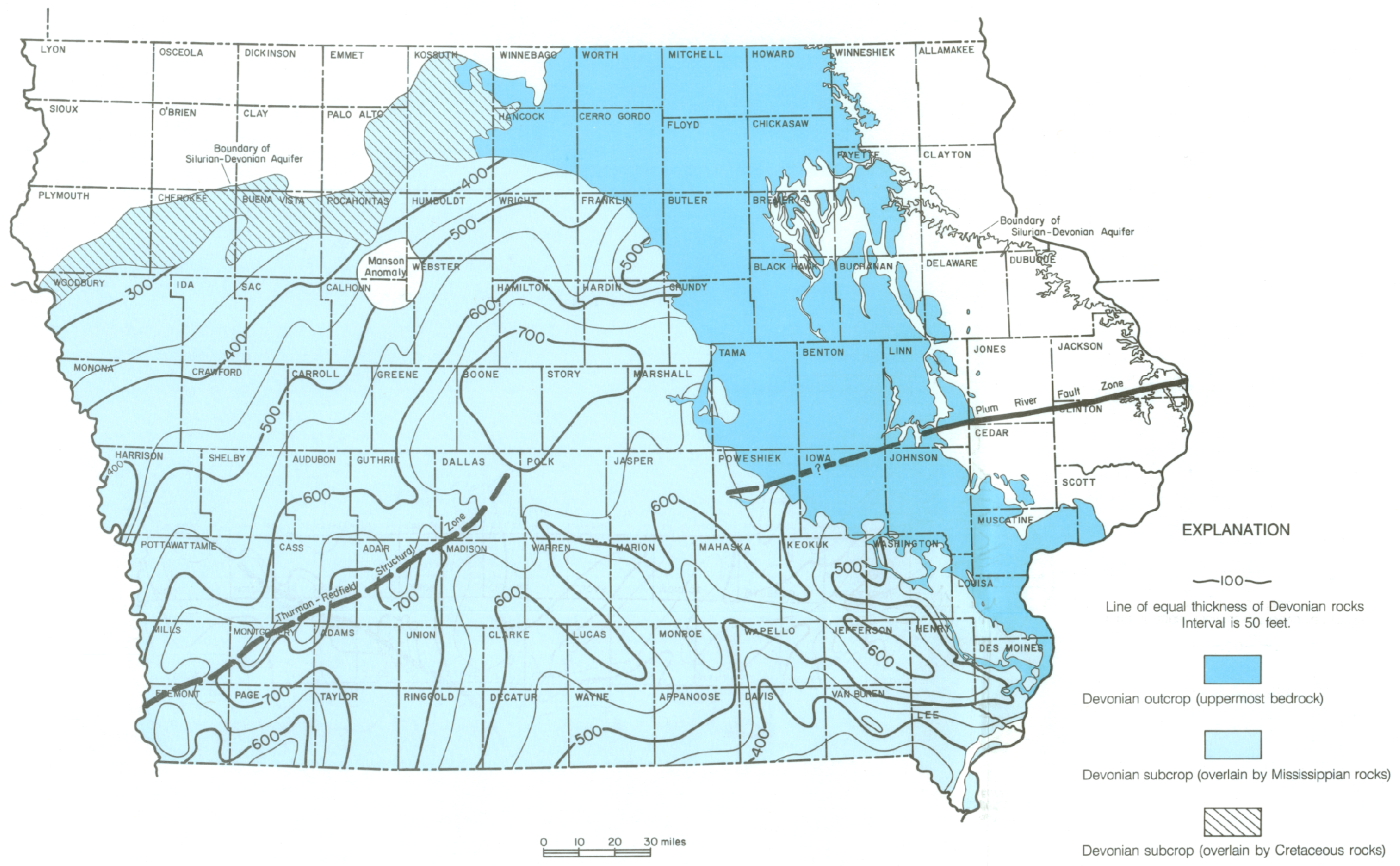

Figure 1. DISTRIBUTION AND THICKNESS OF DEVONIAN ROCKS

Devonian rocks underlie approximately 78 percent of the state, excluding several northwestern and northeastern counties and the Manson Anomaly. They are comprised mainly of shale strata in the upper part with carbonate strata dominant in the lower part. The shale units, the Maple Mill-Sheffield sequence and the Juniper Hill Member of the Lime Creek Formation, are the upper confining beds for the Silurian-Devonian aquifer. The Cedar Valley-Wapsipinicon carbonate sequence is the major water-bearing portion of the Devonian rock sequence. The Kenwood Shale Member in the lower part of the Wapsipinicon Formation is a confining bed locally in southeastern Iowa where the Silurian rocks and Maquoketa Shale are absent. Mississippian-age carbonates overlie the Devonian rocks in the southern, central, and western parts of the state, and Cretaceous shales and sandstones overlie the narrow band of Devonian rocks which extend beyond the Mississippian boundary in northwestern Iowa. Erosional remnants of Pennsylvanian-age shale and sandstone are found resting on Devonian and Silurian rocks in the outcrop area. Devonian rocks rest on Silurian dolostones in east-central, central, and southwestern Iowa, and on the Ordovician Maquoketa Formation where Silurian rocks are not present, except in southeastern Iowa, where the Devonian overlies the Ordovician Galena dolostone.

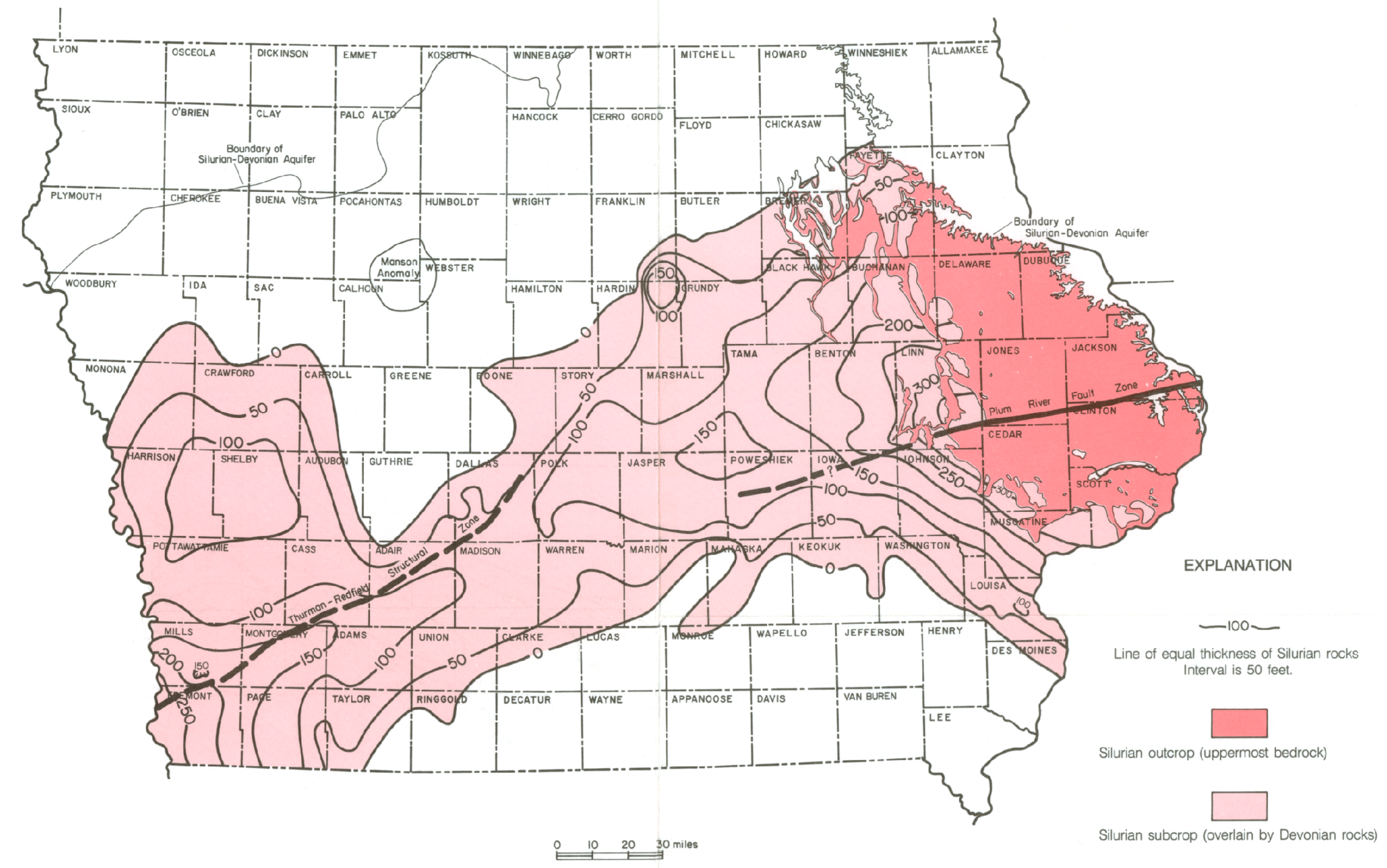

Figure 2. DISTRIBUTION AND THICKNESS OF SILURIAN ROCKS

Silurian rocks underlie approximately 49 percent of the state in a broad, irregular band extending from Clayton and Louisa counties along the Mississippi River to Monona and Fremont counties along the Missouri River. The several formations are practically all dolostone rocks although pockets of shale are found locally. Except in the outcrop area of east-central Iowa, the Silurian rocks are overlain everywhere by Devonian rocks. Scattered Pennsylvanian shale and sandstone outliers overlie Silurian rocks in the outcrop area in eastern Iowa. The Maquoketa Shale underlies the Silurian and comprises a good lower confining layer in the eastern and central parts of the state. In north-central and western Iowa, the Maquoketa Formation consists predominantly of carbonate rocks that are in hydraulic connection with the Silurian-Devonian aquifer.

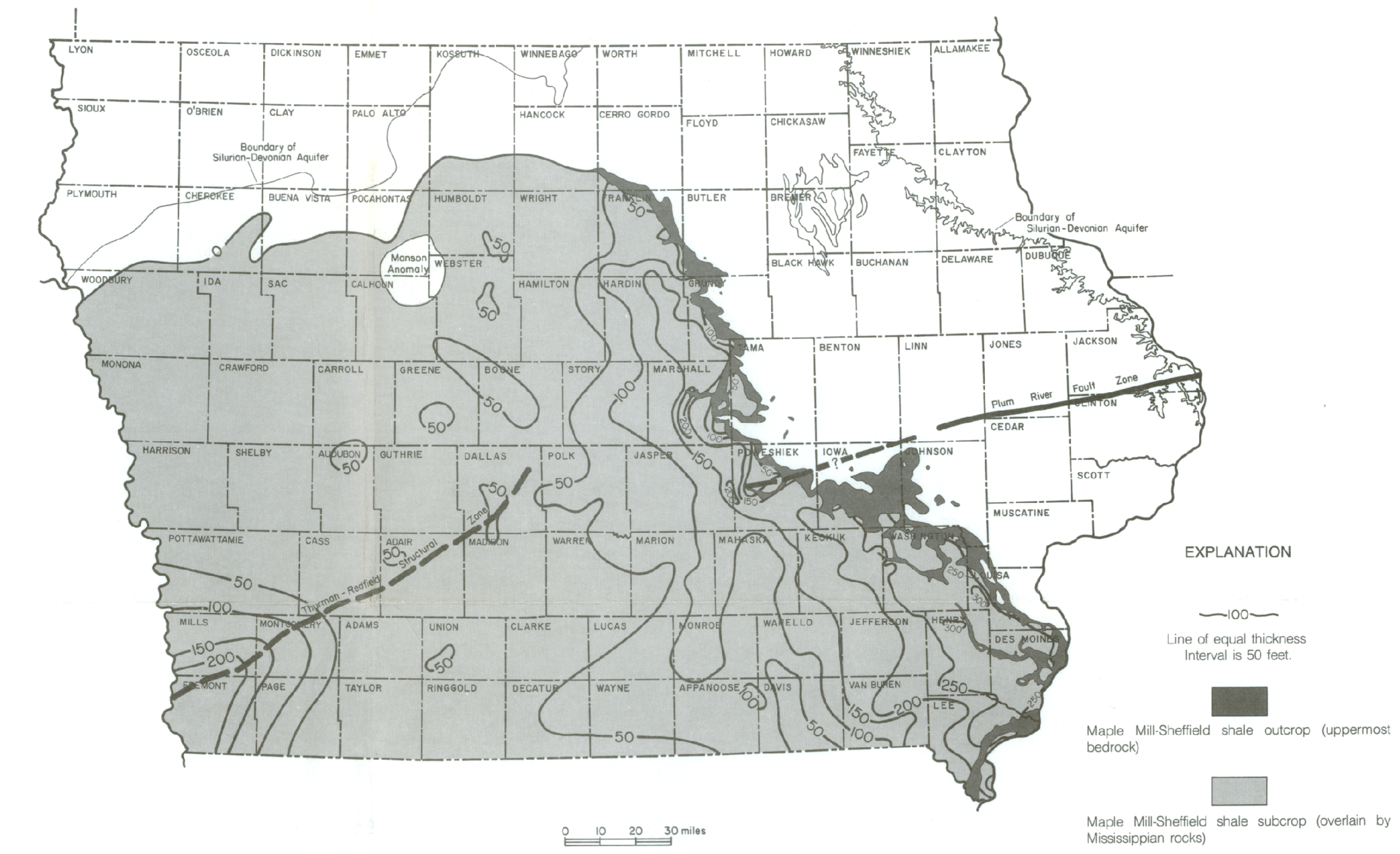

Figure 3. DISTRIBUTION AND THICKNESS OF THE MAPLE MILL-SHEFFIELD SHALE

This map shows the distribution and thickness of the Maple Mill-Sheffield shale aquiclude. It overlies the Lime Creek limestone and shale sequence (Owen, Cerro Gordo, and Juniper Hill Members) in central and southeastern Iowa and Devonian carbonates in western Iowa. The Maple Mill-Sheffield shale, together with the Lime Creek shale, are the upper confining beds for the Silurian-Devonian aquifer. Note that in western Iowa this upper confining bed commonly is less than 50 feet thick and may be only 5-10 feet thick in places. Here the aquifer may be in hydraulic communication with overlying Mississippian rocks.

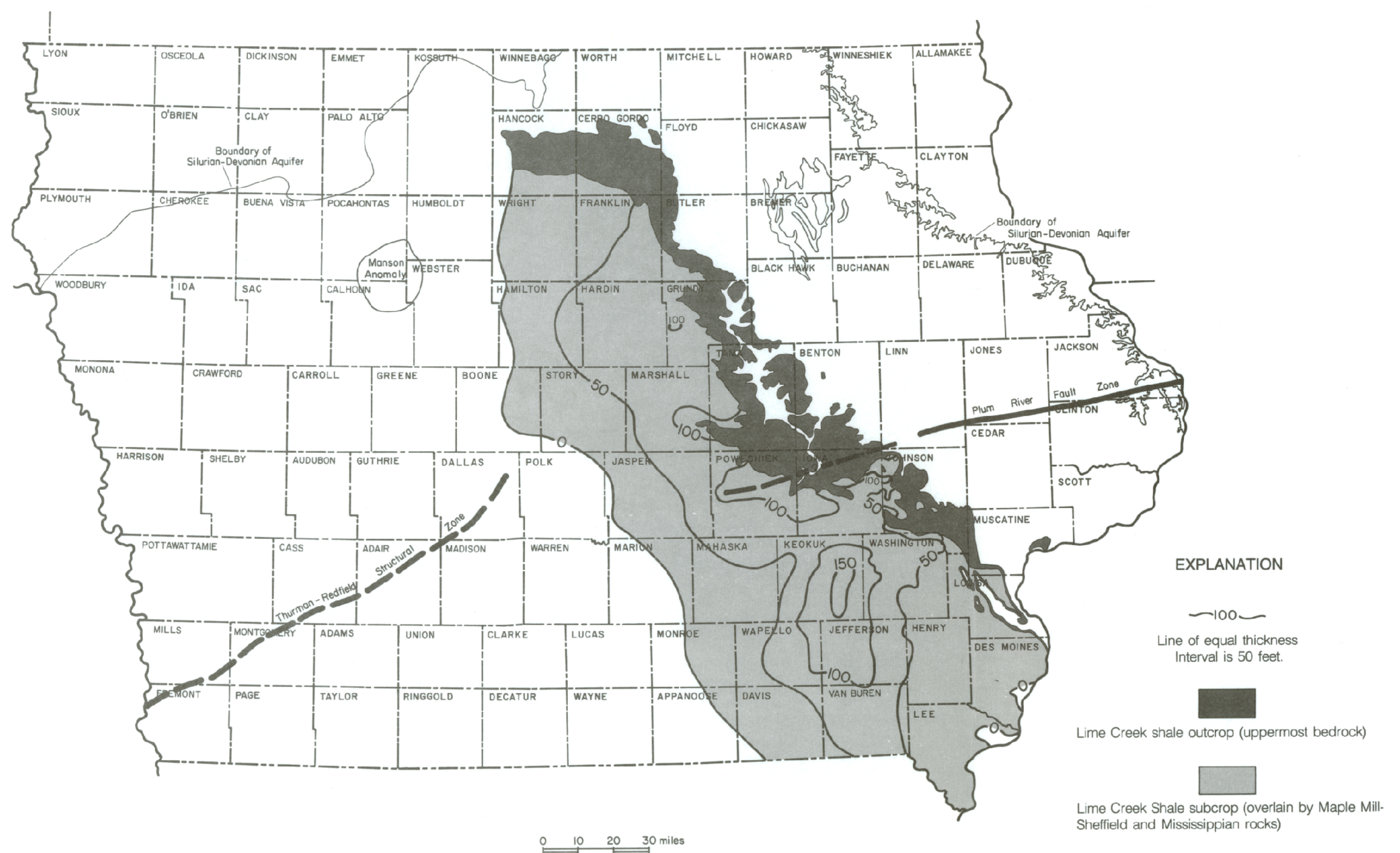

Figure 4. DISTRIBUTION AND THICKNESS OF THE LIME CREEK SHALE

The Lime Creek shale (Juniper Hill Member) is the upper confining bed for the Silurian-Devonian aquifer in a broad belt trending southeast-northwest just west of the outcrop area of the aquifer. In the northern and central part of this region, the Juniper Hill Member is easily identifiable and generally thicker. To the south, the Juniper Hill is less well defined, but sufficiently thick to comprise a confining unit. In the northern portion of the region, chiefly in Cerro Gordo, Hancock, Franklin, and Butler counties, and in Grundy and Tama counties to a lesser extent, the upper members (Owen and Cerro Gordo) of the Lime Creek Formation which are primarily limestone, are locally important as sources of water supply.

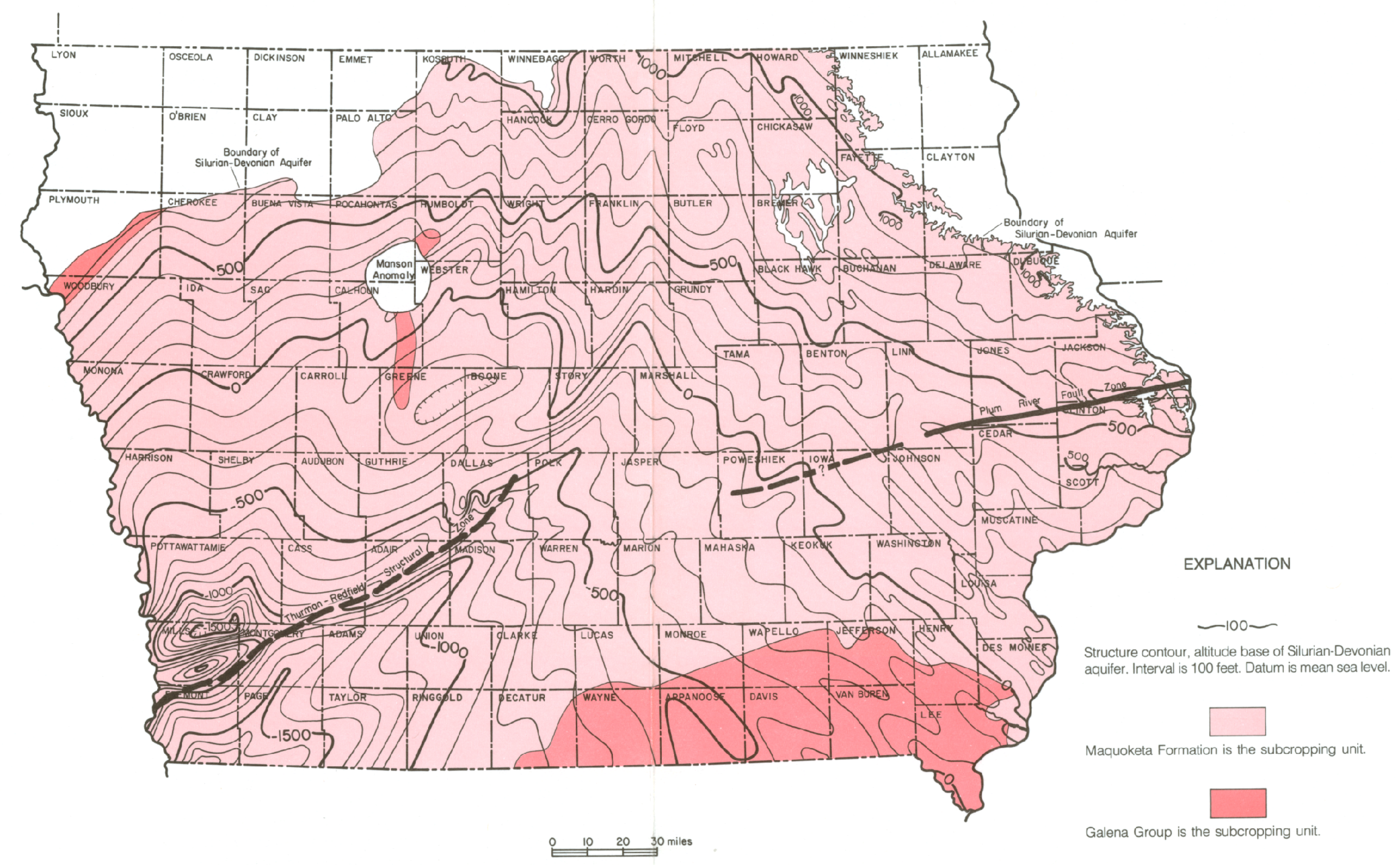

Figure 5. BASE OF THE SILURIAN-DEVONIAN AQUIFER

The base of the Silurian-Devonian aquifer is considered to be the base of the Silurian rocks or base of the Devonian rocks where the Silurian is absent. This map was compiled by contouring the top of the units immediately underlying the Silurian-Devonian aquifer, i.e., the Maquoketa and Galena formations. However, where these formations are mainly carbonates, the Silurian-Devonian aquifer may have no lower confining unit, and probably is hydraulically connected with the Maquoketa and underlying formations. For this reason, the base of the aquifer is poorly defined in northern, western, and southeastern Iowa (see figure 6).

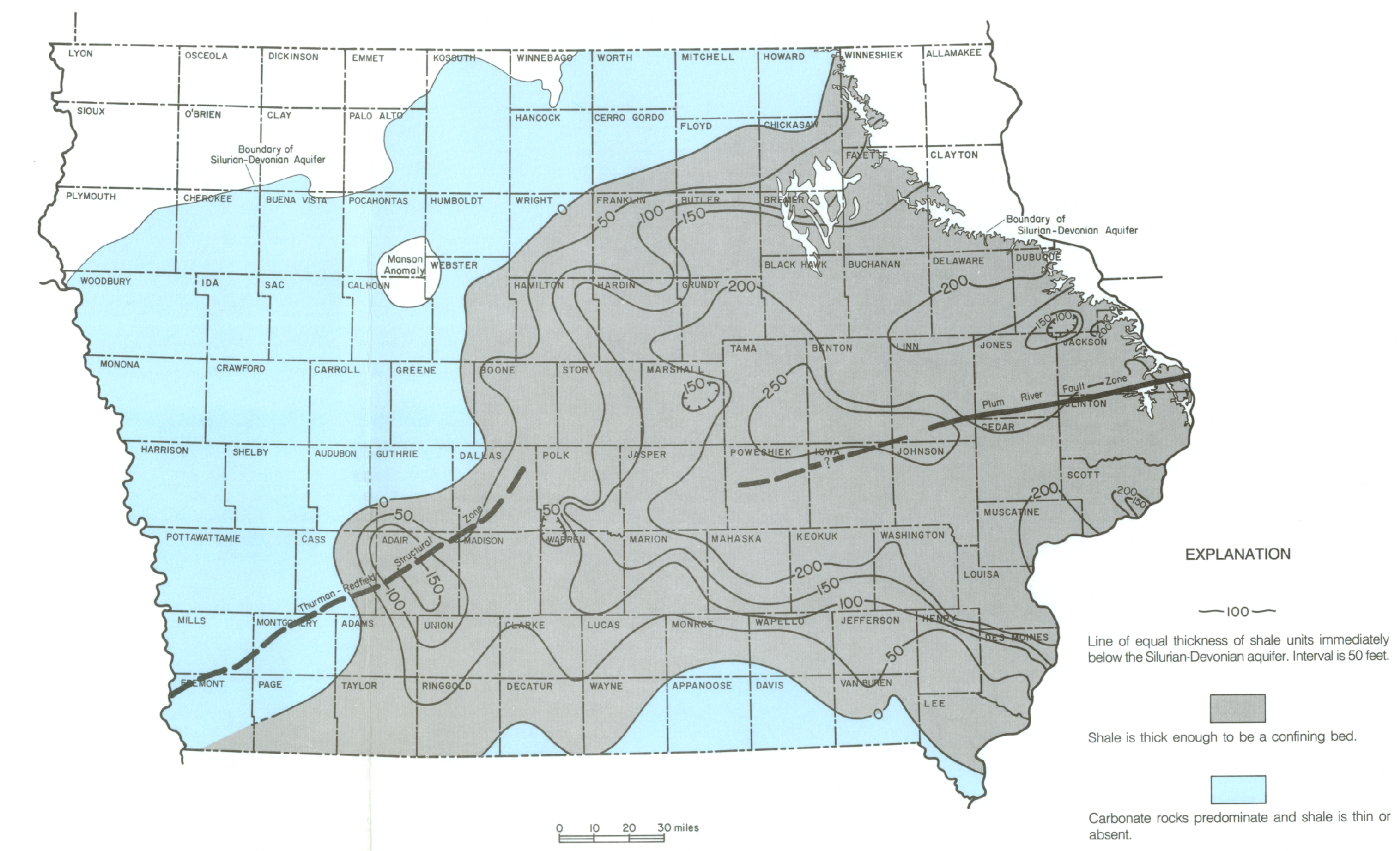

Figure 6. THICKNESS OF CONFINING SHALES BELOW THE BASE OF THE SILURIAN-DEVONIAN AQUIFER

The prinicipal confining beds immediately below the Silurian-Devonian aquifer are the Ordovician Maquoketa shales and the Kenwood shale of the Devonian Wapsipinicon Formation. The Kenwood shale is a prominent confining unit only in southeast Iowa where the Silurian is absent and the Maquoketa Formation is thin or absent. The Maquoketa aquiclude has thin carbonate beds in places. For mapping purposes the Brainard Member is the main shale unit, but the underlying members are included in the total shale thickness where the Fort Atkinson Limestone is thin or absent and the Clermont and Elgin Members contain appreciable shale (see stratigraphic chart, sheet 1). The Kenwood shale is recognized as the lower aquiclude in Des Moines, Henry, Jefferson, Van Buren, and Lee counties. Although the Kenwood Member and overlying Spring Grove and Davenport Members contain considerable evaporite and may be a part of the lower confining units, the evaporite beds are not included in the shale thickness. In a few places the thickness of the Maquoketa and Kenwood shales are combined, for example, as in Keokuk County.

SILURIAN-DEVONIAN AQUIFER OF IOWA

by
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Iowa Geological Survey

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HYDROLOGY

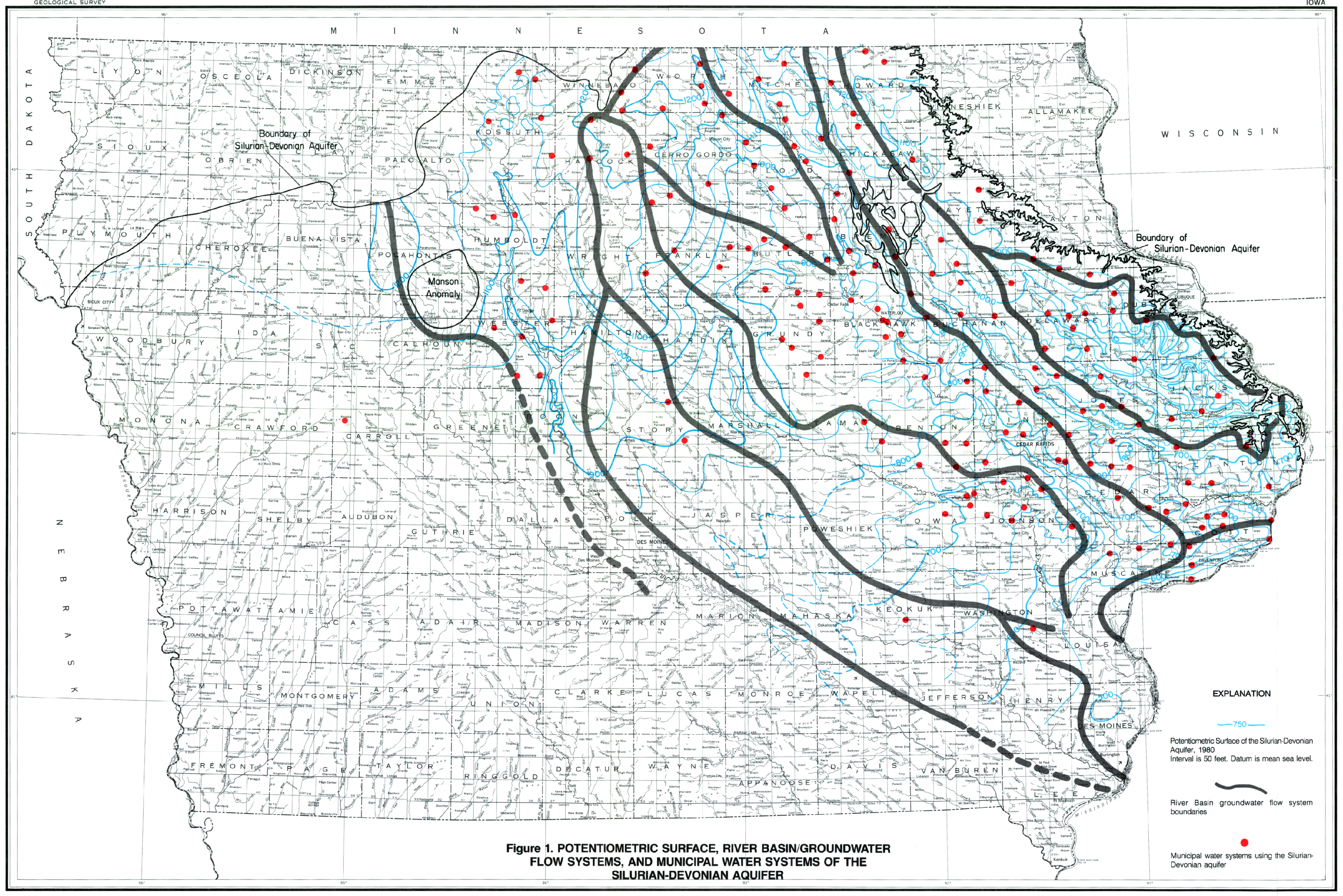

Figure 1. POTENTIOMETRIC SURFACE, RIVER BASIN/GROUNDWATER FLOW SYSTEMS, AND MUNICIPAL WATER SYSTEMS OF THE SILURIAN-DEVONIAN AQUIFER

WITHDRAWALS FROM THE AQUIFER

The quantity of water withdrawn from the Silurian-Devonian aquifer of Iowa is estimated at 27.75 billion gallons a year and categorized as follows:

Use	Quantity (gallons per year)
Municipal	12,250,000,000
Industrial	3,500,000,000
Irrigation	2,000,000,000
Domestic (rural)	10,000,000,000

Data obtained from the Iowa Department of Water, Air and Waste Management and the Iowa Geological Survey indicate 178 municipal systems are supplied totally or in part by Silurian-Devonian wells which serve approximately 310,000 people (see figure 1 and table 1). These systems withdraw about 12.25 billion gallons annually or about 33,550,000 gallons of water a day (gpd), a bit more than 108 gpd per capita. Municipal withdrawals are the most reliable data available because they are based on metered records.

The industrial, irrigation, and domestic withdrawals are estimates based on more limited well data. Commercial, institutional, and recreational wells are included under the industrial heading. There are about 250 wells in this category, and about 185 including at least 15 creameries and dairies for which yield data are available. The average yield from these 185 wells is 195 gpm, but because some may no longer be in use, the average output is conservatively estimated at 150 gpm. At an average pumping period of 8 hours a day, 275 days a year, these wells can reasonably be predicted to withdraw about 13,000,000 gallons a day and about 3.5 billion gallons a year.

Data on irrigation wells pumping from the Silurian-Devonian aquifer were obtained from the Iowa Department of Water, Air and Waste Management. A total of 8000 acres are authorized to be irrigated by 50 wells completed in the Silurian-Devonian aquifer. Assuming that the wells are pumped only 4-5 months during the growing season each year and 8000 acres are irrigated with 8 to 12 inches of water, the total annual withdrawal would range between 1.74 billion and 2.61 billion gallons per year. A conservative withdrawal estimate of 2 billion gallons was assumed for this use.

Total annual withdrawals for domestic wells pumping from the Silurian-Devonian aquifer are estimated to be 10 billion gallons. This is based on 1970 census data which list the rural population of each county and the average number of people per rural household. It is estimated that 60 percent of the rural homes in the outcrop areas of the Silurian and Devonian rocks use this aquifer and that the average withdrawal from each well is 450-500 gpd. This totals approximately 26-28 million gpd and about 9.5-10 billion gallons annually. Only minor domestic withdrawals are expected in the subcrop area. The per capita rural use is about 135 gpd, which includes livestock use. The Silurian-Devonian aquifer supplies water for about 200,000 rural residents.

Approximately 17.5 percent of the municipal and rural population of the state are supplied by wells tapping the Silurian-Devonian aquifer. This does not include industrial and irrigation uses.

Table 1. QUANTITIES OF WATER WITHDRAWN FOR MUNICIPAL USE BY COUNTIES IN MILLIONS OF GALLONS PER YEAR (1980-82 data)

County	Quantity Pumped (M gal/yr)	County	Quantity Pumped (M gal/yr)
Benton	113,880,000	Jackson	9,902,000
Black Hawk	5,361,485,000	Johnson	153,939,000
Bremer	356,056,000	Jones	280,138,000
Buchanan	492,494,000	Keokuk	69,350,000
Butler	351,152,000	Kossuth	100,010,000
Cedar	302,481,000	Linn	424,459,000
Cerro Gordo	97,090,000	Mitchell	216,664,000
Chickasaw	80,629,000	Muscatine	135,050,000
Clay	5,840,000	Scott	384,710,000
Clayton	100,375,000	Story	25,185,000
Clinton	86,870,000	Tama	18,250,000
Delaware	329,595,000	Washington	14,965,000
Dubuque	252,580,000	Winnebago	414,531,000
Fayette	456,615,000	Worth	162,060,000
Floyd	829,645,000	Webster	82,216,000
Franklin	24,638,000		
Grundy	227,359,000		
Hancock	160,965,000		
Howard	62,050,000		
Humboldt	34,310,000		
Iowa	35,680,000		

Total municipal withdrawal
12,250,000,000 gal/yr
÷ 310,000 population =
39,500 + gal/yr/cap =
108.2 + gpd/capita

MAJOR PUMPING CENTERS FOR THE SILURIAN-DEVONIAN AQUIFER IN MILLIONS OF GALLONS PER YEAR (1980)[a]

City	Quantity Pumped (M gal/yr)	City	Quantity Pumped (M gal/yr)
Waterloo-Cedar Falls	5,110,000,000	Lake Mills	165,710,000[b]
Charles City	686,200,000	Monticello	164,250,000
Independence	319,740,000	Osage	152,935,000[b]
Oelwein	243,090,000	Mt. Vernon	136,875,000
Manchester	240,900,000	Evansdale	127,750,000
Forest City	214,985,000	Tipton	125,560,000
Waverly	212,430,000	Wilton	122,275,000
West Union	171,550,000	Dyersville	113,880,000

[a]Some of the municipalities have additional sources of water and the figures shown do not necessarily indicate total water use.

[b]Multiple source — Cedar Valley, Maquoketa, Galena

WELL YIELDS AND AQUIFER CHARACTERISTICS

The yield of a well is the quantity of water it will produce when pumped. It is usually expressed in gallons per minute (gpm). Gordon and others (1978) constructed a generalized potential-yield map for the Silurian-Devonian aquifer. However, this map has limited value because the aquifer has such great variation in yield capability in short distances both laterally and with depth.

In carbonate aquifer systems, well yields are related to whether the wells are situated on or near fracture traces, or intersect large solution openings or caverns or zones of broken rock. The location of a well in the flow system also has an important bearing on the yield. Fracture traces are natural linear features or zones of fracture concentration in consolidated rock formations. They may be 5 to 50 feet wide and several thousand feet to more than a mile in length (Office of Water Research and Technology, 1978). Wells that encounter dense carbonate rock with few openings usually yield only small quantities of water.

Because of the higher density of fractures and solution cavities nearer the surface and consequently the greater hydraulic conductivity, the highest yields from the Silurian-Devonian aquifer are obtained from wells in the outcrop area in the northeast part of the state. Recharge is rapid in this area because the mantle of soil and glacial debris is less than 25-50 feet thick in many places and highly porous. The pollution-hazard map on sheet 4, figure 2, indicates where the surficial materials are less than 50 feet thick in northeast Iowa. The highest-capacity wells usually are found in or near river valleys because dissolution of the limestone and dolostone has progressed farther there than in upland areas, i.e., the transmissivity and storativity of the bedrock are higher in the valleys. The valleys are also discharge zones for the flow systems in these rocks. In some places the valleys appear to be fracture-controlled and are underlain by creviced and broken rocks that have a very high transmissivity. In contrast, the transmissivity and storativity of the bedrock beneath the uplands usually is low, and the water is moving away from these areas toward the nearest controlling stream of the system.

Yields of 100-500 gpm are possible from wells penetrating 100-300 feet of Silurian-Devonian rocks. However, near boundaries where the aquifer is truncated or where it may be discharging to numerous seeps and springs yields may be less. Very large yields have been achieved in wells located in the Cedar River valley at Waterloo-Cedar Falls and farther upstream. The Cedar River and several other northeast Iowa streams appear to run in parallel structurally-controlled valleys. The upper part of the Cedar Valley Limestone commonly is found to be severely broken. Some of the Waterloo city wells and a few irrigation wells between Cedar Falls and Janesville and near St. Ansgar and Orchard have tested as high as 2000-4000 gpm with only a few feet of drawdown. Specific capacities of these wells range from a few hundred to 1000 gpm/ft. of drawdown. (Specific capacity is defined as the ratio of the pumping rate and the drawdown of a production well in gallons per minute per foot of lowering of the water level). The average specific capacity for Silurian-Devonian wells in the upland areas is only 1.0-2.0 gpm/ft. of drawdown.

Controlled pumping tests on wells provide basic information on local aquifer performance. Aquifer performance can be measured by two hydraulic parameters — transmissivity (T) and storativity (S). Transmissivity indicates the rate at which water will move through the formation. It is the flow through a vertical strip of the aquifer one foot wide under a unit hydraulic gradient. The rate of flow is expressed in gallons per day per foot (gpd/ft) or square feet per day (ft^2/day). Storativity expresses the storage capacity of an aquifer. It indicates how much water can be removed from storage in the aquifer for each foot of head loss. This is also called specific yield, especially in unconfined aquifers. It is expressed as the ratio of the volume of water released and the volume of the saturated rock. Most unconfined aquifers have a storativity of 0.01 to 0.3, while in most confined aquifers the storativity ranges from 0.0005 to 0.003. Values for transmissivity and storativity for the Silurian-Devonian aquifer obtained from numerous aquifer tests have ranged up to $T = 2{,}700{,}000$ gpd/ft and $S = 0.03$ where wells are located in zones of fractured or broken rock with high rates of recharge. Examples of wells in this range are the George Hormel & Co well in the NW 1/4 sec. 21, T92N, R14W, Bremer County and the Five-S Farms well in the NW 1/4 sec. 19, T90N, R13W, Blackhawk County.

Although fracture traces are widespread and may follow systematic patterns, they are difficult to locate because of the mantle of glacial till. Studies by M. J. Bounk (personal communication) of the Silurian rocks of eastern Iowa indicate no one joint trend is prominent throughout the area, although there seem to be significant trends over smaller areas. The major trends recognized are: 1) N80-90°E and N80-90°W present over much of the area, 2) N30-40°E varying to N20-30°E in Jones and parts of Dubuque, Jackson, and Delaware counties, and 3) N20-30°W in parts of Linn, Jones, and Jackson counties. Where fracture trace-mapping methods have been adopted with a degree of success in some other states, consistently higher yields have been obtained from carbonate aquifers (Lattman and Parizek, 1964; Office of Water Research and Technology, 1978). However, there may be some limitations to the fracture-trace method of developing wells because of troublesome drilling cave-ins, excess mud, and flowing sand and gravel that occupy the fissures. Such conditions will reduce the local transmissivity and storativity of the aquifer.

Values for T and S as low as $T = 1500$ gpd/ft. and $S = 0.0001$ have been observed where rock openings are minimal or where thick shales overlie the aquifer limiting recharge. These shales and deposits of the minerals calcite and dolomite may have partly filled the secondary openings in the Silurian-Devonian rocks and lowered the aquifer permeability. In the subcrop area of the Silurian-Devonian rocks where younger formations overlie the aquifer, the Lime Creek (Juniper Hill) shale, Maple Mill-Sheffield shale, and thick Pennsylvanian-age shales, recharge occurs at a much slower rate than in eastern Iowa. Recharge in the subcrop area probably is mostly by deep percolation (underflow) from the northwestern part of the state. The average values for transmissivity and storativity for the aquifer are approximately $T = 5000$-15000 gpd/ft. and $S = 0.0003$. However, these numbers have limited regional applicability and there will be a great range of T and S values for the aquifer depending on local hydrology.

WELL DEVELOPMENT

Well development is a technique of improving well efficiency. It is essential to proper completion of a water well, whether it is a newly constructed well or an old well in need of rehabilitation. The purposes for developing a well are to break down the drilling muds and rock cuttings which have coated the surface of the bore hole or that have migrated into adjacent rock openings. Other purposes are to dissolve calcium-carbonate precipitants that have deposited in the well bore and in the formation openings caused by the reduction of pressure during pumping and the consequent release of carbon dioxide. The removal of these clogging materials increases the permeability of the formation in the vicinity of the well. Interviews with Iowa water-well drilling contractors indicate that several mechanical methods and chemical treatments are used in developing wells in carbonate aquifers. The principal methods are pumping, surging, bailing, overpumping, shooting, acidizing, shock chlorinating, and treatment with polyphosphate.

The techniques and chemicals used in development work vary depending on the training and experience of the drillers, the type of well being constructed or rehabilitated, the local geology, and the availability of equipment and chemicals. Pumping, surging, and acid treatment probably are the three most frequently used methods for developing Silurian-Devonian wells in Iowa.

Surging the water in the well and surrounding formation is accomplished by turning the pump on and off, using compressed air, or a surge block. The surging action helps to free any fine material in the voids in the rock in the well bore so it can be drawn into the well. On completion the well is cleaned by bailing to the bottom.

Muriatic (hydrochloric acid) is the most frequently used acidizing agent. Some drillers use 15% inhibited muriatic treating acid, while others use 18° or 20° Baume (27.92 and 31.45 percent) hydrochloric acid. A predetermined quantity of acid generally is pumped through a conductor pipe to the bottom of the well to displace the water in the hole below the casing or opposite the production zone. The acid usually has an inhibitor (an additive to slow the corrosive action of the acid) in it when purchased, but some drillers mix an inhibitor such as diethylthiourea or Knox gelatin in the acid tanker before pumping the acid down the hole. Pressure acidizing is a method of forcing the acid down the well and into the formation. It usually is accomplished either by pouring a large volume of water on top of the acid or by forcing the acid down with compressed air. For pressure acidizing to be successful, the formation to be treated must be sealed-off from overlying formations. The well must also be sealed, usually by cementing the annular space between the casing and hole. The well is then capped to allow gas pressure to build up and further push the acid out into crevices. A pressure gauge is used to monitor pressure and a relief valve is used to help control the amount of pressure. The acid may be left in a well for as long as 24 hours before being pumped out. After the initial chemical reaction has slowed, the well may be surged several times to agitate and dissolve broken rock in the bottom of the hole. Sometimes improved results occur if a well is acidized in two stages. The acid should be pumped out before it is completely spent to prevent clogging by iron precipitating from the acid-water solution. The improvement of the well yield or specific capacity can vary considerably and may range as high as 300 percent or more. Acid development is complex and is generally a major operation that can be both costly and dangerous. It should be performed by professionals experienced in this work.

Polyphosphate treatment accompanied by surging is used by some drillers if the formation crevices are filled with clay. The polyphosphate breaks down the clay so that it can be pumped out.

Shooting or blasting a well with a string of high explosives such as primacord is a technique used to stimulate new wells or clean older wells that have become plugged with fine materials or precipitates. Blasting or dynamiting apparently is not used extensively to develop new limestone wells in Iowa, although shooting lighter primacord shots in older wells that have experienced a loss of capacity is fairly common. The explosion shakes loose the scale and corrosion from the walls of the well and casing, and from openings in the producing formation.

Overpumping is a practice of pumping a well at a higher rate than the designed capacity. This type of development is generally used on larger capacity wells.

Some drillers use shock chlorination to clean wells that have become contaminated and plugged by the growth of iron bacteria.

In summary, a combination of mechanical and chemical treatment may be necessary to obtain the best yield results in wells completed in the Silurian-Devonian aquifer. The work generally is worth the additional cost and is commonly written into well-drilling contracts.

WATER LEVELS

Groundwater levels in the Silurian-Devonian aquifer are related to the availability and rate of recharge, the permeability of the aquifer, the quantity of withdrawals, and whether the aquifer is confined or unconfined. Thus the potentiometric (water pressure) surface of the Silurian-Devonian aquifer (figure 1 above) fluctuates by locality and with time. Large variations are most noticeable in areas of large pumpage where the permeability of the aquifer is low. For example, the deep well at Dayton (Webster County) withdraws only about 75,000 gallons a day from Devonian rocks but has experienced a long-term drop in static water level of 61 feet (figure 2). In this area the permeability of the aquifer is low. Little or no recharge is received from local precipitation because of the deep burial of the aquifer and thick, overlying confining beds. In contrast, the Charles City municipal wells pumping about 1,880,000 gallons a day have not created a significant drawdown cone because the permeability of the Devonian rocks is very high and the aquifer is rapidly recharged from the water table and by underflow. Similarly, at Cedar Rapids, several industrial wells pumping large quantities of water from the Silurian-Devonian source have lowered the potentiometric surface only 27-30 feet since 1940 (figure 3). Although the Silurian-Devonian aquifer is treated as one hydrologic unit in this report, there are head differences between the upper and lower parts of the system in some localities, as shown by studies in Linn, Johnson, and Benton counties (Wahl and Bunker, 1982).

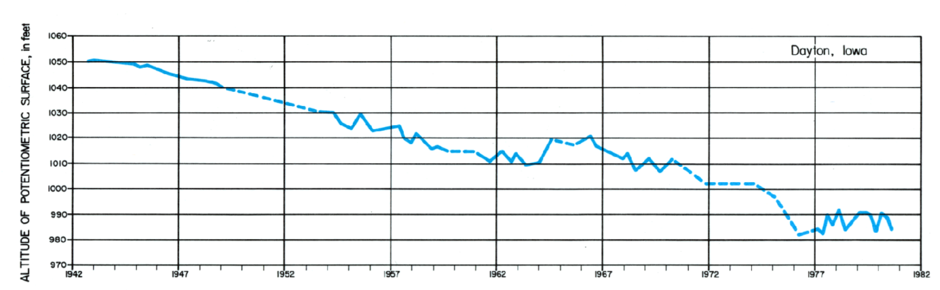

Figure 2. HYDROGRAPH OF DEVONIAN WELL AT DAYTON

This graph shows water-level fluctuations in the Dayton city well (1931, NW NE SE NE 14-86N-28W), 1240 feet deep and completed in the Devonian rocks. For the period shown, the total head loss is about 65 feet. Because the aquifer is confined there is little correlation between precipitation and the well hydrograph.

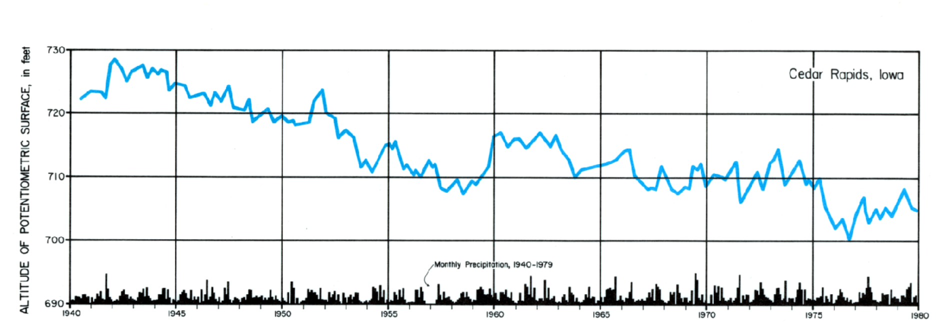

Figure 3. HYDROGRAPH OF SILURIAN WELL AT CEDAR RAPIDS

This graph shows water-level fluctuations in a Silurian well (Floyd Felter, SW SE SW NE 32-83N-7W) 282 feet deep at Cedar Rapids. The consistent decline in the water level is caused by industrial pumping at Cedar Rapids. The sharp fluctuations are the result of seasonal pumpage, mostly for air-conditioning use. There is some correlation between the water level and precipitation, indicating the aquifer receives local recharge.

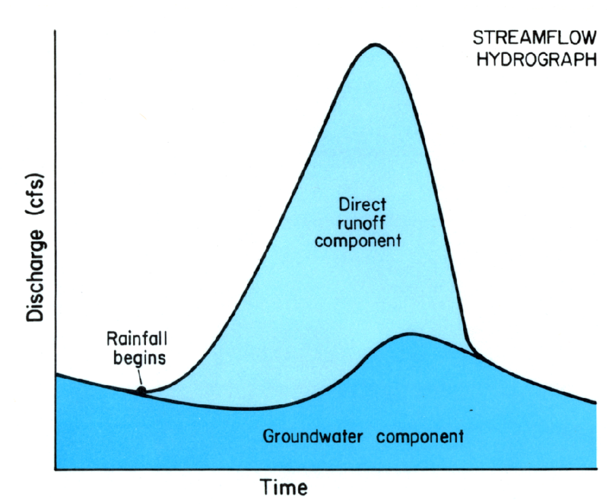

Figure 4. SIMPLIFIED STREAM-DISCHARGE HYDROGRAPH

This illustration shows stream-discharge conditions as influenced by one rainfall event. The flow is separated into two components — direct runoff added to the stream rapidly and groundwater (base flow) added more slowly over a longer period (modified from Sanders, 1980).

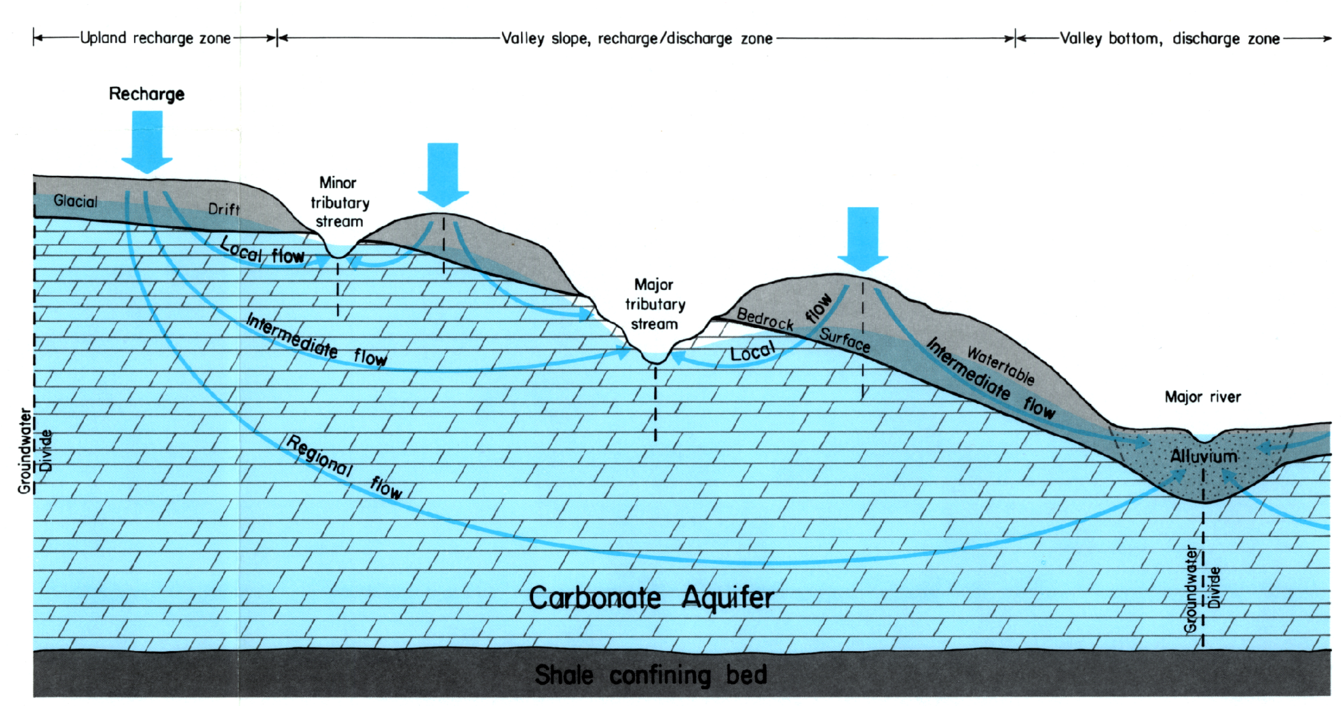

Figure 5. SCHEMATIC TWO-DIMENSIONAL DIAGRAM OF HYPOTHETICAL GROUNDWATER FLOW SYSTEM IN THE SILURIAN-DEVONIAN AQUIFER AND GLACIAL-DRIFT OVERBURDEN IN EASTERN IOWA

GROUNDWATER FLOW SYSTEMS, BASE FLOW, AND AQUIFER STORAGE

Groundwater flow in the Silurian-Devonian aquifer of eastern Iowa is controlled by variations in water levels which correspond with the drainage pattern of major streams — the principal natural discharge areas for the aquifer. At least seven rivers, the Des Moines, Skunk, Iowa, Shell Rock-Winnebago, Cedar, Wapsipinicon, and Maquoketa provide a dominant influence. These "river-basin/groundwater-flow systems" do not correspond exactly to each stream basin, but their boundaries are close enough to match groundwater flow systems and controlling streams. An unnamed flow network occurs along the eastern border of the Silurian-Devonian aquifer where many small streams drain to the Mississippi River. The flow systems in this unnamed network are a function of local topography, drainage, the thickness and composition of the overburden, the elevation and character of the bedrock, and karst features.

The boundaries of the principal river-basin/groundwater-flow systems are shown in figure 1 above. The systems are recharged by precipitation and from the water table. Most of the precipitation runs off directly to streams or is taken up by plants. A smaller percentage infiltrates and takes a more circuitous route through the unconsolidated deposits and bedrock before discharging to river valleys. The water moves by gravity and pressure from areas of recharge to points of discharge into rivers, springs, deeper aquifers, and wells (Freeze and Cherry, 1979). Movement of groundwater in carbonate formations occurs through vertical joints, fractures, and solution cavities, and cracks formed along natural bedding planes. Careful scrutiny of the potentiometric map shows that the Silurian-Devonian aquifer discharges to the major rivers along diagonal flow paths. Locally near some rivers, groundwater flow is practically at right angles to streamflow. Munter (1980) discusses the flow system of the Cedar River basin in the Charles City area in detail. He shows that the river is the discharge point of the flow system, i.e., the uplands are the recharge areas and the lowlands the discharge areas. The overall groundwater movement in the Silurian-Devonian aquifer generally follows the direction of surface flow of the major streams southeasterly across Iowa with discharge to the Mississippi River.

Three of the Silurian-Devonian river-basin/groundwater-flow systems are recharged entirely within the state. These are the Skunk, Iowa, and Maquoketa flow systems. Small amounts of recharge are received by the Shell Rock-Winnebago, Cedar, Wapsipinicon, and unnamed flow systems from southern Minnesota. Here, most groundwater recharge probably discharges to the rivers before reaching Iowa. Minor quantities of water may enter the Devonian rocks in the upper Des Moines River flow system from the overlying Dakota aquifer in Palo Alto and Emmet counties, and perhaps from lateral inflow from Martin and Jackson counties, Minnesota, north of the study area in Iowa.

In addition to the evidence of the potentiometric map, the idea of river-basin/groundwater-flow systems is supported by stream base-flow data collected by the U.S. Geological Survey. A careful observer will note that the streams of northeast Iowa keep flowing even during prolonged dry periods. The explanation is that groundwater flow contributes significantly to the total discharge. Base flow may be synonymous to low flow of the stream in some places. In other places, especially in carbonate rock terrains where the overburden is thin, base flow may comprise more than two-thirds of the stream flow. Numerous continuous-record gaging stations around the state have supplied a large amount of stream-flow data dating back half a century and more. From these records surface-runoff hydrographs have been constructed. The hydrographs reflect two types of contribution from the river-basin flow systems — direct runoff (overland flow) delivered to the stream rapidly, and base flow (groundwater flow) delivered to the stream more slowly in response to long-term discharges to the system (figure 4). Various methods for separating the two components have been developed, all of which are relatively arbitrary. A base-flow index map of Iowa, compiled by Oscar G. Lara of the U.S. Geological Survey, indicates that the groundwater component of the streams of the Silurian-Devonian outcrop area has a range of about 40-75 percent. Although these figures may seem rather high, it is significant that a very large percentage of total stream discharge is from groundwater discharge.

The water in the aquifer is generally artesian (confined), but locally, where the drift mantle is thin and/or permeable, the aquifer may be unconfined and under water-table conditions. A schematic representation of groundwater flow in Silurian-Devonian carbonate rocks is shown in figure 5 above. In the diagram the geology has been simplified to more clearly portray the patterns of flow in the aquifer. The system is shown with a confining unit at the base. This corresponds to the Maquoketa shale in eastern Iowa. The uplands are shown as recharge areas and the adjacent lowlands as areas of discharge. Water is shown moving downward in recharge areas and then laterally and upward in areas of discharge, i.e., in the stream valleys. The symmetry of the system is such that vertical groundwater divides form along upland ridges and in valley troughs where no cross-flow occurs. Local and intermediate flow systems are shown super-imposed on the regional flow system.

In western, southwestern, and south-central Iowa, data are not available to make a reliable head map of the Silurian-Devonian aquifer. Additionally, the aquifer is relatively unconfined between the overlying Mississippian carbonates and underlying Ordovician carbonates. In this region thick Pennsylvanian shales which overlie the Mississippian rocks form the upper confining unit for the entire sequence. By inference from the deeper-lying Jordan aquifer, groundwater flow in the Silurian-Devonian aquifer and other rocks that are in hydraulic communication with it in western and southern Iowa, probably is toward the south and southeast. It possibly divides in northern Missouri with components flowing to the Forest City basin and the Mississippi River or Illinois basin.

Travel distances and times for groundwater in local and intermediate flow systems are relatively short as water moves from the upland recharge areas to the nearest receiving streams, usually no more than a few miles away. Furthermore, groundwater generally moves fairly rapidly through creviced and cavernous limestones and dolostones.

The quantity of water stored in the Silurian-Devonian rocks in Iowa is difficult to predict accurately because of the variable size of the openings in the carbonate strata. The total storage is estimated to be at least 30 million acre feet and may be as much as 60 milliion acre feet. Of this sum, about one-third or 20 million acre feet is developable as good-quality water under present standards. Practically all of the good-quality water is in the outcrop area in the northeast part of the state.

SINKHOLES IN NORTHEASTERN IOWA

One cannot discuss carbonate hydrology without consideration of the effects of karst terrains and sinkholes on the aquifer and on well yields and water quality. This subject was briefly mentioned on sheet 1. The areas of major sinkhole concentration in northeast Iowa are shown in figure 6. The map in figure 6 was compiled from aerial photos, soil and topographic maps, and by field work as part of an on-going Iowa Geological Survey study of the karst region and water-quality problems.

Sinkholes are funnel-shaped, closed depressions that dot the land surface in northeast Iowa. They formed by groundwater solution of near-surface limestone and dolostone formations along joints and fractures, cavern development in the rock, and subsequent collapse of cavern roofs. Hallberg and Hoyer, 1982, indicated the sinkholes of northeast Iowa vary in size, shape, and depth from shallow depressions a few feet in diameter to a few hundred feet long and several tens of feet deep. Generally, they are slightly elongate. The mean diameter of sinkholes in the Silurian karst area is about 69 feet (21 meters) and the mean depth 12 feet (3.7 meters). In the Devonian karst area of Floyd County, sinkholes show a mean diameter of 59 feet (18 meters) and a mean depth of 8 feet (2.4 meters). Sinkholes are most abundant where the soil and glacial drift over carbonate formations are less than 25 feet thick. Most sinks and caves are believed to have developed at the top of the zone of saturation, i.e., at the water table, along joints and fractures down-gradient from upland recharge areas. Sink and cave formation may be unrelated to bedding planes, however.

Groundwater recharge and discharge in the karst area is of two main types: 1) by slow infiltration through porous rock and base-flow seepage to streams, and 2) by surfacewater entry through depressions and sinkholes and rapid open-channel flow through caverns and tunnels to springs or other discharge points in valleys. As might be expected, the surfacewater component greatly increases the sediment, bacteria, and potentially the agriculture chemical content of the water in the aquifers. Investigations in Clayton County indicate that sinkholes may tap extensive networks of underground caves and tunnels. Groundwater may flow in these open channels for long distances without natural filtration which normally exerts a pronounced cleansing effect on the water.

A zone of high porosity and permeability about 50-75 feet above the base of the Hopkinton Formation called the Cyclocrinites Beds by Johnson (1975) and Witzke (1978) appears to be conducive to cave development. This zone may be a major water-yielding interval in some places, notably in Linn County, and in Benton, Delaware, Dubuque, Jackson, Jones, and probably Johnson counties (Wahl and Bunker, 1982).

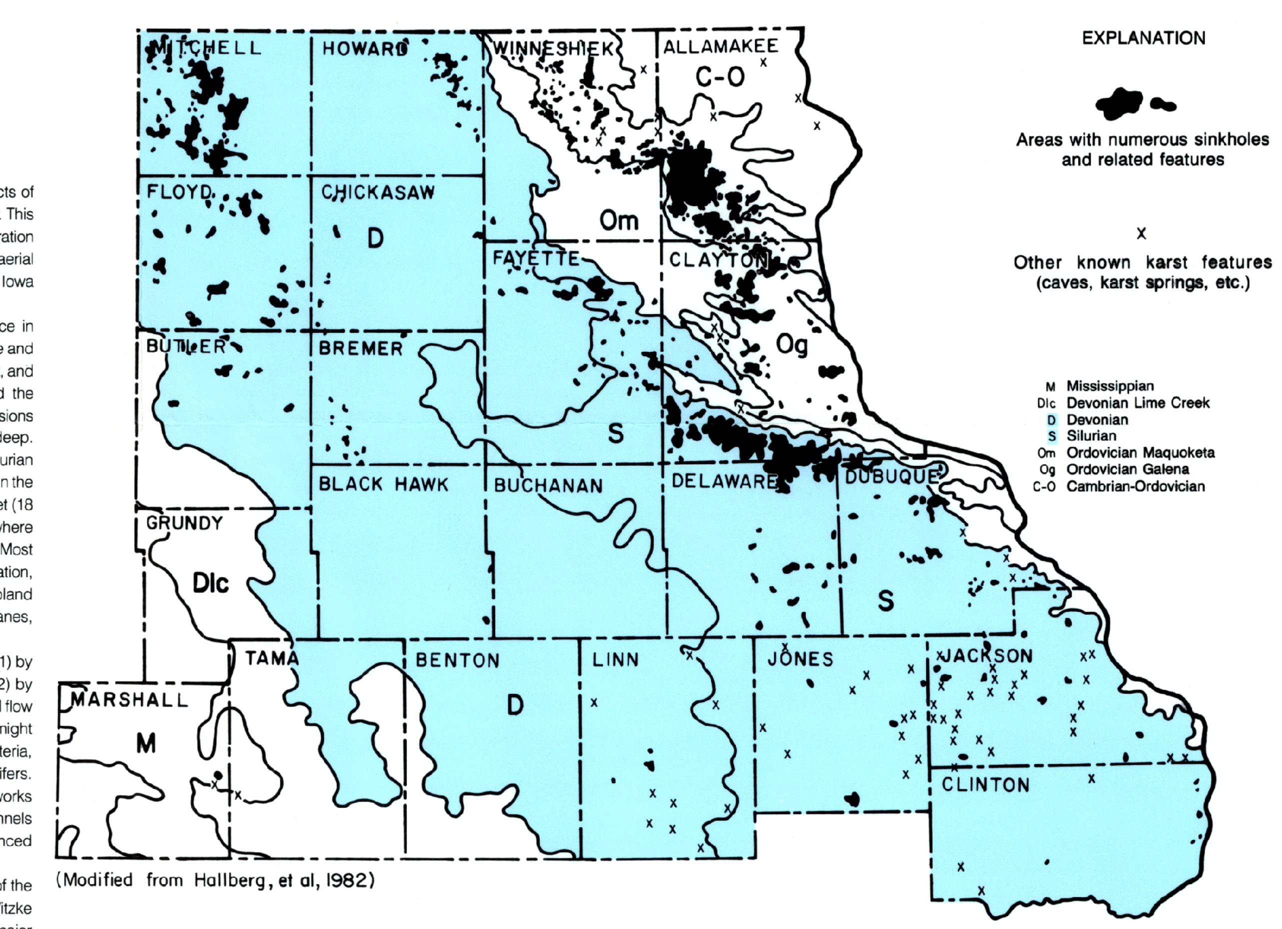

Figure 6. SINKHOLE AREAS

SILURIAN-DEVONIAN AQUIFER OF IOWA

by
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Iowa Geological Survey

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QUALITY OF WATER

WATER QUALITY STANDARDS

In 1974 Congress passed the Safe Drinking Water Act assigning implementation to the U.S. Environmental Protection Agency (EPA). The complimenting National Interim Primary Drinking Water Regulations resulting from that Act went into effect in June 1977. These regulations had to be implemented in each state, and the Iowa Department of Environmental Quality (DEQ), now included in the Department of Water, Air and Waste Management (DWAWM), was given statutory authority in Iowa, i.e., it was made the primary enforcement agency of these rules. State Water Supply Rules and Regulations were published in the Iowa Administrative Code, Chapter 22, in March 1977 as amended. These rules apply to all public water supplies. The public water supplies are divided into community and non-community. Monitoring-frequency differences may occur, but the rules apply to both. A community water system serves at least 15 service connections used by year-round residents or regularly serves 25 year-round residents. A non-community water system is a public water system that is not a community water system. The EPA designated the University (of Iowa) Hygienic Laboratory (UHL) as the State Principal Laboratory to work with the DWAWM in the Laboratory Certification program.

The University Hygienic Laboratory is certified to perform analyses on all water-quality parameters specified in the National Interim Primary Drinking Water Regulations (Splinter, 1980). The parameters are identified as inorganic, organic, radiological, and microbiological. For each parameter specified in the National Interim Primary Drinking Water Regulations there is a maximum contaminant level (MCL). The chemical constituents and properties of water listed below are those usually determined in routine inorganic and radiological water analyses and shown on UHL water analysis sheets.

The EPA also introduced proposed Secondary Drinking Water Regulations. The primary regulations established maximum contaminant levels for chemical constitutents that affect the health of consumers, while the proposed secondary standards affect the esthetic quality of water. Iowa has not adopted the secondary standards and the DWAWM does not enforce them. The MCL of the EPA proposed secondary standards may be exceeded in some community water supplies withdrawing from the Silurian-Devonian aquifer, but in some localities these supplies are the only groundwater alternatives available for communities.

Standards for uses other than drinking water are usually different than listed below. The quality requirements for industries, for example, would depend on how the water is used and therefore, may be quite variable. The concentrations of six constituents and properties of water from the aquifer are shown on the small maps on this sheet. The information should be of assistance to readers in deciding if the water meets their particular requirements.

The chemical constituents (ions) discussed in this atlas are expressed in concentrations of milligrams per liter (mg/L). One mg/L is a milligram (1/1000 of a gram) of an ion in one liter (1000 cubic centimeters) of water. An equivalent measure is one gram of an ion in 1,000,000 grams of water, or one part per million (ppm). Radium concentration and gross alpha activity are reported in picocuries per liter (pCi/L). The water-quality data used in preparing the maps in this section were drawn from the Iowa Geological Survey water-quality file. The information in this file has been accumulated over many years from individual analyses provided by the University Hygienic Laboratory. Most of the information relates to raw water quality in municipal wells.

Constituent or property	Maximum contaminant levels in public water supplies[1]		Significance and comments
	Primary regulations	Proposed secondary regulations	
Iron (Fe)		0.3 mg/L	Iron concentrations of 0.3 mg/L or more are likely to be troublesome, as iron can cause red-water staining of plumbing fixtures and clothing and plug well screens and water pipes. High concentrations affect the color and taste of beverages.
Silica (SiO_2)	NA[2]		Silica contributes to formation of boiler scale, forms deposits on blades of steam turbines, but is not physiologically or agriculturally significant. Most water from the Silurian-Devonian aquifer has concentrations of 5 to 30 mg/L.
pH	NA		The pH expresses the negative logarithm of the hydrogen-ion concentration and indicates whether water is acid or alkaline. A pH of 7.0 indicates a neutral solution, less than 7.0 is acid, more than 7.0 is alkaline. Most supplies from the Silurian-Devonian aquifer have pH values ranging between 7.1 and 7.9 and, therefore, are slightly alkaline.
Specific conductance (micromhos/cm. at 25° C, 77° F)	NA		Specific conductance refers to the ability of the water to conduct an electric current and generally increases in a direct proportion to the presence of ionic species in solution. There is a consistent enough relationship between the dissolved solids and specific conductance of water from the Silurian-Devonian aquifer in the outcrop area that the dissolved solids can be estimated by multiplying the specific conductance by 0.58. This does not apply where the water has an unusual composition, e.g., where it is high in sulfate.
Dissolved solids (Total residue 103° C)		500 mg/L	Dissolved solids indicate the concentration of dissolved minerals in the water and is a measure of the water's suitability for many uses. Concentrations of over 2,000 mg/L, which in Iowa implies a high concentration of sulfate, may have a detectable taste and a laxative effect on people not acclimated to the water. Many water supplies, particularly in western and southern Iowa, contain more than 1,000 mg/L dissolved solids; these supplies are used with no obvious ill effects (figure 3).
Alkalinity (as $CaCO_3$)	NA		Alkalinity is a measure of the concentration of bicarbonate and carbonate ions in water and refers to the water's ability to neutralize acid. In moderate amounts alkalinity does not affect most uses of water. Its significance is usually dependent on the nature of the cations (Ca, Mg, Na, K) associated with it.
Hardness (as $CaCO_3$)	NA		Hardness is caused almost entirely by compounds of calcium and magnesium and is commonly recognized by the increased quantity of soap required to produce lather. Hard water is also objectionable because it causes the formation of scale in boilers, water heaters, radiators, and pipes. Total hardness can be expressed as carbonate and noncarbonate hardness. Carbonate hardness is equivalent to the concentration of bicarbonate and carbonate in the water (that is, the alkalinity); any hardness in excess of this amount is called the non-carbonate hardness (figure 7).
Sodium (Na) and potassium (K)	NA[3]		Sodium and potassium in moderate quantities have little affect on the usefulness of the water. Water that contains more than 100 mg/L of sodium and potassium combined may cause foaming in boilers. High concentrations of sodium may be objectionable for people on a low sodium diet (figure 4).
Calcium (Ca) and magnesium (Mg)	NA		Calcium and magnesium in addition to being the main causes of hardness in water are responsible for the formation of boiler scale and deposits in hot water heaters and pipes. They reduce the lathering or sudsing ability of soaps. They combine with soap to form scum deposits.
Manganese (Mn)		0.05 mg/L	Manganese in concentrations as low as 0.01-0.02 mg/L causes dark brown or black stains on fabrics and porcelains and impairs the taste of coffee, tea, and other beverages.
Nitrate (as NO_3) (as N)	45 mg/L 10 mg/L[4]		Serious and occasionally fatal toxicity has occurred when water high in nitrate has been used by infants. It is the cause of methemoglobinemia, or cyanosis, a sickness that gives a baby's skin a bluish tinge. Nitrate concentrations greater than 5 mg/L as NO_3 may indicate surface contamination.
Fluoride (F)	1.8 mg/L[5] (southern Iowa) 2.2 mg/L (northern Iowa)		Fluoride is desirable in water supplies in concentrations that range from 0.9 to 1.1 mg/L, because it reduces tooth decay. However, mottling of tooth enamel of growing children in Iowa may occur when fluoride concentrations exceed 2 mg/L. The recommended fluoride level is one-half the maximum (figure 6).
Chloride (Cl)		250 mg/L	Chloride concentrations less than 150 mg/L generally are satisfactory for most purposes. More than 250 mg/L generally is objectionable for public supplies because chloride may combine with other ions to give a noticeable taste. Large amounts of chloride in water high in calcium and magnesium increases water's corrosiveness.
Sulfate (SO_4)		250 mg/L	Sulfate may cause detectable taste at concentrations of 300-400 mg/L and may have a laxative effect when the concentration is above 600 mg/L, particularly when combined with magnesium or sodium. This laxative effect is commonly noted by new and casual users of the water but some become acclimated to it in a short time. The effect is noticeable in almost all persons when concentrations exceed 750 mg/L. Sulfate combined with calcium forms a hard scale in boilers and water heaters (figure 5).
Bicarbonate (HCO_3) and Carbonate (CO_3)	NA		Bicarbonate and carbonate contribute to alkalinity of water. Bicarbonate is formed when carbon dioxide in water reacts with carbonate rocks such as limestone and dolomite. Small amounts of carbon dioxide are present in rainwater; more is picked up by water percolating through decaying organic matter. Bicarbonate is the principal anion in much of the earth's natural fresh water and ranges from about 150 to 550 mg/L in supplies from the Silurian-Devonian aquifer. Carbonate is seldom present in natural fresh water.
Trace Metals Arsenic (As) Barium (Ba) Cadmium (Cd) Chromium (Cr) Lead (Pb) Mercury (Hg) Selenium (Se) Silver (Ag) Copper (Cu) Zinc (Zn)	 0.05 mg/L 1.0 mg/L .010 mg/L .05 mg/L .05 mg/L .002 mg/L .01 mg/L .05 mg/L	 1.0 mg/L 5.0 mg/L	Extremely small amounts of trace elements occur in water. Some of these trace metals are toxic to man. Others are essential to life, but in high concentrations can be toxic or esthetically unpleasing. The full significance of these minor elements in human metabolism isn't understood in spite of much research. Regulations of the amounts that can be present in drinking water supplies have been set by the EPA. As of this writing the water from the Silurian-Devonian aquifer does not seem to have objectionable concentrations of any trace metals, except in one or two questionable instances.
Radioactivity Radium (radium-226 and radium-228 combined) Gross alpha activity	 5 pCi/L[6] 15 pCi/L		The effect and significance of low concentrations of radium in public water supplies isn't fully known. However, the EPA takes the position that any dose of ionizing radiation has a potential to produce deleterious effects on human health and that the effect will be proportional to the dose received. Therefore, the maximum contaminant levels established for radium concentration and gross alpha activity in public water supplies is based on the effects on human health that have been observed at higher doses and dose rates. The monitoring of radioactivity in public water supplies is a screening process: in localities where radium-228 may be present in drinking water, radium-226 or radium-228 analyses are required when the gross alpha activity exceeds 2 pCi/L. When the gross alpha activity exceeds 5 pCi/L, the same or equivalent sample shall be analyzed for radium-226. If the concentration of radium-226 exceeds 3 pCi/L the same or equivalent sample shall be analyzed for radium-228. The combined radium-226 and radium-228 concentration should not exceed 5 pCi/L, while the gross alpha activity (including radium-226, but excluding radon and uranium) should not exceed 15 pCi/L. A few communities with water supplies obtained from the Silurian-Devonian aquifer have concentrations above these limits, but by zeolite, reverse osmosis, or lime-soda ash softening treatment the radioactivity is readily removed - as much as 90 percent removal is possible (Schliekelman, 1976).
Temperature	NA		Temperature is a major consideration in use of water for industrial cooling and air conditioning purposes (figure 7).
Corrosivity		Non-corrosive[3]	Corrosivity is a complex characteristic of water related to pH, alkalinity, dissolved oxygen, total dissolved solids, and other factors. It has esthetic, health, and economic significance. At present there is no simple, generally accepted measure of the corrosivity of water. Corrosivity is controlled by pH adjustment, chemical stabilizers, or other means. It is a minor problem in Silurian-Devonian water supplies.

[1]The usage of contaminant level in this atlas follows the U.S. Environmental Protection Agency's (EPA) usage in the National Interim Primary Drinking Water Regulations (Federal Register, v. 40, no. 248 and v. 41, no. 133) and in the Proposed Secondary Drinking Water Regulations (Federal Register, v. 42, no. 62).
[2]NA — Not applicable.
[3]Sodium and corrosivity are currently under study by the EPA to determine whether they should be included in the interim standards. This study began on Feb. 27, 1982 and currently is still active. Eventually these parameters will be re-evaluated.
[4]The maximum contaminant level for nitrate applies also to non-community public water supplies.
[5]The maximum contaminant level of fluoride, which is based on average maximum daily air temperatures, is 2 mg/L for about 95 percent of the state. It is 1.8 mg/L for a few communities in extreme southeastern and southwestern Iowa, and is 2.2 mg/L for a few communities in northeastern Iowa.
[6]The state may require annual monitoring of supplies that exceed 3 pCi/L radium-226.

DATA NOT SHOWN ON MAPS

IRON commonly occurs in troublesome concentrations in the water from the Silurian-Devonian aquifer. In fact, in most places it is practically mandatory to install equipment for iron removal or to stabilize the water to hold iron in solution. The concentration of iron can vary considerably both areally and temporally and can be affected by several factors, some of which tend to raise the concentration and some which tend to lower it. For example, iron may be added to groundwater from contact with well casing, pump parts, piping, storage tanks, and other iron objects which may be in contact with the water. Micro-organisms may dissolve and precipitate iron from water. Naturally-occurring iron may oxidize and precipitate when the water comes in contact with air. Iron concentration is readily removed or reduced by treatment. The available analyses indicate the iron concentration ranges from 0.0 to 31.0 mg/L, with a mean value of 1.54 mg/L and a median value of 0.6 mg/L. About 60 percent of the analyses exceeded the proposed secondary drinking-water standard of 0.3 mg/L.

MANGANESE concentrations range from 0.0 to 2.5 mg/L with a mean value of 0.9 mg/L and a median of 0.4 mg/L. The proposed secondary standard of 0.05 mg/L is exceeded in 38 percent of the water supplies. Aeration and filtration treatment will reduce the concentration to about 0.05 mg/L.

NITRATE concentration in water from the Silurian-Devonian aquifer exceeds the MCL in many places in the northeast part of the state where the aquifer is close to the surface and poorly protected from contamination caused by surfacewater infiltration. The concentration of NO_3 ranges from 0.0 to 300 mg/L with a mean value of 6.6 mg/L and a median of 0.9 mg/L. Wells less than 50 feet deep show the most contamination, but wells located in the karst region or where the overburden is thin will show high nitrate concentrations as deep as 150 feet. If high nitrates are found in deeper wells it generally implies that water from shallower levels is entering the well on account of poor construction or corroded casing.

CHLORIDE concentration in water from the Silurian-Devonian aquifer ranges from about 0.5 to <100 mg/L in the northern half of the state and from about 100 to 1000+ mg/L in the southern half. The dividing lines run roughly from Louisa to Polk to Pottawattamie counties. The area where chloride concentration exceeds the secondary standard of 250 mg/L is shown on the sodium distribution map.

RADIOACTIVITY concentration (Ra*226*) in the water from the Silurian-Devonian aquifer shows a median value of 2.65 pCi/L. Of the 47 observations reporting radium, only six had a value greater than 5.0 pCi/L. Without exception, these high concentrations occur in the subcrop area of the aquifer.

TASTE AND ODOR problems occur in the water from the Silurian-Devonian aquifer in some locations. Concentrations of iron bacteria (Crenothrix, Gallionella, Leptothrix) may gain entrance to shallow wells and develop large colonies in the well and water system and cause rusty or "red-water" in water supplies. The bacteria will build a slime or sludge in water tanks, pipelines, and pumps. The sludge may break loose and flow through the distribution system to clog plumbing fixtures and water-using appliances. These micro-organisms may cause disagreeable tastes and odors, and create problems in food processing and in making beverages. There are scattered reports of hydrogen sulfide gas in Silurian-Devonian water supplies. This gas which is soluble in water has an obnoxious rotten-egg odor that will also make water undrinkable and useless for preparation of food and beverages. It is flammable and poisonous in high concentrations. Most people can detect it if the concentration is 0.05-1.0 mg/L. It also tarnishes silverware and fixtures and may be highly corrosive.

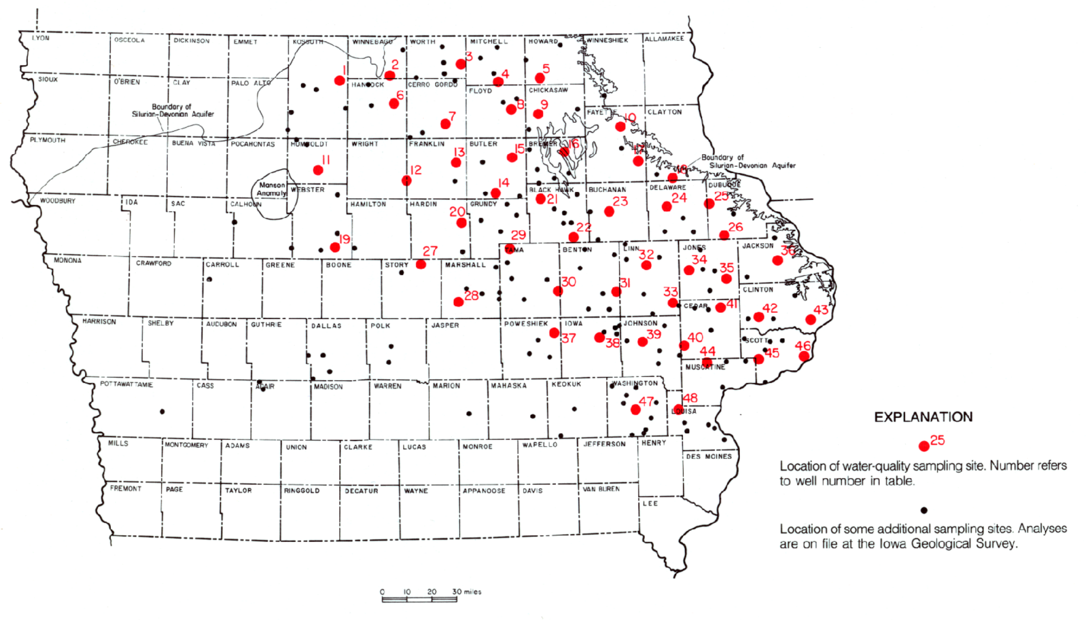

Figure 1. WATER-QUALITY SAMPLING SITES

The chemical-quality data presented on this sheet are based on numerous analyses of water from wells that tap the Silurian-Devonian aquifer. The Iowa Geological Survey has more than 1200 chemical analyses of water on file obtained from Silurian-Devonian wells over the past 50 years. Selected analyses of water from the aquifer in the main areas of use in the north-central, northeast, and eastern parts of the state are shown in figure 1 and in the adjacent table 1. These analyses are representative of the quality of the water from the aquifer where it is used the most. Note that the quality deteriorates along the southwest fringe of the outcrop where the aquifer dips beneath younger rocks and where evaporite deposits occur in the Cedar Valley-Wapsipinicon Formations.

WATER TREATMENT

The most frequently used methods of treatment of community water supplies developed from the Silurian-Devonian aquifer are: disinfection by gas chlorination or hypo-chlorination, and iron and manganese removal by aeration and filtration through sand and anthracite media by pressure or gravity. More than half or 93 (about 52 percent) of these water systems disinfect the water prior to use, and 67 (about 37.5 percent) use aerators and filters to remove iron.

Chemical dosage with phosphate compounds is used by 31 communities for pH adjustment and corrosion control, while 8 communities have alkali feed for pH adjustment. Fluoride is added to the water in 28 communities to bring the level to approximately 1.0 mg/L. Relatively few supplies are softened, but where they are it is usually done by the zeolite ion base exchange method. About 42 communities use no form of treatment.

Quantitative information on treatment of domestic water supplies developed from the Silurian-Devonian aquifer isn't readily available, but softening by ion exchange, iron removal by filtering, and disinfection by periodic shock chlorination are common methods of treatment.

Table 1. CHEMICAL ANALYSES OF WATER FROM SELECTED SILURIAN-DEVONIAN WELLS

Dissolved constituents and hardness in milligrams per liter
Analyses made by the University of Iowa Hygienic Laboratory

	Well Name	Well Location	Year Drilled	Principal Source of Water	Date of Collection	Depth (feet)	Temperature (°C)	Dissolved solids	Iron	Manganese	Calcium	Magnesium	Potassium	Sodium	Carbonate	Bicarbonate	Sulfate	Chloride	Fluoride	Nitrate (as NO_3)	Hardness (as $CaCO_3$) Total	Carbonate	Non-carbonate	pH	Conductivity Micromhos at 25° C	Radium-226 (pico-curies/liter)
1	Titonka No. 2	Kossuth County NW SW NE sec.9,T.97N.,R.27W.	1961	Cedar Valley	10-22-80	300	—	431	1.2	.03	71	27	5.8	65	0	455	34	1.5	0.9	6.3	291	291	0	7.5	720	3.0
2	Forest City No.2	Winnebago County SE NW NW sec.36,T.98N.,R.24W.	1934	Cedar Valley	3-78	142	13	423	.39	.07	100	34	4.2	14	0	467	29	<0.5	0.3	<0.1	395	383	12	7.3	740	4.3
3	Grafton No. 1	Worth County SE SW SE sec.3,T.98N.,R.19W.	1938	Cedar Valley	1-29-80	186	16	277	11	.27	64	19	<0.1	5.8	0	306	2.5	2.0	0.3	<0.1	258	251	7	7.8	470	—
4	Orchard No. 1	Mitchell County SE/cor sec.7,T.97N.,R.16W.	1959	Cedar Valley	7-20-76	220	—	294	<.01	<.01	77	20	0.8	5.0	0	224	37	18	0.2	46	275	184	91	7.5	540	—
5	Elma No. 1	Howard County SE sec.1,T.97N.,R.14W.	1914	Cedar Valley	9-22-75	150	15	360	<.01	<.01	78	23	0.7	9.7	0	249	55	14	.15	11	289	204	85	7.6	560	—
6	Garner No. 2	Hancock County NE NW NE sec.31,T.96 N.,R.23W.	1957	Cedar Valley	4-80	325	—	336	.23	.01	80	38	2.4	8.1	0	438	10	2.0	0.8	<0.1	357	357	0	7.3	660	—
7	Rockwell No. 2	Cerro Gordo County SW NW NE sec.3,T.94N.,R.20W.	1962	Cedar Valley	1-6-81	459	—	384	.17	<.01	69	39	9.3	22	0	445	6.3	7.0	2.3	1.7	333	333	0	7.3	700	1.4
8	Charles City No. 7	Floyd County NE NE NE sec.1,T.94N.,R16W.	1963	Cedar Valley	3-22-77	186	49	257	2.3	.02	63	17	1.4	3.5	0	256	17	1.5	.65	0.2	231	210	21	7.5	440	—
9	Ionia	Chickasaw County NE NW NW sec.24,T.95N.,R.14W.	1950	Cedar Valley	1-9-76	250	10	314	.67	<.01	73	28	1.8	15	0	329	45	<0.5	0.7	0.3	299	270	29	7.4	580	—
10	West Union (East)	Fayette County NE NE SE sec.17,T.94N.,R.8W.	1957	Silurian	4-15-18	64	11	506	.02	<.01	110	34	3.8	24	—	360	38	61	0.2	50	414	295	119	7.4	870	—
11	Dakota City No. 2	Humboldt County Cent. SW sec.6,T.91N.,R.28W.	1947	Devonian Ordovician	3-6-72	1025	12	591	.14	.06	110	45	6.4	12	0	359	180	7.0	.55	3.1	470	294	176	7.1	850	—
12	Dows No. 5	Wright County SE NE NE sec.2,T.91N.,R.23W.	1967	Cedar Valley	5-13-80	752	—	380	.21	.01	62	42	13	16	0	392	37	4.0	2.5	<0.1	328	321	7	7.5	680	—
13	Hansell No. 1	Franklin County NW NW NW sec.28,T.92N.,R.19W.	1958	Cedar Valley	3-24-81	470	—	565	.40	<.01	87	45	5.3	10	0	299	160	2.5	2.2	0.2	403	245	158	7.4	800	—
14	Parkersburg No. 2	Butler County SE NW SW sec.30,T.90N.,R.16W.	1955	Cedar Valley	6-23-80	300	—	247	.47	.05	58	17	1.5	5.8	0	262	18	1.0	0.8	<0.1	216	215	1	7.5	440	—
15	Clarksville No. 3	Butler County NE SW NW sec.18,T.92N.,R.15W.	1981	Cedar Valley	3-24-82	220	—	253	<.01	<.01	67	15	.46	2.1	0	230	29	5.0	0.5	9.6	229	189	40	7.5	470	—
16	Tripoli No. 2	Bremer County SE NE sec.4,T.92N.,R.12W.	1950	Cedar Valley Wapsipinicon	6-20-79	129	12	336	1.3	.07	78	24	1.5	15	0	388	4.0	3.0	.45	0.2	296	296	0	7.4	580	—
17	Arlington No. 2	Fayette County NE NE SE sec.28,T.92N.,R.7W.	1953	Hopkinton Blanding	12-11-79	186	—	287	2.2	.27	72	22	<0.1	5.4	0	304	13	1.0	0.4	1.0	275	249	26	7.7	480	—
18	Edgewood No. 2	Delaware County NW NW NE sec.2,T.90N.,R.5W.	1952	Hopkinton Blanding	3-12-80	269	—	284	1.4	.01	69	22	0.6	5.8	0	320	15	1.0	.35	<0.1	265	262	3	7.6	500	—
19	Dayton No. 3	Webster County NW NE sec.14,T.86N.,R.28W	1952	Mississippian Devonian	4-1-80	1250	—	1180	.10	.05	160	80	16	50	0	340	590	8.0	2.4	0.1	641	279	362	7.3	1500	0.8
20	Steamboat Rock*	Hardin County NW NW NW sec.27,T.88N.,R.19W.	1948	Cedar Valley Wapsipinicon	10-9-48	750	12	2003	0.6	—	342	107	62		0	293	1148	9.0	0.2	0	1295	240	1055	7.6	2118	—
21	Cedar Falls No. 7	Black Hawk County SE SE SW sec.11,T.89N.,R.14W.	1967	Cedar Valley Wapsipinicon	6-11-79	170	10	272	.04	.01	69	20	1.1	4.1	0	278	21	3.0	0.5	0.1	255	228	27	7.7	470	—
22	LaPorte City No. 2	Black Hawk County NE/cor SW sec.25,T.87N.,R.12W.	1948	Cedar Valley Hopkinton-Blanding	5-13-80	250	—	550	.52	.02	90	36	6.8	28	0	343	160	2.0	1.2	<0.1	374	281	93	7.5	820	—
23	Independence No. 6	Buchanan County SE SW sec.34,T.89N.,R.9W.	1969	Hopkinton Blanding	7-25-78	285	12	276	.08	.02	67	19	1.7	6.6	0	259	25	8	0.2	0.2	246	212	34	7.6	470	—
24	Manchester No. 5	Delaware County SW SW SW sec.29,T.89N.,R.5W.	1963	Hopkinton Blanding	10-9-78	263	10	271	.03	<.01	61	22	0.9	2.7	0	226	40	9.0	0.2	21	243	185	58	7.6	480	—
25	Dyersville No. 2	Dubuque County SE SW NW sec.32,T.89N.,R.2W.	1970	Hopkinton Blanding	1-15-76	195	—	405	.08	<.01	77	47	0.8	9.0	0	339	36	27	0.1	30	392	278	114	7.3	690	—
26	Cascade	Dubuque County NE NW SW sec.31,T.87N.,R.1W.	1958	Hopkinton Blanding	1-18-77	200	11	366	.05	<.01	85	36	1.4	5.8	0	350	41	8.5	0.2	5.1	360	287	73	7.2	640	—
27	McCallsburg	Story County NE NW NE sec.22,T.85N.,R.22W.	1951	Cedar Valley	2-26-81	1130	—	363	1.1	.02	73	36	5.5	13	0	381	31	1.0	2.4	0.1	332	—	—	7.5	650	—
28	Melbourne No. 1	Marshall County SW SW NE sec.6,T.82N.,R.19W.	1939	LaPorte City	4-3-79	1340	—	4310	3.4	.04	470	110	15	630	0	257	2500	150	1.5	0.2	1630	211	1419	7.2	4800	3.2
29	Lincoln No. 2	Tama County NE SE NE sec.15,T.86N.,R.16W.	1950	Cedar Valley	4-4-71	528	—	1670	.82	<.05	305	101	5.0	13	0	271	940	2	2.4	0.4	1180	222	858	7.1	1900	—
30	Elberon	Tama County SW SW SW sec.12,T.83N.,R.13W.	1953	Silurian Devonian	5-29-74	635	—	1660	.78	<.01	130	52	17	310	0	315	950	17	2.4	1.4	530	258	272	7.4	2200	—
31	Atkins No. 2	Benton County SE NW SE sec.14,T.83N.,R.9W.	1966	Hopkinton	2-13-78	485	9	405	.07	<.01	62	28	8.2	58	0	488	22	2.0	0.4	<0.1	270	270	0	7.5	820	4.4
32	Alburnett No. 2	Linn County NW NE sec.26,T.85N.,R.7W.	1964	Silurian Devonian	4-18-78	400	11	284	.22	<.01	66	25	2.4	9.0	0	329	9.9	<0.5	0.3	0.1	268	268	0	7.7	500	2.0
33	Mt. Vernon No. 4	Linn County SW NW NE sec.10,T.82N.,R.5W.	1967	Hopkinton Blanding	4-17-78	350	11	321	.28	.01	70	32	8.8	5.1	0	334	26	5.0	0.4	0.2	307	274	33	7.4	670	—
34	Anamosa No. 2	Jones County SE SE SE sec.3,T.84N.,R.4W.	1955	Hopkinton Blanding	5-14-80	405	—	396	.11	.13	81	37	2.5	14	0	370	56	8.0	0.2	0.7	355	303	52	7.5	680	—
35	Wyoming No. 1	Jones County NW NW NW sec.30,T.84N.,R.1W.	1924	Hopkinton Blanding	1-24-78	351	11	388	.12	.12	94	33	2.2	8.9	0	439	14	7.5	0.3	3.1	371	360	11	7.3	670	—
36	Andrew No. 1	Jackson County NE NE SE sec.22,T.85N.,R.3E.	1953	Hopkinton Blanding	1-24-80	250	11	442	.08	.01	78	46	<0.1	9.7	0	394	18	19	0.2	41	384	323	61	7.4	720	—
37	Russell Halloran	Poweshiek County SW SE SW sec.3,T.80N.,R.13W.	1963	Cedar Valley	12-5-67	564	—	1440	1.9	<.05	144	58	8.2	220	0	290	780	7.0	.45	0.2	600	238	362	7.6	1900	—
38	Conroy No. 1	Iowa County NE NW sec.22,T.80N.,R.10W.	1971	Cedar Valley	10-12-78	651	12	2450	1.1	.04	340	150	13	100	0	218	1500	8.0	0.9	0.2	1470	179	1291	7.3	2500	3.3
39	Tiffen No. 2	Johnson County NE SW SE sec.28,T.80N.,R.7W.	1969	Silurian Devonian	6-11-79	305	—	1410	.17	.01	160	70	12	150	0	311	720	6.0	0.6	0.4	683	255	428	7.3	1700	2.8
40	West Branch No. 3	Cedar County NW SE SE sec.6,T.79N.,R.4W.	1968	Silurian Devonian	4-28-77	446	—	456	.83	.21	100	33	2.0	15	0	434	41	14	0.8	0.7	395	356	39	7.3	750	—
41	Clarence No. 3	Cedar County SW SW NE sec.27,T.82N.,R.2W.	1977	Hopkinton	12-11-79	475	—	275	.79	.04	68	21	<0.1	8.0	0	315	6.0	<.05	0.4	<0.1	258	258	0	7.4	460	—
42	Calamus No. 2	Clinton County SW/cor NE sec.17,T.81N.,R.2E.	1937	Hopkinton Blanding	1-22-80	278	—	238	1.1	.07	59	20	1.5	7.9	0	285	1.5	1.0	0.2	0.4	232	232	0	7.7	440	—
43	LowMoor No. 2	Clinton County SE SE SE sec.22,T.81N.,R.5E.	1958	Hopkinton Blanding	4-26-77	322	12	403	1.8	.05	85	36	1.0	7.1	0	386	40	8.0	0.2	<0.1	364	316	48	7.2	650	—
44	Atalissa No. 1	Muscatine County NW/cor. SE sec.11,T.78N.,R.3W.	1938	Silurian Devonian	2-19-80	295	—	373	.06	.05	87	36	1.9	14	0	453	13	2.0	0.3	2.2	366	366	0	7.2	730	—
45	Walcott No. 3	Scott County SW SW SE sec.6,T.78N.,R.2E.	1966	Hopkinton	4-19-79	230	—	353	1.3	.11	78	32	0.1	8.3	0	384	24	4.0	0.3	<0.1	329	315	14	7.4	623	—
46	LeClaire No. 2	Scott County NE NE NE sec.3,T.78N.,R.5E.	1960	Hopkinton Blanding	5-10-77	439	11	449	<.01	.07	94	43	0.7	6.8	0	428	31	14	0.2	16	412	351	61	7.2	730	—
47	Washington County Home △	Washington County SE NW sec.12,T.75N.,R.8W.	1935	Cedar Valley Wapsipinicon	3-29-40	675	17	6864	0.9	0	532	130	1412		—	332	3859	510	4.2	0	1863	272	1591	7.3	—	—
48	Peter Friis	Louisa County SW SW SE sec.12,T.75N.,R.5W.	1964	Cedar Valley	6-20-67	174	—	659	2.1	<.05	83	34	3.7	97	0	390	170	44	0.5	1.8	349	320	29	7.7	1000	—

* Well abandoned and plugged
△ Well not in use

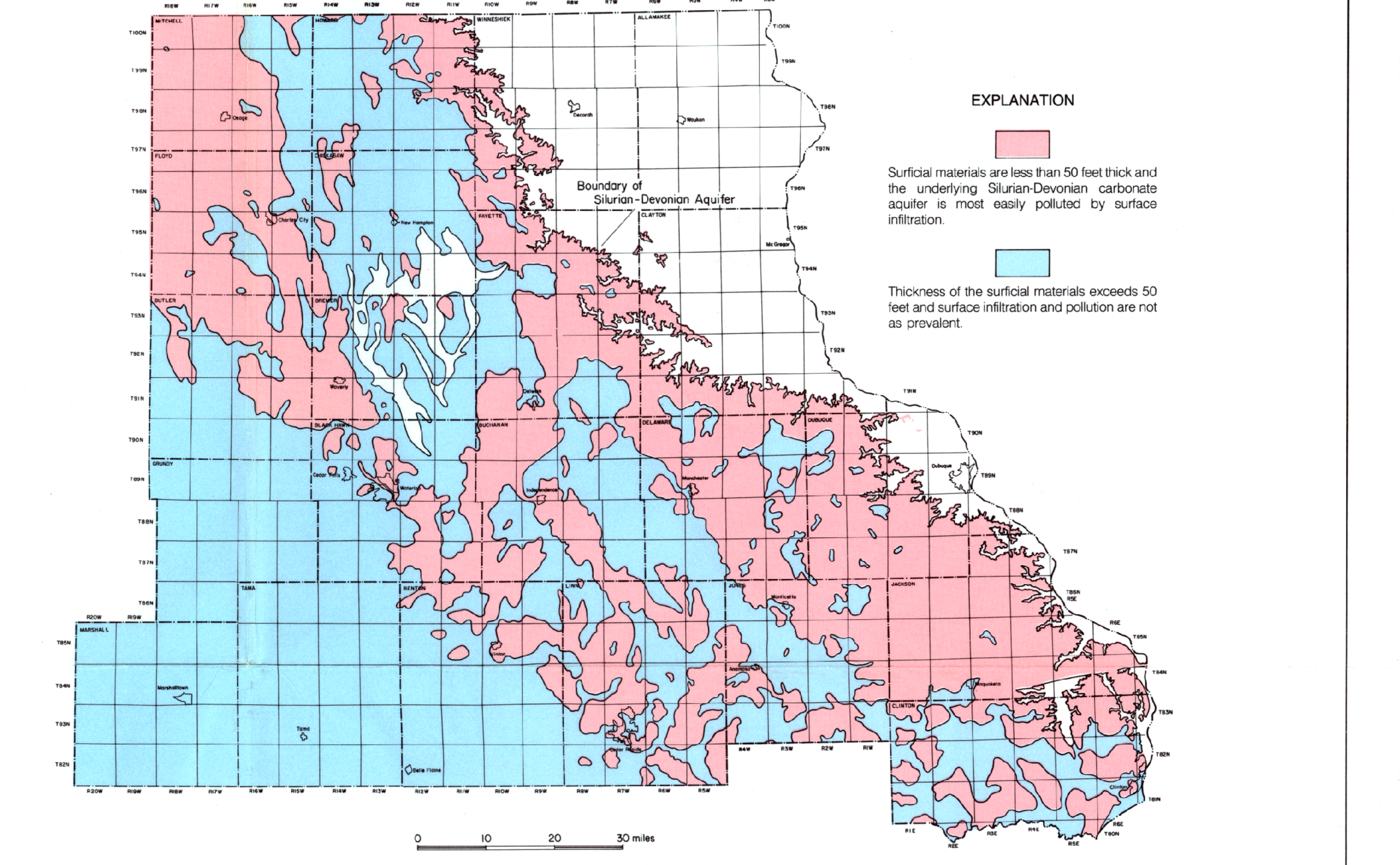

Figure 2. POLLUTION-HAZARD AREAS FOR THE SILURIAN-DEVONIAN AQUIFER OF NORTHEAST IOWA

Where the unconsolidated materials overlying the Silurian-Devonian aquifer and older bedrock in northeast Iowa are less than 25-50 feet thick, and where concentrations of sinkholes occur, groundwater may be severely polluted by nitrate (see also figure 6, sheet 3). The upper bedrock in these areas is highly susceptible to pollution from farmland drainage or by infiltration from point sources of pollution such as manure piles, barnyards, septic tanks, and refuse dumps. Recent studies (Hallberg and Hoyer, 1982) indicate there is a higher percentage of well-water analyses with nitrate concentrations in excess of 45 mg/L in areas where the bedrock is only 0-50 feet below the surface than in locations where the depth to rock is more than 50 feet. Depending on the extent the aquifer is polluted locally, wells may have to be drilled to deeper water-bearing units. Well drillers and engineering consultants should consider these points when locating and designing new wells in these areas. The polluted water in the upper carbonate aquifers must be cased and sealed off in deep wells to provide safe drinking water and to protect the lower aquifers.

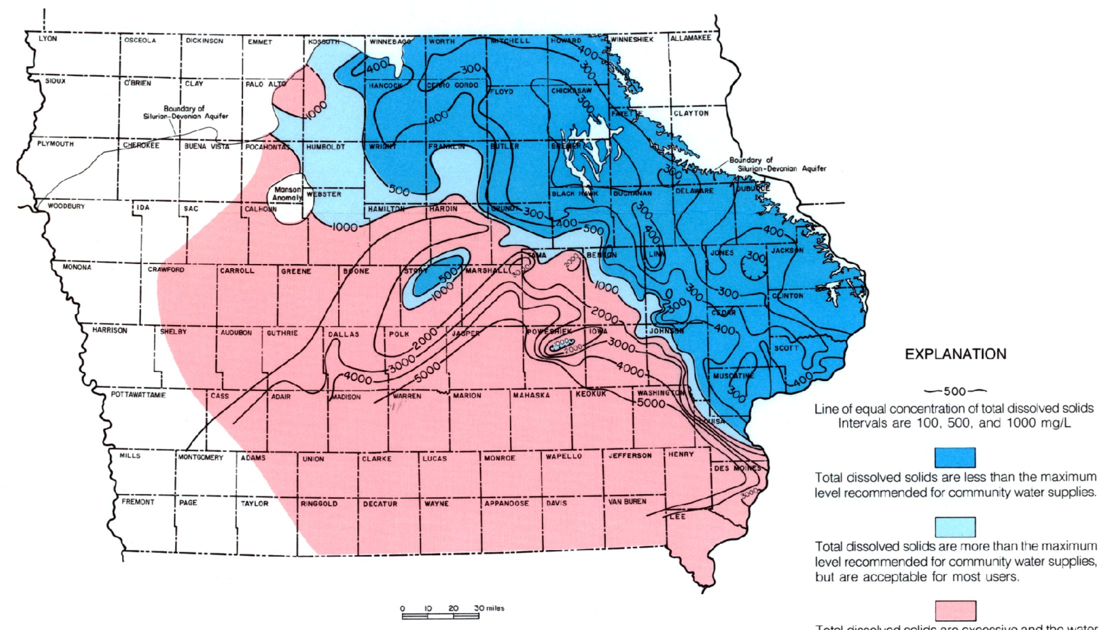

Figure 3. TOTAL DISSOLVED SOLIDS

The concentration of total dissolved solids in the water from the Silurian-Devonian aquifer meets the federal secondary drinking-water standards (less than 500 mg/L) only in the outcrop area of the formations in the north-central, northeast, and east-central parts of Iowa. South and west of the outcrop area where the aquifer underlies younger strata, dissolved solids generally range between 2000-5000 mg/L and indicate poor-quality water for human consumption.

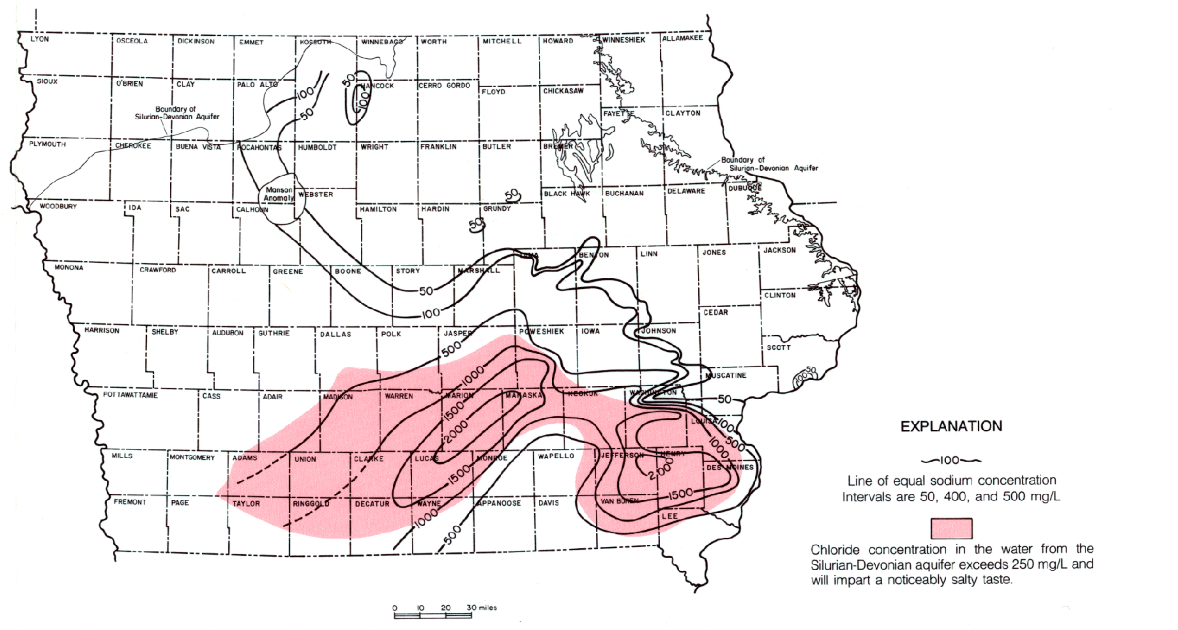

Figure 4. SODIUM CONCENTRATION

Sodium concentration in the water from the Silurian-Devonian aquifer in the outcrop area of north-central, northeast, and east-central Iowa is almost always less than 50 mg/L and will have little effect on the usefulness of the water. In southwest, southern, and southeast Iowa, concentrations of 250 mg/L to as high as 2000 mg/L occur and could have potential health significance to people on low-sodium diets. It will also cause foaming in boilers. Where both sodium and chloride concentrations are high the water will have a noticeably salty taste. Existing data do not support the establishment of maximum contaminant levels for sodium for either primary or secondary drinking-water standards according to the U.S. Environmental Protection Agency. Additional data are being gathered.

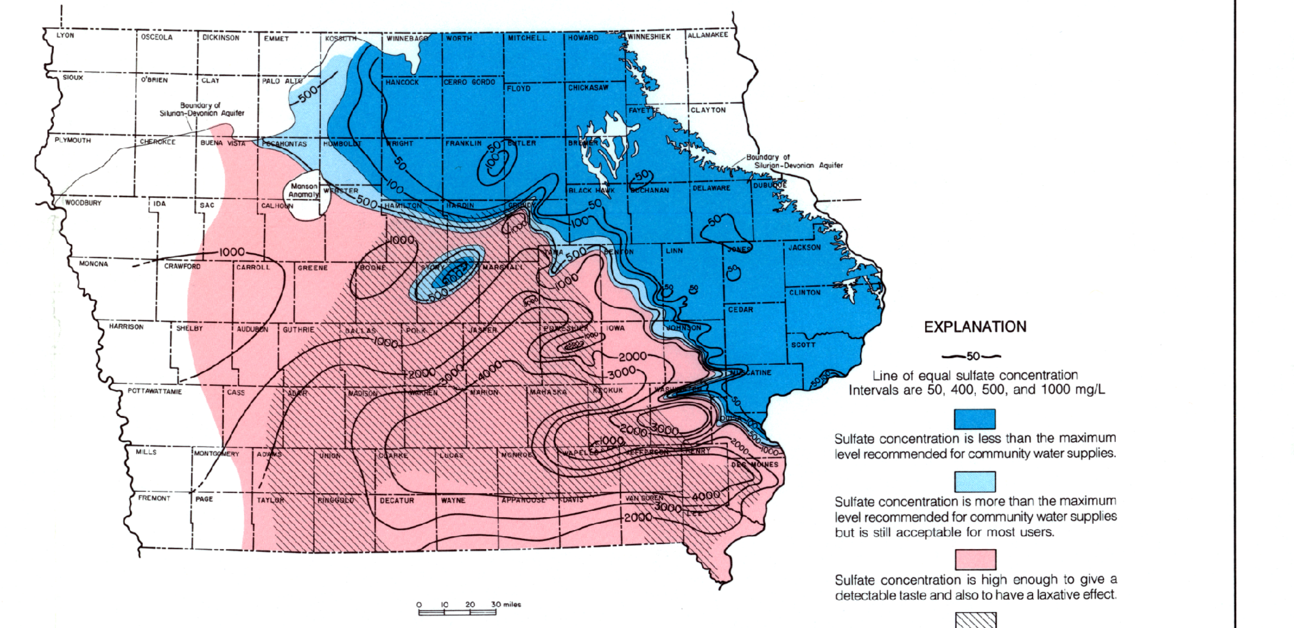

Figure 5. SULFATE CONCENTRATION

Since sulfate is a secondary standard of water quality according to the U.S. Environmental Protection Agency, it is not viewed as a major concern in Iowa water regulations at present. However, widespread distribution of evaporites (gypsum-anhydrite) in the Devonian Cedar Valley-Wapsipinicon carbonate sequence in the central, southern, and southeast parts of the state has a pronounced effect on the chemical quality of the water in these formations. Wells open to the Silurian-Devonian aquifer in this area generally yield water with such high concentrations of sulfate as to be unsuitable for public water supplies. Undesirable features of high-sulfate water are poor taste, laxative effects on transient users, and formation of hard scale in boilers and heat exchangers. The laxative effects are seldom noted in regular users of the water.

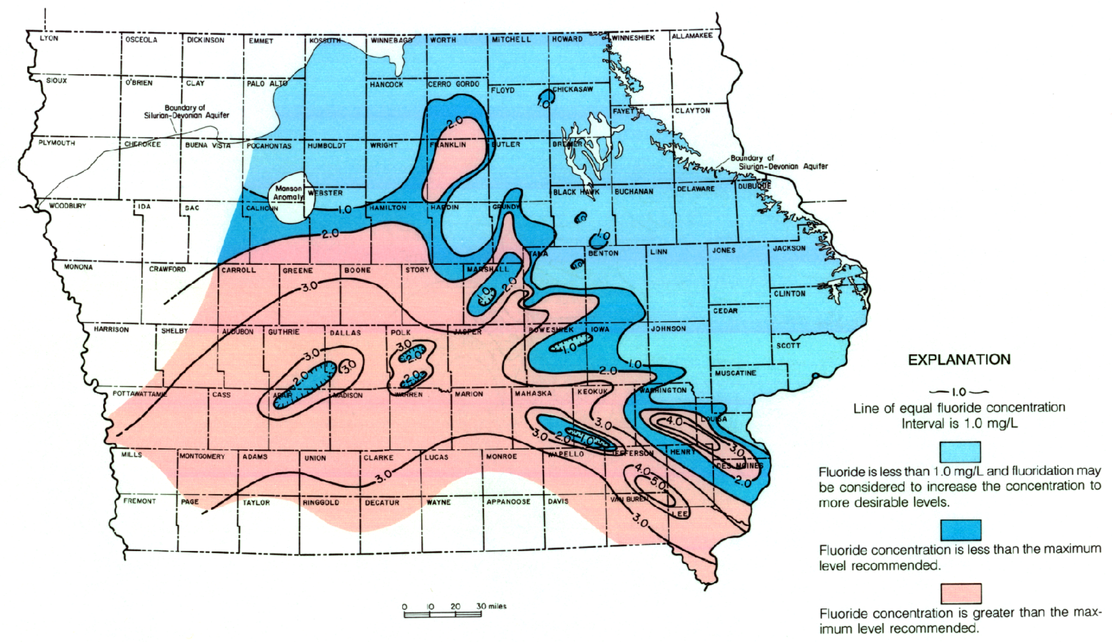

Figure 6. FLUORIDE CONCENTRATION

Fluoride concentration in the water from the Silurian-Devonian aquifer ranges from about 0.1 to 5.0 mg/L. It is acceptable for public water supplies across most of north-central, northeast, and east-central Iowa. An exception is the northwestern half of Franklin County and southern Cerro Gordo County where fluoride concentration appears to exceed 2.0 mg/L. Excess fluoride occurs in most of the southwest, southern, and southeast parts of the state.

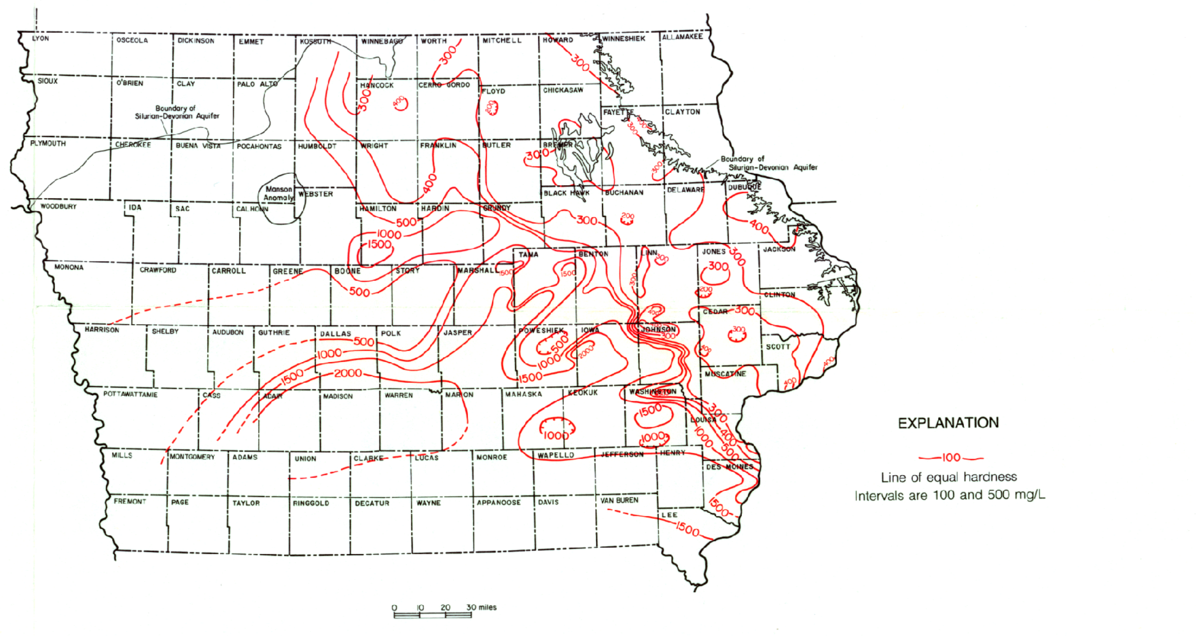

Figure 7. HARDNESS

Hardness as a drinking-water quality parameter was considered, but not included, in the federal secondary regulations for public water supplies. The health aspects of hard water versus soft water is subject to considerable debate. Some scientists and physicians have discouraged the practice of softening drinking water on the assumption that a correlation exists between heart disease and softness of water. However, high levels of hardness have significant esthetic and economic effects, and softening can be considered beneficial from a non-health standpoint. The hardness of the water from the Silurian-Devonian aquifer ranges from 200-2000+ mg/L. In the outcrop area of the aquifer in north-central, northeast, and east-central Iowa, the hardness generally ranges between 300-400 mg/L.

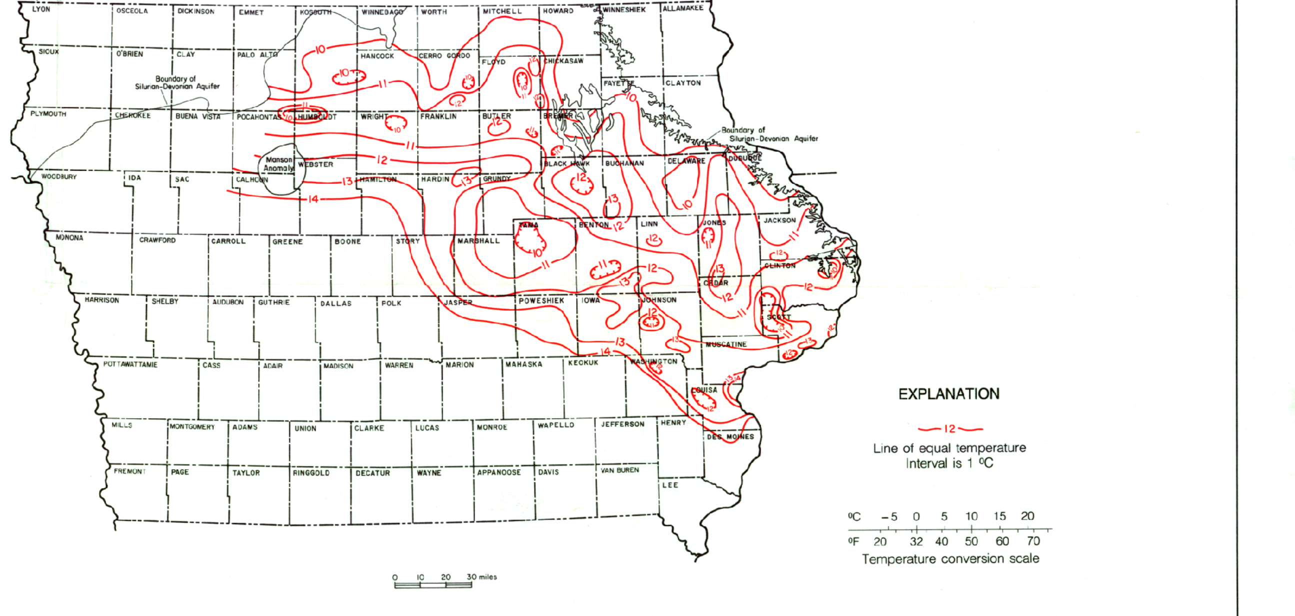

Figure 8. TEMPERATURE

The temperature of the water obtained from the Silurian-Devonian aquifer depends on the location and depth of wells. It ranges from approximately 8.9° C (48° F) in northern and northeast Iowa to about 22° C (72° F) in southwest Iowa. Across most of the outcrop belt the temperature varies between 9° and 14° C (48°-57° F).

SILURIAN-DEVONIAN AQUIFER OF IOWA

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